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Table of Contents

Foreword

Publications of the Institute of Marine Science was begun by Dr. E. J. Lund in 1945 with Volume I, Number 1. For various reasons no subsequent number has appeared. The present issue is Volume I, Number 2, and completes Volume I. It is proposed in the future to carry out the original idea which visualized a continuing publication containing articles on all phases of marine science, with particular reference to the Gulf of Mexico. Each volume will be completed when between 300 and 400 pages of printed material is published, without adherence to a definite time schedule. Worthwhile papers on marine science, especially those concerning the Gulf of Mexico, will be welcomed as contributions. Manuscripts should be sent to the Institute of Marine Science, The University of Texas, Port Aransas, Texas.

Port Aransas
March 1, 1950

G. GUNTER,
Acting Director

Seasonal Population Changes and Distributions as Related to Salinity, of Certain Invertebrates of the Texas Coast, Including the Commercial Shrimp

By

GORDON GUNTER
Institute of Marine Science

INTRODUCTION

From March, 1941, to November, 1942, the writer carried on a study of Texas marine fishes over an area extending from the headwaters of Copano Bay, through Aransas Bay, to five miles offshore in the Gulf of Mexico from Aransas Pass and five miles down the Gulf beach of the north end of Mustang Island. This covered a rather stable salinity gradient from near fresh water to pure sea water, over a running distance of forty nautical miles. The work was carried on as a part of the marine biological program of the Game, Fish and Oyster Commission. It is the second step in a fisheries biological program for the Texas Coast, previously outlined by the author (Gunter, 1943b).

The primary aim in the program was to gather information on the distributions and general seasonal movements of the fishes in the bays and shallow Gulf waters of the Texas Coast. Minnow seines, trawls, trammel nets and beach seines were used in collecting fishes. These gear were less effective in catching invertebrates and did not sample the total invertebrate population as well as they did the fishes. Nevertheless, certain data on invertebrates were obtained and they are presented here, as a supplement to the main program.[1] The area, stations, manner of collecting and treatment of the data have all been described in a previous paper (Gunter, 1945), with a presentation of the temperature and salinity data and the data on fishes. Therefore, the details will not be repeated here. Table 1 shows the number of hauls made each month with the different gear in Copano Bay, Aransas Bay and the Gulf of Mexico.

DATA ON THE SPECIES

Coelenterata

Scyphozoa

Aurellia aurita Linnaeus. Moon Jelly

More than 66 *Aurellia* were taken in 2 trawl hauls in the middle of Aransas Bay and in Lydia Ann Channel, which leads into the Gulf, in the months of August and

[1]I am much indebted to the officials of the Game, Fish and Oyster Commission, who supplied the equipment and gave me a free hand in carrying out the work. I am also indebted to various employees of the Commission, who assisted me at various times. My thanks are due to Dr. Waldo L. Schmitt and Mr. W. W. Anderson who helped with identification of several species.

TABLE 1

The number of hauls made with the different gear are given for all months for the two bays and the Gulf of Mexico.

	1941										1942									
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Aug.	Sept.	Oct.	Nov.
Trawls																				
Copano Bay	—	2	3	3	3	2	3	3	3	3	3	3	3	3	3	—	2	—	—	—
Aransas Bay	2	1	—	3	3	2	4	4	4	4	4	4	5	3	—	—	3	—	—	—
Gulf	—	—	—	1	3	2	2	2	2	—	2	—	3	2	2	—	—	—	—	—
Minnow Seines																				
Copano Bay	—	—	—	4	4	2	4	4	4	4	4	4	4	4	4	4	4	—	—	—
Aransas Bay	—	—	—	7	6	2	7	6	6	6	6	6	5	6	6	6	6	—	—	—
Gulf	—	—	—	2	3	2	2	2	2	2	2	2	4	2	—	2	2	2	2	2
Trammel Nets																				
Copano Bay	—	—	—	3	3	3	4	4	4	4	4	4	4	4	4	4	4	—	5	—
Aransas Bay	—	—	—	2	3	2	3	4	4	4	4	4	6	4	4	4	4	—	4	—
Beach Seines																				
Gulf	—	—	—	—	2	—	—	2	4	2	2	2	3	2	—	2	2	—	—	—

October, 1941. An exact count was not made at all stations. Three hundred and seventy-nine jellyfish were taken in a trawl in the Gulf, 2 to 5 miles SSE of Aransas Pass, in October, 1941. The bottom salinity ranged from 18.9 to 30.9 *per mille* and the temperature ranged from 25.9 to 28.2°C.

Ordinarily, *Aurellia* is found only in the Gulf or lower bay and *Dactylometra* is by far the most abundant scyphozoan in bay waters. During the summer of 1949 *Aurellia* was found in the bays in thousands and was the most abundant jellyfish present. Many were seen as far back as Copano Bay in salinities of 16.0 *per mille.* Although not as virulent as *Dactylometra,* this species caused considerable discomfort to swimmers through sheer force of numbers.

Dactylometra quinquecirrha (Desor). Sea Nettle

This jellyfish was taken only in trawls in Aransas Bay and the Gulf of Mexico in the months of August and October, 1941, and March, 1942. More than 27 jellyfish were caught. The salinity range was from 16.5 to 35.2 and the temperature range was from 15.4 to 28.2°C. This species is common and it was often taken enmeshed and disintegrated in the trammel nets and records of such catches were not kept. General observation showed that the species was sometimes extremely common in protected waters of Copano Bay near Redfish Point during the warm months.

Rhizostomeae

Stomolophus meleagris Agassiz. Cabbagehead

This jellyfish is at times extremely abundant in the bays and shallow Gulf and sometimes impedes the progress of small boats (Reed, 1941). However, during the time of this survey the species was at a low ebb of abundance and relatively few were caught. Records were not kept.

Anthozoa

Alcyonaria

Gorgonacea

Leptogorgia setacea (Pallas). Whip Coral

Strands of this coral were taken on 3 occasions in trawls 2 and 5 miles offshore in the Gulf of Mexico, in April and May, 1942. The salinity range was 26.7 to 33.6 and the temperature range was 20.4 to 23.5°C. Strands of whip coral are often found on the Gulf beach.

Pennatulacea

Renilla mülleri Kölliker. Sea Pansy

The sea pansy is abundant on the bottom of the shallow Gulf and, although the otter trawl is not nearly so efficient as a scrape dredge in picking up these animals, some were caught almost every time a drag was made in the Gulf. *Renilla* was taken in thirteen hauls at stations 2 and 5 miles offshore in the months of July, August, October and November, 1941, and January, March, April and May, 1942. They were taken in greatest numbers in March and April, 1942. The number varied from 3 to 835 individuals per haul and the total was 3,171. The salinity varied from 26.7 to 36.7 and the temperatures were from 13.7 to 28.3°C.

Shrimp fishermen sweep thousands of these "livers," as they call them, up from the floor of the Gulf during every working day. Evidently their large trawls, up to 130 feet in wingspread, sweep the bottom much harder than the 30 foot trawl used in this investigation. One shrimper told me that *Renilla* became much less common at about 15 fathoms depth and was replaced by a small starfish. During a three-day trip on a shrimp boat in September, 1949, the observation was corroborated by the writer.

Ctenophora. Comb jellies

Ctenophores are very common in the bays, especially in Copano Bay in the fall and early winter. In October, November and December, 1941, in the middle and lower parts of that bay, animals caught in trawls were covered with masses of Ctenophore jelly. Ctenophores were caught in smaller numbers in other months. Exact counts of the ctenophores were practically impossible to make and they were not attempted. The temperature and salinity ranges at the stations were 14.6 to 26.4°C. and 11.5 to 13.7, respectively. All specimens examined proved to be *Beroe* and *Mnemiopsis.* According to Mr. Joel W. Hedgpeth, *Mnemiopsis mccradyi* A. Agassiz and *Beroe ovata* Chamisso and Eysenhardt are the most common ctenophores in Texas waters.

Mollusca

Pelycypoda

Ostrea cristata Born

This little oyster was taken 3 times in trawls in the Gulf, 2 and 5 miles offshore, in the months of January, March and May, 1942. The temperature range was 13.7 to 23.5°C. and the salinity range was from 26.6 to 35.2.

Crassostrea virginica (Gmelin). American Oyster

Oysters are very common in the bays and form huge reefs in many places. Oyster reefs cut trawls and they are usually avoided, but at stations near Lap Reef in Copano Bay and in Lydia Ann Channel oysters were picked up several times. Reed (1941) reported that *Ostrea frons* Linnaeus was the "coon" oyster of the Texas Coast. The "coon" oyster is merely *C. virginica,* growing under conditions producing the elongate form. The diverse shapes of oysters growing under varying conditions have been discussed several times in the literature (See Gunter, 1938b).

Gastropoda

Prosobranchia

Tonna galea (Linnaeus)

Four specimens were caught in trawls in the Gulf, 2 and 5 miles SSE of Aransas Pass, in the months of March, April and May, 1942. The temperature ranged from 16.9 to 23.3°C. and the salinity ranged from 29.7 to 33.9.

Urosalpinx sp. Oyster Drill

One individual was taken in a trawl in the Gulf at the Whistling Buoy, 5 miles SSE of Aransas Pass, on March 22, 1942. The bottom temperature was 16.9°C. and the salinity was 33.9.

Thais floridana (Conrad). Gulf Oyster Borer

One specimen was taken in a trawl in Lydia Ann Channel, near the Gulf, on August 24, 1942. The temperature was 30.3°C. and the salinity was 35.0.

Busycon perversum (Linnaeus). Conch

Three individuals were taken in two trawl hauls in the Gulf at the Whistling Buoy station, 5 miles offshore, in May and September, 1942. The temperatures were 23.3 and 29.5°C. and the salinities were 33.6 and 36.6 *per mille*.

Busycon pyrum (Dillwyn). Pear Conch

One conch was taken in a trawl in the Gulf, 2 miles SSE of Aransas Pass, on July 7, 1941. The temperature was not taken. The salinity was 35.5.

Opisthobranchia

Tethys sp.

One specimen was taken in a trawl in the Gulf at the Whistling Buoy station, 5 miles offshore, on May 25, 1941. The temperature was 23.3°C. and the salinity was 33.6.

Cephalopoda

Decapoda

Loligo brevis Blainville. Squid

Two hundred and seventy-six of these little squids were caught, 97 in Aransas Bay and 179 in the Gulf of Mexico. All of them were taken in trawls. Hauls were made much less often in the Gulf but the squid was more numerous there than in the bay. It was found at all seasons in the Gulf, but was not taken in December and January in Aransas Bay. Only one specimen was taken in upper Aransas Bay and only 12 were taken in the middle of the bay. Eighty-four were caught in the lower bay. The squids enter the bay in late winter and early spring and leave again in the fall, remaining largely in the lower bay near the Gulf.

The temperature where the squids were caught ranged from 11.1 to 30.3°C. and the salinity ranged from 17.7 to 37.2. Only 48 squids were caught where the salinity was less than 25.0 *per mille* and only 9 were caught at salinities below 20.0. This species prefers waters of relatively high salinity, but will enter bay or estuarine waters. It is not generally recognized that some cephalopods will enter waters of low salinity and some paleontologists have assumed that the whole group was always completely marine. Even the common octopus is sometimes taken in bay waters as shown below. It is probable that some extinct forms were partly euryhalin similar to *L. brevis.*

The total length of the squids, not including the arms, was measured in millimeters on a shrimp board, of the type described by Weymouth, Lindner and Anderson (1933). One hundred and fifty-eight specimens were measured. The length range was from 28 to 160 mm. Squids less than 24 mm. long were taken in the months July, 1941, and January, March and August of 1942. Individuals 100 mm. long and over were taken in August 1941, March, April, and May, 1942. A ripe female, 135 mm. in length, was taken at the upper end of Aransas Bay on April 28, 1942. The temperature was 23.5°C. and the salinity was 21.9 *per mille.*

Squids below 35 mm. long were taken at both low and high salinities. The very smallest were taken at high salinities. Fifty-one per cent of the squids taken from waters with salinities between 17.7 and 24.7 were over 60 mm. long, while 61 per cent of those taken at salinities between 26.7 and 37.2 were over 60 mm. long. The average size of squids in the saltier water was greater than that of specimens from the less salty water, indicating some relationship between salinity and size.

Loligo pealeii Le Sueur. Squid

Forty-five squids of this species were taken in 3 trawl hauls in the Gulf at the Whistling Buoy station, 5 miles offshore, in the months of July, 1941, and April, 1942. The temperature varied from 20.5 to 28.5°C. and the salinity varied from 30.7 to 35.8 per mile. This squid inhabits waters of higher salinity than *L. brevis* does.

Octopoda

Octopus vulgaris Lamarck

The spermatophore of an octopus was taken in the Gulf at the Whistling Buoy station on March 22, 1944. The temperature was 16.9°C. and the salinity was 33.9. Reed (1941) published a photograph of an octopus from my collection which had been taken by a shrimp trawler in 70 feet of water off Port Aransas. On rare occasions small octopuses are taken by pole and line fishermen from the seawalls at Rockport and Corpus Christi, several miles from the sea, in Aransas and Corpus Christi bays. Octopuses seem to be uncommon on this coast, as is to be expected on smooth bottoms and shores where there are no rocks and protective crevices.

Arthropoda

Crustacea

Stomatopoda

Squilla empusa Say. Mantis Shrimp

Ninety-one specimens were caught in waters ranging in temperature from 13.7 to 25.4°C. and from 16.5 to 34.2 *per mille* in salinity. Four mantis shrimp were taken in Aransas Bay and 87 were caught in the Gulf of Mexico. Eighty were taken 5 miles from shore. Only 6 individuals were taken in water below 30.0 *per mille* salinity. This stomatopod apparently prefers waters of high salinity.

The mantis shrimp were taken in the months of June, October and November, 1941. All were taken in trawls, with the exception of one taken on the Gulf beach in a minnow seine on October 7, 1941. This specimen was a completely colorless larva.

Decapoda

Peneidae

Penaeus setiferus (Linnaeus). Common Shrimp

The shrimp fishery of the South Atlantic and Gulf Coast was based almost wholly on this species. Today around 200,000,000 pounds are produced annually. Louisiana produces approximately half of this amount and Texas ranks second in the production by states. The shrimp fishery is Texas' largest and most valuable fishery. From the fiscal year 1936–37 to 1947–48 the average annual catch has been 15,008,379 pounds, according to statistics collected by the Game, Fish and Oyster Commission. Since 1947 *Penaeus aztecus* has equaled or surpassed *P. setiferus* in the catch, which has almost doubled. The Texas shrimp industry was discussed by Gunter (1943a). More extensive discussions of the industry as a whole have been given by Johnson and Lindner (1934) and others.

Weymouth, Lindner and Anderson (1933), of the Shrimp Investigations of the U. S. Bureau of Fisheries, have presented the most extensive data on the life history of the shrimp. They state that the shrimp spawn in the Gulf from March to September. The eggs are turned loose in the water, where the larvae undergo several molts and changes. After reaching a length of about 8 mm. in a few weeks' time, while floating free in the water, they reach inside (bay) waters and settle to the bottom. Those that do not reach bay waters perish. The little shrimp grow rapidly during the summer, and with the onset of cool weather in the fall they begin to leave the bays for the Gulf. The larger ones move out first and those already in the Gulf leave the beaches and go to deeper water, so that only the smallest shrimp remain in the bays during the winter. Growth is slow in the winter but it accelerates in the spring and the sex organs mature. Spawning takes place then and, since no spent shrimp were found and the largest shrimp disappeared rapidly from the catches in the last part of the summer, the writers concluded that the shrimp spawn and die at about the age of one year. Burkenroad (1934, 1939) has criticized the conclusions of Weymouth, Lindner and Anderson, especially the theory that shrimp die following spawning at the age of one year. Pearson (1939) worked on the early life histories of several Peneidae and in several essential points his findings corroborated the conclusions of his colleagues on the Shrimp Investigations staff.

The number of shrimp I caught is unknown, since the larger catches were measured only by volume, but probably it was in excess of 43,000. Table 1 shows the number of hauls with different gear in various localities. Table 2 gives the monthly catches made by different gear in the two bays and the Gulf of Mexico. Except for one specimen caught in a trammel net, all shrimp were taken in trawls and minnow seines. The meshes of the trammel net and beach seine were too large for taking shrimp. Most shrimp were taken in the otter trawl, which was capable of capturing individuals as small as 30 mm., though not usually taking many smaller than 50 mm., and having its highest efficiency above 60 mm. The minnow seine retained shrimp as small as 18 mm. It caught some as large as 90 mm., but the bulk of its catches were below 60 mm.

Table 2 shows that there were two peaks of abundance, one in spring, the other in the fall. This is shown in both Bay and Gulf catches, and by minnow seine as well

TABLE 2

The numbers of *Penaeus setiferus* caught each month in the different nets in the 2 bays and the Gulf are shown. In cases where exact counts were not made the figures are based on estimates and are labeled app. for approximate.

	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Aug.	Oct.	Nov.
Copano Bay																		
Trawls	72	3	18	125	4,500 (app.)	12,480 (app.)	2,980 (app.)	1,680 (app.)	2,540 (app.)	—	16	147	437	147	—	1,020	—	—
Minnow Seines	—	—	—	—	2	40	169	158	28	—	—	—	—	—	7	5	—	—
Aransas Bay																		
Trawls	—	—	90	480 (app.)	2	2,400 (app.)	3,170 (app.)	3,700 (app.)	2,550 (app.)	2	97	717	1,524 (app.)	—	—	28	—	—
Minnow Seines	—	—	135	25	—	3	248	325	8	—	—	—	1	5	620	7	—	—
Trammel Nets	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—
Gulf																		
Trawls	—	—	165	—	32	3	960 (app.)	235	—	37	—	160	37	2	—	—	—	—
Minnow Seines	—	—	—	5	—	—	—	9	—	—	—	2	—	—	—	—	4	2
Totals	72	3	408	650 (app.)	4,540 (app.)	14,900 (app.)	7,600 (app.)	6,000 (app.)	5,100 (app.)	39	113	1,026	2,000 (app.)	155	627	1,060	4	2

as trawl hauls. The fall abundance was much the higher, in conformity with which the greatest monthly commercial production of shrimp in Texas from 1937–38 to 1943–44 was in October each year, except 1937–8 when it was in September. No live shrimp were taken in Copano Bay in January, and only two in Aransas Bay. Some inside shrimp were killed by a cold spell at this time (Gunter, 1945). The shrimp began to reappear in the bay catches in February, the trawl catch per haul from January through March showing an almost exponential rate of monthly increase (which seems characteristic of the seasonal abundance fluctuations). The summer minimum is also well-defined, though less so than the winter one. The double alternation of minima and maxima is shown by *Penaeus aztecus* as well as *P. setiferus*, though the exact times of peaks and lows differ from one species to the other, as well as with locality for a given species. The significance of the differences in timing of these seasonal and local changes in abundance is best discussed in relation to size frequencies.

Three thousand nine hundred and sixty-four shrimp were measured in total length by the method described by Weymouth, Lindner and Anderson *(op. cit.)*. The smallest shrimp caught were 18 mm. long. They were taken in minnow seines in Aransas Bay in June, 1941 and in Copano Bay in June, 1942. The largest shrimp caught was 184 mm. long. It was taken in the Gulf in a trawl in August, 1942. Length-frequency curves for each month were made from the measurements and are presented in Figure 1. Shrimp taken in both minnow seines and trawls were used. Twenty-two shrimp taken in the Gulf and 902 taken in bay waters in minnow seines, in addition to 474 taken in the Gulf and 2,566 from bay waters in trawls, comprised the total group measured. Four hundred and ninety-six shrimp came from the Gulf, 1,757 from Aransas Bay and 1,711 from Copano Bay. Table 3 shows the numbers of shrimp measured from each of the 3 localities and the nets in which they were caught.

TABLE 3

The numbers of shrimp measured, the numbers from the two bays and the Gulf and the numbers taken in minnow seines and trawls are shown.

	Minnow Seine	Trawl	Totals
Copano	298	1,363	1,711
Aransas	554	1,203	1,757
Gulf	22	474	496
Totals	924	3,040	3,964

The curves differ somewhat from those presented by Weymouth, Lindner and Anderson (1933), based on data collected by Anderson in Georgia in 1931–32, for several reasons. There was considerable difference in both time and space in the collection of data. Weymouth *et al.* made separate curves for males and females and presented curves by half-months, neither of which I did. Their data were also collected only by the shrimp trawl. These conditions tend to give curves with sharper modes and less spread than mine. On the other hand, their curves were based on approximately 13 times as many shrimp and doubtless they represent an adequate sample of the population that can be captured in trawling. The differences between the curves presented here and those given by Weymouth, Lindner and Anderson lie

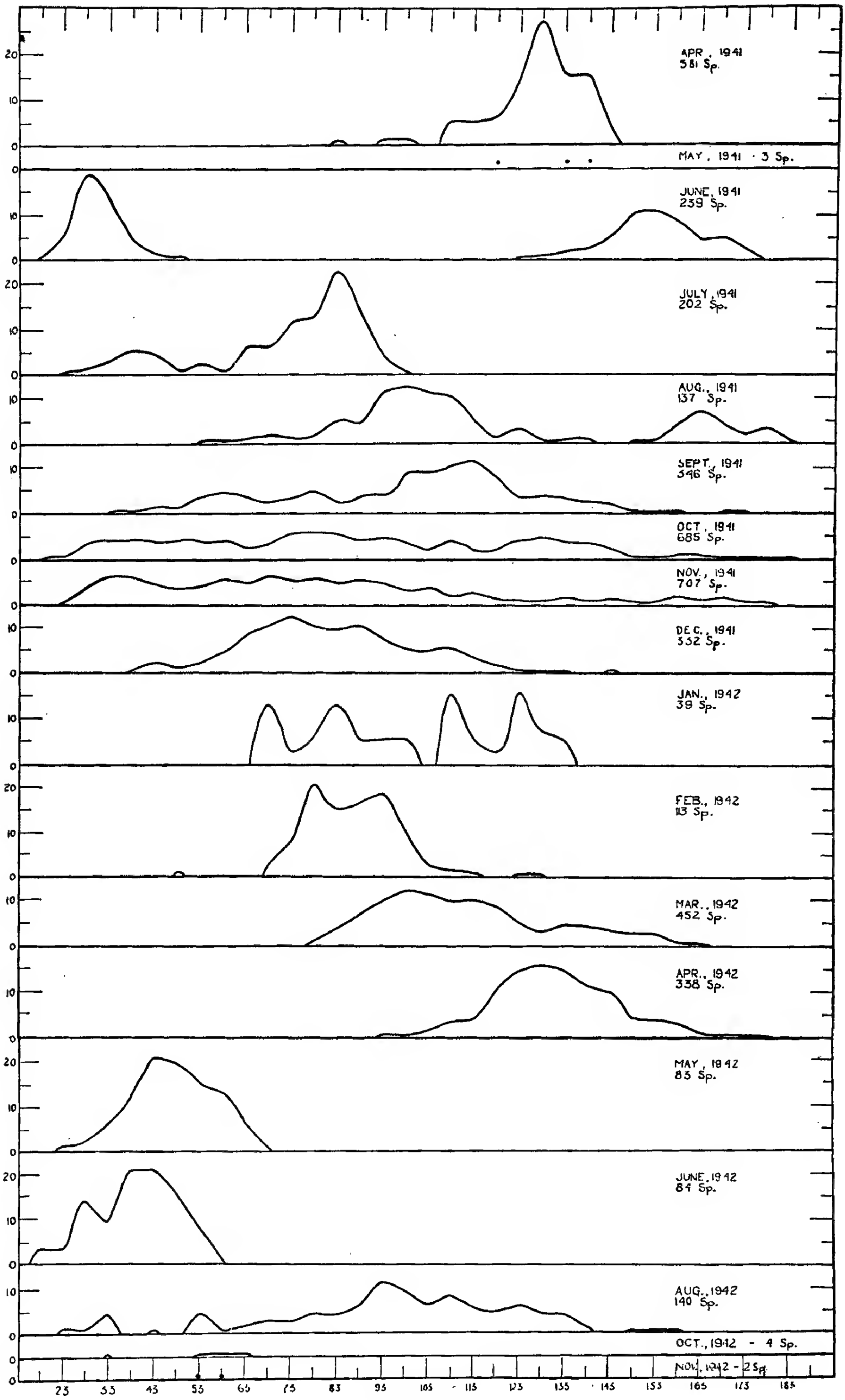

FIGURE 1

Length-frequency curves of *Penaeus setiferus*. The x-axis is in millimeters and the y-axis is per cents.

chiefly in the fact that the Texas curves show a wider spread and less sharp modes. The use of minnow seines as well as trawls gives a better sample of the total population than trawls alone. The modes at smaller sizes arises partly from the combined use of trawl and minnow seine catches and partly from the fact that most of the shrimp were taken in bay waters. In some months hauls were missed and interpretation of the curves involves examination of Tables 1 and 2.

The curves show that very small shrimp were first taken in June in 1941 and were first taken in May in 1942. They seemed to stop coming into the population after October, 1941, but many were present in November. They were all taken in the bays. The seines used did not catch shrimp smaller than 18 mm. in total length which, however, were doubtless present. Weymouth, Lindner and Anderson (*op. cit.*, p. 10) mentioned that young from 7 or 8 to 40 mm. "have been systematically collected during the proper seasons" in Georgia. Further on (*op. cit.*, p. 11) they state that the very young "apparently just emerged from the larval state" can be found from April through September. Other than the statement, they present no data on the small shrimp. They say that the young of the year with modes at 90 mm. in length come into the commercial catch in July. This is shown in their figures 6 and 10. I found the same group in July with a mode at 83 mm., and it could be followed to September, but there was another small group present in July with a mode at 38 mm., which in June had a sharp mode at 28 mm.

A larger group with a mode at 128 mm. in April, 153 mm. in June and 163 mm. in August was also found. This is the same general picture found by Weymouth *et al.*, although they did not present data on the smallest group. The situation is hard to reconcile with a continuous spawning season with the shrimp dying at the age of one year. There are three other possibilities.

It is recognized that in lumping the monthly measurements of shrimp from the different localities, without weighting the different samples so as to represent the whole population of the area, the value of these measurements as a clue to size-changes in the population is reduced. The similar procedure used by Weymouth, Lindner and Anderson (1933), does not give any indication of the relation between changes in size-frequency and changes in distribution. In the present case, the numbers of shrimp per haul in different areas can be obtained by use of Tables 1 and 2; and it can thus be seen that the changes in size-frequency may merely reflect the immigration and emigration of shrimp (*cf.* Burkenroad, 1939). In other words, the samples measured were taken according to a fixed station schedule, which cannot be assumed to have provided shrimp of the different sizes in the proportions in which they actually occurred in the whole population of the region.

A further difficulty in the interpretation of Figure 1 is caused by the lumping of both seine- and trawl-caught samples. Since these two gears tend to catch different size-groups, it will be obvious that apparent separation of modes might be caused which might actually represent, for example, merely the exclusion of shrimp too small for the trawl and too large for the seine. Weymouth *et al.* (l.c.) used the trawl only, so did not have to contend with this source of misinterpretation. However, as will be shown, the inclusion of the small shallow water seined shrimp in the present study brings to light some possibilities not mentioned by Weymouth *et al.*

Comparing Figure 1 and Tables 1 and 2, it will be seen that peak minnow-seine catches per haul were obtained in June and in October-November, with lows in

July-August and December-May (Copano Bay differs from Aransas Bay in not showing any extensive minnow-seine catches till fall). In conformity with these results, individuals of less than 20 mm. were taken only in June and October. This suggests the possibility of two separated peaks of entry of young shrimp into the inside waters.

Now by further comparison of Figure 1 and Tables 1 and 2, it will be seen that the small seine-caught shrimp in June, 1941 (with a mode of 28 mm.), and the small trawl and seine caught shrimp in May and June, 1942 (with a mode at 43 mm.), seem to have been only shrimp of less than 120 mm. present in the bays. Therefore, unless the hauls were not representative samples of the population, or unless there was later immigration of larger young shrimp into the bays from some other region, the shrimp 80 to 100 mm. long, which were abundant in the bays in July and August, must have been produced by growth of the small June shrimp. The indicated rate of growth would be 25–45 mm. per month, with an average probably not less than 30 mm. At such a rate of growth, two generations of shrimp could be produced per year, instead of only one as thought by Weymouth *et al.* It should be noted that Viosca (1920) was led to the original recognition that shrimp grow up in a year or less, by observations analogous to the above; namely, the lack of small shrimp in Louisiana waters until late spring, and the parallel in advance of the maximum size of the newly-appearing small shrimp and the mimimum of the group of larger shrimp present over the winter.

The occurrence of two generations per year would agree with the indication, from numbers and minimum sizes in minnow seine catches, that there are two separated periods of successful spawning, one in spring and the other in the fall. Furthermore, the growth rates indicated are by no means impossible in view of the growth experiments with young kept in aquaria reported by Pearson (1939). Pearson's fastest growth increment was about 20 mm. per month, for two specimens out of 29 tested. In the case of the other, slower-growing young, he believes that over-crowding and small size of aquaria were responsible for reduction of the rate to less than 10 mm. per month. Pearson concluded that if shrimp grew 20 mm. per month, those born in spring could enter the commercial catch in July at a length of 90 mm., thus confirming the deductions of Weymouth *et al.* from the advance of the modes in the samples they measured. This has been considered to mean that shrimp born in spring would spawn the following spring. However, it is notoriously difficult to obtain natural rates of growth of marine organisms in aquaria. If the conditions in which Pearson reared his shrimp were such that less than 10 percent of them attained a growth rate of 20 mm. per month, it would not be surprising if the potential maximal rate were far higher, or if shrimp in nature in favorable years averaged 30 mm. per month over the period from birth to maturity.

On the other hand Anderson, King and Lindner (1949) found no discontinuity of incoming postlarvae between June and September and the curves presented here for September to November indicate an overlap of all sizes of shrimp from 33 to 173 mm. for these three months, indicative of a long unbroken spawning season the previous summer.

An example may now be drawn from Tables 1 and 2 and Figure I to show the danger of judging growth rate merely from change in modal size of unweighted samples. In Copano Bay, the trawl catch per haul rose from 42 in July, 1941 to

2,250 in August to 4,160 in the September peak. The catch per haul in Aransas Bay fell from 160 in July, 1941 to 1 in August; then rose again to 600 in September, 792 in October and 925 in the November peak. In the Gulf, the change was from 16 in August to 1 in September, and then to 480 in the October peak. The August high level in Copano and low level in Aransas was repeated in 1942.

The minnow seine catches showed a relatively high level in Aransas Bay in June, falling to a low in August. At the same time, the minnow seine caught hardly any shrimp in Copano Bay before September. This apparent low frequency of small shrimp in Copano Bay in summer poses the question of the origin of the large trawl catches in Copano Bay in August. What could have happened is, that rapid growth of the batch of small Aransas shrimp, which produced the June minnow-seine peak, resulted in rise in the July Aransas trawl catch parallel to the decline there in seine catch. Next, the Aransas July trawl shrimp moved into Copano Bay, producing the rise in August trawl catch there, and the August low in Aransas Bay. Later, an outward movement of the largest sizes toward the Gulf would be expected, so that Copano, reaching its peak in September, would thereafter lose in population while Aransas gained.

Although the data are insufficient to prove that the above complicated hypothetical movements actually took place, recognition of possibilities of this sort illuminate the changes in length frequency shown in Figure 1. It will be seen that the smaller mode at 38 mm. in July, 1941, produced chiefly by Aransas minnow-seine hauls, shows only a 10 mm. advance over the June minnow-seine mode at 28 mm. However, suppose that the shrimp represented in the June minnow-seine catches were those which produced the July Aransas trawl catches (with a mode at 83 mm.); and suppose that the relatively low frequency of shrimp in the July catches between 48 and 68 mm. were an artifact resulting from the difference in sizes selected by trawl and minnow-seine. Then, the modal size of the entire Aransas July population, derived from the small June shrimp, may actually have lain between the two apparent modes shown in Figure 1.

Next, suppose that, as they grew, the larger Aransas shrimp were moving into Copano Bay in July and August. The Copano shrimp would be larger in size than the Aransas ones, and the Copano population would be rising in numbers as the Aransas population fell. Depending on how the sample catches were distributed between the two Bays during the two months, the difference between the July Aransas mode at 83 mm. and the August Copano mode at 98 mm. might greatly underestimate the actual growth rate of the population during this period.

Study of the graphs of length frequency distributions in Georgia in 1931–32, published by Weymouth *et al.*, shows interesting correspondences to the present data. Sizes below 60 mm. are shown only in July and October, 1931, corresponding to the present suggestion of two separated peaks of appearance of young shrimp, in spring and in fall. These two separated occurrences of small shrimp are hard to reconcile with these investigators' view of an unbroken season of production of young, with a single peak. Comparison of Weymouth, Lindner and Anderson's Figure 6 for "outside" shrimp in July and August, 1931, with the appropriate part of their Figure 10 for "inside" and "outside" shrimp combined, shows that during this period the length frequencies of the growing young taken by trawl in the two areas were about the same. Changes in length-frequency during this period may therefore not have been distorted by differential migration. The advance of the modes during this period was about 30 mm. per month, while the maxima advanced about 40 mm. per month. By September 1, an appreciable part of the population had evidently reached spawning size (and there may have been a much larger number than indicated, outside the depth-limit of the fishery).

The greatly reduced rate of advance of the Georgia modes in winter has been interpreted by Weymouth *et al.* as a result of reduced growth rate during the cold season. However, tagging experiments performed by the Shrimp Investigations have subsequently shown extensive migrations of larger Georgia shrimp to Florida during the cold season (and their return in spring): and also, Burkenroad (1949) has shown that the possibility of winter movement of larger Georgia shrimp into offshore waters, as in Louisiana, has not been excluded. Consequently, the stationary Georgia winter modes might be explicable as a result of rapid fall and winter growth of young shrimp derived from a fall peak in production of young, coupled with continuous emigration of the larger of these individuals out of the range of the Georgia fishery. Thus, the Georgia evidence is not sufficient to exclude the possibility that shrimp born in September might reach maturity the following April, and that their offspring might in turn mature in September.

I am largely indebted to my colleague, Mr. M. D. Burkenroad, for the above suggested explanation of the shrimp's life history. Another circumstance in line with this explanation is the scarcity of small *P. setiferus* in the summer, from about 80 mm. down. I have noted in both Louisiana and Texas that *setiferus* becomes relatively scarce and the shrimp population is dominated by *aztecus* in the bays at that season. This seems to be the normal situation. Weymouth *et al.* called attention to it. Nevertheless, in the late summer and fall *P. setiferus* occurs in vast abundance and supports the heavy commercial catch in the fall. Where these small shrimp all come from so suddenly, if they grow slowly, has always puzzled the writer. From the appearance of the summer population the *aztecus* group should be expected to be the predominant fall shrimp, but this was not the case during any of the years studied. If the small *setiferus* grow slowly, the antecedents of the fall population should be found in great abundance somewhere; but they have not been found. In Louisiana it was easy to suppose that these shrimp moved out from the multitudinous bayous, salt water creeks and shallow areas around the numerous islands. However, in Texas waters such bayous and small arms of the bays are not common and do not form a sizeable fraction of bay waters. Yet the scarcity of small *setiferus* in summer is the same as found in Louisiana. The alternate explanation is that they must come from an extremely fast-growing group of post-larval shrimp not taken by ordinary gear in the summer.

Other possible explanations of the Texas observations are, that while the June modes at 28–43 mm. are the young of the year, the July-August modes at 83–98 mm. are derived from spawning during summer or fall of the previous year. This implies a slower rate of growth, at about 0.4 mm. a day, and does not explain the lack of shrimp corresponding to the 83–98 mm. modes during the preceding spring months. Examination of the length-frequency curves from November to April, when no young were feeding in, shows an approximate rate of growth of 0.5 (0.46) mm. per day during this essentially winter period. A third possibility is that of a January spawning season, as suggested by Lindner (1936), from unknown evidence. However, marine animals tend to spawn either on rising or maximal temperatures, or on falling or minimal ones (Orton, 1920), so that it would be unusual for the same shrimp in the same area to have both a winter and a summer spawning season.

A double spawning season or a season with two distinct beats is not unknown where the season of high temperatures is long. Hopkins (1933) found two spawning peaks in the oysters of Galveston Bay; and the Gulf sardine, *Harengula macropthalma*, shows evidence of two spawning peaks during the season (Gunter, 1945). However, the numbers of very young shrimp appearing in the inside waters do not necessarily follow the numbers of eggs or larvae laid in the Gulf. The success of immigration into the bays must depend on hydrographic factors, and it is conceivable that spawning might have a peak in summer, but immigration be greatest at other times.

No explanation of the life history of the shrimp, which has so far been advanced, is quite satisfying. Several anomalies remain unexplained. In recent years *P. aztecus* has become the dominant commercial species in the western Gulf and *setiferus* has declined in numbers. These facts indicate the need for a careful program to elucidate the life history of the two species of commercial shrimp and their interrelationships.

It has been shown in a previous paper (Gunter, 1945) that there is a relation between the salinity and size of several species of coastal fishes, in that smaller specimens are generally found in the less salty water and the larger individuals are taken in saltier water. A discussion of the literature of the topic, salinity and size, was given in that paper.

Ehrenbaum (1890) found that the young of a shrimp of Northern Europe, *Crago vulgaris*, grew up far inland from the sea, and Havinga (1930) said the young of this species ventured much farther into brackish waters than did the adults. All workers on *Penaeus setiferus* have noted the young grow up in the bays and the very largest shrimp are found in the sea. Viosca (1920) noted that the larger young move seaward through the summer and fall. Weymouth, Lindner and Anderson (1933) corroborated this observation and added that, therefore, "There is always a gradient of decreasing size from the waters of greater salinity toward fresh water." They gave no combined salinity and size data. The writer first noted the relationship between salinity and the size of organisms while working with the Shrimp Investigations several years ago. Nevertheless, the relationship is much clearer in the trawl catches

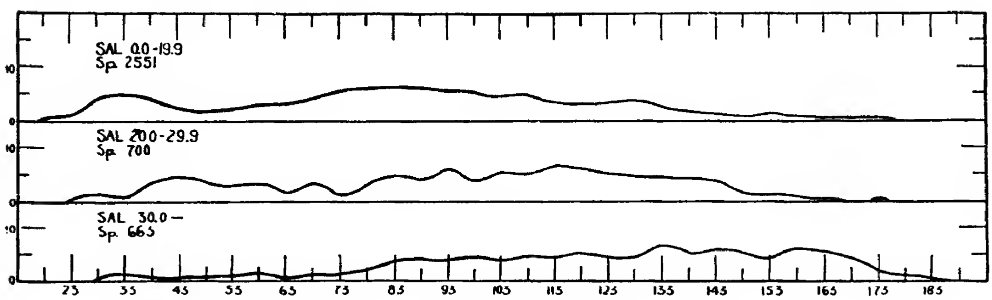

FIGURE 2

Length-frequency curves of the numbers of *P. setiferus* taken at the salinities shown.

or, in other words, in shrimp well past the postlarval stages, than it is in a combination of minnow seines and trawl catches. This is because minnow seines catch small shrimp which have recently entered the bays from the sea and are in the saltier waters near the Gulf, thus tending to obscure the larger shrimp. Figure 2 shows, however, that the overall direct relationship between salinity and size holds true as a whole for all shrimp measured.

Table 4 shows the numbers of shrimp taken at the various salinities. The greatest numbers of shrimp were caught at intermediate salinities. Table 5 gives the number of hauls made with each type of gear at different salinities. Study of this table in connection with Table 4 will give a better understanding of the data presented in Table 4.

TABLE 4

The numbers of several species of invertebrates taken at different salinities are given. The figures for *Penaeus setiferus* and the *P. aztecus-duorarum* complex, *Xiphopeneus krøyeri* and the grass shrimp are approximations based on estimates.

Salinity per mille	0.0–4.9	5.0–9.9	10.0–14.9	15.0–19.9	20.0–24.9	25.0–29.9	30.0
P. setiferus	3,380	5,000	15,110	9,770	5,120	3,560	1,680
P. aztecus / *P. duorarum*	2,931	1,270	990	6,520	1,520	1,400	1,010
X. krøyeri	———	———	———	———	———	1	342 (app.)
T. constrictus	———	———	———	———	1	6	97
C. sapidus	419	202	1,275	947	532	271	299
C. danae	———	———	———	32	16	43	272
S. empusa	———	———	———	3	1	2	86
Grass shrimp	1,733	2,000 (app.)	4,500 (app.)	828 (app.)	50 (app.)	1	8
L brevis	———	———	———	9	33	119	114

TABLE 5

The number of hauls with the different types of nets made at the various salinities are given.

Salinity	0.0–4.9	5.0–9.9	10.0–14.9	15.0–19.9	20.0–24.9	25.0–29.9	30.0
Trawls	14	4	26	19	10	8	28
Nets	18	9	35	26	7	11	8
Minnow seines	17	13	31	33	18	23	34
Beach Seines	———	———	———	———	———	7	13

Penaeus aztecus Ives and *Penaeus duorarum* Burkenroad

Prior to the careful researches of Burkenroad (1939), which cleared up the state of taxonomic confusion relating to the common Peneidae of the South Atlantic and Gulf Coasts of the United States, these shrimp were known to biologists as *P. brasiliensis.* Burkenroad showed that the true *P. brasiliensis* is very uncommon on the United States Coast and he had no record from the northern Gulf of Mexico.

The common Texas species, which formerly went under that name, is *P. aztecus*, and for part of the time the author's work was carried on it was assumed that this was the only species of Burkenroad's *(op. cit.)* Division II of *Penaeus* present. However, field examination indicated that a few *P. duorarum* were being confused with *P. aztecus*, especially in the catches from the lower Aransas Bay and Gulf. Unfortunately, the program was rather far along by that time since separation of the adult of the two species was rather difficult at that time (Burkenroad, 1949), and separation of the young is impossible in the field, all data were lumped. The percentage of *P. duorarum* in the total is unknown, but it seemed to be small and possibly was even less than one per cent.

Not a great deal is known of the natural history of the species of *Penaeus*, Division II, which is one reason why the writer feels constrained to publish these data, although two undifferentiated species are involved. According to Weymouth, Lindner and Anderson (1933) ten per cent of the total shrimp catch of the South Atlantic and Gulf Coasts was at that time composed of *P. brasiliensis* and *Xiphopeneus krφyeri*. *Penaeus brasiliensis*, as used by Weymouth *et al.* is Burkenroad's Div. II of *Penaeus*, and was probably made up chiefly of *P. aztecus* with small numbers of *P. duorarum*. They state that length-frequency data were collected, but none of this group have been published. Burkenroad (1934 and 1939) gave the most extensive information on *P. aztecus*. He pointed out that sexually mature adults are found beyond the inner littoral zone in Louisiana, thus differing from *P. setiferus*. He found the smaller individuals fairly abundant in bay and shallow coastal waters in the summer months, usually in company with *P. setiferus*. He stated that they were more abundant in the higher salinities west of the Mississippi River and less abundant in the less saline coastal waters to the east of the river, although they are found at times in almost fresh waters. He stated that it appears that the young grow up in the bays and migrate offshore to mature and do not return. He found evidence that impregnation and spawning occurs only in water greater than ten fathoms in depth. He says the season of spawning seems to be ill-defined. My data have no bearing on other findings of Burkenroad concerning the natural history of Division II, *Penaeus*, given in his two papers, and therefore they are not summarized.

The remarkable paper of Pearson (1939) presents drawings and complete descriptions of the development stages of several species of Peneidae. All other workers before have contributed less complete findings. He says that the planktonic young of *P. brasiliensis*, for the most part probably *P. aztecus*, were taken in the spring and summer and, unlike *P. setiferus*, also in the winter, although in reduced numbers. He says the planktonic, post-mysis forms are larger than in *P. setiferus*, probably due to more distant offshore spawning area and that the young remain in the plankton through the third post-mysis stage and possibly longer. He further states that the post-mysis larvae arrive in the bays throughout the year and therefore collections of young shrimp by seine and trawl along the Louisiana and Florida coasts show extended size distribution at all times.

The writer caught approximately 15,600 of these shrimp, of which 2,924 were measured. Table 6 shows that they were present throughout the year, although uncommon in the winter. They were most common in the spring and again in the fall, with a low point of abundance in late summer and in the winter. The writer observed in Louisiana, while working on the shrimp, that this group sometimes outnumbered *P. setiferus* in the catches during the warm months. The same thing was found in Texas. A comparison of Tables 2 and 6 shows that *P. aztecus-P. duorarum* outnumbered *P. setiferus* in the catches in the months of May, June, July, 1941 and May, 1942.

This point is of particular interest in connection with recent developments of the Texas shrimp industry. Up to 1948 approximately 95 per cent of the commercial catch consisted of *P. setiferus.* Although the large abundance of small *P. aztecus* in bay waters in summer indicated there must be an abundance of larger shrimp offshore, they were not taken commercially in any numbers. This was ordinarily explained on the grounds that the red shrimp or "brownies," as they are called in common parlance, did not school and were always scattered. Another explanation was that the greater number of them were to be found far offshore beyond the depths ordinarily trawled by shrimp fishermen. In 1948 a sharp decline of *P. setiferus* or white shrimp, as they have recently been differentiated, set in. The Texas shrimpers began to search more diligently and it was soon discovered that the "brownies" could be taken in great abundance at night at depths beyond 10 fathoms, but would not "strike" during the day. Now most shrimping is at night and the shrimp boats tie up or lie at anchor during the day. According to the fishermen the largest catches are made during the full moon and the smallest ones during the dark of the moon. On cloudy days the brown shrimp are sometimes caught during the day. The annual catch of shrimp is slightly greater than it ever was before on the Texas Coast. Shrimping for *P. aztecus* is done in somewhat deeper water than for *P. setiferus*, chiefly at depths from 11 to 16 fathoms. At the present writing the white shrimp, *P. setiferus*, remain in lessened abundance.

Pearson (*op. cit.*, p. 39) stated that, "Owing to the fact that planktonic postlarvae arrive in estuarine areas throughout the year, collections of young shrimp by seine and trawl, along the coasts of Louisiana and Florida, show an extended size distribution at all times." In this respect there is a wide discrepancy between my data and Pearson's finding. In the first place, Table 6 shows that only 77 shrimp of this group (Div. II) were caught from January to March, inclusive, in Texas. Secondly, figure 3 shows that no shrimp less than 48 mm. long was taken during that time and the total length spread was less during these three months than during most of the others. Differences in locale might be invoked to explain these different findings, but the Texas shrimp population should not be greatly different, so far as the life cycle goes, from that of Louisiana. My own data might be questioned on the grounds that I merely failed to catch the small shrimp during the cool months of January and February, when they were in deep water. However, they were taken in December, a cold month, and March is a warmer month. Furthermore, the method of collecting the shrimp did not change at all and all sizes became much less common in trawl catches as well as in the fine-meshed minnow seine. Apparently, the small shrimp, *P. aztecus*, reported by Pearson on the Louisiana and Florida coasts as being present the year around, were simply not present in the late winter and early spring in Texas of 1941–42. There is no reason to assume that the year or season was atypical.

Table 4 shows the numbers of *P. setiferus* and the numbers of *P. aztecus—duorarum* complex taken at the various salinities. Table 6 should be examined in connection

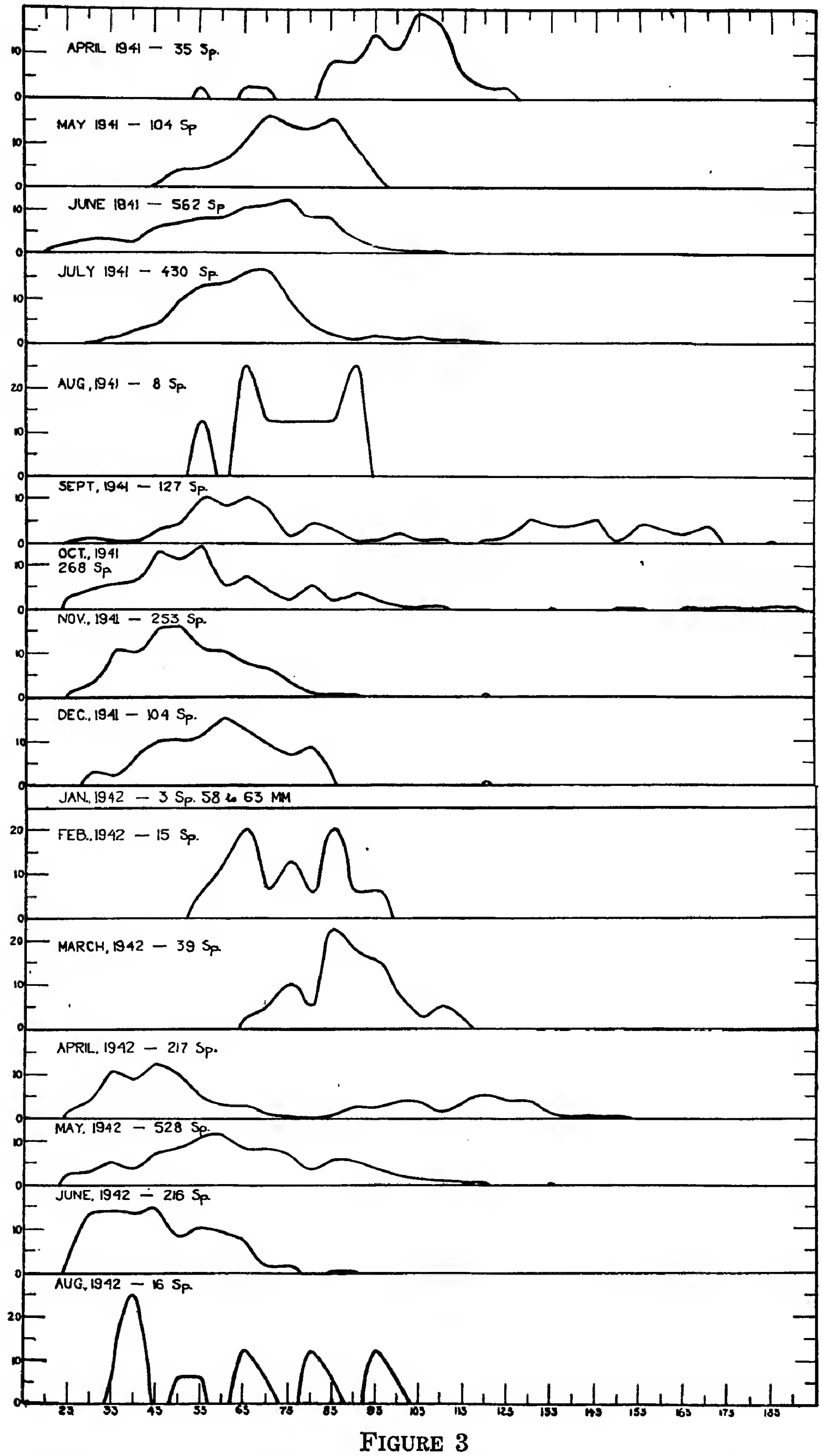

FIGURE 3

Length-frequency curves *P. aztecus,* with which a few *P. duorarum* were mixed.

with Table 5. Fifty-four per cent of the *P. setiferus* were taken at salinities below 15.0 *per mille*, while only 33 per cent of *P. aztecus* and *P. duorarum* were caught at these salinities. Although many specimens were taken in water almost fresh, as Burkenroad (1934) has found before, the *P. aztecus—duorarum* shrimp seem to prefer higher salinities than *P. setiferus*. The range of salinities at which the *P. aztecus—P. duorarum* shrimp were taken was from 2.1 to 36.6 *per mille*. Unfortunately, as stated before, the species were not differentiated.

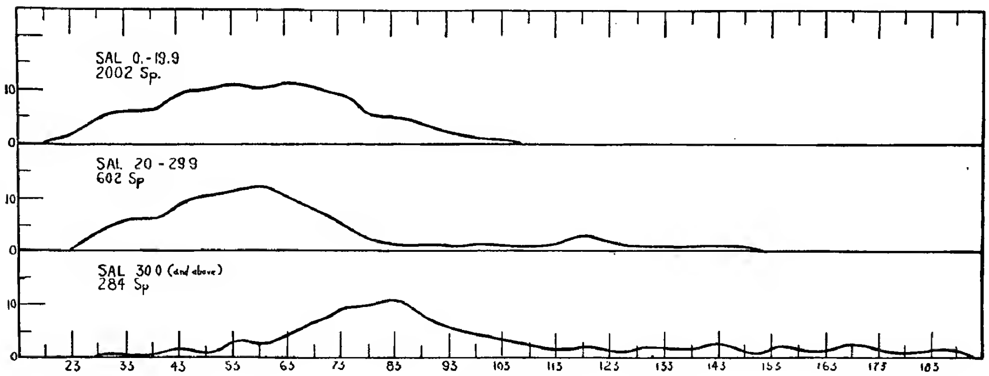

FIGURE 4

Length-frequency curves of the *P. aztecus-P. duorarum* taken at the salinities shown.

Figure 4 shows the length-frequency curves of these shrimp taken at salinities from 2.1 to 19.9, 20.0 to 29.9 and 30.0 to 36.6. It is clear that there is a relationship between the size of the shrimp and the salinity of the water. The largest shrimp were not found in water of low salinities.

Xiphopeneus krφyeri (Heller). Sea bob

This shrimp is used for drying on the shrimp platforms in Louisiana and large catches were sometimes seined on the Gulf beach during the fall. According to Weymouth, Lindner and Anderson (1933), this species contributed 2 to 3 per cent of the total catch of shrimp of the South Atlantic and Gulf coasts. Johnson and Lindner (1934) credit 2½ per cent of the catch to this species. The species has never been produced commercially in Texas.

Little is known of the natural history of this interesting little shrimp. Length-frequencies and other data were collected by the Shrimp Investigations of the Bureau of Fisheries (Weymouth *et al., op. cit.*) but they have not been published. Burkenroad (1934) pointed out that X. krφyeri rarely entered bay waters in Louisiana and had not been taken up to that time in the insufficiently explored outer littoral zone. It is not taken in the depths commonly fished offshore by the present shrimp fishery, 10–18 fathoms, and probably lives closer to shore.

Approximately 550 specimens were taken in the course of this work. Table 7 shows the catches by months. They were taken at all seasons of the year, but were most abundant in the fall. Three shrimp were taken in Aransas Bay in 2 trawl hauls

TABLE 6

The numbers of *Penaeus aztecus* and *P. duorarum* taken each month in the different nets in the two bays and the Gulf are shown.

	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Aug.	
Copano																	
Minnow Seines	———	———	53	115	1	32	129	85	20	———	———	———	193	159	189	27	———
Trawls	44	2,070 (app.)	830	229	———	1	12	5	13	———	2	9	4	2,109	———	10	———
Aransas																	
Minnow Seines	———	———	572	131	———	34	147	307	51	3	———	———	83	1,421	210	17	———
Trawls	———	———	1,254	960 (app.)	1	12	3,260	5	20	———	13	38	199	———	———	1	——— (app.)
Trammel Nets	———	———	———	1	———	———	———	———	———	———	———	———	———	———	———	———	———
Gulf																	
Minnow Seines	———	———	———	15	———	———	———	———	———	———	———	———	———	———	———	———	———
Trawls	———	———	114	8	———	68	14	———	———	———	———	12	26	53	———	———	———
Totals	44	2,070 (app.)	2,823	1,460 (app.)	2	157	3,580 (app.)	402	407	3	15	59	505	3,652	399	55	15,360 (app.)

in November, 1941, and February, 1942. These were taken in the lower bay. Ninety-seven shrimp were taken in one minnow seine haul in the channel leading into the Gulf in October, 1941. The remainder was taken in the Gulf. The water temperatures where the shrimp were caught ranged from 14.4 to 30.0°C. The salinity ranged from 21.2 to 36.7 *per mille*. This shrimp prefers waters of high salinity.

TABLE 7

The catches of *Xiphopeneus krøyeri*, the sea bob, by months are given.

	1941				1942			
	June	Aug.	Oct.	Nov.	Jan.	Feb.	March	April
Aransas Bay								
Trawls	-------	-------	-------	2	-------	1	-------	-------
Minnow Seines	-------	-------	97	-------	-------	-------	-------	-------
Gulf								
Trawls	5	1	9	415 (app.)	16	-------	4	1

Figure 5 shows the total length-frequency curve of specimens taken in inside waters in three hauls at salinities varying from 21.2 to 30.7 *per mille*, compared to a similar curve of specimens taken in the open Gulf in 9 hauls where the salinity varied from 29.7 to 35.2 parts *per mille*. Obviously, only the smaller shrimp venture into the less saline waters.

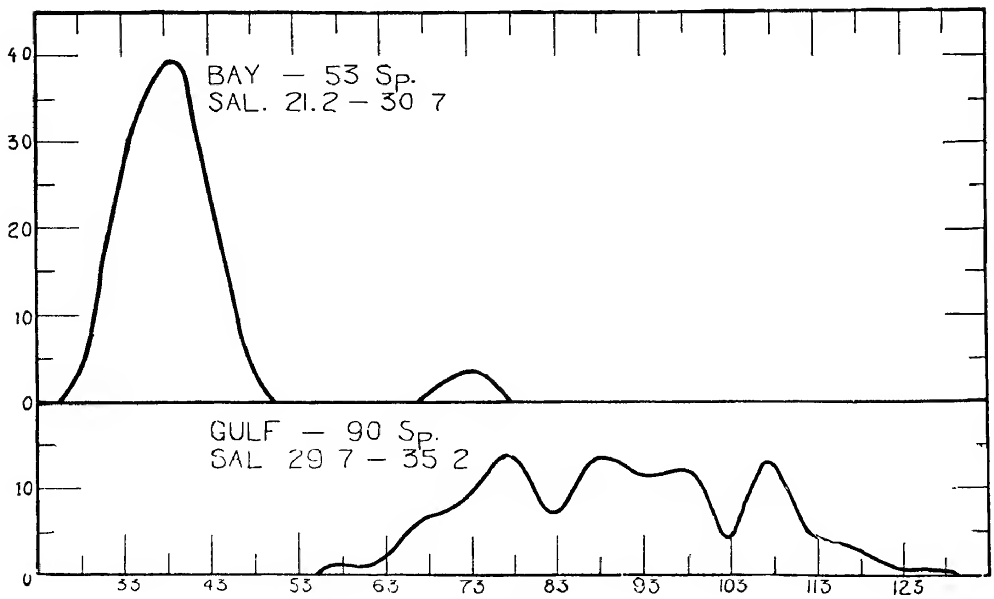

FIGURE 5

Length-frequency curves of *Xiphopeneus krøyeri* taken in the Bay and Gulf waters at different salinities.

Table 8 shows the total length ranges in mm. of *Xiphopeneus krφyeri* taken in the various months. In October the sea bobs caught had a definite length-frequency mode at 38 mm. This was the only month in which a mode was clearly shown by the data.

TABLE 8

The length range and number of *Xiphopeneus krøyeri* caught are given for the various months.

Month	Length Range mm.	No. specimens
June, 1941	94–127	5
Aug., "	(not measured)	1
Oct., "	28–108	59
Nov., "	59-116	57
Jan., 1942	77–115	16
March, "	96–112	4
April, "	76	1

Like other peneids, there is probably great difference between the maximum size of males and females, the females being larger. Burkenroad (1934) pointed out the greater size of females at the maximum size among the specimens he studied. The writer sexed only 5 specimens, all taken in a trawl on June 5, 1941, 2 miles SSE of Aransas Pass in the open Gulf. Two males were 94 and 107 mm. in total length. Three females were 120, 124 and 127 mm. long, respectively. The two largest females had large, dark green ovaries, which I took to be ripe or in an advanced stage of development.

Trachypeneus constrictus (Stimpson)

The shrimp listed under this category were all thought to belong to the one species, but some specimens of *T. similis* may have been included. Mr. W. W. Anderson was kind enough to identify specimens of *T. constrictus* sent to him. One hundred and four shrimp were caught in trawls in 12 hauls made in the months of June, July, October and November, 1941 and January, March and April, 1942. The water temperatures where the shrimp were caught ranged from 13.7 to 28.2°C. One shrimp was caught in the upper end of Aransas Bay on April 28, 1942 where the salinity was 21.9 *per mille*. All other shrimp were taken in the open Gulf at salinities ranging from 29.7 to 35.5. Only 7 shrimp were caught where the salinities were below 30.0 and only 10 shrimp were taken at salinities below 33.0. This species evidently rarely enters waters of low salinities. Fifty-five of these shrimp were taken 5 miles offshore and 53 were taken 2 miles offshore. A few are caught in every drag by shrimp fishermen at 16 fathoms during the summer.

Table 9 gives the minimum and maximum total lengths in mm. and the number of specimens caught each month. Two females, measuring 84 and 91 mm. in length, respectively, had large, dark green ovaries, which I took to be ripe. They were taken 2 miles SSE of Aransas Pass in the Gulf of Mexico on June 5, 1941. The temperature was not taken. The salinity was 34.2 *per mille*. Ripe specimens taken by shrimpers were also seen in September.

TABLE 9

The length range in mm. and the numbers of *Trachypeneus constrictus* caught each month are shown.

Month	Length Range, mm.	Number specimens
June, 1941	44–91	26
July, "	42–54	3
Oct., "	(broken)	1
Nov., "	59	1
Jan., 1942	42–83	23
March, "	29–87	45
April, "	56–74	6

Sicyonia dorsalis (Kingsley)

Ten specimens of this shrimp were taken 5 miles offshore in the Gulf at the Whistling Buoy, SSE of Aransas Pass, on May 25, 1942. They ranged from 49 to 64 mm. in total length. The temperature was 23.3°C. and the salinity was 33.6 *per mille*. Specimens were identified as *S. dorsalis* in the restricted sense of Burkenroad (1939) and not that of other authors. Numbers of these colorful little shrimp, ranging from a handful to a few hundred every drag, are taken by shrimp fishermen along the south Texas Coast during the summer among the thousands of *Penaeus* at depths from 14 to 18 fathoms.

Palaemonidae

Palaemonetes vulgaris (Say) and other species

Over eight thousand grass shrimp, chiefly *P. vulgaris*, but including other species, were caught. The temperature range was from 12.5 to 34.0°C. and the salinity range was from 2.0 to 34.2 *per mille*. No grass shrimp were taken in the Gulf and all except one specimen were taken in minnow seines near the shore in the bays. The one exception was taken in a trawl in Copano Bay following a freeze in January, 1942. This is another example of the fact pointed out before (Gunter 1935, 1941, 1945) that shallow water animals leave the shore area during cold spells and go to greater depths, probably in search of warmer water.

These little shrimp will live in waters of high salinities and probably they are similar to the cyprinodontid fishes in that they do not inhabit the Gulf beach because of lack of cover, rather than because they cannot withstand the salinities (Gunter, 1945). Nevertheless, the grass shrimp were found to be most abundant at salinities around 10.0 *per mille* and they were taken in greater numbers in Copano Bay than in Aransas Bay. These shrimps were often taken in such abundance that counts were not made and therefore exact numerical data cannot be presented.

These little shrimp were taken at all seasons of the year, but none were caught in Aransas Bay between September 5, 1941, and January 13, 1942, and none were caught between November 3, 1941, and January 17, 1942, in Copano Bay. It is probable that they did not die out or disappear at this time, but moved out to slightly deeper water when the temperatures first began to drop in the fall. Egg-bearing females ranged from 20 to 40 mm. in length and were found from May to October.

Holthuis (1949) has recently revised the *Palaemonetes* of the United States, showing that Texas brackish waters contain 3 species, *vulgaris*, *intermedius* and *pugio*. He says the ecological habitats are doubtless different and *pugio* seems to prefer lower salinity than *vulgaris*.

Macrobrachium ohione (Smith). River Shrimp

One specimen was taken in the upper end of Aransas Bay on June 4, 1941. The temperature was 29.8°C. and the salinity was 2.1. This fresh water shrimp sometimes enters brackish water as high as 12.0 *per mille* saline (Gunter, 1937).

Anomura

Paguridae. Hermit crabs

Particular attention was not paid to the common species of hermit crabs, chiefly because it was difficult in the field to extract them from the gastropod shells in which they live and time was given chiefly to the work on fishes. There are two common species; *Pagurus floridanus* (Benedict) was commonly taken in trawls and seines in lower Aransas Bay and the Gulf. Another species, *Clibinarius vittatus* (Bosc), seemed to prefer the less saline waters and was commonly caught in upper Aransas Bay and Copano Bay.

Petrochirus bahamensis (Herbst). Red hermit crab

One specimen of this large, red hermit crab was taken in a trawl in the Gulf, 5 miles SSE of Aransas Pass, on March 22, 1942. The temperature was 16.9 and the salinity was 33.9.

