An Ecological Survey of the Houston Ship Channel and Adjacent Bays

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Abstract

An ecological survey of the Houston Ship Channel and adjacent bays was initiated in the summer of 1957 with data collected at frequent regular intervals. This report includes the comparison of data on temperature, chlorinity, dissolved oxygen, and related quantities with data on fish, shrimp, and crabs caught in trawls. Data are also given on currents, bottom cores, and organic content of sediments.

In the ship channel a dissolved oxygen gradient existed from a low dissolved oxygen concentration in the upper channel to near normal concentrations at the lower boundary of the survey area. The dissolved oxygen in the ship channel below the mouth of the San Jacinto River is greatly influenced by the flow rate of the river which is, in turn, largely controlled by rainfall.

Studies of bottom samples demonstrated that extensive silting has occurred in the ship channel and bays. Low dissolved oxygen, hydrogen sulfide production, and high organic content of the mud in the channel, all indicative of organic pollution, prevent the establishment of a normal bottom fauna.

In the bays adjacent to the channel the dissolved oxygen concentration is independent of the flow rate of the San Jacinto River, being dependent on phytoplankton production of oxygen and, at certain seasons of the year, fluctuating widely in a diurnal cycle. The concentration may range from supersaturation to extremely low concentrations in a relatively short period.

A small temperature gradient was found in the ship channel, two or three degrees higher in the upper channel than in the lower part of the survey area. When dissolved oxygen (D.O.) level is sufficient, a large and diverse population of fishes exists throughout the bays in the survey area and for a considerable distance above the Humble Oil & Refining Company's outfall.

The species composition of this population varies with the season, with predominantly marine fishes during the summer when the salinity is high and predominantly fresh water fishes in the winter when the salinity is lowered. Both the number of species and diversity of fishes present decreased up the channel.

The Humble Oil & Refining Company discharges approximately 15 million gallons of refinery waste water into the lower end of the Houston Ship Channel each day. No lowering of the dissolved oxygen concentration of the ship channel attributable to Humble's effluent was found and no effect was found to be exerted on the fish populations of the ship channel and adjacent bays by Humble's operations.

Contents

Introduction

An ecological survey of the Houston Ship Channel and adjacent bays in the vicinity of Humble Oil & Refining Company's Baytown refinery was begun in the summer of 1957. Humble Oil & Refining Company discharges about 15 million gallons of refinery waste water per day into the lower end of the Houston Ship Channel near Baytown. Determination of what effect, if any, this discharge has on the ship channel and adjacent bays was the primary motivation of the study. Hydrographic, chemical, and biological data were collected at frequent, regular intervals and a study of the bottom composition and fauna was carried out.

The ecology of this area has not been studied intensively in the past. During several years prior to the survey, a number of chemical determinations, particularly of dissolved oxygen content, had been made at irregular intervals in these waters. In 1955 a study was conducted by Humble in which a number of sampling stations were utilized. The results of these studies were not reported in the literature. As a part of the Catherwood Diatometer Survey in the Gulf Coast area, Patrick (1955) made a study of the Houston Ship Channel and Trinity Bay (Hohn, 1959). Reid (1955, 1955a, and 1956) studied the ecology of East Bay, an embayment off Galveston Bay just south of Trinity Bay. Since ecological studies on gulf estuaries are not numerous, Humble Oil & Refining Company made these data available for publication as a contribution to the knowledge of estuarine ecology. This report presents the data, observations, and conclusions of the first year of the study. The observations have been continued in the hope of obtaining a more complete understanding of the various facets of the environment.

Acknowledgment

We are grateful to the Humble Oil & Refining Company for permission to publish the results of this survey. The authors sincerely express their appreciation to Mr. G. F. Viereck for his help in obtaining the field data. The authors are indebted to Dr. Gordon Gunter for the identification of juvenile croakers to species and for kindly giving advice on the taxonomy involved.

Description of the Area

The Houston Ship Channel, above Galveston Bay, is an artificial stream created by deepening and straightening Buffalo Bayou and maintained by periodic dredging. Numerous streams and bays empty into it and receive a tidal exchange, the extent of which depends on the distance up the channel from Galveston Bay, the stage of the tidal cycle, and, especially, meteorological conditions (see maps, Figures 1, 2 and 3). It serves as the sole means of access for ocean-going vessels to the Port of Houston, one of the world's busiest ports. Numerous industries, including chemical and petrochemical plants, oil refineries, a paper mill, and a steel mill line the ship channel and discharge their effluents into it and its tributaries. In addition, the City of Houston and towns and communities along the banks, totalling almost a million people, discharge sanitary sewage into these streams after varying degrees of treatment.

Thus, the upper part of the Houston Ship Channel receives a substantial quantity of waste material and its ability to sustain fish life is, at best, a delicate balance between conditions just barely marginal for typical aquatic life and a biological desert. The upper limit at which aerobic aquatic life is maintaned moves up and down the channel, depending upon the relative amounts of discharged material and the meteorological and hydrographic conditions. Patrick (1955), based on data obtained from the Harris County Health Unit, writes, "the effects of these wastes are very severe as far down the

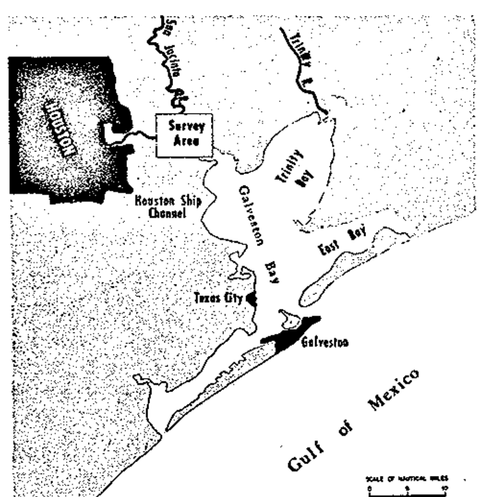


Fig. 1. Location of the survey area on the Texas coast.

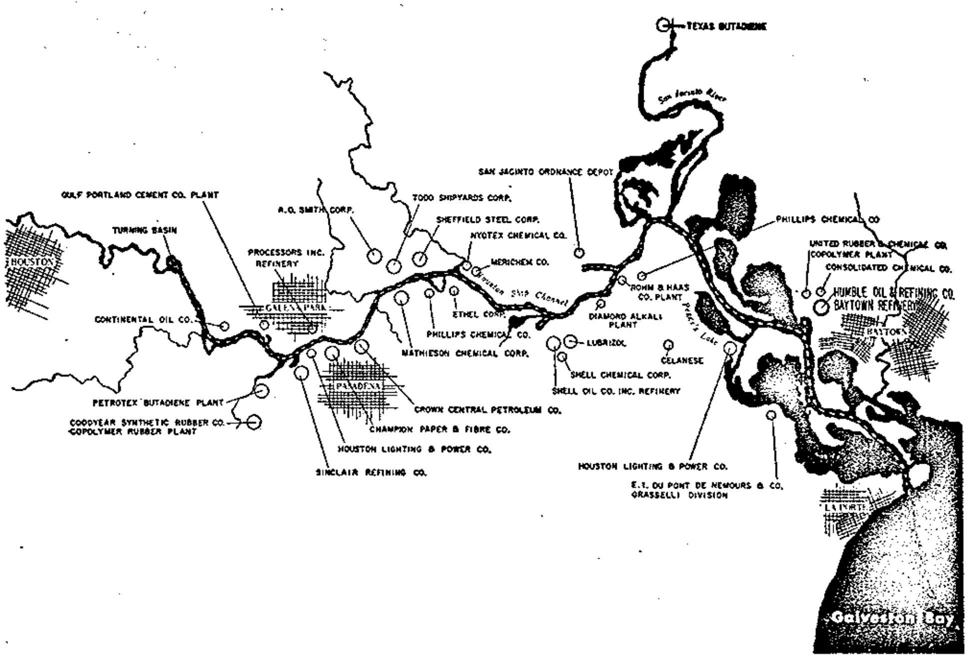


FIG. 2. Principal plants in Houston Ship Channel industrial area.

Channel as the Lynchburg Ferry" (mouth of San Jacinto River). "At this point the first signs of dissolved oxygen are evident and the BOD load is reduced."

The flow of the San Jacinto River has been decreased by the construction of dams on the San Jacinto River and almost ceases during periods of low rainfall. The fresh water from the river and the shallow bays add to the recuperative powers of the water coming down the ship channel, so that there is water of generally higher quality in the channel downstream at Baytown as compared with the channel above the San Jacinto River.

The area routinely studied in the survey extends from Buoy 143, approximately seven miles above Humble's waste outfall to the tunnel crossing approximately two miles below the outfall, and includes stations in the San Jacinto River, Burnett Bay, Crystal Lake, and Scott Bay. A map of the survey area and the location of the sampling stations are shown in Figure 3.

Materials and Methods

Dissolved oxygen determinations were routinely made twice each week at each station by means of a portable polarographic analyzer developed by Tyler and Karchmer (1959). This device has been found to be rugged, simple to use, and produces immediate, accurate results. On one occasion the dissolved oxygen content was determined at frequent intervals at one bay location over a fifty-hour period. Samples for dissolved oxygen determinations were collected in pint bottles at depths of 12 to 16 inches and were analyzed immediately using the portable analyzer. Oxygen was not measured at greater depth where lower values might have been found.

The accurate determination of dissolved oxygen by the polarographic method requires that the temperature of the sample be determined while the polarograph reading is being made. Thus, the temperature of each sample used for dissolved oxygen determinations was recorded during the course of the survey. Since the sample is run immediately after

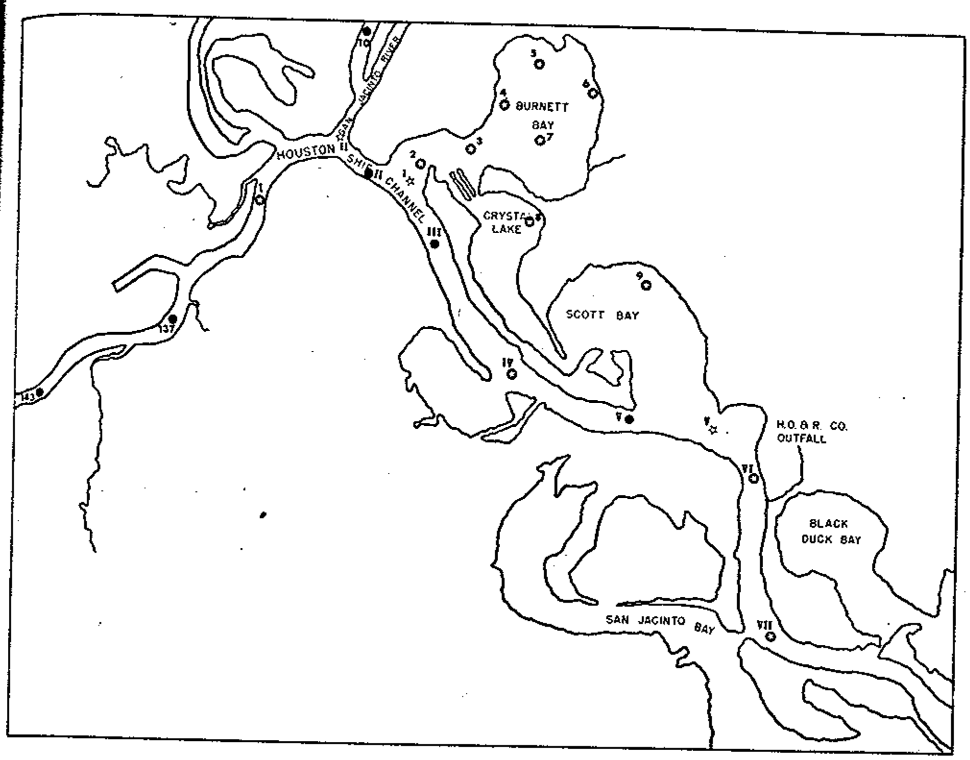


FIG. 3. Sampling Stations. Stars indicate stations sampled on September 1, 1957; black circles indicate stations after January 30, 1958.

being taken, the measured temperature represents very closely the temperature of the channel or bay water 12 to 16 inches below the surface, and is so considered in a later section for the purpose of discussing temperature variations in the survey area.

Determinations of the chloride content of water samples were made routinely at one-week intervals. The water samples were collected at a depth of approximately four inches at certain stations and analyzed by the Volhard method. Measurements of specific conductance and temperature at various depths were taken by the use of a model RB1881 portable Solu bridge and a conductivity cell with 50 feet of connecting cable.

Currents in the Houston Ship Channel and the bays were studied by several methods. Chlorinities were of value in determining current patterns. A Price Pattern Current Meter was used on two occasions for sub-surface current velocity determinations, but was found to be generally unsatisfactory for work in the bays, and frequently in the Channel, because the current velocity was often too low to activate the meter, and in any case, the direction of the current was not indicated. Surface current determinations of the San Jacinto River were made at weekly intervals at Station 10 and at other locations on certain occasions by means of a one-foot by two-foot current cross.

