Report 88-02

OBSERVATIONS ON THE 1986-1987 TEXAS RED TIDE

(*Ptychodiscus brevis*)

Texas Water Commission

October 1988

Jim –
Good luck with EWSR
Best Wishes
Bob

TEXAS WATER COMMISSION

Report 88-02

OBSERVATIONS ON THE 1986-1987 TEXAS RED TIDE (*Ptychodiscus brevis*)

by
Bob Trebatoski

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ABSTRACT

From August 1986 thru January of 1987 a red tide caused by the unarmored dinoflagellate *Ptychodiscus brevis* impacted Texas coastal and Gulf of Mexico waters from Galveston to Port Isabel, TX and extended into Mexican waters. The red tide resulted in extensive fish kills, human respiratory and dermal irritation and closure of shellfish harvesting. This report documents the movement of and areas impacted by the red tide, through plankton and water chemistry samples and boat and aerial surveys. Water chemistry data from samples taken during the bloom were in agreement with those of other red tide studies but failed to correlate with cell densities. *P. brevis* densities ranged to an estimated high of 1.1 million cells/ml (Rockport Harbor). Vertebrate and invertebrates killed during the event were estimated at greater than 22.2 million.

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OBSERVATIONS ON THE 1986-1987

TEXAS RED TIDE

(*Pytchodiscus brevis*)

INTRODUCTION

Texas Gulf of Mexico and bay waters periodically experience fish kills and water discoloration due to red tide organisms. Most often these events are limited in duration and area and are caused by blooms of *Gonyaulax monilata* (Connel and Cross 1950, Gates and Wilson 1960). While *Ptychodiscus brevis* red tides are more common along the west coast of Florida, documented outbreaks have previously occurred, although infrequently, in Texas waters (Lund 1935, Wilson and Ray 1956).

Ptychodiscus brevis (formerly known as *Gymnodinium breve*) (Steidinger 1979) is a biflagellate, unarmored dinoflagellate approximately 24 µm in diameter (Photo 1). Blooms of *P. brevis* initiate in offshore Gulf of Mexico waters. These blooms are hypothesized to originate from "seed beds" of benthic cysts that germinate and release active vegetative cells to the water column (Steidinger 1983) (See Figure 1 for a description of the theoretical life cycle). Excystment is thought to be triggered by environmental factors such as trace metals and chelators, or by biological precursors (ie. other algal blooms) (Iwasaki 1979). The existence of benthic cysts and the triggering mechanism for *P. brevis* are still undetermined.

After excystment, blooms may develop and move toward shore. *P. brevis* blooms are not due solely to cell division rate (0.3-0.5 divisions/day) (Steidinger 1983); physical concentration of cells by wind and current activities are fundamental factors in increasing cell densities (Steidinger 1974). Red tide bloom proportions are reached when cell concentrations exceed 100 cells/ ml of seawater (Steidinger and Joyce 1973). Blooms of *P. brevis* occur annually in the eastern Gulf of Mexico and may become organized and move towards shore, although 75% never reach nearshore waters (Steidinger 1974).

In early bloom stages a high correlation may exist between *P. brevis* cell densities and the number of dead fish. The correlation fails in subsequent stages of the bloom for several reasons: life stage synchrony of the organisms decreases as separate populations age, toxins may persist for up to two weeks regardless of cell condition, and the ability of the organism to alter the chemical composition of the toxin and resultant toxicity (Steidinger pers. comm.).

P. brevis cells release both neurotoxic and hemolytic toxins after decay or rupture of the cell wall. Hemlolytic fractions result in death of fish

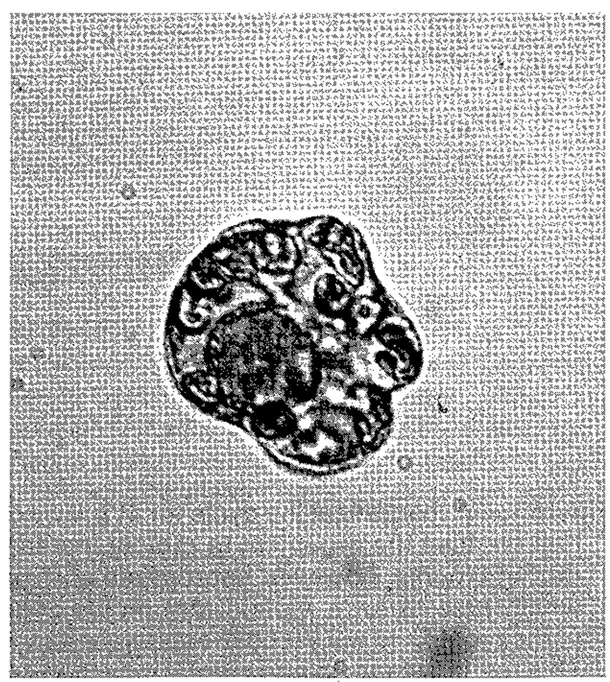


Photo 1.—*Ptychodiscus brevis*

through the rupturing of blood cells (Martin and Martin 1974, Stein and Borden 1984). *P. brevis* neurotoxins are lipid soluble across gill membranes and result in death by depolarizing excitable membranes and blocking nerve impulses (Abbott et al. 1974).

Filter-feeding shellfish in red tide inhabited waters ingest and concentrate the toxins in their tissue. While the shellfish are not harmed by the toxins; their tissue remains toxic to humans. This forces the closure of shellfish harvesting areas to prevent cases of Neurotoxic Shellfish Poisoning (NSP). NSP may occur when shellfish meats with toxin concentration greater than 50 mouse units/100g are consumed. Temporary symptoms (up to three days) include dizziness, tingling sensation in extremeties, dilated pupils and hot-cold reversals (Steidinger 1983).

The level of toxin in shellfish is determined by using the mouse bioassay method in which mice are injected with extracted toxin and distress symptoms and death recorded. Although no human fatalities have been reported, *P. brevis* may be fatal to all vertebrates given sufficient dosage (Abbott et al. 1974). Man would have to consume 50 times the amount of *P. brevis* toxin when compared to the toxins of another dinoflagellate, *Gonyaulax tamarensis* (Mor-

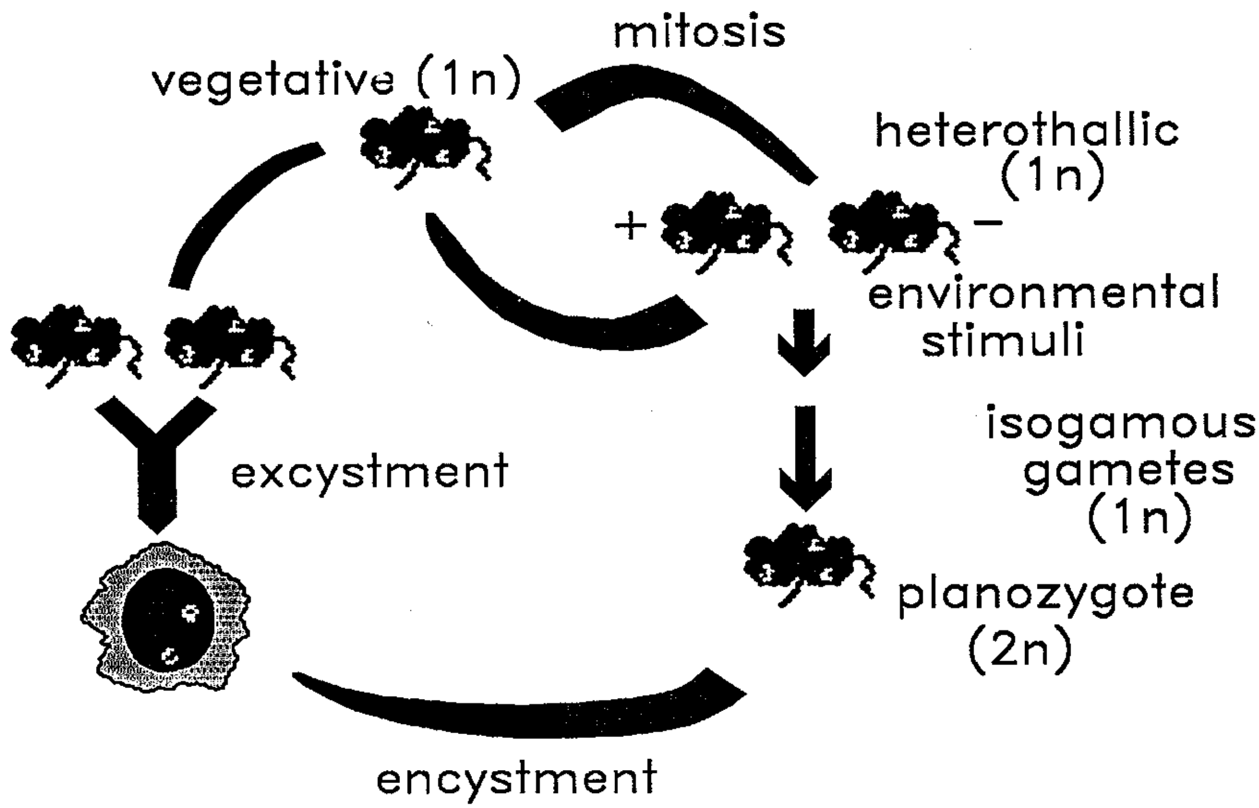


Figure 1.—A theoretical life cycle for *P. brevis* consists of a mitotic (vegetative) reproductive cycle that enables the organism to rapidly increase in numbers. The vegetative cycle predominates during blooms, however, appropriate environmental stimuli may produce isogamous gametes which fuse to form diploid (2n) motile zygotes (planozygotes). Although encystment of the planozygote has not yet been established for *P. brevis*, it has been documented in related species. This resting stage (hypnozygote) may then, upon proper stimuli, give rise to vegetative inoculum (Taken in part from Steidinger 1983, Wilson 1966).

ton and Burklew 1969), which is known to cause human death through paralytic shellfish poisoning (Abbott et al. 1974).

P. brevis also directly affects humans by producing respiratory and dermal irritations when cell wall fragments and toxins in sea spray are inhaled or contacted (Steidinger and Joyce 1973).

This report concerns a *Ptychodiscus brevis* red tide bloom that occurred along the Texas coast in 1986. The event was first reported on 27 August 1986 in Gulf of Mexico waters near Galveston Island. In subsequent weeks the bloom progressed southward along the coastline and into Matagorda Bay. By mid-September, virtually all of Matagorda Bay and parts of Lavaca Bay and Espiritu Santo Bay contained red tide. While the red tide continued to impact the Matagorda Bay area, it also progressed slowly southward until October. During this month, red tide came ashore as far south as Port Isabel, TX and Mexico and became established in Aransas Bay, Redfish Bay, Corpus Christi Bay and parts of Laguna Madre and Copano Bay. Although the bloom had virtually abated by late October; localized, and at times dense, concentrations were encountered through January, 1987.

MATERIALS AND METHODS

Plankton, water quality and areal surface coverage data were collected from 28 August 1986 thru 2 February 1987 during scheduled sampling events and as part of special investigations in response to public query concerning red tide impact. Aircraft used in areal surveys of coastal waters were provided by the Texas Parks and Wildlife Department (TPWD) and the Texas General Land Office (GLO).

A Hydrolab 4041 water quality measurement instrument was used to obtain field measurements of dissolved oxygen, pH, conductivity and temperature. Secchi disc measurements were used to estimate water clarity. Water samples were collected using 1 liter cubitainers in grab samples at 1 foot depths. Laboratory analyses of water chemistry were conducted by the TWC-EPA lab in Houston, TX and the Texas Department of Health (TDH) lab in Austin, TX, using the methods listed in Appendix A. Plankton samples were taken in 1 liter cubitainers as grab samples at 1 foot depths or in a 3 liter Kemmerer sampler at depths greater than 1 foot. Plankton samples were preserved in a 1% Lugols solution. For enumeration, one ml subsamples (3 replicates) were taken from a well-mixed plankton sample and placed into a 1 ml Sedwig-Rafter counting chamber. Two strips (lengthwise) were counted and *P. brevis* densities calculated utilizing EPA (1973) methods. For densities greater than 50,000 cells/ml, 3 one ml aliquots were taken and enough fields were counted to ensure a 95 % confidence interval on mean count.

Data presented in this report were collected by TWC personnel: W. Bowles, J. Bowman, S. Dent, D. Jensen, J. Kendall, R. Lewis, L. Schmidt, F. Shipley, C. Stanley, B. Trebatoski, C. Webster and C. Volz. I recognize the TPWD, TDH and GLO for their cooperation in aerial flyovers and boat surveys. A special thanks to James Bowman, Mike Hoten, Frank Shipley and Chip Volz for their comments and reviews.

SUMMARY OF OBSERVATIONS

On 27 August 1986 the TWC Deer Park office received a report via the United States Coast Guard (USCG) concerning a patch of brown, rusty oil, approximately 200-300 yds. wide and 0.5 mi. long, coming ashore at San Luis Pass. Reports of discolored water and respiratory irritation near the west end of Galvston Island were forwarded to the TWC. These first reports of respiratory irritation caused much public apprehension as citizens speculated that a chemical spill had occurred or even that they were suffering some consequence of the Chernobyl nuclear disaster. Water samples were collected from the Galveston Island Seawall and *Ptychodiscus brevis* was identified in the samples by S. Indelicato of the Universtiy of Houston at Galveston.

The next day, the TWC received reports via the National Marine Fisheries Service and the Galveston County Health Department of large numbers of dead Southern Flounder, Sea Catfish, mullet and Speckled Sea Trout on the Galveston Island Beach. Investigators reported respiratory irritation along the seawall. During the final days of August, numerous airborne irritant complaints were received through the Sea Grant extension agents.

During the initial days of September there were more reports of dead fish near the Freeport, Galveston and Bryan Beach areas and red tide progressed south to the Colorado River area. Red tide reached the Port O'Connor Gulf jetties by 5 September 1986 and quickly moved into Mata-

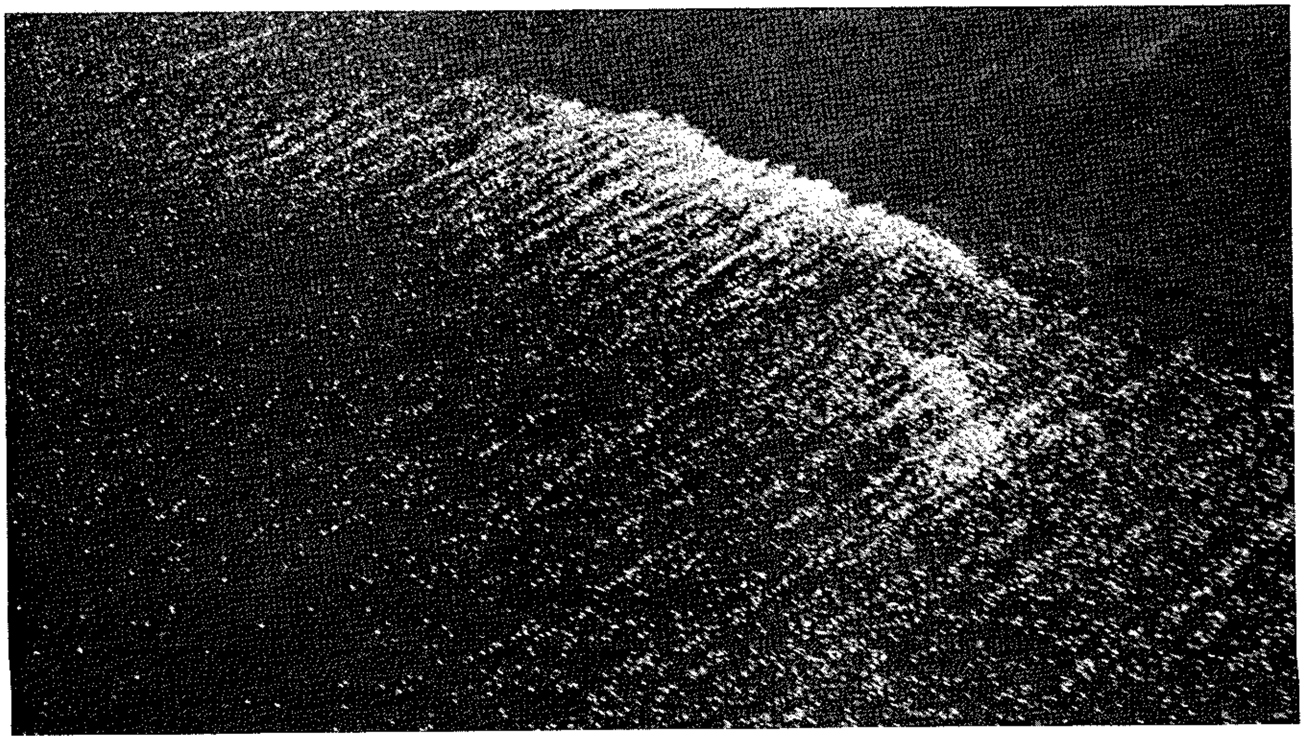


Photo 2.—Large Accumulations of Dead Fish in Gulf of Mexico Waters

gorda Bay via the Matagorda Bay Ship Channel and Cavallo Pass, prompting the TDH to close all shellfish producing waters from San Luis Pass to the Port Mansfield Ship Channel. Tidal and wind movement soon dispersed patches and streaks of the organism throughout the bay. This action also moved the organism into the mouths of Lavaca, Cox and Keller Bays. The organism existed in the Matagorda-Lavaca Bay system througout September. The location of red tide, its boundaries and density were influenced by winds, currents and freshwater inflow and therefore fluctuated daily. The fish that were killed by the organism were concentrated along windrows and windward shores.

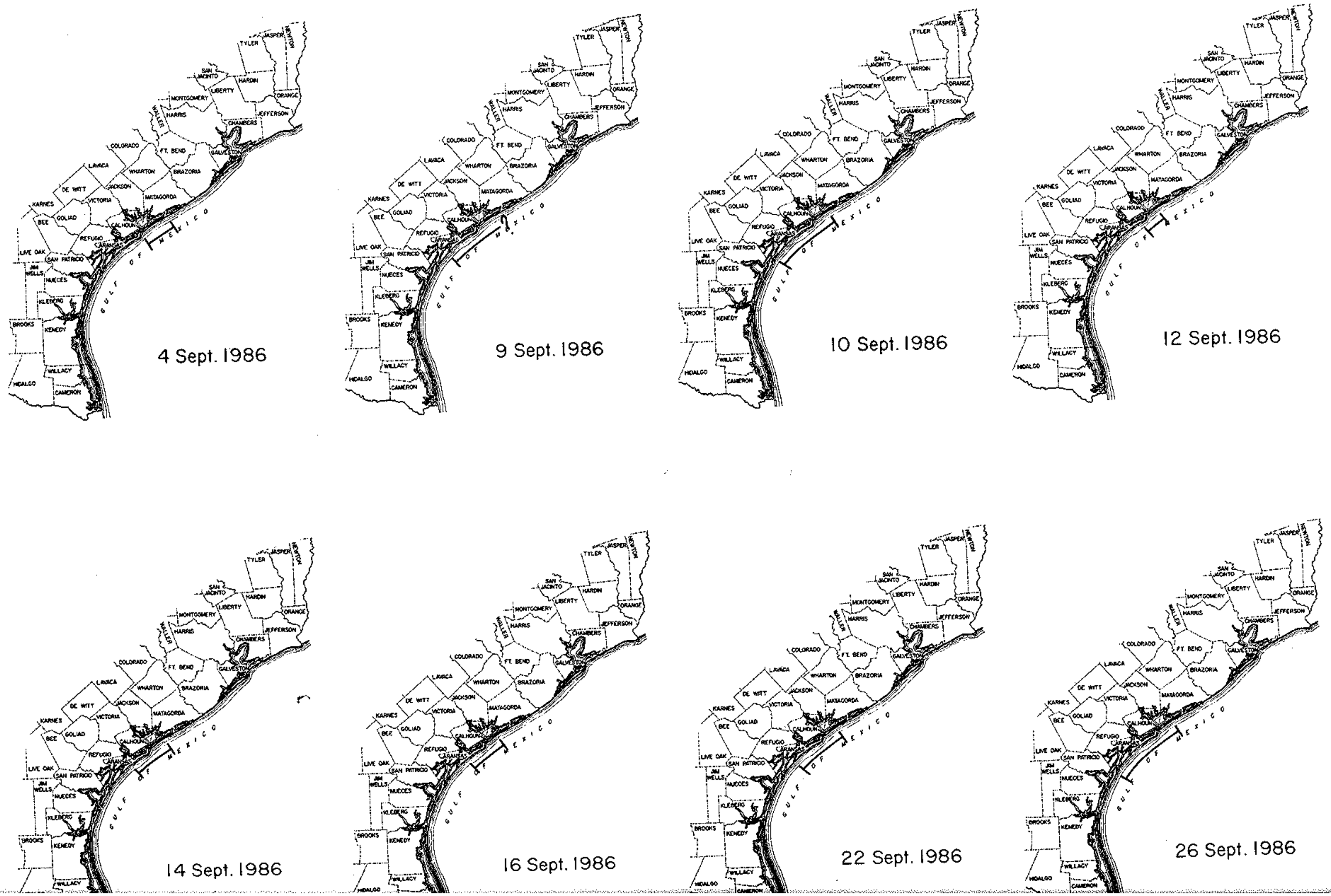
Red tide also moved into Espiritu Santo Bay through Saluria Bayou. Spread of the organism was not as rapid as in Matagorda Bay, but by the end of September all of Espiritu Santo Bay contained red tide and resultant fish kills.

As red tide and dead fish occurred inside the barrier islands they were accompanied by a dramatic increase in public inquiry. In order to provide accurate reports concerning areas impacted by red tide and fish kills over such large areas, flyovers were coordinated among the three state agencies—TWC, TPWD, and TDH.

During the month of September, nine flights were arranged to survey areas being impacted by the red tide organism (Figure 2). Initially the physical nature of the organism (often existing in diffuse patches and streaks), made locating the red tide difficult. Low altitude flights (<1000 ft.) were necessary to observe coastal and bay progression. Often if seas were rough, offshore concentrations were difficult to assess. A concurrent boat-aircraft survey in the Gulf on 16 September 1986 provided positive ground truth correlation with aerial observations and helped refine survey techniques.

Red tide patches surveyed in the Gulf were often accompanied by large accumulations of dead fish (Photo 2). Both dead fish and red tide extended up to 5 miles offshore, and may have been present further than 5 miles, beyond aircraft survey capability. Helicopters were not often available, but when used, their low altitudes improved assessment of red tide and fish kills. They also allowed personnel to land on beaches for water sampling. Landings were at times limited by the intensity of respiratory irritation experienced by investigators near the surf zone.