Brachyura

Calappidae

Calappa springeri Rathbun

Six examples of this crab were taken in 4 trawl hauls in the Gulf, 2 and 5 miles SSE of Aransas Pass, in the months of January and March, 1942. The bottom temperature varied between 13.7 and 17.1°C., while the salinities ranged from 33.0 to 35.2 *per mille*. From one to a dozen are taken each drag by shrimp fishermen at 12 to 16 fathoms.

Hepatus epheliticus (Linnaeus). Spotted crab

Twelve specimens were taken in the Gulf. Nine crabs were taken on the Gulf beach of Mustang Island in a minnow seine during the months of November and December, 1941, and 3 were taken in trawls 2 miles SSE of the pass in January, March and April, 1942. The temperatures ranged from 13.8 to 24.5°C. and the salinity range was 28.7 to 35.2.

Portunidae

Ovalipes ocellatus guadalupensis (Saussure)

Four crabs of this species were taken in 2 trawl hauls in the Gulf, 2 and 5 miles offshore, in the months of September, 1941 and May, 1942. The temperatures were 29.5 and 23.3°C. respectively, and the salinities were 36.5 and 33.6 *per mille*.

Portunus gibbesii (Stimpson)

Thirteen crabs of this species were taken in the Gulf, 2 and 5 miles offshore. They were caught in 4 trawl hauls during the months of January and March, 1942. The temperature range was 13.7 to 16.9°C. and the salinity range from 33.0 to 36.9 parts per thousand salt. Five *P. gibbesii* were taken in lower Aransas Bay, Lydia Ann Channel, in a trawl on October 20, 1941. The temperature was 25.9°C. and the salinity was 19.2.

Callinectes exasperatus (Gerstaecker)

One specimen was taken in a trawl in Lydia Ann Channel on March 15, 1942. The temperature was 18.4 and the salinity was 30.0. The identification is tentative.

Callinectes danae Smith

Three hundred and eighty-three *C. danae* were caught. Three hundred and fifty-four were taken in trawls and the remainder taken in trammel nets and minnow seines. Table 10 shows the monthly catches. This crab was most abundant in the spring and

TABLE 10

The monthly catches of *Callinectes danae* are shown.

	1941					1942					
	June	July	Aug.	Sept.	Oct.	Mar.	April	May	June	Aug.	Oct.
Aransas Bay											
Nets	—	—	—	—	—	—	4	3	—	—	—
Minnow Seines	—	—	—	—	—	—	—	20	—	—	—
Trawls	—	—	—	—	32	3	1	—	—	1	—
Gulf											
Minnow Seines	—	—	—	—	—	—	—	—	1	—	1
Trawls	20	3	1	2	28	200	22	41	—	—	—

it was not caught in the winter. Sixty-four crabs were taken in Aransas Bay and 319 were caught in the Gulf of Mexico. The temperature range where they were caught was from 15.4 to 30.5°C. and the salinity was from 16.5 to 36.7. Table 4 shows that 71.0 per cent of crabs were taken at salinities above 30.0.

Small crabs from 12 to 30 mm. long appeared in May in the lower half of Aransas Bay. Few crabs were taken farther inland. A few small crabs were also taken in the Gulf during the summer. The size of all specimens caught ranged from 12 to 120 mm. in carapace width. Table 11 gives the length-frequency range in mm. of the crabs measured each month.

Shrimp fishermen say that where this crab collects in numbers in the shallow Gulf they always "run" the shrimp from that locality.

Callinectes sapidus Rathbun. Blue crab

The blue crab is rather abundant in Texas waters. Three thousand nine hundred and forty-five were taken in the course of this work. Eighteen hundred and eighty-eight blue crabs were taken in Copano Bay, 1,924 in Aransas Bay and 133 were

TABLE 11

The width-range in mm. of the specimens of *Callinectes danae* measured each month are given.

	1941			1942				
	July	Aug.	Sept.	April	May	June	Aug.	Oct.
Width-range	47–92	102	69–84	37–120	12–108	22	88	29
Number of Specimens	3	1	2	27	64	1	1	1

taken in the open Gulf. Seventy-five crabs were taken in beach seines, 870 were taken in trammel nets, 868 in minnow seines and 2,132 were caught in trawls.

Table 12 gives the catches each month by the different gear for the bays and the Gulf. The crabs were caught in the greatest numbers in the spring. There was a decline in numbers in the winter.

The size of specimens varied from 5 to 218 mm. carapace width. The temperature range at stations where blue crabs were caught was from 8.1 to 34.9°C. and the salinity range was from 2.0 to 37.2 per mille. This animal is euryhalin. It sometimes enters pure fresh water and goes many miles upstream (Gunter, 1938a). Table 4 shows that it was taken in abundance at salinities between 10.0 and 20.0 parts per thousand. This crab seems to prefer brackish waters of the bays in contrast to *C. danae,* which prefers the higher salinities of the open Gulf. Nevertheless, the blue crab does normally live in the open sea and the writer has observed females in berry swimming at the surface of the open sea several miles from shore. Such individuals often undergo attack from sharks and the ling or crabeater, *Rachycentron canadus* (Linnaeus), which they repel or attempt to repel with characteristic pugnacity.

Figure 6 shows that there is a tendency for the crabs of smaller sizes to distribute themselves in waters of lower salinities in greater numbers than the larger sizes do. Churchill (1919) and later authors have pointed out that small crabs migrate from the lower Chesapeake Bay, where they hatch out and undergo larval stages, to the upper bay where the water is less saline.

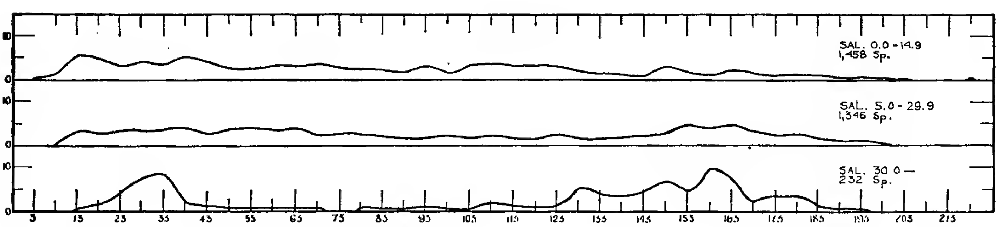

FIGURE 6

Length-frequency curves of the blue crab, *C. sapidus,* at the salinities shown.

One breeding pair was taken in a trammel net at Redfish Point, lower Copano Bay, on June 11, 1941. They were not measured. The water temperature was 30.0°C. and the salinity was 3.0 *per mille.* Two breeding pairs were caught on October 21, 1941, in trawls. One pair was caught in lower Copano Bay. The temperature was 26.2

TABLE 12

The catches of the blue crab, *Callinectes sapidus*, in the different nets are shown by months for the 2 bays and the Gulf of Mexico.

	1941									1942									
	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Aug.	Sept.	Oct.	Nov.	
Copano																				
Trawls	9	49	14	25	34	38	29	27	34	20	208	301	235	253	—	32	—	—	—	—
Nets	—	—	4	11	16	30	17	14	19	16	23	14	21	16	51	46	—	80	—	—
Minnow	—	—	5	18	1	18	34	22	12	21	20	10	4	6	21	12	—	—	—	—
Aransas																				
Trawls	—	—	23	44	2	25	54	35	33	15	52	221	271	—	—	10	—	—	—	—
Nets	—	—	—	18	13	24	31	16	25	1	5	7	19	83	69	75	—	108	—	—
Minnow	—	—	103	91	4	27	51	106	64	50	8	23	33	28	27	30	—	—	—	—
Gulf																				
Trawl	—	—	4	5	4	—	1	1	—	7	—	2	11	4	—	—	—	—	—	—
Minnow	—	—	3	—	—	2	4	—	—	—	—	—	3	—	2	—	3	1	1	—
Beach S.	—	—	—	4	—	—	12	—	—	—	—	1	6	—	52	—	—	—	—	—
Totals	9	49	156	216	74	164	233	221	187	130	316	579	603	390	222	205	3	189	1	3,945

and the salinity was 10.3. The other pair was taken in middle Aransas Bay. The temperature was 25.4 and the salinity was 17.9. The male was 176 mm. wide and the female was 129 mm. wide.

Females carrying eggs were taken from March 22 to August 25, 1942. Newly hatched larvae may then be expected in these waters from March to September. Seventy-one females carrying eggs were taken. Four were caught in March, 27 in April, 14 in May, 21 in June, and 5 in August. The eggs were taken in the various color stages of yellow, yellowish orange, brown and dark brown. All of the "sponges" taken in March were yellow, while those taken in August were brown or black. Forty-two females with eggs were taken in the lower bay near the Gulf, 22 were caught in the surf of the Gulf beach, and 7 were taken offshore in the Gulf in trawls. Only one female in berry was taken as far out as 5 miles in the Gulf.

The salinity range where the egg-bearing blue crabs were caught ranged from 22.9 to 32.4. Forty-one were taken at salinities above 30.0, 23 at salinities between 25.0 and 30.0 and 7 at salinities between 22.9 and 25.0. The average salinity at the stations was 28.4 *per mille.* The temperature range was from 17.6 to 32.0°. Sandoz and Rogers (1944) found that the optimum salinity range for the hatching of the blue crab eggs in Virginia was 23.0 to 28.0 *per mille.* They also found that the temperature range, outside of which the eggs failed to hatch, was 19.0 to 29.0°C. In Texas waters this upper temperature limit is probably slightly higher and possibly the upper salinity limit is slightly higher, also.

The egg-bearing females ranged from 110 to 185 millimeters in width across the carapace. The average width was 155 mm. Some females up to a size of 160 mm. in carapace width were found that were immature, as determined by the triangular shape of the abdomen. Churchill *(op. cit.)* had reported males carrying such females and it is probable that the females will copulate before the abdomen is fully expanded.

Larval crabs in the megalops stage were found in the surf of the Gulf beach many times during the warmer months, but the data were not recorded. The smallest crab caught was 5 mm. in carapace width. Several specimens 8 mm. wide were taken. As indicated above, the crab has a long hatching season in Texas waters. This fact and the fact that the growth rate slows down in the winter are probably sufficient to account for the presence of small crabs during practically all months of the year. Figure 7 gives the carapace width-frequency curves by months of the 3,129 specimens that were measured. The width measurements in mm. were blocked off in groups of five with the points falling on the threes and eights.

Figure 8 gives the width-frequencies of crabs taken in the different gear. The nets and minnow seine hauls were made on the flats or in the shallows and it is clear that, although large crabs come in close to shore and small crabs venture into offshore waters, where they were taken in trawls, nevertheless, the smaller crabs are predominant in the shallow waters. Churchill *(op. cit.)* said that in general the smaller crabs were found in the shallower water. Gunter (1937) found that the same situation held true for the river shrimp, *Macrobrachium ohione,* and reported that in general the smallest fishes were also found in the shallower water on the Texas Coast (Gunter, 1945).

Sexing of crabs was not carried out during most of this work, but it was introduced in June, 1942. In minnow seine hauls in Aransas Bay in June and August the ratio

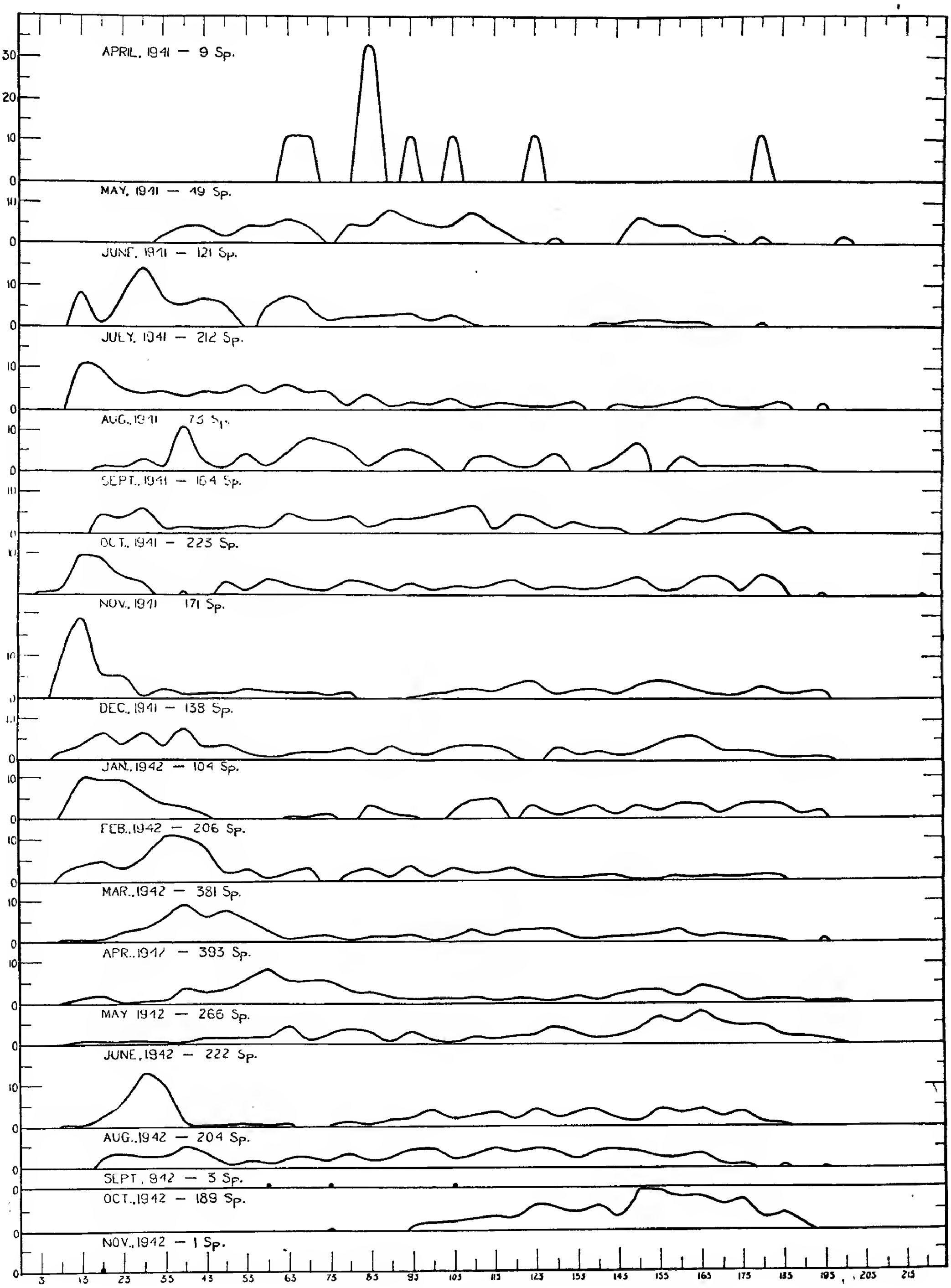

FIGURE 7

Monthly frequency curves of carapace width of the blue crab, *C. sapidus*. Measurements of animals taken in the different gears are combined.

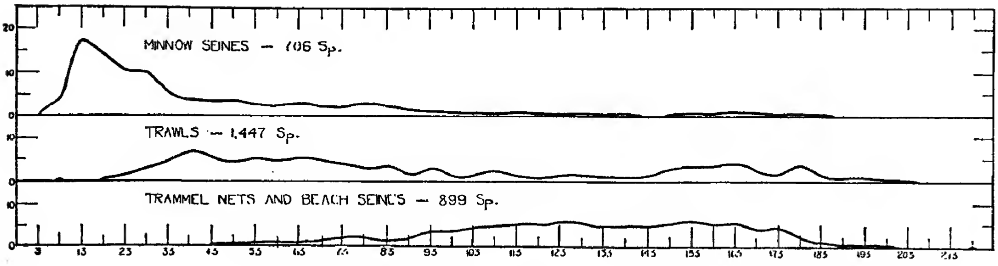

FIGURE 8

Carapace width-frequency curves of the blue crab taken in different gear.

of males to females was 7 to 17 and 9 to 21, respectively. The size range of these crabs was from 11 to 165 mm. in width, only 3 being wider than 100 mm. In trawls in the month of August the ratio of males to females in Copano and Aransas Bays was 7 to 24 and 3 to 7, respectively. The size range was 27 to 191 mm. in width, with only 3 crabs wider than 100 mm. Significant differences in the sex ratios were not found among the 39 crabs taken in minnow seines in Copano Bay in June and August. The sex of crabs taken in trawls was determined only in August, given above, and this comprises the full data on the sex ratio of crabs taken in minnow seines and trawls. The data on the crabs taken in beach seines and trammel nets, are given in Table 13. The size range of all specimens was from 58 to 190 mm. in length, most of them being of adult size. The average width of the 326 males was 140 mm. and of the 159 females was 137 mm. During June and August, 1942, the males in the catches in Copano Bay outnumbered the females by 6 to 1. In October this ratio had changed to 1 to 3.7. Thirteen of the 17 females taken in October in Copano Bay had the immature triangular-shaped abdomen. The size range of this immature group was from 105 to 160 mm. in carapace width. Probably these females entered the brackish water preparatory to pairing in the fall.

TABLE 13

The ratio of male and female blue crabs, *Callinectes sapidus*, taken in trammel nets and beach seines from June to October, 1942, are shown.

		June	August	September	October
Trammel Nets	M.	42	45	----	63
Copano	F.	10	4	----	17
Trammel Nets	M.	66	35	----	67
Aransas	F.	3	35	----	39
Beach Seines	M.	8	----	----	----
Gulf	F.	45	----	----	----

The table further shows that in Aransas Bay the males outnumbered the females by 22 to 1 in June, and that the sexes were present in about equal numbers in August, but the males were almost twice as numerous as females in October. On the Gulf beach the females outnumbered males by more than 6 to 1 in June and September. The data is slight, but the indications of differential distributions of the sexes in Texas waters correspond to what had been found on the blue crab in Chesapeake Bay by Churchill *(op. cit.)* and subsequent workers.

Fifty-nine crabs with the sacculinid parasite, *Loxathylocus texana* Boschma, attached to the abdomen were found. Two crabs had 2 parasites each. Only one parasitized crab greater than 100 mm. in carapace width was found. Parasitized male crabs seemed to assume female characters, and had developed a broadened abdomen, protecting the parasite. Almost all parasitized crabs were females. Peculiarly, only 2 parasitized crabs were found in Copano Bay, and the other 57 came from Aransas Bay.

Arenaeus cribrarius (Lamarck). Speckled crab

More than 32 speckled crabs were caught in the Gulf of Mexico. They were taken in the months of July, September, October and November, 1941, and March, May and June, 1942. In one minnow seine haul on the Gulf beach in October, 1941, several were caught and the number was not determined. In addition 12 crabs were taken in beach seines and 20 were taken in trawls 2 and 5 miles offshore. Three were taken 5 miles offshore and 17 were taken 2 miles offshore. The temperatures at the stations where these crabs were taken varied from 17.1 to 29.5°C. The salinity range was from 26.7 to 36.5 *per mille*.

Xanthidae

Menippe mercenaria (Say). Stone crab

Several small crabs, mainly of the genera *Panopeus* and *Neopanope,* are abundant on oyster reefs. They do not live on mud and seldom are picked up in trawls, which are not operated over shell or oyster reefs. A few were collected in the trawls in the vicinity of the reefs, but records were not kept. These crabs and certain fishes belong to the oyster reef complex or community, and are not spread generally over the bays, except along the shores. The stone crab, *M. mercenaria,* is similarly restricted in distribution. Three stone crabs were caught in the trawl. One crab was taken near Jordan's Pass, Middlebank Reef, in Copano Bay, on October 21, 1941. The temperature was 26.4°C. and the salinity was 11.6. Two were taken in Lydia Ann Channel, lower Aransas Bay, on March 14 and April 23, 1942. The water temperatures were 16.9 and 22.4°C. The salinities were 34.2 and 28.5 *per mille*.

Oxyryncha

Libinia emarginata Leach. Spider crab

Several spider crabs were taken in lower Aransas Bay. Some were unidentified. Of the above species 3 specimens were caught in lower Aransas Bay in January and April, 1942, and 7 were taken in the Gulf in January, March and May, 1942. All specimens were taken in trawls. The water temperature varied from 9.9 to 23.5°C. and the salinity ranged from 17.6 to 35.2 *per mille*. Only one specimen was caught where the salinity was below 25.7.

Bryozoa

Ectoprocta

Zoobotryon pellucidum Ehrenberg. Sea moss

The beaches of the Gulf are sometimes strewn with windrows of this peculiar colonial animal. It is translucent, with no coloring matter on the many branching filaments. Fishermen think it is a plant and many of them call it "hay." Occasionally it is taken in such great abundance in shrimp trawls as to cause trouble to the fishermen. The writer took a great mass of it, amounting to a barrel-full or more, in a trawl, 2 miles SSE of Aransas Pass, in August, 1941. Several wads of it were taken in Lydia Ann Channel in August, 1942. The temperature range was 29.5 to 30.3°C. and the salinity range was 35.0 to 36.7. Smaller amounts of this bryozoan were taken at other times in the Gulf and Aransas Bay, but records were not kept.

Echinodermata

Asteroidea. Starfish

Astropecten articulatus (Say). Short Star

Twenty-eight specimens of this starfish were caught in trawls. Five were caught in the Lydia Ann Channel, leading from Aransas Bay into the Gulf, April 23, 1942. The remaining 23 were taken at the trawl stations on the Gulf in the months of July, August, October and November, 1941 and April and May, 1942. The temperature range was from 18.4 to 28.2°C. and the salinity range was 29.7 to 36.7 *per mille.*

Astropecten duplicatus Gray

Twenty-three specimens were taken in 5 trawl hauls at the Gulf stations in the months of July, August and October, 1941 and April, 1942. The temperature range was 20.9 to 30.0°C. and the salinity range was from 29.7 to 36.7 *per mille.*

Echinoidea. Sea Urchins and Sand Dollars

Mellita quinquiesperforata (Leske). Sand Dollar

Seven specimens were taken in the Gulf, 2 miles SSE of Aransas Pass, in one trawl haul on April 22, 1942. The temperature was 20.9°C. and the salinity was 29.7 *per mille.*

DISCUSSION

Relative Numbers of Species

The nets used in collecting animals during the course of this work were better fitted for the capture of fishes than for taking invertebrates. The minnow seine was operated in the very shallow water near shore. The trammel net was used on the flats along the margins of the bay shores. The beach seine was used at comparable depths on the Gulf beach. The otter trawl was the only collecting gear operated in the deeper waters of the bays and the Gulf. The trammel net and the beach seine had meshes too large for the capture of anything except large crabs, chiefly the blue crab, but the trawl and the minnow seine caught most invertebrates that were free in the water. The larger crabs sometimes avoided the minnow seine. The trawl was the best all around net for collecting invertebrates. It was most deficient in taking the sessile or low-lying bottom species, such as the sea pansy, *Renilla,* the sand dollars, starfish and various gastropods and other molluscs. On the other hand, the trawl used was devised for the taking of shrimp, and shrimp and crabs were taken in considerable numbers. Furthermore, it is probable that the various species of crustacea were taken in numbers approximately proportional to their relative abundance in the waters fished.

Approximately 72,000 specimens of invertebrates were taken. Table 14 gives the numbers caught of all species taken over 100 times. With the exception of the sea

TABLE 14

The total numbers of specimens caught of all invertebrates taken more than 100 times are given.

	Copano Bay	Aransas Bay	Gulf of Mexico	Totals
Penaeus setiferus	26,575 (app.)	15,360 (app.)	1,690 (app.)	43,625 (app.)
Penaeus axtecus—duorarum	6,340 (app.)	9,050 (app.)	310	15,700 (app.)
Palaemonetes spp.	4,280 (app.)	4,025 (app.)	———	8,300 (app.)
Callinectes sapidus	1,888	1,924	133	3,945
Renilla mülleri	———	———	3,171	3,171
Xiphopeneus krφyeri	———	100	450 (app.)	550 (app.)
Callinectes danae	———	64	319	383
Loligo brevis	———	97	179	276
Trachypeneus constrictus	———	1	103	104

pansy, *Renilla mülleri*, and the squid, *Loligo brevis*, the only invertebrates taken in any numbers were crustaceans. Shrimp of the family *Peneidae* are the dominant invertebrates of the shallow waters of the Texas Coast. Of the nine species most commonly taken, shown in Table 14, four were peneid shrimp. Six species of peneids were caught and two of them were very common. In numbers the peneids made up approximately 83.0 per cent of the invertebrates taken and *Penaeus setiferus* alone made up more than 60.0 per cent of the catch. During most of the year, *P. setiferus* is overwhelmingly abundant and the writer (Gunter, 1945) made the statement that this species possibly had a greater species mass than any macroscopic animal in Gulf littoral waters. For a short time during the summer its numbers are exceeded by *P. aztecus* and *P. duorarum*, the former being by far the most numerous and the latter probably negligible, so far as actual numbers are concerned. The blue crab, *Callinectes sapidus*, is present in abundance in the bays and shallow Gulf. Another peneid, *Xiphopeneus krφyeri*, is quite numerous in the Gulf at times in the fall. *Callinectes danae* enters the lower bays only in the summer, but it is fairly common in the Gulf and is the most abundant crab there. According to commercial shrimpers, *vide supra C. danae*, it gathers in large aggregations in the shallow Gulf at times. The grass shrimp, family Palaemonidae, chiefly *Palaemonetes vulgaris*, differ from the common shrimp and crabs in the fact that they are found only in the bays and furthermore are found only in the shallows near shore, similar to the cyprinodontid fishes (Gunter, 1945). They like vegetative and other cover and probably do not live on the Gulf beach because of lack of cover there, but they also prefer the shallows and are not taken in the open bay in those places where cover exists. Although extremely abundant in the shallows, where they are often the predominant animals, due to their restricted habitat along a relatively narrow strip near shore, they do not rank with the common shrimp and blue crab in species mass.

In the Gulf, scrape dredges and other collecting gear might show that the sea pansy, *Renilla*, the sand dollar, *Mellita*, and starfish, *Astropecten*, are more numerous bottom animals than their numbers in the trawl catches showed. It may be they form a definitive biome somewhat similar to the *Strongylocentrotus-Argobuccinum* biome found by Shelford (1930) in the Pacific (Puget Sound).

The relative abundance rank of the oyster, *Crassostrea virginica*, compared to the other predominant animals of this region has not been determined in this study. The oyster is confined to the bays where it collects in vast aggregations or reefs, of which the living part may be a small percentage of the whole. Nevertheless, the living oyster forms a respectable part of the living mass of animal material in most Texas bays. It is usually collected or gathered into more discrete masses or aggregates than most of the species discussed in this paper.

The numbers of invertebrates taken ranged from several thousand, as in the case of *P. setiferus*, to only one specimen, as in the case of several species. This picture of the relative abundance of species is very similar to that found for fishes (Gunter, 1945). In many instances the numbers of a species taken are reflections of the relative abundance of the various species, while in others certain species were not easily caught by the gear used, so that certain species were probably present in greater relative numbers than the catch records show.

Distribution of Species as Related to Salinity

The division of the fauna of the bays and Gulf into separate groups was sharper among the invertebrates than in the case of fishes, previously discussed by the writer (Gunter, 1945). This is probably due in large part to the fact that the invertebrates are poorer swimmers than fishes and do not move about as much. On the other hand, the invertebrates are probably less isolated from their environment, are less able to cope with its changes and are therefore less euryhalin than the fishes are. Similar to what was found for the fishes (Gunter, *op. cit.*) all species could tolerate high salinities, but many species were not found at low salinities. For that reason many invertebrates were found only in the Gulf of Mexico, and many of them that live there near the mouths of the passes venture seldom or never into the bays. Since the bay species could all tolerate high salinities and most of them entered the Gulf, the number of species found in the Gulf greatly exceeded the number of species found in the bays. The number of species taken in the bays only was 4, while the number found in the Gulf only was 22. The number of species taken both in the bays and the Gulf was 20. Therefore the number of species taken in the bays was 24, while the number taken in the Gulf was 42. Similarly, the back bay, Copano Bay, contained fewer species than the more highly saline Aransas Bay. Only 8 species of invertebrates were taken in Copano Bay, while 24 were caught in Aransas Bay. Similar differences between number of species of fishes in the bays and Gulf was found (Gunter, *op. cit.*), but it was not specifically reported in that paper.

Species taken only in the bays were the river shrimp, *Macrobrachium ohione*, a stray from fresh water, the common oyster and the grass shrimp, which possibly was comprised of several species, and the stone crab. The oyster and the grass shrimp are never found in the Gulf and they are the only common invertebrates strictly confined to the bays. As was mentioned before, *vide supra Menippe mercenaria* and

TABLE 15

The species of invertebrates not caught below the salinities given are shown. *Ostrea virginica* and probably *Dactylometra quinquecirrha* may be found at lower salinities than shown here.

Not taken below 30.0 per mille	Not taken below 25.0 per mille	Not taken below 20.0 per mille	Not taken below 15.0 per mille	Taken below 5.0 per mille
Urosalpinx sp.	*Leptogorgia setacea*	*Xiphopeneus krøyeri*	*Dactylometra quinquecirrha*	*Crassostrea virginica*
Thais floridana	*Renilla mülleri*	*Trachypeneus constrictus*	*Loligo brevis*	*Penaeus setiferus*
Busycon perversum	*Zoobotryon pellucidum*		*Squilla empusa*	*Penaeus aztecus*
Busycon pyrum	*Ostrea cristata*		*Callinectes danae*	*Palaemonetes* sp.
Tethys sp.	*Tonna galea*		*Libinia emarginata*	*Macrobrachium ohione*
Loligo pealeii	*Hepatus epheliticus*			*Callinectes sapidus*
Octopus vulgaris	*Arenaeus cribrarius*			
Sicyonia dorsalis	*Astropecten antilliensis*			
Petrochirus bahamensis	*Astropecten dublicatus*			
Calappa springeri	*Mellita quinquiesperforata*			
Ovalipes ocellatus guadalupensis				
Portunus gibbesii				
Callinectes exasperatus				

Gunter (1945), certain crabs and fishes live on live and dead oyster reefs and thus are not found in the Gulf. Numerous gastropods and crabs, listed in the text, are typical of the open sea and the open sea alone.

Table 15 gives the species taken at the various salinities. It verifies the statement that most species can withstand higher salinities, but many cannot withstand lower salinities. The salinity range at which each species was caught is given in the text.

It is significant that the most abundant invertebrates, namely the two peneid shrimp, *P. setiferus* and *P. aztecus*, the blue crab, *C. sapidus*, and the grass shrimp were practically euryhalin and were found at salinities as low and lower than 5 parts per thousand. The same general observation was made on the fishes of the region (Gunter, *op. cit.*). All of the most numerous fishes were found to be almost completely euryhalin.

With the possible exception of the grass shrimp, and the stray river shrimp, the invertebrate fauna taken in the bays in the course of this work was all marine. It is significant that brackish water fauna is marine and not fresh water, as pointed out by Gunter, *op. cit.*, and Pearse (1936). The data on fishes (Gunter, *op. cit.*) likewise show that marine animals will tolerate or become accustomed to lowered salinity better than fresh water animals will tolerate a raised salinity. As the waters become fresher towards the head of the bays, the marine species with a predilection for higher salinities drop out of the picture, while a few others persist, and there is no compensating increase in numbers of species by invaders from fresh water. Although certain fresh water species do invade the lower limits of salt water as has been shown by many authors (see Gunter, 1942, for data on fishes of North and Middle America), the general picture shown by a long series of regular collections is as stated.

Seasonal Cycles

Practically all of the invertebrates listed in this paper spawn and hatch in the spring or at least during the warm part of the year. This holds true for the blue crab, *Callinectes sapidus*, which, nevertheless, breeds in the fall as well as during summer. Fall breeding female crabs apparently lay their eggs the following spring. Some of the numerically important species, such as the two common peneid shrimp, *Penaeus setiferus* and *P. aztecus*, enter the bays as postlarvae in the spring. During the summer the young of *C. sapidus* work farther into the bays from the lower bay and Gulf, where they undergo larval growth and transformation. The squid, *Loligo brevis*, the shrimp, *Trachypenaeus constrictus*, and some of the crabs commonly found in the Gulf also work into the bays in the spring and summer. During the fall and early winter all of these animals, most of them having grown considerably in size, start a movement to or towards the Gulf and many of them are not found in the bays during the winter at all. The seaward movement of the common shrimp, *P. setiferus* is quite striking and the character of the shrimp fishery is determined by it. In late summer and early fall the shrimp leave the flats and shallows and begin to concentrate in open bay waters. By December most of the shrimp have passed to the outside. For a time about half of the shrimp trawlers are working in the Gulf and half in the bays. By December practically no boats continue to work in the bays, all of them going to the Gulf. The shrimp do not entirely leave the bays in the winter, although they may be completely absent from the back bay, Copano Bay, for a time in midwinter. Those remaining in the bays are most concentrated in the lower bay near the passes into the Gulf. The same general picture holds for the other motile, but less numerous invertebrates, and this is similar to the slow seaward movement of fishes in the fall, previously described by the author (Gunter, *op. cit.*).

Even those invertebrates which do not leave the bays in the winter, such as the grass shrimp and blue crab, apparently move away from the edge of shore to deeper water and their numbers become much less in the minnow seine hauls during the winter. This is more apparent for the crab in Aransas Bay and on the Gulf beach than in Copano Bay. The data for the grass shrimp were given above. At the same time the catch of crabs in Copano Bay in trawls, the deeper open water part of the bay, increases.

The only counter movement to the slow seaward movement of most invertebrates in the winter is the entry of the sea bob, *Xiphopeneus krφyeri*, into the bays in the fall and winter. Here again is a phenomenon parallel to what was found among the fishes *(op. cit.)*, where a few species entered the bays in fall and winter counter to the seaward movement of the majority.

This general exodus of shrimp and other invertebrates as well as fishes from the bays is correlated with the annual temperature cycle and not with salinity changes or any other phenomenon. Therefore, it may be stated that temperature is a much more important factor than salinity in the general cyclic movements of marine animals of this region. This holds true in spite of the fact that salinity may be a definitely limiting factor in confining a species to a portion of the waters. Stated in another way, within the limits of salinity which a species tolerates, temperature completely overshadows salinity as a factor effecting movements and migrations of marine animals.

Seasonal Variations in Abundance

The seasonal variations in the numbers of invertebrates caught depended largely on the preponderant species listed in Table 14. The variations have been described for the individual species and the data has been presented in the tables. Nevertheless, they have not been considered all together, although any interested reader could combine the data for himself. In the following discussion the writer attempts to give a succinct description of the seasonal variations in numbers of the invertebrates as a whole, based necessarily upon the most numerous species.

Table 16 gives the numbers of invertebrates caught by seasons and the average catch per haul with the trammel nets and beach seines in Copano Bay, Aransas Bay and the Gulf. The mesh was large and crabs were practically the only invertebrates caught. In Copano Bay all invertebrates caught in trammel nets were blue crabs, *Callinectes sapidus*. On the Gulf beach 12 speckled crabs, *Arenaeus cribrarius,* were caught in the summer and fall and the remaining specimens were *C. sapidus*. The table shows that in general the summer and fall were the times of greatest abundance of *C. sapidus* in the catch of the large nets. The winter catches were low and apparently the blue crab was not present then in such large numbers on the flats and shallows near shore. The decline in numbers caught was most noticeable in Aransas Bay and the Gulf and least in Copano Bay. This is similar to the fish catches (see Gunter, 1945), in which the average number caught per haul rose in Copano Bay during the winter but fell in Aransas Bay and the Gulf.

TABLE 16

The number of invertebrates, average per haul and the number of species caught by seasons in trammel nets and beach seines are shown.

	Copano Bay	Aransas Bay	Gulf
Spring			
No. specimens	55	114	7
No. species	1	3	1
Average per haul	4.6	8.1	1.4
Summer			
No. specimens	122	176	54
No. species	1	2	2
Average per haul	7.2	11.7	9.0
Fall			
No. specimens	142	114	24
No. species	1	1	2
Average per haul	8.4	7.6	4.0
Winter			
No. specimens	56	31	0
No. species	1	1	0
Average per haul	4.8	2.0	0

Table 17 gives the seasonal catches in the minnow seines. Similar to the trammel net and beach seine data, the table shows that the catch declined in winter in Aransas Bay and the Gulf. In Copano Bay, however, it rose. Except for Copano Bay, the summer and fall seem to be the periods of greatest abundance of invertebrates in the shallows close to shore. Table 17 shows further that the number of species in

TABLE 17

The number of invertebrates, average per haul and the number of species caught by seasons in minnow seines are shown.

	Copano Bay	Aransas Bay	Gulf
Spring			
No. specimens	928 (app.)	1,116	5
No. species	3	6	2
Average per haul	77.3 (app.)	65.6	0.8
Summer			
No. specimens	993	6,000 (app.)	27
No. species	4	4	4
Average per haul	55.2	182.0 (app.)	2.5
Fall			
No. specimens	847	1,325	37.0
No. species	4	6	6
Average per haul	70.6	69.7	3.0
Winter			
No. specimens	3,000 (app.)	285 (app.)	1
No. species	4	4	1
Average per haul	250 (app.)	15.8 (app.)	0.2

the catches was greater in Aransas Bay and the Gulf than in Copano Bay. The number of species declined in winter.

In Copano Bay the blue crab, *C. sapidus,* the peneids, *Penaeus setiferus* and *P. aztecus*, and the grass shrimp, *Palaemonetes sp.*, were the only invertebrates caught in the minnow seines. No *P. setiferus* were caught in the spring. The numbers of *C. sapidus* were at a low ebb, while *P. aztecus* (and possibly *P. duorarum*) and the grass shrimp were abundant. In the summer the numbers of *C. sapidus* increased, the grass shrimp and *P. aztecus* remained numerous, but the catch of *P. setiferus* increased and came to outnumber *P. aztecus*. The numbers of grass shrimp declined. In winter the numbers of all species declined, except for the grass shrimp, which increased greatly, thus accounting for the increased catch of invertebrates in Copano Bay in the winter. The grass shrimp disappeared in November and did not return to the catch until February, when large numbers were taken.

Except for a few *C. danae* taken in the spring, a few hermit crabs and 97 *Xiphopeneus krφyeri* taken in the fall, the same 4 invertebrate species found in Copano Bay made up the minnow seine catches in Aransas Bay. In that bay the situation was very much the same as in Copano Bay, except that grass shrimp were practically absent from the spring and fall catches. Their numbers increased in winter, but they were not found in huge numbers as in Copano Bay. *Penaeus setiferus* was much more abundant in Aransas Bay in summer than in Copano Bay. The numbers of all species declined from fall to winter except for the grass shrimp. The spring and fall were about equal in the number of individuals caught and the time of greatest abundance was in the spring. The blue crab and two peneids were numerous, but the large numbers of invertebrates taken in spring were largely due to a great preponderance of grass shrimp, similar to the winter increase in Copano Bay, but coming later in the year. In Aransas Bay *P. setiferus* was outnumbered by *P. aztecus-P. duorarum* in all seasons in minnow seine catches except in the fall.

Table 17 shows that the summer and fall were the seasons of largest catches in minnow seines on the Gulf beach. In winter one crab, *Arenaeus cribrarius,* was the only invertebrate taken in 6 hauls. The number of fishes in the catches likewise declined sharply there in winter (Gunter, *op. cit.*). All animals leave the shallow Gulf beach waters in winter. *Callinectes sapidus* and *P. setiferus* were the most numerous species and were taken at all seasons except winter. The *P. aztecus-P. duorarum* group was present only in the summer, when it outnumbered *P. setiferus*. A few *Xiphopenaeus krφyeri, C. danae* and *Arenaeus cribrarius* taken in the summer and fall were the only other invertebrates taken in minnow seines on the Gulf beach.

Except for certain jellyfish and ctenophores, broken up beyond possibility of counting, one grass shrimp taken in winter and one stone crab taken in the fall, the only invertebrates taken in trawls in Copano Bay were *Callinectes sapidus* and the 2 common peneids. The fall was the time of greatest catch (Table 18), made up largely of *Penaeus setiferus*, and the winter was the time of least average catch. *Penaeus setiferus* was outnumbered by *P. aztecus* in the spring, but the remainder of the time it was overwhelmingly abundant and comprised most of the catch. Blue crabs were most abundant in the spring when several hundred were caught. Their numbers declined to a low in the fall, when less than a hundred were caught and increased again in winter. *Penaeus aztecus* had an abundance peak in spring and

Table 18

The number of invertebrates, average per haul and the number of species caught by seasons in trawls are shown.

	Copano Bay	Aransas Bay	Gulf
Spring			
No. specimens	5,034 (app.)	2,360 (app.)	3,876
No. species	3	11	25
Average per haul	359.0 (app.)	215.0 (app.)	553.7
Summer			
No. specimens	3,908 (app.)	2,114	824
No. species	3	10	15
Average per haul	391.0 (app.)	192.2	137.3
Fall			
No. specimens	14,000 (app.)	10,340 (app.)	2,438 (app.)
No. species	4	11	15
Average per haul	1,556.0 (app.)	862.0 (app.)	406.0 (app.)
Winter			
No. specimens	2,422 (app.)	9,036 (app.)	187
No. species	4	7	13
Average per haul	242.0 (app.)	754 (app.)	93.5

its numbers declined until it was almost absent in winter. *Penaeus setiferus* was least numerous in the spring and increased throughout the summer to huge numbers in the fall, and declined in the winter, when most or all shrimp left Copano Bay temporarily in the last of January.

In Aransas Bay the same common crustacea listed above were the preponderant invertebrates in the trawl catches. Several other crustaceans, a few squid and jellyfish were caught in lesser numbers. Blue crabs were most abundant in the spring. The least numbers were caught in summer with a slight increase in the fall and winter. The least numbers of *P. setiferus* were taken in summer and this is the only season when it was outnumbered by *P. aztecus-P. duorarum* in Aransas Bay. The numbers of both species increased to a peak in the fall, accounting for the greatly increased catch in invertebrates at this season, but whereas the numbers of *P. aztecus-P. duorarum* declined sharply in winter, large numbers of *P. setiferus* were caught in Aransas Bay in the early part of the winter so that the total numbers of invertebrates in Aransas Bay trawl catches remained high, in contrast to the winter decline in Copano Bay.

Table 18 shows that the spring and fall were the seasons of largest catches of invertebrates in trawls in the Gulf. Several species were caught and the common bay crustaceans were equaled or outnumbered by other species. *Renilla mülleri* was the most numerous invertebrate. It was present in vast numbers in the spring and was the most numerous species in the summer and winter. *Penaeus setiferus* was the most numerous species caught in the fall. This shrimp outnumbered the *P. aztecus-P. duorarum* complex at all seasons and none of the latter were taken in the winter. *Callinectes danae* greatly outnumbered *C. sapidus* at all seasons except in the winter, when only 7 of the latter and no *C. danae* were caught. Both species were more abundant in the spring than at any other season. The winter trawl hauls were few in number in the Gulf, see Table 1, and the comparison of the winter catches with those of other seasons is not as good for the open Gulf as for the bays.

Salinity and Size

The young of many marine animals, both fishes and invertebrates, such as the common shrimp, grow up in the bays. Since numbers of them are spawned in the Gulf and work into the bays at an early stage in life, it seems that they have a predilection for the low salinities of bay waters. At first glance, it might appear that they merely prefer the shallows and mud bottoms of protected bay waters to the surf-roiled, sand bottoms of the Gulf beach, irrespective of salinity. However, the bottoms and muds of lower Aransas Bay are equal to those of Copano and the back bays, where the salinities are much lower, and the small animals move slowly into the back bays in many instances, whereas some of them, such as the small redfish, remain in the lower bays. Therefore, it may be said that the young of many species, if not definitely attracted to lower salinities, are at least little affected by them. It appears that the young have a certain predilection or at least tolerance for low salinities not possessed in many instances by the larger animals of the same species. For instance, large so-called "bull shrimp," *Penaeus setiferus,* and similarly the adults of *P. aztecus*, are never found in the waters of Copano Bay, and only very rarely are large *P. setiferus* found in lower bays near the Gulf. The adults of *P. aztecus* are never found in the bays, but always in the open sea. Even species, the adults of which may enter waters of very low salinity, have larger numbers of the young in these waters and fewer of them in saltier water. Therefore, for many species of fishes and invertebrates there is a relation between size and the salinity of the water. In general there is a direct correlation between size and salinity. The smallest animals are in general in the less salty water and the larger individuals are in the saltier water. The situation is not simple or clear cut and it is complicated by the fact that many animals are spawned in much saltier water than they subsequently enter. The data on fishes and a fuller discussion of the topic is given by Gunter (1945). In the text and certain tables, previously discussed in this paper, data are presented showing that the same direct relationship between salinity and size holds true for many of the invertebrate animals of the Texas Coast.

SUMMARY

1. This paper reports the data collected on invertebrates from March, 1941 to November, 1942 in Copano Bay, Aransas Bay and the adjacent Gulf of Mexico during a study devoted chiefly to fishes. The most extensive work was carried on from June, 1941 to August, 1942, inclusive. The area studied extended from the headwaters of Copano Bay to 5 miles offshore in the Gulf of Mexico with a salinity gradient from almost fresh water to pure sea water in a running distance of 40 nautical miles. Minnow seines, trammel nets, beach seines and shrimp trawls were the collecting gear used. Descriptions of the locality, stations, method of collecting, data on fishes and summary of the temperature and salinity data have been presented before (Gunter, 1945).

2. Approximately 72,000 specimens of invertebrates, chiefly crustacea, were caught. The peneid shrimp, *Penaeus setiferus* and *P. aztecus* (mixed with *P.*

duorarum), the grass shrimp, *Palaemonetes,* the blue crab, *Callinectes sapidus,* and the sea pansy, *Renilla mülleri,* were the most common species. The latter was found only in the Gulf, while the greatest numbers of the other species were caught in the bays. Shrimp of the family Peneidae are the most predominant invertebrates of Texas coastal waters. *Penaeus setiferus* and *P. aztecus* (with *P. duorarum*) together made up approximately 82 per cent of the numbers of invertebrates. Two other peneids, *Xiphopeneus krφyeri* and *Trachypeneus constrictus,* were caught in some numbers in the Gulf. The crustacean species were probably taken in numbers more or less proportional to their abundance, but certain others, such as starfish and sand dollars, were probably present in much greater numbers than the catches show. The oyster, *Crassostrea virginica,* is an abundant invertebrate growing in large reefs in the bays. It is not ordinarily caught by the collecting gear used in this study and there is no basis for comparison of its abundance with the more numerous invertebrates (crustaceans) taken in the course of this work.

3. The invertebrate population of the bays is made up chiefly of the peneid shrimp, *Penaeus setiferus* and *P. aztecus,* the blue crab, *Callinectes sapidus,* and the grass shrimp, chiefly *Palaemonetes vulgaris.* Grass shrimp are restricted to the flats and shallows of the bay shores, while the other species are found all over the bays. The average size of shrimps and crabs from shallow waters was smaller than examples of the same species from deeper waters, but neither small nor large individuals were restricted to either place.

4. Most species can withstand high salinities, but many cannot withstand low salinities and therefore the number of species caught in the Gulf was much greater than the number in the bays. Eight species were caught in Copano Bay, 24 in Aransas Bay and 42 in the Gulf.

5. The fauna of brackish waters is marine and is not derived from fresh water. As the waters become fresher along the salinity gradient, certain invertebrates that cannot tolerate lowered salinities drop out of the picture, but others persist. There is no compensating increase in the number of species by invasion of species from fresh water and therefore the number of species in waters of low salinity is low, but those present are marine.

6. Many species grow up in the bays during the warmer months. Certain Gulf species invade the bays in the spring and summer. When the temperatures drop in the fall a great part of the population begins to move to or towards the Gulf. Many species leave the bays entirely in winter and, therefore, the number of species in the bay declines. Similarly, certain Gulf species move out to deeper water and disappear. There is also a movement of crustacea away from the shallows near shore in the fall and early winter. Similar to what was found among the fishes (Gunter, *op. cit.*), this is more noticeable in Aransas Bay and the Gulf than in Copano Bay. The most striking seaward movement is that of the common commercial shrimp. When the temperatures rise in the spring most species spawn and the young start growing up in the bays again. Seasonal variations in abundance of the invertebrates as a whole in the bays are dominated by changes in the population of the 4 species present in greatest numbers, namely, *Penaeus setiftrus, P. aztecus, Callinectes sapidus* and the grass shrimp, *Palaemonetes.* Variations in numbers in the Gulf largely involved population changes of the sea pansy, *Renilla mülleri, Penaeus setiferus, Xiphopeneus*

krφyeri and *Callinectes danae*. In general the summer and fall were the seasons of greatest catches in the trammel nets, beach nets and minnow seines or in other words, in shallow waters. The average catch showed a sharp decline in winter, except in minnow seine hauls in Copano Bay. In trawls the greatest average catch in the Gulf was in the spring and the lowest was in winter. In both bays the fall was the season of greatest average catch in trawls. In Copano Bay the smallest catches were in winter, but in Aransas Bay it fell in summer. In general trawl catches were least in summer and greatest in the fall.

7. Life history notes on several species are presented in the text.

8. Invertebrates in less salty water usually average smaller than those of the same species in high salinities. In general there is a direct correlation between size and salinity. This is a result of movement during the life cycle of the whole population of a species and is not due to "stunted" or restricted groups.

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The Invertebrate Fauna of Texas Coast Jetties; A Preliminary Survey[1]

By

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(Systematic appendix by J. W. Hedgpeth)

I. INTRODUCTION

The coast of Texas, which comprises the northwestern corner of the Gulf of Mexico, is a uniform reach of sand beach some four hundred miles long, extending on an arc from Sabine Pass, about 29° 45′N, 93° 50′W, southwesterly and south to the mouth of the Rio Grande, about 26°N, 97° 10′W. The upper two-thirds of this coast line runs roughly southwest and northeast. Below Aransas Pass the coast runs north and south, veering eastward near the mouth of the Rio Grande. Beween Sabine Pass and High Island, and in the vicinity of Freeport, the Gulf Coast is on the mainland, but far the greater part of the Gulf Coast is on a chain of barrier islands which front a series of shallow coastal bays. The bottom of these bays is for the most part mud; the Laguna Madre, however, has a predominantly sandy bottom. Behind the coastal bays is a system of inner bays, of lower salinity than the coastal or outer bays, which are in turn lower in salinity than the Gulf of Mexico. The coastal bays are connected to the Gulf of Mexico by a series of passes or inlets. Five of these passes are maintained by the United States Army Engineers as navigable channels, reinforced by stone jetties extending into the Gulf. These passes are Sabine, Bolivar (Galveston), Freeport, Aransas and Brazos Santiago.[2]

In addition to these controlled passes, several other passes remain open most of the time. Pass Cavallo, leading into Matagorda Bay, is the most important of these. Other passes, such as San Luis Pass, Cedar Bayou and Corpus Christi Pass, remain in their natural condition, and are open intermittently. The more stable passes are located at the southeastern sectors of the respective bays, and are important units in the salinity complex of bays and Gulf, permitting exchange of water between the Gulf and inland bays.

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[1]The initial study was made during the months of June and July in 1938, 1939, and 1940, and was presented in thesis form (*Marine biology of the government jetties in the Gulf of Mexico bordering the Texas Coast*, by H. L. Whitten. Thesis. The University of Texas, August, 1940. 122 pp.). While there has been no substantial change in the environment since that time, several important papers dealing with the biology of Texas coastal waters have appeared, and some of the material in the thesis which did not concern the specific problem of the jetty fauna has been superseded. While part of the original collection is still available, many critical specimens appear to have been mislaid in the course of seven years. Whenever possible, the identifications have been confirmed and the nomenclature brought up to date. Additional notes on the Port Aransas and Port Isabel areas have been added. This contribution is part of a general and intensive biological and hydrographic survey of the western gulf which was originally suggested and planned by E. J. Lund, Director of the Institute of Marine Science from its inception to September 1949.

[2]A geological analysis of the Texas coastal bays is presented by Price (1947). Some characteristics of the Laguna Madre are discussed by Hedgpeth (1947).

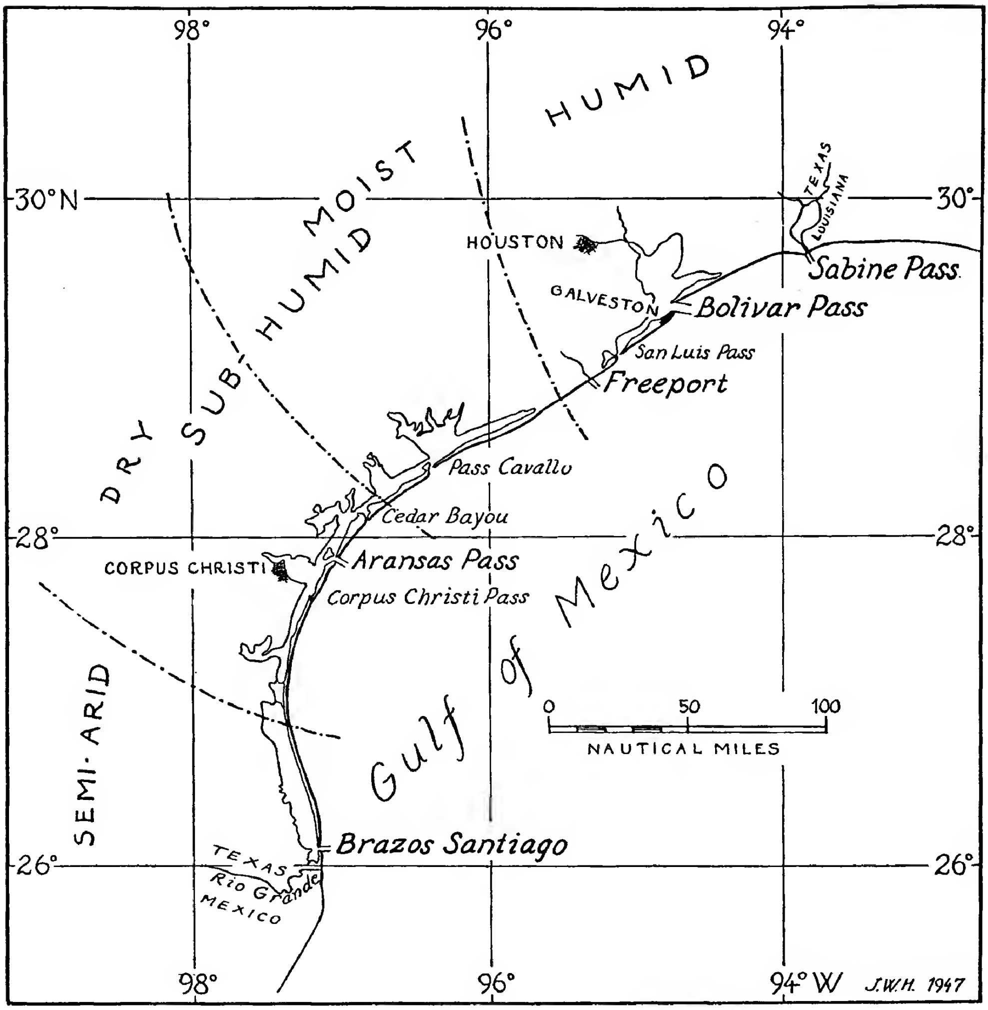

FIGURE 1

The Texas coast, showing climatic zones and passes between bays and gulf. Jettied passes indicated in heavier lettering.

The jetties are placed on the passes, at the important region where salinities are most variable, and the fauna of the jetties from Aransas Pass northwards must be resistant to changes in salinity ranging from 15 to 35 0/00 in "average" years. This range is for the most part seasonal, but runoff from heavy rains sometimes lowers the salinity in the passes within a few days beyond the tolerance of some stenohalin invertebrates. It is probably this salinity range which explains the comparative paucity of the jetty fauna on the Texas coast, and there are indications that there is a greater variety in the fauna on the jetties at Brazos Santiago Pass opposite Port Isabel. This pass opens into the southern end of the Laguna Madre, where the salinity is usually well above 30 0/00. The mouth of the Rio Grande is ten miles below this pass, and in recent years little flood water has escaped across the intervening lowlands into the Laguna Madre because of the intensive use of the water in the Rio Grande for irrigation. Records of surface salinities from the tide station at Galveston (U. S. Coast and Geodetic Survey, 1945), indicate an annual mean of 23.7 0/00, with recorded extremes of 2.5 to 40.1 in the period 1922–1944.

The five pairs of rubble-stone jetties on the Texas coast maintained by the United States Government have been constructed within the past seventy years. As comparatively recent modifications of the shoreline, providing a hitherto absent ecological environment, these jetties are of particular interest. In addition to providing a new environment suitable for rock-living forms, the jetties exert an undetermined influence on the life histories of various fish and invertebrates which spawn in the Gulf and whose young migrate into the bays, which serve as their rearing grounds. A further effect of the jetties is their influence on the fauna of the passes themselves. Formerly these passes were shallow inlets of the type now represented by Pass Cavallo. Now they are long deep channels, continually dredged to a controlled depth of 34 feet or more. Only the problem of the jetties as an ecological environment in themselves has been considered in this paper.

In addition to the salinity factor, other factors of prime ecological importance in relation to the jetties are scour and wave action. Scour is especially important, since the jetties extend at right angles to gently sloping sandy beaches, interrupting the flow of littoral currents and offering surfaces for the sand to work against. The scour action is especially noticeable in the pockets at the angle of jetty and beach. At times this area is very turbulent, and channels are eroded along the outside corners of the jetties. Wave action is especially strong at the extremities of the jetties, but during storms and periods when strong onshore winds act against an outgoing tide, wave action is effective far up the channel between the jetties. It is a common sight to see waves dashing white plumes of spray ten or fifteen feet above the crest of the jetties, and patches of green algae on the concrete caps of the jetty indicate the relative frequency of spray from heavy wave action.

Because of the limited tidal range of 1½ to 2 feet, this factor is important in a reverse manner. Organisms accustomed to larger tidal ranges and the consequent exposure to air for several hours a day do not flourish on the Texas coast, and conversely, few of the sedentary organisms present are adapted to prolonged exposure to air. Although the tidal range is slight, such tides as there are behave in an irregular manner, remaining high or low for several days at a time, especially during the winter and summer. An especially important factor of the limited tidal range, as far as the field ecologist is concerned, is its effect on collecting. The lowest tides are in winter, during northers, and collecting at this time is usually difficult and unfavorable.

While low water temperatures during occasional cold spells kill many fish in the shallow bays, the temperature range at the Gulf shore near the jetties seems to be from 12 to 31.5°C. The usual summer surface temperature a few hundred yards offshore is lower than the beach maximum, but the winter minimum is probably nearly the same. Such low temperatures as 4° C. which have been observed in the bays during cold spells have not been observed in Gulf waters. The annual temperature range near the Gulf shore (but not on the shallows at the beach) is from 9 to 30° C., approximately. This compares closely with the temperature range in the bays, as observed by Galtsoff (1931), Collier (1938) and Gunter (1945). According to the surface temperature records at the U. S. Coast and Geodetic Survey tide stations (1947), the mean range, from 1922–46, is 14.4 to 30.0° C., with the annual means varying from 20.8 to 24.7° C. The lowest temperature recorded in this period was 1.7° C., the highest, about 38.8° C. (102° F.).

Due to wave action, settlement and scouring along the "toes of slope," or bases of the jetties, repair work has been carried on almost continually during the past sixty years. These changes, however, affect the fauna of the jetties only slightly, since the stones are never removed from the original positions. At the time of the initial study, the north jetty at Port Isabel and the south jetty at Sabine were under going repairs at their extreme gulfward ends. During recent years, concrete caps have been placed on portions of the jetties at Sabine, Galveston, Freeport and Aransas Pass. Also, a section of the south jetty at Galveston has been covered with an asphaltic-concrete material as an experiment.

The jetties have these features in common: they are usually a mile and a half, more or less, in length, and are broadly triangular in cross section, and are located in parallel pairs at distances from 800 yards to a mile and a half from each other. At the base, the stones weigh from 15 to 200 pounds each; the core is composed of larger stones, weighing up to two tons each, and the cover stones are large quarry blocks, from six to ten tons each. These cover stones are placed loosely together so that there are large cracks and cavities between them, which afford shelter for growths of algae and colonies of sea anemones (see fig. 2). Several of the jetties usually

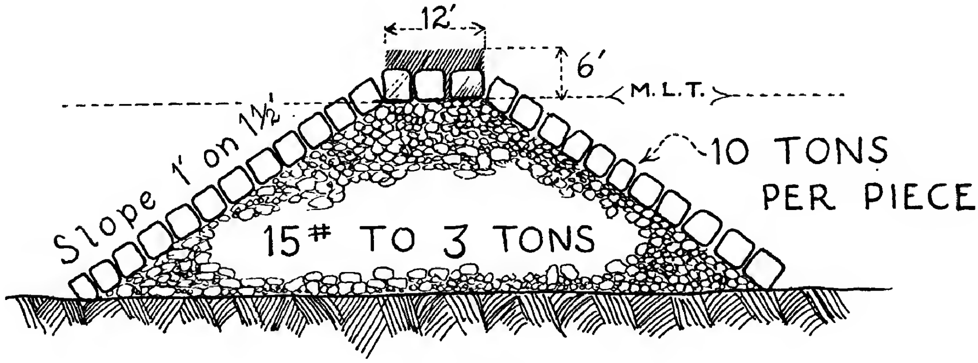

FIGURE 2

Cross section of typical jetty offshore, showing slope with large cover stones, mean low tide level and concrete cap.

accessible to the public are capped with concrete, forming a walk eight to fourteen feet wide. While the base of the jetties is sometimes 150 feet wide, the actual effective rocky area, as a marine environment, is considerably less than the entire surface area of the jetty slopes. Several of the jetties are built on flat bases which extend beyond the slopes. This extension beyond the slope is called the "toe" of the jetty. Often these toes and the lower parts of the slope are covered with sand, so that the effective surface area depends on the amount of sand piled up around the jetty as well as the actual height of the jetty above the bottom.

The stations referred to in this paper are the distances in feet from the origin of the jetty. These stations are usually marked in some manner on the jetty, as they serve as reference points for maintenance. The beginning of the jetty is station 0+00, and stations are marked in tens of feet, separated by a + sign, so that station 0+50 means that point 50 feet from the beginning of the jetty, station 8+00 means 800 feet, and so on (see fig. 3). Inasmuch as the jetties often begin far back on the land, these station numbers have no relationship to the distances from the shore line along the respective jetties.

Collections and observations were limited to the areas on top of, and around the jetties, and beneath the water to a point about five feet below mean low tide.

II. PHYSICAL AND ECOLOGICAL DESCRIPTION OF THE JETTIES

1. The Sabine west jetty

This jetty extends southward into the Gulf 21,860 feet. Between it and the east jetty in Louisiana is Sabine Pass. Water in this pass comes from Sabine Lake, a large body of water fed by the Sabine and Neches rivers. The Sabine jetties are almost one half mile apart, and the average depth of the channel is 36 feet. The width of the jetties about sea level, is four to eight feet, while at the base, or toes of the jetties, the width is forty to eighty feet.

Stations 0+70 to 80+70

The littoral region to the west of the first station is a typical mud flat during low tide. During high tides and storms, water seeps under the concrete cap and around the west side of the jetty, converting the mud flat into a salt marsh. A fiddler crab-rush grass community, composed of the crabs *Uca pugilator* and *Uca minax,* and the seashore rush grass, *Sporobolus virginicus,* was found here. The jetty itself was not overlooked by these crabs, which could be seen scurrying from every crevice on the west wall to the more permanent shelter of their holes among the grass.

High on the leaf blades of approximately every twentieth plant were specimens of the salt marsh periwinkle, *Littorina irrorata.* On the west side of the jetty was a scattering of this littorine in company with the more abundant, smaller *Littorina ziczac.* The small littorines were numerous on both sides of the concrete cap, numbering as high as 150 per square meter.

Also numerous on both sides of the jetty, in all vertical strata, was the blue crab, *Callinectes sapidus.* In 1940, young portunid crabs 4–5 mm. wide were so numerous on the west side (outside) of the jetty that a quart jar could easily be filled from two or three scoops with a small dip net. These young crabs may have been *Arenaeus cribrarius,* since the blue crab migrates into the bays in the megalops stage. Young shrimp were found in the same area, but not plentifully.

On the top and sides of the jetty near the shore regions large isopods, *Ligyda exotica,* were abundant. At times, however, robber flies and horseflies almost outnumbered the isopods. In any ecological work at this station, these insects should not be overlooked.

Stations 80+70 to 131+72

This area is somewhat like the preceding, except for the absence of a muddy shore on the south side. The benthic area, a few feet below the surface at low tide, was easily explored, and it appeared that the dominant species of the past had been the oyster, *Crassostrea virginica.* The shells were abundant, but mud and sand had covered them some time ago. Among the various mollusc shells found bordering the jetty, the following probably live in or on the bottom there: *Tagelus gibbus* and *Natica duplicata.* Dead shells of *Spondylus echinatus* and *Anomia simplex* were also found. It is possible that these live among the jetty rocks.