Tidal data were obtained from the Humble Dock Department, where records of the reading of a tide gauge have been maintained for a number of years. Wind direction and velocity records, also obtained from the Dock Department, are of considerable importance in understanding the hydrography of the area. A tide staff was set up in the entrance to Burnett Bay so that the tidal height at this location could be correlated with that at the Humble Dock. Rainfall data were obtained from rain gauge records of the

Humble Refinery. Elevation data on Lake Houston were obtained from the San Jacinto River Authority.

Bottom studies were made by two methods. In the first method, developed by Dr. J. G. Mackin, cores were collected in Pyrex glass tubes in a coring device developed at the Texas A & M Research Foundation Marine Laboratory, Grand Island, Louisiana. This device is provided with a vacuum arrangement to retain the core when removing the device from the water. The cores were transported to the Texas A & M Research Foundation Marine Laboratory, cleaned, and examined under a strong light. A sketch was made of each core. Each core was then forced by air pressure from the tube into a wooden trough. A one-inch section from each stratum was removed, emulsified in tap water and poured through a series of U.S. standard sieves ranging from 1/10th to 1/200th of an inch in mesh size. A particle size distribution of each section was thus obtained. The sieves were then examined with a stereoscopic microscope.

In the second method, an Ekman dredge was used. With this dredge it was possible to obtain samples in deeper water than with the coring device, but only the top layer of the bottom sediments could be sampled. Samples taken with the Ekman dredge were sieved and studied for bottom fauna and nature of particles after a portion had been removed for chemical analysis. Analyses were made for organic content.

Studies of the fish and larger invertebrates were made at certain localities each week by means of a standard 10-foot otter trawl (1⅜ inches × #9 × #15) with 12 inch × 24 inch trawl boards. Specimens were identified and counted in the field and the data were tabulated along with hydrographic and meteorological data on a collection card. Sampling methods were standardized to the extent that trawls were made at the same location and at the same towing speed each week, initially as follows: (1) Station 2 to Station 3; (2) Station 4 to Station 5; (3) Station 6 to Station 7; (4) around Station 8; and (5) in a circle around Station 9. The trawl between Station 2 and Station 3 was discontinued on January 30, 1957, and a trawl beginning at Station III and continuing up the channel for 700 yards was initiated. In March, trawls starting at Station 137 and at Station VII and, in each case, continuing for 700 yards up the channel were begun.

Data on physical and chemical conditions and the fish and larger invertebrates collected in the otter trawls were first transferred to a specially prepared form for key punching. The data punched on International Business Machine Company (IBM) cards (No. 804118) were then transferred to magnetic tape. A program for the IBM 705 calculator was set up to print out the conditions at which each species was collected so that the relationships of various physical and chemical conditions and the organisms collected could be more readily analyzed. A few species with associated environmental factors were treated on a more numerical basis with the aid of the IBM run.

The data collected on species of particular interest or those on which sufficient data were available were treated in the following ways: the catch per trawl for a species at each station was tabulated by station, date, chlorinity, D.O., and temperature intervals. The intervals used were 500 ppm, 0.5 ppm, and 5° F.

Hydrography

Chlorinity

Chlorinities in this study were routinely determined at one-week intervals at some of the survey stations. These data reported as chlorinities may not be used to calculate salinities because considerable sodium chloride and other inorganic compounds are believed to enter the Houston Ship Channel, thus the normal salt ratio of sea water is upset. The samples were collected near the surface where there is a tendency for fresh water to ride on top of the salt water tidal wedge. All chlorinities obtained in the study are listed in Tables 1 and 2 by station and by date.

Data from typical stations have been selected to show the seasonal variation in chlorinity in the survey area: Station 137 (Figure 4) is typical in salinity of the ship channel above the San Jacinto River; Station 10 (Figure 4) shows the influence of the San Jacinto River; Station 7 (Figure 5) is typical of the bays; Station VII (Figure 5) is the most seaward station to be discussed.

Fluctuations in chlorinities occur in a cyclic fashion and in a seasonal pattern because of variation in the amounts of rainfall and evaporation. Tidal differences, both meteorological and astronomical, influence the chlorinity in a seasonal pattern. Predominant winter winds in this area are from the north causing, during a considerable part of the winter, the tidal exchange to be lessened at the same time that the greatest dilution by run-off and San Jacinto River discharge occurs. In the summer the predominant winds are from the south, intensifying the effect of tides. The tide in the Gulf of Mexico is largely diurnal with a single high and low daily tide, and in yearly fluctuation creates a higher sea level during the second half of the year than in the first half (Marmer, 1954.)

TABLE 1

Chlorinity in ppt at channel stations from October, 1957, through July, 1958

Station	October, 1957					November, 1957				December, 1957			
	3	10	16	17	31	7	14	21	27	5	12	19	26
VII	6.3	7.3	....	0.4	....	....	2.0	2.8	0.5	4.0	7.3	....	6.9
V	....	6.6	....	0.3	3.7	....	1.3	2.4	0.2	3.6	6.6	7.1	6.4
III	....	....	....	....	....	....	....	....	....	....	....	....	....
II	....	....	....	....	....	....	....	....	....	....	....	....	....
I	5.6	6.9	0.3	0.1	4.2	4.6	2.4	2.0	0.1	0.9	3.5	....	3.6
B 137	....	....	....	....	....	....	....	....	....	3.6	5.8	7.2	8.9
B 143	....	....	....	....	....	....	....	....	....	....	....	....	....
10	5.5	3.3	0.3	0.1	0.5	3.7	0.1	0.2	*	0.1	1.0	2.8	1.5

Station	January, 1958					February, 1958				March, 1958			
	2	9	16	23	30	6	13	20	27	13	20	21	27
VII	3.6	5.1	1.5	0.3	1.3	1.6	3.2	5.6	1.1	5.1	6.8	....	7.3
V	3.1	....	....	....	0.8	1.5	2.6	5.1	0.7	4.6	6.4	6.7	6.8
III	....	....	....	....	0.2	1.0	1.7	3.9	0.6	3.5	5.5	6.2	5.6
II	0.2	0.4	*	0.1	0.2	1.2	1.6	3.9	0.2	2.7	5.7	5.0	5.4
I	1.1	1.8	0.5	0.4	0.2	1.6	1.5	3.0	0.6	2.9	5.6	5.0	5.1
B 137	....	....	....	....	....	....	....	....	1.8	4.8	5.6	7.0	6.5
B 143	....	....	....	....	1.5	1.7	2.6	4.0	1.7	4.8	5.4	4.8	6.5
10	0.1	0.1	*	0.4	*	0.5	0.4	2.1	*	1.4	3.5	3.7	3.3

Station	April, 1958			May, 1958					June, 1958			July, 1958			
	2	10	24	2	8	15	22	28	5	12	26	2	10	17	31
VII	7.6	7.4	6.2	5.6	1.2	4.5	5.2	4.6	3.9	2.3	3.1	3.2	4.9	4.2	4.0
V	8.5	6.7	5.6	5.7	0.8	4.4	5.0	4.5	4.8	2.8	4.1	5.1	5.1	4.2	5.4
III	7.6	6.0	4.4	4.9	0.6	4.3	4.6	4.3	4.5	3.5	4.1	5.4	4.6	4.5	4.9
II	7.5	5.6	4.9	4.7	0.4	4.3	4.5	4.1	4.3	3.8	3.9	5.0	4.5	....	4.9
I	7.3	5.3	3.7	3.9	0.4	4.0	4.7	4.4	4.2	4.0	3.6	4.9	4.0	4.2	4.4
B 137	7.2	6.0	4.6	4.1	0.9	4.2	4.5	4.4	3.9	3.9	3.4	4.7	3.9	4.2	4.3
B 143	6.7	5.8	5.1	4.2	1.5	4.2	4.6	4.2	4.0	3.8	3.2	4.7	3.9	3.8	4.1
10	6.1	4.0	2.0	2.7	....	2.8	4.6	3.3	4.2	4.1	3.6	5.0	4.3	4.8	4.5

* Less than 0.1 ppt.

This entire area is characterized by extreme fluctuations in chlorinity over short periods of time, due both to flow of the San Jacinto River and to surface run-off in the ship channel and City of Houston area. We find decreases in chlorinity of as much as 6500 ppm within one week (Figure 5).

TABLE 2

Chlorinity in ppt at bay stations from October, 1957, through July, 1958

Station	October, 1957					November, 1957				December, 1957			
	3	10	16	17	31	7	14	21	27	5	12	19	26
2	5.5	6.7	1.2	0.3	2.7	5.8	1.7	2.5	*	1.1	6.0	6.2	6.3
3	5.4	6.4	1.1	0.4	2.3	4.2	1.7	2.1	*	0.9	5.8	5.9	6.3
4	5.2	6.0	3.1	1.7	2.1	3.8	2.2	1.8	0.3	0.9	2.6	5.4	6.2
5	5.1	3.7	....	1.9	2.0	....	2.4	1.7	0.4	0.9	3.1	5.2	6.0
7	5.2	6.0	2.6	1.0	2.2	....	2.2	1.8	0.3	0.9	3.0	5.7	6.2
6	5.0	6.0	3.1	1.1	2.2	....	1.8	1.7	0.2	1.0	4.2	5.4	6.2
8	5.1	6.4	2.6	1.7	2.9	....	2.3	2.0	0.2	1.5	4.1	6.0	6.1
9	5.4	6.6	3.1	1.3	3.1	....	2.5	2.0	0.1	1.5	4.6	6.4	6.9

Station	January, 1958					February, 1958			March, 1958		
	2	9	16	23	30	6	13	20	13	20	27
2	2.2	2.7	1.5	0.2	....	1.1	1.8	3.8	3.5	5.5	6.0
3	3.1	3.2	1.9	0.4	0.5	0.6	2.2	3.6	3.6	4.8	5.6
4	3.5	3.3	1.9	0.4	0.5	0.5	2.1	....	....	4.5	5.2
5	4.8	3.1	1.8	0.4	0.5	0.4	2.2	....	....	4.5	5.4
7	2.9	3.1	....	0.4	0.5	0.6	....	3.7	3.6	....	5.3
6	4.8	3.1	....	0.3	0.5	....	....	3.7	3.5	....	5.4
8	3.6	3.1	1.5	0.3	0.7	0.9	....	3.9	3.7	5.0	5.8
9	3.1	4.2	2.9	0.3	0.5	1.4	2.4	4.7	4.8	5.0	6.5

Station	April, 1958				May, 1958				June, 1958			July, 1958			
	2	10	16	24	8	15	22	28	5	12	26	2	10	17	31
2	6.8	5.9	....	4.9	....	3.3	4.5	....	4.4	3.7	3.4	....	....	4.5	4.8
3	6.2	6.5	....	4.6	....	2.4	4.4	4.0	4.4	4.1	3.7	....	4.5	4.4	4.6
4	6.2	....	....	4.9	....	2.0	3.5	....	4.2	4.2	....	4.8	4.5	4.5	....
5	6.1	....	....	5.1	....	1.7	....	....	4.1	4.3	....	4.3	4.5	4.5	....
7	6.1	6.3	5.1	5.0	2.3	1.9	....	....	....	....	3.8	4.4	4.9	4.4	4.3
6	6.0	5.9	5.1	5.1	1.9	1.8	....	....	....	....	....	3.8	4.5	4.5	4.3
8	6.8	6.8	....	5.8	....	2.0	....	....	....	3.6	3.6	....	....	4.5	4.4
9	7.4	7.8	....	6.0	2.0	2.4	....	....	....	3.5	4.0	5.5	5.1	....	4.9

* Less than 0.1 ppt.

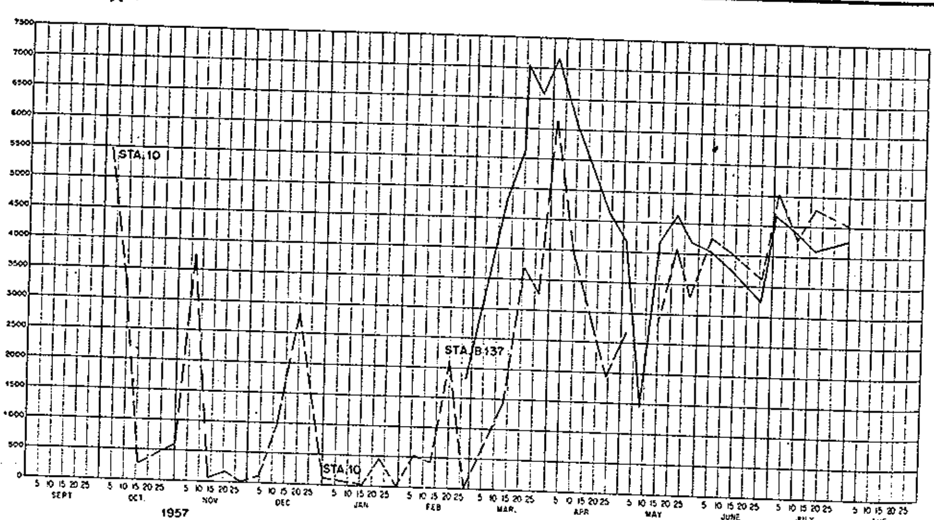


FIG. 4. Chorinities of the upper channel (Station 137) and of the San Jacinto River (Station 10).