Coastal flyovers in late September indicated a southern offshore movement of red tide toward the Port Aransas jetties. On 25 September 1986 TWC


4 Sept. 1986
9 Sept. 1986
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14 Sept. 1986
16 Sept. 1986
22 Sept. 1986
26 Sept. 1986
GULF OF MEXICO

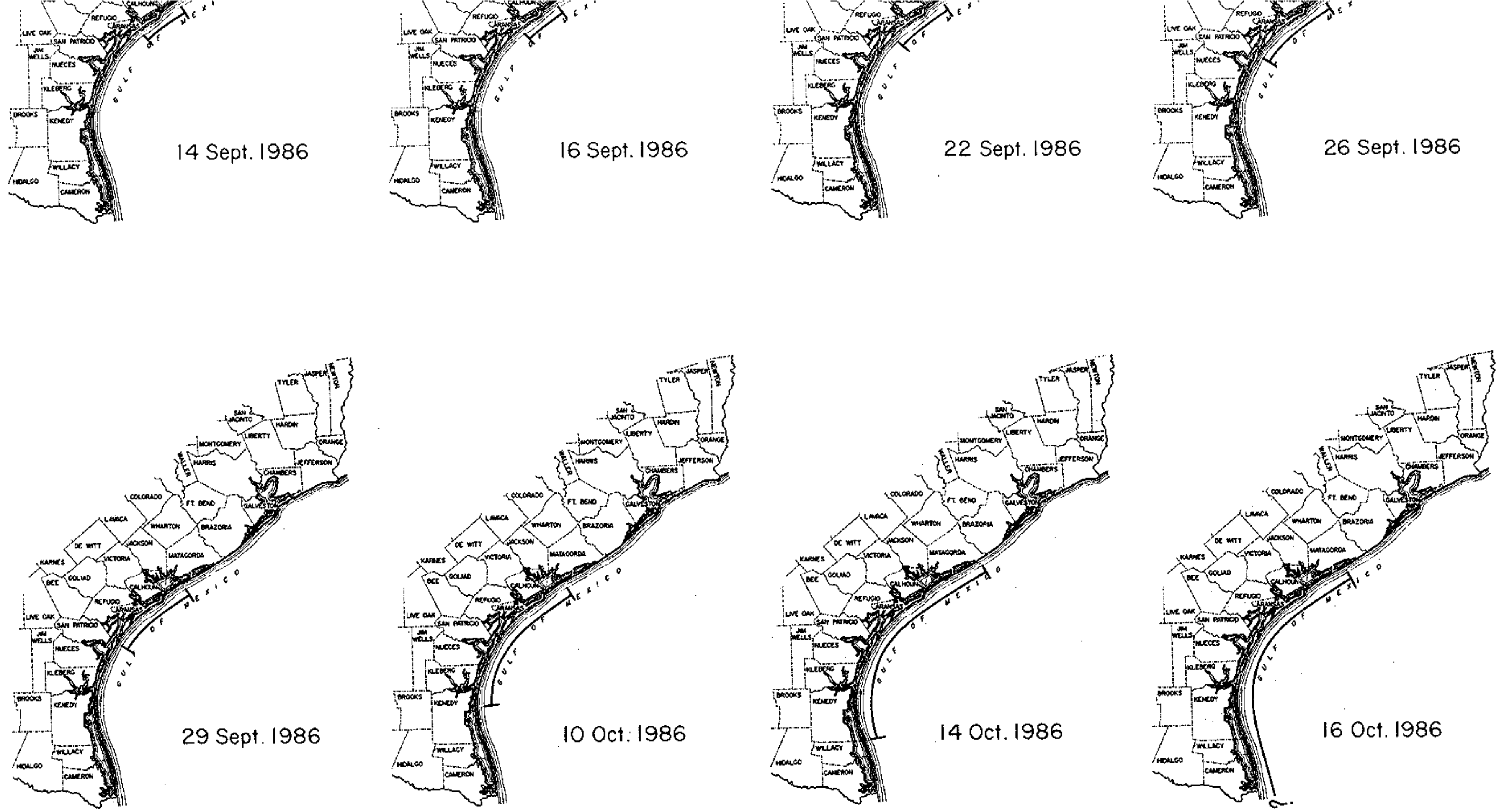


Figure 2
Near Shore Boundaries of Red Tide Along the
Gulf Coast as Estimated by Flyovers

and TDH personnel responded to complaints of fish kills and aerosol irritations near Quarantine Shores in Aransas Bay. Although no obvious discoloration was noted, fish near the Lighthouse Cut appeared stressed, breaking the water surface in apparent respiratory stress, a typical behavior seen repeatedly during the red tide. Analysis of samples revealed *P. brevis* at a density of <1 cell/ml. In the following days TWC received reports via University of Texas Marine Science Institute (UTMSI) that concentrations of 200-1500 cells/ml were present at the Port Aransas jetties.

From Aransas Bay, red tide quickly spread into adjacent bay systems. By mid-October, Aransas, Copano, Corpus Christi and Redfish Bays had periodic, heavy coverage along with extensive fish kills (Photos 3 and 4). At times virtually all of Redfish Bay was impacted and experienced severe fish kills. In spite of presence throughout Corpus Christi Bay, impact in Laguna Madre was limited to its northern mouth. During this month heavy concentrations of red tide occurred along Corpus Christi's downtown bayfront area (causing city officials to temporarily close down city beaches), and also in several boat harbors. High numbers of dead Gulf and bay fish and heavy densities of *P. brevis* were concentrated by wind and tidal action near the Port Aransas-UTMSI boat docks. In response to complaints of respiratory irritation and discolored water at Rockport, TX, investigators took plankton samples at the harbor boat basin. These samples produced startling results: densities of 1.1 million cells/ml and 850,000 cells/ml were detected, probable results of wind stacking in the harbor.

Although an isolated outbreak of red tide was reported at the Old Brazos River, the aerial reconnaissance in October (Figure 2) revealed that the epicenter had shifted south towards Cedar Bayou (at the time not open to the Gulf). During the period from 9 October 1986 through 16 October 1986, movement progressed south beyond the Port Aransas jetties. On 16 October 1986 maximum Gulf coast coverage, an estimated 280 miles, was observed from approximately two miles north of the Colorado River south into Mexican waters. These sightings were accompanied by reports of massive offshore fish kills. Investigators also reported seeing dense patches of red tide extending offshore beyond range of visibility. This information prompted the TDH to extend the the shellfish closure from San Luis Pass south to the mouth of the Rio Grande River.

Plankton samples taken on 16 October 1986 confirmed *P. brevis* concentrations in hundreds/ml, approximately 18 mi. offshore from the Port Aransas jetties. Soon the huge numbers of dead fish offshore moved ashore onto the barrier island

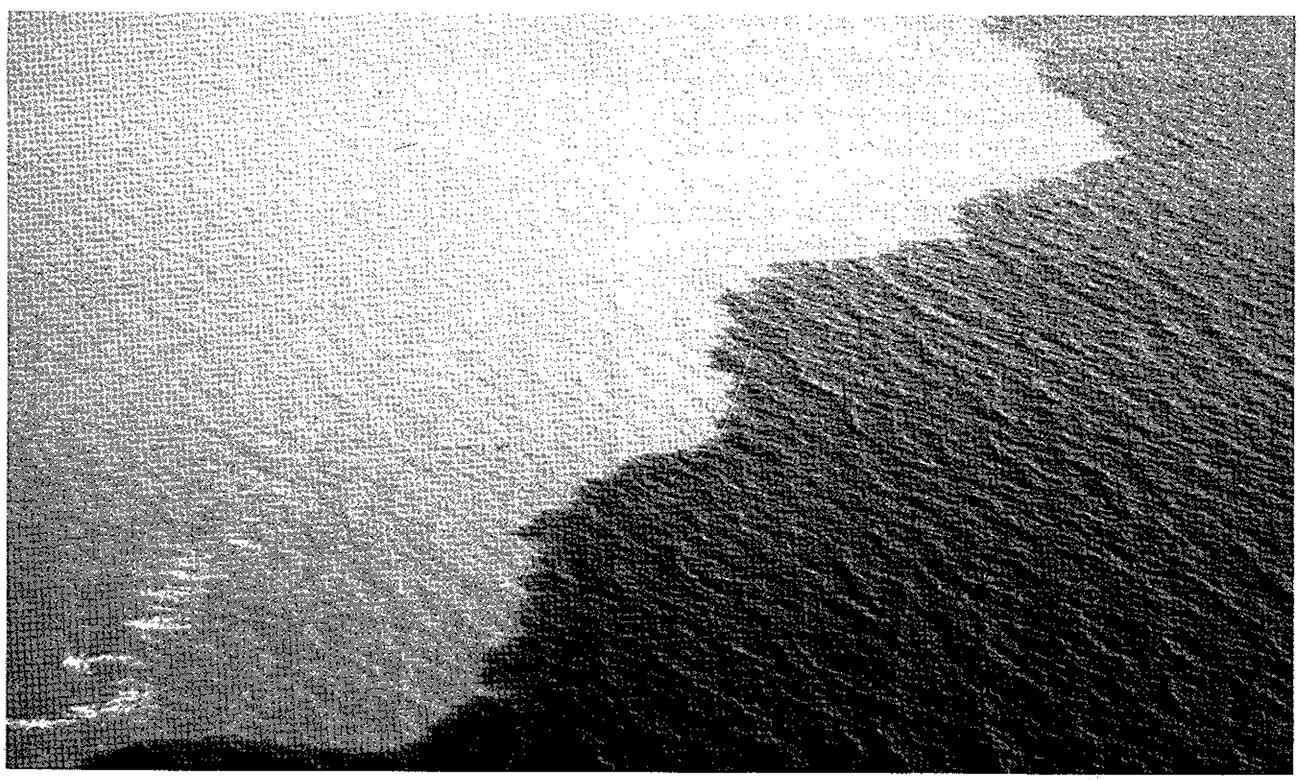


Photo 3.—Heavy Red Tide Coverage and Dead Fish Accumulation in Aransas Bay

Photo 4.—Heavy Red Tide Coverage and Dead Fish Accumulation In Aransas Bay Near Rockport, Texas

beaches (Photos 5 & 6). Investigators estimated dead fish at 100,000 per linear mile over approximately 14 miles of Mustang Island beach. These accumulations extended beyond Mustang Island onto the Padre Island National Seashore south to Mexico. Other investigators drove from North Padre Island to Yarborough Pass and reported similar conditions. The stench of rotting fish along with the exposed bones from the fish bodies which threatened pedestrians and automobile traffic, and the aerosol irritation resulted in temporary closure of Padre Island National Seashore.

Although Aransas, Copano, Corpus Christi and Redfish Bays first experienced severe red tide conditions in October, coverage remained heavy in Matagorda, Lavaca and Espiritu Santo Bays during this month. Red tide had moved into San Antonio Bay via passes from Espiritu Santo Bay and blooms were now observed in East Matagorda Bay south of Old Gulf, TX. Dead and dying fish were reported in all impacted areas.

Aerial reconnaissance of 23 & 24 October 1986 reported cloudy skies, rough water conditions and no red tide observations in both Gulf and bay waters. No further flights were scheduled.

Cell counts reported by TDH and TWC indicated that red tide remained at low densities in Aransas Bay, Copano Bay, Corpus Christi Bay, Redfish Bay and the near shore waters off Port Aransas during late October and most of November. No *P. brevis* were detected in November plankton samples from Lavaca Bay, Matagorda Bay, Espiritu Santo Bay and San Antonio Bay.

Reports concerning red tide blooms ceased until 8 January 1987 when a localized but dense bloom was encountered along the southwest shoreline of Corpus Christi Bay. In February a red tide bloom was reported in Corpus Christi Bay but investigators detected no *P. brevis* cells in the plankton samples. No further reports of *P. brevis* blooms were received.

SUMMARY OF DATA COLLECTED

2 September 1986

TWC investigators surveyed and sampled Bryan Beach and Surfside Beach areas (Figure 3, Table 1). Airborne irritant was noted during the fish kill investigations (Table 2).

Photo 5.—Accumulation of Dead Fish on Mustang Island —Northern Portion—

Photo 6.—Accumulation of Dead Fish on Mustang Island—Central Portion

Table 1.—Water Chemistry—Bryan Beach

D.O.	7.0	mg/l
pH	8.4	
Conductivity	41874	µmhos/cm
Chlorophyll a	4.8	µg/l
Pheophytin	4.4	µg/l
Chlorides	17020	mg/l
Sulfates	2200	mg/l
Ammonia	0.05	mg/l
Nitrate	<0.01	mg/l
Total PO_4	0.202	mg/l
Ortho PO_4	0.039	mg/l

Table 2.—Fish Kill Estimates—Bryan Beach and Surfside Beach

Species	Site 1	Site 2	Site 3	Site 4
Gulf Menhaden	100%	93%	20%	6%
Ladyfish	--	0.5%	4%	.25%
Sea Catfish	--	--	1.5%	--
Southern Stargazer	--	--	1.5%	.25%
Striped Mullet	--	6.5%	73%	90%
Unidentifiable	--	--	--	3.5%
Length of Beach Surveyed	18 ft	21 ft	30 ft	2100 ft
Number of Dead Fish/ft	17	18	2.4	9

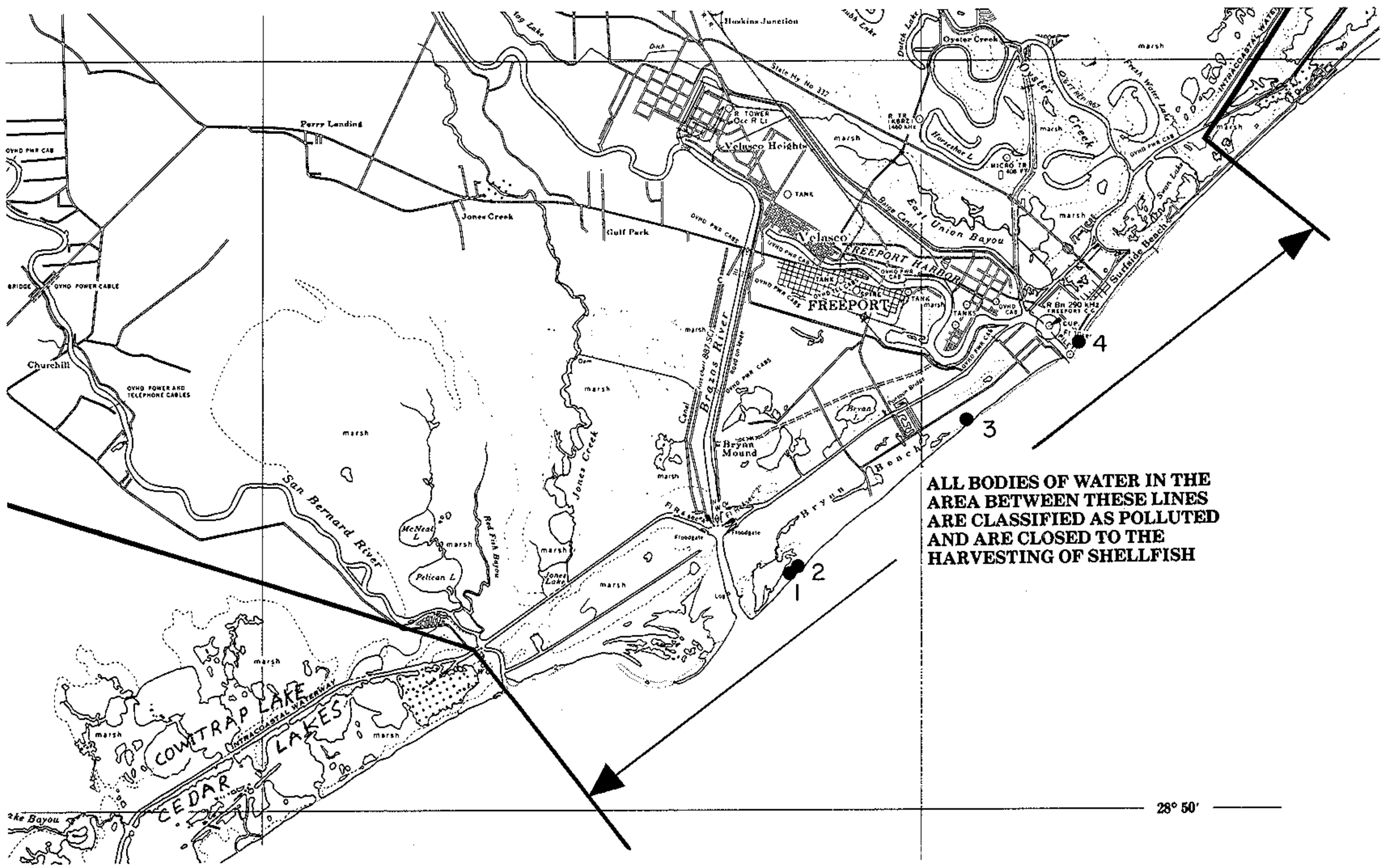


Figure 3

Sample and Survey Locations at Bryan Beach and Surfside Beach

From these data the total number of dead fish over 5.6 miles of beach was estimated at 285,965.

4 September 1986

TWC sampled four Gulf of Mexico locations near the Colorado River (Figure 4) for chemical analyses (Figure 5) and vertical measurement of field paramaters (Figure 6). Investigators noted dead mullet, Sea Catfish, gar and flounder, and airborne irritant at the mouth of the Colorado River. Water was reddish-brown and turbid at sites 1 and 4 and water was clear and green at sites 2 and 3.

5 September 1986

TWC and TDH representatives, sampled three locations in Gulf of Mexico waters near the Port O'Connor jetties (Figure 7). Plankton samples contained 1500 cells of *P. brevis*/ml. Vertical measurement of field paramaters were taken at each station (Figure 8). Dead mullet, menhaden and Pinfish were observed near the jetties. Respiratory irritation from airborne irritants were reported by field personnel.

9 September 1986

Plankton (Table 3) and water chemistry samples (Figure 10-12) were taken from the mouth of Colorado River south to Cedar Bayou in conjunction with scheduled TWC coastal monitoring (Figures 7 and 9). High accumulation of dead fish were noted along the Gulf Beach. Respiratory irritation was experienced by sampling personnel during the investigations. Water samples taken from inside the Port O'Connor Gulf jetties contained 2,580 *P. brevis*/ml and had a water temperature and conductivity of 28 °C and 53,500 µmhos/cm respectively.

16 September 1986

TWC personnel sampled Gulf of Mexico waters from Port Aransas to Port O'Connor jetties approximately 0.75-1 mi. offshore (Figure 13). Vertical measurements of field paramaters (Figures 14A, 14B were taken at ten locations. Plankton samples were taken at 5 ft intervals in the water column (Table 4).

Dying fish were observed in patches of red tide. Typical behavior was characterized by erratic, circular swimming at the water surface. Dead fish such as Red Drum, menhaden, Speckled Trout, Spanish Mackerel, Gaftopsail Catfish, and numerous eels of several species noted. Respiratory irritation from the red tide was reported by the investigators during the survey.

A bloom of a filamentous bluegreen algae *Trichodesmium sp.* (*Oscillatoria*) was observed approximately 1/2 mi. north of the Port Aransas jetties at sample site 2.

9 October 1986

TWC personnel sampled and surveyed various locations in Corpus Christi Bay, Redfish Bay, and Aransas Bay (Figure 15). Plankton samples were taken for enumeration (Table 5). Field measurements were taken in Corpus Christi Bay and Aransas Bay (Table 6). Dead fish were scattered throughout the bays. Respiratory irritation was experienced by investigators. Red tide fish kills and subsequent concentration by currents, resulted in a large accumulation of dead fish in the UTMSI boat basin.