On the walls of the jetty, washed by strong waves from both sides, the barnacles *Balanus improvisus* and *B. eburneus* were making a desperate stand. Half of those examined were dead, but in all there were about fifty barnacles per square meter, mostly above low tide level. A few *Littorina ziczac* were among the barnacles.

Stations 131+72 to 157+80

This area was undergoing repairs to the concrete cap of the jetty, and was not examined in 1940. It has only one dominant community, the Balanus-Littorina community. The animals forming this community became more numerous toward the end of the concrete cap, at station 157+80.

Stations 157+80 to 218+60 (end of jetty)

At the end stations of this jetty, communities of the limpet *Siphonaria naufragum, Balanus improvisus* and *Thais floridana* were found on each rock, with some algae. There were often ten or more snails on each large quarry block. The limpet was not abundant, and was absent at most of the other stations on this jetty.

Algae are not common on the jetty as a whole, although a few species may be found, including *Enteromorpha lingulata* and *Cladophora fascicularis.*

In the water among the jetty rocks about ten mantis shrimp were caught, along with the more common decapod shrimps. Mullet were present in large numbers, but no typical jetty fish were collected.

Five stone crabs, *Menippe mercenaria,* were observed in the area, wedged tightly between the rocks just above water level. No other crabs and no isopods were collected at this end of the jetty. The water is deep in this area and the bottom was not observed.

No collecting was done on the east jetty, since that jetty is in Louisiana. A comparison would probably reveal habitats and species similar to those on the west jetty at corresponding station, except for the absence of a salt marsh and mud area.

2. The Galveston jetties

A. The north jetty

The Galveston north jetty has a wide, concrete cap, extending 2,000 feet from Bolivar peninsula. The remainder of the 25,400 foot jetty is without a cap. The water south of this jetty comes from Galveston Bay. The Galveston jetties are two miles apart, and there is a slight difference between the flora and fauna of the two jetties.

The tidal range is two feet. Wave action is not noticeably rough except near the ends of the jetties, where it is often severe. Although known as the "north jetty," this jetty extends from Port Bolivar in a southeasterly direction, and gradually curves until the last thousand foot section heads due east. Beyond the concrete cap only the large cover blocks project above water, and during high tides the waves often go completely over them.

Stations 0+00 to 20+00 (end of concrete)

The area on the south side of this station was a pocket, formed at the junction of the beach and jetty. A great amount of debris was piled among the rocks which extend from beneath the concrete cap. The beach at this point was as muddy as sandy, and pellets of oil covered both beach and jetty.

The dominant animal of this area was *Ligyda exotica.* These isopods were more abundant here than at any other place studied in this survey. It was interesting to note that over half of this isopod population was composed of young individuals.

Other inhabitants of the area were hermit crabs, *Pagurus floridanus* and *Clibinarius vittatus,* occupying the shells of *Nassarius acuta* and *Thais floridana.* These crabs, *Thais floridana* and the mussel *Mytilus recurvus* were the components of small communities scattered throughout the area on bare rock surfaces. These communities seemed rather unstable, however, and the motile members were continually changing their positions to secure better footing. Farther out on the jetty these communities were more stable, because of a dense growth of algae. The mussel is not entirely sessile, as it can shift its location by producing a new byssus. This enables it to withstand rough waves better than the gastropods. Hermit crabs occurred in about every tenth *Thais* shell. Other crabs had made use of *Natica duplicata.*

Stations 20+00 to 100+00

Beyond the concrete cap, the jetty was much the same to the end. It was divided into two sections for convenience, although there is little difference except that the waves are rougher in the last section.

Thais-Mytilus-Littorina communities were present on every rock in this area. Secondary members of the community were *Siphonaria naufragum, Chthamalus fragilis* and *B. eburneus.* Near stations 100+00 *Chthamalus* became the principal dominant, replacing *Mytilus.* Three species of littorines were present: *Littorina irrorata, L. ziczac* and *L. nebulosa.*

Cladophora was growing on the shells of *Thais,* and on this alga were a few specimens of the amphipod *Carinogammarus mucronatus.* Two species of caprellids were also found. These have been identified as *Caprella acutifrons* and *Caprella sp.* The latter is a small green species.

Immature shrimp were caught in the water between the jetty rocks, as well as a small brown shrimp which probably came from the sargassum. Other decapods present were *Arenaeus cribrarius, Callinectes sapidus* and *Menippe mercenaria.* Young fish of the following species were easily caught in this section: sheephead, *Archosargus probatocephalus,* redfish, *Sciaenops ocellata,* and drum, *Pogonias cromis.*

On the north side of this jetty, a few living specimens of the ctenophore *Mnemiopsis mccradyi* were collected. Several dead "cabbagehead" jellyfish, *Stomolophus meleagris,* were found among the rocks of this region.

Stations 100+00 to 254+00 (end of jetty)

The principal dominants of this section of the jetty were similar to the last, namely *Chthamalus* and *Siphonaria,* with *Thais* and *Littorina* as important subdominants. The blue crabs and stone crabs were still abundant as influents, and a few mantis shrimp and the crab, *Portunus gibbesi,* were also present. Two other species of crabs were found in the lower strata: *Pachygrapsus transversus* was abundant, and a few specimens of *Hepatus epheliticus* were also taken.

B. South jetty

Stations 0+00 to 142+50 (end of concrete)

This part of the jetty is similar to the Galveston seawall. It borders the land area around Fort Point, on Galveston Island. The entire area to the south of this section of the jetty is sandy land, averaging four feet above sea level. No marine forms were found except on the north side of the jetty in this section.

The dominant forms of this entire north side were hermit crabs, *Thais,* littorines and the sea anemones *Bunodosoma cavernata.* These species were not common enough to form communities at any one station, but all were distributed evenly over the entire area, with the exception of the anemones. The anemones occurred at least one foot below low tide level, usually in groups. They were in crevices between rocks in inconspicuous places. Although tolerant of some wave action, they avoided the direct grinding action on the outside rocks. A few *Ligyda* were observed, but no barnacles or limpets were seen. The blue crab and young fish of several species were collected all along this section. In lower strata, dead oyster shells were found in large numbers, but no living oysters were found. The shells were small, indicating that oysters had never been able to get a good start on the jetty rocks.

A rock boring mollusc, *Lithophaga bisulcata,* was found in several small limestone rocks below water level along the jetty. None of these molluscs were found in the granite rocks of the jetty proper, since they cannot bore into this rock. Several wooden piles in the area were attacked by at least two wood boring molluscs, *Bankia gouldi* and *Martesia striata.* A boring isopod, *Sphaeroma quadridentatum,* was abundant in the piles. A related isopod, *Ancinus* sp., was caught in large numbers in open water nearby.

In the flotsam of this region the beach hopper, *Orchestia platensis,* was found in large numbers. As many as thirty specimens were counted under one small clump of rotting seaweed. Insects were also present.

Stations 142+50 to 230+00 (asphalt section)

The second area studied presented many new ecological situations. An asphaltic-concrete cap covers this section, and there is a shallow body of water to the south, known as The Lagoon. To the north of the jetty is a low flat island, only a few feet from the rocks.

The area on the lagoon side of the jetty was an oyster community, with clumps of both dead and living oysters. Blue crabs and fiddlers were also members of this community. On the other side of the jetty could be found the shore crab *Pachygrapsus transversus* and the lady crab, *Ovalipes ocellatus.* Ghost crabs, *Ocypode albicans,* invaded the jetty at night, but are actually members of the sand beach community, since they live in holes in the sand, usually some distance from water.

The top of the jetty was dominated by the tiger beetle *Cicindella dorsalis.* There were approximately ten beetles per square meter.

Hundreds of empty onuphid worm tubes were found on the north side of the jetty. Some of the tubes contained live worms (probably *Diopatra cuprea*). Hermit crabs were found in this section, especially on the bay side. Periwinkles, *Littorina irrorata,* occurred on the lagoon side, and barnacles, *Balanus improvisus,* occurred on both sides of the jetty. The barnacles were not found on the asphalt cap.

This section of the jetty was characterized by a variety of species, few of which were in stable communities. This condition appears to be due partly, at least, to the asphalt which fills most of the crevices between the rocks.

Stations 230+00 to 345+00 (end of jetty)

With the exception of the Port Isabel jetties, this section of the south jetty at Galveston is probably roughest of the jetties, waves lashing the south side of the rock and dashing spray over them most of the time. During high tide collecting is possible only part of the day.

Although rougher than the other sections, this section, as far as investigated, had the same dominant motile species as the north jetty at corresponding stations. These were *Menippe mercenaria, Callinectes sapidus,* and the "sea bob," *Xiphopeneus krφyeri.* On the rocks were communities of *Balanus* and *Siphonaria,* with *Littorina irrorata* as a secondary dominant.

3. The Freeport jetties

The jetties at Freeport are comparatively short. The south jetty is the longer of the two, and is not quite a mile long. These jetties are also closer together than any of the others studied, and the water between them is usually smoother. Although the coast line at this point projects slightly into the Gulf, the jetties are not often repaired. In the following discussion each jetty is divided in two sections, the first section in each case being the part covered by a concrete cap.

A. Northeast jetty

This section extends but a short distance beyond the shore line, and the area to the south is sandy, sloping downward to the beach at station 20+00. Marine life is to be found only on the south side. Since the jetties are not far apart, the water is relatively deep near the edge, often reaching a depth of ten feet within six feet of the toes of the jetty on the channel side.

An abundant growth of algae was found on the rocks at all stations. In this algal area *Caprella-Carinogrammarus* communities occurred on almost every rock. Secondary dominants, occupying barer portions of rocks, were *Mytilus recurvus, Littorina ziczac, barnacles,* limpets, *Thais* and hermit crabs. There was a larger number of species living in the same habitat at this station than at any other single station on any jetty observed, possibly because of the luxuriant growth of algae.

Barnacles in this region were found on lower strata than at other jetties where wave action is stronger. Mussels were not abundant, while at other stations on this jetty they were the dominant animal. A few annelid worms were found among the algae. These were probably *Platynereis dumerilii* and *Lepidonotus sublevis.*

Three species of burrowing crustacea were found in the sand at the base of the jetty, in addition to the small clam, *Donax variabilis.* The crustacea were *Emerita portoricensis, Hippa talpoida* and *Lepidopa myops.* Although these forms cannot be considered jetty forms, it is of interest to note their occurrence so close to the rocks of the jetties.

Stations 25+00 to 45+00 (end of jetty)

This last section was very similar to the first, except that both sides of the jetty were washed by waves which churned back and forth between the rocks. In these openings between the rocks young tarpon, mackerel and redfish were caught. The water on both sides of the jetty was approximately thirty feet deep in this section.

The invertebrate communities were similar to those of the preceding station. No isopods were observed. A few sea pansies, *Renilla mülleri*, were found among the rocks. This form is usually found on muddy bottoms, and its occurrence in this situation is unusual. Sea anemones, as usual, occurred in small groups on the inner rocks. A few large moon snails, also bottom dwelling forms, were found in this section. They were taken in *Balanus-Thais* communities. In some areas *Mytilus* was dominant. A few sea urchins, *Arbacia punctulata,* were found in deep crevices between rocks at station 40+00.

B. Southwest jetty

Stations 0+00 to 46+00 (end of concrete)

The beach area at station 40+00 was similar to the corresponding area on the north jetty. The sand, which was even with the concrete top of the jetty at station 0+00, gradually sloped to the water's edge at station 40+00. From here to station 46+00 the water increased in depth to 13 feet on the north side and 20 feet on the south side of the jetty.

Amphipods were abundant on the rocks, but it was observed that they preferred the channel side of the jetty. *Renilla* and hermit crabs were found in this section.

Stations 46+00 to 49+00 (end of jetty)

This section is very short. It was characterized by communities of barnacles and *Thais,* with *Littorina irrorata* and *Mytilus recurvus* as secondary dominants. Limpets were also abundant. The rock-skipper was common, and constituted an important influent. Hermit crabs were present, as well as some portunid crabs.

4. The Port Aransas jetties

A. North jetty

Stations 0+00 to 35+94 (narrow concrete area)

Inasmuch as the north jetty can be reached from Port Aransas only by boat, observations were restricted, and only the south side of this jetty was observed. The fauna of this area is limited to barnacles and littorines. An opisthobranch mollusc, *Bulla occidentalis,* was common on rocks which supported a growth of green algae. Serpulid worms occurred on dead shells and rocks. One live bryozoan colony, *Membranipora tuberculata,* was found on a rock.

Stations 35+94 to 64+50 (wide concrete area)

The flora and fauna of this area were similar to that of the preceding area. No new species were found and the communities remained the same. In this section the jetty extends into the Gulf so that both sides are bordered by water.

Stations 64+00 to 119+50 (rock area)

This large section was taken as a unit because the biota was the same over the entire 4,500 feet to the end of the jetty. This part of the jetty is constructed with a series of lateral spurs, and since originally observed in 1938–40, it has been broken into sections by wave action so that much of it is no longer accessible except by boat.

In this area were found several jellyfish, *Physalia, Aurellia* and *Stomolophus,* and the ctenophore, *Mnemiopsis.* These pelagic forms were trapped among the jetty rocks. Three echinoderms were collected in crevices: *Astropecten antillensis, Arbacia punctulata* and *Mellita quinquiesperforata.* Only the sea urchin can be considered a jetty form. The others were evidently washed in by a squall which occurred just before the jetty was visited in 1940. This rock area was essentially a *Balanus-Littorina* community. Limpets and mussels were also common. Amphipods were collected in the algae, but no isopods were observed.

Few hermit crabs were observed, but the stone crab was common. One of these was seen about every six meters out to the end of the jetty. Portunid crabs and young shrimp were observed in the water near the rocks. A large nudibranch was found on a rock, evidently washed in from the Gulf.

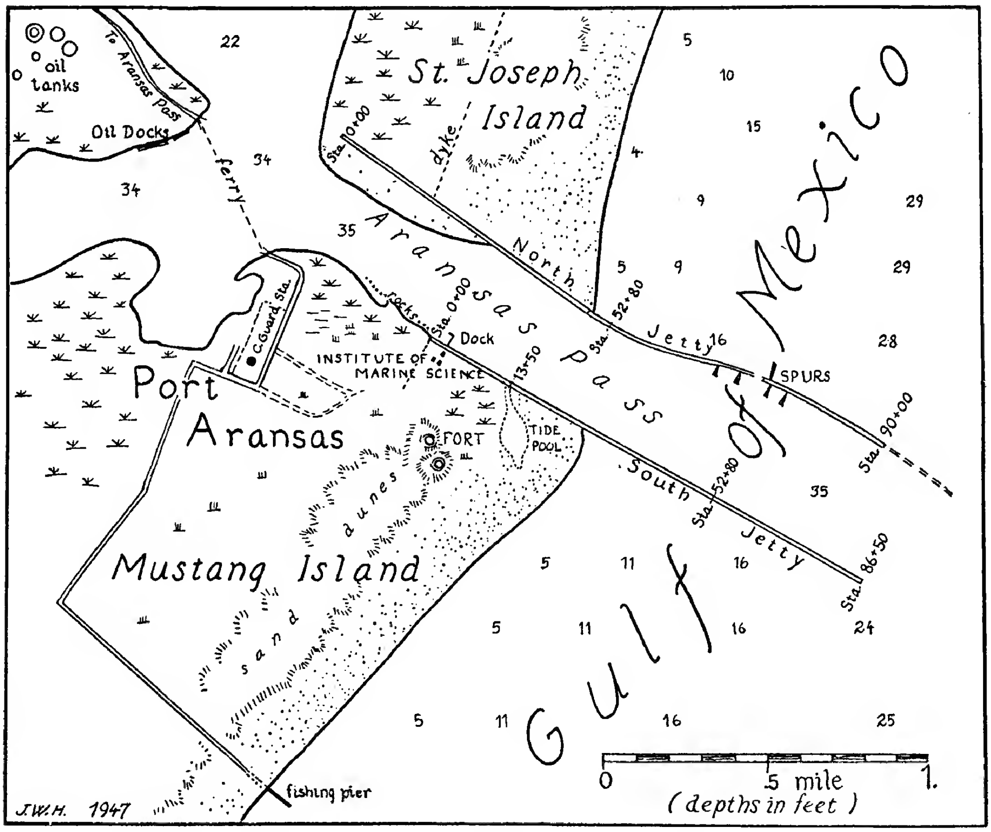

FIGURE 3

Sketch map of Port Aransas area, showing relations of jetties to pass and method of indicating stations.

B. South jetty

Since the initial observations made in 1940 and preceding years on this jetty, the entire jetty has been capped. Certain initial observations made by one of us (Whitten) have not been confirmed by more recent investigations, and the interesting rocky area at the landward end of the jetty was not present at that time. Capping the jetty has reduced by a considerable per cent the niches and crannies formerly accessible to such shelter loving organisms as *Bunodosoma* and *Arbacia.* Although *Littorina irrorata* was reported from this jetty, it was not collected in 1945, 1946 or 1947. The dominant littorine appears to be *Littorina ziczac,* but most of the specimens are very small. The remarks which follow have been brought into agreement with the present condition of the jetty. See Plate 1 for typical views of this jetty.

Stations 0+00 to 3+00

This short section can be considered an ecological unit because the channel side is bordered by a narrow area of rocks lying on shallow sand. These rocks are for the most part of medium size, weighing from 25 to 50 pounds. Westward beyond the end of the jetty this rocky area extends for several hundred feet. There is little life on the jetty itself in this section except a few barnacles and littorines and an occasional limpet. During the daytime the large isopods, *Ligyda,* hide under rocks and in crevices, but are evident in numbers at night time.

The rocks are thinly covered, near the shore, with green algae. Farther out from shore is a thin growth of browns and reds. The most noticeable alga is *Padina.* These rocks are the site of an active community of hermit crabs and *Thais.* The undersides and sheltered lateral surfaces of many of the rocks are occupied by the sea anemone, *Bunodosoma cavernata.* Sometimes there are five or six anemones under one medium sized rock, and occasionally they may be found in the sand. There is also a small inconspicuous anemone, probably an *Anthopleura.* There is a large, active population of crabs, consisting mostly of *Petrolisthes armatus* and immature *Menippe mercenaria. Pachygrapsus transversus* also was found occasionally. Worms are few under these rocks. One small brittle star was found in the sand beneath a rock.

The sessile forms attached to the upper surfaces of the rocks and to the lower parts of the jetty are barnacles, small littorines, and limpets. The population of these species is sparse as compared with that on the seaward end of the jetty. Occasional small oysters are found on the rocks below tide level, but there are no large oysters. They appear to die after attaining a diameter of about an inch. The edible oyster *Crassostrea virginica* is more common, but *Ostrea cristata* is also found here.

Stations 3+00 to 31+50

The outer limit of this station was the end of the concrete cap in 1940. This section includes the north shore of Mustang Island and a short distance bordered on both sides by water. In general this section is a sparse limpet and barnacle community, with occasional *Thais* and small littorines. This cove area formed at the angle of the jetty with the beach is populated with blue crabs and less numberous stone crabs. Between 1,300 and 1,400 feet from the beginning of the jetty a break has developed in the rocks underneath the cap, and a large sand-bottomed tidal pool has formed behind the crest of the beach. Hermit crabs are the dominant invertebrate of this tide pool. At the mouth of the tunnel formed under the jetty, on the south side, is a colony of *Bunodosoma cavernata,* comprising at least fifty individuals. There is probably a climax community of these anemones well inside this grotto. Inasmuch as the jetty has begun to sag noticeably at this point, it will probably soon be repaired and this ecological situation will be eliminated.

Among the rocks on the channel side in this section the anemones are fairly common. *Bunodosoma cavernata* is the dominant species, but a small *Anthopleura* is not rare. Occasional patches of red ochre and purple encrusting sponges occur. Thais is present, but not abundant. Limpets and barnacles are sparse. Active inhabitants of this section are *Pachygrapsus transversus* and *Menippe mercenaria. Ligyda* is probably as common here as anywhere else on this jetty.

Stations 31+50 to 86+50 (end of jetty)

The broad concrete cap of this jetty leaves little of the original rock area accessible. There is only a narrow shelf here and there above tide level. The rest of the jetty is below water, and the rocks fall off precipitously. There is a short section beyond the high concrete cap at the end of the jetty which is accessible. This area supports a flourishing community of barnacles, limpets and littorines, with *Thais* at the lower levels. Below the water line is a dense growth of algae, including *Ulva, Padina, Bryocladia* and *Gelidium.* This growth ends a few feet below the water. When the water is calm, large patches of sponges can be observed below the algal line. In one narrow crevice a scrubby growth of hydroids, principally *Obelia,* could be seen. Anemones, urchins and stone crabs occur sparingly in the deeper holes and crevices.

5. The Port Isabel jetties

The jetties at Brazos Santiago Pass, a few miles opposite the town of Port Isabel, are approximately 150 miles due south of the Port Aransas jetties. Brazos Santiago Pass, between Padre and Brazos islands, is the first effective pass below Aransas Pass. A small pass between the southern end of Corpus Christi Bay and the Gulf is very shallow and often almost dry at low tide, and cannot be considered a major ecological factor on the coast at the present time. Brazos Santiago Pass is about ten miles north of the mouth of the Rio Grande, and does not carry any water from the Rio Grande except when high waters of that river overflow into the marshlands at the southern end of the Laguna Madre.

When these jetties were visited in 1940, both had tramways, and that on the north jetty was being used for carrying out large cover blocks to repair the jetty. Since then this superstructure has been neglected and is broken up in many places on both jetties. According to the engineer in charge of the repair work in 1940, the Port Isabel jetties required more repairs than any of the other jetties on the Texas coast.

A. North jetty

Stations 0+00 to 10+00

The first thousand feet of the jetty is bordered on the north by Padre Island. On the channel side is a sandy area covered with rocks. Littorines, limpets and *Thais* are found on these rocks and the jetty proper, while clinging to the undersides of the rocks can be found a small anemone, *Anthopleura krebsi,* some sparse scrubby hydroids, and a few barnacles. Blue crabs were observed in this area. In February, 1945, several large sea slugs, or "inkfish," were cast up on the beach in this section.

Stations 10+00 to 10+15

This small section includes the beach area on the north side of the jetty. The most conspicuous inhabitant of this beach area was the sand crab, *Emerita portoricensis.* Young individuals seem to comprise about half the total population. There were also a few *Donax.*

Stations 10+15 to 53+30 (end of jetty)

Because of the usually heavy wave action in this region, especially during the spring and summer, it is not often possible to reach the end of the jetty. Since there is no cap on the jetty, there are many deep crevices and grottoes between the large quarry blocks, and the usual barnacle-limpet-littorine association is not as conspicuous as it is on the capped jetties. Near the bottom of the crevices, on the walls and on smaller rocks *Bunodosoma cavernata* is common. At least two, perhaps three, additional species of anemones can be found, including *Anthopleura krebsi.* Hermit crabs and *Thais* also occur in this situation. Although not collected by the authors of this paper, two species of urchins have been taken from this jetty. They are *Arbacia punctulata* and a short-spined green species, probably *Lytechinus variegatus.*

Many of the smaller rocks in the crevices were covered, in 1947, with dense aggregations of amphipods and caprellids, crawling over and among short stubby hydroids.

Two species of living molluscs were collected from this section in 1940 which were not taken from any of the other jetties. These were the Scotch Bonnet, *Phalium (Semicassis) granulatum,* and the bandshell, *Fasciolaria distans.* As both are predacious, soft bottom forms, their presence on the jetty rocks can be considered a sporadic accident. They were not found in 1946 or 1947.

B. South jetty

The south jetty is approximately 2,000 feet south of the north jetty. It is identical with the north jetty except that it is 240 feet shorter. No additional forms were observed during the original study, and this jetty was not visited in 1946 or 1947.

III. DISCUSSION

The Gulf Coast of Texas is a sand beach, and the jetties can only be considered as a subordinate environment. Their total mileage of rocky surface, counting both sides of each jetty, is probably around 20 miles, which if laid out along the shore line, would comprise roughly 5 per cent of the total coast line. Yet this figure has even less relative significance, for 20 miles of natural rocky coastline would be impossible without some outlying reefs or sublittoral rocky bottom, and the jetties have no such environs. They are simply stone fences built on a sandy littoral.

An open sandy beach is far from a biological desert, as Pearse, Humm and Wharton (1942) have shown in their study of a comparable beach area in the vicinity of Beaufort. Many of the species occurring at Beaufort also occur on the

Texas coast. Since these sand beach forms are more or less specialized for this habitat, it is not surprising that few of them are found on the jetties, and that those few are obviously of sporadic or accidental occurrence. The fauna of the jetties, at least that part actually confined to the rocks through necessity or choice, forms a community not found elsewhere on the Texas coast except to some extent on piling, where it includes other elements.

The preliminary nature of this study makes it impractical to draw up generalizations about the character of this fauna in terms used by some ecologists, if indeed that were considered desirable. Furthermore, the Texas jetties are such comparatively small areas that the use of any specialized terminology might serve only to confuse the picture.

At the time the initial study on which this paper is principally based was made, little had been published on the marine biology of the Texas coast, or indeed of any comparable area. The only publication on the marine biology of the Texas coast then available was the incomplete check list by Cross and Parks (1937). Since then there has appeared a pamphlet on shells (Parks, n.d.), and a brochure entitled "Marine Life in Texas Waters" (Reed, 1941). Unfortunately all these publications illustrate the perils which beset the unwary who endeavor to assign names to marine invertebrates without constant recourse to the verdict of authorities on the various groups. Although the excellent handbook by Richards (1938) was available, its emphasis on the restricted fauna of the New Jersey coast limits its usefulness in Texas.

The difficulties involved in undertaking an ecological survey of this character without an adequate check list of species or reference collection need not be elaborated upon. A beginning must be made somewhere, and its is hoped, in view of the preliminary nature of this work, that its deficiencies will be forgiven or at least tolerantly acknowledged. Nevertheless, it is believed that the general character of the fauna of the jetties has been determined, and an adequate beginning has been made for future investigations of more specialized and precise character.

The sessile or sedentary fauna of the narrow intertidal area of the Texas jetties is at best a monotonous community composed of barnacles, limpets, littorines and mussels, and, just below the water line, an anemone. More active members of this fauna are *Thais,* usually inactive when observed, and the single dominant species of hermit crab, housed in cast-off gastropod shells of various species. Occasional vagrants will be found. Sometimes, as at the Port Aransas jetty in 1940, a few characteristic sandy bottom species will turn up. Compared with the rich faunas of the Pacific Coast and South Africa (to name two areas which have been comprehensively treated in recent ecological literature: *vide* Ricketts and Calvin 1938, and Stephenson 1947), this fauna is rather meager, and in the broader view, deserves only to be classified as the "Texas intertidal jetty community."

It is possible to divide the jetty fauna in two ways: from north to south along the coast, and from shore to seaward end. Considering first the north to south differentiation, it appears that certain species which occur on the jetties at Sabine, Galveston and Freeport, become scarcer or less conspicuous on the Port Aransas and Port Isabel jetties. These are *Mytilus recurvus, Littorina irrorata,* and possibly *Balanus eburneus.* These are also the species which appear to decrease in abundance from shore to the end of the jetties, especially on the central jetties. A thorough quantitative survey of the common jetty forms, with critical attention to the species of barnacles and proper consideration of the algae, might indicate some such schematic relationship from north to south as presented in figure 4.

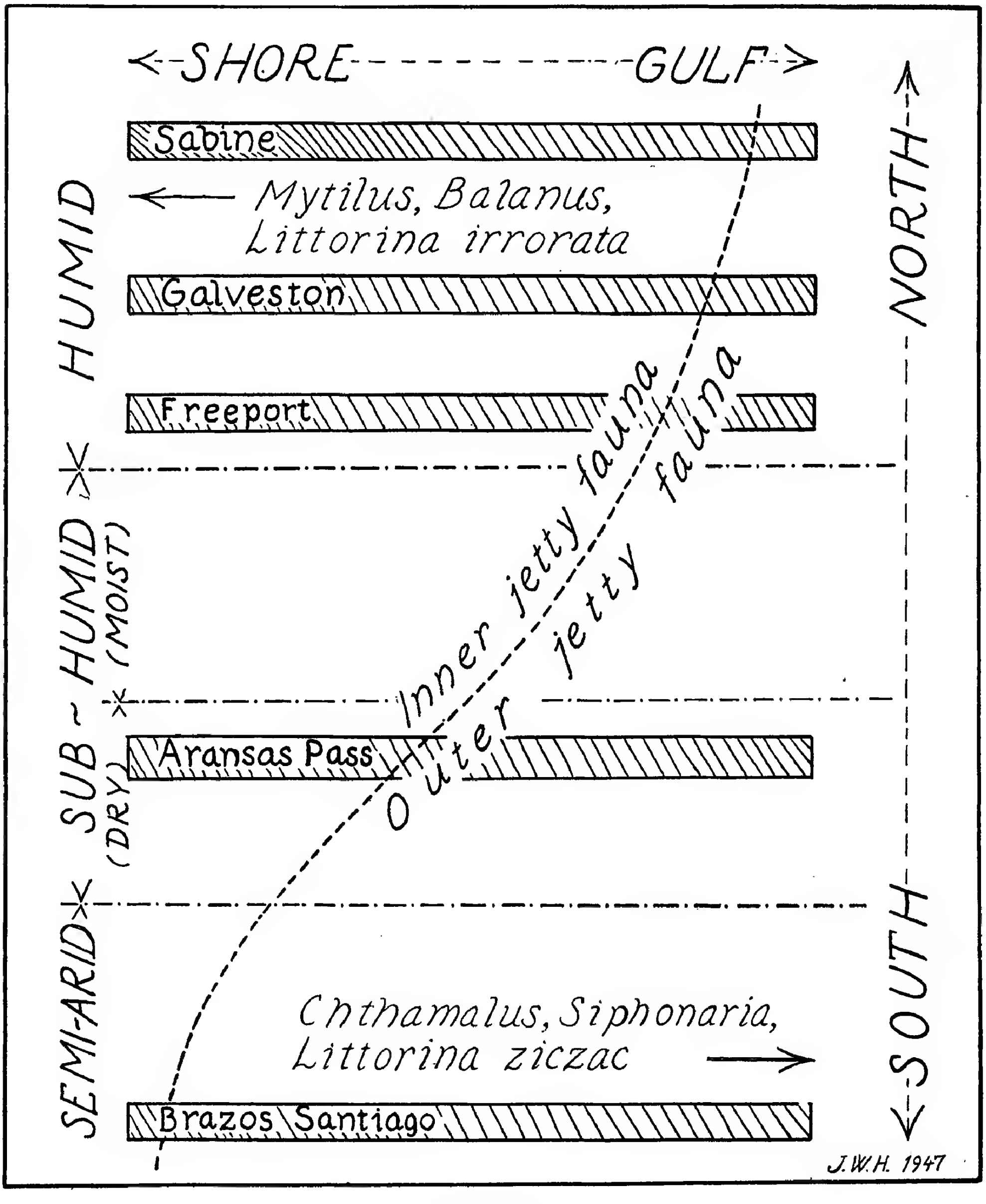

FIGURE 4

Schematic diagram of relationships of intertidal jetty fauna with climatic zones and latitude. Characteristic members of the fauna are indicated.

It is of further interest to note that this apparent faunal difference is correlated with the climatic zonation along the Texas coast, which indicates, empirically, a difference in the mean annual salinity of the respective pass areas. The climatic zones are indicated in figure 1. Port Isabel falls in the semi-arid zone, which means that the rainfall is less than evaporation and that therefore surface water runoff is slight. Since Brazos Santiago Pass profits little from what surface water there is in this area, it is even saltier than might be expected from a casual glance at the map, and salinities of 31.5 0/00 have been recorded in nearby parts of the Laguna Madre in February and March. Port Aransas falls in the sub-humid zone, where precipitation and evaporation are more nearly in balance, and salinities at Port Aransas rarely exceed 30 0/00, especially in winter. The remainder of the passes guarded by jetties fall in the humid zone, where an excess of rainfall over evaporation assures lower salinities (see figure 1).

In addition to the salinity factor, the temperature factor is undoubtedly of importance, but since there is no comprehensive temperature data for the Texas Gulf coast as a whole, it cannot be adequately discussed here. The general aspects of temperature zonation in its relation to geographical distribution have been recently summarized by Hutchins (1947).

The Port Aransas jetties fall in a transition zone, and the composition of their fauna indicates the north-south differences in a lateral manner, *i.e.*, the fauna from shore to the outer end of the jetties repeats roughly, because of the average salinity differences in the pass, the general faunal change from north to south. Hence we find, at the shore end of the jetty, a scattering of *Mytilus recurvus*, an abundant species well out on the northern jetties, and much rarer on the Port Isabel jetties, and young oysters, which do not seem to set on the Port Isabel jetties at all. In past years, *Littorina irrorata* was found on the Port Aransas jetties, but has not been found recently, which probably indicates the influence of some other factor, since it is common in the salt marshes of the region.

The problem of the salinity relationships of motile animals, with particular reference to cycles of seasonal abundance, has been discussed in some detail by Gunter (1945, 1950). These papers contain much useful information and present a picture of conditions in the bays and passes which is a valuable aid to understanding biological conditions on the jetties, although they bear only inferentially on the problem of the jetty fauna.

The factor of wave action must also be considered in describing the jetty fauna, and the greater wave action at Port Isabel may be as influential as salinity in limiting the occurrence of oysters and enabling the shoreward extension of *Chthamalus fragilis*. This may also explain the apparent greater abundance of the euryhalin *Balanus eburneus* on the northern jetties in sheltered sections where wave action is insufficient to sustain a high littoral population of *Chthamalus fragilis*. Although Shelford (1930) suggested that "The taxonomic composition growth form and arrangement of individuals and species of barnacles in communities can be used as an index of salinity," this generalization probably cannot apply to the Texas coast, where the salinity is too variable from season to season to be considered a stabilizing influence on the barnacle population. Further, as MacGinitie (1939) says, "marine communities are anything but static affairs."

With the exception of the barnacles and possibly of the mussel, there appears to be no pronounced zonation of the conspicuous rock inhabiting animals at any one jetty. Many of the forms, including such characteristic species as *Siphonaria naufragum, Thais floridana, Littorina ziczac,* and *Bunodosoma cavernata,* can be found along the entire lengths of the jetties. The molluscs will be found from the high intertidal (*i.e.*, from the extreme high water line) to well below low water (except, of course, the littorine), and the vertical position of the anemone seems to be governed more by suitable substrate than actual tidal levels.

This lack of sharp vertical zonation is to be expected of more or less motile animals which occur both on the gulf shore and in the bays, and which do not seem to have strict light preferences. However, this should not be construed as denying the existence of any sort of zonation on the Texas jetties, for such zonation is conspicuous in the case of the algae, which were not studied, and the barnacles. Little has been done on the problem of zonation in a littoral area in which the tidal factor is comparatively unimportant, although Colman (1932) has remarked upon the conspicuous zonation of algae at Dry Tortugas, where tidal conditions are similar to those on the Texas coast, and concludes from his observations there and on the North Atlantic littoral that the "amplitude of the tide is of minor or even negligible importance in deciding the character of the coastal flora and fauna and their zonation." In a later paper (1943), this question of zonation in the absence of large tidal fluctuations is raised as an "intertidal enigma," and the factor of the splash zone (important in regions subject to the trade winds) is mentioned. These problems offer opportunities for fruitful investigations on Texas jetties.

The barnacles occurring on the Texas coast include the following species: *Balanus eburneus, B. improvisus, B. amphitrite niveus,* and *Chthamalus fragilis.* Of these, *Chthamalus fragilis* is the dominant species of the high littoral, especially at the outer ends of the jetties. *Balanus improvisus* occupies an intermediate position, which it shares, especially near shore, with *B. eburneus.* It is interesting to note that these same species, with the exception of *Chthamalus fragilis,* which is replaced by *Ch. stellatus,* comprise the barnacle fauna of the pilings and breakwaters of the Beaufort area (McDougall, 1943).

Before the advent of man, there were no jetties or piling on the Texas coast, and the marine community which has become established in these situations is a comparatively new community, representing a combination of forms which have been derived from various sources. Several of the species occur nowhere else but on jetties and piling, others are emigrants from the oyster reef substrate, which offers similar hard surfaces for attachment, and a few have settled on the jetties from the adjacent sandy or mud bottoms. Others are ubiquitous forms which occur almost everywhere, and several of these are members of the pelagic sargassum community.

Forms found principally on the jetties include *Bunodosoma cavernata, Chthamalus fragilis, Littorina ziczac* and *Siphonaria naufragum.* As the piling fauna of the Texas coast is as yet uninvestigated, it cannot be said which of these may occur exclusively on rocks, but it is probable that the jetties provide their optimum environment. All of these species but the barnacle are found commonly on the breakwaters in the bays as well as on the coastal jetties, which indicates both their preference for rocky substances as well as their euryhalin character. All these species have free-living larvae, and are thus able to spread over wide areas. As Orton (1919) has indicated, the "normal salinity variations within the habitat of the species (of marine invertebrates) have little effect on breeding," and that such euryhalin invertebrates will breed successfully under favorable temperature conditions, which obviously exist for these species on the Texas coast.

Species which have obviously migrated from the oyster reefs or similar situations (such as accumulations of dead shells in the bottom of the channels) include *Petrolisthes armatus, Menippe mercenaria, Anachis avara, Mytilus recurvus, Thais floridana* and *Arbacia punctulata.* The oyster itself is a poor colonizer of the coastal jetties, although it flourishes on the bay breakwaters, as is to be expected of an animal adapted primarily to the brackish environment of bays.

Certain ubiquitous species have become established on the jetties simply because they are adaptable to almost any environment. Wherever the jetties run close to salt marshes, *Littorina irrorata* can be expected, and *Pachygrapsus transversus* is probably also an emigrant from the marshlands. The characteristic ubiquitous species is the hermit crab, *Clibinarius vittatus,* which shows a surprising ability to traverse vertical rock faces with such heavy burdens as the shells of *Natica duplicata* and *Murex.*

The various bryozoa and hydroids of the littoral zone all occur on the sargassum, as do *Platynereis dumerilii, Caprella, Carinogrammarus mucronatus* and *Ophiactis savingyi,* all characteristic species of the algae growing on the jetties. One would hesitate to ascribe their colonization of the jetties solely to the influence of the sargassum, as these species seem to be universally distributed along the Atlantic seaboard. Certain other characteristic sargassum species were not found on the jetties. Some of these fail to establish themselves despite the frequent standings of clumps of gulfweed on the jetties for the apparent reason that they can only survive in the pelagic habitat of the gulfweed. These include the actinian *Anemonia sargassensis,* which is abundant on sargassum in the spring, the goose barnacles, and the large annelid *Amphinome rostrata.* Others, notably two species of pycnogonids, *Tanystylum orbiculare* and *Anoplodactylus petiolatus,* which are well established littoral species from Florida to Woods Hole, evidently fail to find a suitable environment on the Texas jetties. The gulfweed crab, *Planes minutus,* which sometimes adopts a littoral habitat, is yet to be found on the Texas coast, or from the sargassum near shore.

IV. SUMMARY

1. An ecological survey of the marine invertebrate fauna was conducted on the jetties of the Texas coast during the months of June and July in 1938, 1939 and 1940.

2. The jetties guard five passes to inland bays which are maintained as navigable waterways, but the actual rocky area constitutes a minor percentage of the total coast line, which is a sandy beach 400 miles long.

3. The usual tidal range on the Texas coast is from one and one half to two feet.

4. The passes guarded by these jetties are subject to an annual salinity range of at least 20 parts per thousand (ca 15 to 35 0/00 from Port Aransas northwards) and an annual temperature variation from 9 to 30°C.

5. This study was confined primarily to the fauna of the intertidal community of the Texas jetties. This community, considering the coast as a whole, is composed principally of three species of barnacles, one limpet, one littorine, one mussel, a *Thais,* an anemone, the isopod, *Ligyda,* and a hermit crab.

6. There are indications of a north to south change in the relative abundance of these species, which may be correlated with mean annual salinity of the respective areas, and possibly also with wave action.

7. The jetty fauna represents a composite colonization from various habitats, including the oyster reef, the sand and mud bottom of adjacent areas, the salt marsh, and possibly the sargassum. A few species, found principally on rock works on the Texas coast, probably owe their colonization to their free living larvae.

V. APPENDIX

Annotated list of certain marine invertebrates found on Texas jetties

By

Joel W. Hedgpeth

No effort has been made to present a complete list of the known or suspected jetty fauna at this time, although this list includes several species not mentioned in the foregoing text. Several groups, such as protozoa, porifera and platyhelminthes, were not investigated, and others, such as the smaller arthropods and the annelids, are incompletely listed here. Nevertheless, it is hoped that this list will convey a reasonably accurate idea of the fauna of the Texas jetties, at least insofar as the tidal zone is concerned. Complete acknowledgment for assistance in identifying various groups of invertebrates will be made in a more comprehensive work now in progress.

Phylum PORIFERA

There are some encrusting sponges on the jetties. In crevices there are small patches of a yellowish-cream sponge with conspicuous oscula. Patches of bright purple *(Haliclona)* and red ochre *(Microciona)* sponges occur, especially near the outer ends of the jetties. No domed or papillate growth forms of sponges were observed. Probably there are other sponges lower down among the rocks of the jetties, and the general situation as regards sponges seems to be similar to that at Beaufort, as described by de Laubenfels (1947).

Phylum COELENTERATA

Class Hydrozoa

Order Hydroida

Hydroids are not common on the jetties, and the hydroids that are accessible are small forms which live in crevices and on the under surfaces of rocks. There are undoubtedly several other species besides those listed below. According to Deevey (1950), some 26 species of hydroids are so far known from Texas waters. This fauna contains boreal representatives, which Deevey suggests are Pleistocene relicts.

Suborder Gymnoblastea

Corynidae

Zanclea costata Gegenbaur

A very small species; found on sargassum and epizoic on the larger *Ectopleura grandis*, probably also on the jetty rocks.

Hydractinidae

Hydractinia echinata (Fleming)

This species habitually infests gastropod shells occupied by hermit crabs. While usually below the tidal region, occasional colonies are found on hermit crabs near the jetties. Identified from South Jetty, Port Aransas.

Tubularidae

Tubularia crocea (L. Agassiz)

This is a large tubularian which resembles *Ectopleura grandis* Fraser which occurs in Louisiana and has been collected at Palacios, and Port Aransas, Texas. Clumps of it are found along the beach near Port Aransas, and large bunches of it have been taken from the Dow Chemical intake screen at Freeport. It is possible that it occurs on the jetties, well below the tide line. During the winter of 1947–48 this hydroid was abundant among rocks along the channel at Port Aransas, and on oysters held in rocks under the Institute dock in the pass.

Suborder Calyptoblastea

Campanularidae

Clytia cylindrica Agassiz

This small, unbranched hydroid is common on the sargassum, and grows as short stubble on jetty rocks. Observed at Port Isabel and Port Aransas; probably on the other jetties also.

Gonothyraea gracilis (Sars)

Another small hydroid found on rocks, old shells, and occasionally cast up on the beach. Collected at the Port Aransas jetties.

Obelia dichotoma (Linnaeus)

Evidently the common jetty form. At Port Aransas, this species forms extensive colonies in narrow cracks at the end of the south jetty. It has been observed on all the jetties.

Sertularia inflata (Versluys)

This is the hydroid commonly identified as *Sertularia versluysi* (Cf. Fraser's monograph on the Atlantic hydroids, 1944, pp. 283–284). It often occurs on the sargassum, and occurs occasionally on the jetties.

Order Siphonophora

Although the siphonophores *Physalia pelagica, Velella velella* and *Porpita linneana* are pelagic forms, they are frequently cast up among jetty rocks.

Class Scyphozoa

While the siphonophores are truly pelagic forms, several medusae invade the littoral zone and are found close to the jetty rocks. *Aurelia aurita* and *Dactylometra quinquecirrha* are often seen in the passes. The rhizostome, or cabbage head, *Stomolophus meleagris*, is abundant in spring and summer, and can often be observed swimming close to the jetties, even among the submerged rocks, where it sometimes appears to rest. Young individuals of the spider crab *Libinia* often travel in the bell of this jellyfish as commensals. Since this crab is usually sluggish, it may invade the jellyfish during one of these resting periods unless it infests the medusa during the megalops stage.

Class Anthozoa

Order Alcyonaria

Renilla mülleri Kölliker

Normally a bottom living form, this sea pansy was collected from among the rocks on the north jetty at Port Aransas in 1940.

Order Actiniaria

There is only one common species of anemone on the Texas jetties, but there are evidently several other small, inconspicuous species. Some of these have been collected at Port Isabel and Port Aransas, but have yet to be determined.

Actiniidae

Bunodosoma cavernata (Bosc)

This anemone is found on all the jetties, usually just below the water line. Occasional specimens are found inside the narrow tidal zone, usually under rocks and in other sheltered positions. It is variable in color, ranging from pale yellow cream to deep blue and red in the tentacles and from gray brown to cherry red in the column. The usual color is a greenish blue with red tinges in the tentacles, in combination with a rusty brown column. The warts on the column are always a translucent gray. Some specimens under rocks at the south jetty, Port Aransas, are almost entirely cherry red. The usual size of this anemone when expanded is one to one and a half inches across the disc, and about two inches high. This appears to be the same anemone referred to at Beaufort as *Phymactis cavernata* by Field (1949) and recorded from Porto Rico as *Bunodosoma granulifera* by Duerden (1902).

Anthopleura krebsi (Duchassaing and Michelotti)

A small anemone with translucent white or gray tentacles, and grayish white column. The column is ornamented with rows of bright carmine warts which are larger near the top of the column. It is found under rocks at the north jetty, Port Isabel. A small, completely colorless specimen was also taken here, which may be another species of *Anthopleura*.

Order Madreporaria

Astrangia astreiformis Milne-Edwards and Haime

Although not collected from the jetties, this small coral will probably be found on rocks in the deeper sections. It is common on bits of shell in the channels, which indicates that its salinity tolerance is wide enough to enable it to live on the jetties.

Phylum CTENOPHORA

Class Tentaculata

Mnemiopsis mccradyi A. Agassiz

This ctenophore is often abundant in the bays and the channels, and sometimes large numbers are washed in among the jetty rocks.

Phylum NEMATODA

Nematodes were not collected in the course of this study. Small ones can be found among the clumps of algae, and are evidently less important members of the *Carinogammarus-Caprella* community.

Phylum ANNELIDA

Class Polychaeta

Polynoidae

Lepidonotus sublevis Verrill

Several living specimens were taken from the northeast jetty at Freeport. This scale worm is common on the trawling grounds a few miles offshore, where it is found in old shells, and on the under surface of the sea pansy *Renilla mülleri.*

Neridae

Platynereis dumerilii (Audouin and Milne-Edwards)

Nereids are neither conspicuous nor abundant inhabitants of the jetties, and this is the only species positively identified. It builds a tube of sand grains among the algae on the rocks. This worm is also the common form found on sargassum near the central Texas coast. It is small, usually about one and one half inches long.

Serpulidae

Eupamotus dianthus (Verrill)

Tube worms occur sparsely on the jetty rocks below the tide level. As pointed out by Hartman (1945) these worms do not abound where there is a scarcity of calcareous rock, and the jetties are principally composed of igneous blocks. The usual habitat for these tube worms is old mollusc shells.

Phylum ARTHROPODA

Subphylum Crustacea

Class Copepoda

There are a few small copepods living among the algae on the jetties, but they were not collected during this survey.

Class Cirripedia

Order Thoracica

Lepadidae

Goose barnacles have not been found growing on the jetties. Several species of this family are commonly found on driftwood and sargassum cast on the beach, and are pelagic in habit. Species collected from flotsam on the Texas coast are *Lepas anatifera* Linnaeus, *L. anserifera* Linnaeus and *L. pectinata* Spengler.

Balanidae

Balanus eburneus Gould

This is the common barnacle of Texas bays and the shoreward portions of the jetties. It is also found on shells and occasionally on the carapace of the blue crab.

Balanus improvisus Darwin

Another common bay and shoreward jetty form.

Balanus amphitrite niveus Darwin

This form has been identified from the Port Aransas jetties. It is probably the species seen covering rocks below the *Chthamalus fragilis* zone at the end of the jetty, and its wide distribution indicates that it probably occurs on all the jetties.

Chthamalidae

Chthamalus fragilis Darwin

This is the common high littoral form of the jetties, especially on the outer sections. It occurs in situations well above high tide line where there is sufficient spray to give it enough water. The related *Chthamalus stellatus* is the common barnacle of these situations at Beaufort, but farther north its place is taken by *Balanus balanoides.*

Class Malacostraca

Subclass Stomatopoda

Squilla empusa Say

This normally bottom dwelling form was taken with a dip-net from the Port Aransas jetty in 1940.

Subclass Peracarida

Order Isopoda

Suborder Flabellifera

Sphaeroma quadridentatum Say

Identified from piling near the south jetty at Port Aransas; a wood boring isopod.

Ancinus sp.

Isopods of this genus were taken near the north jetty, Port Isabel, in 1940. They were caught with a dip-net in the surf.

Suborder Oniscoidea

Ligyda exotica (Roux)

The common large, fast running isopod of the jetties. A high-littoral or semi-terrestrial species, which prefers to stay out of the water except when endangered. It is nocturnal and is not often seen in daytime except when stones are overturned. It also comes out on cloudy days.

Order Amphipoda

Suborder Gammaridea

Carinogammarus mucronatus (Say)

This is the dominant amphipod of the jetties, often found in large numbers among the algae of the rocks. It comprises, along with *Caprella, Platynereis dumerilii* and other small animals, the biota of the algae. There are, of course, other species of gammarids and isopods, but they do not appear to be as abundant. Several other species are listed in the original paper as having been identified by Mr. Shoemaker of the U. S. National Museum, but specimens are not represented in the collection. The first two are listed as found on the southwest jetty at Freeport, the others from the north jetty, Galveston: *Jassa marmorata* Holmes, *Amphithoe valida* Smith, *Melita nitida* Smith, *Hyale hawaiensis* (Dana). *Ischyrocerus* sp. was listed, without locality data.

Orchestia platensis Krφyer

This is the small, dark beach hopper found under weeds and decaying matter near and on the jetties. Its larger, pale cousin, *Talorchestia longicornis* (Say), has not been reported from the jetties, probably because it requires sand in which to burrow for its refuge.

Suborder Caprellidea

Caprellidae

The caprellids are in sad need of revision, and their taxonomy is difficult because of the variations between the moults. There appear to be two species at least on the jetties: a common form, referred to *Caprella acutifrons* Latreille, which it may possibly be, and a less common, green species, *Caprella* sp. Critical examination may reveal other species.

Subclass Eucarida

Order Decapoda

Tribus Penaeidea

Peneid shrimp are not normal inhabitants of the jetties, but several species have been caught near the rocks in a dip-net, indicating their sporadic occurrence in this situation. Possibly they were seeking their way into the bays and were deflected by the jetties. Species caught included *Penaeus setiferus, P. aztecus* and *Xiphopeneus krφyeri.*

Tribus Caridea

Palaemonidae

A small brown palaemonid shrimp was recorded from the north jetty at Galveston. Probably this was *Latreutes fucorum* (Fabr.), which has been found on the sargassum and on algae in Aransas Bay.

Crangonidae

One small specimen of the pistol shrimp, *Crangon heterochaelis,* was found under a rock at south jetty, Port Aransas. In winter it is common.

Tribus Anomura

Paguridae

Clibinarius vittatus (Bosc)

This is the common hermit crab of the shore and jetty rocks on the Texas coast, and is found from Sabine to Port Isabel. It is characteristically a light greenish brown with longitudinal cream stripes on the legs. It—or its adopted shells—is often to be seen during periods of low water, high and dry on the beach of the bay shores or on top of the rocks of the jetties, and it can evidently survive for several days out of water.

Pagurus longicarpus Say

A rather small hermit crab, distinguished by the iridescent sheen of its otherwise straw colored legs. It does not have the intertidal habit of the foregoing species, and is uncommon on the jetties.

Pagurus floridanus (Benedict)

Like the *P. longicarpus,* this species is not often found near the shore, and prefers even deeper water, being usually found in the bottom of the channels and offshore in the Gulf. It may have been taken during the jetty study, but specimens are not on hand.

Petrochirus bahamensis (Herbst)

This bright red hermit crab was collected on the north jetty at Port Aransas in 1940. Its usual habitat is the offshore shallows, around ten fathoms. Off Port Isabel it is quite common, and grows to a large size, occupying large shells of *Tonna galea*, *Busycon* and *Murex*. The shells are usually covered with the anemone, *Callicatis tricolor*. Sometimes there are five or six anemones on a single shell. Practically all the shells were also occupied by a small commensal crab, *Porcellana sayana*.

Porcellanidae

Petrolisthes armatus (Gibbes)

Although not collected during the original jetty study, this crab probably occurs on all the jetties, in view of its wide distribution. It occurs among the rocks at the shore end of the south jetty at Port Aransas, and young individuals were found in the algae at the end of the jetty. Others were observed in rock crevices, although it is not common in this situation.

Tribus Brachyura

Brachyrhyncha

Portunidae

The swimming crabs are not normal members of the jetty fauna although the common blue crab, *Callinectes sapidus*, is readily caught along the jetties by amateur crabbers and specimens can usually be seen swimming by. Other portunids noted at the various jetties are *Arenaeus cribrarius*, *Ovalipes ocellatus*, and possibly *Portunus gibbesi* and *Callinectes danae*.

Xanthidae

Menippe mercenaria (Say)

Hay and Shore (1918) have noted the habit of the young crabs of this species of living among stones at the jetties at Beaufort. While the adults usually burrow among oysters, good sized specimens frequent the jetties, living in cracks between the larger rocks.

Grapsidae

Pachygrapsus transversus (Gibbes)

This little grapsoid, while not abundant, is a frequenter of the jetties. It is quick and elusive, and often evades the eyes as well as the hand. It appears to be more common on the northern jetties, thinning out at Port Aransas and is noticeably less numerous on the Port Isabel jetties.

Ocypodidae

Ocypode albicans Bosc

Occasionally the ghost crab invades the jetties on its nightly forays, and its holes are sometimes very close to the rocks of the jetties.

Uca minax (Leconte)

This fiddler crab was reported from the vicinity of the Sabine jetty, but is unconfirmed by the collections. On the central Texas coast it appears to be rarer than the other fiddlers, and prefers the brackish shores of inland bays to the areas near the passes.

Uca pugilator (Bosc)

Often found in burrows near the passes and in salt grass situations on the barrier islands, this crab, like the ghost crab, makes brief nocturnal forays on nearby parts of the jetties.

Subphylum Insecta

While only members of the pelagic hemipteran genus *Halobates* can be considered truly marine insects, several terrestrial insects frequent the littoral zone and are evidently able to survive accidental immersion in salt water. Most conspicuous of these are tiger beetles, which are found along the bay shores and on the tops of the jetties, sometimes beyond the beach line. Staphylinids are occasionally found under bits of algae and refuse. Mention is made, in the original thesis, of "salt water striders" at the west jetty, Sabine, near the shore, which may be *Halobates.* I have taken *Halobates micans* Eschscholtz in a plankton tow at the south jetty, Port Aransas. Several insects are identified in an addendum to the thesis (by entomologists of the Smithsonian Institution) including *Trichocorixa verticalis* (Fieb.), a staphylinid, *Homoeotarsus pimerianus* (Lec) and a cicindellid, *Cicindela hamatus* Brulle. Flies, of course, are always present, especially on the rejected fish caught by anglers, and a green eyed fly *(Tabanus costalis)* is sometimes uncomfortably abundant.

Subphylum Pycnogonida

Diligent search on the Port Aransas and Port Isabel jetties has failed to reveal any pycnogonids, to this author's chagrin. An immature *Achelia* was caught in a small tow net in the cove between rocks and beach at the south jetty, Port Aransas, indicating that it probably came from the jetty, as this genus is not known to be pelagic. Two species, *Tanystylum orbiculare* Wilson and *Anoplodactylus petiolatus* (Krøyer), have been taken from sargassum in the spring, but have not been found on the shore. Another species, *Anoplodactylus pygmaeus* (Hodge), has been taken from a buoy near Galveston. Probably the absence of bushy hydroids on the jetties accounts for this scarcity of pycnogonids. In December, 1947, the appearance of colonies of *Tubularia* among the rocks along the channel a few hundred yards beyond the base of the jetty indicated that this may be a seasonal condition. A few specimens of *Ammothella rugulosa* Verrill were found among the hydroids. However, this is not on the jetty proper and the situation is a more sheltered one.

Phylum MOLLUSCA

Class Amphineura

Order Polyclaphora

Ischnochitonidae

Ischnochiton papillosus (Adams)

One specimen of this small green chiton was collected on the Port Aransas jetty in November, 1945. It is not rare on old oyster shells in Aransas Bay and in the vicinity of Port Isabel. Its occurrence on the jetty may have been accidental. It is inconspicuous, and may have been overlooked even when sought for.

Class Pelecypoda

Order Prionodesmacea

Order Filibranchia

Spondylidae

Spondylus echinatus americanus Lamarck

A single, battered specimen of this mollusc was taken from the Sabine jetty.

Anomidae

Anomia simplex Orbigny

The jingle probably occurs sparingly on all the jetties. Dead shells can be found occasionally, both loose on the beach and attached to large gastropod shells. It is also found on old oyster shells.

Mytilidae

Mytilus recurvus Rafinesque

This mussel occurs on all the jetties, sometimes abundantly enough to be considered as comprising a community, at least on the northern jetties. It is not so abundant at Port Aransas or Port Isabel.

Lithophaga bisulcata Orbigny

This rock boring form is found in soft sandstone and calcareous rock, but not in the granite quarry blocks which comprise the bulk of the jetties.

Order Eulamellibranchia

Ostreidae

Crassostrea virginica (Gmelin)

Young oysters are common on the shoreward portions of the jetties, but they do not become established and no large living specimens have been found. The oysters die off for some reason after reaching a length of about two inches.

Ostrea cristata Born

Although not recorded from Texas in Johnson's check list (1934), this little oyster is fairly common in Texas waters. Live ones have been observed near the shoreward end of the south jetty at Port Aransas, and it is common in the Lydia Ann channel, leading from Port Aransas to Aransas Bay.

Pholadidae

Martesia striata (Linné)

Found boring into piling near the jetties, but not a rock boring form.

Teredidae

The teredos are not jetty forms, except where piles and cross pieces of old tramways remain to provide wood for them to bore into. According to the marine piling investigations of the National Research Council (Atwood and Johnson, 1924), *Teredo bartschi* Clapp and *Bankia gouldi* Bartsch are the most common shipworms on the Texas coast.

Class Gastropoda

Subclass Prosobranchia

Order Aspidobranchia

Neritidae

Nerita versicolor Gmelin

This mollusc is listed in the original thesis from all the jetties, as a "very small" snail, and the identification confirmed by Dr. Bartsch. I have not found it at Port Aransas or Port Isabel on the jetties, and it has evidently become very scarce if not entirely absent from these localities. *Nerita versicolor* may still occur on the northern jetties, which I have not had the opportunity to study.

Order Pectinobranchia

Naticidae

Natica duplicata Say

Dead shells of the moon snail are often carried about on the jetties by hermit crabs, and live specimens were taken from the northwest jetty at Freeport.

Crepidulidae

Crepidula fornicata Linnaeus

The slipper limpet does not appear to live naturally on rocks, but is common on gastropod shells which have become the homes of hermit crabs, and might be therefore considered an involuntary influent of the jetty fauna.

Littorinidae

Littorina irrorata Say

The salt marsh periwinkle is not normally a frequenter of the jetties at Port Aransas, and its reported occurrence on the northern jetties may indicate somewhat lower salinity conditions on portions of jetties actually extending into the salt marsh community.

Littorina nebulosa Lamarck

Found sparingly on jetties from Sabine to Port Isabel.

Littorina ziczac Gmelin

The common littorine of the Texas jetties. It is usually rather small, about the size of a BB shot, and gathers in cracks and pits of the rocks. It is seldom out of the reach of wave action.

Cassididae

Phalium granulatum (Born)

This is the familiar "Scotch bonnet" of the Gulf coast, often cast up on the beach after storms. Clench, in Johnsonia (Vol. 1, No. 16, p. 5), gives the reasons for using this generic name, which is unfamiliar to most amateur conchologists, who are accustomed to such generic designations as "Cassis" and "Semicassis." This species is not a jetty form, but live specimens were recorded from the Port Isabel jetty in 1940.

Thaisidae

Thais floridana Conrad

While perhaps not as abundant as *Littorina ziczac*, this is probably the dominant gastropod of the jetties, because of its larger size. It is found from Sabine to Port Isabel, on the jetties, but less common in the bays, and is not often an oyster pest in Texas waters.

Pyrenidae

Anachis avara (Say)

This small gastropod occurs on the jetties among algae and under rocks. It is also found on oyster shells in the bays. It is not as common on the jetties as it is in the bays.

Nassariidae

Nassarius acuta Say

Recorded from Galveston jetty by Whitten. Not in the collections.

Buccinidae

Cantharus tinctus Conrad

A small, orange banded shell which superficially resembles a young *Thais*. Probably occurs sparingly on all jetties. One specimen was collected at Port Aransas on October 20, 1947.

Fasciolaridae

Fasciolaria distans Lamarck

A live specimen was taken from the north jetty at Port Isabel in 1940.

Subclass Opisthobranchia

Order Tectibranchia

Bullidae

Bulla occidentalis Adams

The bubble shell is normally a mud dweller, but several live specimens were observed by Whitten on the rocks of the north jetty at Port Aransas in 1940.

Order Nudibranchia

Occasionally large pelagic nudibranchs are found on the jetties after storms. They are also taken in the bays, and while uncommon, are found frequently enough to have earned the popular name "inkfish" among the fishermen. The species is probably *Tethys floridensis.*

Subclass Pulmonata

Order Basommatophora

Siphonariidae

Siphonaria naufragum Stearns

This is the common limpet of the Texas coast, occurring on jetties in the bays as well as at the passes. It is also called *Siphonaria lineolata* Orbigny.

Class Cephalopoda

Subclass Dibranchiata

Order Decapoda

The short squid, *Loligo brevis* Blainville, was taken from the north jetty at Port Aransas with a dip net. Another species, *L. brasiliensis* Blainville, was caught from the Port Aransas jetty. This squid is apparently rare in Texas waters.

Order Octopoda

The octopus, *Octopus vulgaris* Lamarck, is occasionally found in the channels and is probably an inhabitant of deep crevices in the jetties, but it cannot be considered common.

Phylum BRYOZOA

Class Gymnolaemata

Order Chilostomata

Bryozoa are uncommon or inconspicuous on the Texas coast, with the exception of large bushy varities (*Amathia* and *Zoobotryon*) which occasionally flare up so abundantly in spring and early summer that they impede nets. The jetty forms are principally the Membraniporidae, lacy encrusting forms found in small patches on the rocks and on shells. *Membranipora tuberculata* (Bosc) and *Acanthodesia savartii* (Audouin) have been identified, and others are probably present. Whitten lists the occurrence of *Bugula turrita* (Desor). *Bugula neritana* Linnaeus is common on shells, rocks and other objects near the jetties and in the outer bays in winter.

Phylum ECHINODERMATA

Class Asteroidea

Order Phanerozonia

Astropecten antillensis Lütken

Specimens of this sand star were taken from the north jetty, Port Aransas, in 1940. The determination was made by A. H. Clark.

Class Ophiuroidea

Order Laemophiurida

Amphiuridae

Hemipholis elongata (Say)

A specimen of this serpent star was found in October, 1947, under a stone near the shoreward end of the south jetty at Port Aransas.

Ophiactis savignyi (Müller and Troschel)

Young specimens of this brittle star, characteristically six legged, are found among the clumps of algae along the jetty at Port Aransas and Port Isabel, and will probably be found on the other jetties. They are very small, usually less than 4 mm. in extent.

Class Echinoidea

Order Centrechinidae

Arbacidae

Arbacia punctulata (Lamarck)

The common purple urchin of the Atlantic coast, especially the Woods Hole region, is found sparingly on Texas jetties.

Echinidae

Lytechinus variegatus (Leske)

This appears to be the green urchin collected from the Port Isabel jetties. Reed (1941) lists it from the Texas coast, possibly from the Port Aransas jetties.

Phylum CHORDATA

Subphylum Urochordata

Class Ascidacea

While no ascidians have been collected from the jetties, it is probable that one species at least occurs on them, but has been overlooked because of its resemblance to a small daub of mud. This is *Molgula manhattensis* (DeKay), which has been collected from old mollusc shells in relatively shallow water offshore at Port Aransas and Port Isabel. Two other ascidians, *Styela partita* (Stimpson) and *S. plicata* (Lesueur) were taken from this habitat off Port Isabel, but neither has yet been found in the bays.