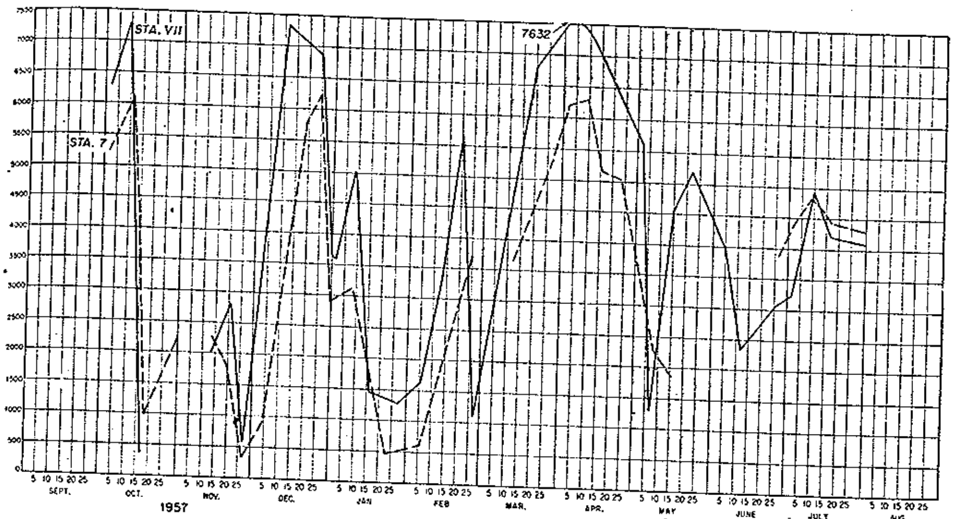


FIG. 5. Chlorinities of the lower channel (Station VII) and of Burnett Bay (Station 7).

There is usually a considerable variation in the salinity in the ship channel from the upper to lower parts of the survey area. This condition is not so pronounced in the bays; water of either high or low salinity is sometimes trapped in the bays and resists transfer for considerable periods as described in the section on seasonal changes in Burnett Bay.

TEMPERATURE

Temperatures in the survey area vary considerably from the station at the Baytown Tunnel Crossing to Station 143, occasionally by as much as 6° F. Considerable variation exists between the temperatures of the Ship Channel and the adjacent bays, and there is some seasonal variation at each station.

Typically, temperatures increase in the Houston Ship Channel from a low point at Station VII (the tunnel crossing) or Station VI to a maximum, for the area being studied, at Buoy 143. The extreme range of temperature measured during the survey period was 7° F (Figure 6) which occurred on March 20, 1958, but the trend was almost always present. It is not known what effect, if any, the gradual increases in the temperature up the ship channel have on the ecology of the area.

The same seasonal temperature trends were present throughout the survey area, but the upper ship channel was almost always a few degrees warmer than other locations. The bays, being shallow and relatively stationary, were influenced more by meteorological conditions than the ship channel or the San Jacinto River (Figures 7 and 8, and Table 5).

The routine measurements of temperature of the ship channel and bays discussed previously were made in the upper one foot of water. On April 15, 1958, and May 6, 1958, studies were made of the vertical distribution of temperature and conductivity. Although the conditions found on these two occasions are not necessarily typical they demonstrate the non-homogeneous nature of the ship channel while, at the same time, they show the homogeneous nature of the bay water. There is also a vertical gradient of conductivity indicated by the data in Figures 9 and 10.

On April 15 the temperature at Station 7 in Burnett Bay was the same at the three

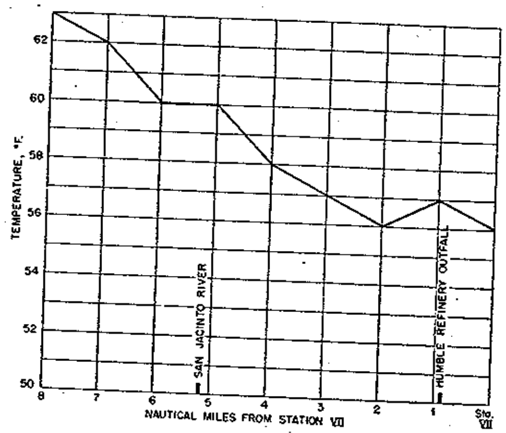


Fig. 6. Distribution of temperature in the Houston Ship Channel on March 20, 1958.

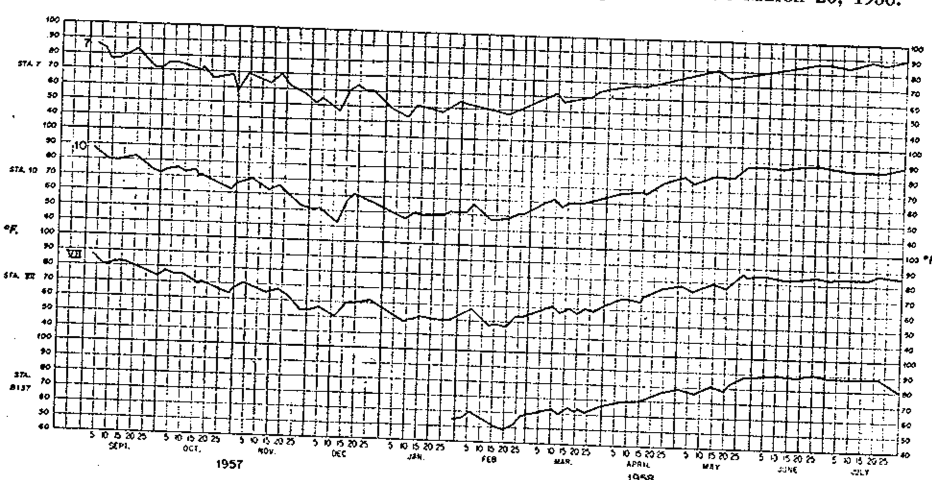


Fig. 7. Temperatures at selected channel and bay stations from September 1957 through July 1958.

depths sampled; the specific conductance was also constant, 14,000 micromhos/cm, at all depths. By contrast, temperatures were elevated from 3°F to 6°F between the surface and the second foot depth in all channel stations. After the initial elevation the temperature remained relatively constant for the remaining depths down to 30 feet. At the time the temperatures were rising, the conductance was also rising. Apparently the cooler, fresher water was flowing down the ship channel on top of a salt water wedge of warmer, more saline water.

Currents

Lines drawn through the points of equal conductance in Figures 9 and 10 outline a salt water wedge which lies under the fresh water inflow. The fresh water inflow from the San Jacinto River on May 6, 1958, appeared to be lens shaped in the upper layer of the channel. The San Jacinto River on this day had a flow rate of 0.86 feet per second and a conductance of 235 to 240.

Data from a hydrographic survey conducted in January are shown in Table 3. The results of the January survey show that the San Jacinto River water, upon entering the channel, rides over the channel water and then continues downstream in the upper layer

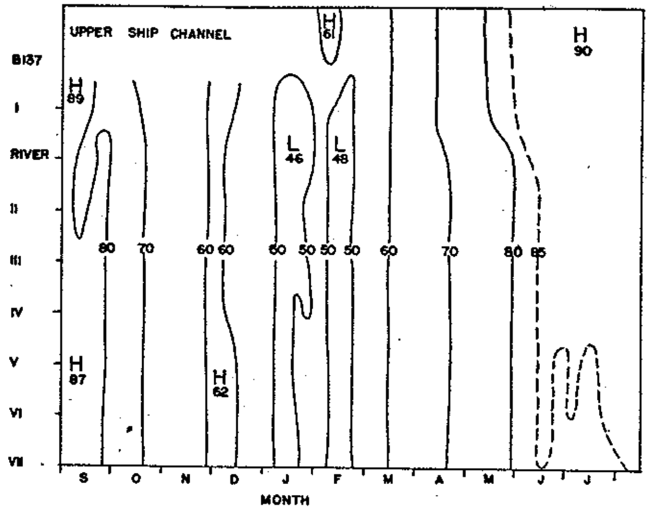
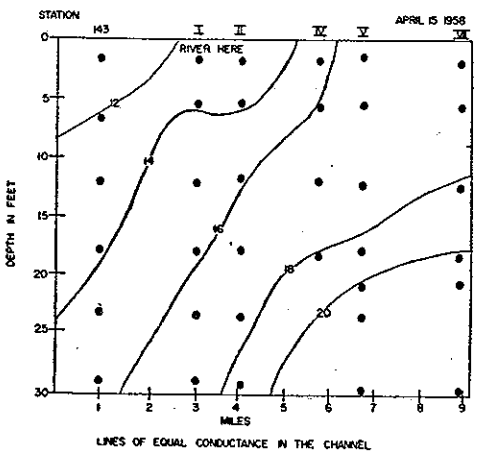


FIG. 8. Temperature of surface water of the Houston Ship Channel in degree Farenheit (°F) and temperature isopleths at 10 degree intervals.



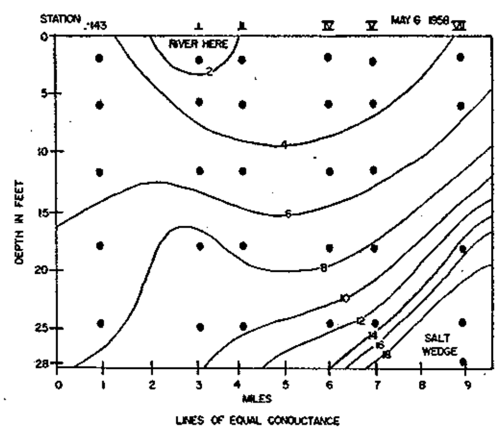


FIG. 9. Lines of equal conductance ($\frac{\text{micromhos}}{\text{cm}} \times 10^3$) in the channel. April 15, 1958.

FIG. 10. Lines of equal conductance in the channel. May 6, 1958.

of the channel for two to three miles. Current velocities indicate that the upper layer of water moving down the channel was pulled into the intake canal of an industrial plant, which lies between Stations IV and V. These data for the channel are representative of the winter condition in which there is sufficient rainfall to cause an appreciable fresh water inflow. Chlorinities of channel samples indicate that the San Jacinto River often shows an appreciable effect over a distance greater than two or three miles downstream and has some effect for a short distance upstream.

The seasonal variation in the hydrography of the area depends to a large extent on the amount of fresh water inflow from the San Jacinto River. The seasonal variation of the San Jacinto River flow is modified by the influence of the Lake Houston Dam on the river and the withdrawal of 92 million gallons of water per day by the City of Houston

TABLE 3

Current data

Date	Time	Location	Method*	Depth	Direction	Velocity, ft./sec.
Jan. 22, 1958	1345	Black Buoy 133	PM	1′	Downstream	0.414
			CC	Surface	Downstream	0.452
	1410	San Jacinto River	PM	6′	Downstream	3.05
	1510	Channel 50 yards east of Burnett Bay	PM	12′	Downstream	1.843
Jan. 29, 1958	1020	Station 2	CC	Surface	300°	0.01
	1050	Station 3	CC	Surface	280°	0.08
	1110	Burnett-Crystal-Cut	CC	Surface	Towards Crystal	0.24
	1150	Narrow Area Crystal-Scott	CC	Surface	......	0
	1210	Scott-Crystal Cut	CC	Surface	Towards Crystal	0.15
	1215	Scott-Crystal Cut West Side	CC	Surface	Towards Crystal	0.27
	1245	Mouth of Scott	CC	Surface	335°	0.27
	0940	Black Buoy 133, Mid-Channel	PM	15′	Downstream	0.50
	0915	San Jacinto River, Station 10	PM	7′	Downstream	0.863
	1000	Station II, Mid-Channel	PM	15′	Downstream	1.128
	1335	Station IV, Mid-Channel	PM	15′	Downstream	†
			PM	6′	Downstream	0.45
			PM	6′	Downstream	0.35
			CC	Surface	Downstream	0.34
	1300	Industrial plant intake canal between Stations IV and V	PM	15′	Downstream	†
	1405	Station V	CC	Surface	Downstream	0.365
			PM	15′	Downstream	†
			PM	6′	Downstream	†
			CC	Surface	Downstream	0
	1425	50 yards east of Black Buoy at tunnel crossing	CC	Surface	Downstream	0

* PM indicates price meter; CC indicates current cross.
† Price meter inoperable due to low velocity.

and the San Jacinto River Authority from the Lake. Thus, as rainfall increases in the fall, the flow rates do not increase proportionately since a large amount is needed to replenish the amount lost to evaporation or withdrawal from Lake Houston through the drier summer months. There is essentially no flow in the river through the drier portions of the year because the withdrawals by the City of Houston are not overcome by the small amount of summer rain. The Lake Houston elevations show that water was coming over the spillway from the latter portion of September through mid-March, intermittently through May, with no flow for June or July.

Flow rate, current direction, D.O., and chlorinity content of the San Jacinto River are shown in Table 4, indicating the seasonal record of fresh water inflow. This fresh water inflow causes considerable seasonal changes in the distribution of salinity in the channel and bays. During the winter months water of low salinity and high D.O. flows into the channel and is highly beneficial since it raises the D.O. content of the channel. Even during the summer period the San Jacinto River flow is beneficial as the ebb flow has a higher D.O. content than the flood flow. After a lapse of time for surface re-aeration and bacteriological activity, a higher quality water returns to the channel.