Table 3.—Densities of *P. Brevis* (#/ml)—East Matagorda Bay, Matagorda Bay System and San Antonio Bay System

Station	Density	Station	Density
2441.01	0	2453.03	0
2451.01	0	2454.01	47
2451.02	47	2455.01	71
2451.03	1152	2461.01	8108
2452.01	0	2462.01	0
2453.01	0	2462.02	0

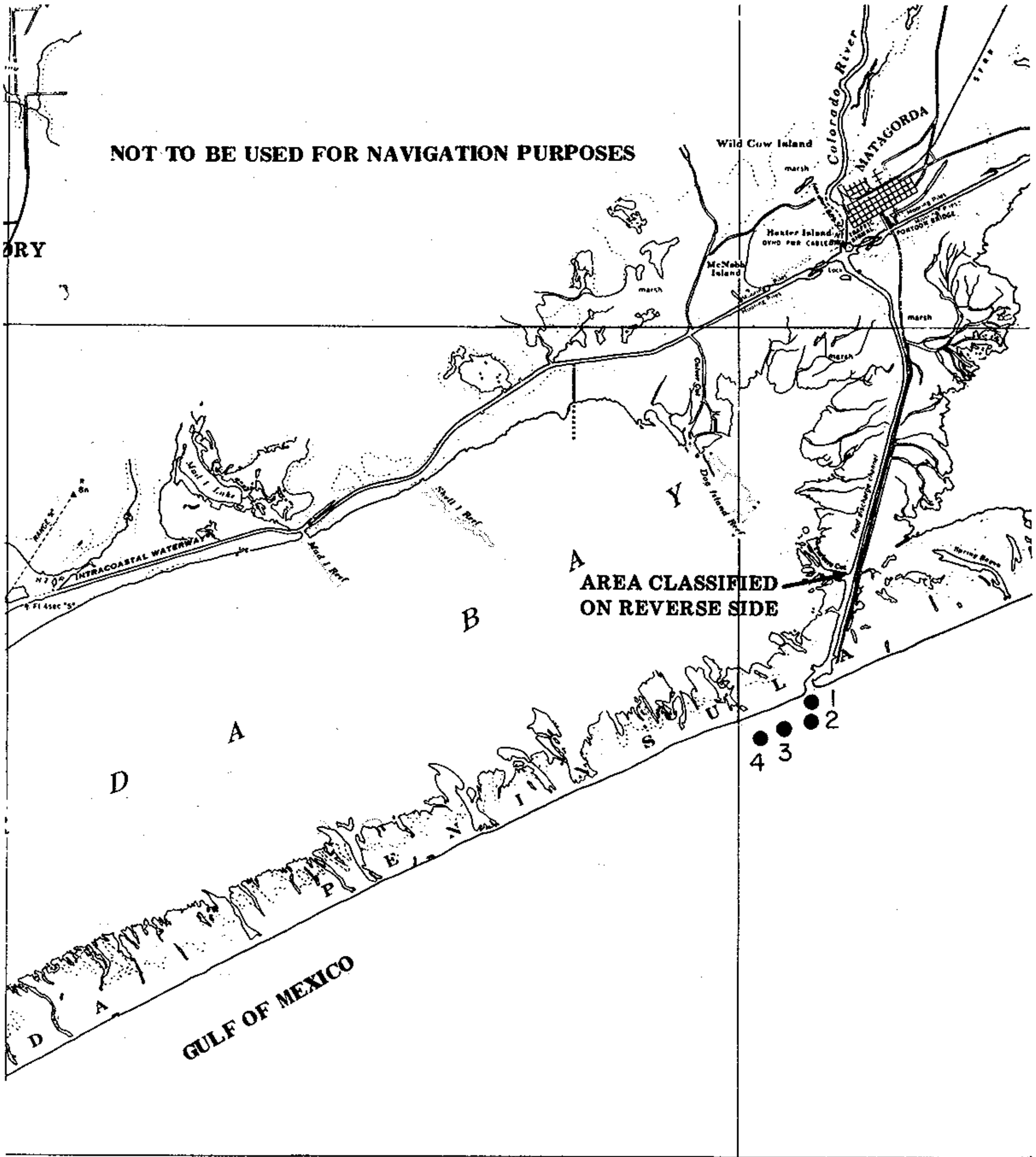
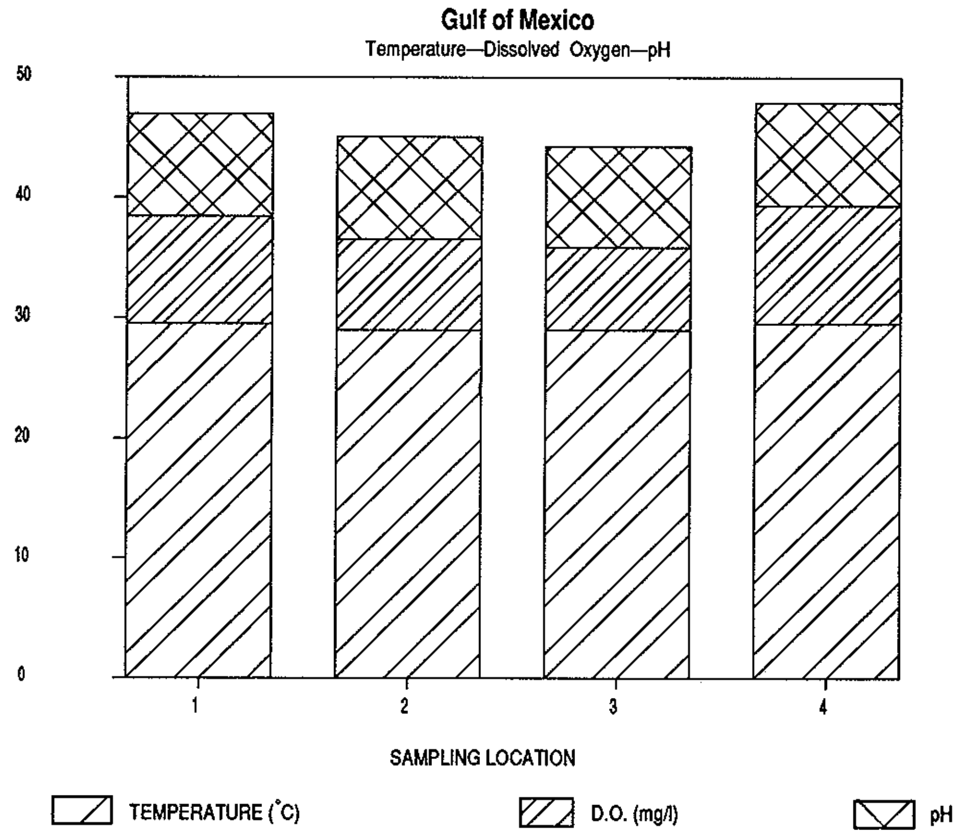


Figure 4
Sample Locations in the Gulf of Mexico Near the Colorado River



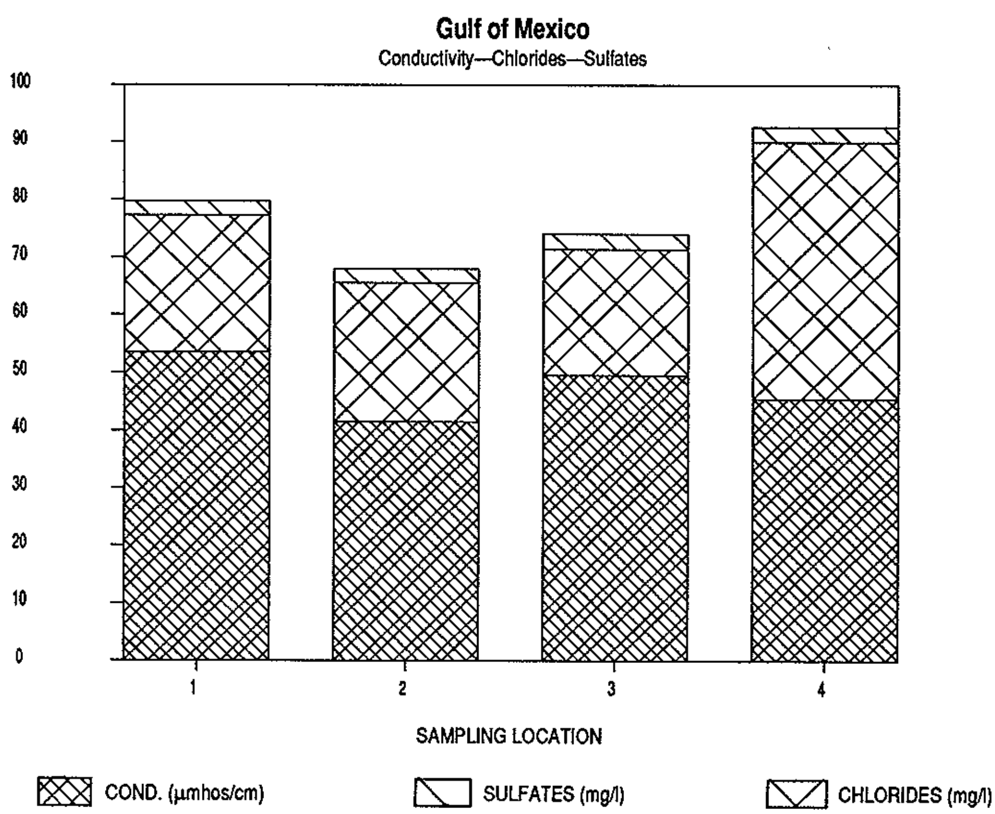
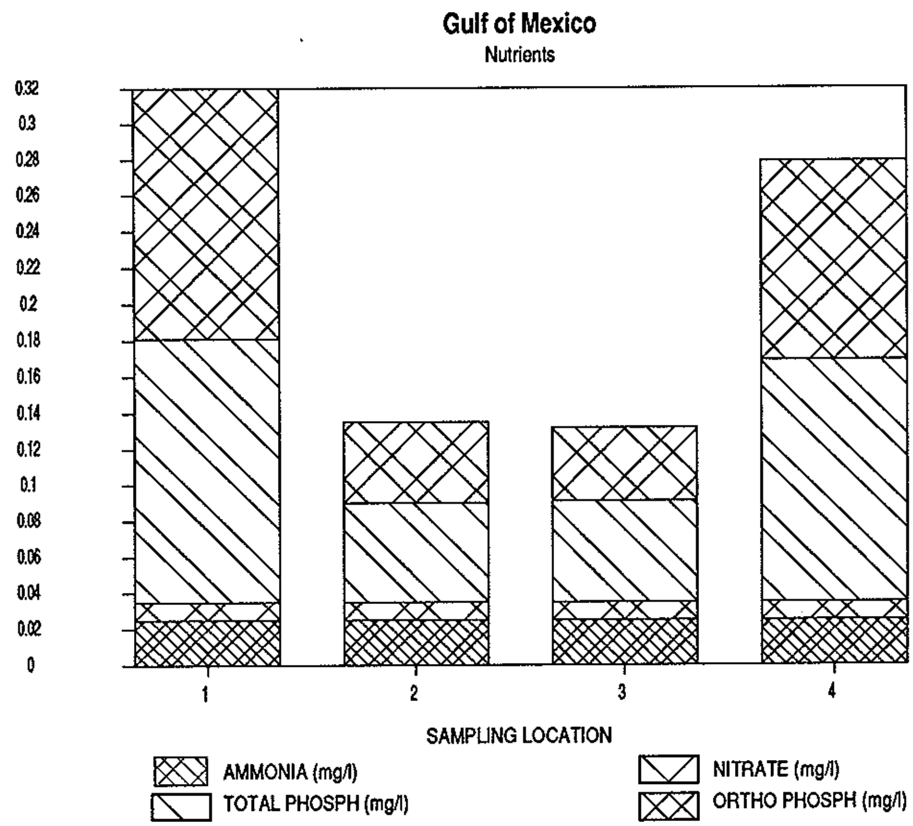
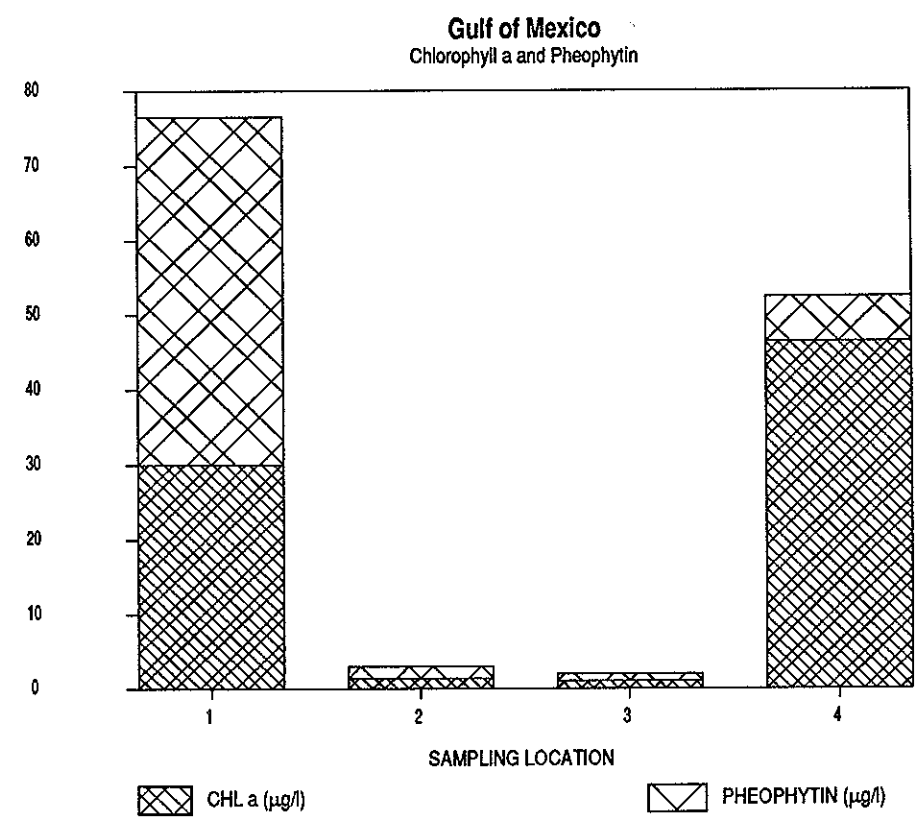
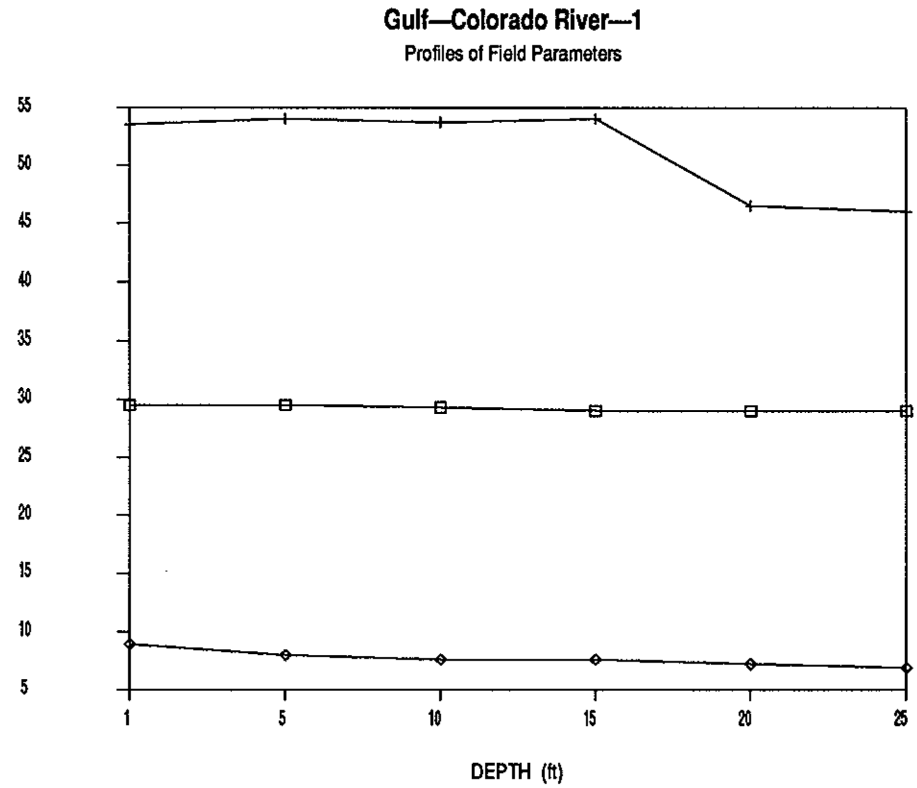


Figure 5.—Field Measurements and Laboratory Analyses





oratory Analyses From Surfside Beach and Bryan Beach



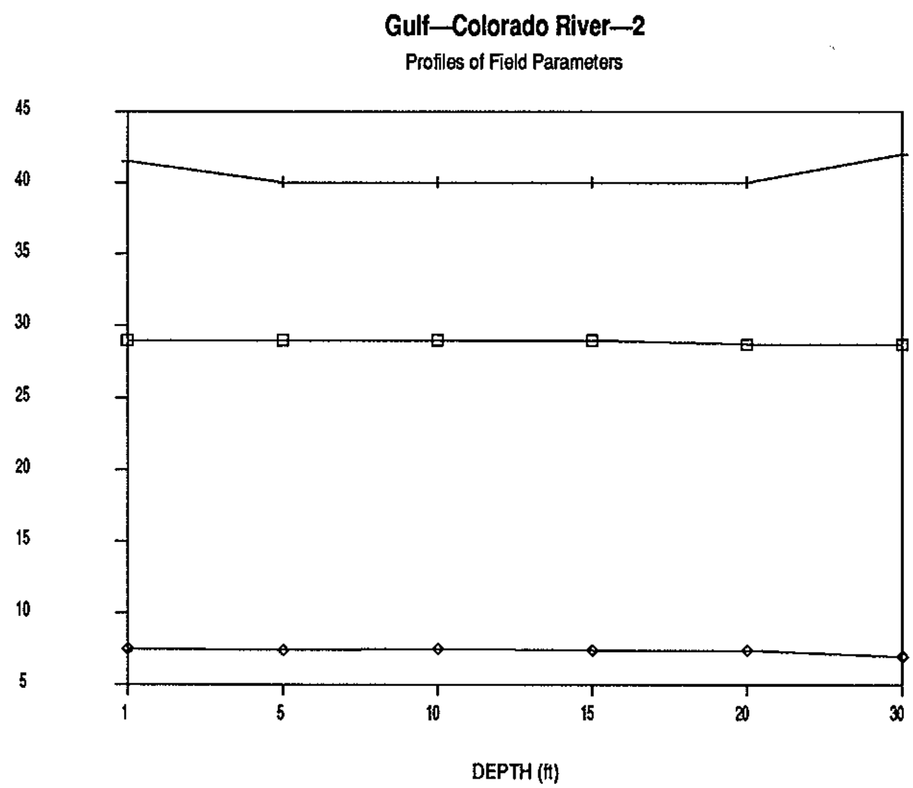
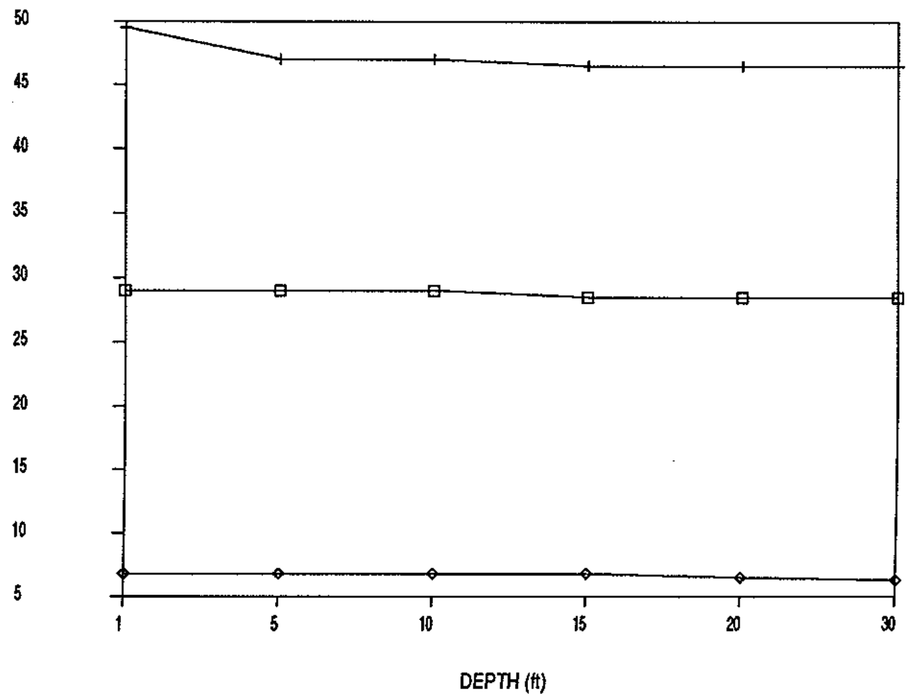


Figure 6.—Field Measurements From the Gulf of Mexic

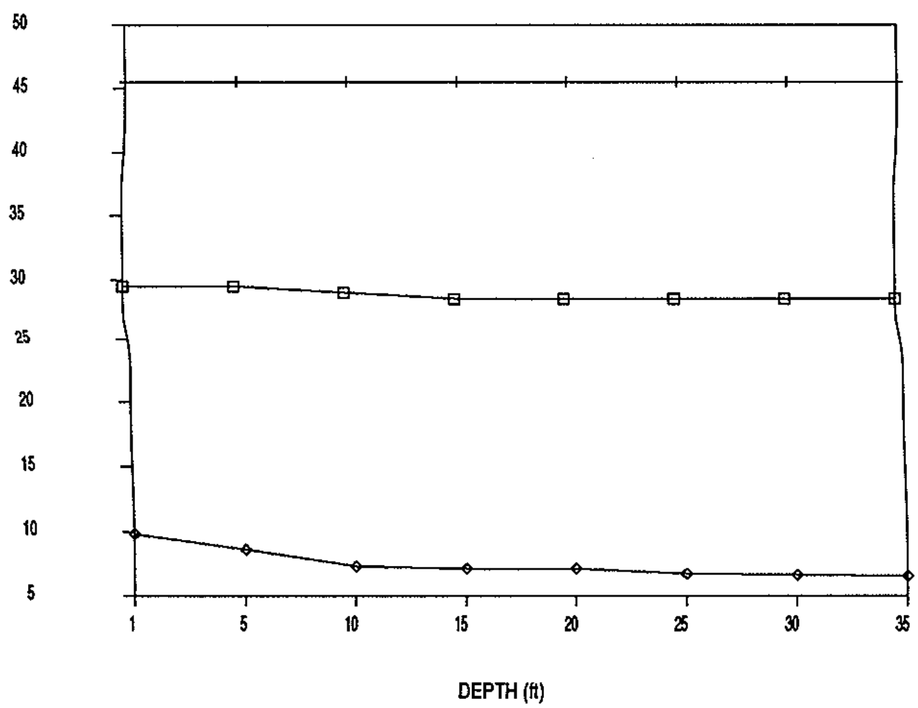
Gulf—Colorado River—3

Profiles of Field Parameters



Gulf—Colorado River—4

Profiles of Field Parameters



LEGEND
□ TEMPERATURE (°C)
+ COND. (μmhos/cm x 10³)
◇ D.O. (mg/l)