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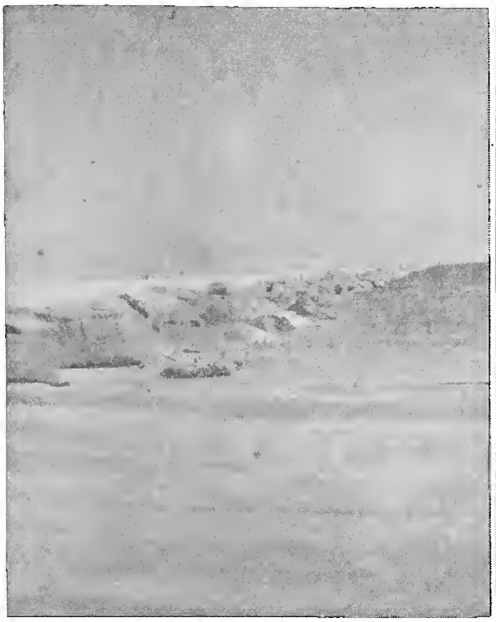
PLATE 1



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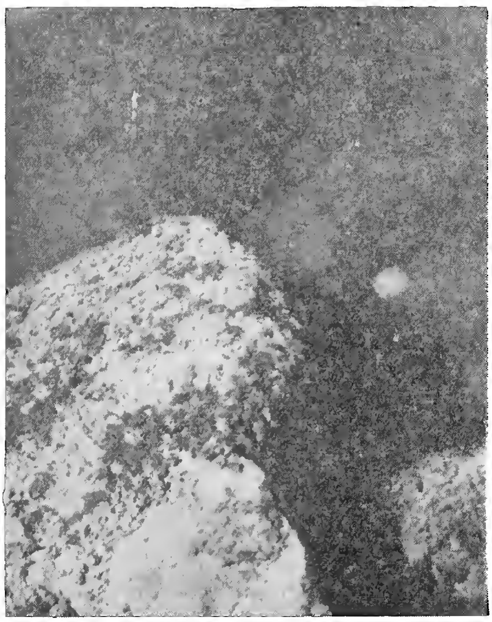

C

D

A. View of South jetty at Port Aransas, from outside corner looking seaward.

B. View of South jetty at Port Aransas, looking shoreward on channel side.

C. View of rocks near end of south jetty Port Aransas, showing algae. Note the *Stomolophus meleagris.*

C. Detail of community on rocks in splash zone, south jetty Port Aransas. The species shown are *Siphonaria naufragum*, *Chthamalus fragilis* and *Littorina ziczac.*

Distributions and Abundance of Fishes on the Aransas National Wildlife Refuge, with Life History Notes

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INTRODUCTION

In 1945 the National Audubon Society and the Fish and Wildlife Service started an investigation of the whooping crane, which has declined almost to the point of extinction. The only known wintering grounds of this bird is the Aransas National Wildlife Refuge on the south Texas Coast. At the instigation of Mr. Harold L. Blakey, then Biologist for the Fish and Wildlife Service, Mr. Joel W. Hedgpeth, formerly of the Texas Game, Fish and Oyster Commission, and I undertook a study of the aquatic animal life of the Refuge available as food for the cranes. The work was carried on from February to July, 1946, when my connection with it ceased. Parts of it were continued by others. The general results and those relating specifically to management problems of the whooping crane will be published elsewhere.

In this paper certain findings primarily concerned with fishes are reported. The fish fauna of the marginal ponds and salt flats of the Texas Coast has not been studied before.

DESCRIPTION OF THE AREA

The Aransas National Wildlife Refuge includes the whole of Blackjack Peninsula, Aransas County, Texas, and lies between St. Charles Bay on the west and north, and San Antonio and Mesquite bays on the east and south. The peninsula is about 16 miles long and from 2 to 7 miles wide. The area is approximately 47,000 acres. Figure 1 is a map of the locality. The base of the peninsula and a central portion running lengthwise down it is covered with heavy, almost impenetrable brush. On the marginal parts, especially on the south side, the ground is lower and forms a wide, treeless flat covered with grass and certain salt-resistant plants, such as Salicornia and Phragmites. Stevenson and Griffith (1946) have given a more complete description of the Refuge.

Greatest attention was given to the salt flats, since the whooping cranes stay on that area, with only occasional trips into the brush. Scattered over the flat are numerous semi-permanent and permanent ponds of brackish and salt water. One of these, known as Long Lake, is a long slough running for several miles down the middle of the flat. The ponds are all shallow and usually less than 50 yards wide. Their levels rise and fall and their areas change considerably with fluctuations in rainfall. Some of the ponds go dry in midsummer and possibly all of them disappear in dry years.

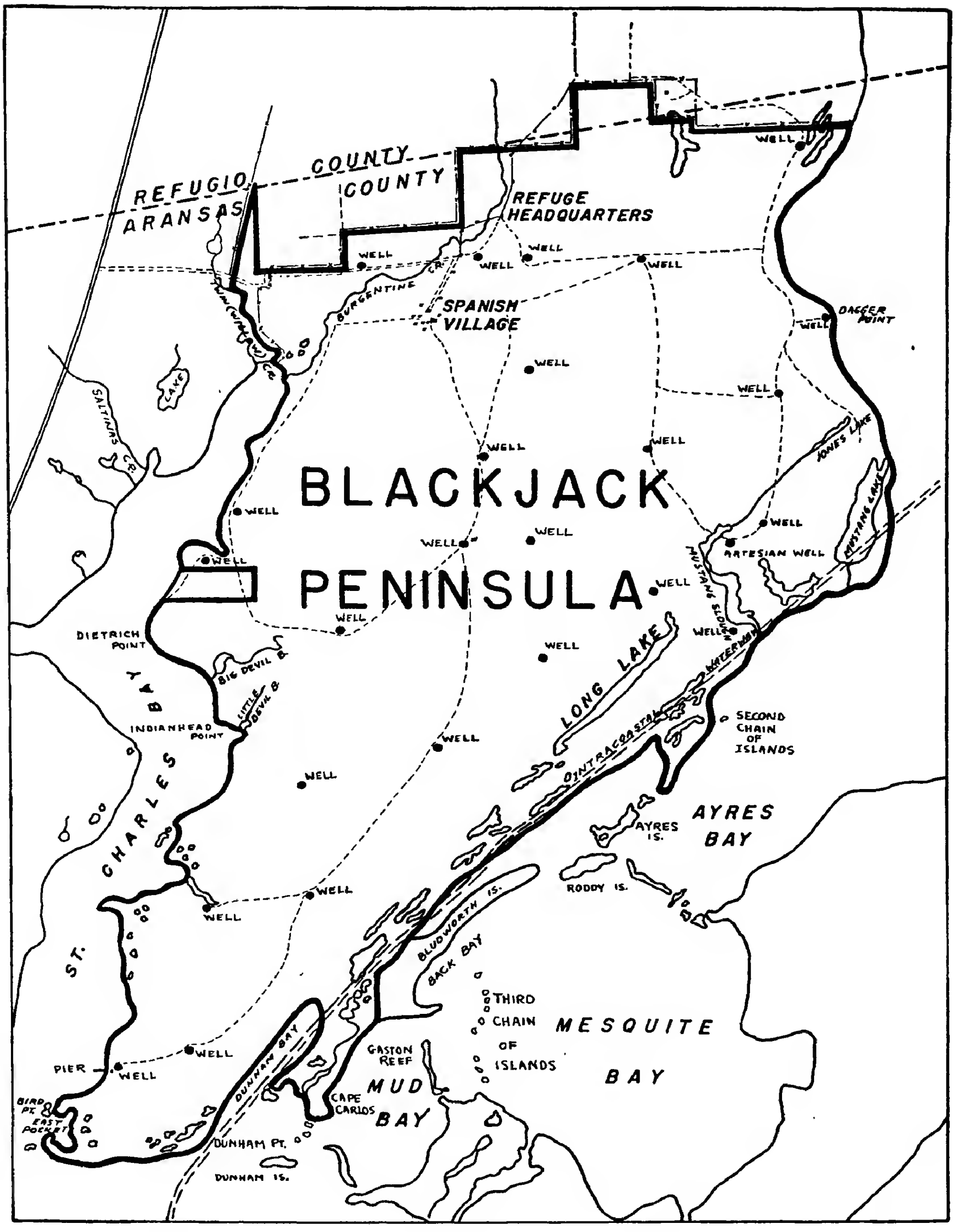

FIGURE 1

The Aransas National Wildlife Refuge. The boundaries are shown with the heavy border. The ponds on the salt flat are shown near the lower right shore of the peninsula.

The ponds get their water from rainfall, sheet drainage towards the bay and from flooding by high tides, which regularly occur in the spring and fall. The chief flooding tides are not daily, but seasonal. Characteristically, in the enclosed

Texas bays, the tide rises and stays high, practically at a level, for days or a week or two at a time every spring and fall. The salt flat ponds are connected with the bays at this time and are not connected at other times of the year except by irregular high tides caused by winds which occur occasionally. Hurricane tides sometimes flood the flats in the summer and fall. They are of irregular occurrence and several years may pass without one.

Farther back from the bay, mostly in the brush and scattered over most of the peninsula, are ponds of fresh or only slightly brackish water, fed from windmill wells. These wells are for cattle, which are allowed to range over the wildlife refuge. Since cranes only visit these fresh water ponds occasionally, they were not studied as extensively as the ponds on the salt flats.

METHOD OF STUDY

Except in the beginning, when unsatisfactory attempts with a large fish seine were made, all collections were made with a seine eight feet deep and fifty feet long with quarter inch mesh. This net caught all species in the ponds and sloughs. Water temperatures and salinity samples were taken at each station. Most fish were measured and their spawning condition noted. Stations were visited between the twentieth and twenty-fifth day of each month. Seining conditions at the stations varied and no uniform method of hauling the seine could be used. Occasionally the banks were in high grass because of heavy rainfall. However, attempts were made to get adequate samples at each station.

For the purpose of comparing the fauna of the bay shores with that of the ponds and sloughs on the Refuge, one station on the bay shore was selected. Another nearby, essentially a bay station, was on a small canal or barrow pit about a half mile from its connection with the bay. Three stations on the lower, middle and upper parts of Long Lake and one at a smaller unnamed pond near the upper end of the peninsula were the salt flat stations. A single pond, fed by a windmill and known as McHugh's Well, was selected as the only fresh water station regularly visited.

RESULTS

Temperature and Salinity

Table 1 shows the monthly average temperatures at the three types of stations. The highest temperature encountered was 34.7°C., found at the lower end of Long Lake on July 24, 1946. There was a light, scattered overcast of clouds at the time and doubtless water temperatures in the shallow ponds go higher at times. The temperature in July in the ponds on the flats averages above 34.0°C. during the middle of the day. The average of 3 stations between 2:00 and 5:30 P.M. on July 24 was 34.2°C. The low average of 32.1° for all four salt flat ponds in July was brought about by the fact that the temperature at one station was taken at 6:55 A.M. before the water warmed up, and was found to be 25.9°C. at that time. Diurnal fluctuations of temperature in the ponds in summer is probably close to 15°C.

TABLE 1

Monthly Average Temperatures in Degrees Centigrade for the Three Types of Stations, Explained in Text.

	February	March	April	May	June	July
McHugh's Well (1 station)	22.5	24.8	30.8	24.5	33.2	30.0
Salt Flat Ponds (4 stations)	19.0	22.7	25.5	28.4	28.9	32.1
Bay Stations (2 stations)	20.9	22.6	28.4	29.6	28.0	33.5

Since the data extends only over half of the year, they do not show annual extremes of temperature to which organisms in the salt flat and inland ponds are subjected. Ordinarily August is the warmest month in south Texas and January is the coldest, but observations were made during neither month. In summer the ponds become hotter than the bay waters, as may be shown by comparing the data with those previously given for the bays (Gunter, 1945, p. 125). During winter northers, the pond temperatures drop precipitously and every fifteen years or so, when the coldest spells come (Gunter, 1941), the ponds partly or completely freeze over.

Table 2 shows the average salinities at the three types of stations. Rainfall data show that precipitation was very excessive in 1946 and doubtless salinities during the time of this study were lower than usual. Since salinity of the ponds is quickly reduced by rainfall in the cooler months and some of the ponds evaporate to complete dryness in the summer, the annual variation in salinity is considerable in years of normal rainfall.

TABLE 2

Monthly Average Salinites at the Three Types of Stations Given in Parts Per Thousand

	February	March	April	May	June	July
McHugh's Well (1 station)	1.4	1.8	0.9	0.4	----	2.6
Salt Flat Ponds (4 stations)	4.4	4.3	7.4	9.3	8.0	12.2
Bay Stations (2 stations)	9.5	11.4	8.5	12.9	7.9	18.3

DATA ON FISHES

Distributions

Table 3 gives the numbers of fishes caught in the 10 minnow seine hauls at the bay stations in the order of their abundance. The number of species increased greatly in the spring. The mullet, *Mugil cephalus*, and the cyprinodontid, *Cyprinodon variegatus variegatus*, made up over half of the numbers of specimens caught and the 21 least species made up only 10 per cent of the total catch. Fourteen species made up only 3.4 per cent of the fishes taken. None of these species are particularly uncommon or rare and while their numbers are probably representative in many instances of their relative abundance, many are simply not commonly found on the bay beach, but live in other environments. For instance, *Mollienisia latipinna, Fundulus pulvereus* and *Lucania parva venusta* are more common in sheltered ponds and ditches in waters of generally lower salinity.

TABLE 3

Species Collected in Ten Minnow-Seine Hauls at the Two Bay Stations Arranged According to Abundance.

SPECIES	NUMBER OF INDIVIDUALS
Mugil cephalus	191
Cyprinodon variegatus variagatus	121
Brevoortia gunteri	95
Leiostomus xanthurus	43
Fundulus grandis	36
Lagodon rhomboides	30
Fundulus similis	23
Bairdiella chrysura	18
Menidia beryllina peninsulae	17
Elops saurus	15
Orthopristis chrysopterus	11
Sphoeroides marmoratus	7
Mugil curema	6
Paralichthys lethostigma	5
Micropogon undulatus	3
Strongylura marina, Lucania parva venusta, Caranx hippos, Sciaenops ocellata, Gobionellus sp., *Citharichthys spilopterus and Symphurus plagiusa*	2
Anchoa mitchilli diaphana, Mollienisia latipinna, Fundulus pulvereus, Eucinostomus sp., *Cynoscion nebulosus, Pogonias cromis* and *Gobiosoma bosc*	1

Table 4 lists the numbers of individuals in families represented by more than 10 specimens at the bay stations. The four most abundant, Mugilidae, Cyprinodontidae, Clupeidae and Scianeidae have been shown (Gunter, 1945) to be represented by the greatest numbers of species in shallow bay waters of Texas. However, it was found that the silverside, *Menidia beryllina peninsulae,* and the anchovy, *Anchoa mitchilli diaphana,* are much more common in the shallow waters near the shores of Aransas and Copano bays than found here in Mesquite Bay.

Table 5 gives the species and numbers caught in 23 visits to the salt flat stations. Nine of the 17 species made up only 2.8 per cent of the numbers caught. The Cyprinodontes are overwhelmingly predominant in this environment. Eight species of this group made up 67.1 per cent of the total numbers. The first 8 species listed, with the exception of *Mugil cephalus, Menidia beryllina peninsulae* and *Leiostomus xanthurus,* can probably all complete their life histories in the salt flat ponds. The cyprinodontids, *Lucania parva venusta* and *Fundulus pulvereus* and the poeciliid, *Gambusia affinis affinis,* are probably strays from fresher

TABLE 4

Numbers of Fishes Taken at Bay Stations Given by Families Represented by More Than Ten Specimens.

FAMILY	NUMBER OF INDIVIDUALS
Mugilidae	197
Cyprinodontidae	183
Clupeidae	95
Sciaenidae	66
Sparidae	30
Atherinidae	17
Elopidae	15
Haemulidae	11

waters. They were taken in the salt flat ponds, following very heavy rains when the whole flat was covered by interconnecting rivulets of sheet drainage. All the other species are marine fishes which must return to the bays or perish. In all probability many of them do perish in these ponds during the hot summers.

TABLE 5

Numbers and Species of Fishes Taken in Salt Flat Ponds.

SPECIES	NUMBER OF INDIVIDUALS
Cyprinodon variegatus variegatus	609
Mugil cephalus	299
Fundulus similis	236
Menidia beryllina peninsulae	128
Fundulus grandis	56
Adinia multifasciata	35
Leiostomus xanthurus	26
Mollienisia latipinna	15
Brevoortia gunteri	8
Lagodon rhomboides	7
Lucania parva venusta	6
Fundulus pulvereus	6
Gambusia affinis affinis	5
Syngnathus sp.	3
Bairdiella chrysura	2
Sphoeroides marmorata	2
Gobiosoma bosc	1

McHugh's Well, on the other side of the peninsula, several miles back from the salt flats, was selected as a typical fresh water pond. It contained only 4 species of fishes, *Menidia menidia atrimentis, Gambusia affinis affinis, Lucania parva venusta* and *Ameiurus melas catulus.* The catfish was caught only once. Table 6 shows the numbers of fishes caught each month. The numbers of all three species of fishes increased from winter to the warm months, the peak for *M. m. atrimentis* coming in May, that for *G. a. affinis* falling in June and for *L. p. venusta* in July.

The last two seem to be somewhat antagonistic as shown by the reciprocal rises and falls in their numbers.

TABLE 6

Numbers and Species of Fishes Caught at McHugh's Well, a Fresh Water Pond.

	Feb.	March	April	May	June	July
Menidia m. atrimentis	23	15	57	291	29	69
Gambusia a. affinis	3	43	28	40	147	111
Lucania parva venusta	5	0	16	216	144	1,116
Ameiurus melas catulus	——	——	——	——	1	——
Monthly totals	31	58	101	538	321	1,288

Two other ponds, Hog Lake and Salada Well, were examined on May 30, 1946. The salinity was 0.4 and 0.7 per mille, respectively. The ponds are not connected with the bay at any time except by a hurricane tide. The numbers and species of fishes caught are given in Table 7. The mixture of marine and fresh water species indicates that some connections with the bay, probably during the terrific hurricane of 1945, had previously occurred. Following periods of heavy rains, small rivulets drain from the ponds into the bay, which may afford entrance to the pond for certain euryhalin marine animals.

TABLE 7

Species, Numbers, and Size Range of Fishes Taken at Fresh Water Stations, May 30, 1946.

SPECIES	NUMBER	SIZE RANGE IN mm.
Mollienisia latipinna	51	12–25 (several gravid females)
Cyprinodon variegatus variegatus	49	23–52
Gambusia affinis affinis	44	13–51 (several gravid females)
Mugil cephalus	28	33–85
Lucania parva venusta	23	13–43
Menidia beryllina peninsulae	14	25–95
Fundulus grandis	3	57–88
Fundulus pulvereus	1	58
Tadpoles	8	———
Blue Crab *(Callinectes sapidus)*	Several	Small to adult

GENERAL CONSIDERATIONS

Examination of the tables will show that the Cyprinodontes made up 28.5 per cent of the fishes caught on the bay shore, 67.0 per cent of those taken in salt flat ponds and 79.3 per cent of those taken in the fresh water ponds. Taking all pond stations on the Refuge, the Cyprinodontes made up 74.9 per cent of the catch.

It is evident that in the small pond environment where they are subjected to great extremes of heat, cold, and salinity and probably to lack of oxygen, too, the Cyprinodontes reign supreme. The ability of this group of small fishes, known as killifishes, to withstand hard environmental conditions is proverbial among ichthyologists. Their abundance in waters undergoing extreme variations of temperature and salinity, such as those on the Aransas Refuge, is an *a priori* expectation. It is interesting to note that no cyprinids or centrarchids were taken on the Refuge, even in the larger, fresher and more stable ponds.

Four Cyprinodontes, *Fundulus pulvereus*, *Lucania parva venusta*, *Mollienisia latipinna* and *Gambusia affinis affinis*, largely avoided the salt flats and bay shores, and probably in a normally dry year they would not be found there at all. They evidently prefer fresher waters. On the other hand, *Cyprinodon variegatus variegatus*, *Fundulus similis* and *Fundulus grandis* were most abundant in the saltier waters.

The writer has shown (Gunter, 1945) that as the salinity gradient declines, from the open sea to the river mouths, the numbers of species of fishes decline. Examination of the tables will show that from the bay shores to the fresh water ponds fartherest from the bay the numbers of species decline. Twenty-nine species were caught on the bay, seventeen on the salt flats, eight in fresh water ponds having had previous connections with the bay, and four in an isolated fresh water pond.

Life History Notes

Cyprinodontidae. Killifishes

Lucania parva venusta (Girard). Southern Rainwater Fish

One thousand five hundred twenty-two specimens were caught. The smallest was 10 mm. long and the largest was 62 mm. The salinity where they were caught ranged from 0.7 to 16.3 per mille. The writer (Gunter, *op. cit.*) previously found that in the open bays this fish ranged into salinities as high as 24.2 *per mille*, that the greatest numbers were taken at salinities from 10.0 to 15.0 and that none were taken in waters below a salinity of 2.1. On the Aransas Refuge, however, only eight fish were caught above a salinity of 2.5. One thousand four hundred and ninety-two fish were caught in McHugh's Well where the salinity varied from 0.9 to 2.6 per mille.

Among the larger fish males could be distinguished from females by color differences as early as February, but the greatest intensity in colors of the males was not seen until May and it declined in June and July. This is evidently a breeding coloration. The pelvics and anals of the males range from pale to dark orange color with a black border at this time, and the dorsal fin becomes much darker than that of females. Females began ripening in February and a few were gravid in July, but the peak months of spawning seemed to be May and June.

Most of the fish were caught in May, June and July. Total length-frequency curves showed two groups, from 18 to 33 mm. and 43 to 53 mm. in length. In April and May there were many fish around 18 mm. in length, but they had mostly disappeared through growth and the larger group was also largely gone in July. The crude mode during most months was 23 mm., but in April and May most fish were from 17 to 25 mm. long, while in June and July the majority were from 21 to 30 mm. long.

Fundulus grandis Baird and Girard. Gulf Killifish

This species was not taken in the first two monthly rounds of stations. Possibly it was not present on the salt flats until after the spring high tides. Only 74 specimens were taken, 38 in the ponds. The salinity ranged from 0.4 to 18.6 *per mille* but only 3 fish were taken where the salinity was less than 4.3. The species was found at 13 stations, but over half of those taken were at 3 stations where the salinity was above 13.0. The species seems to prefer open and partly salty waters to inland ponds.

Ripe females were taken in April and May. They were 65 to 91 mm. long. Thirty-one males, determined by color, ranged from 61 to 118 mm. in length with the mean at 75.7 mm. Thirty-three females ranged from 54 to 115 mm. long and the mean length was 82.1. These and previous data (Gunter, *op. cit.*) indicate that females grow to larger size than males. No fish comparable to the larger ones previously reported in open bay waters were found. Either the fish do not grow to maximum size in the ponds or leave when they get big. Two small specimens, 21 and 31 mm. long, taken in July, were evidently young of the year.

Small fish agreeing with the descriptions of *Fundulus pallidus* Evermann, a supposedly rare species from the Texas Coast, were found to merge gradually into *F. grandis* when a series of increasing size was compared. It is concluded that *F. pallidus* is a synonym of *F. grandis.*

Fundulus pulvereus (Evermann)

This species has been uncommonly reported in the literature since it was described in 1891. It was found by Evermann in creeks and bayous near the coast, but was not taken during my rather extensive sampling of open bay waters (Gunter, *op. cit.*). The species seems to prefer sheltered, brackish waters, although nothing has been written about its salinity range. Only 8 specimens were taken, all in May and July. They ranged from 17 to 58 mm. in length and the salinity range was 0.4 to 16.0 *per mille.*

Fundulus similis (Baird and Girard). Black Chub

Two hundred and fifty-two fish, from 20 to 113 mm. long, were caught at salinities ranging 1.4 to 18.6 *per mille.* Some were taken during each month and they were taken only at the bay stations and on the salt flats. None were taken in the fresh water ponds. Only 16 fish were taken at salinities below 4.8 *per mille.* As has been shown before (Gunter, *op. cit.*) this species seems to prefer medium to high salinities. I have never taken it in pure fresh water. It ranges all over the shallows of the bays, venturing occasionally to the Gulf beach near the passes.

Ripe females were taken on March 25, a month earlier than previously recorded *(op. cit.)*, and on until June. Ripe females stripped very easily. Ninety-four ripe females ranged from 65 to 113 mm. in length and the mean length was 87.8 mm. Fifty-five ripe males ranged from 49 to 95 mm. in length and the mean length was 72.8 mm. The ripe fish were most numerous at a salinity of 2.0.

Fish from 58 to 108 mm. long with a few larger and smaller were present in February through May, with only a few left in June, and none in July. They were bimodal at 73 to 78 and at 88 mm. during the time, but showed distinct signs of growth. Most fish were less than 83 mm. long in February and March and most of them were above that length in May and June, while in April they were about evenly divided. None of the group was less than 68 mm. long after March. The very smallest fish, 20 mm. long, first appeared in May, although some from 38 to 48 mm. long were present in March and April. By July only fish from 20 to 48 mm. in length were found.

Adinia multifasciata Girard

All specimens were taken in Long Lake in May and July. The salinity range was 3.1 to 16.3. Twelve fish taken in May were 25 to 29 mm. long. Twenty-three taken in July measured from 12 to 37 mm. in length. The writer has shown *(op. cit.)* that this little fish is sometimes found in salinities as high as 35.7 parts per thousand. I have never found it common on the Texas Coast and very little seems to be known of its life history.

Cyprinodon variegatus variegatus Lacépède. Sheepshead Minnow

Allen (1942) noted the large numbers of this little fish along the shores of Texas bays and Gunter (1945) gave catch records showing that near shore it outnumbered all other species of fishes, except *Menidia beryllina peninsulae.* Tables 3 and 7 show that it was also the most abundant fish on the shore and ponds of the Aransas Refuge and overwhelmingly abundant in the salt water ponds.

Nine hundred and twenty-four specimens, from 15 to 54 mm. long, were taken at salinities ranging from 0.4 to 18.6. Fish from 15 to 47 mm. long were present in February. The approximate mode of the length frequency curve was at 43 mm. and the curve was skewed strongly to the left. Only a few fish below 20 mm. long were present. This small group disappeared thereafter, by growing up, and in March, April, May and June the population ranged from 20 to 54 mm. long, most fish being from 25 to 45 mm. long with a mode at 38 mm. In July a large number of small fish came into the population again and the population was distinctly divided into two groups, a large group from 40 to 54 mm. long with a sharp mode at 43 mm. and smaller fish from 15 to 35 mm. long with a wide peak at 20 to 30 mm. Males in breeding colors, the so-called blue males, were first seen on April 24 and were observed throughout July, but in decreasing numbers in the latter month. One hundred and thirty-two of them ranged from 28 to 54 mm. in length. Allen (1942) has observed that tiny *C. v. variegatus* appear in San Antonio Bay in May. Gunter (1945) concluded that spawning covers a long period and that the young at a length of around 18 mm. keep coming into the population from June to September.

Two fish were found feeding on Chara and other algae.

Poeciliidae. Top Minnows

Mollienisia latipinna Le Sueur. Sailfin Molly

Sixty-seven fish were taken at salinities ranging from 0.4 to 16.3, 52 in May and 15 in July. They measured from 11 to 52 mm. long. One fish was taken in the barrow pit near the bay, 15 were caught in the salt flat ponds and 51 were taken in fresh water pond. Only 4 fish were taken at salinities above 7.4. Several females carrying eggs were noted on May 30.

This species can withstand very high salinities, but appears to prefer low salinities and enclosed shallow waters or both. The writer took only one specimen in the open bay, during an ecological study of Texas marine fishes covering almost two years (Gunter, *op. cit.*).

Gambusia affinis affinis (Baird and Girard). Mosquito Minnow

Five fish were taken in Long Lake and 416 fish were taken in the fresh water ponds. The salinities varied from 0.4 to 3.1. This species was found in the upper end of Long Lake only following heavy rains. Only one fish was taken where the salinity was greater than 2.6 *per mille*. Evidently this fresh water fish will venture into waters that are only slightly salty.

The size of specimens varied from 10 to 53 mm. in length. According to Hildebrand (1917) the young are 8 to 10 mm. long at birth. Fifty-seven males measured from 16 to 32 mm. long with a sharp mode at 24 mm. skewed sharply downward, over half of them being 23 mm. long and less. Naturally some of the females were as small as the males, but 100 gravid females taken during all months were from 20 to 52 mm. long with a mode at 33 mm. Most of them, 66 to be exact, were between 31 and 40 mm. long. The size of gravid females decreased as the season progressed. Of 52 females 33 mm. long and less, 49 were taken in May and June. This can be explained on the basis of Hildebrand's *(op. cit.)* observation that young females, born earlier in the season, may give birth before the season is over.

Monthly length-frequency curves showed that fish from 36 to 53 mm. were present in April, May and June, but practically disappeared in July. At the same time the approximate mode of the total population regressed from 33 to 23 mm. Possibly the larger fish die off after spawning.

Atherinidae. Silversides

Menidia beryllina peninsulae (Goode and Bean). Gulf Silverside

One hundred and ninety-three fish from 24 to 95 mm. in length were caught in waters ranging from 0.4 to 16.9 parts per thousand salt. Seventeen fish from 32 to 90 mm. long were caught at the bay stations. One hundred and twenty-four fish from 24 to 65 mm. long were taken in the salt flat ponds. Apparently only the smaller fish invaded the flats. However, 52 fish in the fresh water ponds were 25 to 95 mm. long. They had probably been land-locked for several weeks. Ten ripe females 77 to 90 mm. long were taken at the bay stations in March. The writer has shown *(op. cit.)* that spawning of this species extends at least from February to August. Small fish first appeared in April, as I previously noted.

Menidia menidia atrimentis (Kendall)

All specimens were taken in McHugh's Well. Temperatures, salinity and the numbers caught are given in Tables 1, 2, and 6.

Length frequency curves showed the fish from 38 to 93 mm. were the only ones present in February and March, with most fish above 53 mm. in length. In

April the young came into and predominated the catch with a sharp mode at 18 mm. Rapid growth took place and in July the mode was at 28 mm., the curve being skewed to the right and no fish under 18 mm. long were present. The large group of fish were then very much in the minority and only stragglers up to 63 mm. long were caught. Thirty ripe females 41 to 95 mm. long were taken in February and March.

This species is cannibalistic. One fish 92 mm. long had eaten two smaller ones 28 and 29 mm. long.

Mugilidae. Mullets

Mugil cephalus Linnaeus. Striped Mullet

Young mullet were found in the salt flat ponds in February, measuring from 26 to 40 mm. long. They grew apparently as rapidly as their congeners in the bay shore and attained a length of 66 to 88 mm. in July, although it is probable that this was not a closed population and some may have come in at high tides from time to time. Two hundred and ninety-four little mullet were taken on the salt flats and apparently the young of the abundant fish spreads over this area as well as the shallow bay waters, after they work their way in from the Gulf where they are spawned (Gunter, *op. cit.*). Small mullet were also taken in the fresh water ponds, though not McHugh's Well. They were common every month but began to be less numerous in July.

ACKNOWLEDGMENTS

Mssrs. Harold L. Blakey and Joel W. Hedgpeth worked with the author at all times in the field and I am much indebted to them.

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ADDENDUM

Mr. Robert P. Allen, of the National Audubon Society, who has been studying the Whooping Crane for the past two years, furnished the writer with some notes on fishes of the Aransas Refuge, collected in the course of his work. They are worthy of inclusion here.

On January 29–30, 1948 the south Texas Coast was visited by a cold wave. On January 30 small numbers of silversides, *Menidia beryllina peninsulae,* were found dead in Long Lake. The water temperature was 3°C. at 10:50 A.M. On February 1, near Cape Carlos on Mud Bay, Mr. Allen found several hundred menhaden, *Brevoortia gunteri,* lesser numbers of silversides, *M. b. peninsulae,* and a few trout, *Cynoscion nebulosus,* dead and piled in windrows on the beach. They had evidently been killed by the cold wave.

The following four stations were all visited on March 30. They extend in a line along the west (landward) side of the road and to the west of the salt flats, at or about the 3 foot contour line, for about the middle third of the peninsula.

At a strong overflow from the Sierritos Well, *Lucania parva venusta* and *Mollienisia latipinna* were found.

A barrow ditch along the roadside, which was also an overflow from the Retama Well, was entirely evaporated on March 30. It contained dead "mud puppies," tadpoles, *Rana* sp., several score of small *Mugil cephalus* and a few *M.b. peninsulae.* Farther down, about 3 miles, in the barrow ditch, which contained rain water and overflow water from the same well, crawfish (*Cambarus* sp.) and numbers of immature *M. cephalus* were found.

The last station, a barrow ditch near the Carlos Well, was dry at the end of the summer of 1947 and contained no water until the first rains in November. On March 30, 1948, numbers of crawfish, *Cambarus* sp., blue crabs, *Callinectes sapidus,* all less than 50 mm. in width; *M. cephalus, M. b. peninsulae, Fundulus pulvereus* (males and females), *Lucania parva venusta* and *Mollienisia latipinna* were taken there. The fish were small or immature. According to Mr. Allen there was no apparent connection between this station and the bay and there had been no overflow or flooding from storm tides since the hurricane of 1945. Evaporation was rapid in April. The water, as at all the other stations, is considered to be fresh and so registered on hydrometers. However, all of the wells are slightly brackish in taste and the water is weakly saline, but not from the sea.

Mr. Allen's puzzlement over how the small marine fishes and crabs got into this apparently blocked-off pond parallels the writer's in similar circumstances on the south Texas coast (Gunter, Copeia 1947(3): 203–204).

Notes on the Marine Invertebrate Fauna of Salt Flat Areas in Aransas National Wildlife Refuge, Texas

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INTRODUCTION

The observations discussed in this paper are the result of an ecological survey of the salt marsh areas of the lower part of the Aransas National Wildlife Refuge, located on Blackjack Peninsula between St. Charles, Mesquite and San Antonio bays, Aransas County, Texas (Fig. 1). A small part of the upland area of the refuge lies in Refugio County, but the salt flat area is entirely within Aransas County. This work was undertaken during the months of February through July, 1946, at the suggestion of Mr. Harold L. Blakey, then Biologist for the U. S. Fish and Wildlife Service, stationed on the Refuge. The work was carried out in co-operation with Dr. Gordon Gunter, of the Institute of Marine Science, and the author, then Marine Biologist for the Game, Fish and Oyster Commission. The purpose of the study was to ascertain the food resources of this area for large wading birds, in particular the whooping crane *(Grus americana)*. This bird, now approaching extinction, is reduced to a known population of 32 individuals, more or less. These birds winter on Aransas Refuge, and fly to Canada to breed during the summer, leaving the Rufuge in April and returning in October. The principal emphasis of the original study was on the fish population of the area, and on the larger invertebrates, but the planktonic forms were collected when water levels permitted. The fish population is considered in detail in a separate paper (Gunter, 1950 B).

During the fall of 1946 and the winter of 1946–47, the author made further observations in co-operation with Mr. Robert P. Allen of the National Audubon Society, who is working on the life history of the whooping crane, and with Mr. Blakey. Work on the whooping crane is now being carried on by Mr. Allen, and I wish to thank him for providing observation and specimens from the area for the fall and winter of 1947–48, and for helpful criticism of this paper.

I

Description of the Area and Methods of Study

The salt flat area of the Refuge lies along the southeast tip of Blackjack Peninsula, adjacent to Mesquite Bay. It is separated from the bay itself by a series of small islands and the Intracoastal Waterway. The salt flats proper lie within the area described by the three foot contour line, and are broken up by several systems of shallow ponds which varied in salinity from 2.0 to 17.0 0/00 during the six months of the study. Most of these ponds are only a few inches deep and are connected by

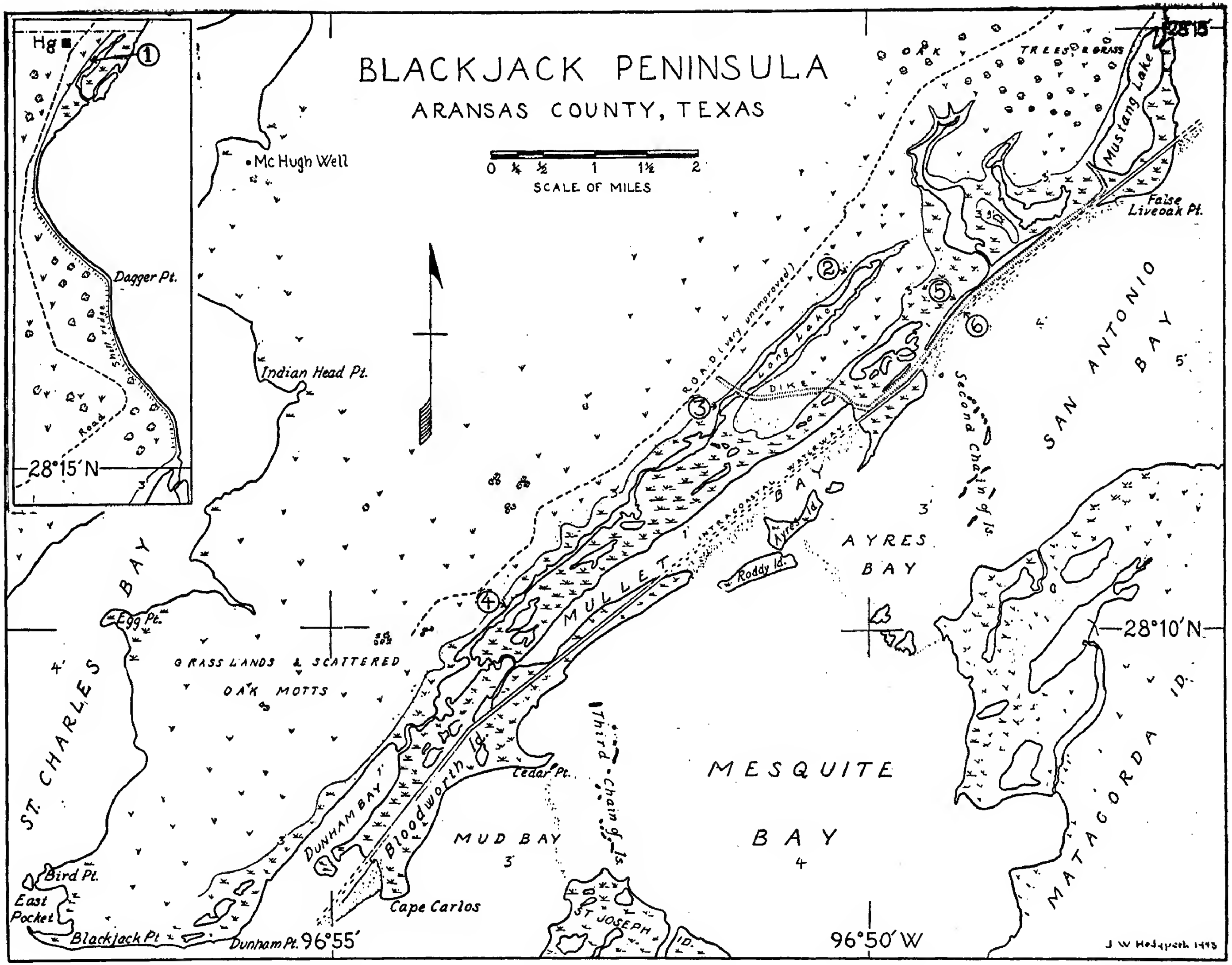

Figure 1

Sketch map of Blackjack Peninsula, showing location of stations used in this study.

devious channels with each other and with the bay. They receive supplies of salt water from the bay especially during high spring and fall tides, while some of them are so well connected with the bay that they are subject to the ordinary tidal variation, which has a range of less than two feet in this region. The area is subject to periods of heavy rainfall which lower the salinities of the ponds and render travel of any sort across the mud exceedingly difficult. During summer, many of the ponds dry up, and others become very shallow, attaining higher salinities by evaporation. Surface temperatures in these shallow ponds often reach 34.5°C. during the summer. The land near the bay shore is soft mud, grading towards sandy loam about a mile from the edge of the peninsula as the elevation rises to four or five feet above sea level. The vegetation is composed of various salt marsh plants such as *Distichlis spicata, Monanthochloe littoralis, Spartina spartinae* and *Borrichia frutescens* on the higher ground, replaced by bushier growths of *Lycium* and several species of *Salicornia* nearer the bay shore.

A series of stations was laid out over this area to include representative situations, from the shallow ponds near the higher limits of the salt flat to a borrow ditch directly connected with the bay and thus subject to direct tidal action, and the shore of the Intracoastal Waterway (*i.e.,* of the bay). These stations were visited monthly, during the third week of the month. A minnow seine of quarter inch mesh was used in making hauls for fish, crabs and shrimp, and general observations of the vicinity were recorded. Effort was made to dig out the burrowing forms and collect certain creatures such as fiddler crabs and molluscs. Temperatures and salinity samples were taken regularly at each station. The results of these observations, insofar as marine invertebrates are concerned, are summarized in Table 1. In addition to the salt water stations, a fresh water station was occupied, at McHugh's Well, on the other side of the Refuge near the shore of St. Charles Bay. Except for some sporadic records of the blue crab, no marine invertebrates were observed at this station and it is not considred in detail in this paper.

The stations are as follows: (See fig. 1).

McHugh's Well. A fresh to faintly brackish stock pond, in a grassy swale about one-fourth to one-third mile from the bay.

1. Headquarters pond. A shallow pond connected with the bay, near Refuge headquarters. The bottom is mud of firm but sticky texture. The pond is bordered by a thick growth of salt marsh grasses.
2. Head of Long Lake. The area selected for the station is a mudbottomed embayment in grass. The surrounding land is sandy loam with hummocks of grasses.
3. Middle Long Lake. The station was located at a corner formed by a dike which runs across Long Lake, but which has been cut through. The bottom is soft muddy sand.
4. Lower Long Lake. The lowermost part of the Long Lake pond series, with sandy to mud bottom. Vegetation on the west side is rather sparse and tends to be confined to hummocks, but on the east side is more dense. The water is seldom more than six inches deep and is often less.
5. Borrow pit. This is a deep ditch made by removal of dirt for the dike along the bay shore. The bottom is soft mud, and the water of this ditch is immediately connected with the bay.

TABLE 1

Data and collections at stations on Aransas Refuge, February–July, 1946

Stations			Annelida		Arthropoda								Mollusca				Notes
			Laeonereis culveri	Neanthes succinea	Palaemonetes intermedius	Penaeus aztecus	Penaeus setiferus	Callianassa j. louisianensis	Uca pugnax	Uca pugilator	Callinectes sapidus	Clibinarius vittatus	Tagellus gibbus	Rangia cuneata	Littorina irrorata	Melampus coffeus	
Station 1	0/00	°C											Dead shells observed at all stations				
Feb. 21	8.8	13.5	x					x		x				d.		x	
Mar. 26	13.2	22.6	x	x	x												Notomastus sp.
Apr. 24	9.3	30.1				x								d.			
May 21	7.6	24.0									x						
June 21	5.0	32.9	x		x						x						Corixids
July 24	16.0	15.9	x								x						" "
Station 2																	
Feb. 22	1.9	20.1								x	x						
Mar. 25	1.4	22.6									x						
Apr. 25	3.08	26.9								x	x						
May 21	4.3	24.2	x						x ov.		x						
June 21	—	—															
July 24	8.9	33.3									d.						
Station 3																	
Feb. 21	4.8	21.7	x		x						x						
Mar. 26	2.0	22.5			x ov.						x						
Apr. 24	4.4	23.5	x		x ov.			x			x						
May 20	11.2	29.0	x					x			x						
June 22	—	27.4			x												
July 24	16.3	34.5									x						

TABLE 1—(continued)

Data and collections at stations on Aransas Refuge, February–July, 1946

Stations			Annelida: Laeonereis culveri	Annelida: Neanthes succinea	Arthropoda: Palaemonetes intermedius	Arthropoda: Penaeus aztecus	Arthropoda: Penaeus setiferus	Arthropoda: Callianassa j. louisianensis	Arthropoda: Uca pugnax	Arthropoda: Uca pugilator	Arthropoda: Callinectes sapidus	Arthropoda: Clibinarius vittatus	Mollusca: Tagellus gibbus	Mollusca: Rangia cuneata	Mollusca: Littorina irrorata	Mollusca: Melampus coffeus	Notes
Station 4																	
Feb. 21	4.3	23.2	x								x						
Mar. 26	2.5	23.0	x														
Apr. 25	12.8	22.4	x					x									beetle larva
May 20	14.0	28.5				x					x				d.		Pinnixa cristata
June 22	11.3	26.4								x	x						
July 24	7.4	34.7			x					x	x						
Station 5													Dead shells observed at all stations				
Feb. 22	12.2	19.0						x	x		x						
Mar. 25	5.9	22.6						x	x	x							
Apr. 25	8.3	27.5	x		x	x		x	x	x	x						
May 20	13.0	29.5						x			x	x					
June 22	8.6	28.5				x		x			x						
July 24	17.0	33.5															
Station 6																	
Feb. 22	9.5	22.0	x								x				d.	x	
Mar. 25	16.9	22.6	x			x				x	x						
Apr. 25	8.6	29.4	x		x	x				x	x						Macrobrachium ohione
May 20	12.8	29.8				x	x				x						Ctenophores.
June 22	7.1	27.5				x					x						
July 24	18.6	33.5				x					x						

d. = dead shells. ov. = egg bearing.

6. Shore of Intracoastal Waterway. The station is located in a small cove across the dike from the preceding station. The bottom is hard sand and oyster shell. The northern boundary of the cove is a small grassy area inhabited by fiddler crabs.

II

General Discussion

Some discussion of the ecological environment of the area of this study will be found in the papers by Stevenson and Griffith (1946) and Allen (1942), but both of these papers are concerned primarily with the food relationships of birds, insofar as they touch upon the salt flat areas, and this study appears to be the first effort to assay this environment on the Texas coast. Several species of large birds, including herons, ibises, roseate spoonbills and white pelicans, frequent the area, as well as numerous smaller shore and wading birds. Numerous tracks indicate a thriving population of raccoons, and armadillos. Snakes and turtles are not rare. Deer are occasionally observed on the open flats. In addition to all this indigenous fauna, cattle were grazing all over the salt flat area to the shore of the bay itself. In 1947 an experimental plot, about one mile square, was fenced off from the cattle. The predominant element of the fish fauna of the ponds on these flats is composed of cyprinodontids of various species, with occasional influxes of mullet from the bay waters. (See Gunter, 1950 B.)

As might be expected from the marginal nature of the environment, the invertebrate fauna is not rich in species, although certain forms, especially the worms, grass shrimp and blue crab, are often abundant. The nereid worms are evidently one of the staple items in the diet of many of the birds, including even such a large bird as the whooping crane, for its characteristic bill marks were observed at the site of many worm burrows. Such salt flats as these are ideal locations for fiddler crabs, but they were not as abundant on the flats during the time of the study as they were in other areas, especially on St. Joseph Island a few miles across the bay from the Refuge.

In all, seventeen species of invertebrates, which might be termed marine or brackish water types, have been found on Aransas Refuge. This total includes the pulmonate *Melampus coffeus,* which is found only among the salt marsh plants. One fresh-water shrimp, *Macrobrachium ohione,* was found on the bay shore in a haul composed principally of *Penaeus aztecus.* On two occasions corixid bugs were found, in water at salinities of 5.0 and 16.0 0/00, and once a large beetle larva was collected in water of 12.8 0/00.

While the salinities ranged from 2.0 tc 18.6 0/00 (sta. 6) at the stations during the six months of the study, the actual salinities, insofar as many of the burrowing forms are concerned, were probably much higher. At station 2, on July 24, the water was about two inches deep and it was necessary to bury the bottle in the mud in order to obtain enough water for a sample. This pond had been dry a few days before, and the water present on that date had come from a recent rain. Yet the salinity was 16.0 0/00, the highest recorded for that station in the six month period. This capacity of the substratum to retain water of higher salinity than the overflowing water has been noted by Reid (1932), and Alexander, Southgate and

Bassindale (1932), and these authors suggest that this retention of salts by the bottom may be a factor favoring the growth of burrowing animals in such situations.

Although the general size and shape of the ponds has been fairly constant for the last several years, to judge from aerial photographs, they are subject to considerable seasonal and periodic variations because of fluctuations in precipitation and prevailing winds. Rainfall during 1946 and 1947 on the Aransas Refuge was ten inches in excess of the 21 year average for Austwell, a few miles away, and the monthly differences are even more striking (Table 2). Summer fluctuations are especially marked. In 1946 the rainfall was .61 inches in July and 9.88 inches in August. Such an increase, occurring in a month when strong northerly winds are rare, means a good stand of water in the ponds during the fall. During the late fall and winter, northerly and northeasterly winds often sweep the shallow ponds bare of water or pile it up at the southern ends of the ponds.

TABLE 2

Precipitation on Aransas Refuge, 1946, 1947.

	21 yr. average at Austwell (1910–30)	Aransas Refuge 1946	1947
Jan.	1.75 in	3.62 in.	2.27 in.
Feb.	1.39	2.69	.60
Mar.	1.91	3.57	1.11
Apr.	2.33	1.95	4.78
May	3.81	1.62	4.39
June	3.92	6.34	4.01
July	2.28	2.78	.61
Aug.	1.76	7.66	9.88
Sept.	4.93	5.86	3.06
Oct.	4.17	3.39	1.84
Nov.	2.20	2.77	7.41
Dec.	3.24	1.16	3.42
Annual	33.69	44.01	43.38

While the tidal range is comparatively slight, tide water is often pushed into the salt flat ponds by southeasterly winds during the early summer, and there are occasional abnormal high summer tides associated with hurricanes in the Gulf of Mexico. The area lacks, however, the regular tidal fluctuation which is so marked on the California or New England coasts, and the general aspect of the fauna is more constant. Nevertheless, an interesting change was noted in this fauna in the winter of 1947–48, when the pistol shrimp, *Crangon heterochaelis,* made its appearance on the salt flats in considerable numbers. Whether this represents a new invasion for this species, which is common along the bay shores in shallow holes and under oyster shells, or the upswing of a population cycle, cannot be determined. A similar case seems to be that of the razor clam, *Tagellus gibbus.* This clam was often found alive in this area by Allen (1942) in a previous study, but no live specimens were collected in 1947 or 1948. It would appear, from the numerous shell fragments, that *Tagellus* is not altogether absent, but it is evidently rarer than it was in 1940. These apparent fluctuations seem to emphasize the tolerance of the remaining species to an environment whose changes are irregular and sometimes extreme.

On the basis of this field study, it appears that the dominant invertebrate of the salt flats is blue crab, *Callinectes sapidus*. Crabs were observed at all stations, and their remains indicate their importance as a food item for both birds and raccoons. Probably of almost equal importance in species mass is the shrimp *Penaeus aztecus*, but its occurrence is more seasonal. Because of the blue crab's protracted spawning season in Texas waters, there is always a reservoir of potential emigrants to the salt flats in the bays at all times of the year except during cold periods when the crabs do not move about. Crabs breed in the bays, often at low salinities, but the females must go to the lower bays or the gulf to spawn. Probably few crabs ever leave the Refuge alive. The worms are apparently the base of the food pyramid on the salt flats, for there is little else on the bottom in the way of food for the crabs and shrimp, except each other. In some areas, especially at lower Long Lake, each dip of the spade turns up at least half a dozen worms, and the population per acre must be immense.

With the exception of *Melampus, Palaemonetes,* an occasional fiddler crab, and possibly *Callianassa,* all the invertebrates found on the Refuge must return to the bay, and some of them to the Gulf of Mexico, to spawn. Therefore the bulk of the invertebrate population is maintained by migration from the adjacent bays. At one time it was planned to convert the salt flat areas of the Aransas Refuge to a fresh water marsh by an elaborate system of dykes and ditches, and several extensive ditches were in fact dug. Such a project, if feasible from an engineering standpoint, might in time produce a fresh water environment, although the retained salts in the mud would probably make the area an unsuitable environment for either brackish water or purely fresh water types for some time, until a new equilibrium had become established.

The present equilibrium is one of long standing, in human terms, for the parallel complex of ponds and separating ridges represents the troughs and bars of the former Pleistocene shore line. Although the fluctuations of tide, wind and rainfall impose their own system of dynamics on the fauna which has found foothold or persists here, the situation is one of precarious equilibrium rather than that of the "tension zone" of a tidal estuary (cf. Pitelka, 1942). The fauna of the salt flat ponds is marine; above the three foot contour line this fauna abruptly ends except for the sporadic forays of individual blue crabs, and it is replaced in the ponds and ditches of the higher ground by a fauna composed of crayfish, aquatic insects, freshwater entomostraca, ostracods, gammarids and molluscs. The "tension zone" is not in the salt flat ponds, but in the region between them and the fresh water ponds, which in some areas is temporarily connected during periods of heavy rainfall.

The marine character of the fauna of brackish, low salinity waters bordering the sea has been emphasized by Gunter (1945), and its significance for the problem of the migration of animals from sea to land has been summarized by Pearse (1936, pp. 19–27). Pearse's summary is concerned principally with estuaries, but his generalization (p. 27) holds true for the peculiar environment found on these salt flats as well: "Many animals struggle long ages to get through [an estuarine doorway] and fail. Only a few attain freshwater by this route." It is not without significance that more than 50 per cent of the invertebrate fauna of this area is composed of decapod crustaceans, and that Cambarus, which forms extensive colonies above the critical line between salt and fresh water, is also a decapod crustacean. The decapod crustaceans are by far the most successful invertebrate forms in this region (as they are in many other transitional environments), which is neither altogether land nor still remains part of the sea.

III

Annotated List of the Invertebrate Fauna

The author is indebted to Dr. Olga Hartman of the Allan Hancock Foundation for determination of the annelids, and to Drs. Waldo L. Schmitt, Fenner A. Chace, Jr. of the U. S. National Museum and L. B. Holthuis of the Royal Natural History Museum at Leiden for help with the crustacean determinations.

Annelida

Polychaeta

Nereidae

Neanthes succinea (Frey and Leuckart)

A specimen of this worm was taken at Station 7 o nMarch 26, at a salinity of 13.2 0/00. Others were collected by R. P. Allen early in 1947 on the salt flat area in the vicinity of Lower Long Lake. This worm is abundant on the south shore of Copano Bay in soft mud and may prefer somewhat more stable conditions than exist on the Refuge. It is a larger, more succulent worm than the following species.

Laeonereis culveri (Webster)

This nereid was collected at all stations except no. 2 at the head of Long Lake, where the situation was unfavorable for digging. It is evidently the most important burrowing form on the salt flats, and is obviously resistant to periods of low salinity and temporary droughts.

Capitellidae

Fragments of a worm identified as *Notomastus* sp. were collected at Station 6 on the bay shore, February 21, 1946.

Arthropoda

Decapoda

Peneidae

Penaeus aztecus (Ives)

This shrimp occurred sporadically at all localities in the area except Station 3, the middle of Long Lake. It was not found in February, but was caught from March through July on the bay shore. A sample of 85 specimens was caught at that locality on April 25, at a salinity of 8.6 0/00. The size range of this sample was 15 to 70 mm. with the modes at 30 and 55 mm. The following month, at Station 1, salinity 13.0 0/00, more than 300 shrimp were taken. The water at this time was so shallow that the shrimp could not escape by jumping over the net as they did at most of the stations, which partly explains the larger sample. The size range of the May sample

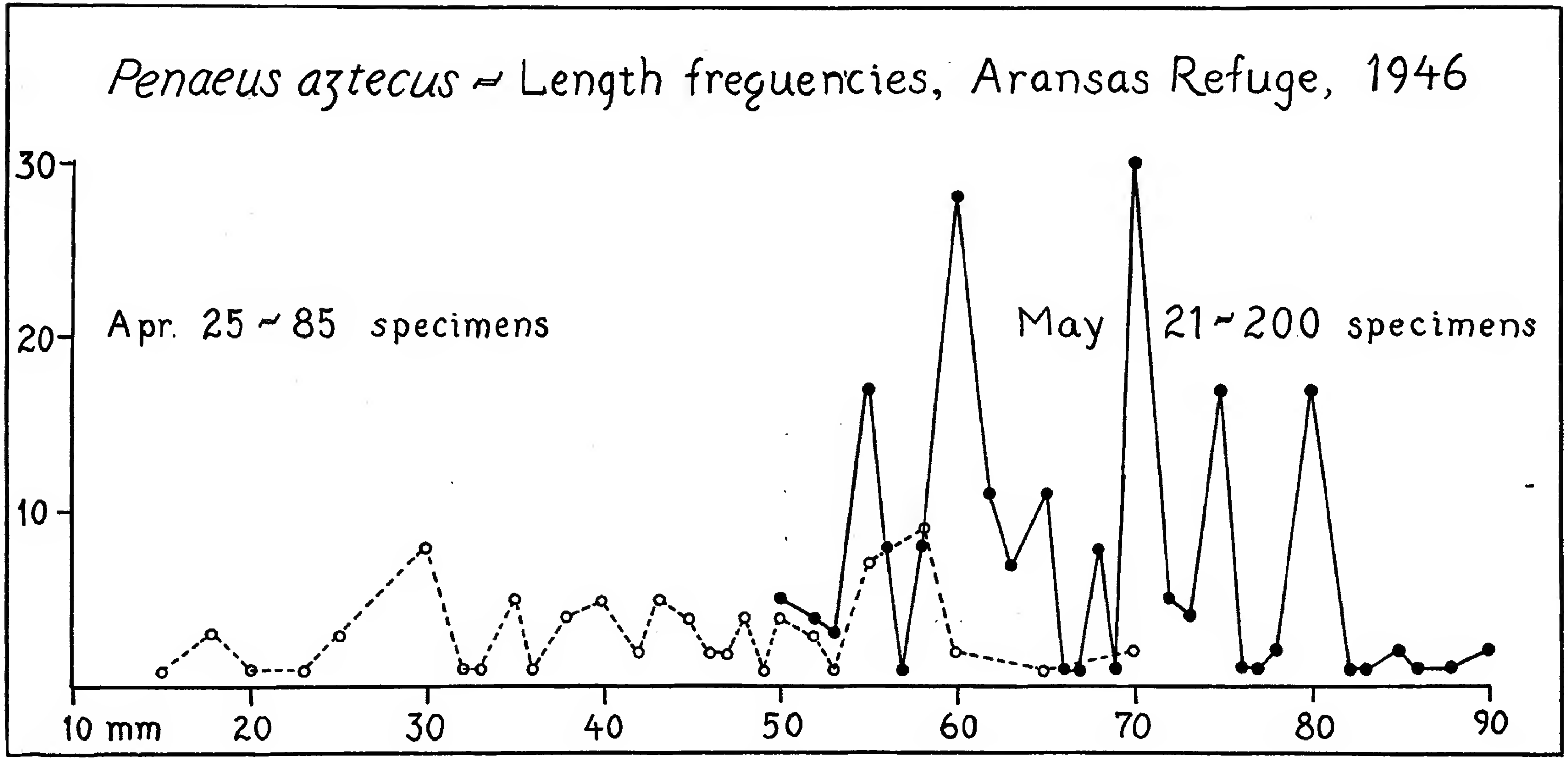

FIGURE 2

Length-frequencies of two samples of *Penaeus aztecus* collected at Aransas Refuge.

(based on 200 measured specimens), was 50–90 mm., with the major mode at 60–70 mm. and a second, smaller mode at 80 mm. (Fig. 2). This is clearly an indication of movement into the salt flat area from the bay population, since few shrimp were taken here the month before. The difference in size ranges in these samples for successive months suggests a growth rate of 30 mm. during the month, and a population composed of two separate size classes separated by a thirty day interval.

Penaeus setiferus (Linn.)

A few specimens of this shrimp were taken in May on the bay shore. Its absence from the salt flat area suggests an important difference in the life cycle of this species as compared with *P. aztecus*. As Gunter (1950A) points out, *P. aztecus* is often more common in the shallow bays during the summer than *P. setiferus*.

Crangonidae

Crangon heterochaelis (Say)

This pistol shrimp is fairly common among oysters, under rocks and among algae in the bays from central Texas to Louisiana, and is locally known as "lobster." In 1946 and the winter of 1946–47 it was not observed or collected on the salt flats, but in the late summer of 1947 it was found there in shallow burrows and has become one of the more important elements of the fauna during the winter of 1947–48. *Crangon* is now reported as "abundant" in the borrow ditch and at the middle and lower Long Lake stations. As there is no apparent change in the *Callianassa* population, the factors affecting *Crangon's* occurrence on the Refuge are apparently unrelated to possible fluctuations in *Callianassa.*

Palaemonidae

Palaemonetes intermedius Holthuis

For many years the closely related species of this genus have been confused in the literature, and the common species of this area has until recently remained undescribed. Specimens collected on the Refuge have kindly been determined by Dr. L. B. Holthuis, who has recently described the species (Holthuis, 1949).

Grass shrimp were often observed during the study, but only a few specimens were taken. It was found at all stations except the head of Long Lake and the borrow ditch. Ovigerous females were collected in February, March and April. It is probably ubiquitous on the salt flat area.

Macrobrachium ohione (Smith)

One specimen of this river shrimp was taken, on the bay shore on April 25 at 8.6 0/00. Several species of *Macrobrachium* occur sporadically on this coast, but they are essentially fresh water forms (Hedgpeth, 1949).

Callianassidae

Callianassa jamaicense var. *louisianensis* Schmitt

This burrowing mud shrimp occurs generally over the salt flat area, but is especially common along the borrow ditch. Here, on the muddy sloping banks of the ditch, its open holes, about one fourth to three eighths of an inch in diameter, are obvious features. Because of the sharp angle of the bank, it can be more easily collected here than at the other stations. Holes were observed at all stations except at the head of Long Lake. The salinity range of the stations where *Callianassa* is known to occur is 5.0 to 17.0 0/00, but the actual salinity of the water within the mud shrimp's burrow is probably higher. While the mud shrimp is sensitive to jarring of the ground and retreats to the bottom of its burrow, which may be two or three feet deep, it can be caught by stealth and is evidently sought by large wading birds such as the whooping crane. Stevenson and Griffith (*op. cit.*, p. 170) record observations of cranes probing for "mantis-shrimps." The mantis shrimp, *Squilla empusa* Say, is characteristically a Gulf form and seldom occurs in the bays, and was not found on the salt flat area. Hence there is little doubt that *Callianassa* is the organism concerned.

In the comparatively still water of the salt flat ponds, *Callianassa* holes are conspicuous as small grayish mounds with a volcano-like aperture. The aperture and upper parts of the burrow are somewhat smaller than the main burrow, which is about the size of the index finger. The burrow is lined, as are those of *Callianassa major* and *Upogebia affinis*, by some secretion of the animal, so that portions of the burrow, when dug up, retain their shape although the surrounding mud may be very soft.

The habits of this species are evidently more similar to those of *Callianassa californiensis* of the Pacific Coast (MacGinitie, 1934), than to those of *Callianassa major* of the Atlantic Coast. The latter is a sand living species (Pohl, 1946), frequenting the open beaches of the ocean. Evidently *Callianassa jamaicense* has a much lower oxygen requirement and tolerates higher temperatures than *C. major.* Like other species of mud shrimps, *Callianassa j. louisianensis* spends most of its life in its burrow, and no specimens were found outside the burrows. The burrows are nearly vertical, and are often branched near the top so that there are two or more openings. As Pearse (1945) has noted for *Upogebia affinis,* a little fountain of water can often be observed spouting out of an occupied burrow. While *Upogebia affinis* occurs on the Texas coast, it was not encountered on the Aransas Refuge. It would appear from Pearse's *(op. cit.)* experiments that *Upogebia* may require a higher salinity than is sometimes available on the salt flats, or that *Callianassa* is less affected by the variations which occur.

Callianassa j. louisianensis is not only a frequenter of salt flats, but lives in the bottom of the bays as well. It comprises, according to Gunter (1945, p. 40), a considerable item in the food of the hardhead catfish, *Galeichthys felis.* There is as yet no information on breeding for this mud shrimp, and no ovigerous specimens were found. This variety was described by Schmitt (1935) from Grand Isle, Louisiana, and I am indebted to him for verification of the identification.