DISSOLVED OXYGEN DISTRIBUTION IN THE CHANNEL

On several occasions dissolved oxygen concentrations in the ship channel reached low concentrations critical for many living organisms. Dissolved oxygen content usually varied considerably at a given time in the ship channel between the upper and lower limits of the survey area. All dissolved oxygen determinations with the location and date are listed in Figure 11 and Table 5. Certain representative data are discussed here to show typical conditions in the channel, but the data for any period may be found in Figure 11.

The dissolved oxygen data obtained in the Houston Ship Channel on January 16, 1958, a time of heavy rainfall and subsequent low chlorinities, are presented in Figure 12. It will be seen that the dissolved oxygen at the upper boundary of the sampling area was 2.5 ppm; it then rose to more than 11.0 ppm at the mouth of the San Jacinto River, and dropped only about 2.0 ppm in the remaining 5 miles to the downstream boundary

TABLE 4

Hydrographic data on the San Jacinto River, Station 10

Date	Time	Velocity ft./sec.	Direction Downstream or upstream	D.O. ppm	Chlorinity, ppm
Nov. 14*	0945	1.00	D	9.0	75
Jan. 16*	1000	1.67	U	11.7	39
22*	1345	2.42	D	......	....
27	1400	0.56	D	10.5	....
30	1100	1.00	D	10.4	25
Feb. 3	1025	1.28	D	10.1	....
6	0950	0.13	D	7.3	540
13	1035	0.77	D	9.7	420
17	1025	......	....	9.0	....
20	1045	slight flow	U	10.7	2095
24	1107	0.62	D	......	....
27	1125	1.47	D	9.8	39
Mar. 10	1015	0.28	U	8.1	....
13	1150	0.81	D	7.5	1420
17	0910	0.77	D	5.2	....
20	1115	0.74	D	5.4	3550
21	0950	0.30	U	2.3	3700
24	1010	0.10	U	6.8	....
27	1117	0.16	U	7.1	3266
Apr. 2	1115	0.40	D	2.9	6141
7	0955	0.14	D	6.9	....
10	1007	0.77	D	6.1	3976
15	1115	0.78	D	5.0	....
16	0930	0.41	D	3.2	....
24	1145	0.21	U	6.5	1952
May 2	1200	0.23	D	3.9	2698
6	1200	0.87	D	7.6	....
15	1100	0.46	D	4.3	2840
22	1042	0.69	U	2.0	4583
28	1340	0.31	U	8.1	3284
June 5	1220	0.57	U	1.5	4242
12	1100	0.23	D	4.7	4083
17	1152	0.73	U	2.3	....
26	1300	0.65	D	4.9	3621
July 2	1140	0.51	U	1.9	5041
8	1020	0.08	U	3.5	....
10	1155	0.16	U	3.0	4295
16	1215	0.13	U	......	....
17	1200	......	....	2.9	4792
22	1100	......	....	2.5	....
26	1055	0.52	U	......	....
31	1200	0.13	U	4.7	4508

* Under Highway 73, San Jacinto River Bridge.

TABLE 5

Dissolved oxygen data in ppm at bay stations from September, 1957, through July, 1958

Station		September, 1957								October, 1957								
		3	6	9	13	16	20	27	30	3	7	10	14	16	17	21	29	31
1	°F.	87	85	80	81	81	85	75	74	75	75	75	74	68	69	69	62	68
	D.O.	1.6	1.2	1.9	1.3	1.5	1.3	2.0	1.7	1.1	2.6	2.0	7.3	4.5	5.8	2.9	6.3	2.2
2	°F.	88	85	80	81	81	84	75	73	75	75	75	....	70	70	68	61	67
	D.O.	4.6	1.7	1.2	1.8	2.3	2.6	2.3	3.0	3.5	2.7	2.0	....	3.5	5.6	3.9	7.1	10.5
3	°F.	88	85	80	80	79	85	74	72	75	74	75	....	69	70	66	60	65
	D.O.	4.4	1.6	1.7	4.1	2.1	5.0	2.3	5.0	13.2	5.8	2.0	....	3.9	6.2	6.9	8.4	15.0
4	°F.	87	83	77	78	78	82	71	71	74	74	73	....	69	72	65	58	66
	D.O.	11.6	7.6	5.8	5.4	2.3	7.9	5.3	7.7	11.1	7.7	8.1	....	6.2	7.3	10.6	10.1	12.0
5	°F.	87	83	75	78	80	81	71	70	74	75	73	....	69	72	65	57	66
	D.O.	11.7	8.9	8.1	9.6	3.0	6.5	4.1	7.3	13.2	10.8	9.4	....	9.1	8.5	8.5	12.3	12.0
6	°F.	86	83	76	78	80	83	73	71	75	75	74	....	70	72	65	61	68
	D.O.	10.6	8.5	7.9	8.3	2.7	8.6	4.2	6.1	11.0	9.8	9.1	....	7.7	6.8	7.8	7.3	12.0
7	°F.	86	84	76	77	80	83	71	71	75	75	73	....	70	72	65	68	57
	D.O.	7.1	8.3	6.8	9.1	3.0	8.2	4.1	6.2	8.8	10.0	9.2	....	4.8	6.2	7.4	11.9	15.0
8	°F.	88	85	78	79	81	84	73	72	76	76	74	....	70	73	66	59	69
	D.O.	9.4	5.8	3.9	7.8	5.2	5.0	3.1	4.5	8.9	6.7	6.0	....	4.1	7.3	6.6	9.6	12.0
9	°F.	86	82	76	79	81	....	71	70	75	75	75	....	70	73	65	59	68
	D.O.	11.5	9.0	7.6	10.4	8.3	....	2.2	6.6	9.4	8.6	6.6	....	4.4	6.5	8.0	10.6	12.0

Station		November, 1957						December, 1957								January, 1958						
		4	7	14	18	21	27	2	5	12	16	19	23	26	30	2	9	13	16	23	27	30
1	°F.	70	70	63	65	63	53	52	52	52	60	62	59	60	56	....	....	....	....	....	....	....
	D.O.	4.1	1.8	7.7	8.7	6.5	10.4	9.6	8.1	3.9	5.6	6.1	4.4	3.4	8.1	....	....	....	....	....	....	....
2	°F.	70	70	64	69	63	53	52	53	52	60	62	59	59	57	51	48	50	50	50	....	52
	D.O.	6.0	5.1	6.1	7.8	4.8	10.4	8.4	5.5	3.8	3.6	5.2	6.6	4.9	7.4	6.8	8.1	10.8	11.2	8.2	....	8.9
3	°F.	70	70	63	69	63	53	52	52	50	60	63	59	59	57	47	47	50	51	48	....	52
	D.O.	9.3	6.5	6.8	6.2	5.9	10.9	9.5	9.6	5.7	7.6	6.3	6.4	6.7	7.8	8.9	7.5	12.3	12.3	11.0	....	9.4
4	°F.	70	70	63	69	62	55	....	53	43	60	64	59	59	....	48	45	50	51	48	....	52
	D.O.	10.0	8.6	11.2	7.7	8.4	9.6	....	10.8	12.0	7.9	8.2	8.1	7.3	....	10.2	11.8	14.2	13.1	10.4	....	10.0
5	°F.	69	....	62	69	62	55	....	53	45	60	63	59	58	....	50	43	51	51	47	....	54
	D.O.	9.2	....	7.7	8.2	9.5	9.7	....	10.4	11.0	7.4	8.7	8.8	7.8	....	10.5	12.8	14.4	13.6	11.2	....	12.1
6	°F.	70	....	63	69	62	57	....	55	53	60	64	60	59	....	53	45	51	....	47	....	54
	D.O.	2.2	....	8.5	8.7	10.1	10.4	....	9.8	4.4	5.7	8.0	4.9	8.2	....	9.8	11.7	13.6	....	10.7	....	10.2
7	°F.	69	....	63	69	62	57	51	54	46	60	63	60	60	....	49	44	51	....	47	....	54
	D.O.	8.4	....	7.7	8.7	9.2	10.8	11.7	10.6	12.0	6.0	7.0	7.7	7.3	....	9.4	11.6	14.2	....	11.6	....	9.0
8	°F.	71	....	65	68	62	57	53	55	44	60	64	60	60	57	51	46	51	52	49	....	54
	D.O.	10.9	....	6.5	8.4	8.2	10.9	8.5	7.6	11.2	7.0	7.3	7.6	5.6	8.0	10.5	9.8	11.2	11.9	10.1	....	8.9
9	°F.	71	....	65	69	62	58	52	55	48	60	64	60	60	57	49	45	51	54	50	....	54
	D.O.	10.7	....	7.2	8.0	9.0	10.2	10.6	6.2	7.5	7.0	8.6	6.8	7.4	6.8	9.7	12.8	14.8	13.8	9.7		8.8

TABLE 5—Continued

Dissolved oxygen data in ppm at bay stations from September, 1957, through July, 1958

Station		February, 1958							March, 1958							April, 1958					
		3	6	13	17	20	24	27	10	13	17	20	21	24	27	2	7	10	15	16	24
2	°F.	50	59	48	....	48	52	....	63	56	61	60	....	61	63	65	69	69	....	69	77
	D.O.	8.6	5.3	7.4	....	7.5	8.3	....	4.1	12.3	12.1	4.9	....	4.0	8.3	8.5	2.7	5.5	....	1.9	4.2
3	°F.	53	59	44	....	49	....	....	62	56	61	57	....	61	65	66	69	68	....	68	77
	D.O.	9.5	8.9	11.8	....	7.0	....	....	6.8	12.3	12.9	11.6	....	5.7	8.6	12.0	4.4	11.1	....	3.6	6.9
4	°F.	....	59	44	[illegible]	[illegible]	[illegible]	[illegible]	62	[illegible]	[illegible]	58	[illegible]	60	63	65	[illegible]	[illegible]	[illegible]	[illegible]	70

TABLE 5—Continued

Dissolved oxygen data in ppm at bay stations from September, 1957, through July, 1958

Station		February, 1958							March, 1958							April, 1958					
		3	6	13	17	20	24	27	10	13	17	20	21	24	27	2	7	10	15	16	24
2	°F.	50	59	48	....	48	52	....	63	56	61	60	....	61	63	65	69	69	....	69	77
	D.O.	8.6	5.3	7.4	....	7.5	8.3	....	4.1	12.3	12.1	4.9	....	4.0	8.3	8.5	2.7	5.5	....	1.9	4.2
3	°F.	53	59	44	....	49	....	....	62	56	61	57	....	61	65	66	69	68	....	68	77
	D.O.	9.5	8.9	11.8	....	7.0	....	....	6.8	12.3	12.9	11.6	....	5.7	8.6	12.0	4.4	11.1	....	3.6	6.9
4	°F.	....	59	44	....	....	....	....	62	....	....	58	....	60	63	65	....	....	....	....	79
	D.O.	....	9.5	12.1	....	....	....	....	11.3	....	....	12.8	....	10.5	14.4	9.9	....	....	....	....	8.6
5	°F.	....	59	44	....	....	....	....	63	....	....	58	....	....	60	66	....	....	....	....	79
	D.O.	....	10.2	11.4	....	....	....	....	11.7	....	....	12.8	....	....	13.5	10.5	....	....	....	....	7.7
6	°F.	....	....	....	....	48	....	....	64	55	....	....	....	....	66	67	....	67	....	67	79
	D.O.	....	....	....	....	10.6	....	....	11.9	14.0	....	....	....	....	15.3	11.7	....	10.1	....	13.5	8.3
7	°F.	....	....	....	....	47	....	....	62	56	....	....	....	60	63	66	67	68	....	68	....
	D.O.	....	....	....	....	11.4	....	....	11.5	12.2	....	....	....	10.4	14.4	10.9	7.8	11.5	....	13.5	....
8	°F.	....	60	....	....	47	....	....	62	56	....	58	....	60	67	67	66	68	....	....	79
	D.O.	....	7.7	....	....	11.0	....	....	12.0	14.0	....	12.8	....	11.6	18.0	13.0	6.4	12.8	....	....	9.6
9	°F.	....	60	45		46	....	....	62	57	....	58	....	61	63	65	67	67	....	....	78
	D.O.	....	8.2	12.0	0	10.6	....	....	14.1	13.4	....	13.0	....	12.0	18.0	12.5	7.9	12.2	....	....	6.6