ıe Gulf of Mexico Near the Mouth of the Colorado River

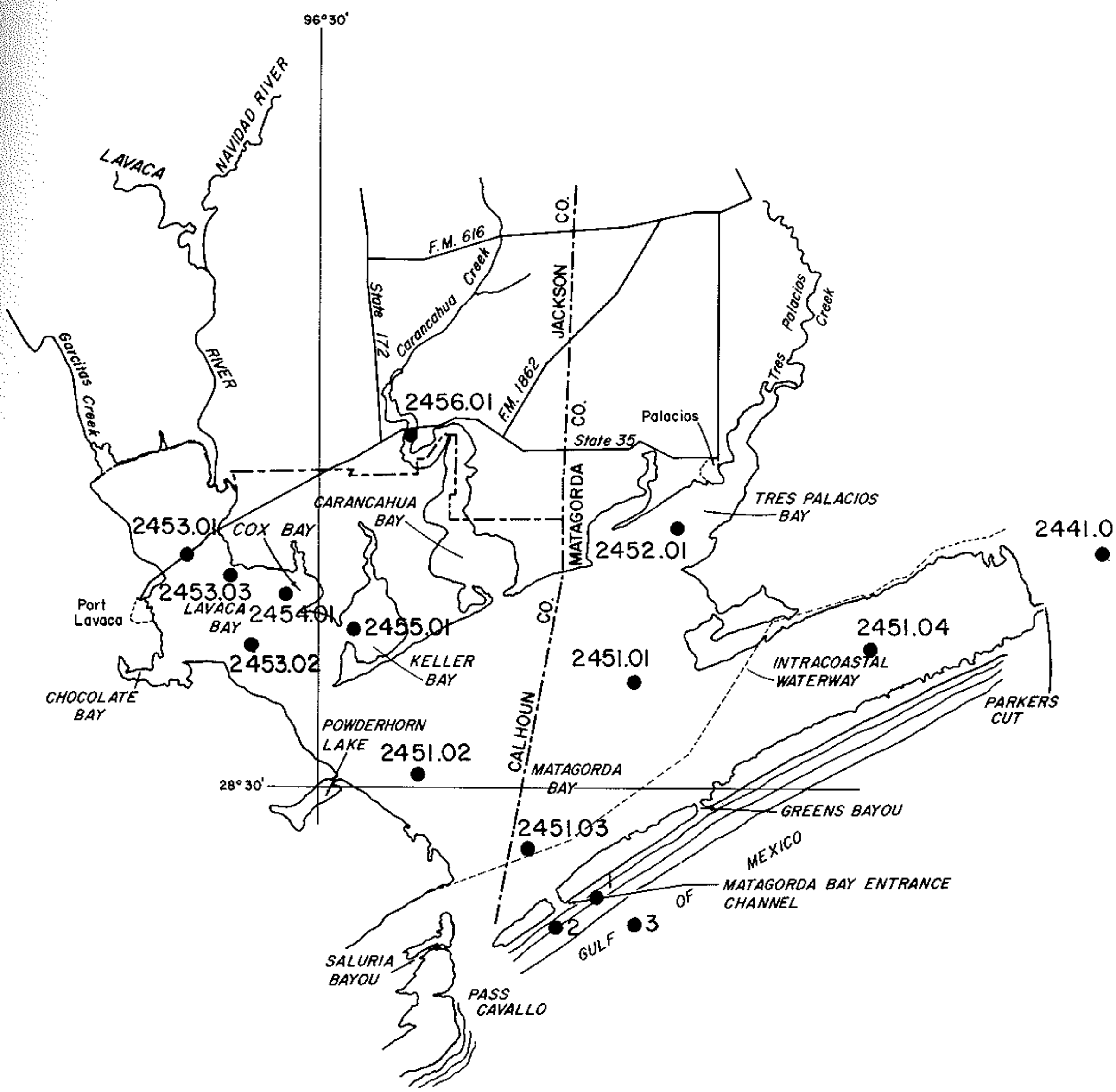
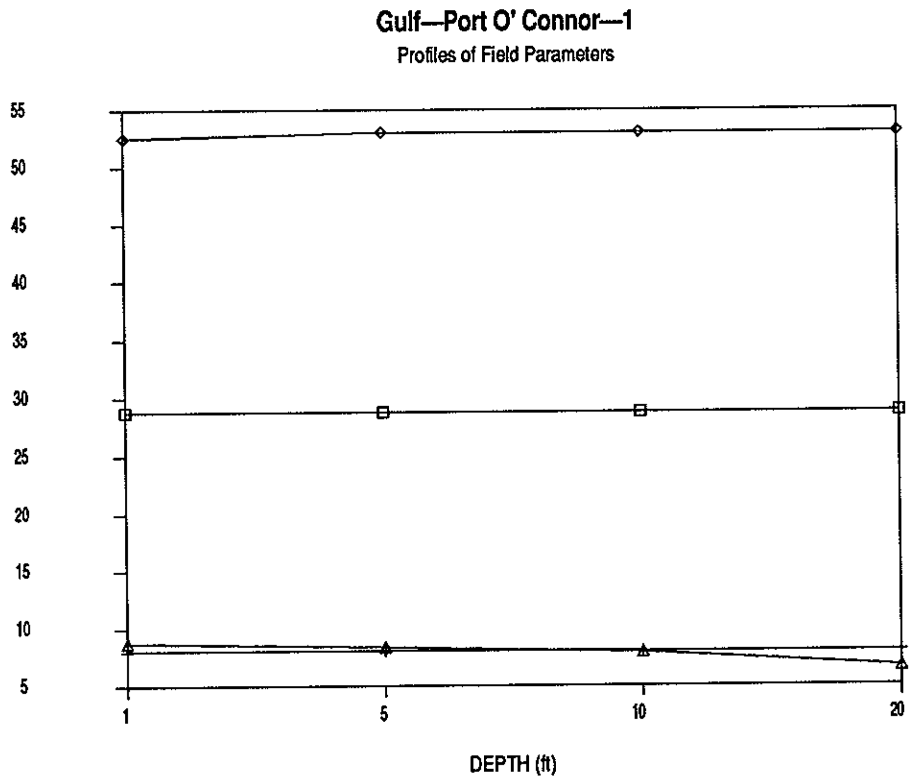


Figure 7

Stream Monitoring Network Station Locations in the Matagorda Bay System and Sample Locations Near the Port O' Connor Gulf Jetties



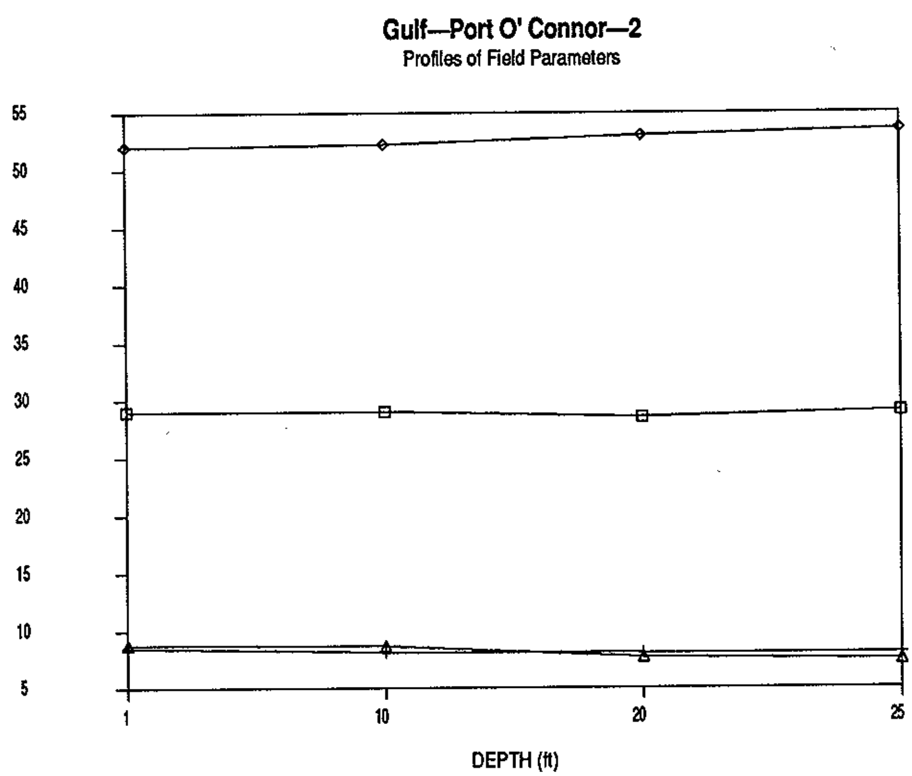
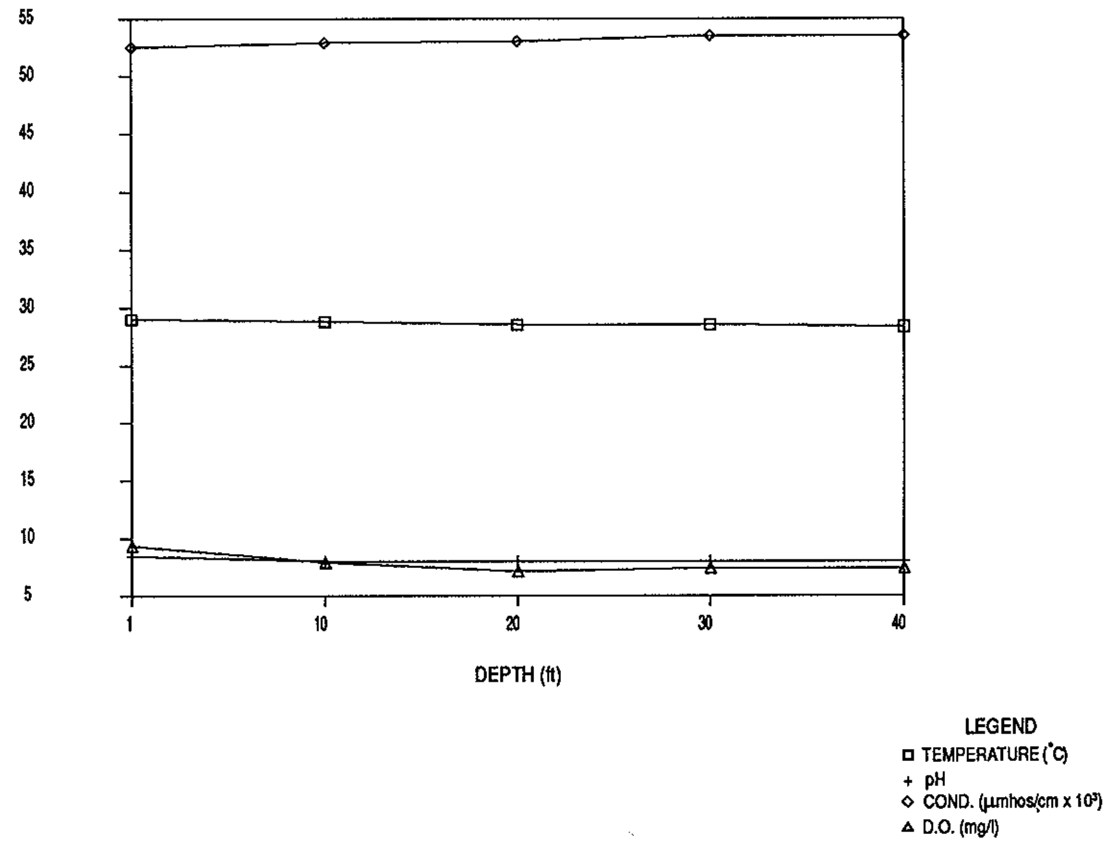


Figure 8.—Field Measurements From the Gulf of

Gulf—Port O' Connor—3

Profiles of Field Parameters



From the Gulf of Mexico—Port O' Connor Jetties

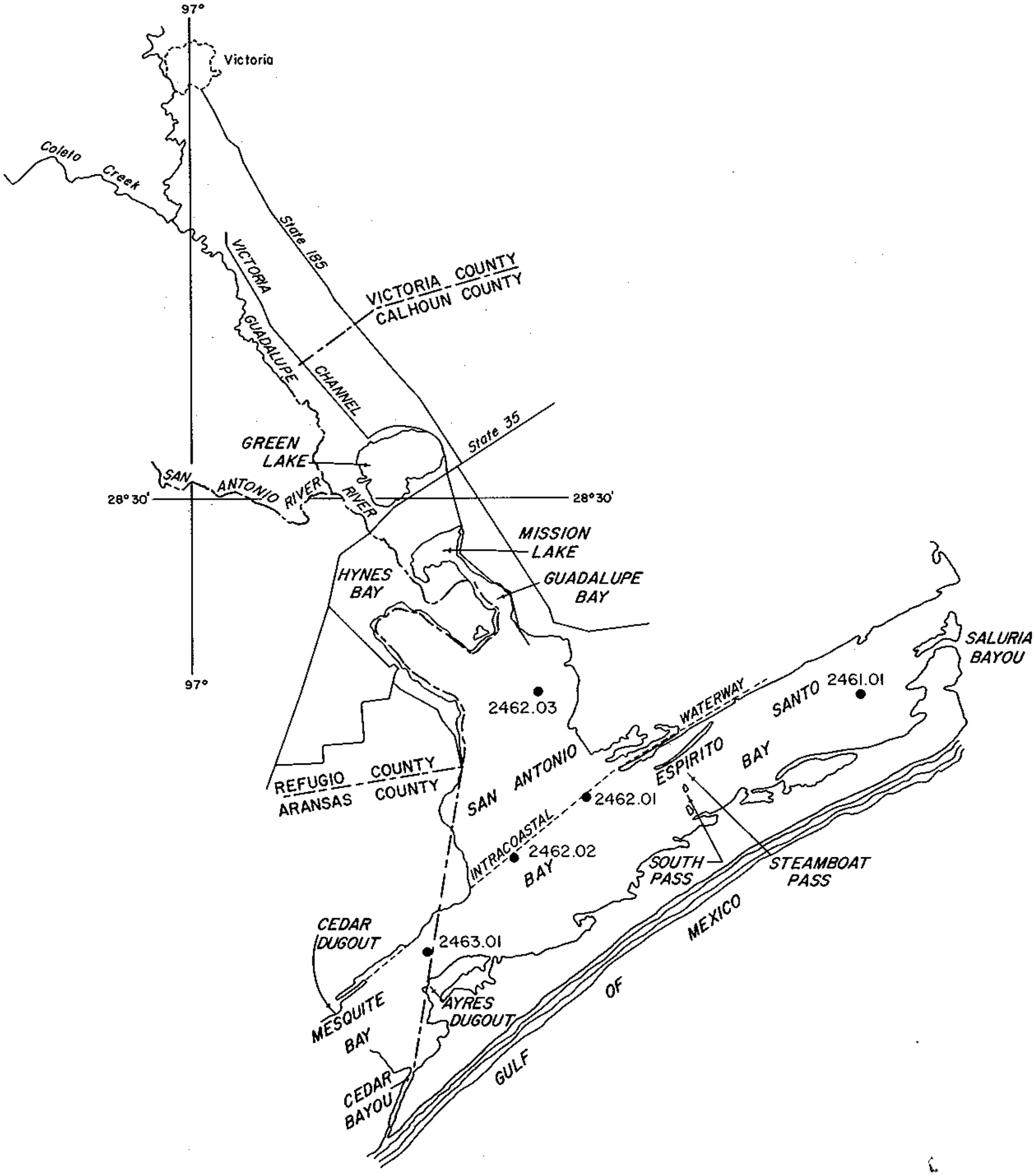
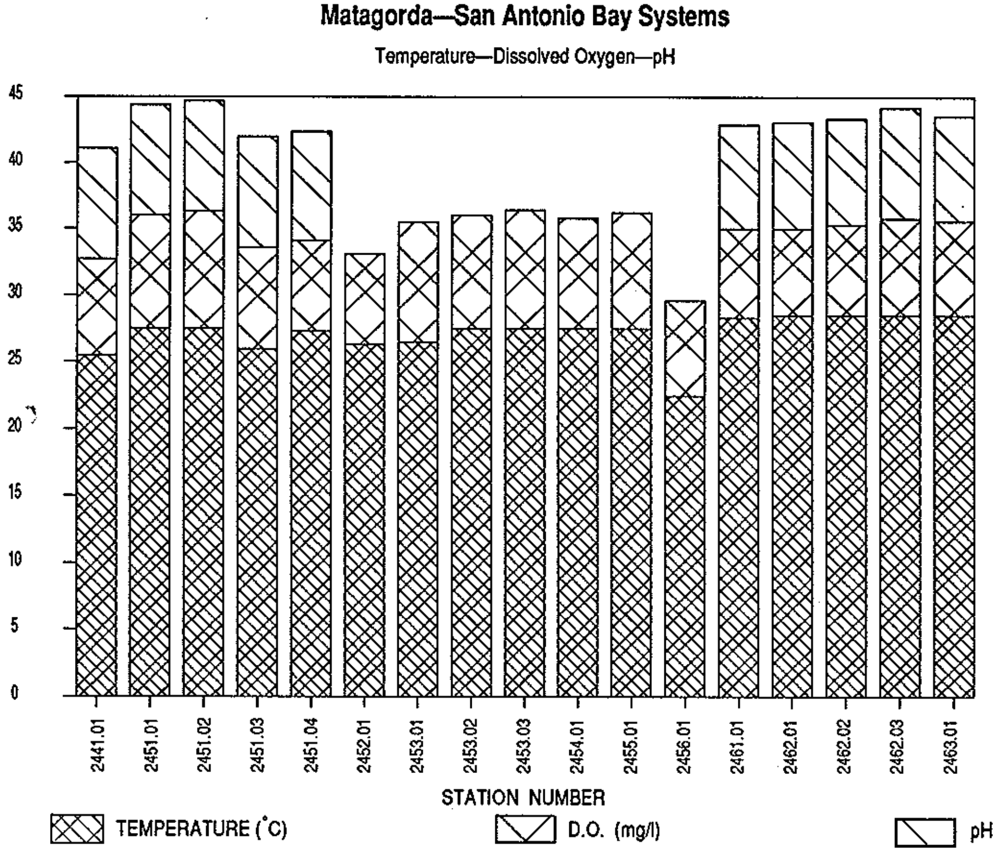


Figure 9

Stream Monitoring Network Stations in the San Antonio Bay System



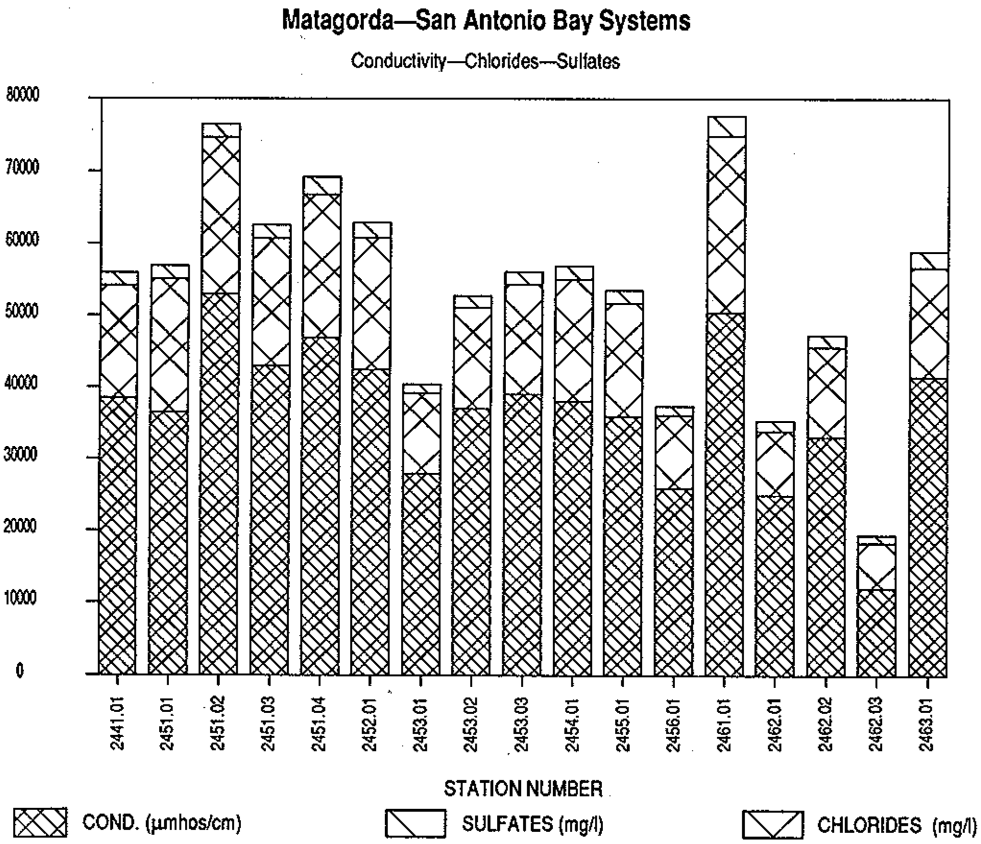
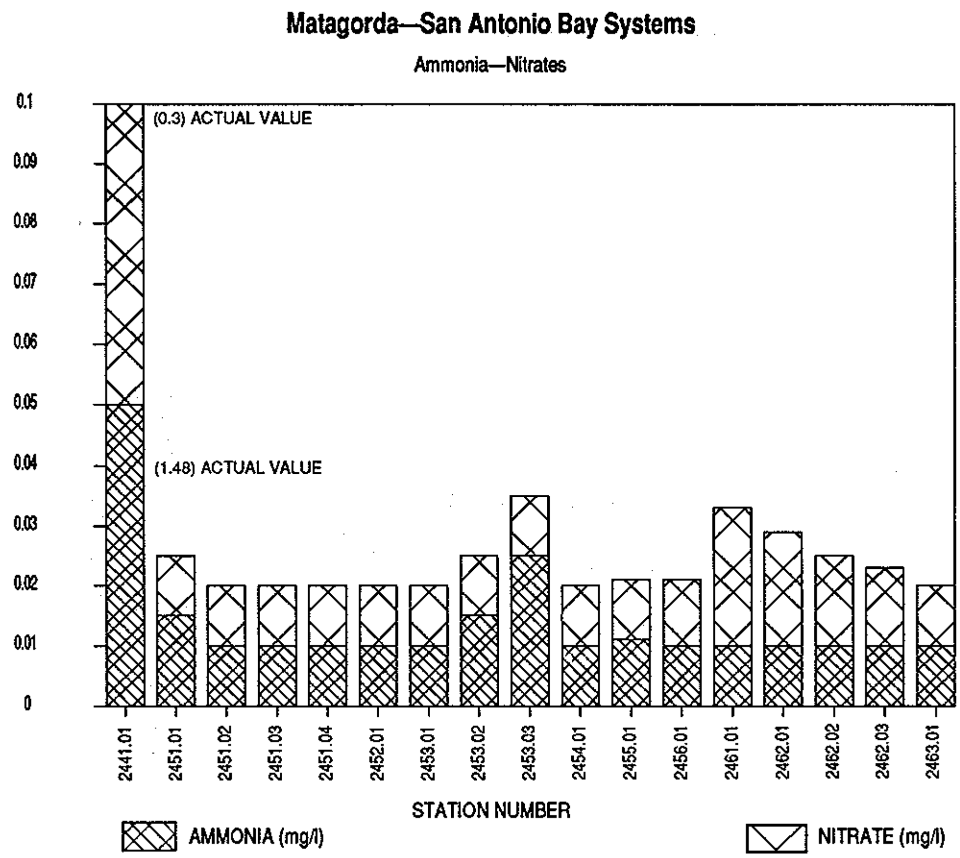


Figure 10.—Field Measurements and Laboratory Analyses From TWC Stream Monitoring Network Stations