Paguridae

Clibinarius vittatus (Bosc)

This hermit crab occurs on the bay shore along the Refuge, and was also taken from the borrow pit adjacent to the bay shore. It was not observed on the salt flats proper, although occasionally specimens are found well inland beyond their usual range, where they have evidently been carried by birds and rejected or dropped. It was found occupying the shells of *Littorina irrorata, Natica duplicata, Fasciolaria distans* and *Busycon perversum.*

Portunidae

Callinectes sapidus Rathbun

The blue crab is one of the dominant elements in the food chain cycle of the Aransas Refuge salt flats, comparing in bulk if not in numbers with some of the fish. It is the most ubiquitous and conspicuous invertebrate member of the salt flat fauna and one of the important elements in the diet of the whooping crane. The cranes have often been observed eating crabs, and *Callinectes* remains have been recovered from droppings (Stevenson and Griffith, *op. cit.*).

During the six months of the field survey, the blue crab was taken or observed at all the stations, although absent from one or two on occasion. An average of 33 crabs were caught and measured each month, and the total number caught in the six months period was 199. Many crabs were observed evading the net while the haul was being made, and others regained the water before they could be measured. While the numbers involved can hardly be considered a significant sample, certain indications brought out by the monthly catches are of interest. Small crabs, in the 20–30 mm. range (carapace width), occurred commonly in the samples in February and March, but were scarce in April and May, reappearing in the samples in June and July. The males outnumbered the females 125 to 74, and were especially predominant in June and July.

The crabs were found in water ranging from 2.0 to 18.6 0/00. On May 21 a female crab, 95 mm. in carapace width, was caught at McHugh's Well, where the salinity was 0.4 0/00 on that date. Other crabs were observed at this station in July when the salinity was 2.6 0/00. This isolated stock pond is a quarter mile from the bay shore and has no direct connection with salt water, and is separated from the bay by a slight rise in the ground. It would appear that the crabs must have travelled overland to reach this pond, probably during a period of heavy rain. Crabs are occasionally seen in roadside ponds on the Refuge, well outside the salt flat area. The blue crab is no stranger to fresh water, and sometimes travels up rivers for considerable distances (Gunter, 1938).

The occurrence of small crabs in February and June agrees with the data on the life history of this species being gathered by the Game, Fish and Oyster Commission (see their Annual Report for 1946–47, pp. 11–12). The spawning season lasts from late March or early April through September in the lower bays and along the Gulf Beach on this part of the coast. The small crabs of February, 1946 were probably the last of the previous year's hatch, while those of June–July were probably the first of the 1946 hatch. That these dates may vary from year to year is indicated by the data gathered in 1947 in Aransas Bay, when the peak of the 20–30 mm. class occurred in April. It is possible that in 1947 the spawning season was delayed by the very cold weather of January, which resulted in severe fish mortality along the central Texas coast.

It is probable that there is a steady supply of small crabs entering the salt flat area from early summer to nearly midwinter, but the greater part of the population appears to be made of crabs of the 50–60 mm. and 70 to 80 mm. classes, which evidently move in with the high tides. The population is certainly greater than indicated by the samples, for the shallow ponds of the area are easily combed over by birds and raccoons, and their combined efforts constitute a 24–hour drain on the supply. Out of the total of 199 crabs measured, only 33 were 100 mm. or larger, and 20 of these were males. Since the larger males frequent fresh water, it is evident that few crabs are allowed to attain an undisturbed old age on the salt flats. The largest crab measured was a male of 171 mm., taken with three other males more than 100 mm. at the borrow pit on April 25. Four large females (*i.e.*, 98 to over 100 mm.) were taken at the same time. On this same date, three males of breeding size were taken in the same haul with four adult females at middle Long Lake. All of the crabs were hard-shelled, and may possibly have been breeding shortly before, or were getting ready to breed. As there is little shelter for crabs on the salt flats, they would be especially vulnerable during moulting and breeding.

Pinnotheridae

Pinnixa cristata Rathbun

One pinnixid crab was taken in a seine haul on May 20, at lower Long Lake. The salinity was 14.0 0/00. Probably more of the crabs may be found in the burrows of worms and *Callianassa*, although none were found when digging for these organisms. This appears to be the first published record of a species of *Pinnixa* from the Texas coast.

Ocypodidae

Uca pugnax (Smith)

This fiddler crab is common on the bay shore and along the borrow pit, but is rare on the higher, drier salt flat areas. Nevertheless, an ovigerous female was collected near the head of Long Lake on May 21. The embryos had reached the pre-zoea stage. This indicates a much earlier breeding season on the Gulf Coast than on the northeast coast near Long Island and Woods Hole, as given by Crane (1943).

Uca pugilator (Bosc)

The common fiddler crab of the salt flat area. It also occurs near the bay shore in company with *U. pugnax*. Pearse (1914) characterised *pugnax* as a mud burrower and *pugilator* as a sand burrower, and this separation is essentially true for the occurrence of these crabs on the Aransas Refuge. The specimens of *pugnax* found at the borrow ditch were in mud, while the *pugilators* were found in sand a short distance from the muddy edge of the ditch. At the lower Long Lake station on May 20 there was evidence of a new fiddler colony being established on the sandy shore a few yards from the water. A dozen or more small fiddler holes had recently been dug in a hundred square foot area. A month later these holes were all gone. Probably the fluctuating level of the pond drove them to higher ground among the hummocks of marsh grass, if they had survived the birds and raccoons. Rathbun (1918, p. 401) has published a vivid note by J. D.

Mitchell, a famous Texas naturalist of bygone days, on the role of this fiddler crab in the food chain of the marshlands.

Zoea of this species were taken in a plankton sample at lower Long Lake on May 20, at a salinity of 14.0 0/00. They agree with Hyman's (1922) figures of the first zoeal stage, and had evidently hatched only a short time before. The occurrence of zoea in this typical salt flat pond indicates that the fiddler crab may complete its entire life cycle without going to the bay. However, it probably prefers to spawn in the bay, as very few zoea were found in this sample, and they were not observed on other occasions.

Mollusca

Pelycypoda

Sanguinolariidae

Tagellus gibbus (Spengler)

While no live specimens were collected, dead shells were observed at all stations, and the evidence of bird droppings indicates that this is an important food item. This clam lies in the mud beyond reach of the shovel and retreats down its burrow too quickly to be overtaken by surprise. Live specimens were taken by Allen in 1940, and it is evidently scarcer in recent years.

Solenidae

Solen sp.

Fragments of a small razor clam have been found in bird droppings on the Refuge, identified as *Solen* sp. It is probably *Solen viridis* Say.

Mactridae

Rangia cuneata (Gray)

Numerous dead *Rangia* shells were found along the bay shore and on the salt flats, but no live colonies were discovered. To judge from its occurrence at Green Lake, a few miles north of Aransas Refuge, this species prefers situations with a permanent stand of water above the mud (in which it lives only a few inches below the surface), and may occur only in the bottom of the deeper, more permanent ponds of the refuge.

Gastropoda

Littorinidae

Littorina irrorata Say

No live specimens of the common salt marsh periwinkle were found on Aransas Refuge, although it would appear that the lower areas near the bay are ideal sites. Dead shells were found occasionally over the entire area studied. Stevenson and Griffith (*op. cit.*, p. 171), report on observation of whooping cranes picking up small snails near the border of the Refuge. Probably these were littorines, since they are often found on bare or almost bare ground. Live littorines are abundant in the salt marsh areas on St. Joseph's Island, a few miles across the bay from the Refuge, and their absence or scarcity, in the area studied indicates either lack of suitable fodder, a low cycle of abundance, or excessive predation by large birds.

Ellobiidae

Melampus coffeus (Linn.)

This small, inconspicuous pulmonate occurs, to judge from its dead shells, over the entire area of the salt flats. Live specimens were collected at stations 1 and 6.

IV

Summary

1. An ecological survey of the fish and invertebrate food resources of the salt flat area of Aransas National Wildlife Refuge, Texas, was conducted from February to July, 1946.
2. Six stations, four on salt flat areas and one in a ditch near the bay and the sixth on the bay shore itself, were established, and collections and observations were made during the third week of each month.
3. Seventeen species of marine or brackish water invertebrates were collected. Ten of these were decapod crustacea, of which the most abundant were the blue crab, *Callinectes sapidus*, the peneid shrimp, *Penaeus aztecus*, and the grass shrimp, *Palaemonetes intermedius*. Two species of nereid worms are common. The molluscan element of the fauna includes two bivalves and two gastropods. A detailed discussion, with life history notes, of each species is presented.
4. The populations of most of these invertebrates are maintained by migrations from adjoining bay areas.
5. An additional species, *Crangon heterochaelis*, not collected in the original study, made its appearance in the area in late 1947.
6. Salinities ranged from 2.0 to 18.6 0/00, but there are indications that the salinities in the burrows of burrowing forms are consistently higher.

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An Introduction to the Hydrography of Tidal Waters of Texas

By

Albert Collier and Joel W. Hedgpeth

TABLE OF CONTENTS

An Introduction to the Hydrography of Tidal Waters of Texas

By

ALBERT COLLIER* AND JOEL W. HEDGPETH†

INTRODUCTORY NOTE

This paper is a presentation of the hydrography of a series of bays on the central Texas coast, with particular reference to temperature and salinity conditions, tides, and climatic factors. It endeavors to give a descriptive explanation of the geomorphology, salinity exchange, tidal cycle and temperature conditions which characterize the waters concerned, primarily as an aid to understanding the biological cycles which are governed by these physical conditions. As such, it is essentially an introduction, pointing the way to more intensive studies in the future and serving as a source of general information to workers in other parts of the world interested in comparing the conditions encountered on the Texas coast with those of their own regions.

The basic field data on which this study is based were gathered by Collier during the years 1936–38 when he was Marine Biologist for the Texas Game, Fish and Oyster Commission. Circumstances prevented completion of the study at that time. Since then, a number of records and analyses of climatic factors, stream discharges and silt loads, and geological studies bearing upon the general hydrographic picture have become available, and various successors to the post of Marine Biologist have conducted ecological surveys of one kind or another in the principal area concerned which have produced incidental hydrographic data. This material, along with the results of earlier studies, has been gathered together and correlated in the analysis which follows.

The section on the Laguna Madre is altogether the work of Hedgpeth, who also arranged all of the more recent data used in all sections of this paper.

We are indebted to many individuals and organizations for information and data, especially to the Corpus Christi field office of the U. S. Engineer Department for tide gauge records and other data, and to the U. S. Coast Guard and Geodetic Survey and the Geological Survey for unpublished data on tide levels and stream discharges. The Game, Fish and Oyster Commission has kindly resubmitted the original field data of the Marine Laboratory, which are now on file there. We wish to thank Dr. W. Armstrong Price, of Texas A. & M. College, and Dr. Gordon Gunter for many helpful suggestions and criticisms, and Dr. H. A. Marmer who checked the section on tides.

I. INTRODUCTION

A. Historical Note

Hydrography, like general marine biology, has not been a subject of intensive study on the Gulf Coast until the last few years. The first concerted effort to

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gather information on temperature and salinity conditions in the bays of Texas, and along the Gulf Coast in general, appears to have been a part of the study of marine boring organisms conducted by the National Research Council in 1922–23 (Atwood and Johnson, 1924). Temperature and salinity data were gathered at important ports, and presented simply as graphs, and the original data, at least for Corpus Christi and Port Aransas, are no longer to be found. Although there were several surveys of oyster bottoms in Texas bays during the first decades of the century, no systematic attempt to gather hydrographic data in connection with these studies was made until 1926–27, when Galtsoff (1931) conducted his general survey. The report on this work includes the only data for hydrographic conditions for the entire bay system from Corpus Christi to Galveston under approximately comparable conditions, and no investigation of its scope has since been attempted.

About the same time that Galtsoff conducted his survey, a study of the life histories of the redfish and other sciaenids was made by Pearson (1929), in the course of which some hydrographic data were obtained, but very little of this was published. However, that published fragment provides us with the only set of salinity readings from the Laguna Madre to Nueces and Copano bays. In 1929 Hopkins (1931) made a study of oyster spawning and setting in Galveston Bay, providing salinity records for the period from April to August, 1929, in Galveston Bay.

In 1935 a survey of oyster pests in Texas waters was conducted by Federighi and Collier, during which limited hydrographic data were collected. This report still remains in manuscript, but contains data of interest since the study was made following one of the major floods of Texas history, and the greatest of record on the Nueces River (Dalrymple and others, 1939).

The intensive hydrographic survey of 1936–37, herewith reported in detail for the first time (a preliminary analysis was published by Collier, 1937) was designed to provide a working knowledge of the physical factors involved in the development of oyster culture and other fisheries activities. That portion of Collier's program executed in 1938 was part of the co-operative investigations carried out by the Fish and Wildlife Service (then Bureau of Fisheries), and various state conservation agencies into the biology of the commercial shrimp, *Penaeus setiferus*. The bulk of this work is also unpublished, but a general account of this investigation, together with references to other published fragments, will be found in Anderson, Lindner and King (1949). This long lag in publication of the results of studies essential to our understanding of marine biological problems on the Gulf Coast is due in part to difficulties of securing funds for publication during the pre-war depression.

In 1945 Gunter (1945a) published his investigations on fish populations, presenting hydrographic data for the area of particular interest for a 20 month period in summary form, from March, 1941 to October, 1942. From July, 1946 to October, 1948, weekly salinity samples and temperature readings were taken by airplane from the northern part of the Laguna Madre by the Game, Fish and Oyster Commission, and in August, 1946, a monthly station run from Copano Bay to the Gulf of Mexico was inaugurated as part of a study of the life history of the blue crab in Texas waters.

This study is still being carried on, and so far has produced some hydrographic data of varying usefulness since the number of stations occupied seems to be steadily decreasing.

Hydrographic studies in other brackish water regions of North America are surprisingly few in view of the importance of these areas to fisheries resources, and that "detailed knowledge of the typical, average and extreme physical conditions in temperature, density, salinity and current . . . at all hours of the day, during each month and during each of a series of years" which Michael (1916) declared was needed for an understanding of the relations between marine organisms and their environment, is still almost as far away as it was thirty years ago. At the present time, however, a great body of data is being gathered for certain waters in Louisiana, in connection with a study of oyster mortality, which will fill in part this gap for at least one region.

The first essay on estuarine hydrography in the tidal waters of the United States seems to be that of Sumner *et al.* (1914) on the physical conditions in San Francisco Bay, based on two years work by the Fish Commission Steamer Albatross in 1912 and 1913. A few years later, San Francisco Bay was the center of an intensive study, including hydrographic observations, inspired by the outbreak of shipworms in the bay. A summary of this investigation will be found in Hill and Kofoid (1927), and additional aspects were presented by Miller *et al.* (1928). There are two important studies of Monterey Bay which should be mentioned. Bigelow and Leslie (1930) investigated certain hydrographic factors relative to quantitative plankton studies, and Skogsberg (1936) issued a comprehensive report on thermal conditions. While a great amount of detailed and meticulous work has been done with the chemistry of the waters of the Puget Sound area, we are without a comprehensive hydrographic treatment of this major estuarine area, and must turn to the summary of five years records in San Juan Channel (Phifer and Thompson, 1937). A more integrated treatment, of the Canadian waters immediately north of Puget Sound, is to be found in the papers of Hutchinson *et al.* (1928, 1929), and Lucas and Hutchinson (1927).

Chesapeake Bay has received, as might be expected, much more detailed notice. During the years 1915–22 the U. S. Bureau of Fisheries conducted a hydrographic and biological survey of Chesapeake Bay, which was summarized by Cowles (1930), and in the same year there appeared the Coast and Geodetic Survey bulletin on the tides and currents in Chesapeake Bay (Haight, Finnegan and Anderson, 1930). Together, these papers give us a fair picture of the conditions in Chesapeake Bay, although their co-ordination is up to the reader. The papers of Newcombe, Horne and Shepherd (1930), Nash (1947) and Beaven (1948), provide further data, but a comprehensive study of Chesapeake Bay as a whole is yet to be undertaken. As this is written, a Chesapeake Bay institute, dedicated to such a comprehensive study, is in the formative stages.

For many years (since 1922 on the Gulf Coast), the U. S. Coast and Geodetic Survey has been taking daily temperature and density readings at its tide gauging stations. This information, published as monthly ranges and averages, provides useful comparative data for many locations along the Atlantic, Gulf and Pacific coasts of North America.

B. General Description of the Aransas Hydrographic System

1. Geomorphology

The area considered here is the system of bays and tidal lagoons which join the Gulf of Mexico through Aransas Pass. This pass is a jettied inlet about 130 miles north of the Rio Grande, at 27°50′15″N, 97°02′45″W. For the sake of brevity, we have called this the Aransas Hydrographic System (fig. 1).* It includes a system of bays extending from Espiritu Santo Bay (which is partly subject to the influence of Pass Cavallo) to the Laguna Madre at that part where it is blocked off from the remainder by an extensive development of sand and mud flats in the vicinity of Murdoch Landing. These bays are separated from the Gulf of Mexico by a series

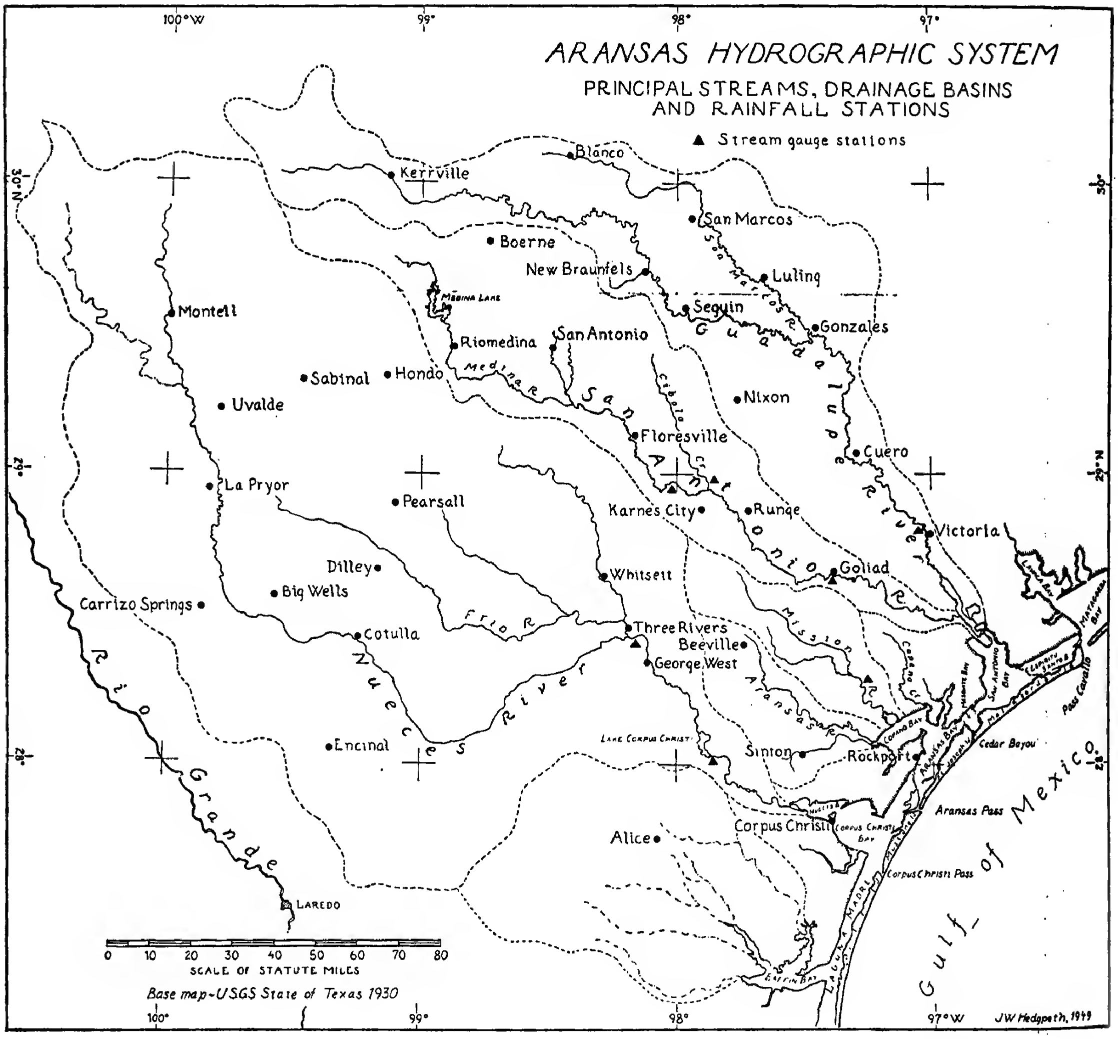

FIGURE 1
General map of Aransas Hydrographic System.

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*Figures 2, 11, 12, 13, 14 and 23 will be found in a pocket at the end of this volume.

of barrier islands whose Gulf beach forms a broad arc extending in a northeasterly-southwesterly direction. The inner shores of these islands are extremely irregular, indented by ponds and short bayous, and the width of the barrier islands varies from somewhat less than a mile in several places, to about four and a half miles near the northern end of St. Joseph Island. The southern ends of the islands are usually narrower than the northern ends.

The outer bays, which lie immediately behind these islands, are the segmented fragments of the coastal lagoon. They vary from five to six miles in width between the inner shores of the barrier islands and the mainland shore, except for San Antonio and Corpus Christi bays, which are embayed river mouths, cutting through the mainland shore. Behind these components of the coastal lagoon is a series of back bays, rejuvenations of a former coastal lagoon. These include, in this system, Nueces, Copano and Alazan bays.

All these bays are comparatively shallow. The deepest, Corpus Christi Bay, has a maximum depth of 15.5 feet, followed by Aransas Bay with a maximum depth of 14 feet. The average depths are much less. The bottom contour of Corpus Christi Bay resembles in profile a frying pan, falling off abruptly from the shores to a more or less uniform depth of twelve feet. Aransas Bay is more like a flat bottom vegetable bowl. A better idea of the relationships and proportions of these bays may be obtained by inspecting figure 2 and table 1.

TABLE 1

Physical Characteristics of Bays of Aransas Hydrographic System

BAY	Area Sq. Mi. (by Planimeter)	Appr. Shore-line Miles	Ratio Shore-line to Area	Maximum Depth m.l.w.ft.*	Aver-age Depth m.l.w.	Aver-age Width Miles*	Width Depth Ratio†	Volume (Million cu. ft.) Mean Low Water	Mean Tide Level (0.25 ft.)
San Antonio	132.0	92.0	1:1.4	7.8	4.0	6.8	1.2:1	14,720	15,640
Espiritu Santo	53.5	4.16	1:1.3	8.0	4.9	9.0	1.2:1	7,383	7,756
Ayres	2.3	6.3	1:0.4	4.0	2.5			164	180
Mesquite	13.5	17.6	1:0.8	5.5	2.8	3.5	.67:1	1,054	1,148
Carlos	3.9	7.5	1:0.5	4.0	1.4			154	181
Aransas	92.3	69.5	1:1.3	14.0	6.3	9.4	.67:1	16,340	16,983
St. Charles	13.6	31.5	1:0.4	5.0	2.5			959	1,054
Copano	69.5	53.0	1:1.3	8.0	5.0	9.9	1.2:1	9,688	10,172
Mission	5.7	8.8	1:0.6	2.8	2.0		.67:1	318	358
Port	4.7	10.7	1:0.4	4.0	3.1			417	450
Redfish	16.8	27.7	1:0.6	5.0	1.4			670	787
Corpus Christi, N. of Ship Channel	9.3	22.0	1:0.4	10.0				1,228	1,293
Corpus Christi	150.0	60.5	1:2.5	15.5	9.4	13.4	.9:1	39,309	40,354
Nueces	30.4	33.4	1:0.9	6.0	2.3	6.0	2.2:1	1,966	2,178
Oso	6.8	18.9	1:0.4						
Laguna Madre	62.0	85.0	1:0.7	10.0	3.3	1.6		5,704	6,136
Laguna Madre (charted)	117.0	90.0	1:1.3			3.1			
Baffin Bay	102.0	134.5	1:0.8	10.0	5.0				
CHANNELS:									
Lydia Ann	1.0			22.0	13.8			415	422
Corpus Christi	0.8			34.0					
Aransas Pass	0.4			35.0					
Total, m.l.w.	887.5							100,489	105,092

*From Price, 1947, Table 1, with additions.
†From Price, Figure 5.

This bay system is separated from Pass Cavallo on the north by an asymmetrical tidal delta which is the result of tidal action in Pass Cavallo. This tidal delta does not prevent the intrusion of saline water into Espiritu Santo Bay, as indicated by Galtsoff's isohalines (1931, fig. 8), but it and the chains of spit-like islands in Espiritu Santo Bay probably serve to divert a large part of the discharge of the Guadalupe River into Aransas Bay, to judge from the close correlation between the salinities in Aransas Bay and the discharge of the Guadalupe. Mesquite Bay, a small shallow circular bay intermediate in position between San Antonio and Aransas Bay, is connected to the Gulf of Mexico by Cedar Bayou, a small natural pass which is usually narrow and shallow, and evidently not a significant factor in the hydrographic economy of the bay as a whole. In 1936 through 1938, when most of the field work for this study was being done, Cedar Bayou was completely closed. It was dredged open by the Game, Fish and Oyster Commission in 1939–40 and has remained more or less open since that time.

Aransas Pass, the main outlet for this system, is a channel about 800 yards wide, dredged to a depth of 34 feet, and reinforced by jetties extended about a mile from shore. In the 1850's this pass crossed St. Joseph Island opposite the lighthouse. At that time, the tidal delta of Harbor Island was probably in the same relative position in relation to the bays and pass as that of Pass Cavallo is today. It appears from the old maps reproduced by Pricé (1947) that Pass Cavallo has been more stable during the cartographic period than Aransas Pass.

The next pass encountered is Corpus Christi Pass, just below the junction of Corpus Christi Bay and the Laguna Madre. This pass now has 3 positions, 2 being filled by sand and inactive. The old, southernmost pass is indicated on maps as late as the 1920's as being somewhat larger and more stable than the two new 1933 passes. One of the new passes was dredged open by the Game, Fish and Oyster Commission in 1939, without permanent effect. During the summer months in recent years Corpus Christi Pass—the middle position—has at low tide been closed. High tides put a few inches to 2 or 3 feet of water through it. At times Mustang and Padre islands are joined. A major influence in the near demise of Corpus Christi Pass has been the lowering of hydrostatic head by the dredging of the ship channel across Corpus Christi Bay and the maintenance of Aransas Pass at a depth of more than 30 feet. The late history of Corpus Christi Pass is not a migration of the inlet, but a slight shift toward the southwest is indicated by the greater amount of sanding of the northernmost of the two new inlets of 1933. This pass became completely closed during the early part of 1949 and afforded no interchange between bay and Gulf waters except at the time of a storm tide raised by a hurricane which passed offshore in the early part of October.

From Aransas Pass southward there is no effective inlet to the bay waters for nearly 150 miles, until Brazos Santiago, opposite the town of Port Isabel, is reached.

In spite of the tremendous silt loads which enter the coastal waters of Texas, especially from Corpus Christi northwards (the combined load of the San Antonio and Guadalupe rivers is 1,500,000 tons or 43,560,000 cubic feet per annum), the depths of the coastal bays remain fairly constant over long periods of time. In a study of the ratios between depth and width of the various bays in differing climatic zones Price *(op. cit.)* has demonstrated that there is an equilibrium between the forms of the bays and the natural forces operating in these bays. This equilibrium

TABLE 2

Principal Drainage Basins, Aransas Hydrographic System

	Total Area, Sq. mi.	Gauging Station	Net Area, Sq. mi.	5 year (1940–44) Av. annual discharge: Sec. ft. days	Cu. ft. x 10^9	Flood peaks: 100 yr. max. c.f.s.	50% Expectancy	Silt load: Acre ft.	Tons	Remarks
Guadalupe	...	Victoria	5,676	756,967	65.40	...	...	497	765,906	Silt, 2.3 yr. av.
San Antonio	...	Goliad	3,918	285,703	24.68	...	...	530	807,354	Silt, 5 yr. av.
Totals	10,400		9,594	1,042,670	90.08	1,200,000	48,000	...	...	Flood peaks derived from graphs by Commons (1945a, b.)
Mission	970	Refugio	643	50,256	4.34	480,000	17,200	...	...	
Aransas	850		...	49,500	4.28	550,000	22,000	...	...	Annual discharge estimated from Mission River
Nueces	16,920	Three Rivers	15,600	...	...	1,500,000	60,000	527	803,318	Silt, 20 yr. av.
		Mathis	16,600	452,216	39.07	...	...	185	284,153	Flood peaks controlled by dam above Mathis. 86% of flow returned to bay.
Totals	29,140		...	1,594,642	137.78	...	...	...	...	Silt, 5.8 yr. av.

is apparently demonstrated in several ways, as the width-depth ratios derived by Price are directly mirrored by the ratios of shoreline to area (see table 1).

Whether this equilibrium can be upset by the damming of streams remains to be seen, as the only dam immediately affecting the silt load in this system, that at Mathis on the Nueces, has not been installed for a long enough period. Price *(ibid.)* has demonstrated a conspicuous shoaling of Corpus Christi Bay as a result of the division of that bay by the dredging of the ship channel and the piling of the spoil in midbay, which effectively divides the bay into smaller segments. The Mathis dam, permanently installed after a preliminary failure, has been effective as a silt trap since 1934, and, as a result, the silt load of the Nueces has been reduced from 803,318 tons per year at Three Rivers to 284,153 tons below the dam, a reduction of roughly 65%. This has reduced the capacity of the reservoir by about 18% in eight years, and the need for a new reservoir is now imperative if the water supply for the city of Corpus Christi it to be maintained. The installation of another dam will probably reduce the silt load discharged into the bay even more and perhaps retard the shoaling of Corpus Christi Bay.

An important influence on the past history of the coastal bays, in particular those falling within the drainages of major rivers such as the Colorado and Brazos, has been the tendency of deltas to encroach upon the bays. Wadsworth (1941) suggested that the Colorado River has shifted its mouth from Tres Palacios Bay eastward to upper Matagorda Bay in relatively recent times, but the necessary evidence for such a history has not been presented. As a result of a log jam, and probably other factors, the Colorado was in 1924 in the process of abandoning its present narrow valley south of Wharton by filling it. It then probably would have flowed eastward to the San Bernard River through its former broad valley. When finally freed of the blockage by dredging about 1930, the Colorado silted upper Matagorda Bay at an accelerated rate and built its delta across the bay to Matagorda Peninsula. A channel was then dredged for the river to the Gulf of Mexico. While this episode has been cited as an example of the damaging effect of human meddling with natural processes, it seems probable that some such result was inevitable and man only speeded up the process in his effort to rescue the agricultural areas upstream from the log jam. Apparently much larger bays have been destroyed by delta growth in the past, in more humid areas of the coast. Even such a comparatively small river as the Guadalupe is engaged in filling the upper part of San Antonio Bay.

2. Climatic factors and the hydrologic cycle

The system of estuaries and tidal lagoons under consideration is subject to the influence of a drainage area composed of two moderately large rivers and several smaller streams, comprising a total area of nearly 30,000 square miles. This area lies, for the most part, in the semi-arid and dry subhumid zones of Thornthwaite's (1931, 1948) classification. These zones are based on consideration of many meteorological factors and require computations for which data are not easily available over a world wide basis (Blair, 1943, pp. 125–126; Thornthwaite, 1948, pp. 57–59, 71–72), but their variation from year to year, as indicated by Thornthwaite's atlas (1941), agrees with the mean salinity conditions of the bays for those years of which we have record.

Within these zones, however, there are wide local variations in runoff conditions, since runoff is dependent in large degree on nonclimatic factors such as slope and type of terrain. Gannett's runoff map (1908) shows only two lines for Texas, a ten inch annual mean line roughly demarking the line between the Sabine-Neches and Trinity watersheds, and a three inch line running from north to south on a line through Wichita Falls to New Braunfels, and thence curving southeast to reach the coast in the vicinity of Aransas Bay. The more recent study of Commons (1945a) divides the state into several irregular areas based on the records of major floods, which are best understood from an examination of figure 3. The

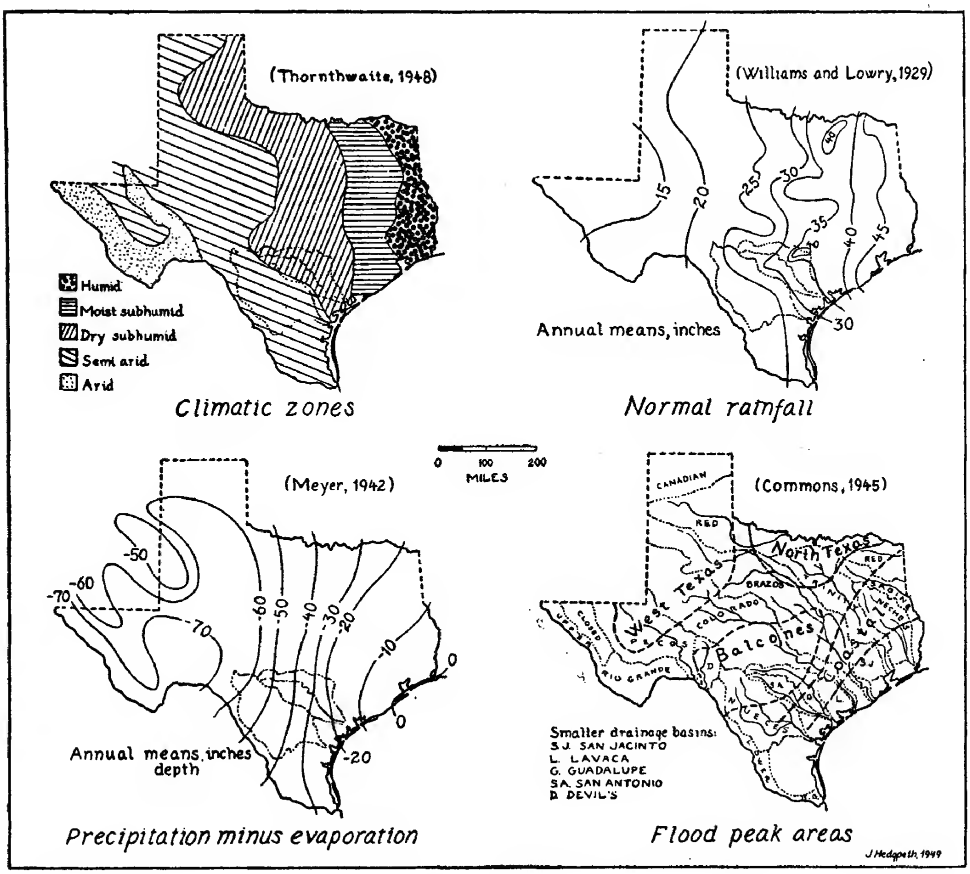

FIGURE 3

Climate, rainfall, evaporation and flood patterns in Texas

isohyetal map (Williams and Lowry, 1929, Pl. 1) of the state shows consistent agreement with Thornthwaite's zones and indicates the correspondence between rainfall and climate, insofar as the drainage areas in this system are concerned, is fairly close. Somewhat more than half of the drainage area of the San Antonio-Guadalupe rivers lies between the 30 and 35 inch isohyets, and most of the remainder is found between the 25 and 30 inch isohyets. A small area on the northeast lies within a 40 inch ishoyetal nucleus which is considerably west of the principal 40 inch isohyet. Somewhat less than half of the area of the Nueces drainage lies between the 25 and 30 inch isohyet, while the balance is between the 20 and 25 inch isohyets.

The seasonal distribution of rainfall is defined by a double peaked curve for Corpus Christi, the Nueces and the San Antonio-Guadalupe drainages. The principal rainfall peak for Corpus Christi occurs in September, with a secondary peak in May and June. This same curve, with somewhat lower values, describes conditions over the Nueces drainage. Thus there occurs, from November well into March, a pronounced period of "winter drought." The situation over the San Antonio-Guadalupe basin is somewhat different in that the higher peak occurs in

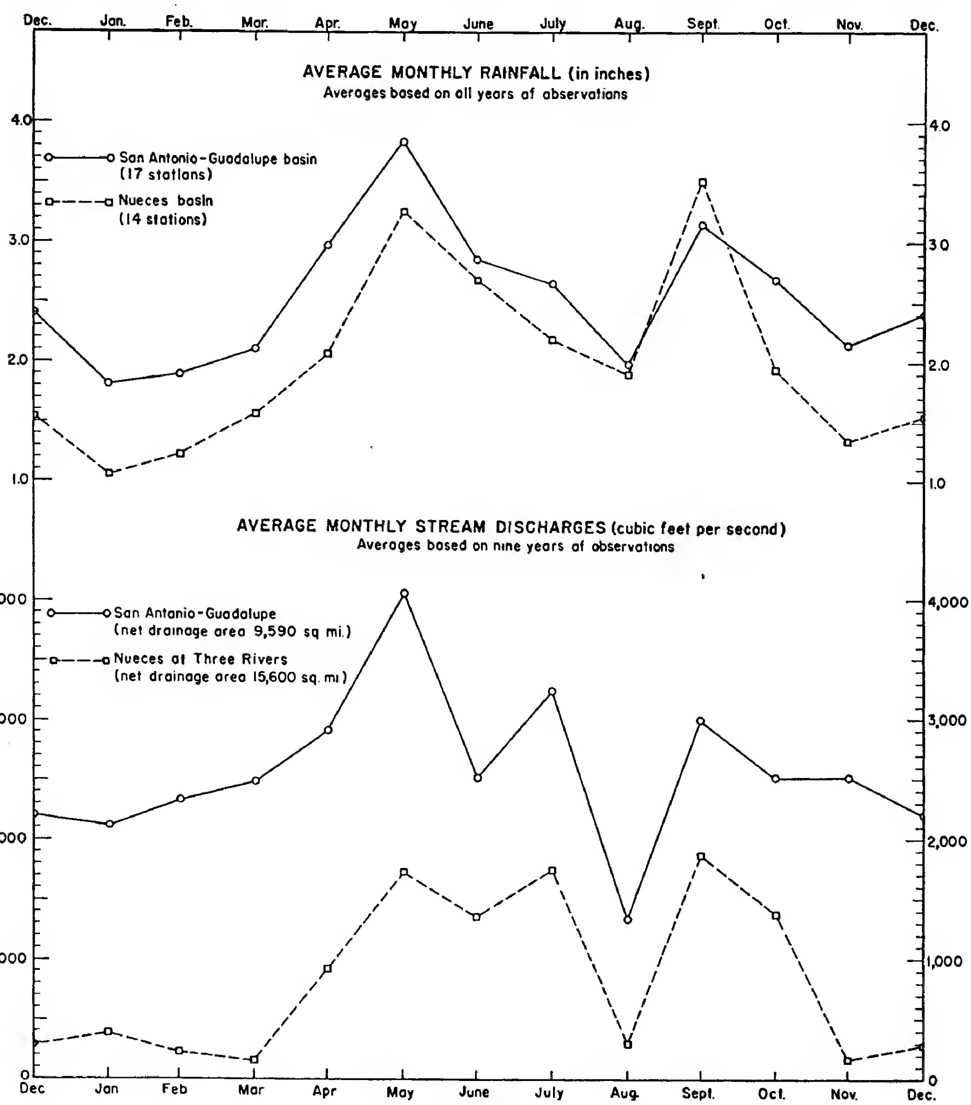

FIGURE 4

Monthly average rainfall and stream flows, San Antonio-Guadalupe and Nueces rivers the spring and rainfall is somewhat higher in December (fig. 4). Turning northward to Galveston, we find a different situation. Here the rainfall exceeds that of Corpus Christi during all months, and while the main peak occurs in September, the secondary peak has shifted well into June, and is much less pronounced, so that there is not the well defined drier period during July and August which is found at Corpus Christi and, to a reduced extent, over the San Antonio-Guadalupe drainage.

The high September peak for Galveston and Corpus Christi is a reflection of tropical storms, which are most frequent during this month. The spring rainfall peak is of more importance to the runoff cycle, and most of the major floods on Texas streams occur in May and June.

The effects of this rainfall and climatic pattern are evident in the average stream discharges of the two larger rivers affecting the bays of this system. The Nueces, with a drainage area 18% larger than that of the San Antonio-Guadalupe, had a mean annual discharge for the five year period 1940–44 of 43% less than that of the San Antonio-Guadalupe for the same period. For all years of record (32 for the Nueces, 15 and 14 for the San Antonio-Guadalupe) the percentage is the same. The runoff of the San Antonio-Guadalupe is roughly three times that of the Nueces per unit area (fig. 4).

This difference in average discharges is closely parallel with the differences in rainfall, although here it is obvious that greater evaporation, and possibly a more porous terrain, has reduced runoff in the Nueces watershed, since mean annual precipitation over the San Antonio-Guadalupe is only one and a half times greater than over the Nueces per unit area.

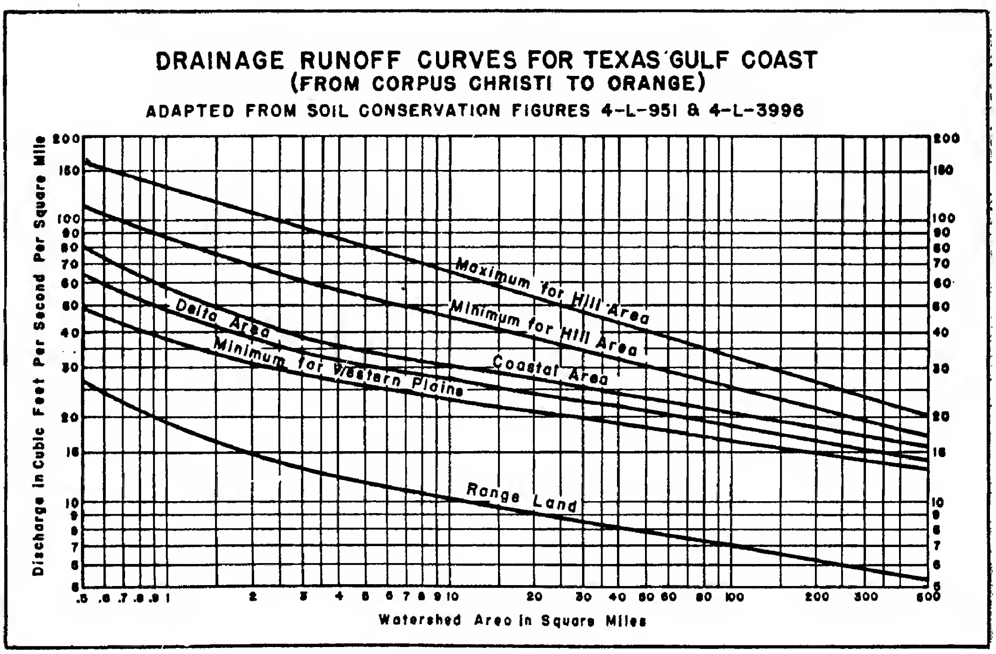

FIGURE 5

Flood runoff characteristics, adapted from Commons, 1945a, b

TABLE 3

Monthly and Annual Means of Climatic and Hydrographic Elements, Central Texas Coast and Galveston

	Yrs. of Record	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yr.
Rainfall, Inches														
San Antonio-Guadalupe Drainage (av. 17 st.)	20–74	1.82	1.88	2.18	2.99	3.85	2.90	1.99	2.26	3.15	2.72	2.18	2.47	30.39
Nueces Drainage (av. 14 st.)	25–53	1.05	1.22	1.56	2.06	3.25	2.68	2.18	1.89	3.50	1.93	1.34	1.54	24.20
Beeville	52	1.70	1.71	2.23	2.14	3.72	3.12	3.05	2.30	3.56	2.42	2.22	2.38	30.55
Alice	39	1.33	1.40	1.62	1.57	3.16	3.11	2.33	2.24	3.64	2.52	1.43	1.82	26.17
Corpus Christi	60	1.56	1.48	1.60	1.78	3.22	2.59	1.53	2.27	4.49	2.47	1.99	1.45	26.38
Galveston	76	3.41	2.83	2.68	3.06	3.42	4.37	3.71	4.28	5.57	4.36	3.33	3.75	44.77
Air Temperature, °C														
Corpus Christi	60	12.2	13.7	17.2	20.6	23.6	26.3	27.6	27.6	25.9	21.7	17.1	13.6	20.6
Galveston	76	12.1	13.5	16.9	20.3	23.8	27.1	28.6	28.3	26.7	22.6	17.4	13.6	20.8
Relative Humidity, %														
Corpus Christi	43	79.0	78.0	77.3	77.6	78.0	77.3	76.3	74.3	76.3	75.0	76.3	77.0	77.0
Galveston	44	83.0	82.3	80.3	79.3	78.0	76.6	74.3	74.3	74.0	73.6	77.0	80.3	77.6
Wind, dir. and m.p.h.														
Corpus Christi	62	N	SE	SE	SE	SE	SE	SE	SE	SE	SE	N	N	SE
	62	10.8	11.8	13.4	14.3	14.0	13.1	12.2	11.6	10.8	10.3	10.6	10.4	11.8
Galveston	57	SE	SE	SE	SE	SE	S	S	S	SE	SE	SE	N	SE
	78	11.2	11.5	11.6	11.8	11.2	10.4	9.5	9.2	9.9	10.2	10.9	11.1	10.7
Evaporation, Inches														
Beeville	37	2.30	2.80	4.44	5.20	6.21	7.04	7.13	7.22	5.54	4.47	3.08	2.44	57.92
Corpus Christi	*	1.20	1.70	2.30	3.40	4.70	5.90	6.60	6.30	5.70	4.60	2.90	1.70	47.12
Galveston	*	.94	1.30	1.64	2.60	4.10	5.60	6.20	6.10	5.70	4.60	2.70	1.30	42.66
Gulf of Mexico	*	4.50	4.25	3.75	3.75	4.25	4.50	5.00	5.75	6.25	6.75	6.50	5.70	60.95
Precipitation Minus Evaporation														
Beeville	—	—0.60	—1.09	—2.21	—3.06	—2.49	—3.92	—4.08	—4.92	—1.98	—2.05	—0.78	—0.06	—27.37
Corpus Christi	—	0.36	—0.22	—0.70	—1.62	—1.48	—3.31	—5.07	—4.03	—1.21	—2.13	—0.91	—0.25	—20.69
Galveston	—	2.47	1.53	1.08	0.46	—0.68	—1.23	—2.49	—1.82	—0.13	—0.24	0.63	2.45	2.03
Mean Sea Level, m.l.w.														
Rockport	22mos.	—0.27	—0.14	0.24	0.28	0.43	0.19	0.08	0.32	0.45	0.64	0.21	—0.01	0.21
Corpus Christi	19mos.	0.11	0.15	0.16	0.15	0.09	0.29	0.13	0.04	0.32	0.39	0.03	—0.11	0.15
Port Aransas	19mos.	0.06	0.17	0.22	—0.03	0.03	0.45	0.11	0.18	0.35	0.37	0.03	—0.23	0.14
Galveston	36 yrs.	0.30	0.37	0.48	0.69	0.87	0.78	0.52	0.61	1.09	1.09	0.72	0.49	0.67

Table 3 (Continued)

Monthly and Annual Means of Climatic and Hydrographic Elements, Central Texas Coast and Galveston

	Yrs. of Record	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yr.
Barometric Pressure Millibars														
Corpus Christi	....	1020.0	1018.3	1015.9	1013.5	1012.9	1013.2	1014.9	1014.6	1014.6	1016.3	1019.3	1019.6	1016.1
Galveston	....	1021.0	1019.3	1017.3	1015.6	1014.6	1014.9	1016.3	1015.6	1015.6	1017.3	1020.0	1020.7	1017.3
Gulf of Mexico	....	1018.0	1018.0	1017.0	1015.0	1014.0	1014.0	1015.0	1015.0	1014.0	1015.0	1018.0	1018.0	1015.0
River Discharge, c.f.s.														
San Antonio	15	368	378	394	611	841	533	642	322	878	827	523	392	6709
Guadalupe	14	1600	1644	1816	2131	3291	2346	3137	888	1764	1579	1614	1609	23419
Mission	9	17.1	130	57.1	120	221	90.4	231	134	76	111	48.1	31.9	1267.6
Nueces, Three Rivers	32	247	301	370	783	1567	2036	1359	525	1564	1010	291	255	10308
Nueces, Mathis	....	67.1	240	144	695	2414	1951	2352	292	2843	1758	188	127	13071
Silt Load, Tons														
San Antonio	5	28.948	29,463	46,943	71,548	168,867	69,700	76,887	37,883	141,898	99,602	21,800	13,815	807,354
Guadalupe	2	70,875	58,000	149,960	66,350	93,160	47,220	8,445	42,920	84,980	57,363	64,033	22,600	765,906
Nueces, Three Rivers	20	32,064	17,569	35,461	85,904	169,082	130,807	84,661	39,874	102,120	62,262	17,359	26,155	803,318
Nueces, Mathis	5	976	1,092	2,403	10,942	17,072	30,395	67,455	2,518	82,422	66,204	1,570	1,104	284,153
Water Temperature, °C														
Aransas Bay	52mos.	15.3	14.6	16.6	24.3	25.8	28.8	29.3	30.1	29.2	23.1	15.7	16.7	22.4
Copano Bay	49mos.	13.4	14.6	17.6	22.4	26.1	29.0	29.9	29.9	29.5	24.5	16.5	16.1	22.4
Laguna Madre	2	11.8	11.4	17.7	23.8	27.4	29.1	29.9	30.1	28.8	26.0	16.8	16.8	22.4
Port Aransas														
Gulf of Mexico	41mos.	14.5	11.1	15.0	21.6	25.2	28.2	29.4	29.3	29.1	24.4	20.2	18.1	22.2
Galveston	24	13.9	15.1	17.5	21.8	25.8	29.0	30.3	30.6	28.9	24.9	19.2	15.4	22.8
Salinity, o/oo														
Aransas Bay	52mos.	17.5	18.1	12.2	20.7	18.7	18.1	12.9	25.4	21.3	15.0	16.7	21.3	18.1
Copano Bay	49mos.	10.2	10.1	11.4	12.2	10.2	10.7	7.0	8.8	10.8	8.8	10.4	13.9	10.3
Laguna Madre	2	48.2	47.3	44.0	47.2	52.2	59.1	68.0	64.6	60.1	54.5	45.1	46.6	53.0
Gulf of Mexico														
Port Aransas	41mos.	29.5	31.6	31.2	30.3	29.8	32.5	34.2	36.3	31.6	30.1	30.4	29.5	31.5
Galveston	23mos.	22.2	21.0	21.7	21.2	19.5	20.4	25.2	30.0	27.8	25.5	25.1	23.5	23.7

*From charts computed by Meyer (1942). Gulf of Mexico values are means of figures for off Galveston and Port Isabel.

This does not mean, of course, that the Nueces cannot produce a flood whose effects on the salinity of the bay are as great as those which have occurred on the San Antonio-Guadalupe drainage. Nueces Bay was turned into a fresh water lake in 1935 and salinities as low as 4 0/00 were observed over oyster reefs in Corpus Christi Bay (Federighi and Collier, MS). According to Commons (1945a), the possible magnitude of floods on Texas streams is governed by a combination of topography and storm patterns, and his classification of the state transgresses, to some extent, the climate zones and isohyets (fig. 3). From his graphs of flood peaks and flood frequencies (1945b) it is possible to draw up a graph indicating the maximum possible floods which may occur on the streams in this hydrographic system. (See table 2.)

These studies, based on 801 station years of records on Texas streams, indicate that the 50% expectancy is a flood of 4% of the possible maximum. In other words, floods with peak discharges roughly between 50,000 and 60,000 cubic feet per second on the San Antonio-Guadalupe and Nueces can be expected at least half the time. This peak was exceeded on the Guadalupe alone on July 3–5, 1936, and on the San Antonio-Guadalupe on July 8, 1942, to cite two of the eight years concerned in this study. The four per cent peak of 60,000 c.f.s. on the Nueces at Three Rivers was almost reached on July 9–10, 1942, with a peak of 51,000 c.f.s. and exceeded on June 15, 1935, with a peak of 66,000 c.f.s.

Even such a small stream as the Mission River (for which gauge records are available only since 1939), exceeded its 4% peak of 17,200 c.f.s on July 7, 1942, with a peak of 30,300 c.f.s. and salinities in Copano Bay ranged from 0 to 5 0/00 for six weeks following this flood.

In the Aransas system the annual river increment is on the order of one and one third times the volume of the bays involved. The great bulk of this water is removed by tidal flow.

The erratic behavior of rainfall and floods in Texas has often been a subject for comment, both serious and humorous. Because there are few natural barriers to climatic movement in the vast area embraced by the political boundaries of Texas, the five basic climatic types which normally lie in broad bands extending northerly to northwesterly from the Gulf Coast shift about considerably from year to year, with resultant effects on the hydrographic economy of the bays. Texas, without exaggeration, might be called a meteorologic battleground. Anything can happen and often does, and the often violent changes in the weather have added both to folklore and serious traveller's tales.

Virtually nothing is yet known, however, of the biological effects of these floods, except that oyster reefs in the inner bays may be occasionally wiped out. The quantities and nature of the nutrients and other materials brought down by the rivers to the bays have remained undetermined. For the entire northern Gulf of Mexico there seems to be but one fragmentary contribution to this problem (Riley, 1937). The importance of the material borne by the rivers to the coastal lagoons cannot be overemphasized when it is realized that these bays are the principal haunts of the oyster and the nursery grounds for the shrimp which comprise the major fisheries resource of the area and for many species of marine fish. As

Nelson's (1947) essay indicates, the study of the problem of contributions from the land to the sea has barely begun. Perhaps not the least important, from the standpoint of such a calcium consumer as the oyster, is the effect of land drainage upon the buffer capacity of sea water (Mitchell and Solinger, 1934).

From the long range viewpoint, the climate of Texas seems to be undergoing a slow change toward a drier, warmer type. Some evidence for this on biological and geological grounds has been adduced by Price and Gunter (1942). More striking is the past evidence of greater abundance of oysters in localities now marginal environments for this mollusk. Oyster shells are common in Indian middens on the shores of Baffin Bay, which is now too salty for the oyster, and vast submerged reefs down to 60 feet below the surface of present bay bottoms indicate that the bays were formerly less salty and possibly cooler in the Pleistocene than they are today. These seem to be indications that the oyster population of Louisiana is on a slow decline which is not connected with commercial oystering activities or industrial development, but more a reflection of gradually increasing salinity. Here, however, the cause may be in part the controlling of the Mississippi River by levees. A chart of the shoreline changes on the delta since 1838 (USC&G Chart A-634) shows a vastly accelerated deposition since the first surveys which must be in part due to raising of the levees, as well as to poor agricultural practices.

Another line of evidence in behalf of climatic change is Meyer's (1947) demonstration of a fifty year trend towards increased evaporation in most parts of the United States except parts of the Rocky Mountain and Great Plains areas. Evaporation along the Gulf Coast is less than in such regions as Montana, despite the much higher mean temperature of the Gulf Coast, but there is nevertheless a deficiency of rainfall over evaporation northward along the Texas coast until one reaches Galveston. This deficiency is around —20 inches in the Corpus Christi area, and is greatest during June, July and August. At Beeville, some 60 miles from the coast, mean annual evaporation is more than 10 inches greater than at Corpus Christi, and the deficiency over rainfall is —27 inches. At Beeville there is no month in the year during which precipitation exceeds evaporation. The deficiency increase in a northwesterly direction from the coast until it reaches —70 inches in the Pecos drainage. At Galveston there is a mean annual surplus of rainfall over evaporation of about 2 inches, with deficiencies from May through October. According to Meyer's summary (*op. cit.*, p. 62), "annual evaporation from the Gulf of Mexico exceeds precipitation on the Gulf by about 30 inches," and is particularly high from August to November. This evaporation constitutes the major source of rainfall for the Mississippi Valley.

The high rate of evaporation a few miles from the coast over the drainage areas tributary to the tidal waters of the central Texas coast explains the apparent paradox of rains of normal or above normal proportions having little affect on the the salinity of the bays, if those rains are distributed more or less evenly over the month, whereas a rainfall which may be below normal for a monthly period may reduce salinity if it should occur on a single day. On the other hand, it must not be forgotten that a prolonged period of rainfall will saturate the ground and runoff may then increase disproportionately to rainfall.

3. The Aransas system as compared with other areas

It is not generally realized that the tidal waters of the Gulf coast have several characteristics in common with those of the middle and south Atlantic coasts. If one proceeds northward from the tropical extreme at Key West with its narrow temperature range and fairly constant salinity to Eastport on the Bay of Fundy, a typically boreal area, it can be seen that the temperature curve for the Texas coast is more like that of mid-Chesapeake Bay at Solomons than Key West in average range, although the means for all the months are higher and summer temperatures are similar to those at Key West. It must be remembered that these curves (fig. 6) are based on data obtained at tide gauging stations and evidently represent extremes found in harbors, which are not typical of the open surface records which are the principal bases for Fuglister's (1947) isotherms. According to these isotherms, the Atlantic coast in the vicinity of St. Augustine, Florida most closely resembles the Texas coast at Galveston, insofar as temperatures are concerned. Salinities in the bays and at the passes on the Texas coast more closely resemble those of such typically estuarine areas as Solomons, Maryland.

It is of particular interest to compare conditions at Beaufort, North Carolina with those of the Texas coast, since we know perhaps more about the fauna and ecological associations in the Beaufort area than anywhere else on the middle Atlantic coast. Unfortunately, the available temperature and salinity data (Gutsell, 1930, McDougal, 1943) are incomplete. The best series of observations is that by Gutsell, giving maxima and minima for five years (1924–1928) at Piver's Island. From these figures and the U. S. Coast and Geodetic Survey data, the following table is derived:

1. Maximum and minimum average water temperatures to nearest degree Centigrade, Beaufort, North Carolina. (Av. 1924–28).

	J	F	M	A	M	J	J	A	S	O	N	D
Max.	15	15	18	22	26	29	30	30	30	18	20	18
Min.	5	8	8	13	19	22	25	25	23	13	11	5

2. Maximum and minimum average water temperatures to nearest degree Centigrade, Galveston, Texas. (Av. 1922–46).

Max.	22	25	30	31	32	35	36	39	35	33	30	29
Min.	2	7	6	9	20	24	26	26	21	18	10	6

From this tabulation it appears that the waters of the Beaufort region have temperature characteristics much like those of Galveston, although the summer maxima at Beaufort are lower and the winter minima somewhat higher. The average range of salinities at Galveston is from 19.5 to 30.0 0/00; at Beaufort the range is 21 to 36 0/00.

This similarity of hydrographic conditions is accompanied by a striking agreement in the fauna of the respective coastal waters, of both invertebrates and fishes. It is apparent that the fauna as a whole is limited by the minima rather than the maxima, since the warm-temperate species greatly outnumber the tropical species in the fauna of the Texas coast. There is, of course, a seasonal variation in the fauna, especially during the summer months when tropical species move near the shore with the higher temperatures. The temperate character of the

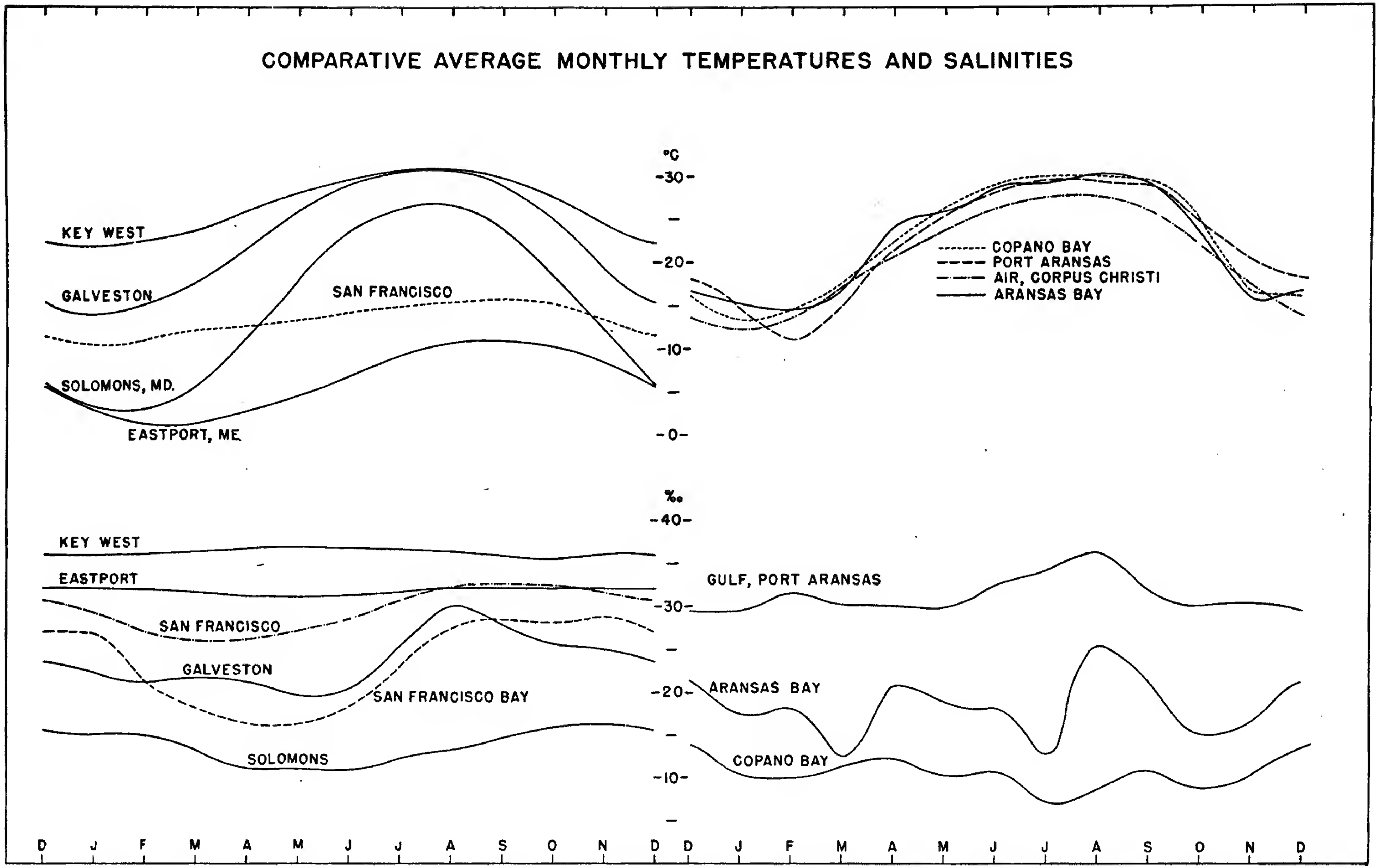

FIGURE 6

Comparative temperature and salinity averages

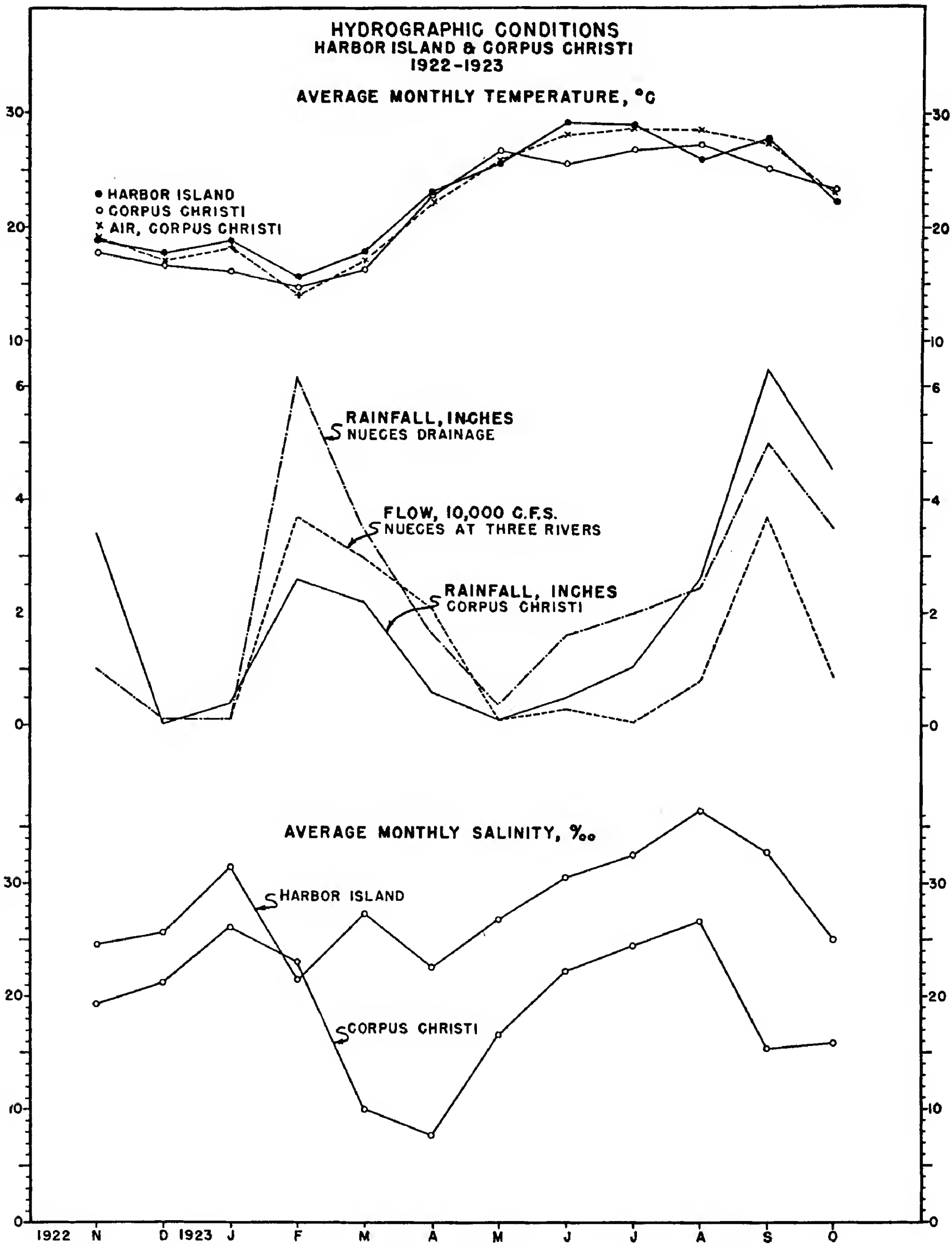

FIGURE 7

Temperature, salinity, rainfall and river discharge, Corpus Christi and Harbor Island and Nueces River, 1922–23 fauna of the northern Gulf Coast in general is best observed among the fishes, to judge from the papers of Gunter (1941, 1945a) and Storey (1937). The general temperature conditions governing distribution are summarized by Hutchins (1947). More recently Deevey (1950) has pointed out that the temperature conditions prevailing in this area are associated with the survival of a number of Pleistocene relicts in the hydroid fauna of the Louisiana and Texas coasts.