Station		May, 1958								June, 1958				July, 1958						
		2	6	8	15	20	22	27	28	5	12	17	26	2	3	8	10	17	22	31
2	°F.	....	....	....	79	77	78	....	85	88	85	87	86	87	....	85	....	88	88	89
	D.O.	....	....	....	6.6	1.6	2.0	....	4.1	3.5	11.6	3.2	12.6	3.2	....	1.3	....	4.0	3.5	3.9
3	°F.	....	....	....	....	78	79	....	89	88	85	87	87	87	....	83	....	88	87	89
	D.O.	....	....	....	....	1.7	3.3	....	4.6	4.8	8.5	3.6	12.8	3.3	....	8.8	....	4.7	6.8	5.6
4	°F.	....	....	....	79	....	77	....	....	88	85	....	....	85	....	85	84	88	....	....
	D.O.	....	....	....	8.3	....	11.6	....	....	15.0	10.6	....	....	10.5	....	13.0	10.5	12	....	....
5	°F.	....	....	....	80	....	....	....	....	87	86	....	....	83	....	82	84	89	....	....
	D.O.	....	....	....	9.7	....	....	....	....	15.0	15.0	....	....	11.3	....	8.0	11.6	12.0	....	....
6	°F.	....	....	77	80	....	....	....	....	....	....	....	....	84	....	83	84	91	....	89
	D.O.	....	....	10.3	6.2	....	....	....	....	....	....	....	....	10.9	....	8.8	9.8	12.0	....	11.0
7	°F.	....	....	....	80	75	....	....	....	....	....	....	86	85	....	84	85	88	87	89
	D.O.	....	....	....	9.5	7.5	....	....	....	....	....	....	13.3	11.6	....	12.4	10.9	12.1	10.9	11.0
8	°F.	....	....	....	80	....	....	....	....	....	86	....	87	....	....	....	....	89	....	89
	D.O.	....	....	....	10.6	....	....	....	....	....	15.0	....	13.2	....	....	....	....	12.0	....	11.0
9	°F.	....	....	78	80	....	....	....	....	....	86	....	87	86	....	84	85	....	....	88
	D.O.	....	....	6.6	9.7	....	....	....	....	....	16.0	....	13.2	13.2	....	12.8	12.8	....	....	10.1

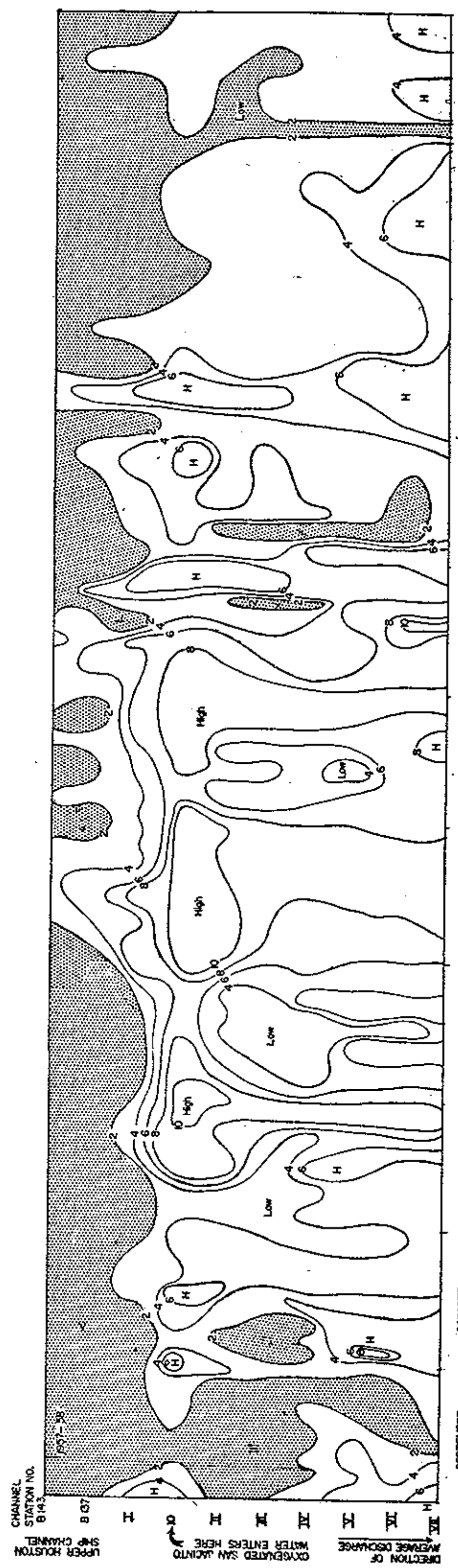
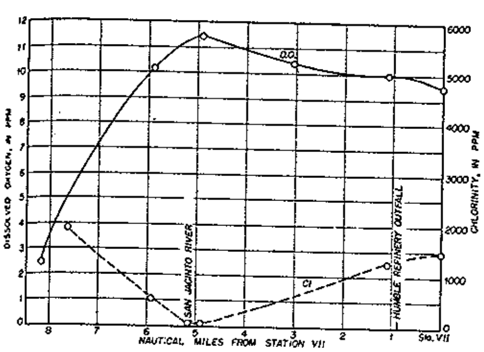


FIG. 11. Concentrations of dissolved oxygen of the Houston Ship Channel in parts per million (ppm) and dissolved oxygen isopleths at 2 ppm intervals.



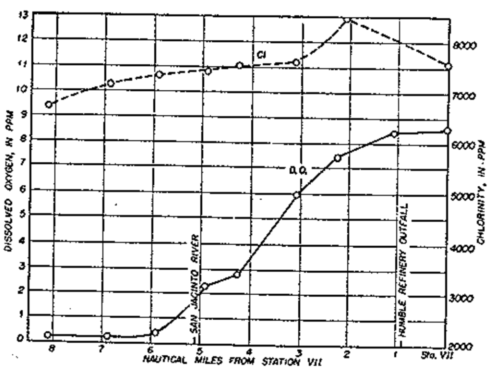


Fig. 12. Dissolved oxygen and chlorinity in the Houston Ship Channel on January 16, 1958, a time of heavy rain and runoff.

Fig. 13. Dissolved oxygen and chlorinity in the Houston Ship Channel on April 2, 1958, a time of little inflow of river and rain water.

of the survey area. The correlation with chlorinity demonstrates clearly that heavy rains and San Jacinto River flow increase dissolved oxygen in the ship channel.

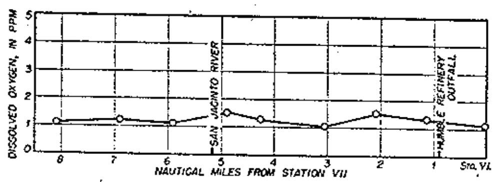
April 2, 1958, was a time when chlorinities were high throughout the survey area with no rainfall and little flow from the San Jacinto River. For that reason it was selected as representative of hydrographic conditions the reverse of those on January 16, 1958. When the data of dissolved oxygen and chlorinities are plotted against location (Figure 13), we find that after the first mile there was a steady increase in the concentration of dissolved oxygen from the upper to the lower boundaries of the portion of the ship channel. At this time there was very little gradient of chlorinity.

The dissolved oxygen data for July 8, 1958, presented in Figure 14, are representative of the Houston Ship Channel in the poorest condition encountered in regard to dissolved oxygen concentration. On this date the D.O. varied only between 1.0 and 1.5 ppm throughout the part of the ship channel within the survey area. This condition very rarely occurs. Chlorinities were not determined on this date, so the relationship of the phenomenon to salinity is not known. These dissolved oxygen concentrations are below the levels necessary to sustain almost all species of fish.

May 8, 1958, was selected as a day in which the dissolved oxygen concentration was at its highest level throughout the channel. We find (Figure 15) that the dissolved oxygen reached almost 4.0 ppm at the farthest point up the channel, rose above 7.0 ppm at the San Jacinto River, and remained at approximately this level throughout the rest of the survey area. This pattern differs from that on January 16, 1958 only in the higher dissolved oxygen content in the channel above the influence of the San Jacinto River.

Seasonal Pattern of Dissolved Oxygen Concentrations In the Surface Waters of the Ship Channel

Throughout the portion of 1957 and 1958 in which data are available, we find that there is almost always a greater concentration of dissolved oxygen at the lower end of the area under study than at the upper end (Figure 11). The San Jacinto River when flowing, especially during periods of heavy rainfall, greatly increases the dissolved oxygen content of that portion of the ship channel lying below it and even for a considerable distance above it as was mentioned previously in the discussion of Station I. Partial re-oxygenation by tidal exchange with less polluted water is greater in the lower portion



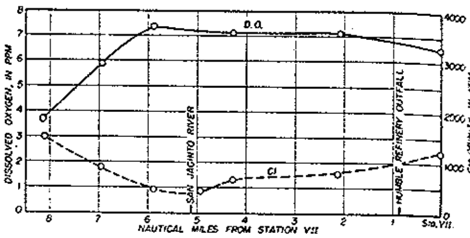


Fig. 14. Dissolved oxygen concentration in the Houston Ship Channel on July 8, 1958, a time of minimum oxygen content.

Fig. 15. Dissolved oxygen and chlorinity in the Houston Ship Channel on May 8, 1958, a time of maximum oxygen content.

of the ship channel. The oxygen demands, both biochemical (BOD) and chemical (COD), created by industrial and domestic waste material have a greater effect in the upper channel and are reduced toward the lower channel. Because of the heavy oxygen demands, it is difficult to establish a seasonal picture of dissolved oxygen concentration in the upper channel or to correlate the D.O. with rainfall and salinity. Reference to Figure 16 indicates that in some periods, for example, February, 1958, the D.O. in the upper channel (Station 137) followed the trend of the lower channel (Station VII) though the oxygen content was almost always considerably lower in the upper channel. At other times there was little correlation. During the entire period of study the lower channel (Station VII) dropped as low as 2.0 ppm in dissolved oxygen on only three occasions: September 13, 1957; July 7, 1958; and July 22, 1958. At no time during the survey did the D.O. drop as low as 1.0 ppm at that location.

Station VI, located nearest to the outfall of the Humble Refinery (see map, Figure 3) and approximately one mile above Station VII, has a dissolved oxygen concentration which, when plotted over the year, is found to follow rather closely the curve of Station VII (Figures 16 and 17).

As expected, there is a correlation between the amount of San Jacinto River flow, chlorinity at Station 10, and dissolved oxygen concentration at Station 10 (Figure 18). When the river flow is high, chlorinity is low and dissolved oxygen concentration is high. From a seasonal point of view, the oxygen content rises in winter and drops in summer. Water flowed over the spillway at Lake Houston from September 27, 1957, through December 11, 1957, and from December 13, 1957, until March 14, 1958. There was intermittent flow in the period between March 14, 1958, and April 14, 1958, then spillway flow from April 14 to May 31, 1958. It can be seen in Figure 18 that the period between May 31 and July 31, 1958, in which no flow over the Lake Houston spillway occurred, was the period of lowest dissolved oxygen concentrations at Station 10.

Based on the data obtained in 1957, we can say that the D.O. in the upper channel probably fluctuates independently of seasonal conditions; and that the D.O. at Station 10 is dependent on the flow over the Lake Houston spillway and is highest in the winter, lowest in the summer months, and intermediate in the fall and spring. The lower end of the survey area (Stations VI and VII) has the same seasonal pattern as Station 10. They are influenced by the San Jacinto River, but modified by tidal effects and flow from both the upper channel and the bays.

In July, 1955, prior to this study, a series of dissolved oxygen determinations were made by a modified Winkler technique in approximately the region of the ship channel in the present study. Oxygen values, as shown in Table 6, were much lower in 1955 than in 1957–58. Possibly the effluents of the industrial concerns and municipal sewage plants above the Battleship Texas (Station I) have been greatly improved or the difference in rainfall between 1955 and 1957–58 resulted in a much improved ship channel from the standpoint of dissolved oxygen content.

Dissolved Oxygen Distribution in the Bays

A series of dissolved oxygen transects across Burnett Bay have been plotted to show typical dissolved oxygen patterns under various conditions. These charts (Figures 19 through 22) have Station II in the channel as the initial point to show conditions in the

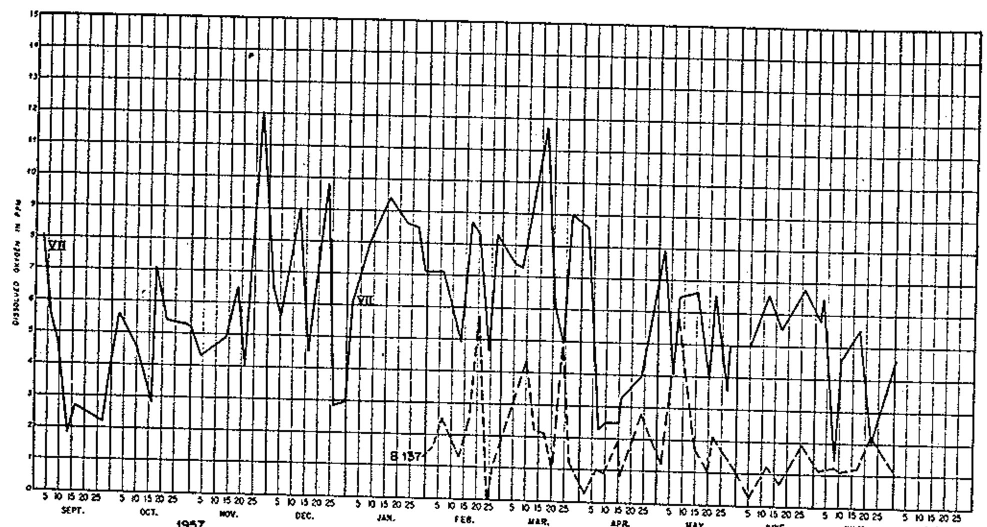


Fig. 16. Dissolved oxygen concentrations in the Houston Ship Channel at the upper (Station 137) and lower (Station VII) limits of the survey area between September 1957 and July 1958.