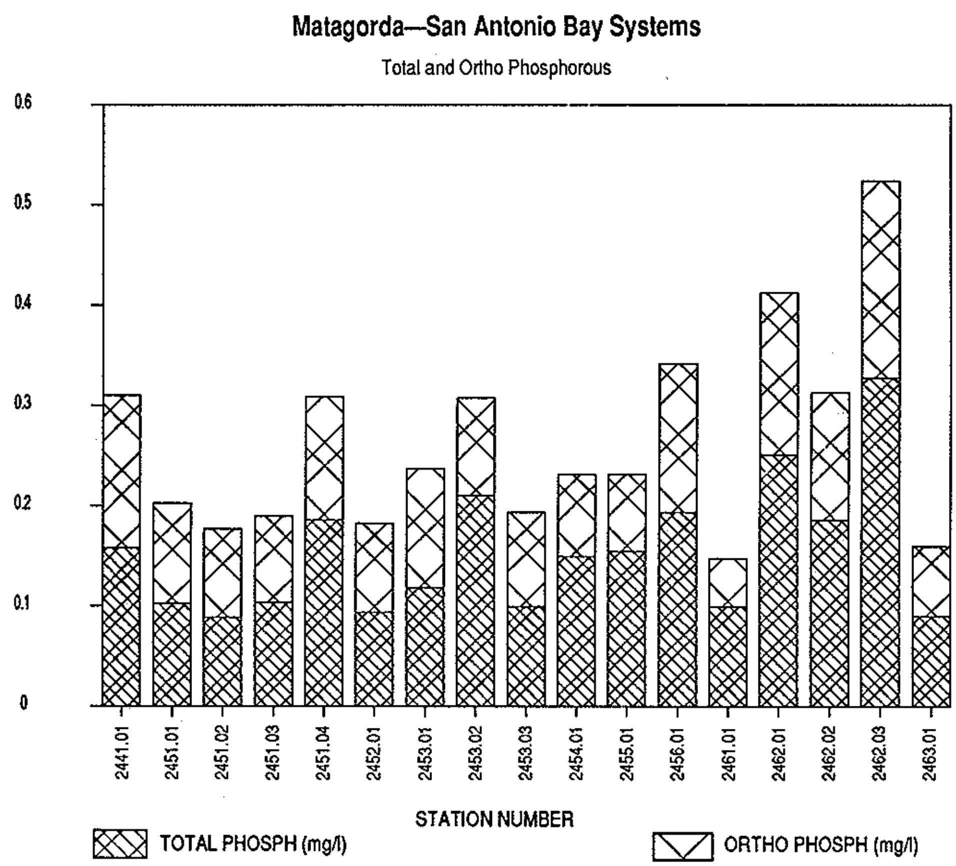
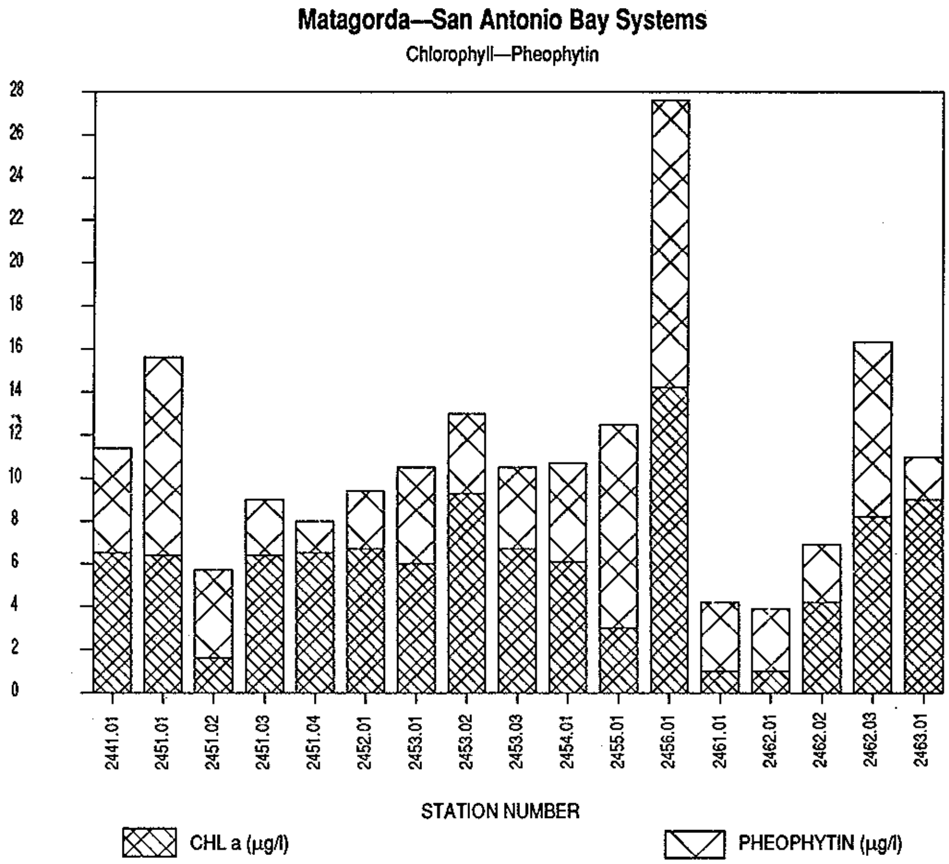


Figure 11.—Field Measurements and Laboratory Analyses From TWC Stream Monitoring Network Stations



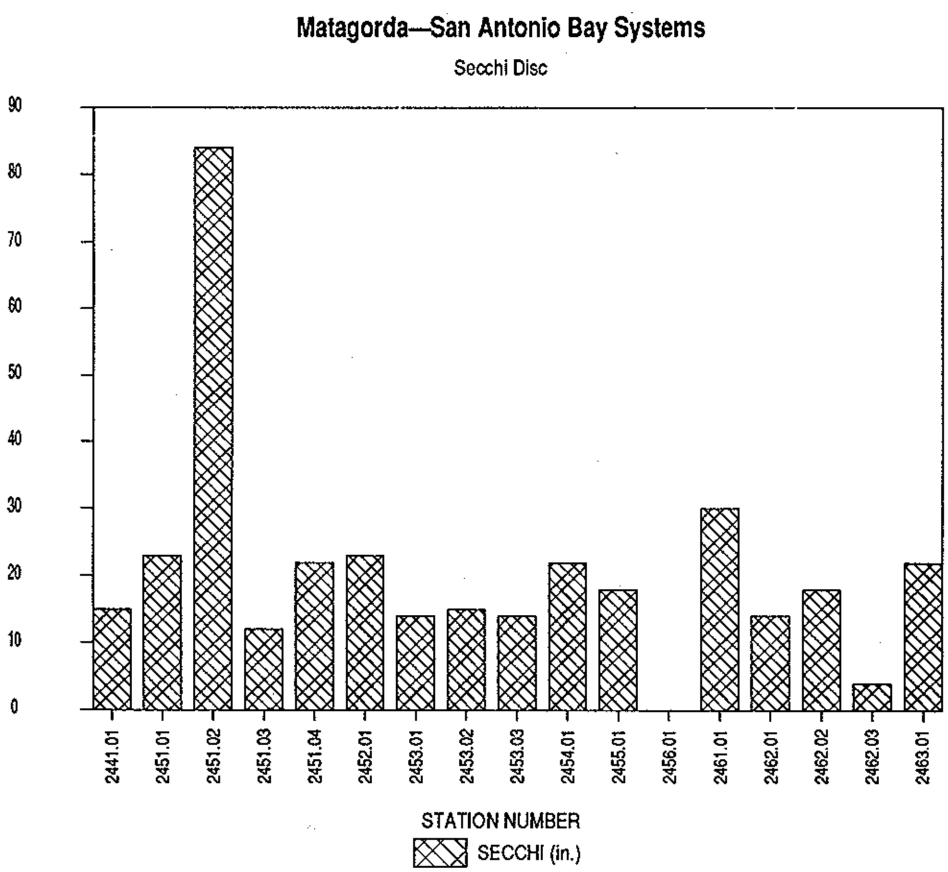


Figure 12.—Field Measurements and Laboratory Analyses From TWC Stream Monitoring Network Stations

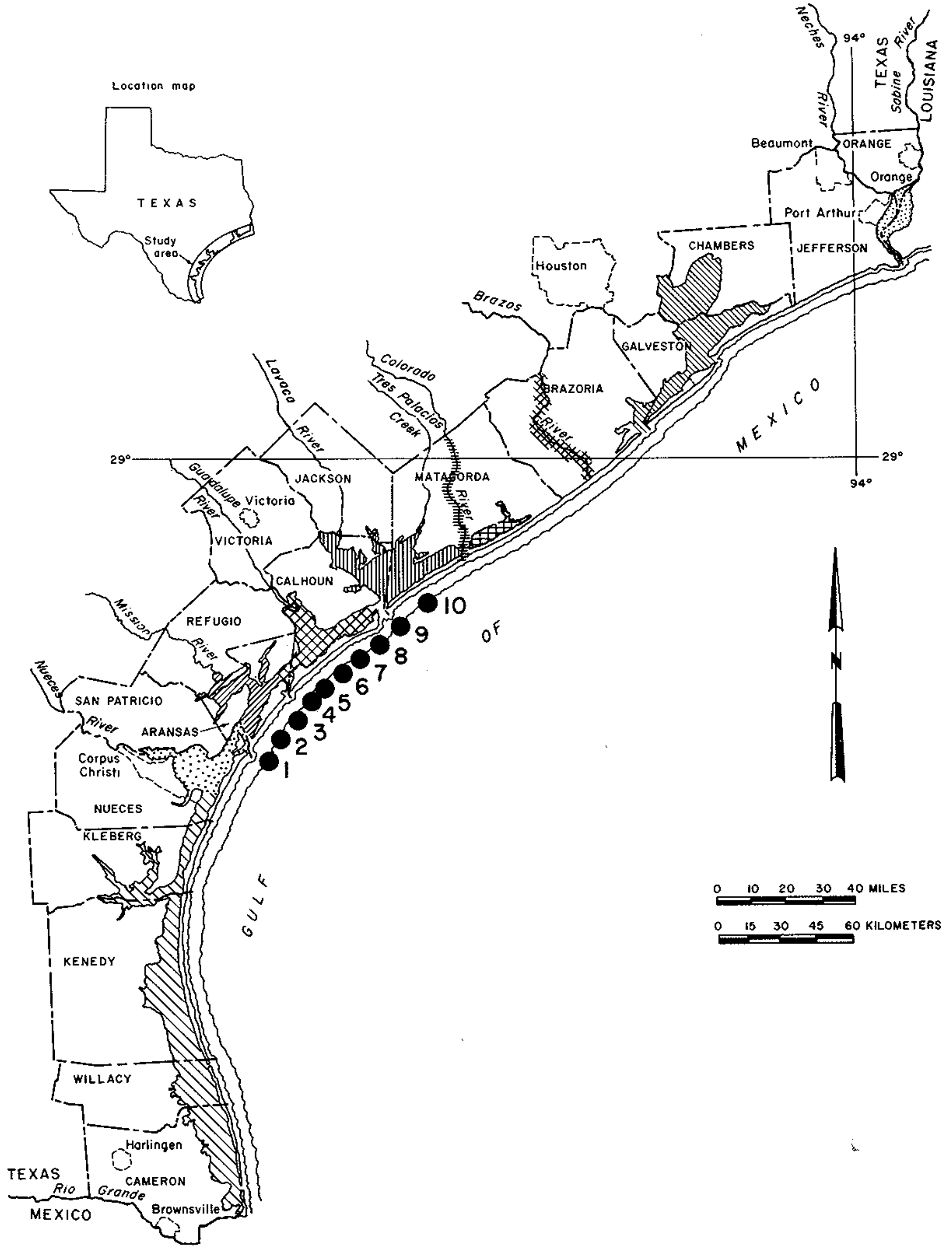
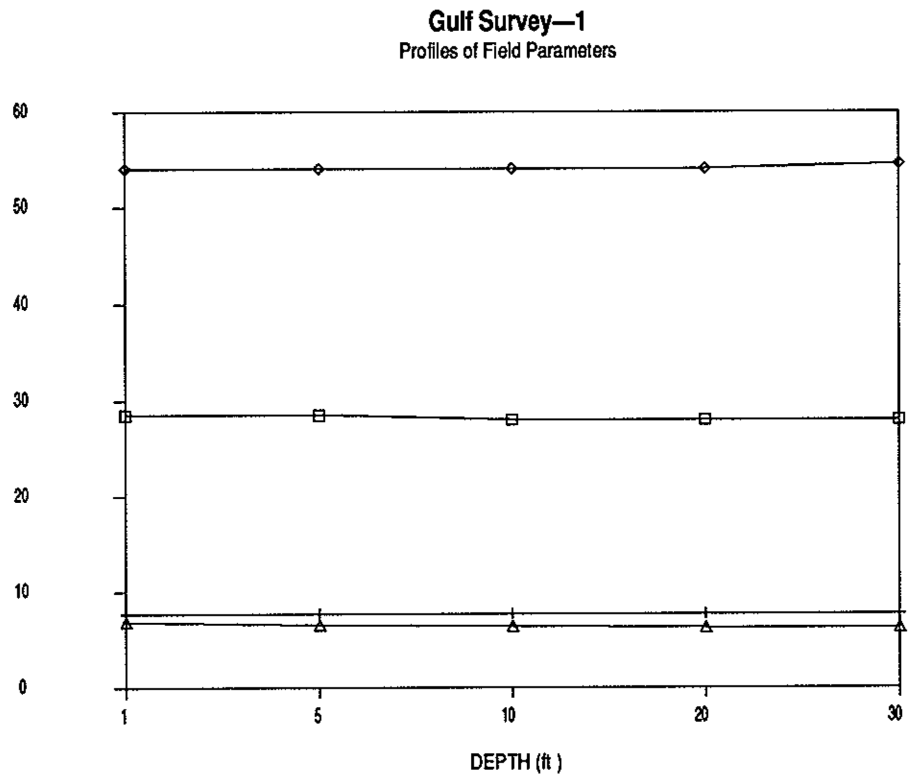


Figure 13

Gulf Sample Locations From Port Aransas to Port O' Connor

Base from Official State Highway Map of Texas, 1971



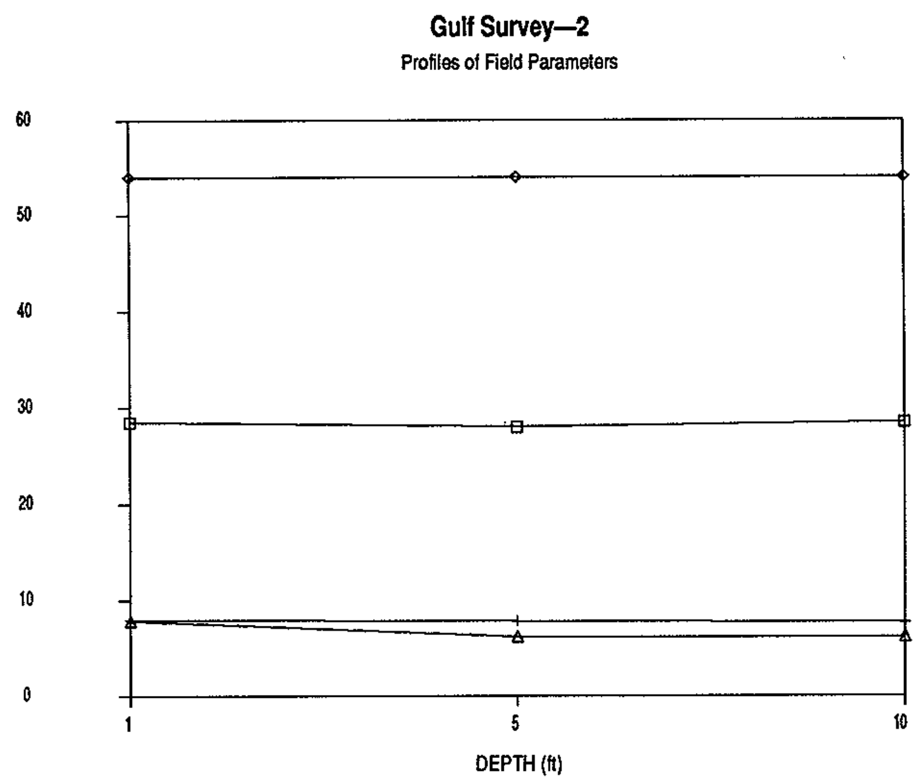
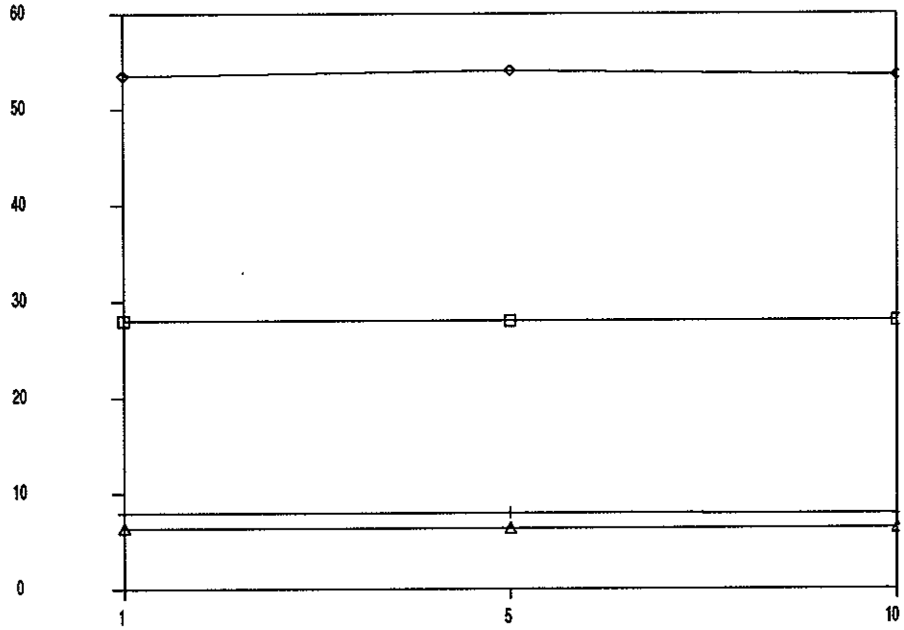


Figure 14A.—Field Measurements at Variou
Port Aransas to Port O' (

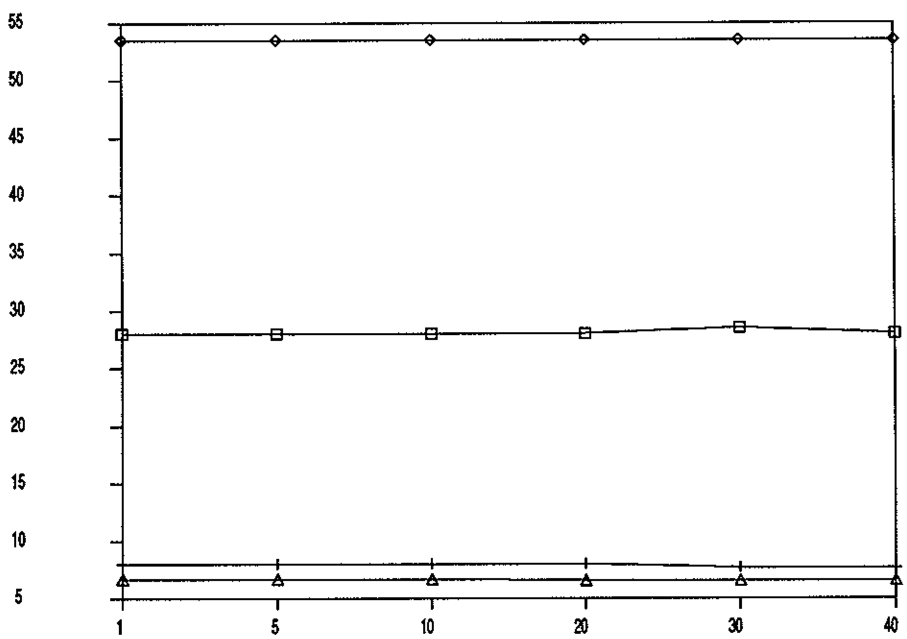
Gulf Survey—3

Profiles of Field Parameters



Gulf Survey—4

Profiles of Field Parameters

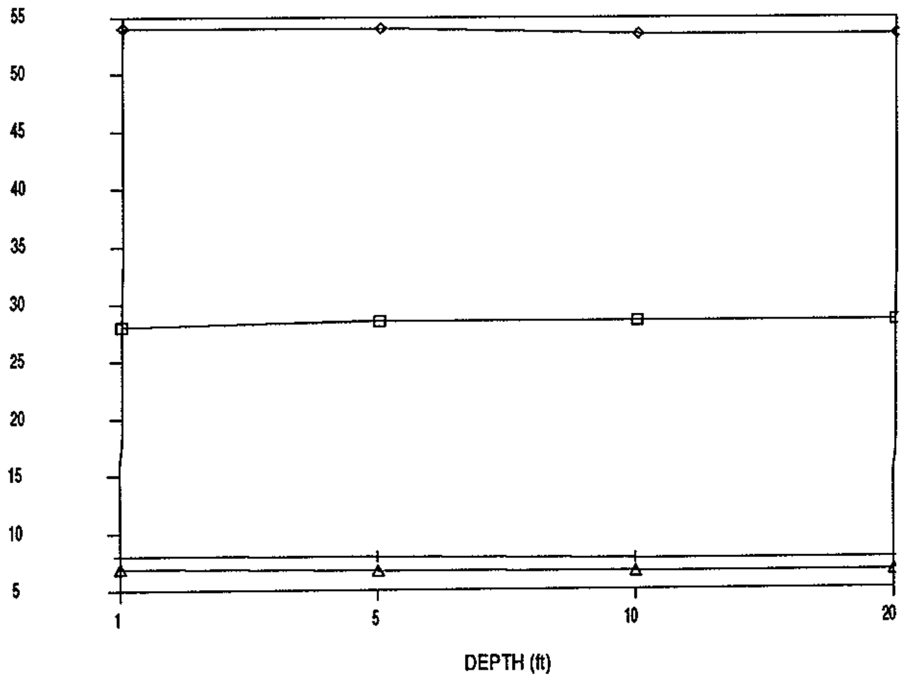


LEGEND
- □ TEMPERATURE (°C)
- + pH
- ◇ COND. (µmhos/cm x 10³)
- △ D.O. (mg/l)