Some species, of course, can tolerate a rather wide range of conditions. The most conspicuous of these is the oyster, probably because its fixed mode of life places it at the mercy of all the changes even in the optimum parts of its natural range. But the oyster did not survive in San Francisco Bay, with its narrow temperature range and uniformly higher salinities. While temperatures fall well within the extremes encountered by the oyster on the east coast, salinities are uniformly higher, and it is probably this higher salinity, as well as narrowed temperature range, which has prevented establishment of the oyster in San Francisco Bay. Several species brought along with the oyster have, however, become permanent members of the fauna of the bay. These include a small mud crab, *Rhithropanopeus harrisii;* and the oyster drill, *Urosalpinx cinerus* (Jones, 1940).

As already stated, there is little information available on hydrographic conditions for the Texas coast as a whole. The data for Corpus Christi and Harbor Island, opposite Port Aransas, as derived from the graphs of a year's record (Atwood and Johnson, 1924) indicate that the same relationships obtain between these areas and the rainfall and stream discharges on the Nueces as were found for Aransas Bay, the Gulf of Mexico at Port Aransas and conditions on the San Antonio-Guadalupe drainage in later years (fig. 7). Rainfall was above normal in both 1922 and 1923, so the salinities recorded for Corpus Christi were probably somewhat lower than normal at this time. Those at Harbor Island are, for most of 1923, lower than more recent averages for the vicinity of Port Aransas, although the data are not strictly comparable. The data of Pearson (1929) and Galtsoff (1931) indicate that Corpus Christi Bay is usually somewhat more saline than Aransas Bay (fig. 8), as might be expected from the more limited development of oyster reefs in Corpus Christi Bay, and that average salinities become progressively lower as one proceeds up the bays to Galveston Bay, on the borderline between the moist subhumid and the humid zones.

II. HYDROGRAPHIC CONDITIONS, 1936–37

A. Methods, stations, etc.

The hydrographic study of 1936–37 was carried out over a series of 22 stations in Aransas Bay and 15 in Copano Bay. The stations were selected so as to give a pattern from which isohalines and isotherms could be readily interpolated, and to be representative of the bay areas as a whole (fig. 9). Because of the reefs in Copano Bay, it was not possible to distribute the stations evenly along the northern shore. All stations were easily located from the boat by reference to prominent landmarks. Temperatures at surface and bottom (the latter with a reversing thermometer) were recorded at all stations and samples of the surface water were obtained from a bucket, and of the bottom water by means of a

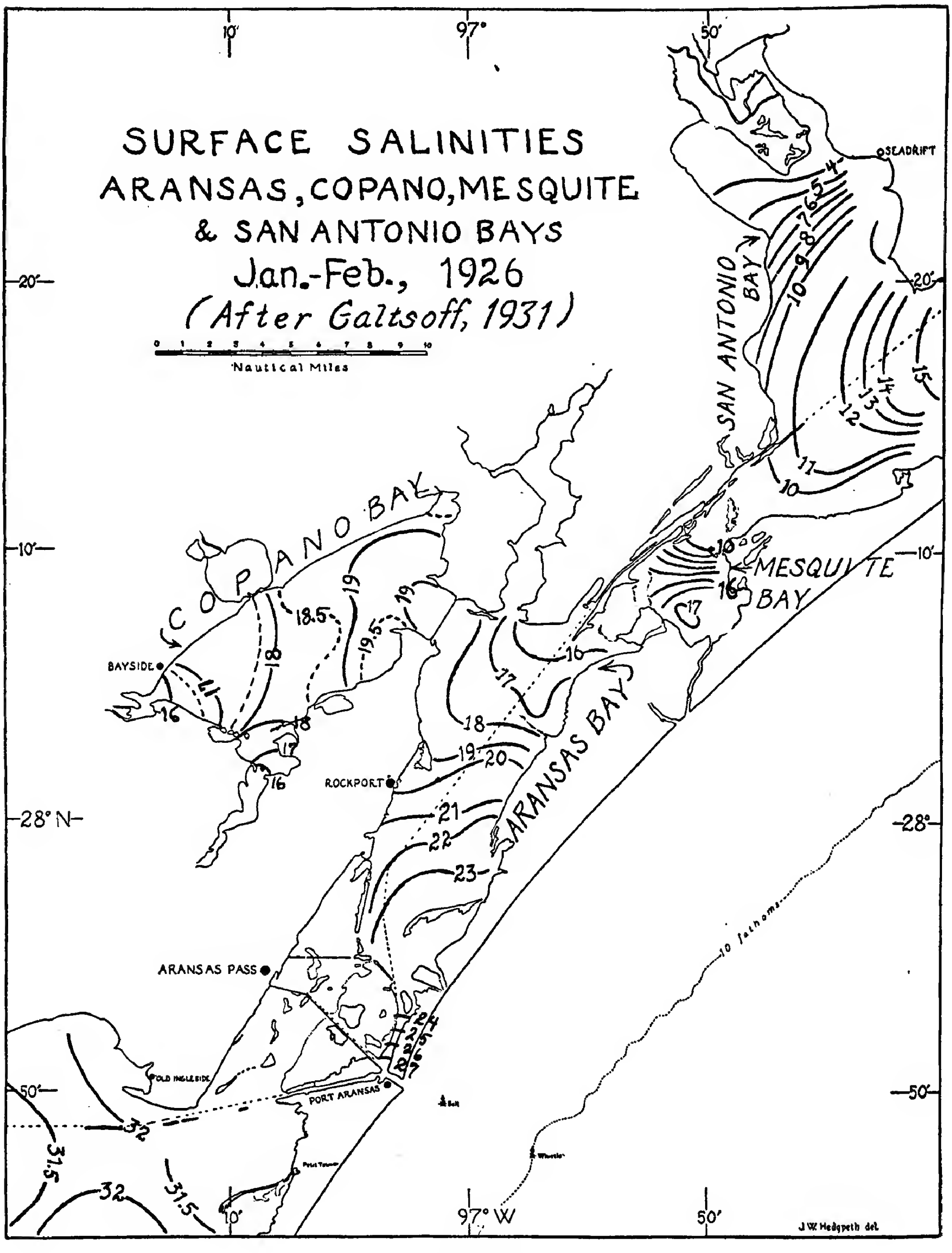

FIGURE 8

Isohalines according to Galtsoff (1931)

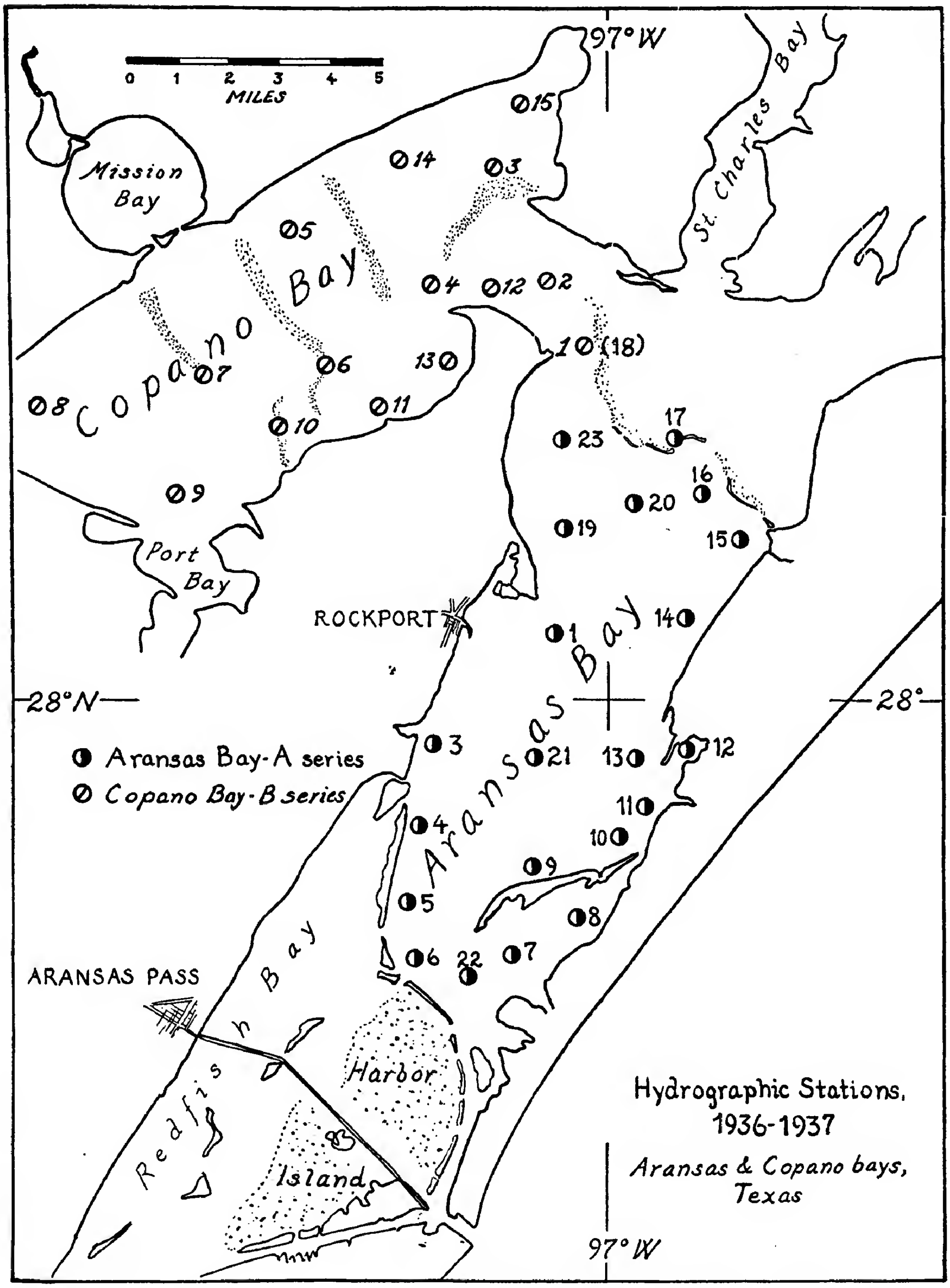

FIGURE 9
Station map, Aransas and Copano bays

Foerst cylinder or Greene-Bigelow bottle. The water samples were placed in citrate of magnesium bottles and brought ashore for salinity determinations.

An effort was made to complete a station run every week, from the period beginning June 16, 1936, to June 2, 1937, but this was not always possible because of the obligations of other duties, and in the winter during the norther season, while hurricane threats disrupted the program to such an extent in September, 1936, that only one run was completed that month.

During the first months of the study, salinities were determined by standardized sea water hydrometers and by titration, each method serving as a check on the other, but in 1937 the use of hydrometers was abandoned.

Tide gauge records from automatic gauges at Port Aransas and Corpus Christi from June, 1936, through 1938 were made available by the U. S. Engineers' office, and from February, 1937, through February, 1939, a tide station was maintained at Rockport in co-operation with the U. S. Coast and Geodetic Survey. This station was reinstated in 1948 after construction of a permanent marine laboratory at Rockport.

In the ten years since the data were gathered, the notes have passed through several hands and suffered three hurried removals during hurricanes, and many of the original data sheets for the months of June, July and August, 1936, have been lost. However, summaries of these periods, including weekly averages, preliminary graphs and transcriptions of the salinity readings, survived these vicissitudes, and enough of the data are in hand to make possible an analysis of the salinity cycle for the entire year in Aransas Bay (see figure 13, tables 4a, 5 and 6).

The rainfall and stream discharge data employed in this treatment have been derived from the Climatic Summaries and Monthly Climatological Data of the Weather Bureau and the Geological Survey Water Supply Papers. Rainfall over the respective drainage areas was computed by adding together all records of stations on the drainages and dividing this by the number of stations. These stations, 17 on the San Antonio-Guadalupe and 14 on the Nueces, are indicated on figure 1. During 1936 and 1937 there was no stream gauge on the San Antonio River at Goliad, and in order to obtain an approximate idea of the stream discharge the records for the gauging station at Falls City on the San Antonio, and for the tributary of Cibolo Creek, were added together. Averages for Goliad during the period of simultaneous record, and the estimated flow at Goliad were entered on a hydrograph. The result seems to be reasonably close to expected conditions, and since the San Antonio is a smaller stream than the Guadalupe, the percentage of error is further reduced when the discharge of the Guadalupe is added to the total. This procedure was used for obtaining monthly and weekly means only. The daily discharges on figure 12 are simply the sum of gauge records for the San Antonio at Falls City, Cibolo Creek and the Guadalupe at Victoria.

B. Temperatures

The average monthly temperatures for both Copano and Aransas bays are presented on figure 6, together with the 62-year average air temperatures off Corpus Christi. These curves are based on all months of record, totalling together about five years of observations scattered through the last ten years, and indicate that there is a close correspondence between air and water temperatures in these shallow bays. The mean temperature variations change from year to year as Gunter (1945a) has emphasized, but the yearly range is fairly constant except in years of "freezes," when the range is extended from around 25° to 30°. At such times, when water temperatures fall to about 4°C., large numbers of fish and some invertebrates are killed. Surface temperatures may drop from 20° to 4°C. within a few days. Gunter *(op. cit.)* has summarized these episodes up to 1945. A major freeze occurred in January, 1947, and fish mortality was very heavy, particularly in the Laguna Madre. Not all cold spells are fatal to fish, as it requires several days of low temperatures, combined with low tide levels, to kill fish on a large scale. During January and February of 1949 the coldest weather of record was experienced in many parts of Texas, and ice formed on the shallow flats of Harbor Island. A few dead fish were seen, but there was no major catastrophic mass mortality.

The annual range of monthly averages in Copano Bay is 16.5°; in Aransas Bay it is 13.5°. The lowest average in Copano Bay is 13.4° in January, and in Aransas Bay the low month is February with an average of 14.6°. July and August, with averages of 29.9° are the warmest months in Copano Bay, and the high in Aransas Bay is 30.1°, in August.

Perceptible differences between surface and bottom temperatures, at such shallow depths as six or seven feet, occur throughout the bays. In winter, especially during northers, bottom temperatures tend to be from .5 to 1 degree higher than surface temperatures, while in summer they are usually cooler than surface temperatures. The differences are seldom more than one degree. During periods of strong winds these differences may be due to turbulence, but usually they are the result of evaporation.

It is unfortunate that we do not have a sufficient number of temperature data at the mouth of Aransas Bay to present a picture of gradients, both temporal and areal, for that locale. Because the temperature of bay waters changes rapidly with the sudden climatic changes characteristic of the region, and the temperature of the deep water of the Gulf does not change so readily, there will often be some rather steep gradients around the mouths of the passes. This may be rather significant when it is considered that a number of marine organisms spawn near the mouth of these passes with the offspring dependent upon safe entry to the estuary for survival. The locus of such a thermocline would tend to determine the degree of proximity of a spawning population to a pass, which in turn determines the chances of a given egg or larva reaching the mouth of the pass to be carried in by tidal flow. This, of course, is particularly applicable in the spring when late "northers" will keep the bay waters cool after the Gulf water has begun to warm.

C. Aransas Bay

1. Description of the bay

Aransas Bay is isolated from the immediate effects of river drainage by Copano Bay and the small chain of bays between San Antonio and Aransas Bay, and is separated from the Gulf of Mexico by a long narrow channel, Lydia Ann Channel. It is shaped roughly like an inverted bottle with the neck pointing south and the bottom open at both corners and the middle. At the northwest corner it joins Copano Bay through the two-mile width of Copano Strait. The middle of the bottom opens into St. Charles Bay, a narrow bay with a sharp double bend or jog near its middle. While Copano Bay receives the discharge of two small, but not inconsiderable rivers, the drainage of St. Charles Bay is mainly surface runoff from the immediate area. The northeast corner of Aransas Bay is blocked off by a series of islands and shoals from Carlos or Mud Bay, which in turn is separated from Mesquite Bay by another system of islands and reefs.

Aransas Bay itself can be divided into three well defined regions. The development of oyster reefs across the northern part of the bay has effectively segmented the bay here so that it is characteristically shallower than the main basin, and evidently serves as the settling basin for sediments from St. Charles and Mesquite bays. The second region is that south of this system of reefs. The lower, or southern boundary, of this region appears to be a line southeasterly from the tip of the triangular island, north of Rockport (Ninemile Point) to the area between Mud Island and the shore of St. Joseph Island (Blind Pass), roughly skirting the deeper part of the main basin of the bay. The bottom relief shows this area to be subjected to more rapid silting than the third, or remaining, region of the bay. The contours (fig. 10) suggest that a large part of this deposition has its origin in Copano Bay and to some extent through the Long Reef-Grass Island reef system from the upper portion of the bay. This region is also an area of mixing for the fresh waters from the streams and the saline waters from the Gulf.

The third region is made up of the remainder of the bay. It receives water directly from the Gulf of Mexico via Aransas Pass and Lydia Ann Channel, and is the high salinity area of the bay. An interesting feature of the bottom topography of this region is the low ridge on the bottom which extends along the western side and is especially prominent toward the southern end (see fig. 10). This ridge is apparently not the result of any permanent geological substructure of the bay, and has been developing during the last forty years (according to the U. S. Coast and Geodetic Survey charts). It may be the result of electro-chemical silting along the interface of highly saline and less saline waters.

Mud Island, near the southeast corner of Aransas Bay, has been built since 1833, forming a small shallow bay to the south.

2. Weekly variations in salinity

Average weekly salinities for three areas in Aransas Bay, and that part of Copano Bay nearest the mouth of the Aransas River from October, 1936, to June, 1937, are presented, together with the tidal range at Port Aransas, rainfall and stream flow for the San Antonio-Guadalupe rivers, in figure 11. From this it can be seen that the closed basin of Copano Bay is not subject to the same immediate influences that bring about reduction of salinities in Aransas Bay, and is to be considered, from the hydrographic standpoint, a separate body of water. The true salinity gradient from the Aransas Bay system by-passes Copano Bay to continue through Mesquite and San Antonio bays to the delta of the Guadalupe. It is true that the yearly pattern of monthly variation shows agreement between Copano and Aransas bays; but the action in Copano Bay is evidently slower, and often comes about more through the

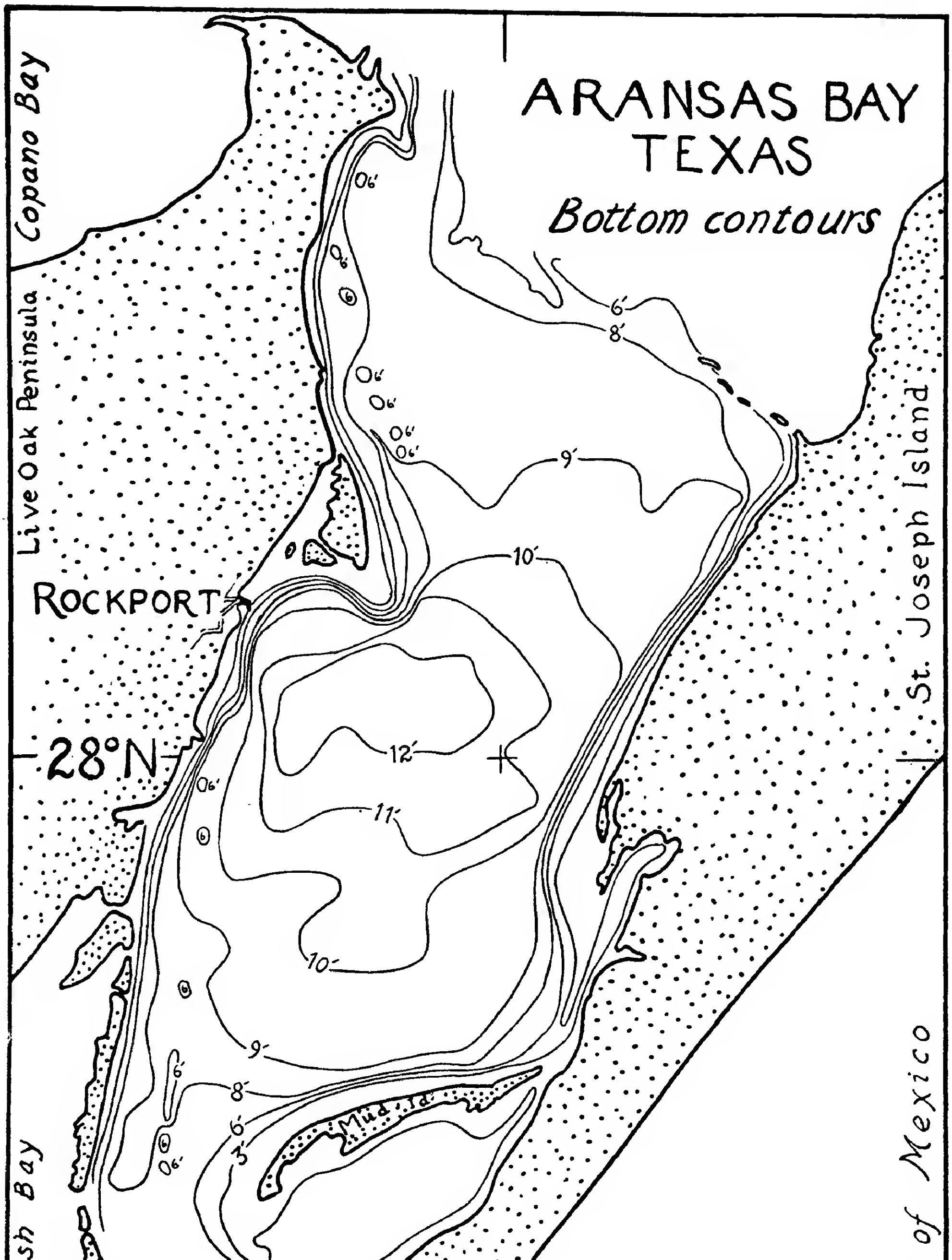

FIGURE 10

Bottom contours, Aransas Bay

backing up of Aransas Bay water into Copano Bay, and from the rainfall and discharge of the two small drainages which immediately affect it. Furthermore, the monthly averages for Copano Bay include that part of the bay immediately subject to the tidal action occurring in Aransas Bay.

The pattern of salinity variation as correlated with rainfall has more effect on salinity during the equatorial phases of the tide than during the tropical phases. Between October 1 and 8, 1937, there was a total of 22.12 inches of rain over the drainage, a daily average of 2.75 for this period. This rainfall is reflected in the salinities by a pronounced drop in all three regions of Aransas Bay on October 12, toward the close of the equatorial tides, although the rainfall itself occurred during the tropic phase. This same pattern is plain during the period ending December 21, although the bottom salinity of lower Aransas Bay was not affected. The heaviest rainfall of this nine month period occurred between March 3 and 8, 1937, when 38.25 inches fell over the drainage basin, a daily average for that period of 6.38 inches. Although this rainfall was much greater than that of the first week of October, its effect on the salinity of Aransas Bay was proportionally much less, the drop in October being from 4 to 7 0/00 as opposed to a drop of 1 to 4 0/00 in March. This is probably due to greater range of tides at this time of the year, which serves to accelerate exchange with Gulf water.

It is to be noted that all the salinities taken during, or immediately at the close of, the tropic phases are usually higher than those taken during the equatorial phases, except during the first half of February when the lower range of all tides did not bring about a noticeable change in bay salinities. After mid-February, when the tidal range began to increase, salinities were raised. From this it is obvious that the tropic tides of this area are of prime importance in bringing about salinity exchange between the bays and the Gulf, and somewhat offset the influence of rainfall and runoff which may occur a few days before such periods. Conversely, a heavy downpour whose runoff reaches the bays during the equatorial phases will have a proportionately greater effect in reducing salinities than it would during the tropic periods.

Active mixing of salinities occurred during the period from November 15 through the middle of December, except for the bottom salinities in the lower bay. This is coincident with the greater variation in tidal level at this time of the year. Conditions were temporarily established during January and February, the salinities for the various areas remaining narrowly separate, and from March on to June 2, the various salinity averages not only remained distinct, but tended to become more widely separated, in spite of the rainfall during the first week of March. The failure of this heavy precipitation to affect the salinity sequence can be explained by the occurrence of 21–20 inches, or more than half the rainfall for the period, on a single day, March 5. This followed a month of light rains, and it is probable that most of this March downpour was absorbed by a thirsty soil so that runoff was consequently lower.

There appears to be a general tendency for the salinity over the bay as a whole to increase during the winter months, coincident with the low period of mean annual rainfall in this area and increased evaporation over water surfaces, but it seems probable that this is also due in part to the greater effectiveness of the tidal action at this period in bringing Gulf water into the bays. Cowles (1930) commented upon the existence of a non-tidal current during the winter months in lower Chesapeake

Bay, caused by the movement of surface water seaward from the coast during periods of northerly winds. As a result of this wind movement, subsurface water tends to move in the opposite direction in a compensating action (Sverdrup, Johnson and Fleming, pp. 489, ff). Such a compensating wind current is improbable in the shallow bays of the Texas coast, but it seems likely that more saline, subsurface water moves coastward in the Gulf during the winter and finds its way into the bays through tidal action.

The months of May through July of 1936 were marked by excessive rainfall in the region, especially on the Guadalupe drainage. Over 131 inches fell during May, an average of 7.7 inches for the 17 rainfall stations. The average was 5.0 inches in June, and 6.4 in July. As a result, there occurred one of the greatest floods of record on the Guadalupe River in early July, with a peak discharge of 129,000 cubic feet per second recorded on July 3. A detailed description of this flood is given by Dalrymple and others (1937).

The mean discharge for this month was 18,430 c.f.s., with a total runoff of 1,133,000 acre feet. This caused a sharp drop in salinity in Aransas Bay, with salinities as low as 1.8 recorded, and the mean for the entire month was 7.4 0/00. By mid August, however, the salinity of the bay as a whole had returned to 17.0, only 1.4 0/00 less than the preceding June average. Unfortunately, the field data for the period between August 2 and 31 are lost, since it is apparent from inspection of the remaining data that the effective re-establishment of the salinity equilibrium occurred during this period. Weekly averages for the entire period are available, however (fig. 12), and when plotted against the tidal curve, reveal that the tidal ranges at this period of the year were a material force in raising the salinity of Aransas Bay after this flood.

3. Salinity exchange patterns

While no current measurements were made in Aransas Bay during the survey of 1936–37, some idea of the patterns of water movement can be inferred from a study of the isohalines and isotherms (figs. 13, 14), for various stages of the tide. These indicate a somewhat serpentine course of surface water during a falling or standing tide, flowing from the northwest in the region of Copano Strait southeasterly toward Mud Island, where there is evidently a clockwise eddy which tends to return the bay water northward along the face of the more saline water from below Mud Island, roughly along the line of the low bottom ridge described on page 148. On a strong rising tide, this water is pushed westward so that the eddy constricts into an ellipse.

The salinity gradient is more gradual during periods of standing or falling tides, and temperatures tend to become stratified at such periods (fig. 15). During rising tides, however, the salinity gradient steepens and the lower salinities are backed up to the upper end of the bay. This action is much less pronounced in Copano Bay, where several transverse oyster reefs divide the bay into segments and tidal action is damped. In Aransas Bay the movement of denser waters of higher salinity sometimes by-passes, or slides, under less saline water, as on May 17 (fig. 16). Such a condition probably represents the manner in which the bay waters recover from heavy discharges, at least after the major part of the discharge has passed through the bay.

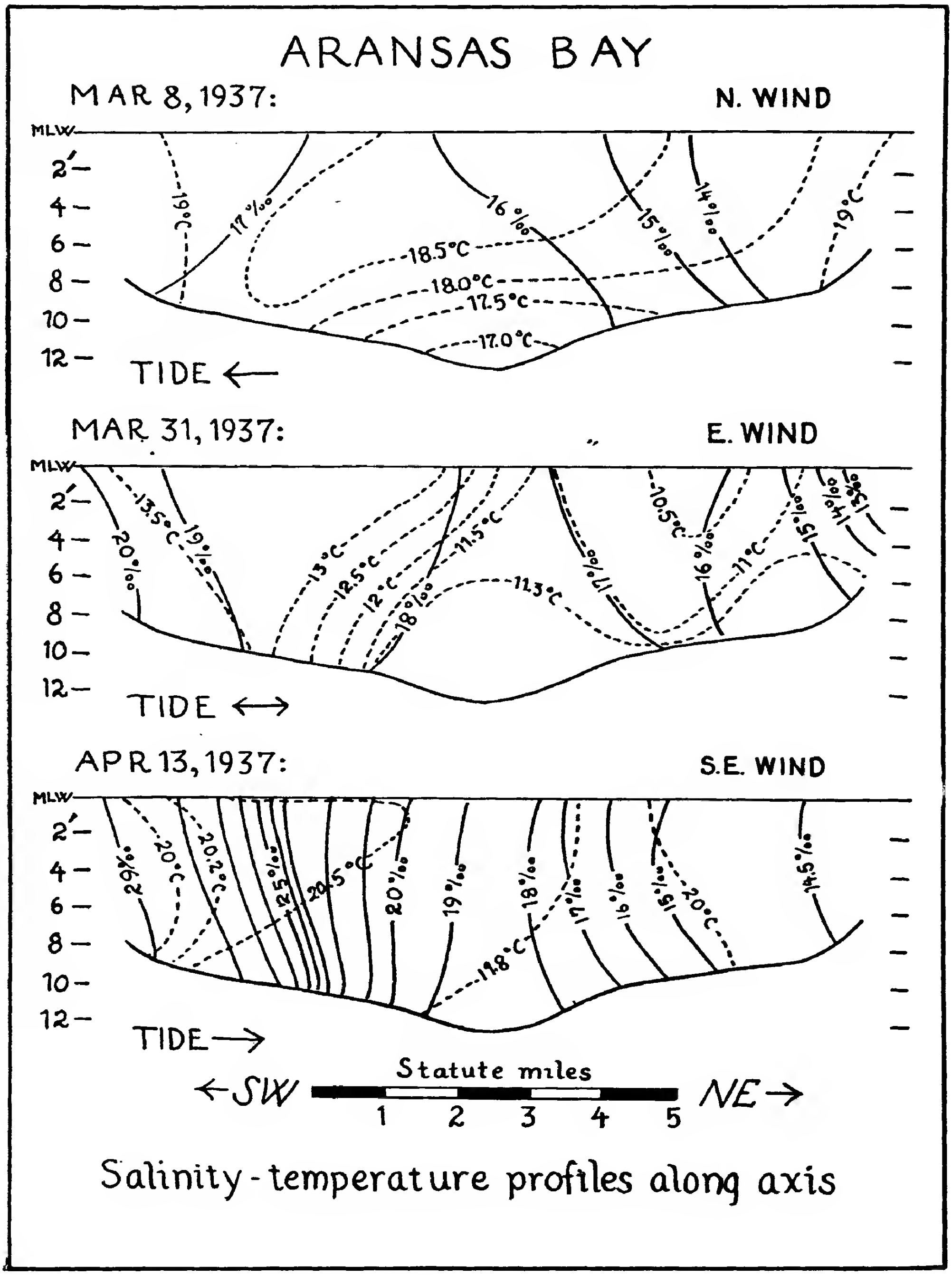

FIGURE 15

Temperature and salinity profiles, Aransas Bay

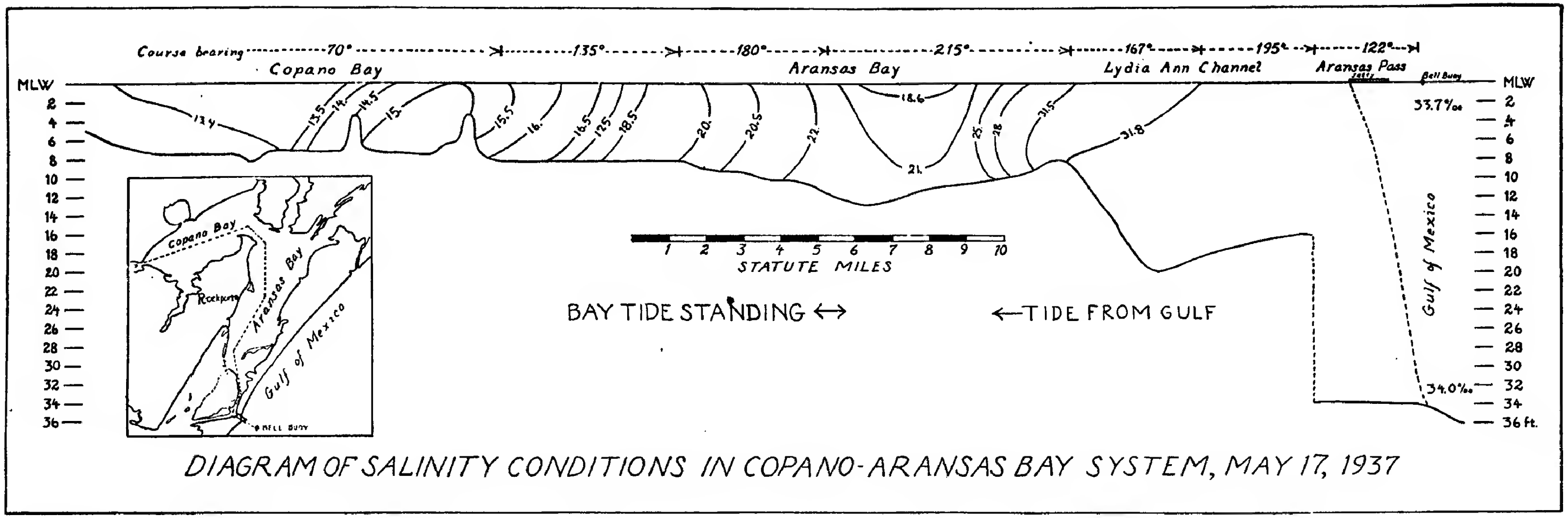

DIAGRAM OF SALINITY CONDITIONS IN COPANO-ARANSAS BAY SYSTEM, MAY 17, 1937

FIGURE 16

Salinity conditions from Copano Bay to Gulf of Mexico, May 17, 1937

4. Later years of record

Hydrographic data for subsequent years are much less complete than for the year 1936–37. During the calendar year 1938 some hydrographic data were compiled in connection with weekly samplings of the shrimp population of Aransas (8 stations) and Copano (4 stations) bays. Gunter (1945a) took temperature and salinity readings from March, 1941, through October, 1942, in connection with a study of fish populations. These are preserved only as monthly range and averages. In August, 1946, the Game, Fish and Oyster Commission inaugurated an investigation into the life history of the blue crab, *Callinectes sapidus*, which is still under way. Since the data for all these surveys are much more limited, they are presented here only as monthly ranges and averages (table 4). These averages, together with rainfall and stream discharge records, are presented in figure 17.

As fragmentary as these data are, they are in general agreement with the year 1936–37 in their relationships between rainfall and runoff, except for the year 1948, when rainfall was more evenly distributed throughout the year than usual and stream discharges were consistently below normal. Data for Aransas Bay for this later period were based on about four stations, however, and the omission of one station in May, 1948, is reflected by a false uncorrelated drop in the average salinity for that month, since the omitted station is usually the most saline of the series. These values appear higher than might be expected from rainfall distribution, but are in agreement with extremely low discharges from June, 1947, through September, 1948, the last available record. It is to be regretted that more data were not gathered for what was obviously a critical year in the hydrographic regime of these waters.

From the various records available, five twelve month periods of various "years" can be selected, and the yearly values compared (fig. 18). Up to the year 1947–48 these show fairly close correlation between rainfall, runoff and the annual average salinity of Aransas Bay. For the year 1947–48, the flow of the San Antonio-Guadalupe was much more below normal (nearly 50%) than rainfall, which was about 25% below normal. The average annual salinity for Aransas Bay, on the basis of these five years, is 23 0/00, which by inspection of the graph for the years 1938 and 1941–42, when rainfall was not as far below normal as it was during 1947–48, appears to be too high a value. It would appear that, for a possibly non-existent "normal" year, the average annual salinity of Aransas Bay should be somewhere between 19 and 20 0/00. Since the stream flow figures are based on a nine year average for the purposes of comparison with the salinity data (long term averages are presented in table 3), they are probably only slightly less reliable than an annual salinity average based upon the five years of record available.

It is apparent that only in years of above normal precipitation does the salinity of Aransas Bay fall low enough to be considered an optimum oyster environment. This is probably the principal factor for the restriction of the principal oyster reefs to the upper part of Aransas Bay, where salinities are usually somewhat lower than over the bay as a whole.

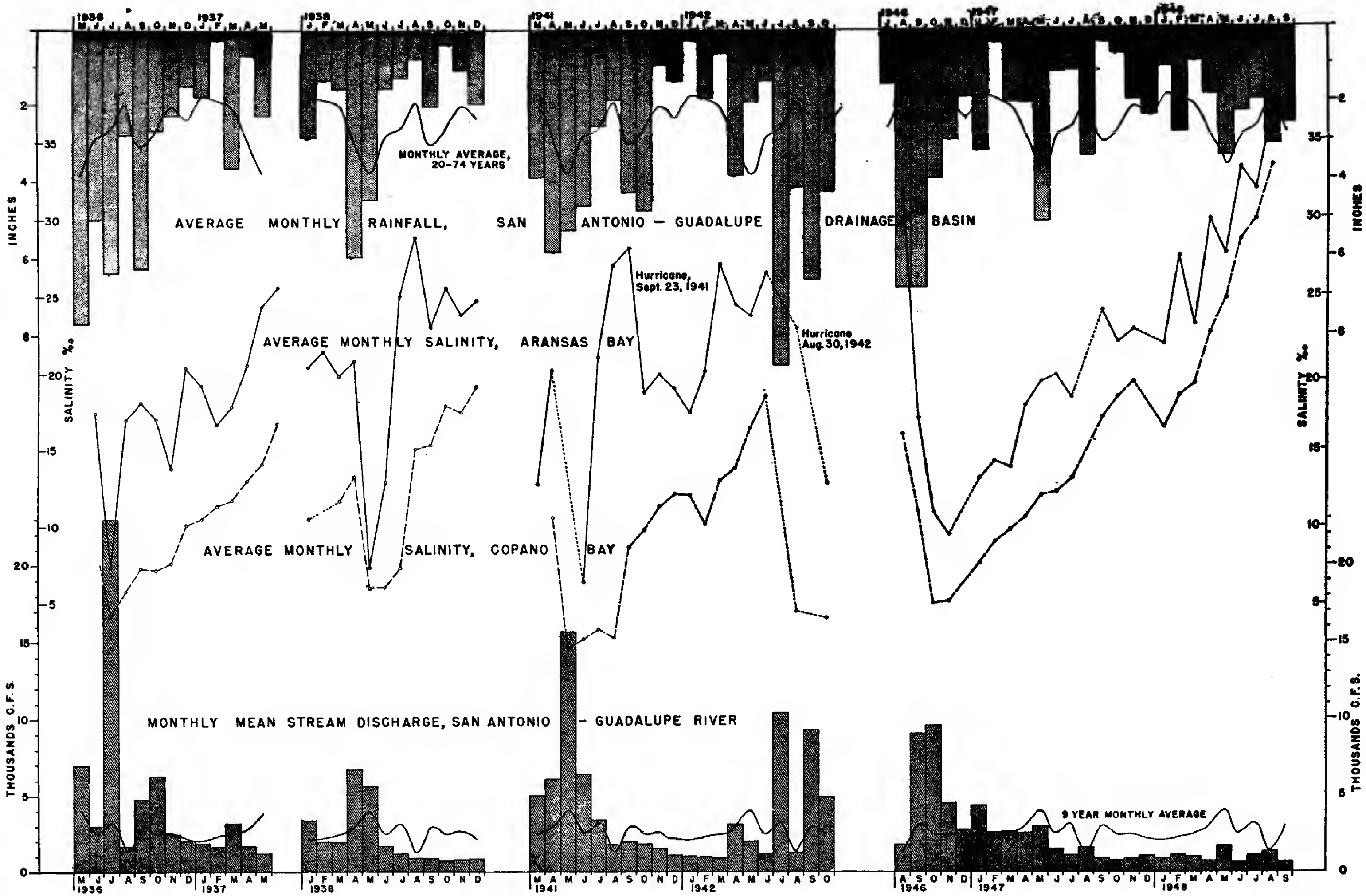

FIGURE 17

Monthly relationships of salinity, rainfall and runoff, Aransas Bay, 1936–1948

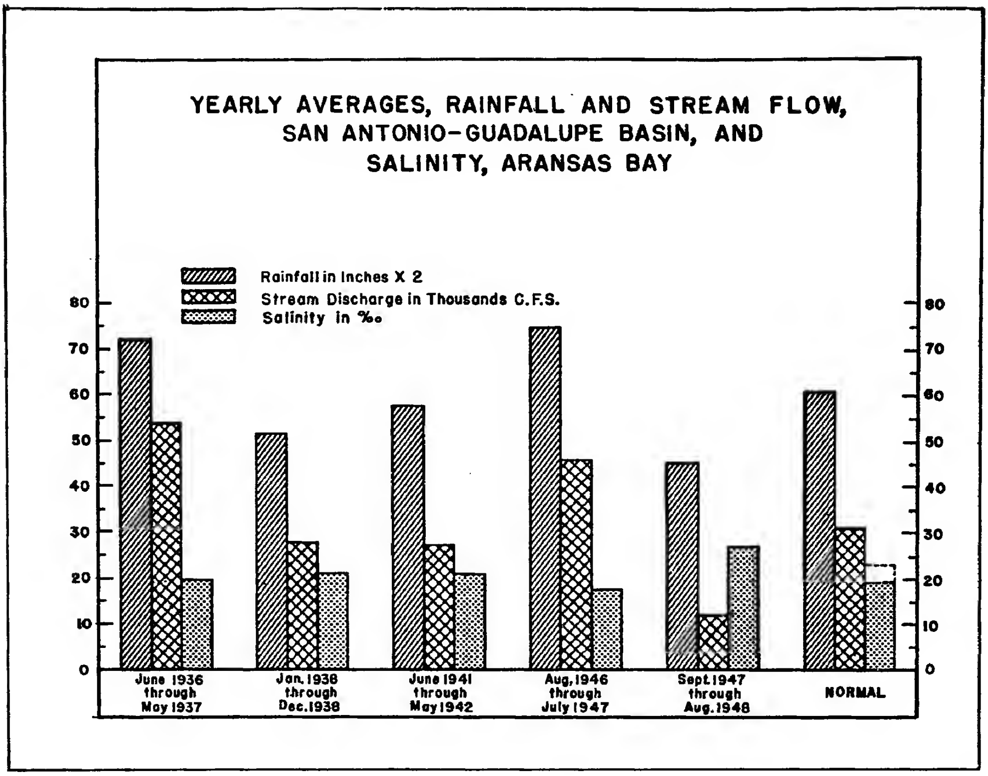

FIGURE 18

Yearly averages, salinity, rainfall and runoff

D. Copano Bay

1. Description of the bay

Copano Bay is joined to Aransas Bay at its northeast corner somewhat like siamese twins. The name of this bay, incidentally, i of Indian origin and is pronounced with stresses on the first and last syllables (like such words as pelican and revenue). Copano Bay receives the drainages of two large creeks or small rivers, Mission River, which enters the almost circular Mission Bay which is located tangentially at the middle of the northwest shore of the bay, and the Aransas River which discharges into the southwest corner of the bay. Drainage at the northern end is principally from marshlands. At the southeast corner is a narrow appendix, Port Bay. There is a series of transverse oyster reefs across the middle part of the bay and some longitudinal reefs off the mouth of the Aransas River and in the vicinity of Redfish Point.

With the exception of the reefs, the floor of this bay is seven feet below mean low water with an occasional spot eight feet in depth. In this regard, it is more like Corpus Christi Bay than Aransas Bay. Whether the occurrence of oyster reefs in transverse ridges across the main axis of this bay (and to a lesser extent in Aransas Bay) is in any way related to physical and hydrographical factors is an interesting problem, somewhat outside the province of this paper. Such transverse oyster reefs are not peculiar to Texas bays, but since Grave's (1905) attempt to explain their origin, no one seems to have studied the problem.

2. Hydrographic conditions (1936–37)

At the time of the survey of 1936–37, no gauges were maintained on streams draining into Copano Bay, and there were but two weather stations to provide rainfall data. In 1939 a gauge was installed on the Mission River and a weather station established at Refugio. It is unfortunate that no better records are available for former years, since Copano Bay is important as a source of seed oysters in the Aransas area and a thorough study of its hydrography is a prime

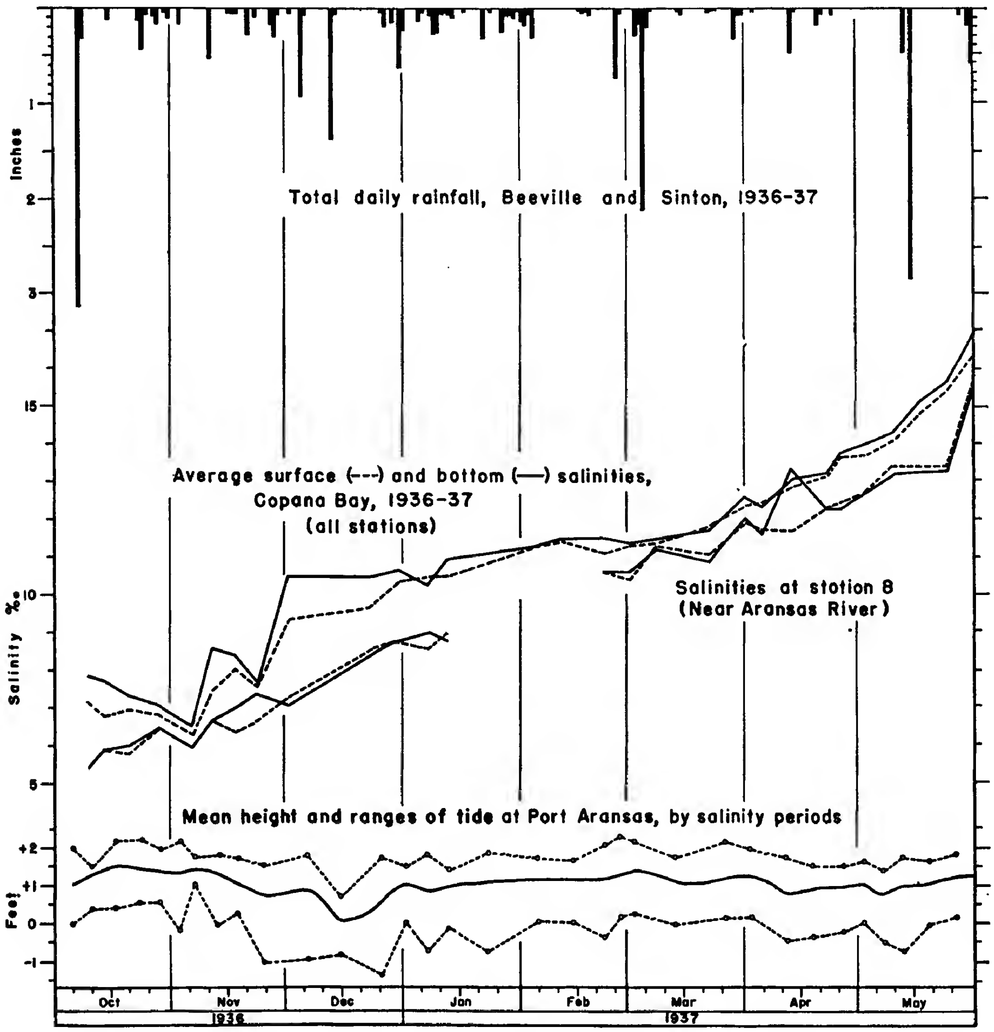

FIGURE 19

Weekly salinity and rainfall conditions, Copano Bay, October 1936–June 1937 desideratum. Nevertheless, with what records are available, some interesting things come to light.

An examination of the graph of weekly salinities and rainfall at Sinton and Beeville on the Aransas drainage indicates that as the weather warms up and evaporation increases, rainfall on this drainage has little effect on the salinity of the bay as a whole (fig. 19). Salinity drops are noticeable after the moderately heavy rainfalls of October and December, but the rainfall of May, which was almost equal to that of October, did not halt the steadily increasing salinity of the bay as a whole, and only stalled the process at the station nearest the Aransas River for a few days.

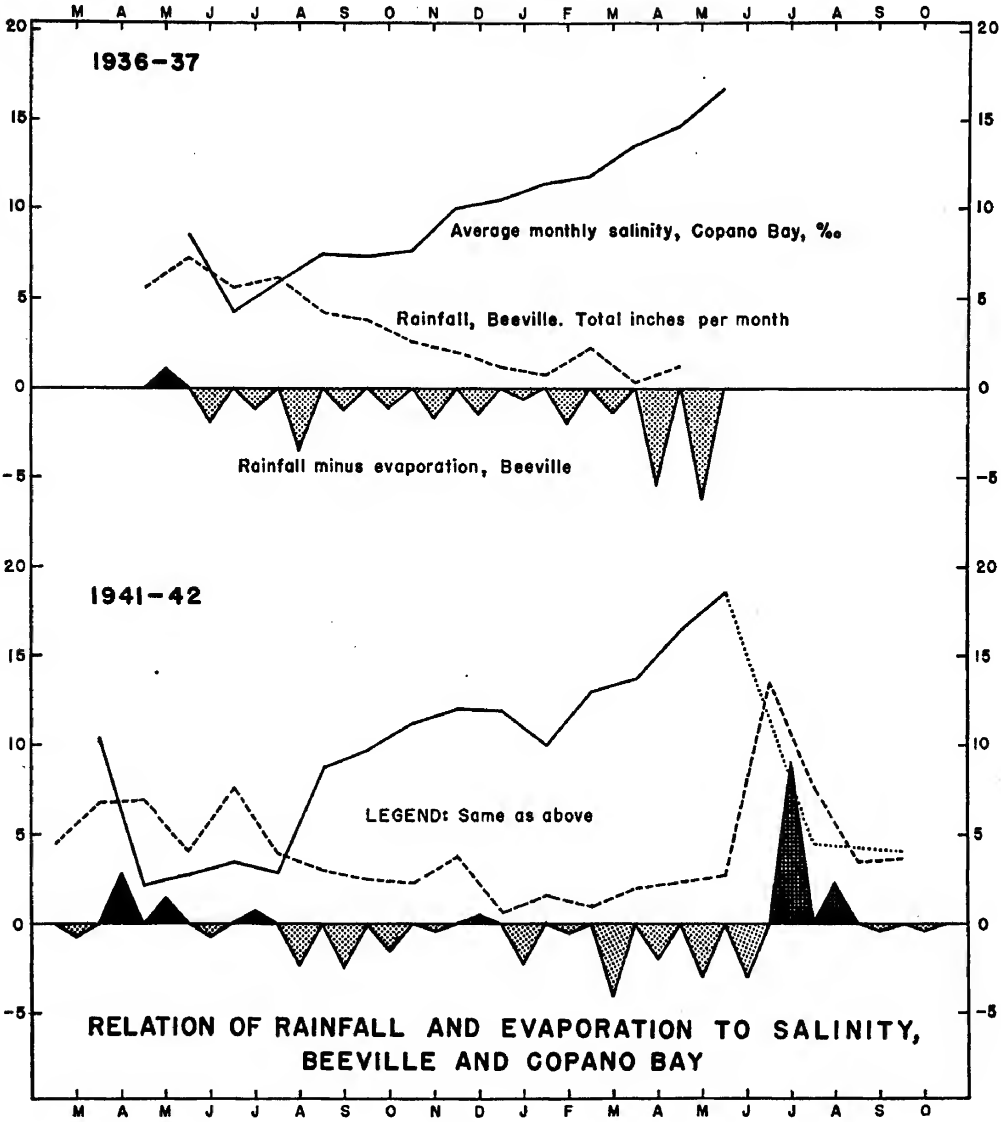

FIGURE 20

Salinity in Copano Bay, evaporation and rainfall at Beeville

If one examines the relationship between rainfall and evaporation at Beeville, it is apparent that only a very heavy downpour, accompanied by reduced evaporation, will produce a sharp drop in the salinity of Copano Bay, at least insofar as the contribution from the Aransas River is concerned (fig. 20). Probably the

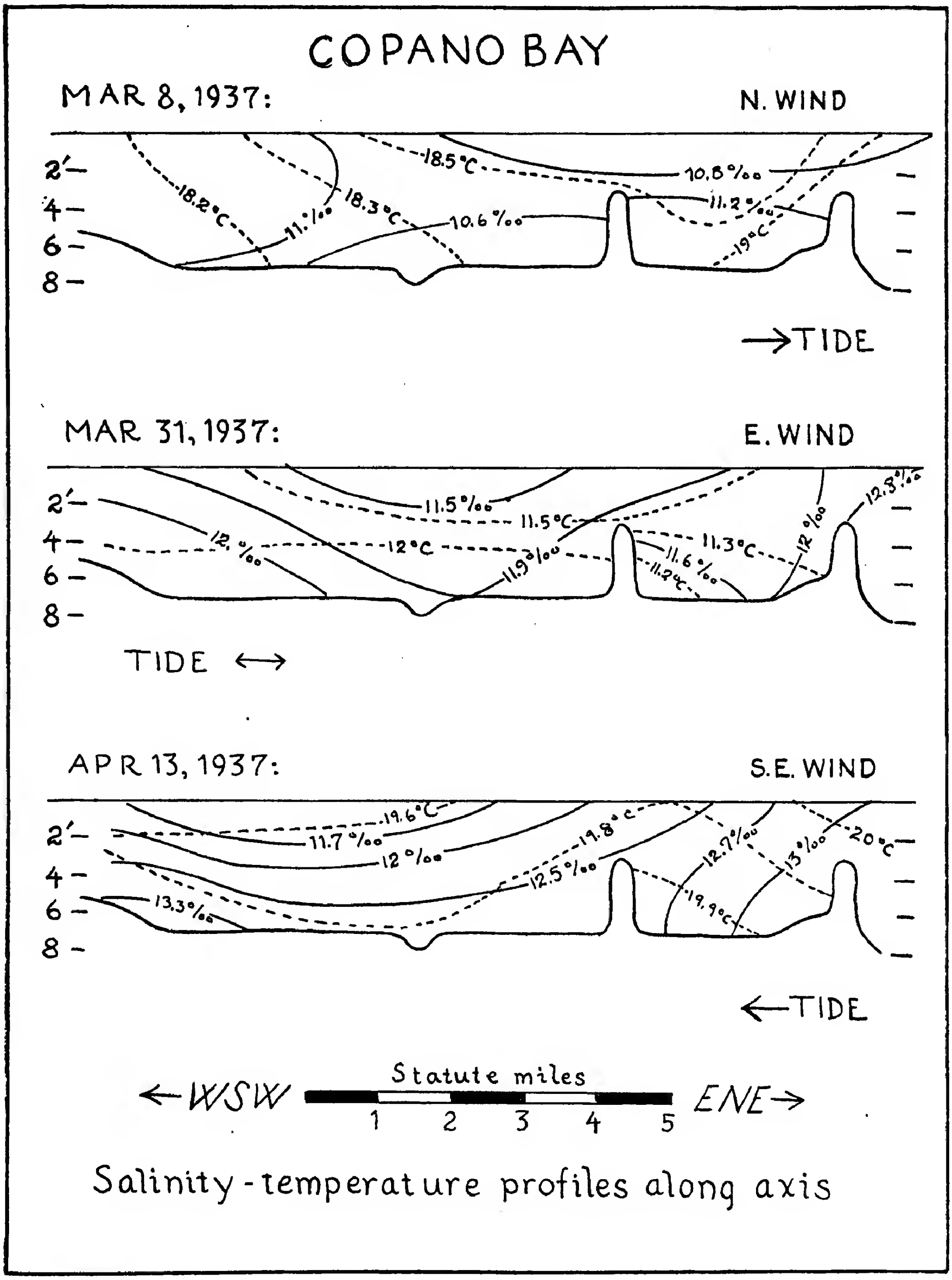

FIGURE 21
Temperature and salinity profiles in Copano Bay

same conditions obtain for the Mission River drainage. It is also possible for a salinity drop to be accompanied by an evaporation excess over rainfall. Of course, it must be realized that these records represent an inland station some miles from the bay, and that they are at best approximate when applied to this problem.

The effect of the transverse oyster reefs on the hydrographic economy of Copano Bay is well illustrated by the profile diagrams of temperature and salinity conditions (fig. 21). In this series of profiles, the right side is nearest the tidal influence, and the values are those near, or on the main axis, of the bay as far as Copano Strait, thence bending eastward. The reefs, which rise to within four feet of the surface at mid bay, act as partitions, separating the water below into different but narrowly separated temperatures and salinities. The profile for March 8 represents conditions as found during a norther, when surface temperatures were lower than those at the bottom. This is reversed in the lower part of Copano Bay in the diagram for March 31, when the wind was out of the east during most of the daytime hours, but there was evidently a distinctive water mass retained behind the main transverse reefs of the bay which was not materially effected by the prevailing wind conditions on this date.

3. Other years of record

While the salinity drops of 1941, 1942 and 1946 can be correlated with rainfall (including surplus over evaporation), and peak stream discharges, that of 1938

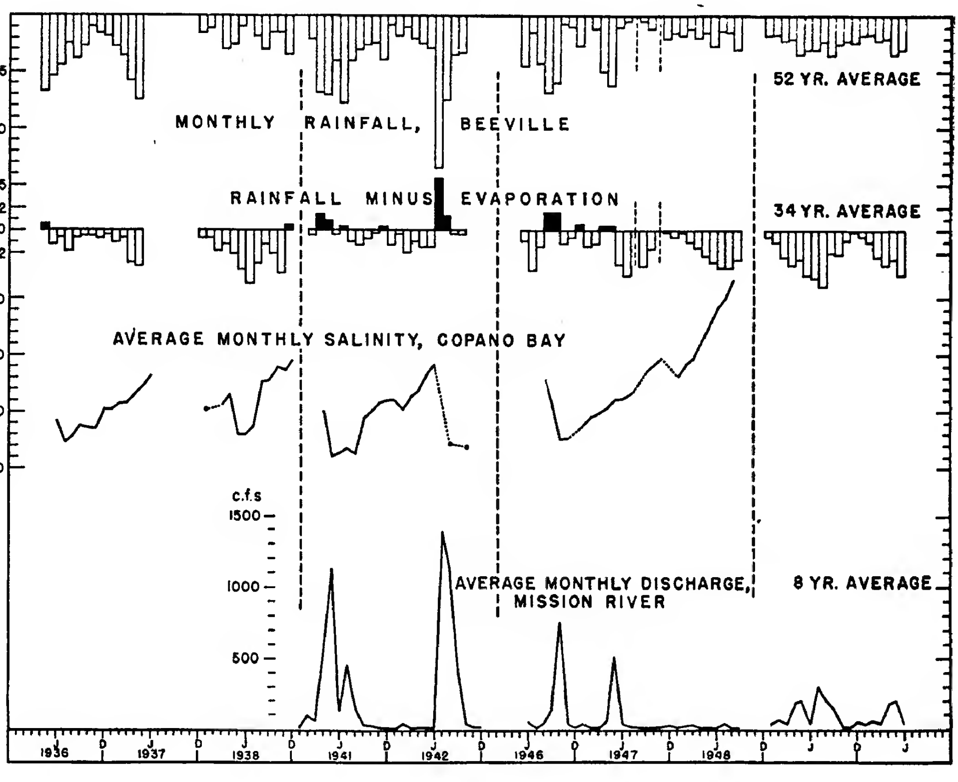

FIGURE 22

Monthly relationships of salinity, rainfall and stream dishcarge in Copano Bay, 1936–1948 is not indicated by the records at Beeville (fig. 22). The lowering of the salinity of Copano Bay during May, 1938, occurred at the same time the salinity of Aransas Bay was reduced by heavy rains and stream discharges of April of that year, while rainfall at Beeville was actually about 13% below normal. On occasions Copano Bay has been found to have a higher salinity than Aransas Bay, when major floods on the Guadalupe drainage add great quantities of water to the lower bays. This condition occurred in July, 1935, after the major floods of that year, and a series of salinity samples taken during mid-July had an average of 10.8 0/00 for Copano Bay and 8.8 0/00 for upper Aransas Bay (Federighi and Collier, MS). This condition, also observed by Galtsoff in 1926 (see fig. 8), however, is transitory; for Copano Bay is normally a fresher body of water than Aransas Bay. This is primarily because of the reduced tidal effect in Copano Bay, since it receives an annual increment of river water only about nine times its mean low water volume, as opposed to a possible increment of 60 times its volume for Aransas Bay.

Thus, it is apparent that what fresh water does get into Copano Bay tends to remain there longer, whereas in the Aransas Bay it is flushed out by tidal action within a few weeks. These bays, almost completely landlocked and separated from each other by islands and narrow straits, establish individual hydrographic economies which even the mighty force of Texas floods cannot upset for very long.

4. Temperature-Salinity relationships with Aransas Bay

The monthly temperature-salinity relationships with Aransas Bay are distinct and fairly constant, as indicated by the T-S diagrams (fig. 23). Because of the differing series of months and omitted months, only the data for 1936–37 and 1941–42 are strictly comparable. Both twelve month periods show the same basic monthly pattern of relationships, and when compared with the diagram for averages of all months of record (except August, 1947), indicate that on the average October is least saline, and April and August the most saline months for both bays, and that December and March are almost identical in their temperature-salinity relationships for both bays. By March the bays have begun to recover from the lower winter temperatures, and warm rapidly through May. Cooling after the summer high temperatures starts in September and progresses rapidly to November.

III. THE LAGUNA MADRE

A. Description and methods of study

Of all the various bodies of water falling within the area of this study, the upper part of the Laguna Madre is in many ways the most interesting. Here we are able to see the death throes of a coastal lagoon, deprived of its river drainage and at the mercy of moving sand and excess evaporation. The situation in the Laguna Madre is a picture of what may happen in future ages to other coastal bays to the north, if the climate becomes drier.

The Laguna Madre as a whole is a narrow coastal lagoon extending from Corpus Christi Bay to Port Isabel in a broad southeasterly to southerly arc for a distance of 115 miles. It is seldom more than five miles wide and often much less. Its northern end is almost cut off from Corpus Christi Bay by a high sill of sand bars which are exposed at ordinary tide levels. About 40 miles south of Corpus Christi Bay, roughly where the Gulf coast of Texas commences its turn toward the southwest, the Laguna is divided by a barrier of sand and mud flats which are above all but the highest tides. These flats extend for more than fifteen miles before the open water of the southern part of the Laguna is encountered.

Although the charts of the U. S. Coast and Geodetic Survey (numbers 1286 and 1287) show open water in this region, the flats which separate the Laguna into two separate hydrographic units have been an effective barrier for many years. It has been the general impression that the Laguna Madre was divided in half by the hurricane of 1919, and this impression has been published as fact by Hedgpeth (1947) and Gunter (1945b), but it is now suspected that the shoaling process has been more gradual. Extending westward at right angles to the upper part of the Laguna Madre is Baffin Bay, a somewhat deeper body of water with three narrow arms. This bay has the same salinity characteristic as the adjacent Laguna Madre.