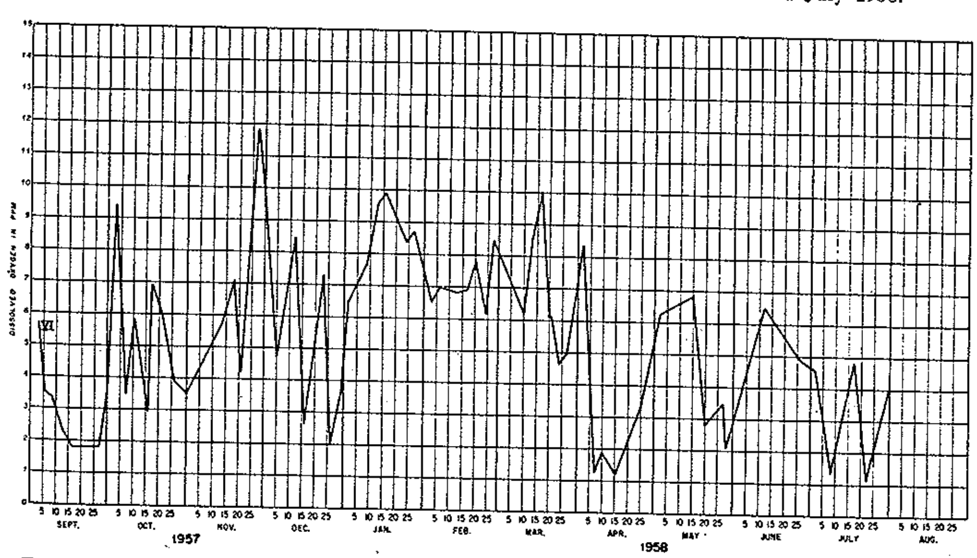


Fig. 17. Dissolved oxygen concentration near the Humble Refinery Outfall (Station VI) from September 1957 through July 1958.

channel, then Stations 2, 3, 7, and 6 (see map, Figure 3) across Burnett Bay to demonstrate changes in the distribution of dissolved oxygen levels relative to distance from the ship channel.

On April 2, 1958, a day typical of those when the salinity is higher in the channel, the

TABLE 6

Dissolved oxygen concentrations at channel stations from July, 1955, through December, 1955
(All data collected at mid-channel)

Date	Location of sample point						
	Battleship Texas	300 yards above San Jacinto River	300 yards below San Jacinto River	Mouth of Peggy's Lake	Power line crossing	Opposite Humble effluent outfall	Tunnel crossing
July 18	1.3	1.4	2.4	4.5	3.5	1.9	1.9
July 21	0.0	0.4	1.2	1.2	1.0	1.9	5.6
July 25	0.0	0.0	0.2	1.7	3.2	0.9	2.0
July 28	0.2	0.6	0.5	1.3	1.6	0.9	1.4
August 1	0.0	0.0	0.3	1.2	1.7	0.9	1.7
August 4	0.1	0.2	0.5	0.9	0.4	2.2	2.7
August 10	0.1	0.0	0.1	0.5	1.0	1.5	1.1
August 17	0.4	0.7	1.4	2.4	2.1	1.8	2.2
August 23	0.0	0.0	0.0	0.3	0.6	0.7	0.7
August 30	0.3	0.7	0.2	1.6	5.7	2.0	3.0
September 7	0.0	0.0	0.6	0.4	0.2	0.9	0.4
September 14	0.4	0.5	0.6	1.3	1.5	1.1	1.8
September 21	0.0	0.2	0.2	1.4	0.7	1.5	1.8
September 28	0.0	0.0	0.0	0.6	2.0	1.1	1.7
October 5	0.0	0.0	0.0	0.0	1.1	1.4	3.3
October 12	0.0	0.0	0.0	0.2	1.1	0.8	1.7
October 19	0.0	0.0	0.0	0.0	1.3	1.6	2.0
October 26	0.0	0.0	0.0	0.0	1.4	1.4	2.8
November 2	0.0	0.0	0.0	0.4	2.3	2.8	3.3
November 9	0.3	0.4	0.5	0.7	2.1	2.3	2.8
November 16	0.4	0.7	0.6	1.1	2.0	2.3	2.6
November 23	0.0	0.2	0.2	0.5	1.5	1.7	2.2
November 30	0.6	0.6	0.6	2.2	5.1	4.4	6.2
December 7	0.3	0.4	0.4	0.5	0.9	0.9	1.9
Nearest station in present survey	I	II (Before Jan. 30)	II (After Jan. 30)	IV	Between V and VI	300 yards below VI	VII

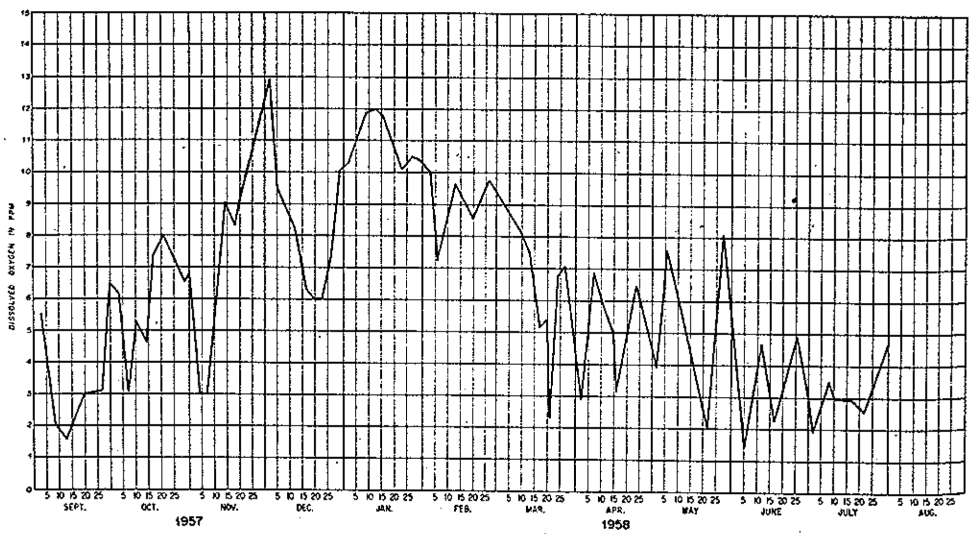
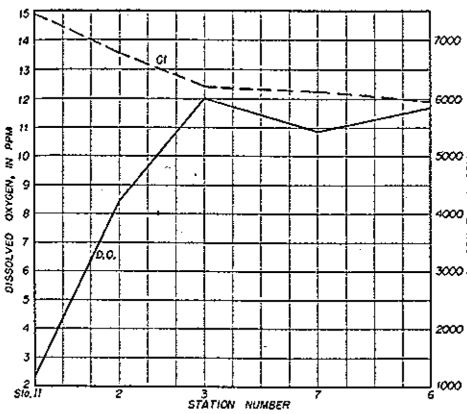


FIG. 18. Dissolved oxygen concentrations in the San Jacento River (Station 10) from September 1957 through July 1958.



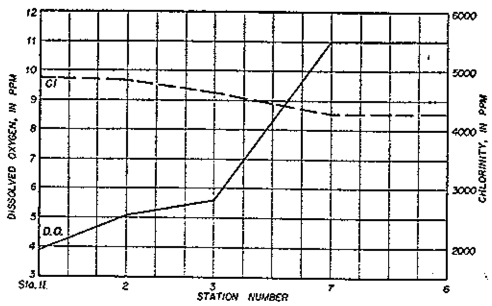


FIG. 19. Dissolved oxygen and chlorinity distribution in Burnett Bay. April 2, 1958.

FIG. 20. Dissolved oxygen and chlorinity distribution in Burnett Bay. July 31, 1958.

oxygen content rapidly increased as the chlorinity gradually dropped (Figure 19). Both dissolved oxygen and chlorinity were essentially constant beyond Station 3 (see map, Figure 3).

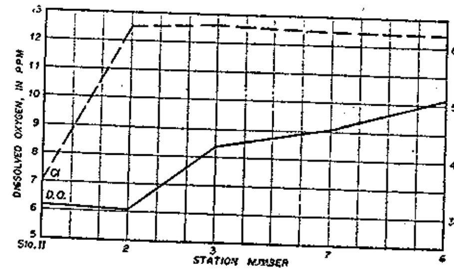
On July 31, 1958, the chlorinity of the ship channel and Burnett Bay were very nearly the same. Once again, there was an evaluation of dissolved oxygen across a transition zone (Figure 20).

A situation in which the chlorinities in the bays were higher than in the ship channel existed on December 26, 1957 (Figure 21). This was a time, discussed previously, of high rainfall, heavy river runoff, low salinity, and high dissolved oxygen. Although the dissolved oxygen at Station II in the channel was unusually high, 6.0 ppm, the D.O. continued to increase all the way across the bay. It appears from the chlorinity curve in the figure that little or no mixing occurred beyond Station 2.

The data for October 16, 1958, a period of heavy rainfall, had an oxygen pattern with the dissolved oxygen content high in the channel, low in the transition zone, then high across the bay (Figure 22).

Diurnal Cycle of Dissolved Oxygen

On one occasion, July 8, 1958, after several overcast days, dissolved oxygen content of Burnett Bay water near Station 6 was determined at frequent intervals over a 50-hour period. These data are presented in Figure 23. At 6:00 A.M. on July 8, 1958, the dissolved oxygen content was at the lowest point but soon rose to 20.0 ppm and above with the peak occurring about 5:00 P.M., then the D.O. concentration began to drop. By 7:00 A.M., July 9, however, it had been reduced only to 8.5 ppm, remaining approximately 5.0 ppm higher than it had been at the same time on the previous morning. July 9 was cloudy and the dissolved oxygen concentration did not rise above 11.8 ppm during the day. By 6:00 A.M. of July 10, the D.O. concentration had dropped to 7.1 ppm, 1.4 ppm lower than at the same time the previous morning. July 10, however, was clear and the dissolved oxygen concentration soon built back to saturation. It appears likely that the D.O. concentration would have continued to drop had the cloud cover continued for several more days.



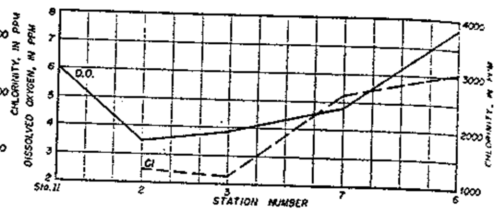


FIG. 21. Dissolved oxygen and chlorinity distribution in Burnett Bay. December 26, 1957.

FIG. 22. Dissolved oxygen and chlorinity distribution in Burnett Bay. October 16, 1957.

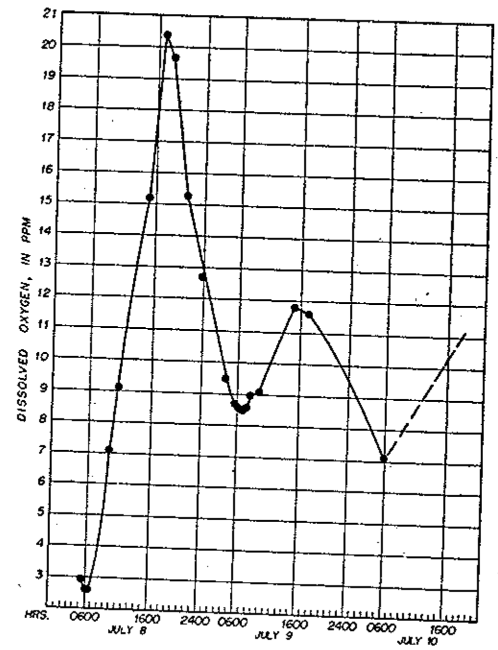


FIG. 23. Dissolved oxygen concentration in Burnett Bay over a 48 hour period.

Seasonal Dissolved Oxygen Concentrations in Burnett Bay

In considering the seasonal distribution of D.O. in the bays as shown by the data obtained at Station 7 (Figure 24), two facts must be borne in mind. As discussed earlier, there is a large daily fluctuation in D.O. concentration in the bays and during the year in which these data were obtained rainfall was heavier than for the past several years. Since these data were obtained at approximately the same time each day, they were considered comparable. The general seasonal trend was for the D.O. to be low in the fall, high in the winter, dropping in the spring, and rising again in the summer.

Data on Other Chemical Substances in Channel Water

The absence of dissolved oxygen in the Houston Ship Channel from the Houston Turning Basin to the San Jacinto River, a distance of 13.3 nautical miles, indicates that large quantities of organic and inorganic industrial and municipal wastes enter the channel. Seasonal variations and changes in hydrographic conditions have at times extended the low oxygen conditions of the channel (0.5 ppm) 16.5 nautical miles downstream.

Certain inorganic materials introduced into the channel may actually be beneficial as they accelerate the reduction of the introduced organic material. Phosphate, ammonia, nitrates, and other materials which are needed to support micro-organism populations are introduced into the channel by industrial and municipal wastes. Phosphate is not believed to be a limiting factor in the biological oxidation of organics as large quantities of phosphate enter the channel through its extensive use in the treatment of cooling tower water. The roles of sulfates and nitrates in providing oxygen for the reduction of organic materials are illustrated by data from studies made in the Thames estuary. Nitrates and sulfates in the Thames estuary account for about 8.9 to 10.6 per cent of the oxygen from all sources (calculated from data given by Gameson and Barrett, 1958). In contrast to the Thames estuary, which receives principally sewage wastes, the Houston Ship Channel receives large quantities of industrial wastes and consequently receives a relatively larger quantity of nitrates and sulfates than the Thames. For these reasons it is believed that the quantities of nitrates and sulfates introduced into the Houston Ship channel by industrial wastes play a significant role in preventing the area of dissolved oxygen depletion from being larger than that found.