ments at Various Depths in Gulf Waters—
ısas to Port O' Connor

Gulf Survey—5

Profiles of Field Parameters



Gulf Survey—6

Profiles of Field Parameters

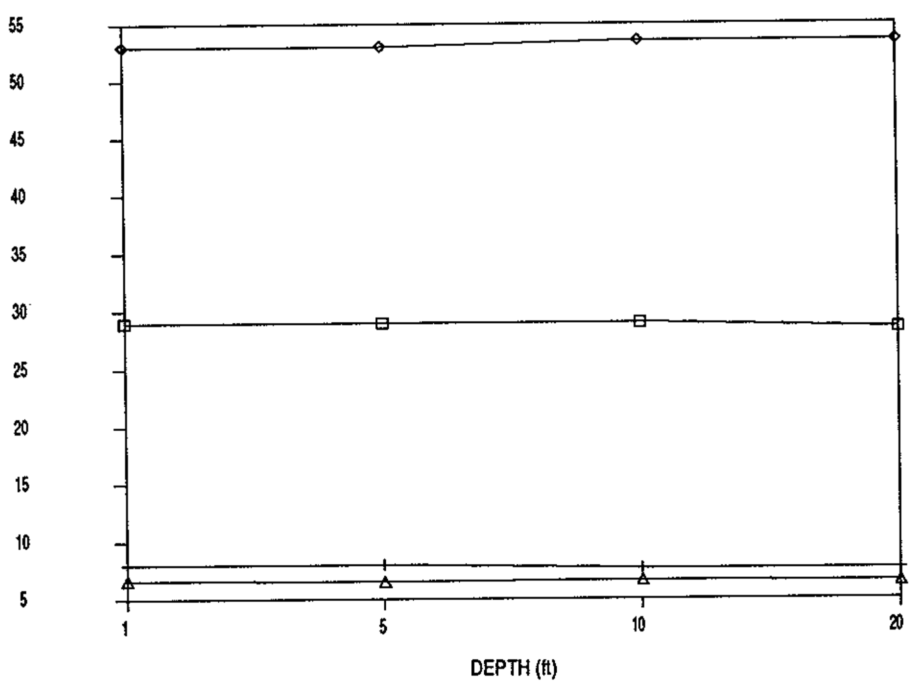
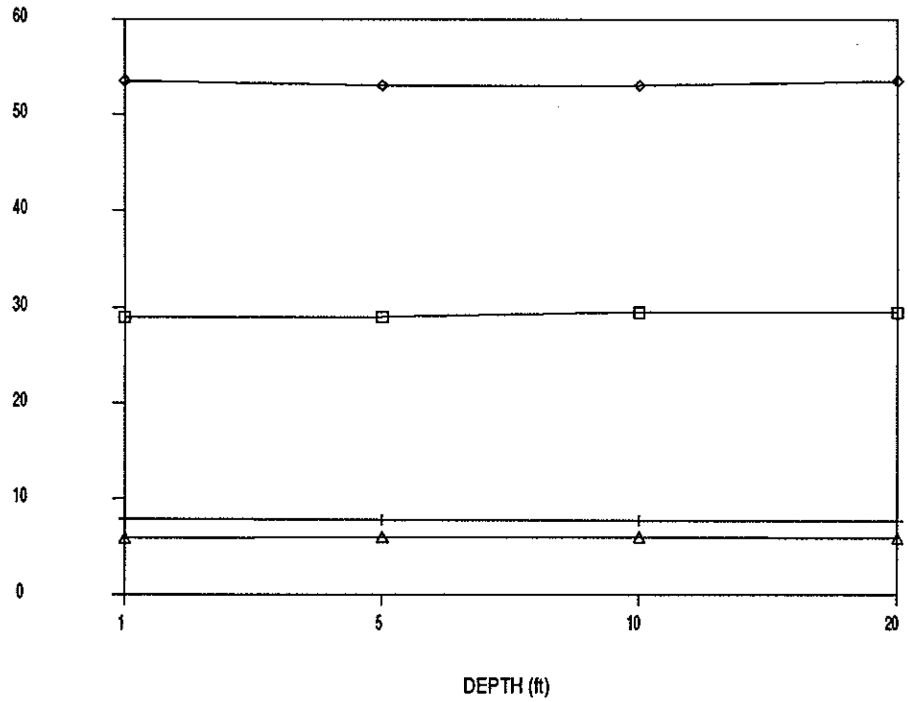


Figure 14B.—Field Measurements at Vario
Port Aransas to Port O

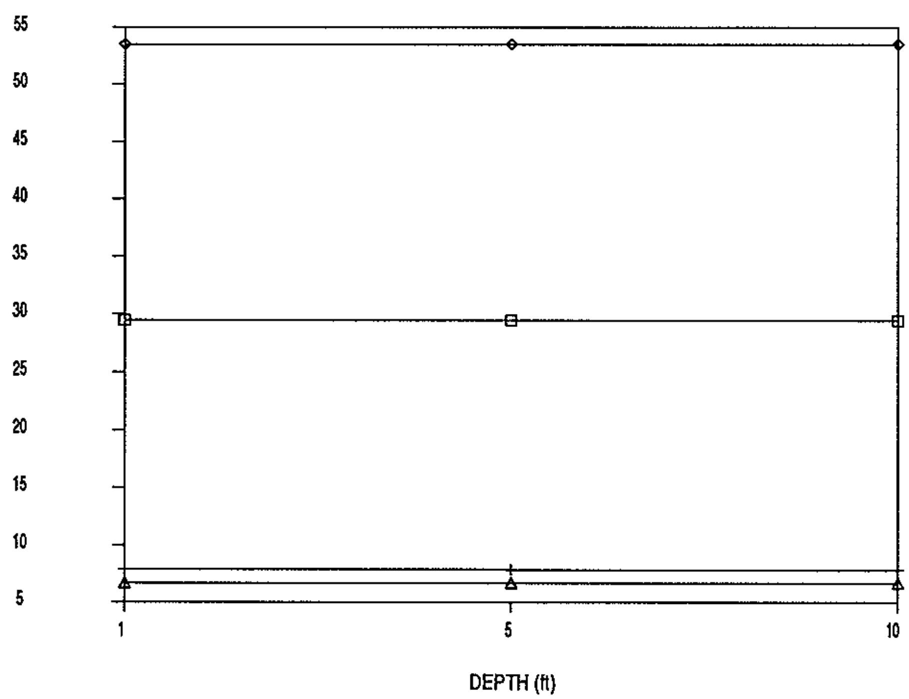
Gulf Survey—7

Profiles of Field Parameters



Gulf Survey—8

Profiles of Field Parameters

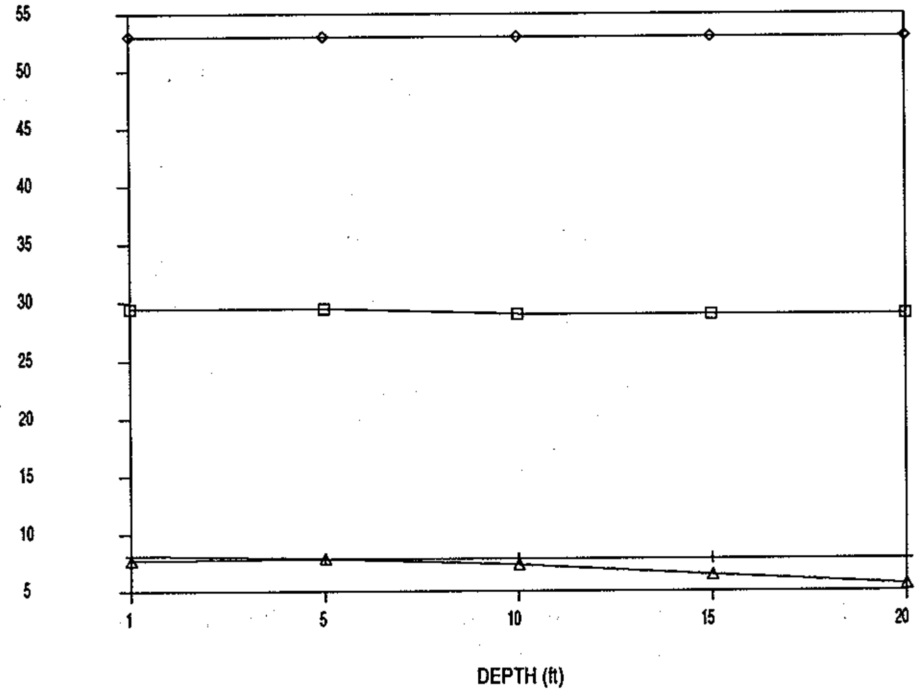


ements at Various Depths in Gulf Waters—
ansas to Port O'Connor

LEGEND
□ TEMPERATURE (°C)
+ pH
◇ COND. (µmhos/cm x 10³)
△ D.O. (mg/l)

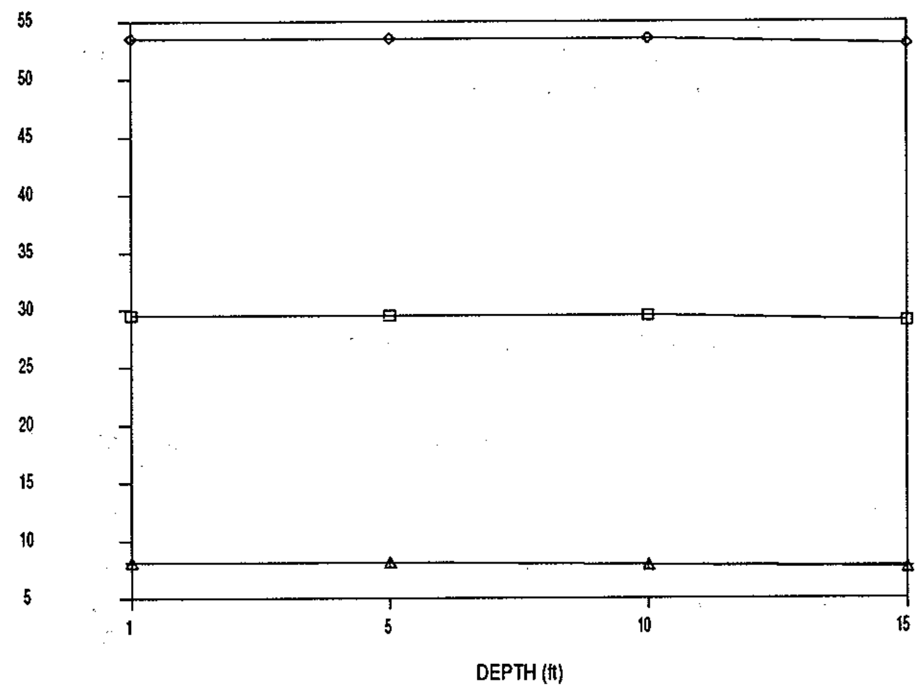
Gulf Survey—9

Profiles of Field Parameters



Gulf Survey—10

Profiles of Field Parameters



LEGEND
- □ TEMPERATURE (°C)
- + pH
- ◇ COND. (µmhos/cm x 10³)
- △ D.O. (mg/l)

Figure 14B. Continued

Table 4.—Densities of *P. brevis* (#/ml) at Various Depths in Gulf Waters—Port Aransas to Port O'Connor

Sample site	1 (ft)	5 (ft)	10 (ft)	15 (ft)
1	0	0	0	-
2	0	0	0	-
3	0	0	0	-
4	94	0	0	-
5	0	0	0	-
6	94	94	117	-
7	0	0	47	-
8	3384	7685	3878	-
9	12666	11586	4724	729
10	7278	2608	587	493

Table 5.—Densities of *P. brevis* (#/ml)—Corpus Christi Bay System and Aransas Bay System

Map location	Sample site	Density
A	Corpus Christi Bay-Mid Bay	5428
B	NW Corpus Christi Bay	4230
C	Corpus Christi Ship Chan. & ICW	3595
D	La Quinta Chan. at Ingleside	12220
E	End of La Quinta Channel	3760
F	Aransas Bay at Mud Island	17789

Table 6.—Field Parameters—Corpus Christi Bay and Aransas Bay

	Map location D	Map location F
Temperature (°C)	27.3	27.1
pH	8.5	8.2
Conductivity (µmhos/cm)	54400	57200
Dissolved Oxygen (mg/l)	14.1	10.2
Secchi (in.)	36	38

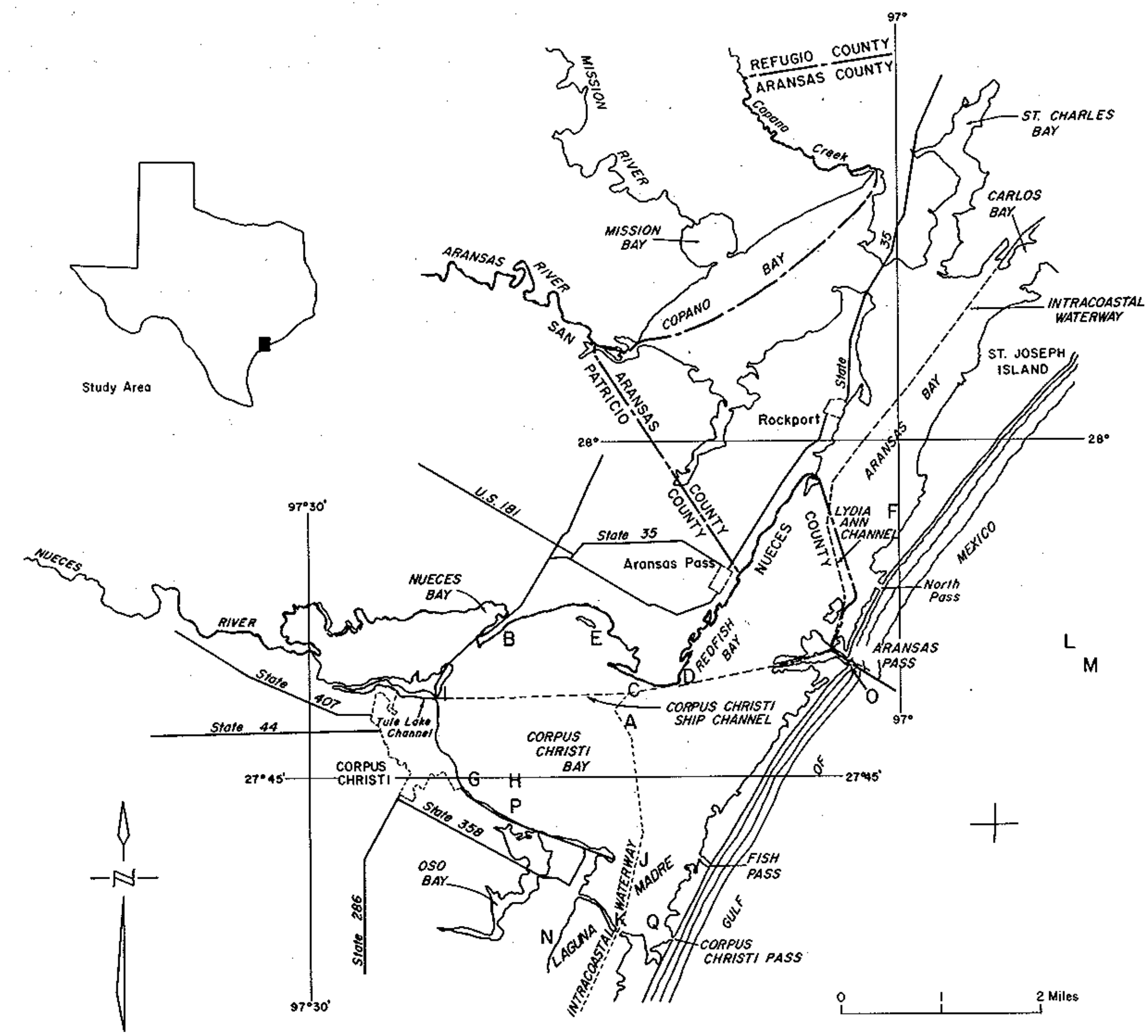


Figure 15
Plankton Sample Locations in the Corpus Christi Bay System

16 October 1986

TWC personnel sampled plankton in Corpus Christi Bay, Laguna Madre, Redfish Bay and the Gulf of Mexico (Figure 15, Table 7). Investigators reported aerosol irritation offshore and at bay sites along with widespread fish kills.

16 October 1986

TWC personnel collected samples near the Port Mansfield area in Laguna Madre and at the Port Mansfield Gulf Jetties (Table 8; Figure 16). Thousands of dead fish floated in and out of Port Mansfield channel including mullet, menhaden, Speckled Sea Trout, Sea Catfish and approximately 50 Red Drum > 30 inches (total length). Investigators reported respiratory irritation and discolored water at jetties, but not in Laguna Madre. *P. brevis* was identified in Gulf samples, but not in Laguna Madre samples.

19 October 1986

Plankton samples taken in Laguna Madre at Baffin Bay and at Bird Island contained no *P. brevis* (Figure 16).

22 October 1986

Plankton samples from Central Power and Light-Barney Davis power plant intake were analyzed by the TWC. The samples contained 1,750 cells per ml (Figure 15-N).

23 October 1986

TWC personnel sampled plankton at Port Aransas jetties and portions of Corpus Christi Bay (Figure 15; Table 9).

Table 7.—Densities of *P. brevis* (#/ml)—Corpus Christi Bay System

Map location	Sample site	Density
G	Corpus Christi Bay off Airline Rd	30785
H	Corpus Christi Bay off Cole Park	21056
I	Corpus Christi Bay at Port Entrance	0
J	Corpus Christi Bay at Laguna Madre	423
K	Laguna Madre at Spid (SH 358)	446
L	Gulf at 18 Fathom Rig	117
M	Gulf 1 mi. W. of 18 Fathom Rig	1128

Table 8.—Water Chemistry—Port Mansfield Area

Location	Sample site	Depth (ft)	Temp (°C)	pH	Cond (μmhos/cm)	D.O. (mg/l)
A	P. Mansf. Ship Channel	1	25.2	8.2	54100	6.6
B	Laguna Madre S of P. Mansf.	1	25.1	8.2	54200	6.6
C	P. Mansf. Jetties	1	25.2	8.2	54000	6.2
		5	25.2	8.2	54300	6.2
		20	25.1	8.1	54300	6.1

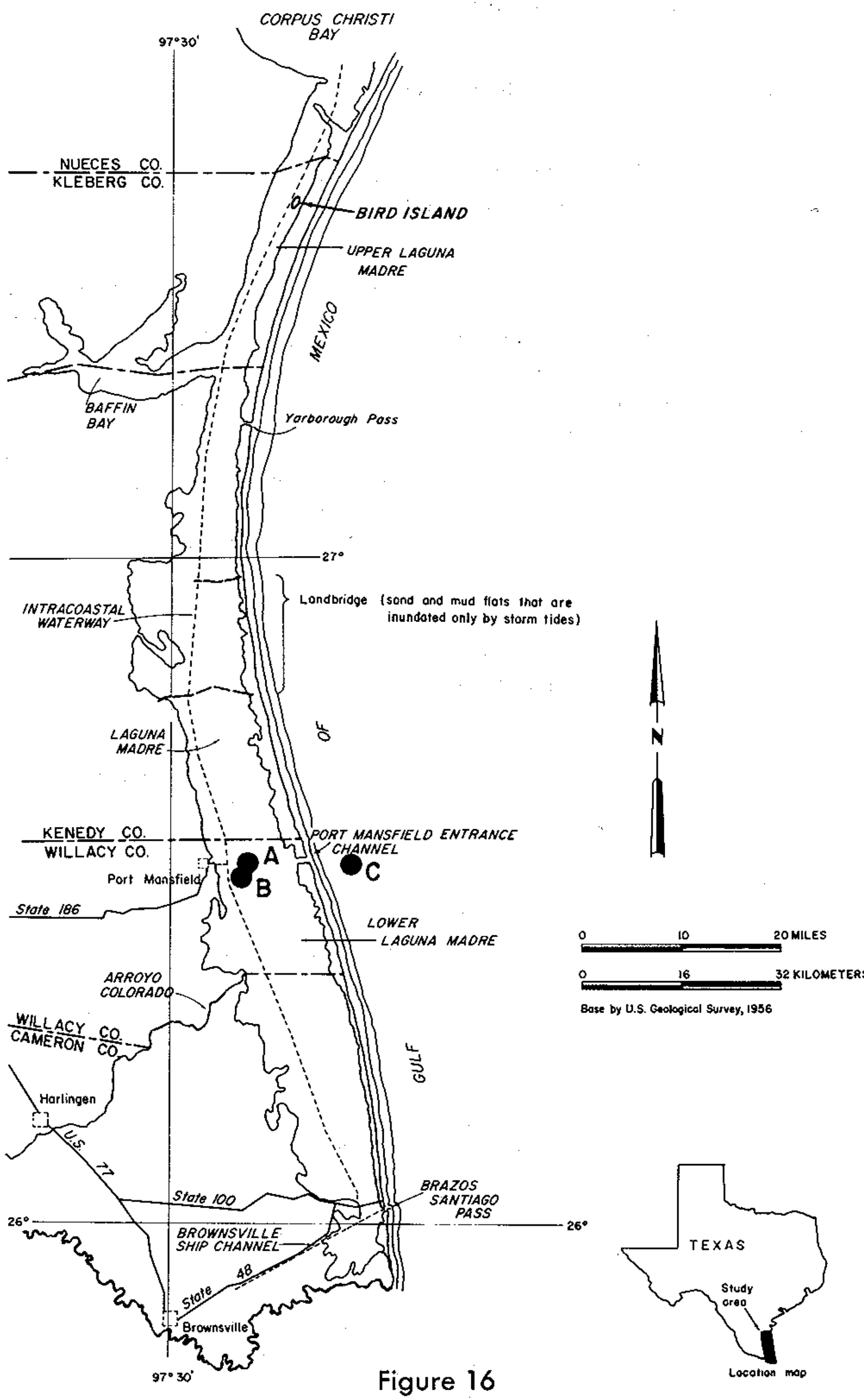


Figure 16

Sample Locations in Laguna Madre and the Gulf at the Port Mansfield Ship Channel

Table 9.—Densities of *P. brevis* (#/ml)—Corpus Christi Bay System

Map location	Sample site	Density
O	Port Aransas Jetties	260
P	Corpus Christi Bay at Swantner Park	40
Q	Padre Island Subdivision Canals	50

3 November 1986

TWC coastal monitoring program water chemistry samples (Figures 18-20) were taken in Corpus Christi Bay at mid bay and along the southwest shoreline (Figure 17). No red tide was observed.

4-6 November 1986

Plankton and water chemistry samples were taken from Colorado River to Mesquite Bay. Conductivity measurements indicate that these areas received substantial fresh water inflow as all bay conductivities were lower than September 1986 values (1986 TWDB Bays and Estuaries data). No *P. brevis* cells were detected in plankton samples.

18 November 1986

TWC coastal monitoring program water chemistry samples (Figures 18-20) were taken in Aransas Bay, Redfish Bay and in Corpus Christi Bay along its northern shore (Figure 17). No red tide was observed.