Depths in the Laguna Madre and Baffin Bay are for the most part very shallow, ranging from a few inches to three or four feet with occasionally deeper holes. As a result of these shallow depths, lack of permanent stream drainage, the high rate of evaporation and the sand bar separating it from Corpus Christi Bay, the upper Laguna Madre is very saline. The monthly average salinity (including Baffin Bay) is slightly above 50 0/00, and salinities well over 100 0/00 are found in some years.

Despite these high salinities, the upper Laguna is an important source of fish, and during those years when the combination of high salinities, high temperatures and low tides cause conspicuous mortality among the fish population, there is lively public interest in the problems of the Laguna. On July 19, 1946, the Game, Fish and Oyster Commission instituted a weekly sampling flight by light seaplane, which lasted until October 27, 1948. Six stations were visited (fig. 24), usually within a period of about two hours, and the temperature was recorded. A sample of the water was taken at each station. The "salinities" were determined by means of sea water hydrometers and Knudsen's tables. Samples of very high salinity were diluted with distilled water, and final reading from the tables multiplied by the dilution factor.

In view of the peculiar composition of these waters, the results, aside from hydrometer errors, are not strictly comparable with salinity readings for waters of normal concentrations. It might have been more accurate to express these results simply as densities, but salinity, especially when referred to the average ocean water value of 35 0/00, is a more readily grasped abstraction.

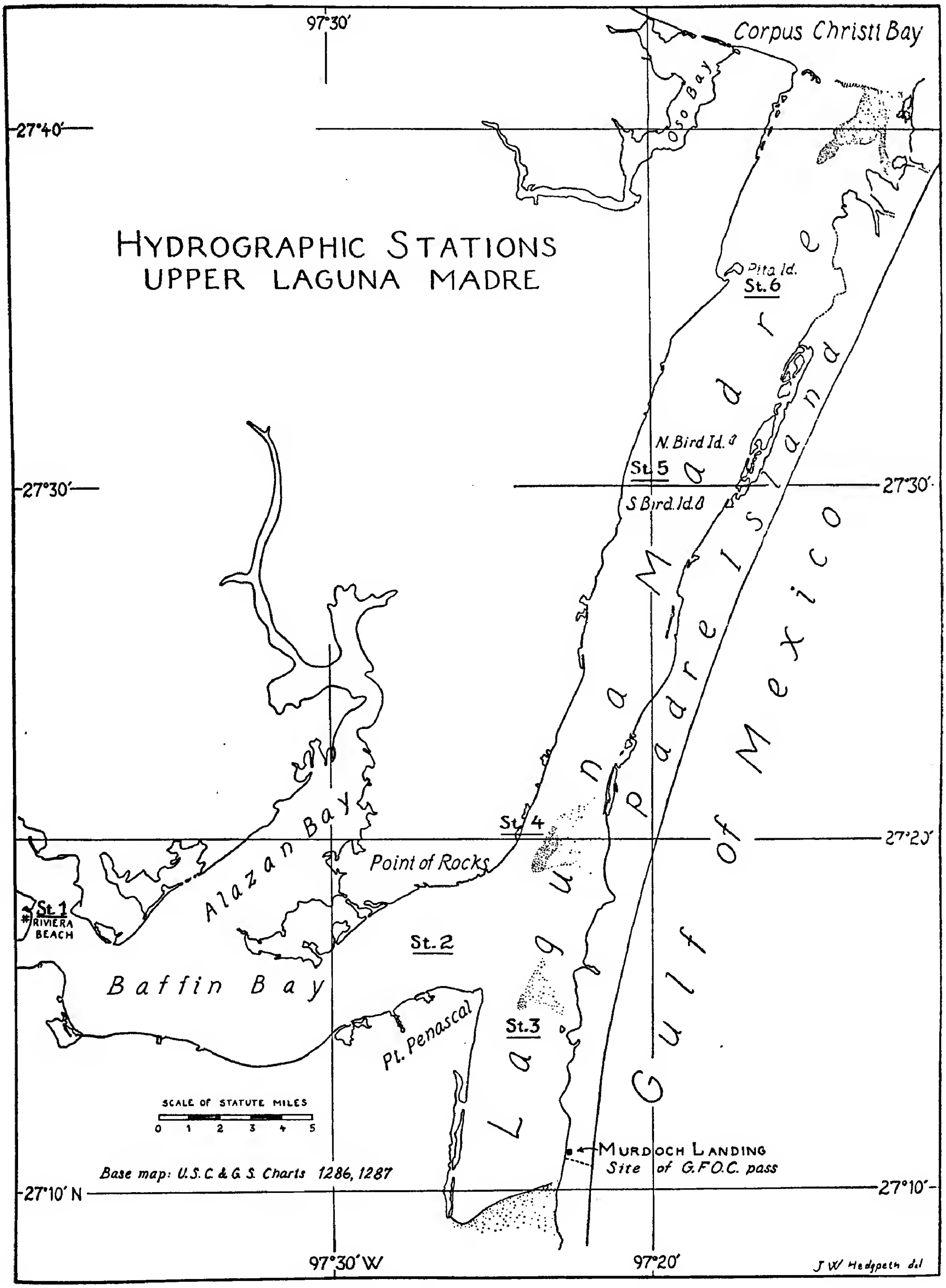

FIGURE 24

Station map, upper Laguna Madre

Few analyses seem to have been made of the waters of the Laguna Madre. An analysis on a sample of water taken from Baffin Bay at Riviera Beach on September 15, 1948, gave the following results, as compared with normal sea water:

	Riviera Beach (Analysis by A. & M. College Chemistry Department)		"Normal" sea water (Sverdrup, Johnson & Fleming Table 35, p. 173)	
Density	1.0426		1.0243	
Cl^-	38.810	0/00	18.9799	0/00
$SO_4^=$	1.383	"	2.6486	"
HCO_3^-	0.134	"	0.1397	"
CO_3^-	0.017	"		
Na^+	20.750	"	10.5561	"
Mg^{--}	2.358	"	1.2720	"
Ca^{++}	0.598	"	0.4001	"
SiO_2	1.439	"		
Al_2O_3	0.058	"		
Fe_2O_3	0.007	"		
sus. solids	0.076	"		
total salts	64.050	"	34.4816	"

The most conspicuous difference indicated by this analysis is the great reduction of sulfate, proportionately one-fourth the concentration found in normal sea water. This is to be expected, since the sulfates precipitate out of sea water first when it is evaporated.

A preliminary discussion of salinity exchange in the Laguna Madre has been presented elsewhere (Hedgpeth, 1947), based on the first six months of observations. The entire series of data for the upper Laguna is presented in table 7.

B. Salinity exchange

In addition to the barrier of flats which divides the Laguna Madre into two separate hydrographic units, there is an extensive shoal which narrows the width of the Laguna Madre in the Point of Rocks area, immediately north of Baffin Bay. This area is indicated on the charts as an isolated bar, but it is actually a complete constriction of the Laguna at ordinary stages of the tide. This constriction is indicated by Burr (1930) on a sketch map with fair accuracy. In figure 24 this bar has been sketched in according to aerial obseravtions made in 1946. Burr suggested that this bar would eventually cut the Laguna in half again at this point, and that "it can be but a matter of years until Baffin Bay, cut off from the north, will become a dead sea and probably dry up" (*op. cit.*, p. 57).

At the present time it is this constriction, more than anything else, which inhibits the exchange of salinities between Corpus Christi Bay and Baffin Bay and adjacent parts of the Laguna. This was demonstrated by the first six months of weekly salinity samples, which revealed a separation of the waters of the Laguna Madre into two different parts, with the salinity of the intermediate bottleneck region at Point of Rocks swinging back and forth between the two, but eventually becoming identified with the more saline waters of Baffin Bay, and the blind pocket at Murdoch's Landing. There has been no basic change in this pattern over a two year period (fig. 25). Each year salinities have built up to high values in

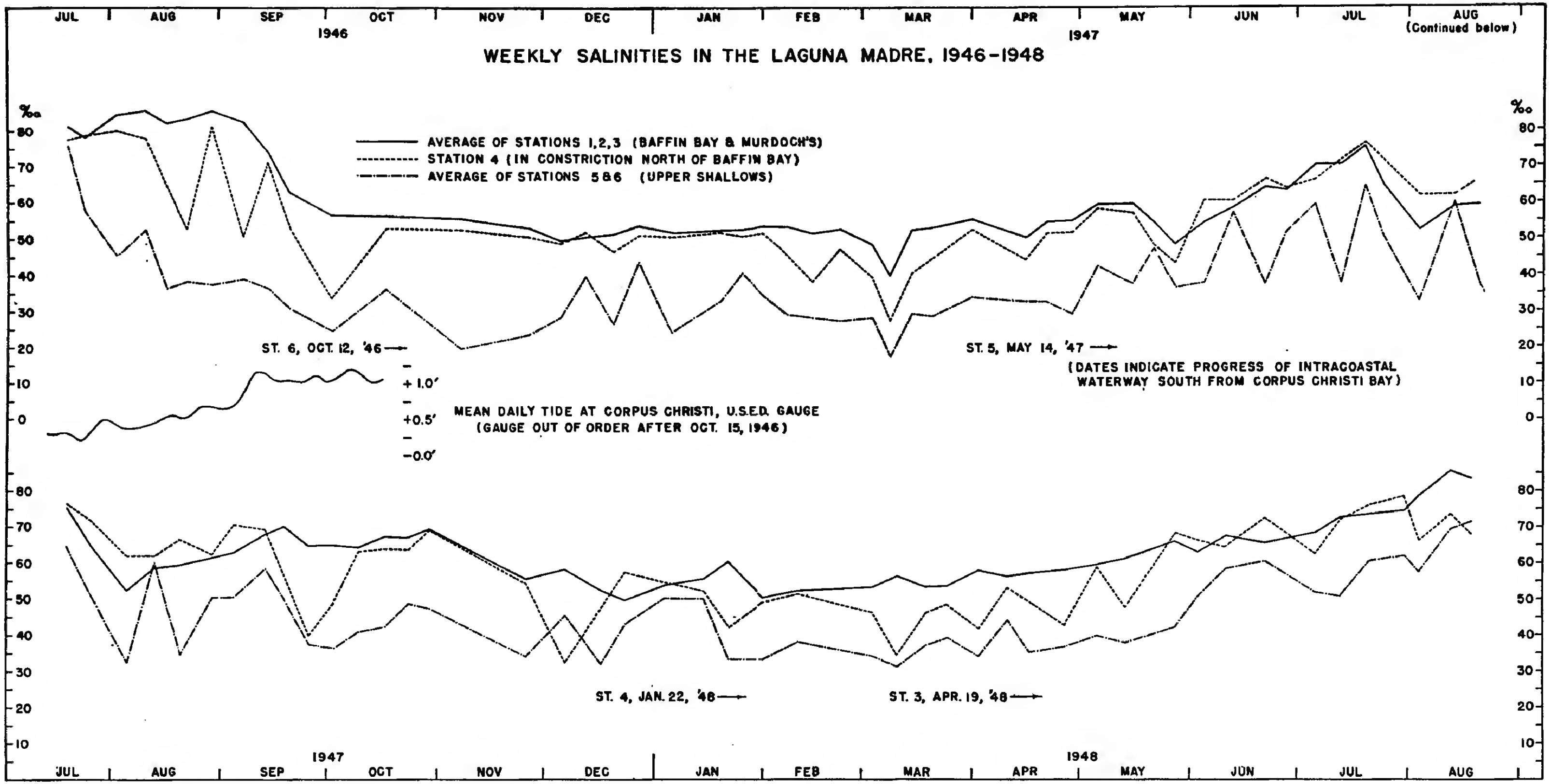

FIGURE 25

Salinity exchange by areas, upper Laguna Madre, 1946–48

June and July, and have fallen coincident with the increase in average sea level during late September and October by a mixture with less saline waters from Corpus Christi Bay.

At the time these samples were being taken, the Intracoastal Waterway was being dredged into the Laguna Madre from Corpus Christi Bay. This channel, about 15 feet deep and 150–200 feet wide, was completed through the dry flats to join the channel dredged northward from Port Isabel about the end of July, 1949. Hope has been expressed by those concerned over summer fish mortalities that this channel will prevent the building up of lethally high salinities. During the progress of the channel down the Laguna from Corpus Christi Bay, however, there

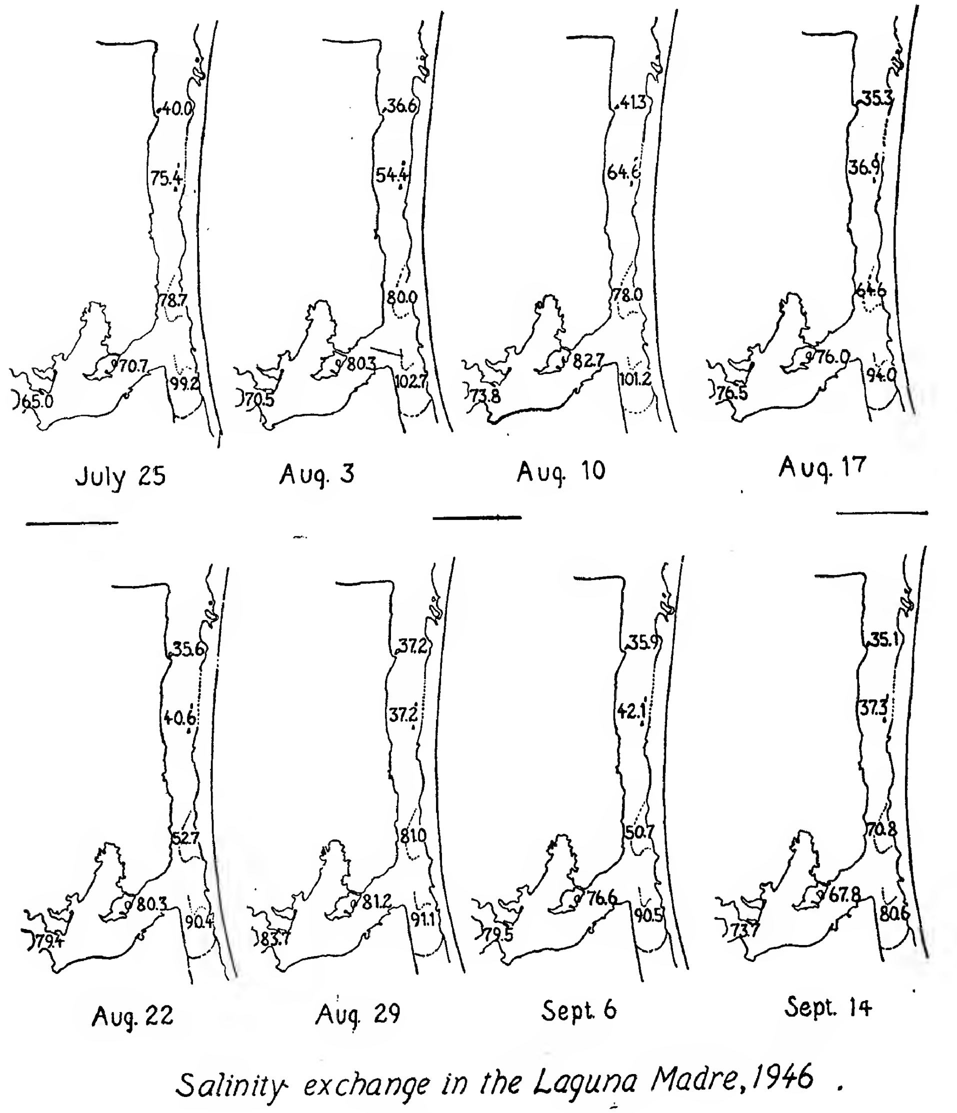

FIGURE 26

Patterns of surface salinities during fall rise of tides, Laguna Madre, 1946 was no perceptible effect on salinity relationships. The dredge passed the vicinity of Murdoch Landing about April 20, 1948, but salinities well over 80 0/00 occurred there in August of that year. Whether there is enough tidal action through this channel to alter the picture is yet to be determined.

As the result of the disastrous fish mortality in Baffin Bay and the upper Laguna in July, 1938, the clamor for a pass opening directly to the Gulf of Mexico increased, and the Game, Fish and Oyster Commission embarked upon a program of pass cutting in 1939. Corpus Christi Pass was dredged, Cedar Bayou was opened, and at the end of 1940 the dredge was ordered to proceed to Murdoch's to rescue the Laguna.

The pass at Murdoch's was first opened in April, 1941, and was completely closed by shifting sands by October of that year. In four years of effort to dredge this pass, it remained open a total of about 10 months and never was effective in changing the salinity. Gunter (1945b), who took the readings at that time, showed that the pass did not permit influence of the Laguna waters by the Gulf for a greater distance than one-fourth of a mile from its mouth. As a result of his report to the Commission the effort was abandoned and the dredge was sold.

The reason for this failure is not far to seek. Inasmuch as this pass was only 80 feet wide, and Baffin Bay alone is more than a hundred square miles in area, the amount of water which could be exchanged is infinitesimal, as compared with the total volumes of highly saline water. Under the present conditions of rainfall, evaporation and runoff, it would require something like 70% of the entire volume of the upper Laguna and Baffin Bay combined to maintain an annual mean salinity of 50 0/00, on the assumption that the average salinity of the incoming water would be 26 0/00.

This figure of 70% is at best an approximation, based on the formulae given by Sverdrup, Johnson and Fleming (pp. 147–148), in which the total volume of incoming water necessary to maintain stable salinity conditions is slated to be the product of the outflow, plus the product of evaporation over precipitation and runoff, *i.e.*, $Ti = Tu + D$. These values can be determined on the basis of salinities and meteorological and runoff values:

$$Ti = D\frac{Su}{Su\text{-}Si}, \qquad Tu = D\frac{Si}{Su\text{-}Si}$$

Evaporation loss over the Laguna Madre-Baffin Bay area is 25 inches, or roughly two feet, per annum, or 9,030 million cubic feet for 160 square miles. Since the upper Laguna drainage lies in an areic basin with inconsequential runoff reaching the bay waters, it can be disregarded. Runoff for the Baffin Bay area is estimated to be about the same as that of Frio River basin at Derby, whose area is similar to that of the Baffin Bay drainage, with comparable rainfall and evaporation. This runoff is 2,210 million cubic feet per year, probably somewhat high for Baffin Bay, because half or more of drainage area is deep sand. This gives us an approximate figure for D of 6,820 million cubic feet. Since we assume the salinity of the area to be twice that of the incoming water, Ti, or the total volume of incoming water necessary to maintain such a salinity equilibrium, is 13,650 million cubic feet, or 70% of the total volume, 19,642 million cubic feet, of the upper Laguna Madre.

No pretense can be made for the accuracy of this computation in view of the empirical figures used, but it would seem that the figure of 70% of the total volume is not too far off, and probably under rather than over, the actual requirements, in view of the salinity changes which are induced by the high tides of the fall months. It is plain that only the volumes of water brought into the Laguna by tidal action could produce the observed effects (see figs. 25, 26, 27). A one foot

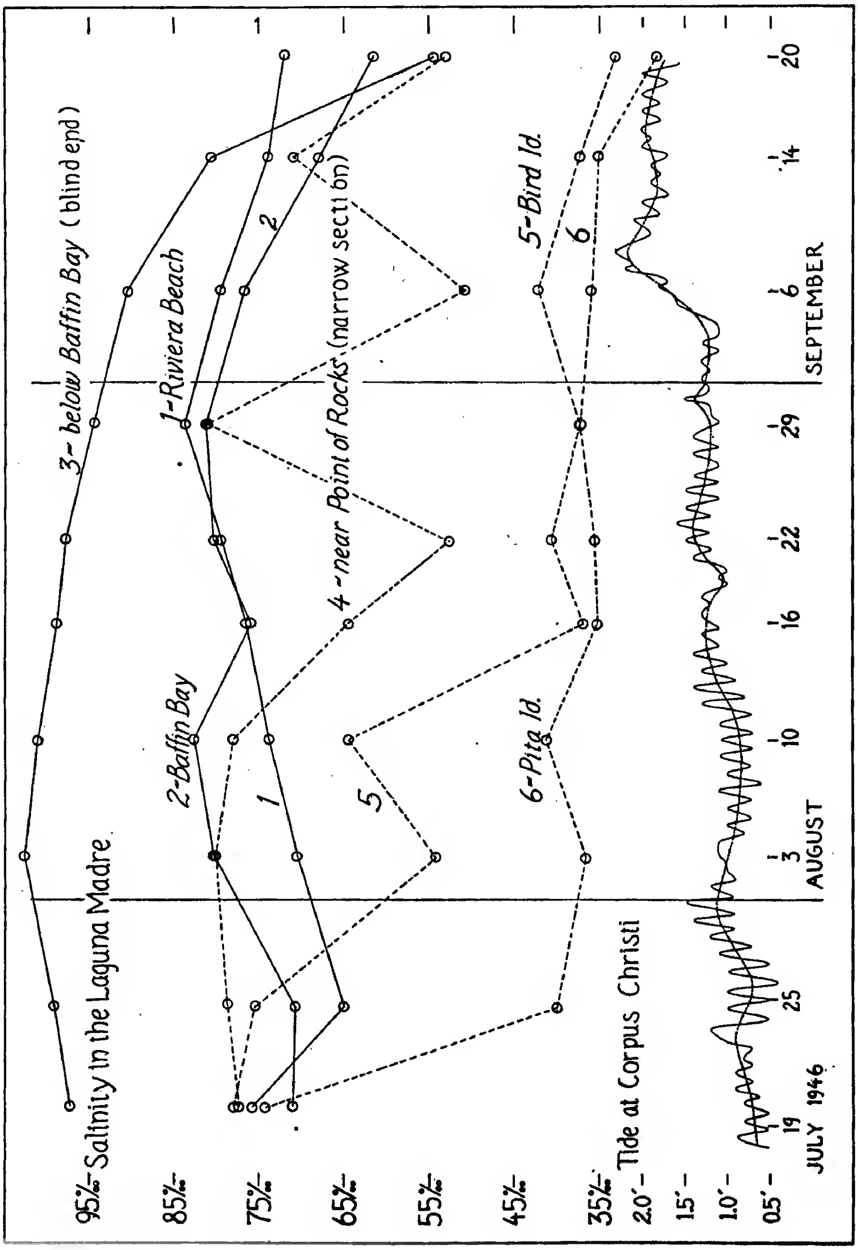

FIGURE 27

Salinity exchange by stations in the upper Laguna Madre, with daily tide at Corpus Christi. The tide curve is to staff gauge datum. To refer to mean low water subtract .83

tidal prism moving at the comparatively moderate speed of one knot (6,000 feet per hour) across the approximately five mile width of the Laguna at Corpus Christi Bay would move about 1,050 million cubic feet into the Laguna over a twelve hour period. As this is slightly more than 5% of the total volume, it is little wonder that the average salinity seldom falls below 45 0/00.

These computations are inspired by the construction of a solid fill causeway across the Laguna Madre just below Corpus Christi Bay, which will leave something less than half a mile of open water between this already oversaline body of water and Corpus Christi Bay. It would appear that even worse days are ahead for the Laguna when this causeway is completed (it was commenced early in 1949).

The annual drop in salinity in the Laguna during the high fall tides is evidently a regular occurrence of long standing. It was observed by Pearson during October, 1925, when average salinities dropped from 67 to 51 0/00, although he attributed this drop to heavy rainfall during September (the entire year was one of less than normal rainfall, however). Burr (1930) reported an overnight drop in salinity from 84.6 to 60 0/00 at Point of Rocks on September 12–13, 1930, after a high tide had covered the flats in that area. He attributed this 29% drop to the leaching of fresh water from subsurface of the tidal flats, as "no such dilution would have been possible had such tide been of daily occurrence." According to Alexander, Southgate and Bassindale (1932), the water retained in tidal subtrata is of higher salinity than the overlying water, and it is highly improbable that any great volume of fresh water can be found anywhere on the Laguna flats.

So far, all the salinity records available seem to be of samples taken at the surface, and it would be expected that salinities even a foot or two below the surface would be somewhat higher, in view of the great densities involved, as there is probably a well marked stratification between the tidal prism and the underlying water, especially from Point of Rocks southward. (Fig. 28.)

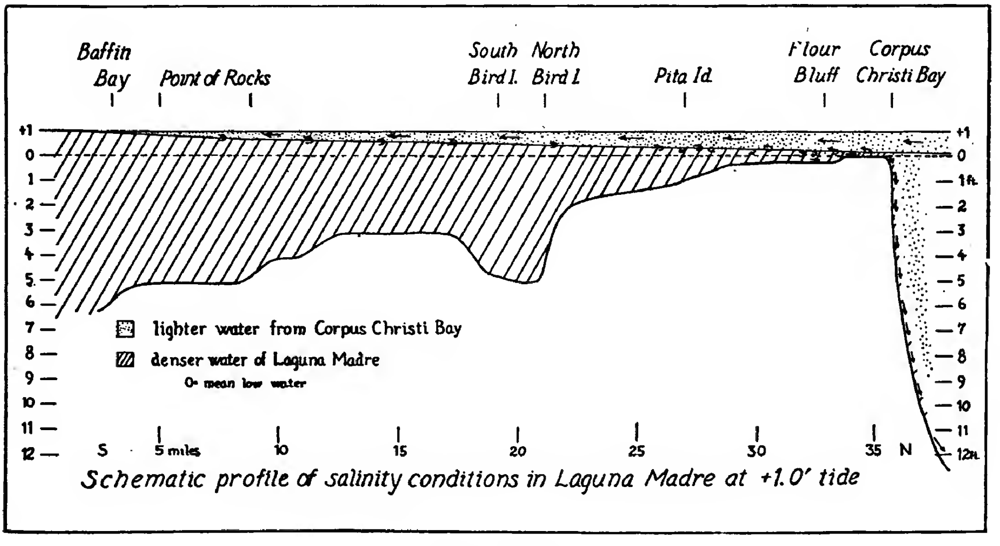

FIGURE 28

Schematic profile of upper Laguna Madre showing tidal prism

Phenomenally low salinities were observed in Baffin Bay in May and June of 1941 following the 6 and 10 inch rainfalls of April and May in the region. On May 21, it rained 5.51 inches at Corpus Christi, and surface salinities of 2.5 and 6.5 were observed on June 25 (Annual Report, Texas Game, Fish and Oyster Commission, Marine Laboratory, 1948). Salinities of near "normal" values were not recorded for nearly a year after this series of cloudbursts. Since these heavy rains occurred both at Alice and Corpus Christi, it is reasonable to assume that they were similar over the surface area of the Laguna in view of these reductions in surface salinities. Total precipitation for April and May at Alice and Corpus Christi were 16.48 and 17.84 inches, respectively.

IV. TIDES

Because most of the bays of the Texas Gulf Coast have highly restricted openings to the Gulf of Mexico, their tide levels in general reflect the average sea level for a given tidal regime in the Gulf. Their responses to tidal changes in the Gulf of Mexico are considerably dampened, and in order to get an insight into the biological significance of Gulf Coast tides it is necessary that these phenomena be studied in some detail.

The passes control the entrance of eggs, larvae, and juveniles of marine animals to the inner waters and their protected nursery and incubation areas. The relatively high current velocities of these passes (from a few tenths of a knot on equatorial tides to better than two knots on tropical tides) and their periodicities could influence the survival of a given year class considerably.

The flats and marshes available to the young, both as to area and time, are determined altogether by the nature of the tides.

It is not within the scope of this paper to present an exhaustive treatment of the theory of tides and its application as to why Texas coast tides are what they are. It is our purpose to briefly characterize the tides in the following pages in such a way that the material will be useful to the practicing marine biologist, and to point out certain phases which we feel to be worthy of further investigation.

A. Daily and hourly tides

The characteristics of the tides of this region are illustrated in figure 29. In this figure are plotted the declinations of the moon for midnight and noon (time adjusted to 97°W.) with the hours of each day of the new moon and perigee indicated for the period May 8–21, 1937. With these are plotted, on a two hourly basis, the tidal variations for Port Aransas, Rockport and Corpus Christi.

From the period May 8–14 inclusive (Port Aransas), there was one tidal cycle per 24 hour period, with a maximum range of 2.5 feet on May 11–12 when the moon reached its northernmost declination. Following this, we have the period May 15–20 with a tendency towards two tides per day, but of a very weak character, and almost no variation from noon on the seventeenth until noon on the eighteenth. From this it can be said that the diurnal sea tides of the Gulf Coast are of the mixed type with one low and one high per 24 hour period of maximum range (the above example 2.5 feet), and two highs and two lows per

24 hour period with a minimum range (in the above example 0.3 ft.) (see Marmer, 1932).

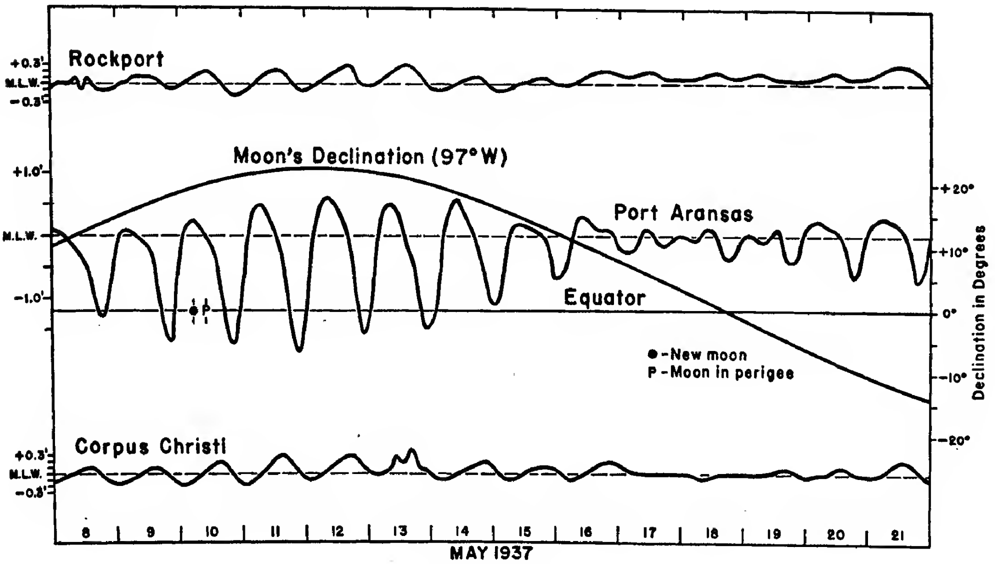

FIGURE 29

Characteristics of the tides of the Texas Gulf Coast

As distinguished from the sea tides represented by the curve for Port Aransas in figure 29 we have the estuarine tides represented by the curves for Rockport and Corpus Christi in the same figure. In both cases these curves represent a much dampened reflection of the sea tides, with almost a complete lack of periodic variations during the period of minimum range (May 15–19). In Aransas Bay, (Rockport curve) during the period of maximum range, the estuarine high is reached from 4 to 5 hours later than the corresponding high for the sea tide (Port Aransas), and the low from one to three hours later.

The above gives a general idea of the type of tides that can be expected in the inland coastal waters of the Gulf of Mexico and their relationship to the sea tides. This discussion is based on a given period according to actual observation, but is subject to wide quantitative deviation according to the degree of proximation of full or new moon, perigee and maximum declination. These are the dominant factors influencing the tidal variation and, of course, have been long recognized, and our main purpose in presenting this material at all is to demonstrate that in spite of wind and other local factors, the actual tides are in very close agreement with the theoretical values as they appear in the Tide Tables published by the U. S. Coast and Geodetic Survey.

B. The equatorial-tropical sequence

As pointed out above, there are two kinds of daily tide, and these can be designated as "tropical tides" and "equatorial tides," and these should not be confused with "spring" and "neap" tides. The "tropical tides" would be those of maximum range which occur as the moon reaches its maximum declination, north or south. The "equatorial tides" would be those of minimum range, which occur as the moon passes the equator. These are adequately demonstrated in figures 29 and 30. Again, as pointed out above, the exact range and nature of

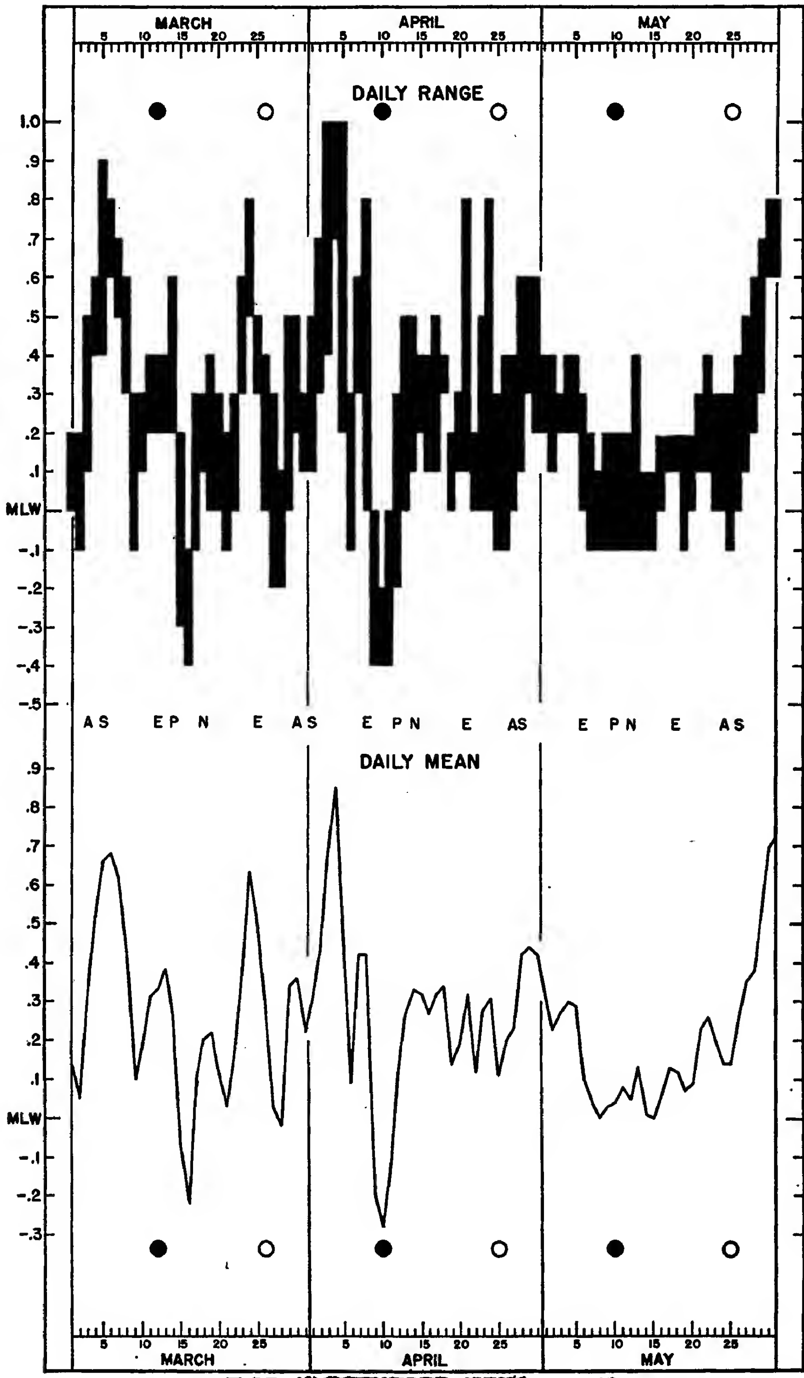

FIGURE 30
Tide at Rockport, Texas, March–May, 1937

the tropical-equatorial sequence varies according to the various relationships of the moon's position to the earth. These are reviewed here for the sake of clarity.

From the ecological point of view, the water level variation coincident with the cycle of tropical and equatorial tides is probably the most important so far as the lagoons are concerned. It is these variations which bring about the largest exchange of water between lagoon and Gulf, and which alternately expose and flood the greatest area of tidal flat and marsh.

C. Wind effects

Probably the most noticeable fluctuations in bay levels are those caused by the wind. At times, these are so striking that they have given rise to the general opinion that the tides in the bays are primarily "wind tides." Thus, one finds in the tide tables (*e.g.* for 1949, p. 197) the statement with reference to Port Aransas: "Inside, in the various bays, the periodic tide is negligible, the variation in water level depending principally on the wind." It is true that the effect of winds can vitiate any tidal predictions based on harmonic analysis, but the effect of the wind is more correctly evaluated if considered as a disturbance of the primary tidal forces which govern the fluctuations in bay levels.

The most obvious and easily demonstrated wind effect is that of the northers. These storms, in a matter of minutes, cause a complete change in direction and a reversal, sometimes as great as 200%, of the velocity of the wind. A diphasic swing, or seiche of roughly two hours duration, is set up by the impact of the norther, in which the rebound has twice the amplitude of the initial depression of bay level. This oscillation occurs in Aransas Bay about one hour before it does in Corpus Christi Bay. After this oscillation, which lasts about two hours, a secondary swing is observed in Corpus Christi Bay (fig. 31).

On these particular dates, there was no general fall in bay level after the onset of these seiches. Aransas Bay, in fact, became stabilized at a somewhat higher level. This is in part due to the tidal conditions at Port Aransas. On April 20–21 there was a semi-daily, equatorial tide, and on June 4 the tide at Port Aransas was falling until several hours after the norther struck, and then turned. When there is a strong daily type of tide at the flood stage when a norther hits, a different effect is observed, as on March 5. Here there occurs an erratic wobbling in the levels of the Aransas and Corpus Christi bays. Of course, it must also be pointed out that the change in direction and force of the wind was not as pronounced as on the other dates. Nevertheless, it seems apparent that a strongly rising tide will dampen to some extent the oscillation induced by the wind.

An example of the more usual and obvious effect of a sustained norther is represented in the curves for April 5. Here a steadily blowing norther has lowered the level of Aransas Bay against the strong tropic tide of the period. After a lowered level, Corpus Christi Bay became stabilized at midday, and maintained a steady level for the rest of the day. We would naturally expect the tide level of Aransas Bay to fall more conspicuously, since the outlet is at the southern end.

Another fluctuation, perhaps induced by variation in barometric pressure, is noticeable in Aransas Bay. This is a difference of about 0.1 ft. in level, possibly hourly in period. This, however, may be entirely local, reflecting some condition in the vicinity of the tide gauge. Since the barograph record is available only for Corpus Christi, it does not reflect immediate conditions over Aransas Bay.

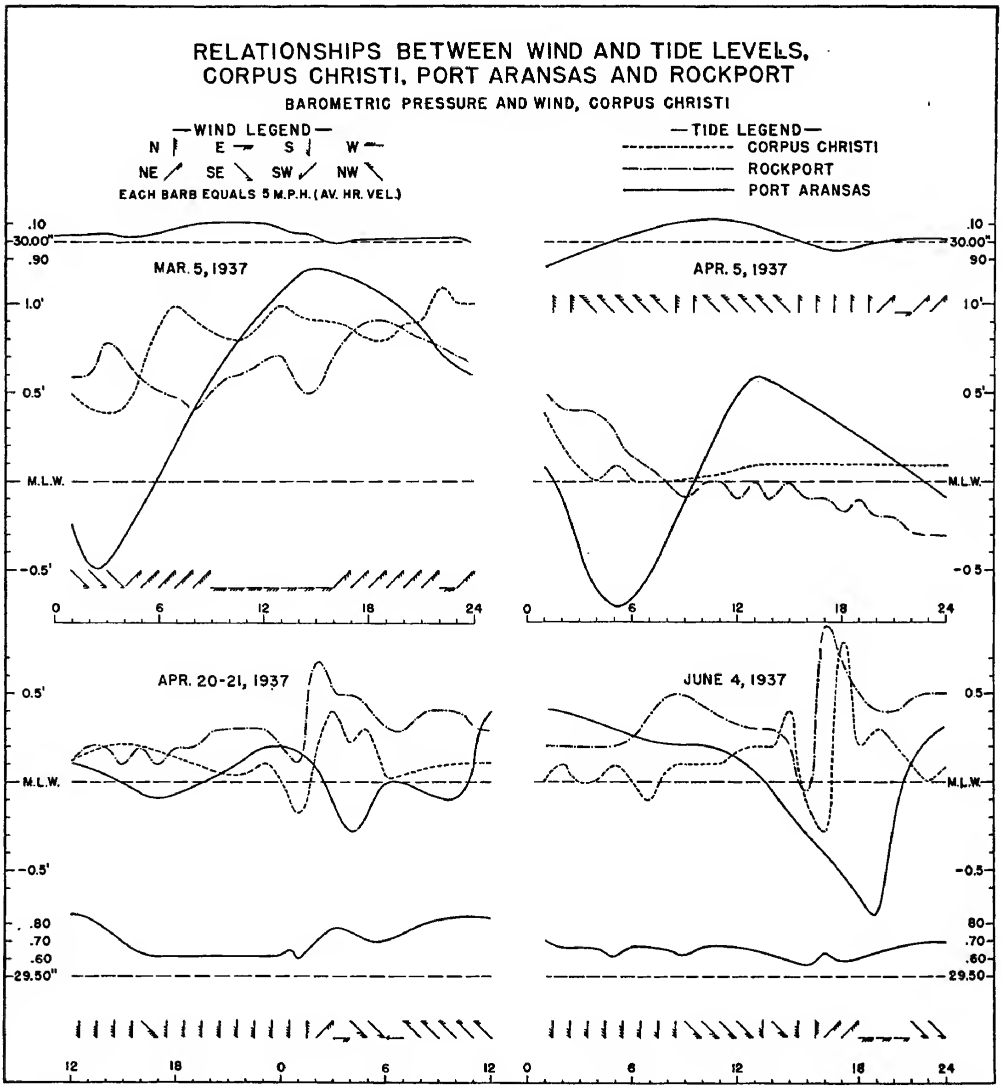

FIGURE 31

Relation between wind and tide levels,, Corpus Christi, Port Aransas and Rockport

It should be emphasized that the curves presented here are more or less a random sample. A thorough study of the relationships between wind and tide levels would doubtless add more interesting information and provide the basis for a more integrated generalization of conditions than is presented here.

One of the most pronounced, and unwelcome, wind effects is the hurricane tide. A small, localized hurricane came ashore at Port Aransas on June 27, 1936 (see

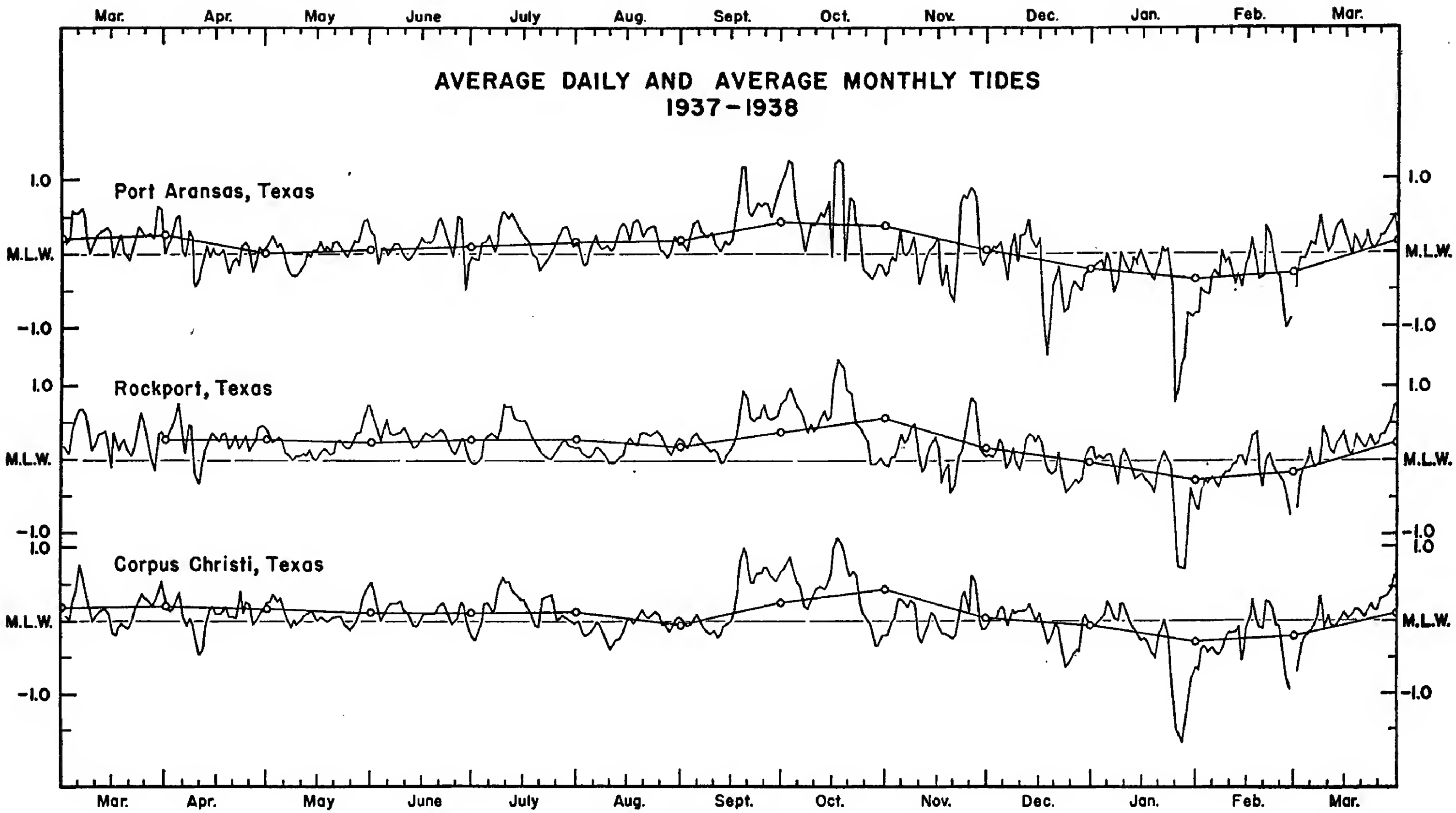

FIGURE 32

Average daily and average monthly tides, Port Aransas, Rockport and Corpus Christi, 1937–38 fig. 12), causing a pronounced rise in tide. A hurricane several hundred miles away will cause somewhat higher tides in this area, and a major storm may raise bay levels 15 or 16 feet (Tannehill, 1945). A tide of 16 feet occurred at Corpus Christi during the storm of 1919, and a high tide, possibly about 14 feet, occurred at Port Lavaca in 1945. In order to produce such high tides, the bay affected must be on the right of the storm path as the storm crosses the coast at right angles to the shore line. The hurricane tides are a result of the piling of water against that side of the bay which is facing the counter clockwise direction of the storm winds.

D. Seasonal sea level

Variations in average sea level through the year have long been noted and accredited to various causes (Marmer, 1926; Montgomery, 1937). Figure 32 illustrates the variation in the Aransas Bay region. The high levels observed during March and April for the spring months, and during September and October for the autumn, are spoken of as the "spring tides" and "fall tides" respectively by coastal inhabitants.

From the point of view of the coastal fisheries of the Gulf of Mexico, this phase of tidal study is as important as any. Some of the principal fisheries are dependent upon the young gaining the protection and nourishment offered by the tidal flats during the early days of their lives. The degree to which a given year class is successful might depend upon the extent, both spatial and temporal, to which the tidal flats and low marshlands are flooded. This is variable from year to year, and, so far as the authors can learn, this factor has not been studied in connection with annual fisheries production. It is suggested here that such a study might prove fruitful on the Gulf Coast.

V. SUMMARY

1. The Aransas Hydrographic System, a part of the shallow coastal lagoon and back bay complex of the tidal waters of Texas, and its contributing drainage area, is described. The total area of bays concerned is roughly 750 square miles, and the land drainage area is about 30,000 square miles.

2. This system is connected with the Gulf of Mexico through Aransas Pass, an artificially deepened and jettied inlet near the center of the Texas coast.

3. The lower part of this drainage area lies in the semi-arid climatic zone, the upper part mostly in the dry sub-humid, and a small part in the moist sub-humid zone.

4. Rainfall is erratic and shifty over the drainage area, frequently causing floods which reduce salinities in the bays. Annual precipitation in the area concerned is 26 to 30 inches, with high peaks in spring, and in September near the coast.

5. Evaporation exceeds precipitation over the area concerned during most of the year and there is an annual deficit of 25 to 50 inches from the coast toward the interior.

6. Salinity characteristics are estuarine, ranging from nearly fresh water at the river deltas to more than 30 0/00 in the pass. An exception to this is the Laguna Madre, where salinities are often over 80 and sometimes 100 0/00.

7. The annual temperature range in bay waters is around 25°C., with occasionally greater ranges in years of very cold winters. The waters are on the whole temperate rather than tropical.

8. Salinity exchange in the bays is more pronounced during the tropical tide periods, which have greater ranges than the equatorial tides. In the Laguna Madre the seasonal rise in sea level is the prime agent in bringing about salinity exchange between that body of water and Corpus Christi Bay.

9. The tide at Port Aransas is of the mixed type, with a regular progression of daily and semi-daily tides. Tides in the bay are similar but somewhat dampened and less in range and amplitude.

10. During the equatorial or semi-daily tides, the tide "vanishes" so that there is a continued stand above sea level.

11. There are pronounced differences in monthly sea level, with higher levels in the spring and autumn months.

12. Wind disturbances affecting tides are of two types: Northers, which set up a diphasic swing in bay levels when their impact is abrupt and forceful, or a continued depression of bay levels if sustained, and hurricanes, which pile up water as high as 15–16 feet in bays to the right of their course.

13. Tables of essential data, including monthly means of climatic and hydrographic factors and physical measurements of the bays, are presented.

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TABLE 4a

Salinity and Temperature Ranges and Averages, Corpus Christi and Harbor Island, Texas, 1922–23
(Computed from Graph, Atwood & Johnson, 1924)

	Corpus Christi				Harbor Island			
	°C		o/oo		°C		o/oo	
	Range	Average	Range	Average	Range	Average	Range	Average
1922								
November	15.2–25.0	17.7	5.0–28.5	19.2	13.8–26.5	18.6	17.7–30.0	24.5
December	7.7–22.2	16.6	14.0–28.0	21.1	10.8–24.1	17.7	21.5–31.5	25.5
1923								
January	10.0–20.0	16.1	23.5–27.5	26.0	12.7–21.6	18.8	25.0–34.0	31.4
February	5.0–18.3	14.7	5.0–28.0	23.0	4.4–22.7	15.5	15.5–25.0	21.3
March	7.2–22.7	16.3	0.5–21.5	10.0	7.7–23.3	17.7	21.5–30.5	27.2
April	12.7–26.6	22.7	1.5–11.0	7.7	14.4–28.3	23.0	20.5–27.0	22.6
May	24.4–29.4	26.6	9.7–18.5	16.6	23.8–28.3	25.5	21.0–33.5	26.7
June	23.8–27.2	25.5	20.2–24.0	22.2	28.3–30.5	29.1	27.5–33.7	30.5
July	26.6–27.7	26.6	22.9–28.0	24.5	28.3–30.0	28.9	26.0–37.0	32.5
August	26.6–28.3	27.2	20.5–30.0	26.7	27.7–28.8	28.6	26.5–38.2	36.4
September	24.4–26.6	26.1	2.5–29.2	15.4	23.8–29.4	27.7	29.0–37.0	32.8
October	15.5–26.6	23.3	3.5–22.5	15.9	15.5–29.4	22.2	17.5–30.5	25.0

TABLE 4b

Salinity and Temperature Ranges and Averages, Copano Bay and Aransas Bay—1936 and 1937

	Copano Bay						Aransas Bay					
	No. of Readings	°C Range	°C Average	No. of Readings	o/oo Range	o/oo Average	No. of Readings	°C Range	°C Average	No. of Readings	o/oo Range	o/oo Average
1936												
June	....	*	29.7	....	*	8.5		*	31.3	*	†12.5–28.0	17.4
July	....	*	29.3	....	*	4.2		*	29.2	200	1.8–29.7	7.4
August	....	*	30.1	....	*	5.8		*	30.6	*	† 6.0–34.0	17.0
September	15	28.5–30.0	28.8	29	3.8–10.9—19.0‡	7.3	19	28.5–30.5	29.8	38	12.7–30.1	18.1
October	97	15.0–26.8	21.8	108	5.4–10.1—13.4	7.2	150	15.2–26.5	22.0	152	3.7–30.1	17.0
November	120	12.8–16.9	14.4	119	6.0–13.0—22.6	7.6	204	10.6–18.1	14.8	204	5.4–31.7	13.8
December	90	15.0–19.8	16.6	89	7.1–24.5—26.2	10.1	116	11.8–22.0	15.7	120	12.0–33.1	20.4
1937												
January	58	12.2–19.0	15.6	58	7.6–14.0—15.8	10.5	124	7.5–17.0	13.7	124	8.8–34.7	19.2
February	48	10.9–17.6	13.3	47	9.9–15.5	11.3	136	10.5–16.1	13.8	133	11.3–26.2	16.7
March	105	10.1–19.4	15.3	118	10.6–14.2—15.9	11.7	145	10.0–20.3	15.7	168	12.1–31.0	17.8
April	118	14.2–24.8	20.1	118	11.4–15.8—16.1	13.0	166	15.0–26.0	20.4	168	12.9–29.5	20.5
May	120	23.5–27.5	25.5	120	12.5–18.0—19.0	14.6	168	23.5–28.6	25.3	168	16.7–34.0	24.3
June	30	26.2–27.5	26.7	30	14.8–19.9	16.7	42	26.2–27.5	26.6	42	20.4–30.9	25.5

*Data lost; averages from tabular summaries.
†Original field data lost; figures read from graphs.
‡Third figure is bottom salinity at St. 7.

TABLE 4c

Salinity and Temperature Ranges and Averages, Copano Bay and Aransas Bay—1938

	Copano Bay						Aransas Bay					
	°C			o/oo			°C			o/oo		
	No. of Readings	Range	Average	No. of Readings	Range	Average	No. of Readings	Range	Average	No. of Readings	Range	Average
1938												
January	8	18.6–19.8	19.1	8	7.3–14.4	10.5	38	14.8–19.4	17.0	39	16.2–32.7	20.4
February	....	....	....	....	....	....	13	11.2–13.4	11.8	12	15.8–27.1	21.4
March	8	17.4–18.2	17.8	8	8.4–14.9	11.2	31	17.4–20.8	18.8	31	11.3–25.4	19.8
April	16	19.8–25.8	22.4	17	9.9–25.4	13.3	52	17.0–24.8	21.3	57	14.8–34.0	20.8
May	4	26.0–26.6	26.4	4	4.4– 5.5	6.04	16	25.8–28.0	26.4	20	5.4–10.1	7.4
June	8	28.6–29.8	29.1	10	4.9– 7.02	6.1	36	28.0–30.2	28.9	48	4.4–22.7	12.9
July	8	29.0–29.4	29.1	10	6.09– 9.2	7.39	25	25.4–31.4	29.5	33	9.1–37.4	25.0
August	4	30.0–30.4	30.4	4	11.4–19.6	15.18	9	29.4–31.4	30.2	4	27.6–31.6	28.8
September	12	27.5–29.6	28.5	12	12.1–19.2	15.3	24	26.5–30.0	28.3	24	13.8–32.1	23.0
October	12	20.5–26.4	24.3	11	15.4–21.6	17.9	23	18.5–26.8	24.2	22	17.4–33.3	25.5
November	16	10.5–23.0	15.2	16	16.0–20.0	17.5	34	10.6–23.5	15.6	35	18.6–30.1	23.8
December	4	16.6–17.3	16.9	4	17.9–20.5	19.1	8	16.2–17.8	16.7	9	21.5–26.5	24.7

TABLE 4d

Salinity and Temperature Ranges and Averages, Copano Bay and Aransas Bay—1941 and 1942

	Copano Bay						Aransas Bay					
		°C			o/oo			°C			o/oo	
	No. of Readings	Range	Average	No. of Readings	Range	Average	No. of Readings	Range	Average	No. of Readings	Range	Average
1941												
March	....	....	....	....	....	....	4	17.2–19.5	18.1	4	9.8–18.0	12.8
April	4	21.0–22.0	21.5	4	10.0–11.2	10.6	2	23.0–24.0	23.5	2	17.3–23.0	20.2
May	5	27.2–30.0	28.0	6	2.0– 2.3	2.1	....	....	....	....	....	....
June	11	28.0–32.0	29.4	12	0.0– 5.0	2.7	10	28.2–33.0	30.7	13	1.8–18.3	6.4
July	13	28.0–34.0	29.6	13	2.1– 4.9	3.4	11	27.2–34.9	30.0	14	5.2–36.4	21.0
August	9	29.0–32.0	30.0	8	2.1– 6.3	2.8	6	26.6–33.0	28.9	7	13.2–37.2	27.1
September	14	27.1–30.5	28.8	13	3.7–12.7	8.7	17	28.5–32.0	29.6	17	17.1–37.1	28.0
October	14	23.0–31.3	21.7	14	6.6–11.6	9.8	17	25.4–28.5	27.0	18	14.0–30.7	18.7
November	14	14.9–23.3	19.0	14	8.4–13.7	11.3	18	14.4–27.0	19.4	18	13.3–30.1	19.9
December	13	14.6–19.5	16.8	14	10.0–12.4	12.1	17	14.0–22.5	16.1	18	12.1–27.4	19.0
1942												
January	14	12.3–17.5	14.9	14	10.2–13.9	12.0—	18	7.8–16.9	11.9	18	14.7–24.9	17.4
February	14	10.6–18.5	16.0	13	2.3–12.6	10.1	18	11.1–16.5	13.5	18	8.8–31.7	20.1
March	14	13.0–22.2	16.9	14	11.1–15.7	13.0	19	15.5–19.4	18.1	19	16.7–34.2	27.1
April	12	21.4–26.0	23.7	13	13.2–14.7	13.8	15	21.6–26.0	23.9	15	17.7–29.0	24.4
May	14	22.4–27.2	24.4	13	15.2–18.4	16.4	9	26.0–31.0	28.3	10	18.0–32.4	23.7
June	7	29.6–33.2	31.3	8	17.7–20.4	18.5	7	29.1–33.0	30.0	10	18.2–34.0	26.5
July	....	....	....	....	....	....	....	....	....	....	....	....
August	10	29.4–31.0	30.1	12	3.2– 5.7	4.5	16	28.4–32.0	30.4	16	9.1–35.6	22.9
September	....	....	....	....	....	....	....	....	....	....	....	....
October	5	20.2–25.8	22.8	5	3.3– 4.6	4.1	4	23.5–25.0	24.4	4	7.4–23.9	12.9

TABLE 4e

	Copano Bay						Aransas Bay					
	No. of Readings	°C Range	°C Average	No. of Readings	o/oo Range	o/oo Average	No. of Readings	°C Range	°C Average	No. of Readings	o/oo Range	o/oo Average
1946												
August	6	29.3–30.9	30.0	6	13.7–17.4	16.0	8	27.8–36.7	29.0	8	19.5–37.3	31.6
September	6	29.5–31.5	30.8	6	2.1–16.2	11.06	10	28.0–33.6	30.5	8	14.0–19.3	17.1
October	6	23.2–28.0	25.0	6	1.0– 8.1	5.03	9	21.2–31.5	25.0	8	6.4–14.6	10.9
November	6	13.5–16.5	14.2	6	4.1– 5.6	5.1	10	14.5–21.5	16.3	8	6.1–24.1	9.5
December	....	....	....	....	....	....	....	....	....	....	....	....
1947												
January	9	10.0–14.5	11.7	5	5.6– 8.9	7.6	10	11.0–14.5	12.3	6	9.5–23.3	13.2
February	1	21.8	....	4	8.3–10	9.05	3	14.0–23.5	19.6	5	9.2–27.2	14.2
March	....	....	....	5	9.3–10.4	9.8	....	....	....	8	9.1–18.4	13.9
April	10	20.5–25.4	23.8	10	9.9–11.8	10.6	12	20.5–25.2	23.2	12	11.4–30.4	17.9
May	19	21.5–26.5	25.0	21	9.8–16.5	12.0	16	18.4–28.2	24.6	24	11.5–31.8	19.5
June	17	27.3–30.4	28.2	18	8.3–15.0	12.2	12	24.6–36.0	26.5	20	13.1–33.0	19.9
July	5	29.2–29.6	29.4	10	9.5–16.6	13.1	3	29.4–34.5	31.1	2	17.1–19.7	18.4
August	....	....	....	....	....	....	....	....	....	....	....	....
September	....	....	30.6	8	15.4–19.7	17.1	....	....	30.3	4	20.8–25.4	24.0
October	....	....	27.6	8	16.9–19.3	18.4	....	....	26.6	5	18.0–24.1	22.0
November	....	....	23.0	14	13.1–24.7	19.4	....	....	19.9	10	19.4–31.3	22.8
December	....	....	....	....	....	....	....	....	....	....	....	....
1948												
January	....	....	17.1	8	14.4–18.3	16.4	....	....	16.1	4	18.6–23.1	21.8
February	....	....	12.2	7	15.9–21.9	18.5	....	....	9.7	5	21.4–36.6	27.5
March	....	....	17.5	7	17.4–21.4	19.3	....	....	17.1	5	22.7–23.3	23.1
April	....	....	25.2	7	20.7–25.0	22.5	....	....	24.0	6	25.0–35.6	29.9
May	....	....	27.6	5	21.8–29.0	24.7	....	....	28.4	6	25.4–29.1	27.6
June	....	....	29.6	12	24.3–32.2	28.6	....	....	29.8	17	28.3–38.5	33.2
July	....	....	30.6	12	26.7–33.3	29.9	....	....	29.7	16	26.6–38.0	31.9
August	....	....	31.1	10	31.3–36.3	33.4	....	....	30.1	21	32.3–39.5	36.8

TABLE 4f

Salinity and Temperature Ranges and Averages, 1946, 1947 and 1948

LAGUNA MADRE—NORTHERN PART

	No. of Readings	°C Range	°C Average	No. of Readings	o/oo Range	o/oo Average	No. of Readings	°C Range	°C Average	No. of Readings	o/oo Range	o/oo Average
1946												
July	12	29.0–35.0	30.1	12	40.0– 99.2	73.5	....	....	....	....	....	....
August	30	26.6–33.6	29.8	30	35.3–102.7	67.3	....	....	....	....	....	....
September	18	26.8–30.2	28.9	18	33.1– 90.5	58.0	....	....	....	....	....	....
October	12	24.8–26.5	25.5	12	24.2– 68.5	45.4	....	....	....	....	....	....
November	12	15.4–20.2	17.4	12	17.4– 61.2	42.0	....	....	....	....	....	....
December	24	11.0–21.0	16.9	24	22.1– 54.8	45.4	....	....	....	....	....	....
1947							1948					
January	24	4.0–20.0	11.7	24	24.1– 55.5	45.7	24	5.6–18.2	11.9	23	33.9– 62.2	50.7
February	18	11.6–15.0	13.7	18	27.2– 55.9	45.5	6	7.9–10.3	9.2	6	37.1– 55.3	49.2
March	30	11.0–21.5	15.6	30	26.9– 57.4	42.9	24	16.1–25.0	19.9	24	31.4– 60.4	45.2
April	24	21.0–28.5	24.4	18	30.0– 56.8	45.2	24	18.5–26.5	23.2	24	34.3– 60.6	49.2
May	24	25.8–29.0	27.7	24	30.5– 64.6	50.1	24	25.0–28.6	27.2	18	34.1– 74.2	54.4
June	24	28.2–31.0	29.4	24	33.0– 70.8	56.1	18	26.8–31.0	28.8	18	42.5– 70.8	62.2
July	24	28.0–31.1	29.9	24	37.6– 99.0	64.5	24	28.0–32.0	29.9	24	48.7– 82.3	66.1
August	24	28.0–31.5	29.9	24	32.1– 66.3	62.6	24	29.0–32.7	30.8	18	56.0–113.9	75.5
September	24	25.0–31.0	28.8	23	37.3– 72.0	60.0	....	....	....	....	....	....
October	30	25.1–28.2	26.6	30	36.3– 75.0	58.2	....	....	....	....	....	....
November	6	16.2–16.9	16.5	6	34.2– 58.9	48.3	....	....	....	....	....	....
December	18	10.3–25.5	16.8	18	31.3– 58.9	47.9	....	....	....	....	....	....