The evolution of gases which are produced by the bacteriological decomposition of organic materials is clearly visible in the waters above the mouth of the San Jacinto River. Hydrogen sulfide and dissolved oxygen have been determined quantitatively and simultaneously in the upper region of the survey area.

A number of water samples were taken at mid-channel at a depth of about six inches and analyzed for one or several of the following: hydrocarbon, phenol, and sulfide content; chemical oxygen demand (COD), and pH. The results of these analyses are presented in Table 7. Because of the limited chemical data and a realization of the problem of adequately sampling the channel, only a few general conclusions are made.

Considering the large amounts of organic materials that are thought to enter the

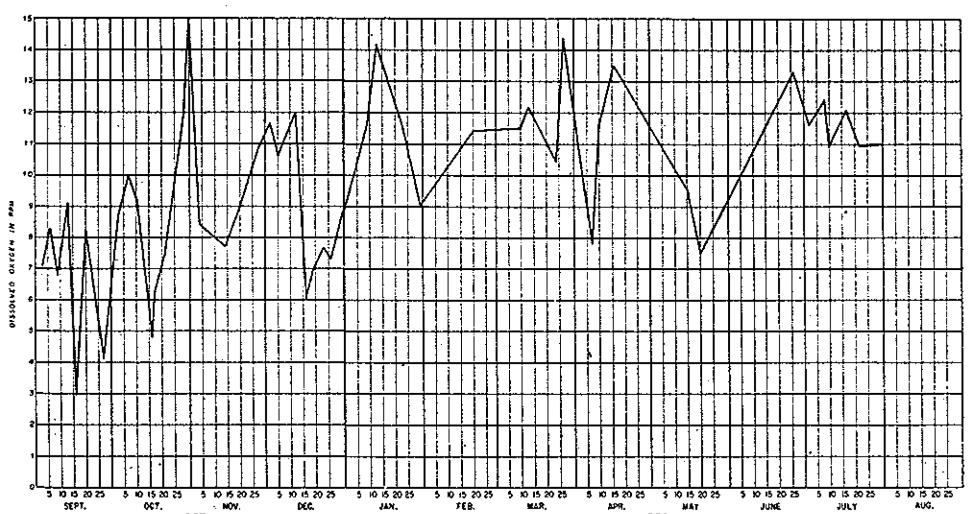


FIG. 24. Dissolved oxygen concentrations in Burnett Bay (Station 7) between September 1957 and July 1958.

TABLE 7

Chemical analysis of channel water

Date	Mid-channel location	Sulfides* ppm	Hydrocarbons† ppm	Phenol‡ ppm	pH	COD§ ppm
Oct. 16	Station No. 1	..	5.0	1.0	......	....
Dec. 16	Station No. 1	0.0	0.0	0.0	......	....
Dec. 17	No. 1 Dock	0.0	1.0	0.0	......	....
Jan. 9	Buoy 141	0.0	4.0	1.0	7.10	....
Jan. 9	Buoy 134	0.0	0.0	...	......	....
Jan. 16	Buoy 141	0.0	1.0	4.0	7.10	....
Jan. 27	Station No. 1	....	5.9	2.8	......	....
Jan. 29	Buoy 133	....	2.0	4.0	......	....
Jan. 30	Buoy 143	....	7.0	14.0	6.86	....
Feb 3	Buoy 143	....	0.0	11.0	7.03	10.0
Feb. 6	Buoy 143	0.0	4.0	13.0	7.06	....
Feb. 13	Buoy 143	....	3.0	7.0	7.09	1.0
Feb. 13	Buoy 137	....	0.0	5.0	......	....
Feb. 17	Buoy 143	....	0.0	1.0	......	12.0
Feb. 17	Buoy 137	....	...	....	......	0.5
Feb. 20	Buoy 143	....	1.0	4.0	7.06	2.0
Feb. 20	Buoy 137	....	1.0	0.0	......	....
Feb. 24	Buoy 143	....	2.0	1.0	6.92	4.0
Feb. 27	Buoy 143	....	1.0	0.0	6.92	0.5
Feb. 27	Buoy 137	....	1.0	0.0	7.02	....
Mar. 10	Buoy 143	....	0.0	0.0	7.06	4.0
Mar. 10	Buoy 137	....	2.0	1.0	7.07	....
Mar. 13	Buoy 143	0.085	2.0	0.0	7.10	2.0
Mar. 13	Buoy 137	0.085	0.0	0.0	7.32	....
Mar. 17	Buoy 143	0.68	13.0	0.0	7.16	4.0
Mar. 17	Buoy 137	0.25	1.0	0.0	6.98	2.0
Mar. 20	Buoy 143	1.0	2.0	3.0	7.05	....
Mar. 20	Buoy 137	0.5	3.0	1.0	7.07	....
Mar. 21	Buoy 160	0.4	4.0	0.0	6.88	7.0
Mar. 21	Buoy 137	0.8	1.0	0.0	6.97	5.0
Mar. 24	Buoy 143	0.0	....	....	......	....
Mar. 27	Buoy 143	0.0	....	....	......	....

Analytical methods:

* Short cut method assuming no mercaptides. Karchmer and Dunahoe (1948), p. 918.

† Simard, *et al.* (1951).

‡ Murray (1949).

§ Chemical oxygen demand, cold permanganate titration. Standard methods for the examination of water and sewage, 9th edition, p. 123.

channel, the hydrocarbon contents determined for upper channel samples (Stations 143 and 137) were surprisingly low.

The pH in the upper channel (Station 143) ranged from 6.8 to 7.2, averaging about 7.0. These data indicate a predominance of acidic material is introduced into the channel since the normal pH range of surface fresh water is 6.0–8.0 and of sea water is 8.0–8.4.

Based on the chemical analysis of channel water for February, March, and April, there was usually at least a 30 per cent reduction in the hydrocarbon, and phenol content between Station 143 and Station 137. The reduced hydrocarbon content at Station 137 could be due to several factors including: (1) the greater dilution by the San Jacinto River water and salt tidal water on Station 137 as compared to 143, and (2) the additional detention time for bacteriological action from Stations 143 to 137. Statistically, there was no correlation between hydrocarbon content and phenol content at either Station 137 or Station 143; correlation coefficients for this being $r = -0.328$ at 137 and $r = -0.06$ at 143.

Bottom Studies

Cores were taken in the ship channel and bays on December 17, 1957. A sketch of the gross appearance of each of these cores is shown in Figure 25. Thick strata of fine grained deposits indicated that the bays were settling basins or areas of deposition. The cores indicated a complex history of deposition, probably the result of repeated dredgings. For example, Core No. 1 showed that the bottom in the upper channel, at Beacon 133, consists of a layer of sand overlaying a three-inch stratum of soft black mud, which rested on a base of fine sand mixed with large amounts of plant debris. Both the lower strata contained many more foraminiferan tests per inch than did the upper sand layer.

A limited number of channel sediment samples were taken with an Ekman dredge 15.2 cm × 15.2 cm, screened, and examined for particulate matter and fauna. The organic content was determined on a previously dried portion of each sample.

The absence of living organisms and the limited amounts of forams, shell, bivalves, and other deposited forms indicate the unsuitable environment for most bottom organisms on the bottom of the channel. Annelids more typical of a normal environment were found only in the shallow areas of the channel in the vicinity of Peggy's Lake.

Particulate material in the form of black conglomerates, possibly oil coated solids or ion sulfide bodies, were more evident in the near vicinity of Humble's outfall and in mid-channel samples from Peggy's Lake and above than in the other areas sampled. The frequency of the black conglomerates seems to be correlated with the organic content of the samples.

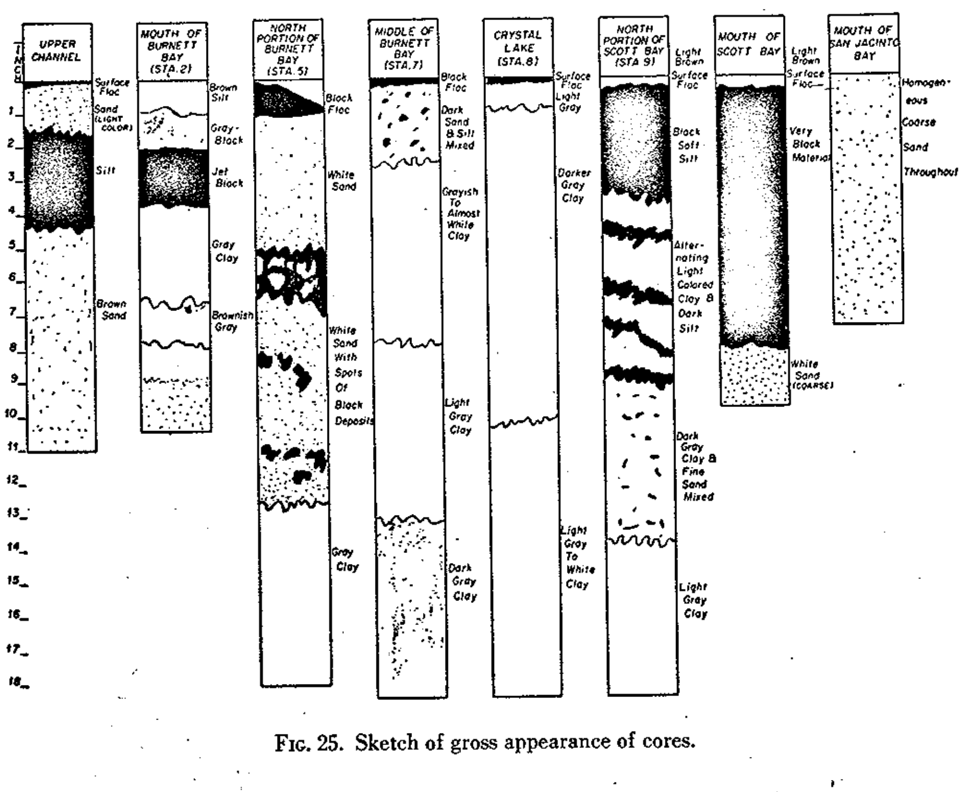


FIG. 25. Sketch of gross appearance of cores.

Organic Content of the Sediments

The organic content of the channel sediments was measured (Table 8) and compared with data on the hydrography of the area, environmental factors, and sources of organic material. Sludge samples were partially dried overnight at 75°C. The dried material was pulverized by a Braun Pulverizer. The infrared spectrum from 2 to 15 microns was determined on CCl_4 extracts of the samples. Because of the complexity and low concentration of organic materials, no compound or type identification were possible from the infrared (I.R.) spectra. The method of determining the organic content using the I.R. spectra as described by Simard *et al.* (1951) was employed on the extracts. The organic content was calculated on a dry sediment basis. There is a 60 per cent reduction in organic content on mid-channel sediment from Buoy 137 to Station IV (4780 ppm to 1920 ppm), a distance of 3.9 miles, and a slight increase in the vicinity of Humble's outfall (2390 ppm), while the organic content 675 yards downstream from the outfall was the same and at 1520 yards the content was higher (3200 ppm). A reduction in the organic content should take place downstream from the source due to conversion by bacterial activity. Reductions under aerobic conditions have been reported as 50 per cent to 80 per cent per week on a mineral oil emulsion (Ludzak and Kinkead, 1956) while under anaerobic condition the reduction is not significant (Ludzak *et al.*, 1957). The greater amount of bacteriological activity, therefore, may take place below the San Jacinto River where there is a more suitable aerobic environment.

The phenomenon of oil breaking from oil coated solids when they are disturbed is well established. The gasification process which occurs in the channel results in a disturbance of the bottom sediments. This action tends to raise the oil and solids toward the surface, with the solids quickly resettling. The reverse procedure also takes place quite rapidly as the oil becomes emulsified by finely divided solids and settles to the bottom again. In an estuary both the solids and oil may generally move downstream while the amount of oil is reduced by biological activity. This movement of oil and sludge is substantially increased by the additional turbulence provided by loaded ocean-going ships moving in the channel.

The rapid emulsification of free oil which then settles, plus the apparent rapid settling of the oil-coated suspended solids, account for the much higher organic content on samples taken at 50 yards from the outfall. As might be expected, organic content downstream is 21,720 ppm while upstream it is 11,800 ppm.