25 November 1986

TWC coastal monitoring program samples (Figures 18-20) were taken at northern mouth of Laguna Madre (Figure 17). No red tide was observed.

8 January 1987

TWC and TDH personnel sampled a localized, dense bloom of *P. brevis* along the south west shoreline of Corpus Christi Bay. Concentrations of *P. brevis* ranged from 60,000-100,000 cells/ml. Lower concentrations (<30 cells/ml) were detected throughout the bay.

2 February 1987

TWC and TDH personnel surveyed and sampled locations througout Aransas Bay, Redfish Bay, Corpus Christi Bay and the northern Laguna Madre. Although discolored water was observed along the southwestern portion of Corpus Christi Bay, the color was due to a bloom of *Prorocentrum* sp. and no *P. brevis* cells were found.

As part of its coastal monitoring program, the TWC sampled Redfish Bay (Figure 17) on monthly intervals. Chemical analyses from 8 August 1986- 5 January 1987 (Figure 21) provides data immediately prior to, during and after the *P. brevis* red tide.

DISCUSSION

Approximately 126 species of fish were reported by TPWD from red tide fish kills (Appendix B). Although many neritic species were affected, Striped Mullet and Gulf Menhaden were most abundant in dead fish counts, perhaps due solely to their high abundance food chain position as planktivores. Fish kill observations during this event agree with those from other red tides; a wide range of consumer levels and habitat specific fishes were affected (Steidinger and Joyce 1973, Quick and Henderson 1974).

The TPWD estimate of 22.2 million vertebrates and invertebrates killed during the red tide appears to be conservative. Data presented here produce an estimate of 1.7 million fish killed over just a two day period, and fish kills were reported for 28 days. The estimates of numbers of dead fish and species identification were complicated by wind shifts which moved dead fish from shore to shore, by currents that exchanged and scattered bay and Gulf species and by the sinking of some species in warm waters that hastened tissue decomposition.

P. brevis cell densities encountered in Gulf waters were comparable to Florida outbreaks (Morton and Burklew 1969, Steidinger and Joyce 1973). Sample results from the 16 September 1986 Gulf Survey revealed that high concentrations of *P. brevis* existed just below the water surface (1ft) and were

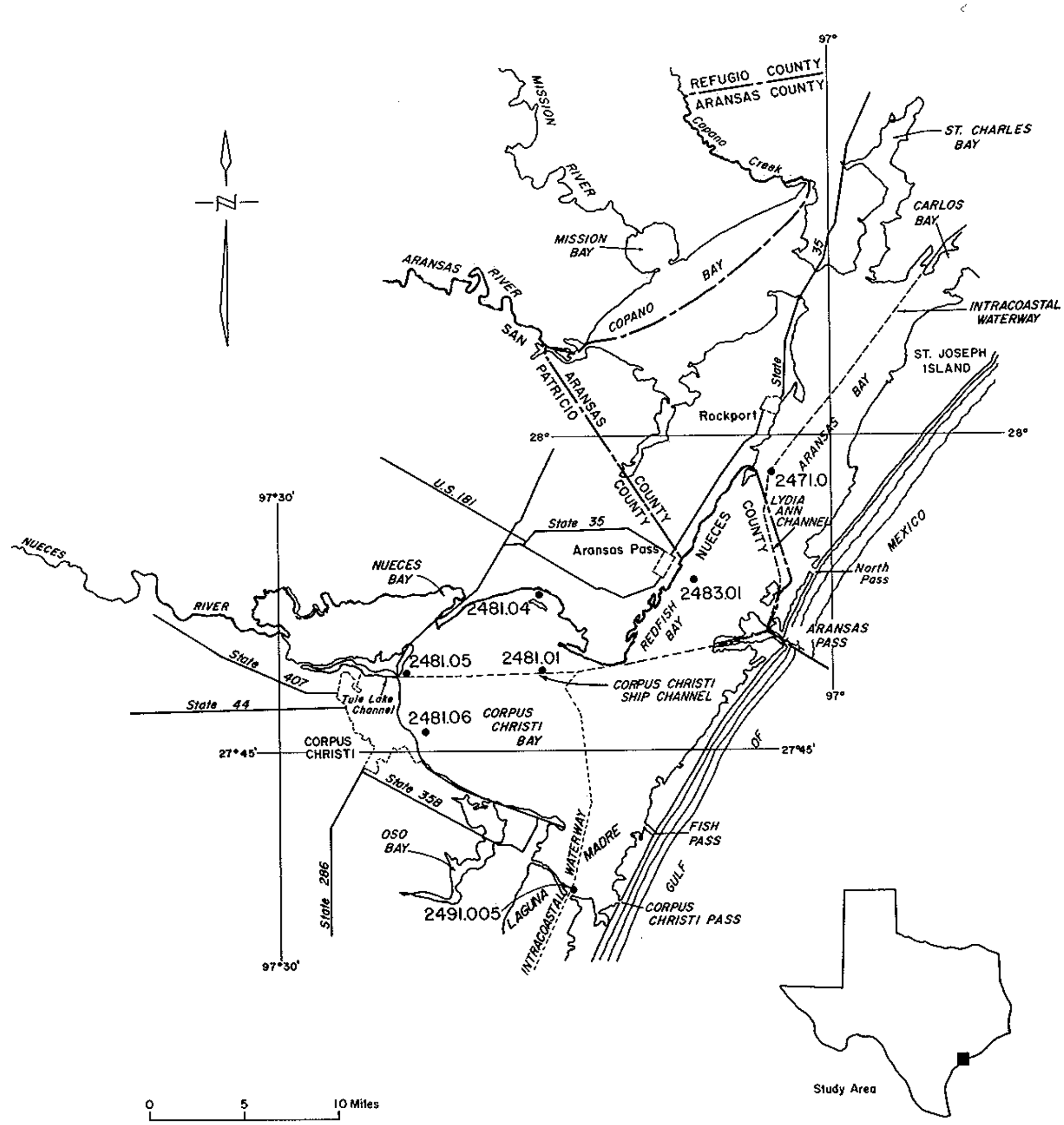
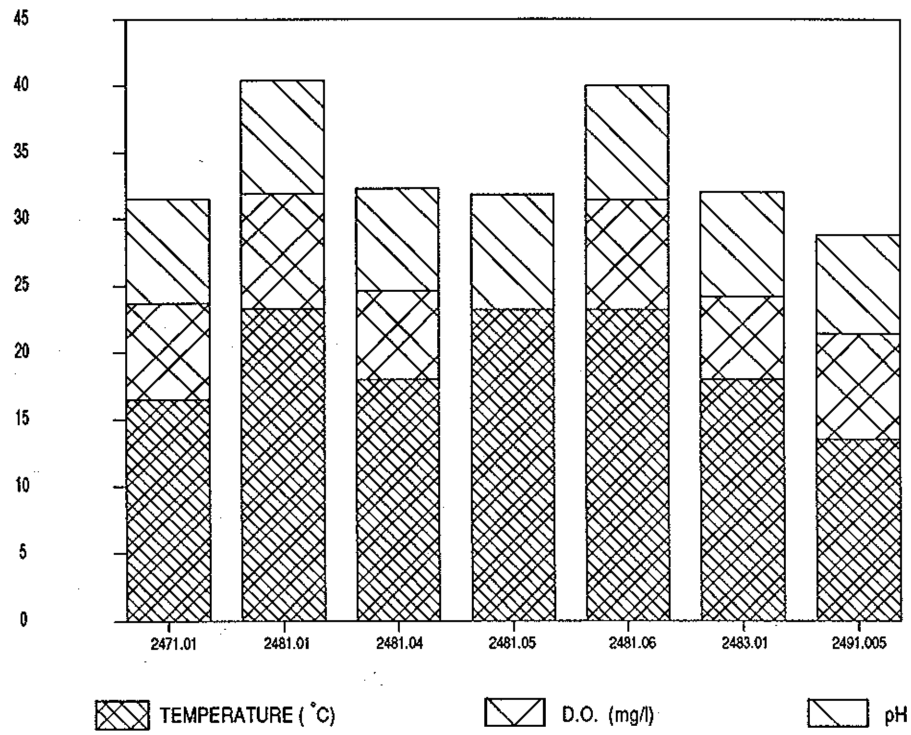


Figure 17

Stream Monitoring Network Stations in Aransas Bay, Redfish Bay, Corpus Christi Bay and Northern Laguna Madre

Corpus Christi—Redfish—Aransas Bays

Temperature—Dissolved Oxygen—pH



Corpus Christi—Redfish—Aransas Bays

Conductivity—Chlorides—Sulfates

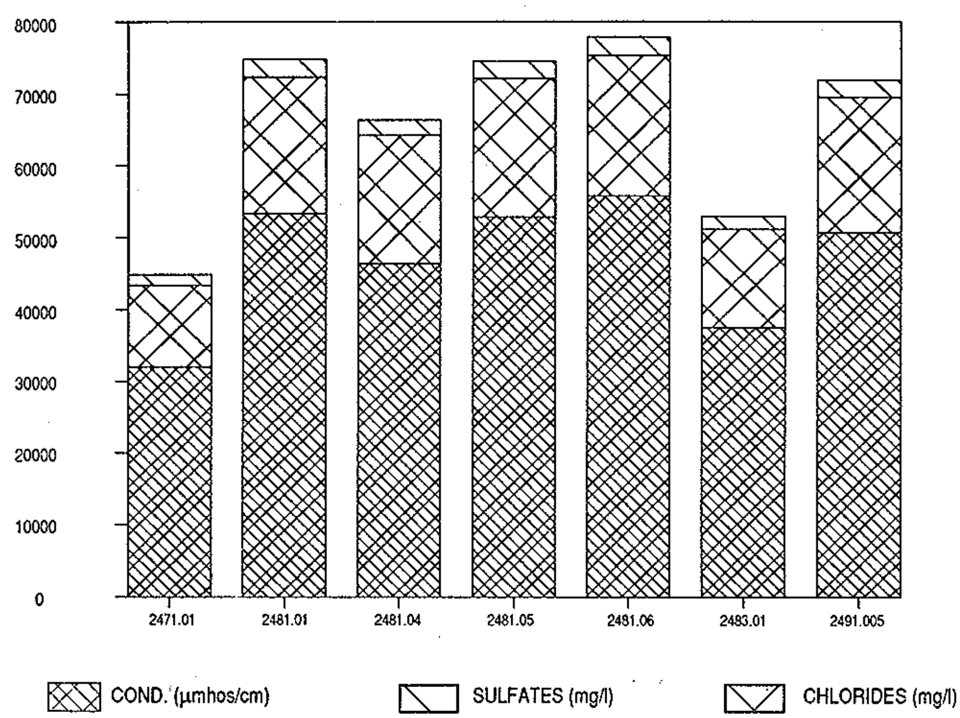
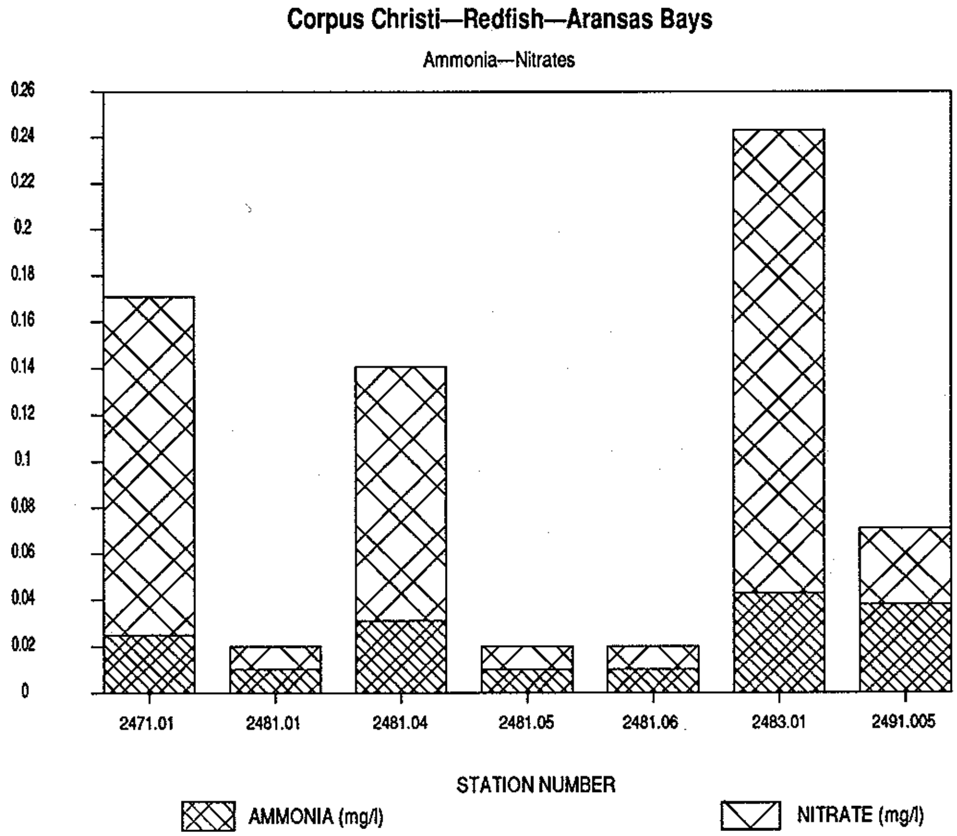


Figure 18.—Field Measurements and Laboratory Analyses From TWC Stream Monitoring Network Stations



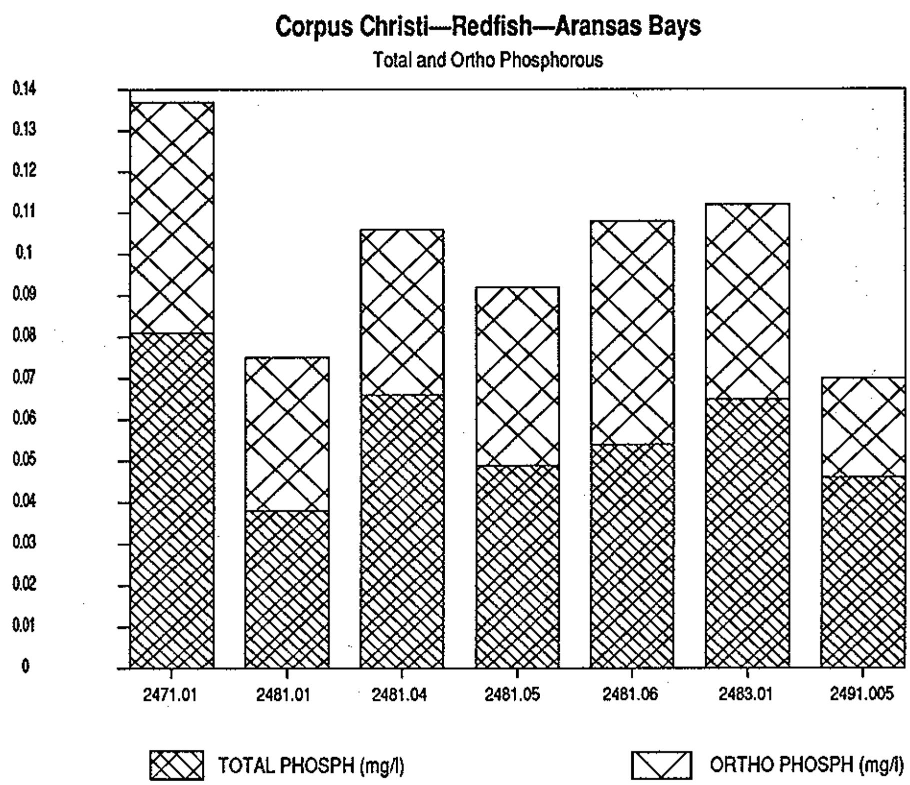
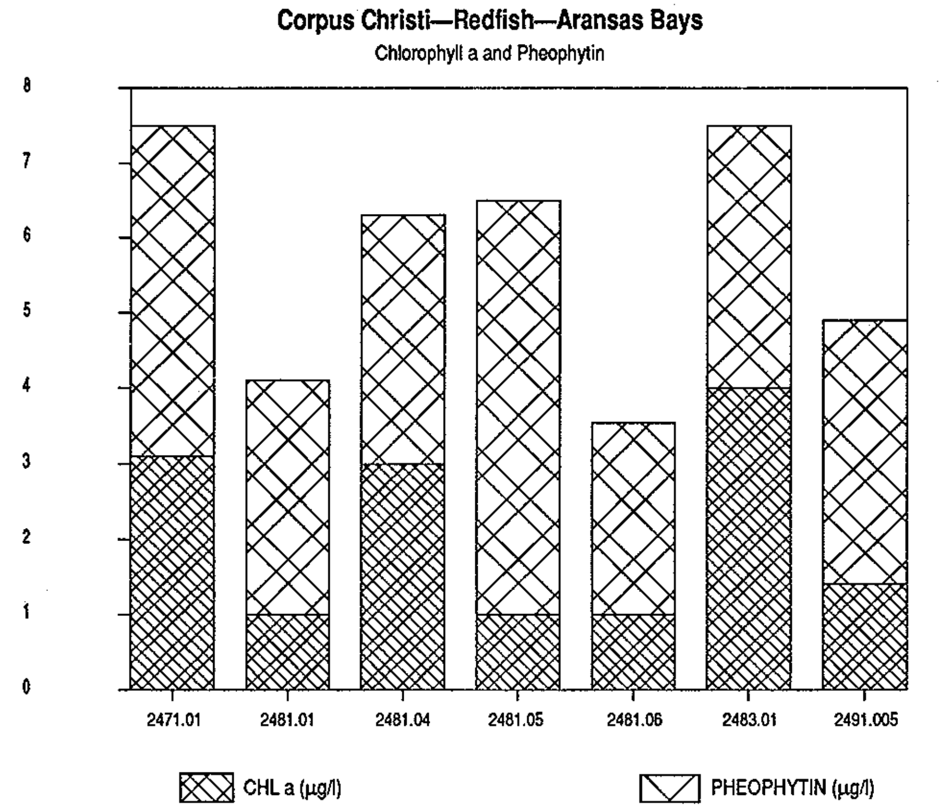


Figure 19.—Field Measurements and Laboratory Analyses From TWC Stream Monitoring Network Stations



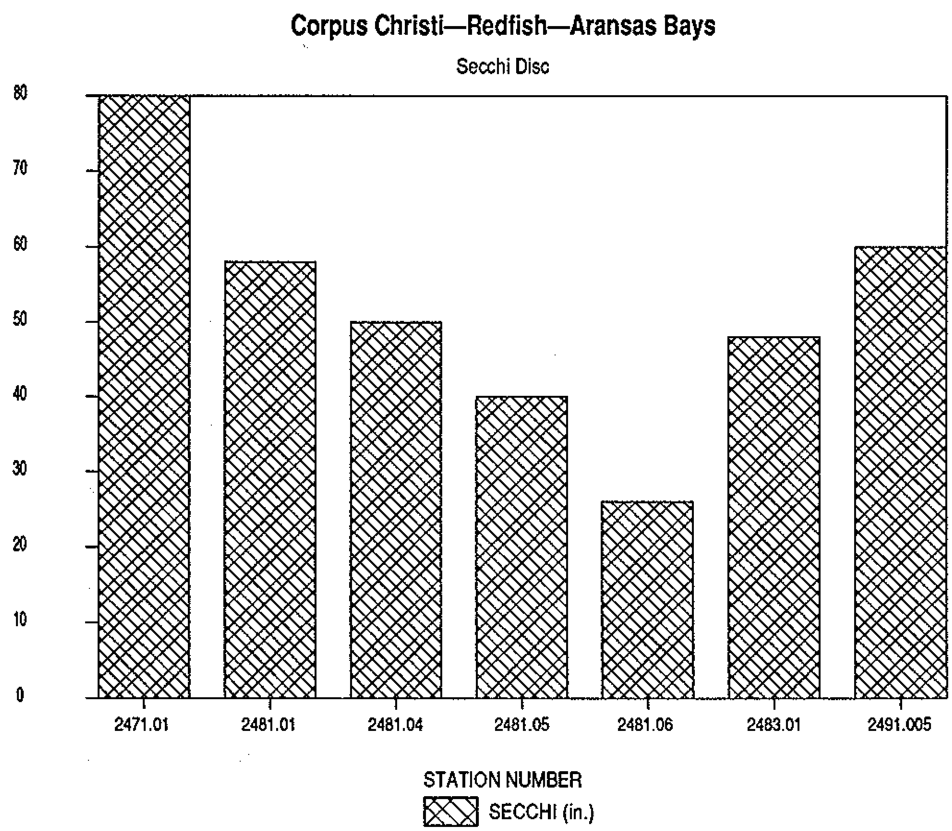
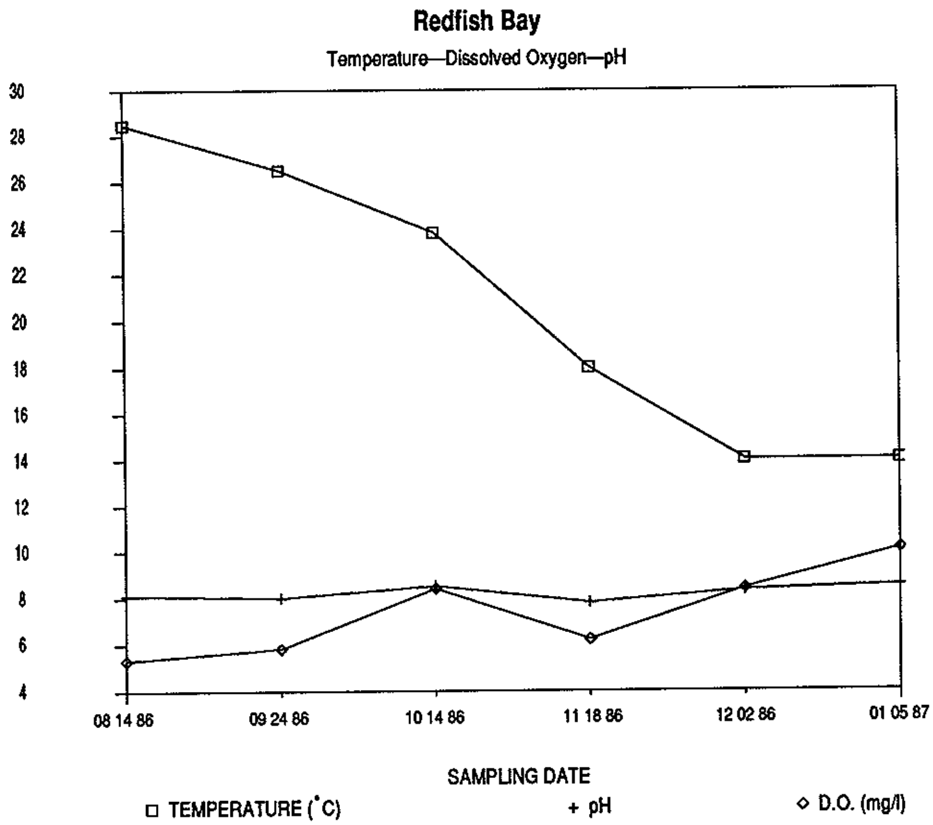