TABLE 5

Hydrographic Data—Aransas Bay—1936–37

Station	Level	1936 July 8 S°/oo	July 11 S°/oo	July 14 S°/oo	July 17 S°/oo	July 23 S°/oo	July 28 S°/oo	Aug. 2 S°/oo	August 31 T °C	August 31 S°/oo	September 19 T °C	September 19 S°/oo	October 8 T °C	October 8 S°/oo	October 12 T °C	October 12 S°/oo	October 19 T °C	October 19 S°/oo	October 27 T °C	October 27 S°/oo	November 5 T °C	November 5 S°/oo
1	Surface	5.5	....	2.7	3.9	....	5.7	8.2	28.25	16.8	30.5	13.8	24.5	13.9	23.0	10.0	26.2	10.8	17.5	10.0	15.4	9.9
	Bottom	5.8	7.8	3.9	4.0	....	5.9	8.3	....	16.9	....	19.0	25.1	16.0	22.8	10.4	....	25.3	17.9	12.3	14.8	10.2
3	Surface	10.1	6.2	3.7	4.0	4.7	6.6	7.8	27.75	18.4	28.5	12.7	25.0	17.7	22.0	11.0	25.0	10.4	18.0	13.3	14.0	10.4
	Bottom	10.2	6.2	4.1	5.1	4.7	6.8	8.8	....	19.3	....	22.7	26.2	18.1	22.0	11.6	25.3	16.0	19.0	13.4	14.6	10.4
4	Surface	10.1	6.5	4.7	4.0	4.4	9.0	8.0	28.0	18.8	28.5	12.9	25.0	18.5	22.0	12.0	25.0	14.0	18.2	12.7	14.0	10.4
	Bottom	10.1	6.9	5.2	5.6	4.7	8.8	19.0	....	21.0	....	21.5	26.0	18.6	21.8	12.2	25.4	16.2	18.8	12.8	14.2	10.7
5	Surface	9.9	6.9	5.3	4.5	5.1	10.2	15.8	27.75	18.8	28.5	13.9	25.2	20.6	22.0	12.9	25.3	16.3	18.6	12.5	14.5	15.3
	Bottom	10.1	7.0	5.4	5.6	5.3	27.5	29.0	....	22.2	....	16.2	25.2	20.0	21.8	12.3	25.6	24.3	18.6	12.5	14.0	19.0
6	Surface	10.1	7.1	5.6	4.4	5.7	16.7	21.3	28.0	21.2	28.5	13.7	25.5	21.7	22.0	12.2	25.3	16.0	17.8	12.5	14.5	16.5
	Bottom	10.1	7.0	5.8	5.3	7.8	28.6	31.8	....	23.1	....	30.1	26.0	22.2	21.9	12.6	25.2	26.5	18.6	12.8	14.8	21.2
7	Surface	13.0	7.7	9.8	6.1	7.7	13.6	19.2	27.25	23.0	29.0	26.3	25.0	24.3	22.1	16.4	25.2	17.0	16.5	16.0	13.0	20.8
	Bottom	14.8	13.0	14.4	11.1	7.8	29.7	29.2	....	25.1	....	29.0	25.4	25.5	22.2	17.5	25.3	27.0	16.6	19.6	15.9	28.2
8	Surface	18.0	16.2	9.5	9.0	9.0	13.2	20.6	27.0	29.3	29.5	24.3	25.0	21.8	21.8	16.2	25.3	18.8	17.0	15.0	11.8	19.7
	Bottom	18.1	14.8	13.7	11.6	9.0	17.3	21.0	....	30.5	....	28.4	24.9	21.8	21.5	17.5	25.3	19.0	17.3	14.9	11.7	20.0
9	Surface	11.1	7.3	5.1	5.2	5.4	6.6	8.8	27.25	21.5	29.5	15.4	24.5	17.5	21.6	11.6	25.4	12.9	17.5	9.8	14.2	10.7
	Bottom	11.5	7.5	5.3	4.7	5.2	15.8	28.6	....	21.4	....	23.1	24.4	17.9	21.5	12.2	25.7	20.7	16.1	9.9	15.5	11.1
10	Surface	12.4	6.6	5.4	4.1	5.3	6.3	7.5	27.25	23.2	29.75	15.9	23.8	15.6	23.1	11.2	25.6	7.3	16.8	8.0	11.5	9.2
	Bottom	12.3	11.4	6.9	5.2	5.1	5.6	14.4	....	....	....	15.6	23.8	15.8	21.1	11.0	25.7	14.5	15.8	8.6	13.5	9.4
11	Surface	13.6	....	6.7	6.4	7.2	7.4	7.2	27.25	23.0	30.5	24.0	23.0	16.8	22.5	11.6	26.2	13.4	15.5	8.3	14.0	13.3
	Bottom	13.7	13.0	11.1	9.4	7.2	7.3	7.5	....	9.5	....	25.1	24.2	16.6	21.9	13.9	26.2	14.0	15.2	11.2	10.6	14.5
12	Surface	14.5	9.4	10.4	7.4	7.7	7.6	7.9	26.75	23.2	30.5	21.7	24.0	16.9	23.0	14.0	26.5	13.8	16.4	12.3	11.8	15.2
	Bottom	14.6	13.7	11.3	8.5	7.7	7.6	7.9	....	23.8	....	26.3	24.0	16.9	21.8	14.4	26.4	14.0	15.3	13.6	11.4	15.2
13	Surface	8.3	....	4.9	4.3	4.7	6.0	7.8	27.25	18.9	29.25	18.9	24.0	13.9	22.8	10.2	25.6	12.4	18.2	9.0	14.5	9.7
	Bottom	10.3	6.7	5.3	5.2	4.5	5.6	17.9	....	22.7	....	22.5	24.5	14.2	22.3	10.9	25.0	10.9	17.8	12.1	14.8	12.1
14	Surface	7.2	....	5.4	3.7	4.0	6.0	7.5	27.25	19.2	29.0	19.4	....	....	23.0	10.0	25.5	10.6	18.0	7.1	14.0	6.6
	Bottom	10.6	5.2	5.3	5.3	3.9	5.6	12.2	....	22.3	....	22.7	....	....	21.6	10.4	25.0	11.0	18.0	11.7	14.8	11.9
15	Surface	9.5	5.8	4.9	3.6	3.9	5.0	7.6	27.0	17.2	29.25	21.5	....	....	23.5	10.2	26.0	9.1	17.0	4.3	13.2	5.8
	Bottom	11.0	8.7	6.4	3.7	4.0	5.2	12.1	....	24.4	....	23.4	....	....	22.6	11.0	25.0	9.4	17.0	4.3	14.2	10.5
16	Surface	6.4	5.2	5.6	4.1	....	4.7	7.1	27.25	15.9	29.5	16.5	....	....	23.0	9.3	26.2	8.8	17.2	3.9	14.0	5.8
	Bottom	10.2	9.5	7.3	3.2	....	5.0	9.6	....	25.3	....	23.8	....	....	22.9	10.5	25.0	9.4	17.0	3.9	15.2	11.7
17	Surface	....	....	1.8	2.7	....	5.1	7.8	27.5	17.2	30.0	13.5	....	....	22.7	6.3	26.3	8.8	15.5	3.7	13.8	5.4
	Bottom	....	6.7	7.1	2.8	....	5.2	8.9	....	24.0	....	21.9	....	....	22.7	11.2	26.3	8.7	18.4	11.2	15.1	9.9
19	Surface	....	....	2.7	3.2	....	5.5	7.6	27.25	13.8	30.0	14.4	22.5	10.9	23.0	8.4	26.4	8.3	17.0	8.5	14.0	6.4
	Bottom	....	....	3.1	4.0	....	5.9	7.6	....	17.6	....	20.2	23.4	14.6	22.3	9.8	25.6	8.3	17.2	9.4	14.8	7.0
20	Surface	....	....	2.3	2.8	....	5.5	7.0	28.0	13.8	30.5	13.1	22.8	14.4	23.0	8.1	26.0	9.4	17.6	10.2	14.9	7.5
	Bottom	....	....	5.3	2.8	....	5.2	7.0	....	17.6	....	16.2	23.8	15.1	23.3	9.6	....	10.8	17.7	10.4	14.0	7.5
21	Surface	8.0	....	3.4	4.9	....	5.7	7.5	27.5	18.9	29.5	15.0	24.8	16.4	20.3	11.4	25.6	11.7	18.8	11.9	15.0	11.9
	Bottom	9.5	6.5	6.9	5.1	....	14.0	17.1	....	26.5	....	21.2	24.8	16.4	21.2	12.6	25.3	21.5	18.8	12.0	14.7	12.3
22	Surface	....	....	....	....	....	....	....	....	....	....	....	25.0	23.6	23.0	13.1	25.4	14.8	17.4	11.9	14.0	17.0
	Bottom	....	....	....	....	....	....	....	....	....	....	....	25.4	23.6	22.8	14.0	25.2	28.8	17.9	11.7	16.0	30.0
23	Surface	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
	Bottom	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

TABLE 5 (Continued)

Hydrographic Data—Aransas Bay—1936–37

		November 10		November 16		November 23		November 30		December 17		December 21		December 29		January 5		January 12		January 17	
		T °C	S°/oo	T °C	S°/oo	T °C	S°/oo	T °C	S°/oo	T °C	S°/oo	T °C	S°/oo	T °C	S°/oo	T °C	S°/oo	T °C	S°/oo	T °C	S°/oo
1	Surface	14.2	11.3	16.5	10.9	13.0	12.0	16.3	11.6	13.8	16.5	16.0	12.5	19.6	17.5	15.4	17.1	10.0	12.4	15.3	16.9
	Bottom	13.5	10.9	16.4	10.9	13.6	14.1	16.7	12.8	13.4	17.7	14.3	14.6	20.0	17.7	15.5	20.7	10.5	13.2	15.2	16.5
3	Surface	14.0	12.3	16.0	11.5	15.0	14.4	15.5	12.8	13.0	19.0	13.9	14.4	19.3	20.5	15.0	20.4	9.5	15.9	14.6	16.6
	Bottom	14.0	12.3	16.8	11.2	14.9	14.0	16.9	18.4	11.8	19.4	14.0	14.6	19.3	20.4	14.8	20.9	9.5	18.2	15.5	16.3
4	Surface	13.8	12.0	16.0	11.3	15.0	14.0	15.5	13.0	12.5	19.4	13.5	14.8	20.3	20.9	15.2	22.5	9.5	16.2	16.0	17.0
	Bottom	13.8	12.0	16.0	11.6	14.9	14.4	17.8	15.4	12.2	21.3	13.8	17.9	19.2	21.0	14.0	21.7	9.5	16.1	15.4	17.4
5	Surface	13.9	12.8	15.8	11.3	14.5	14.8	15.5	14.5	12.7	21.6	13.0	16.2	19.4	21.4	15.4	24.7	9.5	15.8	16.0	17.7
	Bottom	14.0	13.3	15.7	11.5	14.7	14.5	17.9	32.5	12.8	20.5	14.4	29.3	19.0	21.3	13.3	28.6	9.5	17.3	15.4	17.5
6	Surface	14.0	13.3	15.5	11.0	14.8	13.4	15.6	14.8	12.3	21.7	13.4	17.9	19.2	22.1	15.3	23.0	9.4	15.8	14.8	18.3
	Bottom	13.8	13.3	15.8	11.3	14.8	13.6	17.9	22.9	13.2	21.9	15.2	33.1	19.1	22.6	13.4	23.4	9.5	17.1	15.3	18.4
7	Surface	13.0	19.5	16.1	15.9	13.5	20.7	16.3	22.3	13.0	22.1	14.0	21.3	19.7	26.6	15.0	25.7	8.0	25.3	15.5	26.6
	Bottom	13.3	21.7	16.4	16.9	14.0	24.0	18.1	31.7	13.0	26.4	15.1	23.9	19.5	29.4	14.6	28.3	9.0	25.4	16.0	26.6
8	Surface	14.0	24.1	16.6	17.9	14.0	22.4	16.5	24.0	12.3	22.8	14.0	21.3	20.0	31.3	15.0	29.7	7.5	24.3	15.5	26.6
	Bottom	14.5	24.1	16.5	21.3	14.0	21.5	17.7	25.7	12.7	22.6	14.4	22.3	19.4	31.4	16.0	34.7	7.5	25.4	15.5	26.6
9	Surface	14.1	10.8	15.5	11.3	14.5	11.9	15.8	14.4	12.5	20.0	14.0	15.7	19.2	25.0	15.2	23.8	9.0	13.4	15.0	17.8
	Bottom	14.8	10.8	15.4	11.3	14.8	11.9	16.8	14.1	12.8	21.7	15.4	29.2	19.3	30.2	15.7	23.3	9.3	16.8	15.0	17.9
10	Surface	12.5	8.3	16.8	11.6	12.0	9.9	16.5	13.7	12.9	18.3	14.5	16.6	19.5	25.9	15.3	21.1	7.0	12.4	15.5	17.8
	Bottom	12.2	8.3	16.3	11.6	12.8	10.8	16.4	13.6	12.5	18.4	13.9	17.8	19.3	29.7	16.7	20.3	8.5	12.3	15.4	17.8
11	Surface	12.6	10.4	17.0	11.3	12.8	11.9	16.5	13.7	13.0	16.2	....	....	19.8	26.0	15.1	20.7	8.6	13.2	15.7	18.3
	Bottom	12.5	10.8	17.0	12.9	12.8	12.4	16.4	14.1	12.6	17.5	....	....	19.2	28.9	16.5	21.2	8.7	24.0	16.2	18.0
12	Surface	13.2	13.6	17.0	11.7	13.0	13.7	17.0	15.2	13.7	16.3	....	....	20.1	29.0	15.0	23.7	8.5	23.2	17.0	18.3
	Bottom	12.6	13.7	17.0	11.9	13.0	13.7	16.8	18.8	13.6	15.9	....	....	19.6	28.9	15.7	25.7	8.5	23.6	15.7	18.4
13	Surface	14.0	9.6	16.5	14.2	14.2	10.9	15.9	14.1	12.5	25.8	15.2	13.7	19.0	22.4	15.5	18.9	10.5	10.8	14.5	18.4
	Bottom	14.1	11.7	16.0	21.0	14.8	10.8	17.1	19.4	16.2	20.0	13.9	17.7	19.4	28.5	15.5	21.9	10.7	16.1	15.1	26.6
14	Surface	14.0	8.8	15.5	14.1	14.3	9.6	15.8	12.4	13.2	27.7	15.6	13.6	22.0	28.5	....	....	11.0	11.1	15.0	18.3
	Bottom	14.0	11.2	15.6	21.7	14.7	10.2	17.0	22.4	12.6	15.3	15.0	17.1	19.3	25.3	....	....	10.7	17.4	14.5	23.3
15	Surface	13.8	7.4	15.2	18.6	14.0	7.3	17.0	11.7	13.2	14.7	15.1	14.0	19.0	23.4	15.2	14.5	10.5	....	15.0	24.3
	Bottom	13.7	9.5	15.3	20.8	13.9	6.7	16.3	17.0	12.7	14.5	16.0	16.0	19.0	23.5	15.4	18.3	10.5	17.4	14.5	22.4
16	Surface	14.0	7.8	16.0	14.6	13.8	6.5	16.5	13.8	13.0	14.0	15.1	13.4	19.1	21.8	15.0	12.3	10.5	10.4	15.1	16.1
	Bottom	13.9	10.0	15.4	20.5	13.8	6.5	16.5	22.3	12.0	13.7	14.1	15.7	19.0	21.8	15.4	19.2	10.4	17.7	14.6	24.1
17	Surface	14.3	9.0	16.0	11.3	13.8	6.0	17.0	10.4	13.0	12.3	16.0	14.2	19.5	19.7	15.1	25.9	9.5	8.8	15.8	15.4
	Bottom	13.7	9.5	15.2	16.5	14.0	6.1	16.2	21.7	12.5	12.8	14.4	16.5	19.3	19.6	15.2	21.2	12.5	18.1	15.2	15.5
19	Surface	14.0	11.2	16.5	11.0	14.0	10.7	15.4	12.7	....	....	15.0	12.1	19.0	15.7	15.2	15.3	10.5	11.5	15.0	16.1
	Bottom	13.9	11.5	15.9	13.4	14.0	10.8	16.7	12.1	....	....	13.8	15.9	19.6	22.3	15.4	21.9	12.5	16.7	14.9	15.1
20	Surface	13.1	10.0	16.3	10.2	14.0	12.4	16.3	11.3	13.2	15.3	....	12.0	19.0	15.4	15.3	16.6	10.5	12.4	15.0	14.9
	Bottom	13.0	10.4	16.1	10.8	14.6	12.4	17.3	23.4	13.4	16.0	....	16.7	19.8	23.0	....	16.5	12.4	12.9	15.0	15.0
21	Surface	14.3	11.1	15.8	11.2	15.0	13.3	15.3	13.7	12.5	16.5	....	15.8	19.5	21.0	16.4	20.7	9.5	16.1	15.5	15.5
	Bottom	14.2	10.7	15.5	11.3	15.1	13.2	17.8	21.7	12.4	24.5	....	17.8	19.1	30.2	16.0	20.8	9.5	16.3	15.0	17.7
22	Surface	14.0	11.7	15.4	11.2	14.5	12.5	15.2	14.6	12.5	21.6	15.0	27.0	19.2	22.5	15.2	24.7	9.0	14.5	15.0	21.1
	Bottom	14.4	12.0	15.7	11.7	14.5	13.7	17.3	30.6	13.2	27.9	15.4	34.6	19.0	28.4	14.0	26.6	12.2	15.9	15.7	22.8
23	Surface	....	....	....	....	14.0	10.2	16.5	11.9	12.8	26.9	17.0	13.3	19.7	15.9	15.3	15.8	10.5	11.9	15.1	16.6
	Bottom	....	....	....	....	13.9	11.5	17.5	25.3	12.3	14.6	14.3	16.6	19.6	23.4	16.0	20.9	12.4	18.6	14.9	19.9

TABLE 5 (Continued)

Hydrographic Data—Aransas Bay—1936–37

		February 1		February 4		February 11		February 17		February 22		March 2		March 8		March 22		March 31	
		T °C	S‰	T °C	S‰	T °C	S‰	T °C	S‰	T °C	S‰	T °C	S‰	T °C	S‰	T °C	S‰	T °C	S‰
1	Surface	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	Bottom	----	----	----	----	----	----	15.7	15.9	16.0	17.1	13.5	16.3	18.5	15.4	18.0	14.9	11.0	17.0
3	Surface	----	----	----	----	----	----	15.0	17.0	16.1	16.7	13.5	16.3	17.4	16.1	----	15.2	11.1	17.1
	Bottom	14.0	17.0	----	----	13.0	17.7	15.0	18.3	15.5	20.3	15.0	17.5	19.0	16.3	19.0	16.5	14.0	19.2
4	Surface	14.3	17.5	----	----	13.5	20.1	15.6	18.6	15.4	20.1	15.1	18.3	19.1	16.3	----	16.5	14.0	19.1
	Bottom	14.5	18.3	----	----	----	----	15.0	17.8	15.8	19.4	15.5	17.8	19.0	16.7	19.2	18.3	13.5	19.1
5	Surface	14.1	17.4	----	----	----	----	15.1	18.2	15.4	19.4	15.1	17.7	19.0	16.8	----	18.8	13.3	19.2
	Bottom	14.5	19.1	----	----	13.0	19.7	15.0	17.9	15.5	20.7	15.0	19.9	19.0	17.4	19.0	19.6	13.5	19.0
6	Surface	14.1	18.3	----	----	12.9	23.4	15.2	18.0	15.3	20.7	15.1	22.1	19.0	17.7	----	21.3	13.4	19.5
	Bottom	14.5	18.2	----	----	----	----	15.0	18.4	15.1	20.8	15.4	18.6	18.8	17.7	18.8	22.9	13.5	20.7
7	Surface	14.1	17.3	----	----	----	----	14.9	18.7	15.2	20.9	15.2	24.3	18.0	17.5	----	23.0	13.5	20.5
	Bottom	16.0	23.3	----	----	----	----	15.1	16.5	15.0	22.3	14.5	21.2	19.5	19.0	19.2	24.5	13.5	19.9
8	Surface	16.0	23.2	----	----	----	----	15.2	23.2	15.7	26.2	16.3	24.9	19.5	22.3	----	24.6	13.0	20.5
	Bottom	16.0	25.3	----	----	12.0	24.9	----	----	14.5	24.7	15.5	21.7	19.5	21.3	19.2	24.2	12.6	21.6
9	Surface	16.0	25.1	----	----	12.9	25.5	----	----	15.1	----	14.4	21.9	20.0	21.5	----	24.3	12.4	21.7
	Bottom	14.6	19.1	----	----	13.0	19.4	15.0	17.5	16.0	21.5	15.0	17.9	18.5	17.5	19.0	19.0	13.5	19.0
10	Surface	14.3	18.9	----	----	12.8	20.3	15.4	18.7	15.5	21.3	15.1	17.8	18.4	17.1	----	18.8	14.0	18.0
	Bottom	14.3	18.6	----	----	----	----	15.5	17.4	15.2	20.3	15.0	19.0	20.0	16.5	19.0	17.7	12.6	17.1
11	Surface	14.3	18.6	----	----	----	----	15.1	18.3	15.2	20.4	15.3	18.7	19.4	17.4	----	17.8	13.0	17.9
	Bottom	14.5	18.4	----	----	----	----	15.5	17.0	15.2	19.7	15.0	19.0	20.3	17.3	19.4	17.5	13.5	17.7
12	Surface	14.3	18.6	----	----	----	----	15.5	18.7	14.9	19.7	15.3	18.3	19.4	17.3	----	17.5	13.2	18.0
	Bottom	16.0	18.7	----	----	12.0	19.6	15.0	17.0	15.0	20.0	15.5	16.5	20.2	16.6	19.6	19.5	13.0	18.2
13	Surface	15.9	18.8	----	----	12.0	19.9	15.1	18.7	14.3	20.1	15.4	16.6	19.0	16.5	—	19.7	13.1	18.2
	Bottom	----	----	----	----	----	----	15.5	17.0	15.2	19.1	14.5	18.0	18.1	16.4	18.1	17.4	13.2	17.3
14	Surface	----	----	----	----	----	----	15.5	17.4	16.1	20.1	16.3	18.3	18.0	17.4	----	17.1	11.2	17.7
	Bottom	----	----	11.0	15.3	13.4	15.8	15.5	14.6	15.2	16.6	14.3	18.3	18.6	17.4	18.1	17.8	11.0	17.3
15	Surface	----	----	11.0	14.9	14.0	15.8	15.5	17.4	16.1	17.9	16.3	18.3	18.0	16.8	----	17.5	11.4	17.1
	Bottom	----	----	----	----	----	----	15.5	14.0	15.7	15.6	14.5	17.9	18.5	16.7	18.3	17.7	11.5	15.2
16	Surface	----	----	----	----	----	----	15.4	16.7	15.7	15.0	15.3	17.9	18.3	17.3	----	17.7	12.5	16.1
	Bottom	----	----	10.8	12.8	14.0	15.0	15.6	13.4	15.2	15.0	14.0	17.3	19.0	17.3	18.5	16.5	12.5	14.1
17	Surface	----	----	11.2	12.7	14.0	16.2	15.1	16.5	15.1	14.9	15.2	17.3	18.2	16.7	----	16.9	11.3	15.3
	Bottom	----	----	----	----	----	----	15.5	13.4	15.3	14.4	14.0	16.3	19.2	15.0	18.1	15.7	12.5	12.1
19	Surface	----	----	----	----	----	----	15.1	14.5	15.2	----	15.3	17.1	18.4	15.9	----	16.2	11.3	16.2
	Bottom	----	----	----	----	----	----	15.5	13.2	16.0	13.2	13.6	15.7	18.0	13.7	18.0	15.4	10.0	14.0
20	Surface	----	----	----	----	----	----	15.7	12.5	15.1	13.4	14.0	15.4	18.0	14.1	----	15.0	11.0	14.5
	Bottom	----	----	11.5	12.4	14.0	14.1	15.5	13.4	16.0	14.1	14.0	15.3	18.0	14.0	18.0	14.6	10.5	15.9
21	Surface	----	----	13.0	12.7	16.0	13.6	14.9	14.4	16.1	14.2	13.4	16.1	18.0	14.0	----	14.6	11.0	15.9
	Bottom	14.5	17.3	----	----	13.5	18.8	15.0	16.9	15.6	20.7	14.5	17.8	18.5	17.1	18.4	17.9	13.5	16.7
22	Surface	14.3	17.7	----	----	12.7	19.0	15.2	----	15.6	20.0	14.4	17.7	17.4	----	----	17.8	12.3	18.6
	Bottom	14.6	18.6	----	----	12.5	21.5	15.0	19.1	15.5	21.0	----	31.0	19.0	17.0	18.5	25.5	13.5	20.4
23	Surface	14.0	18.6	----	----	12.1	22.3	15.0	19.1	15.2	21.0	----	30.9	19.3	17.0	----	26.5	14.0	20.9
	Bottom	----	----	10.5	12.5	14.0	14.2	15.6	13.4	15.7	14.9	14.0	15.7	19.3	13.6	18.4	16.2	12.0	13.3
		----	----	11.0	11.3	14.0	14.6	15.5	14.8	15.7	14.9	14.1	15.5	20.2	15.0	----	16.2	11.3	14.5

Table 5 (Continued)

Hydrographic Data—Aransas Bay—1936–37

		April 7		April 13		April 22		April 26		May 3		May 10		May 17		May 24		June 2	
		T °C	S°/oo	T °C	S°/oo	T °C	S°/oo	T °C	S°/oo	T °C	S°/oo	T °C	S°/oo	T °C	S°/oo	T °C	S°/oo	T °C	S°/oo
1	Surface	15.5	14.9	18.8	15.0	24.5	16.5	21.5	17.9	24.2	19.4	25.2	22.8	24.6	22.3	27.0	23.6	26.5	20.9
	Bottom	15.2	16.6	19.8	15.2	24.0	19.0	21.8	19.7	24.7	19.4	24.6	22.6	24.4	22.3	26.9	23.6	26.6	21.1
3	Surface	18.0	19.0	20.2	20.9	26.0	20.4	22.0	20.0	25.3	21.7	26.3	23.6	25.7	24.3	28.0	27.2	27.2	23.5
	Bottom	18.0	18.8	20.4	20.9	25.2	20.3	22.0	24.0	25.1	21.7	26.2	23.4	25.7	24.1	28.0	27.2	27.2	23.5
4	Surface	18.0	20.5	20.2	22.1	25.6	22.3	22.3	26.2	25.2	23.0	26.3	20.3	25.6	24.2	28.0	28.0	27.2	23.5
	Bottom	17.5	21.1	20.6	22.6	25.0	22.3	22.0	24.9	24.6	23.0	26.2	25.5	25.8	24.1	28.0	28.0	27.1	23.5
5	Surface	17.6	20.8	20.2	26.1	25.5	22.3	22.2	28.0	25.3	23.4	25.2	28.6	25.6	25.7	28.0	29.3	27.2	23.8
	Bottom	17.4	24.5	20.2	26.5	25.0	22.0	22.0	28.0	24.6	25.5	25.8	28.6	25.2	27.2	28.0	29.3	27.2	23.8
6	Surface	18.0	23.0	20.0	28.0	25.5	22.8	23.0	28.4	25.4	26.1	25.8	30.4	26.2	28.9	28.0	29.5	27.3	25.3
	Bottom	17.2	27.1	20.0	28.0	25.2	22.4	22.8	28.3	24.5	26.7	24.2	31.2	25.4	28.9	28.0	29.5	27.2	25.4
7	Surface	18.4	24.1	20.5	26.5	25.5	24.9	22.0	26.3	25.5	26.1	26.2	27.9	26.4	30.0	28.3	30.5	27.3	31.6
	Bottom	18.5	26.6	21.0	27.4	25.2	24.9	22.2	26.2	25.6	26.1	26.2	27.9	26.3	28.8	28.2	30.4	27.2	31.4
8	Surface	19.4	23.3	20.7	24.6	26.0	25.0	22.0	25.4	25.3	27.1	26.7	27.2	26.5	28.4	28.3	31.2	27.5	30.9
	Bottom	19.5	23.6	20.7	24.6	25.3	26.3	22.2	25.1	25.3	27.0	26.7	27.1	26.4	28.4	28.3	31.0	27.4	30.6
9	Surface	18.3	18.8	20.3	22.9	25.0	21.9	22.0	26.3	25.6	22.3	26.5	25.1	25.7	25.0	27.5	26.8	27.0	28.9
	Bottom	19.4	25.9	20.3	25.0	24.0	22.4	22.0	26.2	25.6	22.8	25.0	30.0	25.5	30.0	27.8	27.0	27.3	29.1
10	Surface	18.0	18.8	19.6	19.0	25.3	23.0	21.5	22.1	25.5	23.7	26.6	23.4	26.0	24.3	28.0	27.4	25.8	27.8
	Bottom	18.6	19.4	19.9	19.4	25.0	23.2	21.5	22.4	25.3	23.4	26.4	23.3	25.6	24.3	27.5	28.0	25.9	28.0
11	Surface	18.5	19.7	20.4	22.8	25.5	22.4	21.2	22.8	25.8	23.0	26.7	23.3	26.5	24.2	28.0	27.9	26.3	28.7
	Bottom	18.8	20.0	20.3	23.6	25.0	22.6	21.6	22.8	25.4	23.3	26.5	23.2	26.0	24.2	28.0	27.8	26.4	28.6
12	Surface	18.7	20.5	20.6	21.6	25.0	21.1	21.6	22.0	25.6	21.7	26.0	22.1	26.6	23.8	28.6	26.8	26.6	27.8
	Bottom	19.0	19.6	20.6	22.8	25.0	21.3	21.6	21.7	25.7	21.9	25.2	22.4	26.1	23.0	28.6	27.1	26.5	28.2
13	Surface	18.5	17.8	19.9	18.3	23.8	19.6	22.0	20.9	25.1	21.3	25.6	21.5	25.6	24.0	27.7	25.8	26.7	23.4
	Bottom	19.8	18.0	19.8	18.6	23.6	20.0	21.8	20.8	24.0	21.5	25.6	22.4	25.0	25.3	27.2	25.7	26.8	28.2
14	Surface	18.4	17.5	20.0	17.4	24.6	18.7	22.0	17.4	24.5	20.9	25.6	20.5	25.8	24.2	27.5	24.2	26.7	24.0
	Bottom	19.8	18.2	19.8	17.4	24.6	19.0	21.6	17.7	24.1	21.2	25.6	21.5	25.2	24.6	27.1	24.3	26.9	26.6
15	Surface	18.6	17.8	19.9	17.8	25.0	16.5	22.0	16.9	26.5	20.0	26.0	18.0	25.5	22.0	27.8	20.0	26.6	25.0
	Bottom	18.5	17.9	19.8	17.5	24.0	16.6	21.9	17.4	24.3	20.0	25.2	19.2	25.2	22.5	26.7	20.8	26.4	26.6
16	Surface	18.0	16.2	20.0	17.4	24.6	16.1	22.5	17.7	26.3	19.1	26.0	17.8	25.5	20.0	27.5	19.5	26.6	23.7
	Bottom	18.8	16.2	19.8	17.8	24.0	16.1	22.2	17.7	24.5	19.5	25.6	19.1	25.2	20.0	27.3	19.7	26.4	24.1
17	Surface	18.0	16.3	20.0	17.4	24.6	16.3	22.5	17.7	25.0	18.7	25.7	17.4	25.6	20.0	27.2	19.2	26.6	23.6
	Bottom	18.8	17.8	20.4	17.1	24.0	16.1	22.2	17.7	24.6	19.6	26.0	17.8	24.8	20.1	27.1	19.2	26.4	23.3
19	Surface	16.7	13.7	19.8	15.3	24.0	15.3	21.2	16.1	23.5	16.7	24.9	17.4	24.2	18.8	26.8	18.2	26.2	23.0
	Bottom	15.5	12.8	19.8	15.3	23.8	15.5	21.4	16.1	23.8	17.7	24.5	17.7	24.2	19.2	26.6	18.2	26.2	23.4
20	Surface	15.8	15.5	20.0	14.8	24.0	15.4	21.3	16.1	24.0	18.0	25.0	19.9	24.2	18.6	26.9	20.0	26.3	21.7
	Bottom	15.0	15.5	20.0	14.9	23.5	17.3	21.4	16.7	24.3	19.1	24.8	19.9	24.6	21.2	26.8	20.0	26.3	21.9
21	Surface	18.0	17.7	20.7	19.5	....	20.8	22.3	22.1	25.5	20.3	25.8	22.0	26.4	27.0	27.7	26.3	26.7	24.0
	Bottom	18.8	17.9	20.9	19.7	....	21.1	22.3	22.0	24.5	20.9	25.6	21.7	25.5	28.2	27.3	26.3	26.8	27.4
22	Surface	17.6	26.7	20.5	29.2	25.2	22.8	22.6	29.5	25.0	27.2	25.6	33.8	26.1	31.6	28.0	32.1	27.5	27.9
	Bottom	17.4	28.4	20.6	29.4	24.6	23.7	22.6	29.5	24.6	27.2	24.8	34.0	25.4	31.8	27.9	32.0	27.4	27.8
23	Surface	18.5	15.4	20.0	14.5	25.0	15.9	22.6	18.6	26.0	17.9	25.7	17.9	25.2	20.7	27.5	19.1	26.7	21.9
	Bottom	18.7	15.5	20.4	14.6	24.0	15.8	22.5	17.3	25.2	19.7	26.0	17.9	25.5	20.9	27.5	19.0	26.8	20.4

Table 6

Hydrographic Data—Copano Bay—1936–37

		1936 Sept. 21		Oct. 9		Oct. 13		Oct. 20		Oct. 28		Nov. 6		Nov. 11		Nov. 17		Nov. 23		Dec. 1	
		°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo
1	Surface	28.5	8.1	22.3	10.8	23.0	6.8	26.0	8.0	17.0	8.6	13.8	6.4	13.8	10.3	16.2	9.9	14.0	10.2	15.5	21.6
	Bottom	....	19.0	22.8	11.7	23.3	13.4	24.8	11.3	16.9	8.7	14.3	6.9	14.2	22.6	15.8	13.4	14.7	10.0	16.8	26.2
2	Surface	28.5	7.2	22.1	9.6	22.8	7.9	26.0	8.0	17.4	8.2	14.5	....	13.5	9.5	16.1	9.2	13.8	9.1	15.5	12.0
	Bottom	....	10.9	22.8	12.2	22.3	10.1	25.6	7.8	17.5	8.2	....	6.9	15.0	13.0	15.9	10.9	14.3	9.1	16.8	24.5
3	Surface	29.5	8.4	....	....	24.2	7.6	26.0	7.3	17.0	6.7	15.5	6.1	13.0	7.7	16.3	8.2	13.5	7.7	15.5	9.5
	Bottom	....	8.3	....	....	23.1	8.1	....	7.5	17.1	6.4	14.0	6.1	13.4	7.1	15.9	8.7	13.9	7.7	15.5	8.9
4	Surface	28.5	6.3	....	....	24.3	8.3	25.6	7.5	17.5	6.7	15.3	6.2	13.0	7.1	16.5	8.4	13.8	7.8	15.6	8.5
	Bottom	....	6.4	....	....	23.7	8.5	....	8.5	17.8	6.7	14.0	6.5	13.6	7.7	16.2	8.7	13.6	7.8	15.4	8.3
5	Surface	29.5	7.4	....	....	23.4	6.0	25.8	6.0	16.6	6.1	14.0	6.4	13.0	6.4	16.3	7.8	13.5	7.1	15.5	7.9
	Bottom	....	7.5	....	....	23.3	7.0	....	5.8	16.5	6.1	13.4	6.6	13.5	7.1	15.5	7.9	13.8	7.3	15.2	8.3
6	Surface	29.25	5.6	....	....	23.2	6.0	25.5	7.8	16.5	6.5	13.6	5.8	12.8	7.1	16.7	7.9	13.8	7.1	15.4	7.8
	Bottom	....	6.3	....	....	22.5	6.4	....	6.4	16.6	6.5	13.2	6.4	12.7	6.6	15.5	7.4	14.2	6.9	15.4	7.8
7	Surface	29.5	....	22.3	6.2	23.5	6.2	23.3	6.7	16.8	6.5	13.6	6.5	12.7	7.0	16.5	6.7	13.5	6.6	15.6	7.7
	Bottom	....	6.3	22.0	6.3	21.9	6.0	....	6.2	16.6	6.2	13.4	6.0	12.6	7.0	15.6	7.3	14.0	6.7	15.5	7.7
8	Surface	30.0	3.8	22.6	5.4	23.5	5.9	25.5	5.8	16.5	6.5	13.5	6.0	13.0	6.7	16.3	7.0	14.0	6.7	15.5	7.3
	Bottom	....	6.4	22.3	5.4	22.9	5.9	....	6.0	16.3	6.5	13.4	6.0	12.9	6.7	16.0	6.4	13.7	7.4	15.8	7.1
9	Surface	29.75	4.4	22.5	6.3	23.4	6.6	25.2	6.0	16.1	7.1	13.0	6.6	12.5	6.9	16.8	7.4	13.5	6.9	16.2	7.5
	Bottom	....	5.5	22.2	6.8	22.2	6.3	....	6.5	16.1	7.1	13.0	6.7	12.5	6.9	15.9	7.7	13.7	7.4	16.2	7.7
10	Surface	29.0	8.4	21.5	5.9	23.2	7.0	25.2	6.8	16.0	6.9	12.9	6.6	12.5	6.6	16.8	7.5	13.0	7.4	16.2	7.9
	Bottom	....	5.5	21.3	6.2	22.4	7.1	....	6.8	15.0	6.9	12.8	6.4	12.7	6.9	16.0	7.4	13.7	7.3	16.2	8.2
11	Surface	29.5	5.7	21.8	6.6	22.7	7.0	25.0	7.3	16.0	7.0	13.0	6.5	12.8	8.5	16.9	7.9	13.0	7.5	16.3	9.0
	Bottom	....	6.2	21.6	6.8	21.7	7.1	....	6.8	15.1	7.1	13.2	6.4	12.6	8.5	16.6	8.3	13.4	7.8	15.2	8.8
12	Surface	30.5	5.8	21.6	7.7	23.3	7.2	26.5	7.4	15.5	6.6	14.5	6.5	13.0	7.4	16.5	8.3	13.5	8.2	16.3	8.8
	Bottom	....	7.0	21.4	7.9	22.5	10.6	26.0	7.5	15.6	9.5	....	6.6	13.9	7.4	16.8	8.1	13.8	7.8	16.0	9.5
13	Surface	30.0	5.4	21.6	6.2	22.5	7.5	26.5	7.5	15.9	7.1	13.6	6.4	13.0	8.3	16.8	7.9	13.0	7.8	16.4	9.0
	Bottom	....	5.4	21.6	7.5	21.5	7.6	26.1	7.8	16.0	7.3	14.5	7.1	13.9	8.7	16.7	8.2	13.2	7.9	16.3	8.8
14	Surface	29.5	8.7	....	....	23.0	6.8	26.0	6.4	17.0	6.4	14.2	6.5	13.0	6.5	16.8	7.9	13.5	6.6	15.7	8.1
	Bottom	....	8.7	....	....	21.6	6.3	....	7.8	16.7	6.4	13.5	6.4	13.3	6.4	16.0	8.2	13.7	6.9	15.2	7.9
15	Surface	29.5	8.3	....	....	23.5	6.3	26.3	6.8	17.0	6.2	15.0	6.4	13.0	6.4	16.5	8.2	14.0	6.7	15.1	7.9
	Bottom	....	8.5	....	....	22.6	6.3	....	7.5	16.8	6.4	13.8	6.7	13.2	6.4	15.9	7.9	13.2	6.7	15.0	7.8

TABLE 6 (Continued)

Hydrographic Data—Copano Bay—1936–37

		Dec. 23		Dec. 29		Jan. 7		Jan. 17		Feb. 4		Feb. 11		Feb. 22		March 2		March 8		March 22	
		°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo
1	Surface	16.3	10.7	19.0	16.4	....	....	12.6	13.0	....	....	....	....	16.4	12.8	13.5	13.3	18.0	12.7	18.0	14.4
	Bottom	15.9	11.9	19.8	18.8	....	....	12.5	15.8	....	....	....	....	16.3	13.3	13.5	12.9	17.4	13.2	....	14.4
2	Surface	15.5	10.9	18.9	15.3	17.5	13.6	12.5	12.4	11.0	13.4	14.6	12.5	16.1	12.2	13.5	11.9	18.2	12.4	18.0	14.2
	Bottom	15.6	12.7	19.7	17.1	17.2	13.6	10.8	14.0	11.8	13.4	13.9	12.7	16.1	15.5	13.3	12.8	18.0	12.4	....	14.0
3	Surface	15.5	10.3	18.9	11.5	17.2	10.2	13.0	10.6	....	....	....	....	17.6	11.5	14.0	10.9	19.0	11.6	18.0	....
	Bottom	15.7	10.8	19.5	11.5	17.0	10.8	13.4	11.5	....	....	....	....	17.1	12.8	14.2	10.9	19.4	11.7	....	11.7
4	Surface	16.0	9.4	19.0	10.8	17.5	13.2	12.5	10.4	....	....	....	....	17.6	11.3	14.0	11.6	19.0	10.9	18.0	11.7
	Bottom	15.9	10.6	19.5	10.8	17.3	13.8	12.4	11.5	....	....	....	....	17.3	11.2	14.1	11.5	19.4	11.3	....	11.6
5	Surface	16.0	9.5	19.5	9.6	17.5	10.2	12.5	10.3	....	....	—	—	17.0	10.3	14.0	10.9	18.8	10.7	17.8	11.3
	Bottom	15.9	9.6	19.8	10.4	17.5	7.6	13.1	10.3	....	....	....	....	16.4	10.8	14.3	10.8	18.4	10.7	....	11.6
6	Surface	15.6	9.5	18.8	9.4	18.0	10.0	12.2	9.8	11.5	10.3	14.0	10.9	17.0	10.8	14.0	11.2	18.5	10.9	18.0	10.9
	Bottom	15.4	9.1	19.2	9.2	17.8	10.0	12.7	9.6	11.8	9.9	14.3	10.9	17.1	10.8	14.3	11.3	18.4	11.2	....	10.9
7	Surface	15.5	9.0	18.9	9.1	17.5	8.3	12.2	9.0	11.0	10.4	14.5	10.7	17.0	10.6	13.5	11.3	18.5	10.8	18.0	10.8
	Bottom	15.5	9.0	19.4	8.8	17.4	9.5	12.3	9.0	12.0	10.4	14.5	10.7	16.3	10.6	14.0	10.7	18.3	10.6	....	10.7
8	Surface	15.4	8.6	19.0	8.7	17.6	8.6	13.0	9.0	....	....	....	....	16.6	10.6	14.0	10.4	18.3	11.3	17.9	11.1
	Bottom	15.5	8.5	19.7	8.7	17.4	9.0	13.5	8.8	....	....	....	....	16.3	10.6	14.3	10.6	18.2	11.2	....	10.9
9	Surface	15.5	8.7	19.0	8.4	19.0	9.4	13.6	9.1	....	....	....	....	16.5	10.6	13.5	10.7	18.2	11.3	17.6	11.2
	Bottom	15.6	9.1	19.4	8.4	18.1	8.4	13.2	9.1	....	....	....	....	16.1	10.4	14.0	10.8	18.2	11.3	....	11.1
10	Surface	16.0	9.4	19.0	8.2	18.8	9.3	14.0	9.6	....	....	....	....	16.5	10.8	13.5	11.3	18.5	10.8	18.0	11.5
	Bottom	15.9	9.5	19.5	8.2	18.0	8.4	13.5	9.6	....	....	....	....	16.1	10.7	13.4	11.3	18.2	11.3	....	11.5
11	Surface	16.0	9.6	19.4	9.1	19.0	11.3	14.0	10.6	....	....	....	....	16.5	11.1	13.4	11.7	18.2	11.6	17.6	11.9
	Bottom	15.8	....	19.3	8.9	18.4	11.3	14.0	10.7	....	....	....	....	16.1	11.2	13.4	11.9	18.2	....	....	11.5
12	Surface	16.9	10.4	19.4	9.7	19.0	13.0	13.5	11.1	....	....	....	....	....	....	13.5	11.7	18.0	....	17.8	12.0
	Bottom	16.9	11.0	19.7	9.9	18.6	13.4	14.0	11.2	....	....	....	....	....	....	13.4	11.7	18.2	11.7	....	12.0
13	Surface	16.3	10.0	19.5	9.6	18.3	12.7	14.0	11.2	11.0	11.9	15.0	11.7	16.8	11.3	13.5	11.7	18.2	12.4	17.7	11.7
	Bottom	16.1	10.2	19.3	9.5	18.2	10.0	14.0	11.1	10.9	12.3	14.0	....	16.2	11.3	13.4	11.9	18.2	12.1	....	11.5
14	Surface	15.8	10.0	19.0	10.3	17.3	8.8	12.4	10.8	....	....	....	....	17.0	11.0	14.0	10.7	18.5	10.9	18.0	11.2
	Bottom	15.6	9.6	19.8	9.8	17.3	8.8	12.6	10.9	....	....	....	....	16.4	11.0	14.3	10.6	19.0	10.8	....	11.2
15	Surface	15.9	9.4	18.9	9.5	17.5	8.6	12.6	10.8	10.9	10.4	14.0	11.5	17.2	10.8	14.0	10.8	18.8	11.2	18.0	11.3
	Bottom	15.8	9.4	19.6	10.1	17.2	9.5	12.5	10.8	12.0	10.4	14.1	11.3	17.2	11.2	14.1	10.9	19.2	10.9	....	11.3

Table 6 (Continued)

Hydrographic Data—Copano Bay—1936–37

		March 31		April 5		April 13		April 22		April 26		May 3		May 10		May 17		May 24		June 1	
		°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo
1	Surface	10.5	14.2	17.0	13.3	20.0	16.1	23.5	15.0	21.0	15.9	24.5	15.9	24.9	16.6	24.2	16.2	26.8	17.0	26.2	16.9
	Bottom	10.3	15.9	16.2	13.3	20.0	15.9	23.4	14.8	20.8	15.9	24.1	16.1	24.2	17.0	24.3	17.7	26.5	19.0	26.4	18.4
2	Surface	10.6	13.4	17.3	13.2	20.1	14.4	24.0	14.4	21.5	15.5	24.3	14.9	25.0	14.6	24.6	15.8	27.0	16.3	26.5	16.5
	Bottom	10.1	13.4	17.0	13.2	19.9	15.0	23.8	14.4	21.2	15.4	24.3	16.3	24.6	15.5	24.4	16.5	26.8	16.3	26.3	19.9
3	Surface	12.3	11.6	17.2	13.0	20.0	14.2	24.8	14.8	21.5	15.0	26.0	15.2	26.0	15.9	25.2	16.5	27.6	17.0	27.5	19.4
	Bottom	11.3	12.1	16.4	12.8	19.8	15.8	24.2	15.0	21.4	14.9	25.4	15.5	25.5	17.1	25.2	16.5	27.6	18.0	27.3	19.5
4	Surface	11.5	12.1	17.0	12.7	20.1	13.3	25.0	13.4	21.5	13.6	26.6	14.4	25.5	14.8	25.2	15.0	27.5	15.0	27.5	15.9
	Bottom	11.5	12.1	16.9	12.7	19.8	13.2	24.6	13.2	21.6	14.9	25.3	15.3	26.4	14.2	25.6	15.0	27.5	15.0	27.3	16.1
5	Surface	12.0	11.6	17.0	12.0	19.8	12.7	24.6	13.0	21.6	12.7	26.5	12.8	25.5	13.8	25.0	15.0	27.1	16.5	27.2	18.0
	Bottom	11.4	11.7	17.2	11.9	20.0	12.4	24.6	13.2	21.2	12.5	24.4	12.8	25.6	14.1	24.9	15.0	26.9	16.3	26.6	18.4
6	Surface	11.5	11.7	17.0	12.5	19.8	12.5	24.0	12.4	21.5	13.2	24.6	12.5	25.5	13.6	25.0	14.5	26.9	15.4	27.0	16.9
	Bottom	11.2	11.6	17.0	12.3	19.9	12.4	23.8	12.5	21.5	13.8	24.6	12.9	25.6	14.2	24.9	15.0	26.8	16.2	26.8	17.3
7	Surface	11.5	11.5	16.0	11.9	19.6	11.7	24.2	12.1	21.2	12.4	25.5	12.7	25.1	13.2	24.9	13.4	27.1	13.7	26.3	15.2
	Bottom	12.0	11.9	16.2	11.6	19.8	11.4	23.8	12.4	21.3	12.4	24.5	12.5	25.4	13.6	24.6	13.4	27.0	13.6	26.5	15.9
8	Surface	11.0	11.9	16.5	11.6	19.6	11.7	24.0	12.3	21.5	12.4	25.5	12.7	25.4	13.4	24.8	13.4	27.2	13.4	26.6	14.8
	Bottom	12.0	12.0	14.6	11.7	19.8	13.3	23.6	12.3	21.4	12.3	24.3	12.7	25.4	13.2	24.6	13.3	27.0	13.3	26.4	14.8
9	Surface	11.2	12.1	15.5	11.7	19.6	11.7	24.4	12.1	21.3	12.8	24.6	13.0	25.2	13.0	24.5	13.2	26.7	14.6	26.5	15.4
	Bottom	12.0	12.0	14.2	11.6	19.6	12.1	24.4	11.9	21.2	12.6	24.7	13.0	25.1	12.9	24.4	13.2	26.6	14.6	26.5	15.4
10	Surface	11.0	13.3	16.3	11.9	19.7	11.9	24.5	12.0	21.1	13.0	24.8	12.7	25.0	13.2	24.7	13.4	26.5	14.2	26.5	14.9
	Bottom	11.3	13.4	15.2	11.5	19.7	12.0	24.3	12.3	20.9	13.2	24.1	13.3	24.8	13.2	24.5	13.3	26.5	14.5	26.4	15.3
11	Surface	10.6	13.2	15.5	12.7	19.8	12.0	24.0	12.5	21.3	14.0	23.5	13.4	25.0	13.6	24.3	14.2	26.6	15.0	26.6	15.7
	Bottom	11.1	13.6	14.6	13.0	19.4	11.7	24.2	12.5	21.2	14.1	23.9	13.7	24.6	14.6	24.4	14.4	26.6	15.2	26.5	15.5
12	Surface	10.5	12.8	16.0	12.5	20.0	12.9	23.8	12.9	21.3	14.4	24.1	14.0	24.8	14.1	24.2	14.5	26.6	14.6	26.6	15.7
	Bottom	11.0	12.8	16.2	12.4	20.2	12.9	23.8	12.9	21.3	14.2	23.6	14.1	24.7	13.2	24.3	14.5	26.6	14.8	26.4	15.9
13	Surface	10.5	13.2	15.3	12.9	19.9	12.0	....	....	20.3	13.8	24.0	14.0	24.7	13.8	24.5	14.4	26.7	15.0	26.6	15.7
	Bottom	11.1	13.3	14.5	13.2	19.3	12.0	....	....	20.5	13.8	23.9	14.0	24.2	13.2	24.2	14.4	26.5	15.0	26.6	15.7
14	Surface	12.5	11.2	17.5	11.7	20.2	12.9	24.6	14.0	22.0	12.8	26.7	13.2	25.6	13.3	25.0	16.5	27.3	16.5	27.0	18.3
	Bottom	12.0	11.2	16.5	11.7	19.8	13.0	23.8	12.7	21.2	12.8	25.2	13.7	25.3	13.3	24.9	16.5	27.2	16.3	26.8	18.2
15	Surface	12.2	11.5	17.4	12.8	20.0	13.0	24.5	13.8	21.5	13.3	26.6	14.1	25.4	15.4	25.0	16.7	27.5	16.6	27.1	18.2
	Bottom	12.0	11.9	16.6	12.3	19.8	13.3	23.6	14.0	21.1	13.2	25.1	14.8	25.4	15.5	24.9	16.7	27.3	16.6	27.0	18.8

TABLE 7

Hydrographic Data, Laguna Madre (Northern Half). Surface Records*

	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6	
	°C	o/oo	°C	o/oo	°C	o/oo	°C	o/oo	°C	o/oo	°C	o/oo
1946												
July 19	31.2	75.6	30.2	71.0	31.2	97.2	32.6	77.4	35.0	77.9	33.0	74.3
25	29.0	65.0	29.4	70.7	30.2	99.2	29.6	78.7	30.8	75.4	29.6	40.0
Aug. 3	30.2	70.5	30.6	80.3	30.8	102.7	30.6	80.0	31.6	54.4	30.6	36.6
10	30.2	73.8	30.2	82.7	31.3	101.2	32.0	78.0	33.6	64.6	33.6	41.3
16	29.4	76.5	30.4	76.0	31.2	94.0	30.4	64.6	30.4	36.9	29.4	35.3
22	28.0	79.4	28.0	80.3	28.2	90.4	28.0	52.7	28.0	40.6	26.6	35.6
29	28.8	83.7	28.6	81.2	29.2	91.1	28.6	81.0	28.6	37.2	28.8	37.2
Sept. 6	28.0	79.5	29.6	76.6	30.2	90.5	30.0	50.7	30.2	42.1	29.8	35.9
14	29.8	73.7	29.8	67.8	29.6	80.6	29.2	70.8	29.5	37.3	29.6	35.1
20	28.0	72.0	27.8	61.4	27.7	54.4	28.2	53.0	27.4	33.1	26.8	28.3
Oct. 2	24.8	68.5	25.2	64.4	26.5	36.0	26.2	33.8	24.8	24.2	25.4	24.9
17	25.6	55.1	25.0	58.4	25.8	55.1	26.4	52.8	26.0	39.9	25.6	32.7
Nov. 7	18.8	47.2	20.2	58.4	20.0	61.2	19.4	52.5	18.4	22.5	18.4	17.4
29	15.4	53.5	16.0	52.8	16.0	52.8	16.0	50.7	15.4	23.7	15.4	23.2
Dec. 5	15.3	52.7	15.8	50.0	15.4	45.8	16.2	48.9	14.8	27.6	16.0	28.7
12	20.6	50.8	20.8	49.6	21.0	51.2	20.8	51.7	20.0	44.3	19.8	35.5
20	12.8	51.5	14.2	52.1	13.2	50.0	12.2	46.8	11.0	31.2	11.8	22.1
27	20.0	54.8	21.2	52.1	22.0	54.2	21.8	51.0	20.2	46.3	20.2	41.7
1947												
Jan. 6	4.0	56.8	4.0	48.9	4.3	46.8	4.2	50.6	4.2	24.1	4.0	24.1
19	9.4	54.8	11.2	52.8	10.4	49.1	10.3	51.9	10.0	36.7	9.6	29.4
25	16.0	52.3	16.5	54.0	19.0	51.4	20.0	50.9	16.2	41.4	16.6	40.6
31	16.2	55.5	15.6	51.8	15.3	53.4	15.3	51.8	14.2	38.8	13.7	30.6
Feb. 7	14.0	54.9	15.0	53.4	14.4	51.3	14.8	45.9	13.6	29.1	13.0	29.2
14	13.9	55.9	13.3	51.3	13.0	47.6	13.3	38.1	12.6	28.8	11.6	27.9
22	14.0	54.9	14.7	50.7	14.7	52.9	14.2	47.2	13.6	27.2	14.0	27.9
March 3	11.4	57.8	11.5	41.6	12.0	46.4	12.0	39.8	11.9	28.3	11.8	28.3
8	13.0	55.8	13.0	48.4	12.5	45.6	12.0	37.8	11.0	28.0	11.0	26.9
14	17.0	56.6	17.0	49.8	16.0	50.0	16.0	40.4	16.0	29.9	17.0	28.4
20	17.0	57.6	17.0	50.8	16.5	50.6	17.0	44.8	17.5	29.7	16.5	28.2
31	20.5	57.4	20.5	53.2	21.0	55.2	20.5	52.6	21.0	38.9	21.5	29.2
April 9	25.0	....	25.5	....	24.5	....	24.0	....	26.0	....	25.0	....
15	22.0	51.8	24.0	54.0	21.0	44.7	21.5	44.4	21.0	35.3	21.0	30.3
21	25.0	54.4	25.5	54.0	28.0	55.6	25.0	51.6	25.0	33.8	25.0	31.0
28	23.0	57.0	25.0	51.2	28.5	56.8	27.5	51.8	25.0	30.0	23.5	28.7
May 5	29.0	57.1	28.0	58.6	29.0	63.6	28.0	58.6	29.0	45.2	29.0	40.1
14	27.6	57.7	27.7	57.1	27.7	64.6	27.8	57.1	28.0	42.6	28.2	32.3
21	26.5	54.3	26.7	54.0	26.7	56.6	26.0	48.5	26.4	61.8	25.8	32.7
27	27.8	34.5	27.2	54.6	28.6	56.7	28.2	43.5	27.2	30.5	27.8	42.2
June 3	29.0	45.3	28.5	59.2	30.4	59.6	29.0	60.8	29.2	39.8	29.5	37.2
12	29.5	53.9	29.5	55.4	29.6	67.2	30.0	60.7	31.0	61.2	29.0	54.3
21	29.0	64.5	28.6	57.8	29.0	70.4	28.2	66.6	29.2	41.0	29.3	33.6
27	29.0	58.6	28.4	61.8	29.2	70.8	28.9	64.0	29.4	47.9	29.5	55.9
July 5	30.8	54.9	30.5	70.9	31.2	84.6	30.7	66.6	30.0	65.1	29.4	46.7
12	29.2	59.9	29.2	65.2	29.8	86.5	29.5	71.8	30.0	37.9	29.7	37.6
19	30.1	67.0	31.1	60.6	29.8	99.0	30.2	76.2	30.2	65.1	29.4	64.0
26	29.6	64.6	30.0	67.4	30.5	62.8	29.5	71.8	28.0	62.0	28.0	39.8
Aug. 5	29.2	60.8	29.4	57.7	30.0	38.5	29.0	62.0	29.0	32.9	28.0	32.1
13	29.6	59.4	30.1	56.1	30.4	60.9	30.0	62.0	30.3	60.9	30.2	59.4
20	29.4	55.4	30.5	63.3	29.4	58.9	29.5	66.3	29.1	32.2	28.5	34.8
29	30.6	56.1	30.8	63.3	31.0	64.9	30.0	62.1	30.5	51.5	31.5	49.1
1947												
Sept. 4	29.6	62.0	29.8	60.9	31.0	66.3	31.0	70.6	30.5	50.8	30.2	....
13	29.4	68.3	29.0	64.0	29.6	72.0	30.0	69.3	29.8	62.4	29.5	54.4
18	29.2	67.1	29.5	68.3	29.7	74.6	29.8	57.1	29.2	59.8	29.7	41.5
25	25.0	68.3	25.5	59.8	27.0	67.1	25.3	40.0	26.0	38.1	26.8	37.3

*The salinity values given in the mimeographed report of the Texas Game, Fish and Oyster Commission Marine Laboratory (1948, pp. 114–117) are somewhat different than those given here. Some weeks were omitted, and the figures for January 21, 31, and February 10, 1948, are temperature readings. The data in this table are directly from the original compilation, and are the basis for the graphs and discussion in this paper.

TABLE 7 (Continued)

Hydrographic data, Laguna Madre (Northern Half). Surface Records

	°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo	°C	°/oo
	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6	
Oct. 2	25.3	67.8	25.4	67.8	25.5	59.8	25.6	48.9	25.1	36.3	25.4	36.3
9	27.2	64.3	27.2	64.3	28.2	65.9	28.0	63.2	27.3	44.8	27.5	37.4
16	26.3	65.8	26.2	63.1	27.2	74.4	27.0	64.0	26.7	49.1	26.6	38.0
23	26.3	65.5	26.1	64.7	26.8	71.3	26.5	63.9	27.2	56.0	27.5	42.0
29	26.5	64.7	26.6	68.9	27.6	75.0	27.0	69.2	27.0	54.2	27.2	40.9
Nov. 25	16.4	57.4	16.8	58.9	16.2	50.9	16.9	54.7	16.4	34.2	16.7	34.2
Dec. 6	23.0	57.9	22.5	58.9	25.5	58.9	25.4	32.4(?)	24.0	49.4	23.8	42.4
16	10.4	58.9	11.6	52.6	10.3	47.2	10.7	47.8	10.8	31.3	10.3	33.2
23	15.7	58.9	15.5	58.9	16.5	32.4	15.4	57.9	16.0	32.4	16.0	54.7
1948												
Jan. 3	16.2	56.9	16.5	52.7	18.2	52.7	17.0	54.3	17.0	46.4	17.0	54.3
14	15.5	56.9	14.5	55.3	15.2	55.3	14.5	52.7	11.0	54.3	10.5	46.4
21	10.5	62.2	13.5	60.2	10.5	60.0	10.7	42.6	9.8	....	9.6	33.9
31	7.0	60.0	7.9	52.4	6.6	40.2	6.4	49.5	5.6	33.9	6.2	33.9
Feb. 10	10.3	55.3	10.2	51.8	8.6	50.0	10.2	51.8	8.2	39.5	7.9	37.1
March 3	18.8	60.4	18.3	54.8	18.8	46.6	17.7	46.6	16.6	34.6	16.1	34.3
10	17.4	54.8	18.2	58.9	17.8	56.4	17.6	34.6	17.6	31.4	19.1	31.4
18	21.6	54.6	21.0	58.9	25.0	46.6	24.8	46.6	21.5	40.1	21.2	34.6
24	21.6	56.2	21.2	54.8	21.6	51.0	22.7	48.9	21.4	40.6	21.0	38.5
April 2	19.1	60.0	19.6	60.0	17.7	54.8	19.5	42.0	18.6	34.3	18.5	34.3
10	26.2	56.4	26.5	56.4	25.4	56.4	25.6	53.3	26.4	44.2	26.0	44.5
16	23.3	58.0	22.7	58.0	23.3	56.4	23.5	49.5	23.5	37.5	23.0	33.8
26	24.0	60.6	24.2	53.1	25.5	60.6	25.5	43.0	25.5	36.4	26.0	37.7
May 5	28.2	59.2	28.5	57.0	27.2	63.4	27.5	59.2	28.6	40.4	27.5	39.6
13	25.0	59.2	25.4	63.4	25.7	61.8	25.5	47.9	25.2	34.1	25.2	41.9
19	27.0	....	28.2	....	28.0	....	27.7	....	27.0	....	27.8	....
27	27.5	64.8	28.0	59.3	28.0	74.2	28.0	68.3	28.0	42.3	28.2	42.7
June 2	27.5	66.5	28.5	63.8	28.0	59.8	28.0	66.5	27.5	58.4	27.0	42.5
10	29.4	65.5	29.0	63.4	26.8	74.2	28.8	64.4	29.5	63.4	29.5	53.6
21	28.8	63.4	30.5	63.4	29.4	70.8	31.0	72.4	30.5	60.8	30.0	60.8
July 5	29.8	65.3	30.0	65.3	30.2	76.3	31.0	62.6	31.0	55.6	31.0	48.7
12	29.0	66.6	29.0	69.3	29.5	82.3	29.6	72.0	29.7	49.0	30.0	52.8
20	30.0	70.4	30.0	66.4	29.6	84.5	29.8	76.0	30.8	61.1	30.5	59.4
30	29.1	74.6	28.0	74.6	29.0	74.6	30.0	78.4	32.0	59.5	31.1	64.6
Aug. 3	32.7	74.6	31.2	74.6	31.0	87.6	31.0	66.1	29.5	59.5	30.5	56.0
12	30.3	75.9	29.0	75.9	31.1	113.9(?)	31.0	73.6	31.0	62.2	31.2	77.0
18	30.0	88.8	30.6	81.2	31.0	81.2	31.0	68.0	31.2	71.5	32.0	71.5
27	31.5	80.6	30.2	65.8	30.8	101.1	30.5	56.6	30.6	60.5	30.2	56.2
Sept. 3	29.5	85.3	29.0	78.6	28.6	65.6	29.0	51.2	29.5	47.4	29.0	47.4
14	27.5	64.0	29.0	62.4	27.3	62.4	27.5	62.4	27.7	56.6	27.5	50.2
21	29.2	62.0	29.1	65.5	29.2	62.0	29.8	62.0	29.0	56.8	29.0	37.1
27	22.5	67.0	23.2	66.0	23.5	62.8	23.5	56.9	22.0	50.1	21.5	50.0
Oct. 4	25.6	70.5	25.3	70.5	27.2	57.2	25.7	65.2	25.9	57.2	25.8	42.0
14	27.5	62.5	27.0	70.5	27.6	65.7	27.0	62.5	27.2	49.2	27.5	42.2
20	19.0	69.6	21.5	62.2	19.7	69.1	21.0	63.3	19.8	61.1	19.9	70.0
27	21.5	61.1	22.7	69.1	22.6	61.1	22.0	61.1	22.5	53.3	22.2	51.6