Figure 20.—Field Measurements and Laboratory Analyses From TWC Stream Monitoring Network Stations



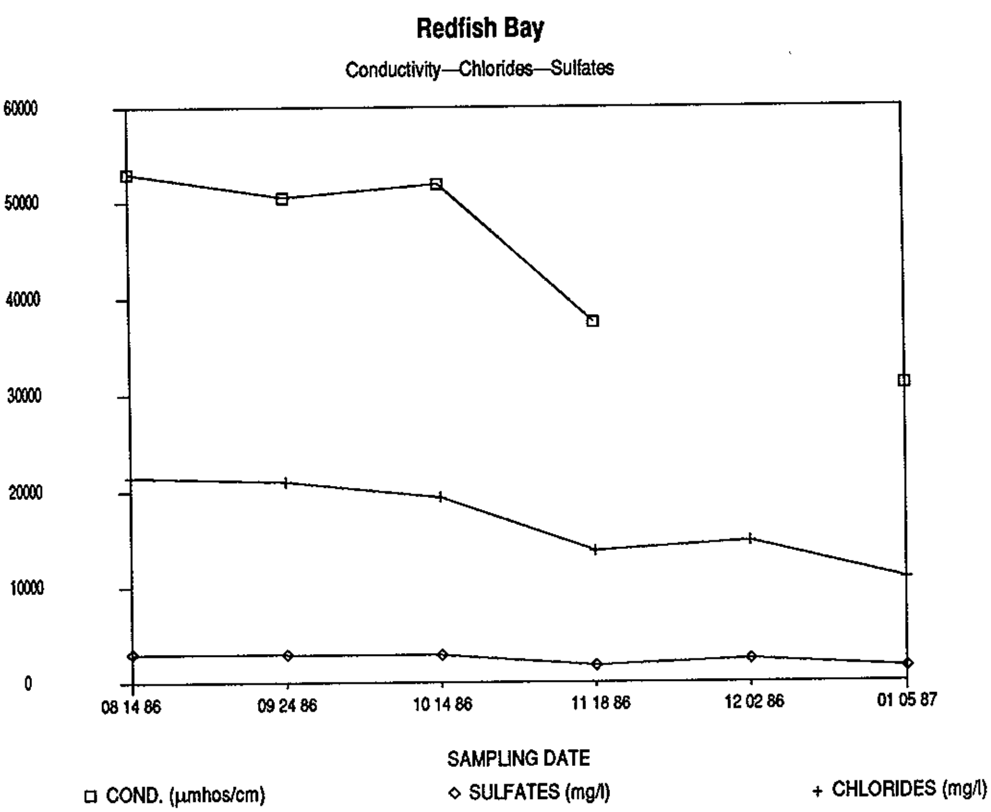
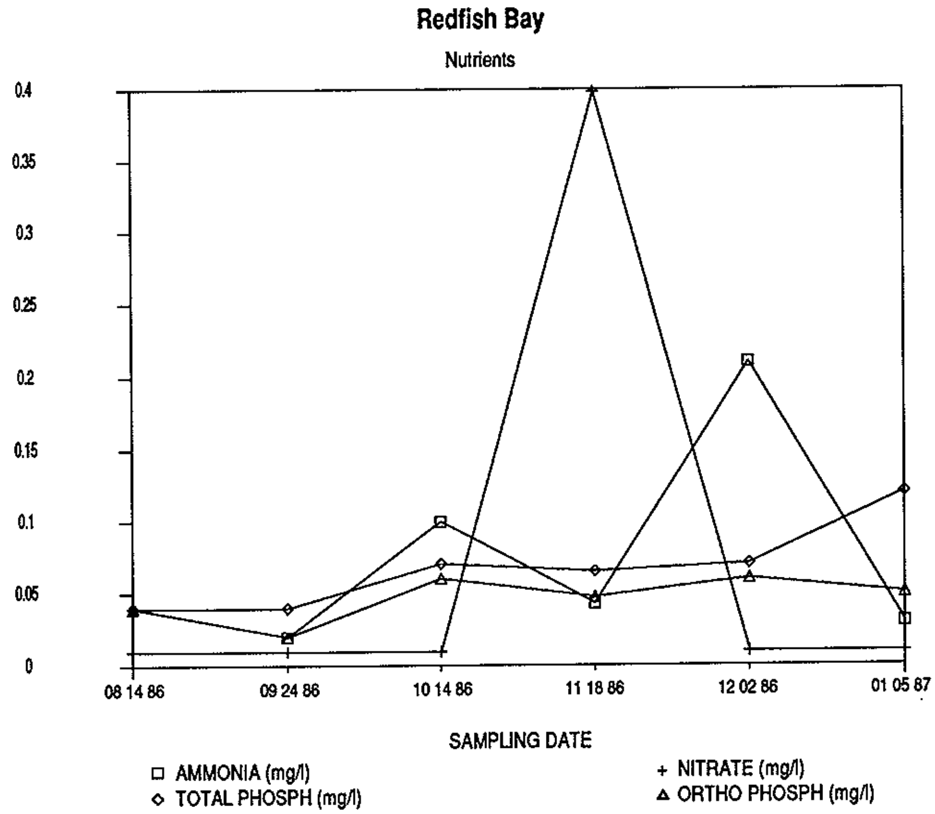
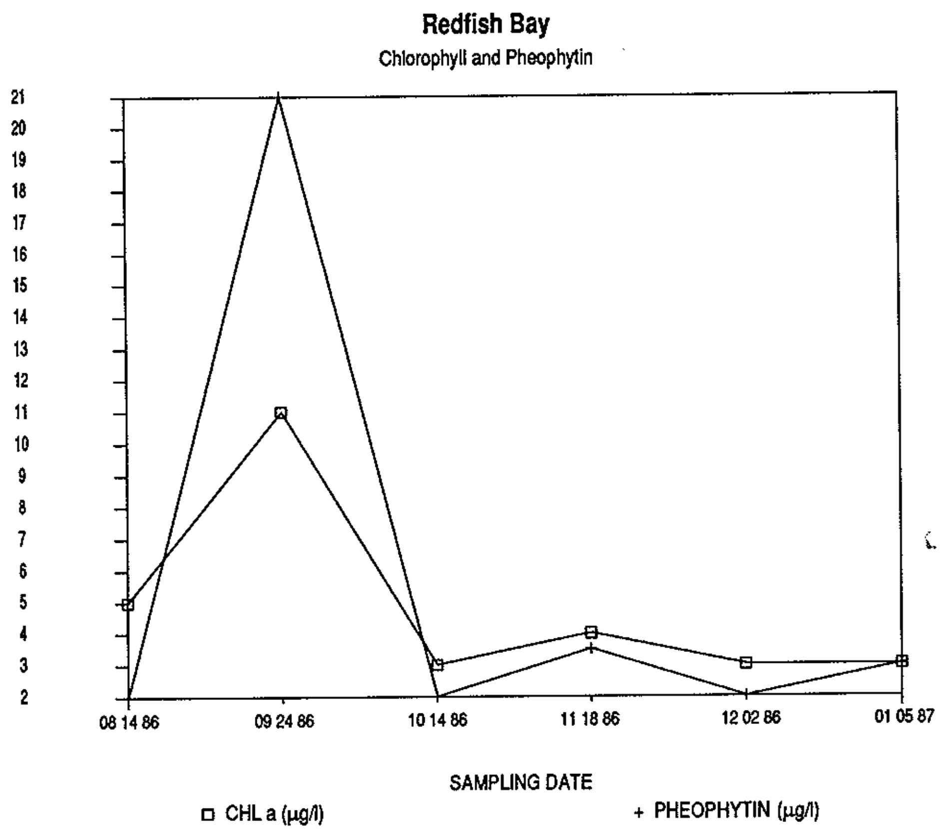


Figure 21.—Field Measurements and Labrat





nts and Laboratory Analyses From Redfish Bay

distributed to 15 ft depths (bottom). The red tide sample taken furthest offshore was 18 mi. out on 16 October 1986 with a concentration of 1,128 cells/ml (Figure 15), although red tide almost certainly existed further offshore than this. The highest *P. brevis* cell counts encountered were 1.1 million cells/ml and 850,000 cells/ml near Rockport on 6 October 1986 and 600,000 cells/ml in Corpus Christi Bay off the southwest shoreline on 8 January 1987 (Figure 15). These high densities appear to be the result of physical concentration in confined areas.

Field measurments of dissolved oxygen, pH, conductivity and temperature taken at all sample sites (Figures 5,6,8,10,14A,14B,18,21) are within reported ranges found for *P. brevis* (Iwasaki 1979). Unlike many algae blooms involving other species, there were no great increases in pH and dissolved oxygen when high densities of red tide were encountered, perhaps a result of the smaller role which cell division rate plays in *P. brevis* blooms.

Vertical measurement of field parameters at Gulf locations revealed little depth variation in measured parameters; Gulf currents and wave action apparently mix nearshore waters thoroughly (Figures 6,8,14A,14B). Although plankton concentrations at Gulf station #9 (Table 4) were high throughout the water column, dissolved oxygen values were not elevated at corresponding depths (Figure 14B), perhaps attributable to reduced photosynthetic activity from light attenuation with depth (Wetzel 1983). Gulf stations 1-3 (Figure 14A) were unimpacted by red tide at the time of the survey and comparison of field data with heavily impacted stations (9&10) (Figure 14 B) revealed few differences. Elevated pH and dissolved oxygen levels at station #2 (Figure 14A) likely resulted from a surface bloom of the blue-green algae *Trichodesmium* sp. at this station, which has been reported to be a precursor to *P. brevis* red tides (Iwasaki 1979).

The distribution of red tide, as indicated by cell counts and aerial surveys, appeared to be limited by wind, currents and freshwater inflow. Conductivity levels (mainly influenced by chlorides and sulfates) for confirmed red tide locations ranged from greater than 30,000 µmhos/cm to 57,000 µmhos/cm (Figures 5,6,8,10,14A,14B,18,21). These values were higher than 83 % of the average values for these stations over the last five years (TWC Stream Monitoring Network historical data). Above average values probably resulted from reduced inflow of fresh water and from warm temperatures and strong winds producing high evaporation rates which provided suitable oceanic salinity conditions for *P. brevis.*

Temperature values ranged from 25.5 to 30 °C for most of the bloom (Figures 5,6,8,10,14A,14B,18, 21). Red tide exisited in Corpus Christi Bay during periods when temperatures were as low as 15 °C. Matagorda and San Antonio Bay systems were fresher, a result of increased rainfall and inflow, and cooler in November than in September (TWDB Bays and Estuaries data), and no red tide was detected at these stations.

Secchi disc measurements taken during the surveys (Figures 12,20) were difficult to interpret. Various factors, such as suspended sediment and sampling time, apart from *P. brevis* concentrations influenced the measurements.

Nutrient values (NH_3, NO_2, Total PO_4, Ortho PO_4) for surface water (1ft) samples (Figures 5,11,19) agree with reported values found in other *P. brevis* red tides (Murphy et al. 1975, Ingle and Martin 1971, Wilson 1966). Neither those studies nor this data revealed a strong nitrogen and phosphorous correlation with cell count, and support evidence that indicates *P. brevis* is not nutrient limited (Murphy et al. 1975, Ingle and Martin 1971, Wilson 1966). This lack of correlation may also in part be due to the abilities of *P. brevis* to utilize low levels and organic forms of nutrients (Donnely et al. 1966, Iwasaki 1979). Concentrations of NH_3 and NO_2 from samples taken during the red tide (Figure 11,19) were lower than five-year averages at all bay sample stations (TWC Stream Monitoring Network historical data), yet were sufficient for sustaining *P. brevis* populations.

Many of the high phosphorous and nitrogen nutrient values found in the bays corresponded to areas that receive high fresh water inflow, such as the Guadalupe River, Lavaca River and Colorado River (Figure 11). This has historically been a situation common in Texas bays and estuaries (TDWR LP-115) apart from red tide. Elevated Total PO_4 and Ortho PO_4 levels were observed at Colorado River stations #1 and #4 along with high chlorophyll a values (Figure 5), a trend not seen at other sample sites during these events. Investigators reported very turbid waters at these sites, which suggests a very high *P. brevis* concentration (similar to observations in the Rockport Harbor). High cell counts may only be acheived with the aid of physical (wind and current driven) concentration mechanisms. Therefore the elevated phosphorous levels may merely be an artifact of cell density, or fluvial nutrient loading. No plankton samples were taken to verify these results.

Chlorophyll a and pheophytin values revealed no trends with corresponding red tide concentrations. *P. brevis* patchiness, cell age, growth rates, light conditions and nutrient concentrations no doubt influenced these results.

Water quality data obtained from monthly sampling of Redfish Bay (Figure 21), indicate that red tide flourished during conditions of warm water (24 °C) and high conductivity (50,000 µmhos/cm). Populations were, however, sustained at lower temperatures (18-14 °C) and conductivities (30,000-38,000 µmhos/cm). At this location, pH was stable and dissolved oxygen fluctuated (6.5-10 mg/l) in typical responses to temperature and sunlight. Variable nutrient levels resulted from the influence of freshwater inflow and tidal exchange; and were within previously reported ranges for this station (TWC Stream Monitoring Network historical data).

In these investigations we did not detect obvious cause and effect relationships between chemical parameters and the presence of red tide. Observation and sampling began after the bloom was in progress and thereby limits discussion of water chemistry to support of, rather than initiation of, the bloom. The water chemistry-red tide relationships were further complicated by organism characteristics such as vertical patchiness and locomotor patterns, as well as meteorological variability, seasonality, sampling times and sample depth. The lack of clear cause-effect, has been characteristic of other studies of red tide population dynamics (Iwasaki 1979).

A suspected source for initiation of the red tide was a rainfall (3.27 inches, NOAA-pers. comm.) near the Port of Houston-Galveston area just prior to the first red tide reports. These rains may have provided offshore waters with suitable conditions for the hypothesized seed bed excystment. Although such a seed bed off the Texas coast has not been identified, the high probability that *P. brevis* forms benthic resting cysts like other red tide organisms (Steidinger 1983) and the fact that red tides have previously occurred in Texas coastal waters (Lund 1935, Wilson and Ray 1956) tend to support its existence. As in most red tide studies, observation and sampling in this study began when the bloom was already in progress, after any chance to observe bloom initiation and preexisting conditions had passed; therefore, we may only hypothesize about the events leading to the bloom.

CONCLUSIONS

The negative influence of the red tide reached beyond the marine community. The unsightliness and smell of decomposing fish, irritation by aerosol effects, shellfish harvesting area closures and contamination, public reluctance to consume fish products, decreased tourism and cleanup costs were some of the negative results experienced by the public.

The end result of such a red tide may, however, include some positive aspects. A large scale bioperturbation may have a rejuvenating effect on marine communities (Margalef 1968), providing more energy flow and resulting in a more dynamic system (Paine 1966). It may provide a means of controlling disease by removing unfit individuals (Steidinger 1983). These positive aspects as well as prediction of red tides are some of the areas which need further investigation.

Currently red tides are unpredictable. Perhaps it is their unpredictability coupled with relative infrequency (particularly in Texas) that allows them to remain enigmas. Scientists cannot be readily prepared to study such sporadic events, events that often have progressed past the initiation phase. At the present time we can only perform laboratory studies and monitor our waters for the presence of red tide organisms and when found, provide accurate information to the public.

APPENDIX A

Laboratory Procedures for Water Analyses

Parameter	Units	Method
Total Phosphorus	mg/l as P	Persulfate digestion followed by ascorbic acid
Orthophosphorus	mg/l as P	Ascorbic acid
Sulfate	mg/l	Turbidimetric
Chloride	mg/l	Automated thicyanate
Chlorophyll a	µg/l	Trichromatic
Pheophytin a	µg/l	Pheophytin correction
Ammonia Nitrogen	mg/l as N	Distillation and automated colorimetric phenate
Nitrate Nitrogen	mg/l as N	Automated cadmium reduction

APPENDIX B

Fish Species Observed in Red Tide Fish Kills
(taken from TPWD data)

Scientific Name	Common Name
Achirus lineatus	Lined Sole
Alosa chrysochloris	Skipjack herring
Aluterus schoepfi	Orange Filefish
Anchoa hepsetus	Striped Anchovy
Anchoa mitchilli	Bay Anchovy
Anguilla rostrata	American Eel
Archosargus probatocephalus	Sheepshead
Arius felis	Hardhead Catfish
Astroscopus y-graecum	Southern Stargazer
Bagre marinus	Gaftopsail Catfish
Bairdiella chrysura	Silver Perch
Balistes capriscus	Gray Triggerfish
Bascanichthys bascanium	Sooty Eel
Brevoortia gunteri	Finescale Menhaden
Brevoortia patronus	Gulf Menhaden
Brotula barbata	Bearded Brotula
Caranx crysos	Blue Runner
Caranx hippos	Crevalle Jack
Carcharhinus limbatus	Blacktip Shark
Chaetodiptera faber	Atlantic Spadefish
Chilomycterus shoepfi	Striped Burrfish
Chloroscombrus chrysurus	Atlantic Bumper
Citharichthys spilopterus	Bay Whiff
Conodon nobilis	Barred Grunt
Cynoscion arenarius	Sand Seatrout
Cynoscion nebulosus	Spotted Seatrout
Cynoscion nebulosus	Silver Seatrout
Cyprinodon variegatus	Sheepshead Minnow
Dasyatis sabina	Atlantic Stingray
Dormitator maculatus	Fat Sleeper
Dorosoma cepedianum	Gizzard Shad
Dorosoma petenense	Threadfin Shad
Echiophis punctifer	Stippled Spoon-nose Eel
Elops saurus	Ladyfish
Epinephelus adscensionis	Rock Hind
Epinephelus nigritus	Warsaw Grouper
Epinephelus niveatus	Snowy Grouper
Equetus umbrosus	Cubbyu
Eucinostomus argenteus	Spotfin Mojarra
Eucinostomus gula	Silver Jenny
Euthynnus alletteratus	Little Tunny
Fundulus grandis	Gulf Killifish
Fundulus similis	Longnose Killifish
Gobiesox strumosus	Skilletfish
Gobionellus boleosoma	Darter Goby
Gobiosoma bosci	Naked Goby
Harengula jaguana	Scaled Sardine
Hemiramphus brasiliensis	Ballyhoo
Holacanthus sp.	Unidentified Angelfish
Hypleurochilus geminatus	Crested Blenny
Hyporhamphus unifasciatus	Halfbeak
Ictiobus bubalus	Smallmouth Buffalo
Labrisomus nuchipinnis	Hairy Blenny
Lagocephalus laevigatus	Smooth Puffer
Lagodon rhomboides	Pinfish
Leiostomus xanthurus	Spot
Lepisosteus spatula	Alligator Gar
Lepophidium graellsi	Blackedge Cusk-eel
Lobotes surinamensis	Tripletail
Lucania parva	Rainwater Killifish
Lutjanus campechanus	Red Snapper
Lutianus synagris	Lane Snapper
Megalops atlantica	Tarpon
Menidia beryllina	Inland Silverside
Menidia peninsulae	Tidewater Silverside
Menticirrhus americanus	Southern Kingfish
Menticirrhus littoralis	Gulf Kingfish
Micropogon undulatus	Atlantic Croaker
Monacanthus hispidus	Planehead Filefish
Mugil cephalus	Striped Mullet
Mugil curema	White Mullet
Myrophis punctatus	Speckled Worm Eel
Narcine brasiliensis	Lesser Electric Ray
Oligoplites saurus	Leather Jacket
Ophichthus gomesi	Shrimp Eel
Ophidion holbrooki	Bank Cusk-eel
Ophidion welshi	Crested Cusk-eel
Opisthonema oglinum	Atlantic Thread Herring
Opsanus beta	Gulf Toadfish
Orthopristis chrysoptera	Pigfish
Paralichthys albigutta	Gulf Flounder
Paralichthys lethostigma	Southern Flounder
Pogonias cromis	Black Drum
Polydactylus octonemus	Atlantic Threadfin
Porichthys plectrodon	Atlantic Midshipman
Priacanthus arenatus	Bigeye
Prionotus tribulus	Bighead Searobin
Rhizoprionodon terraenovae	Atlantic Sharpnose Shark
Sciaenops ocellatus	Red Drum
Scomberomorus cavalla	King Mackerel
Scomberomorus maculatus	Spanish Mackerel
Scorpaena plumieri	Spotted Scorpionfish
Selene setapinnis	Atlantic Moonfish
Selene vomer	Lookdown
Serraniculus pumilio	Pygmy Sea Bass
Sphoeroides parvus	Least Puffer
Squatina dumerili	Atlantic Angel Shark
Stellifer lanceolatus	Star Drum
Strongylura marina	Atlantic Needlefish
Symphurus civitatus	Offshore Tonguefish
Symphurus plagiusa	Blackcheek Tonguefish
Synodus foetens	Inshore Lizardfish
Trachinotus carolinus	Florida Pompano
Trichiurus lepturus	Atlantic Cutlassfish
Trinectes maculatus	Hogchoker
Unidentified fish	Unidentified Fish
Urophycis floridanus	Southern Hake
Class Osteichthyes	Unidentified Bony Fish
Family Balistidae	Family Leatherjackets
Family Batrachoididae	Family Toadfishes
Family Blennidae	Family Combtooth Blennies
Family Carcharhinidae	Family Requiem Sharks
Family Clupeidae	Family Herrings
Family Cynoglossidae	Family Tonguefishes
Family Exocoetidae	Family Flying Fishes
Family Gobiidae	Family Gobies
Family Gerreidae	Family Mojarras
Family Mullidae	Family Goatfishes
Family Ogcocephalidae	Family Batfishes
Family Ophichthidae	Family Snake Eels
Family Sciaenidae	Family Drums
Family Scombridae	Family Mackerels
Family Scorpaenidae	Family Scorpionfishes
Family Serranidae	Family Sea Basses
Family Tetraodontidae	Family Puffers
Family Triglidae	Family Searobins

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