Diversity and Distribution of Fishes and Larger Invertebrates

Discussion and Distribution of the Species

Following are taxonomic lists and discussion of the fishes and larger invertebrates collected by otter trawls in the Houston Ship Channel and adjacent bays. Notes on chlorin-

Table 8

Chemical analysis of channel sediments, June 17, 1958

Location	Organic content, ppm
Mid-channel, 0.75 mile below refinery outfall	3,200
Mid-channel, 0.30 mile below refinery outfall	2,390
Mid-channel, 0.0 mile from refinery outfall	2,390
Mid-channel, 2.20 miles above refinery outfall (Station IV)	1,920
Mid-channel, 6.06 miles above refinery outfall (Station 137)	4,780
50 yards above outfall and 15 yards from eastern shoreline	11,800
50 yards below outfall and 15 yards from eastern shoreline	21,720

ity, temperature, and dissolved oxygen are included with special comments on movement of fresh water and salt water fish in the estuarine area under study. An effort is made to compare the diversity and distribution of biota of the industrialized Houston area with that of other areas studied in the Rockport area by Gunter (1945 and 1950) and in the Galveston Bay area by Reid (1955, 1955a, and 1956).

Penaeus spp.: A total of 5,039 undifferentiated Penaeus were collected in the study. Large numbers of shrimp were present in the bays during August and September, 1957.

Penaeus setiferus (Linnaeus): White shrimp were caught in all bays in which trawls were made; a total of 3,123 taken in the bays and channel were identified as this species. The largest collections were made on July 17, 1958 (1,006) and July 10, 1958 (668). The first shrimp identified as *P. setiferus* appeared on November 14, 1957, as compared to October 10, 1957, for *P. aztecus*. No *P. setiferus* were collected between January 30 and May 2, 1958, migration out of the area apparently having occurred. In other areas Gunter (1950) found that essentially all *P. setiferus* moved out of the bays by the end of December. Chin (1960) shows that white shrimp are always present in Galveston Bay, but that during the winter, shrimp are not abundant in the bay.

Penaeus aztecus Ives: Brown shrimp were collected more frequently and in much larger numbers than *P. setiferus* in the fall and spring. Chin (1960) in the same calendar year found that brown shrimp dominated the bait fishery in Galveston Bay in June. White shrimp first appeared in the fishery in July and became increasingly more important until, in October, brown shrimp comprised only 18 per cent of the catch and had virtually disappeared by November. Our data indicate that *P. aztecus* is much more numerous than *P. setiferus* in the bays in the Baytown area in the fall and spring. The seasonal distribution tends to follow that of Galveston Bay as shown by Chin in that the heavy populations of October (and, presumably August and September) decreased rather rapidly during November, and disappeared completely after December 12, 1957. No *P. aztecus* were collected between December 12, 1957, and May 8, 1958.

Palaemonetes sp.: Grass shrimp were taken on 35 occasions and at all bay stations except between Stations 2 and 3 at the mouth of Burnett Bay, with a total of 489 collected. The maximum numbers were found in December, when 200 were taken in a single trawl in Crystal Lake. No specimens were collected prior to November 27; none were taken in January and the first 20 days of February. The range of conditions over which grass shrimp were caught in the bay was between 44°F and 89.5°F in temperature, and 1.9 ppt to 6.5 ppt chlorinity.

Callinectes sapidus Rathbun: The blue crab is one of the dominant animals in the bays of the survey area. A total of 1,535 *C. sapidus* were collected over a wide chlorinity (190 ppm–7,380 ppm) and temperature range (44°F–89.5°F), being taken in 94 out of the 96 bay trawls.

Data on crabs are related to dissolved oxygen in the environment below.

Dissolved Oxygen Interval	Number of Channel Trawls	Number of Trawls With Crabs	Average Number of Crabs in Catch
0–0.5	3	0	—
0.6–1.0	0	..	..
1.1–1.5	6	0	....

1.6–2.0	2	1	15
2.1–2.5	8	2	15
2.6–3.0	3	1	3
3.1–3.5	2	1	16
3.6–4.0	2	2	4
4.1–4.5	1	0	....
4.6–5.0	4	4	23
5.1–5.5	3	3	12
5.6–6.0	3	3	33
6.1–6.5	4	3	8
6.6–7.0	5	5	18
7.1–7.5	1	1	3
7.6–8.0	5	5	5

Few crabs were collected at low concentrations of oxygen. It was noted that when the concentration of D.O. dropped below 1.0 to 2.0 ppm, crabs were observed out of the water on floating objects, or ashore. Carpenter and Cargo (1957) have shown that significant mortality of blue crabs occurred at 28 to 30°C with a 0.86 D.O. and at 24 to 26°C with 0.71 ppm D.O. This ability of *C. sapidus* to exist at much lower concentrations of oxygen than most fishes has been shown by the channel trawls. Often blue crabs were the only animals caught in a trawl. It must again be pointed out that D.O. was determined on samples taken at a depth of about 1 foot while channel trawls were at a depth of five to nine feet where oxygen concentrations may have been lower.

Lepisosteus productus (Cope): Two specimens of the spotted gar were taken in the survey, both at Station 4–5 in Burnett Bay. One specimen was collected on February 13, the other on March 20, and at a chlorinity of 2.2 ppt and 5.0 ppt.

Lepisosteus spatula (Lacepede): Twenty-five specimens of the alligator gar were collected in the study. All but five were caught at Station 4–5 in Burnett Bay. All specimens were collected between the months of November and March. Temperature may affect the ease with which they can be caught as no gars have been taken during the warm water period in the summer even though large numbers of gars were seen.

Lepisosteus platostomus (Rafinesque): Two specimens of the short nose gar were collected in Burnett Bay at 2.3 ppt and 1.9 ppt chlorinity.

Brevoortia sp: The taxonomic keys for the clupeids state the shoulder spots of *B. patronus* is usually followed by one or more additional spots while *B. gunteri* does not have any additional shoulder spots. Those menhaden with shoulder spots taken in this study were tabulated as *B. patronus* while those without additional shoulder spots were tabulated as *Brevoortia sp.* Not one of the specimens tabulated in the field as *Brevoortia sp.* when examined in the laboratory has been identified as *B. gunteri.* The presence of only *B. patronus* is in agreement with Reid (1955). If the menhaden tabulated as *Brevoortia sp.* are, in fact, all *B. patronus,* the per cent range of *B. patronus* without shoulder spots from 0 per cent to 29 per cent for the bays and from 32 per cent to 85 per cent for Station VII (Table 9). One plausible explanation for this significant difference in per cent of *B. patronus* without shoulder spots in the bay as compared to the channel is that generally larger specimens were captured in the bays. It was further noted that the shoulder spots did occasionally appear on specimens that were in the same size class as those without a series of shoulder spots.

TABLE 9

Catch of Menhaden *(Brevoortia patronus)* and the distribution of shoulder spots in 1958

Station	May 22	May 28	June 5	June 12	June 26	July 2	July 10	July 17	July 31
With shoulder spots									
VII	61	......	21	23	15	30	25	46	68
4–5	......	......	71	97	......	100	95	100	......
6–7	......	......	......	......	......	98	90	100	100
8	......	......	......	100	......	......	......	82	97
9	......	......	......	......	......	83	86	......	......
Without shoulder spots									
VII	39	......	79	77	85	70	75	54	32
4–5	......	......	29	3	......	0	5	0	......
6–7	......	......	......	......	......	2	10	0	0
8	......	......	......	0	......	......	......	18	3
9	......	......	......	......	......	17	14	......	......
Number of Menhaden caught per trawl									
VII	146	300*	132	258	185	235	110	26	334
4–5	......	......	41	63	......	52	55	92	......
6–7	......	......	......	......	......	69	163	37	36
8	......	......	......	4	......	......	......	40	65
9	......	......	......	......	......	87	49	......	......

* Estimated.

Brevoortia patronus Goode: Thirteen hundred and sixty-two specimens of *B. patronus* were collected at all bay stations and at all channel trawl stations except at Buoy 137. It was present in small numbers in the bays during October and November, but was absent from the survey area between December 5, 1957, and May 8, 1958, when small numbers were collected from the channel at Stations VII and III and between Stations 6 and 7 in Burnett Bay. Beginning in the latter part of May and the first half of June and continuing through July, a large number of *B. patronus* were found in the channel and in the bays. It was never taken above the mouth of the San Jacinto River in the trawls. This form was found in the bays in a wide chlorinity range, from 1,030 ppm to 6,600 ppm, but was most abundant at a chlorinity range of 3.9 ppt to 5.2 ppt.

Reid (1955) found that East Bay supported a large population of this species, although it had been considered the high salinity form of the genus in the past. Gunter (1945) found a peak abundance of *Brevoortia sp.*, which he felt included *B. patronus* and another species, in April and a low point in June and July. This is in contrast to our data which show the greatest abundance during this time. Our data agree with Gunter's data showing an exodus of this form from the bays in mid-winter.

Dorosoma cepedianum (LaSueur): The gizzard shad was taken over a wide range of temperature and chlorinity as shown by its presence in 92 of the 96 bay trawls. A total of 6,903 specimens of this species have been collected. The population increased in the fall until the winter trawl samples taken from November through February were composed chiefly of gizzard shad. The monthly catches are shown below:

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
Bay Trawls	10	12	13	17	8	9	8	5	3	11
Trawls With Catch	10	12	13	17	8	6	7	5	3	11
Number of Fish Per Catch	15.3	64.4	54.1	213.4	92.5	8.0	13.7	25.8	16.0	25.9

Since the gizzard shad has been reported to spawn in fresh water in the spring, the high winter population in the bays may be the result of migrating through the area from Galveston Bay to spawn.

The much smaller catches in the channel may be correlated with low oxygen concentrations there. The lowest concentration of oxygen at which gizzard shad were caught was 4.6 ppm and of the 20 trawls taken at 4.6 ppm or above, shad were taken in 6 of them.

Dorosoma petenensis (Günther): The threadfin shad, formerly in the genus *Signolosa*, was found to be a common fish in the area, a total of 742 being collected. The threadfin shad, like the gizzard shad, was found over a wide range of temperature and chlorinity (0.19 ppt—7.4 ppt), but it was not found as abundantly nor was there a high winter population. These generalities can be seen in the monthly catches shown below:

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
Bay Trawls	10	12	13	17	8	9	8	5	3	11
Trawls With Catch	9	11	10	13	5	3	6	3	1	1
Number of Fish Per Catch	13.8	19.9	9.2	6.1	8.0	1.4	3.9	3.0	0.3	0.1

The lowest concentration of D.O. in the channel at which threadfin shad were caught was 4.6 ppm which was the same minimum concentration at which gizzard shad were collected.

Anchoa mitchilli Hildebrand: On August 20–21, 59 specimens of the bay anchovy were taken in Burnett Bay. Subsequently it was collected 10 times, a total of 19 specimens, but only a few specimens were taken after October 31, 1957. Reid (1955) found this species to be third in number of fishes caught in East Bay, but he states it is probably the most abundant fish in the bay.

Ictiobus bubalus (Rafinesque): A single specimen of smallmouth buffalo was taken by trawl, three times in Burnett Bay and once in Scott Bay. All specimens were taken in December and January when the water temperature was between 44°F and 54°F. Chlorinities ranged between 0.5 ppt and 3.2 ppt, when they were collected.

Cyprinus carpio Linnaeus: One specimen of this fresh water carp was taken on November 14, 1957 in Scott Bay at a chlorinity of 2.5 ppt, a temperature of 65°F, and a dissolved oxygen content of 8.0 ppm. Neither Gunter (1945) nor Reid (1955 and 1956) list this species as occurring in Texas bays. Breder (1929), however, lists it as an occasional stray in Chesapeake and New York bays.

Bagre marina (Mitchill): Gafftop catfish were collected in Scott Bay, in September and on July 10, 1958, at chlorinities from 4.4 ppt to 4.9 ppt.

Galeichthys felis (Linnaeus): Large numbers of sea catfish were taken in Scott Bay in the collections of August 20–21, 1957. This species remained common in the bays until October. It was not taken from December until March 20, 1958, and it was not common again until June.

Ameiurus melas (Girard): Two black bullheads were taken in Crystal Lake (October 31, 1957, chlorinity 2.9 ppt, temperature 69°F; December 26, 1957, chlorinity 6.1

ppt, temperature 60°F). This species was found in the bays during the winter when the chlorinity was reduced by heavy rains.

Fundulus grandis Baird and Girard: Because of the preference of the gulf killifish for shallow water, numbers in trawl collections were not a true indication of the numbers of *F. grandis* in the bays. It was taken on 18 occasions, with a total of 50 specimens collected.

Fundulus similis (Baird and Girard): Two specimens of longnose killifish were collected between Stations 4 and 5 in northern Burnett Bay on December 26, 1957.

Cyprinodon variegatus Lacepede: The broad killifish was caught in the trawls on 14 occasions with a total of 69 specimens being taken. It was collected in all the bay stations except between Stations 6 and 7 but was never taken in the ship channel. The hydrographic conditions in which it was collected were about the same as those for *F. grandis.*

Strongylura marina (Walbaum): Two needlefish were collected on September 27, 1957, at Station 8 in Crystal Lake.

Urophycis floridanus (Bean and Dresel): A single specimen of the southern hake was taken in Burnett Bay on April 2, 1958 at a chlorinity of 6.1 ppt.

Menidia beryllina (Goode and Bean): The gulf silverside was collected in six different trawls with a total of 10 specimens taken. Large schools have been noted moving up the channel during the months of June and July. Chlorinities were quite variable, but temperatures were fairly low—ranging from 44° to 58°F.

Mugil cephalus Linnaeus: The striped mullet is unquestionably the dominant fish in the survey area. On many occasions no specimens were taken in the trawl when the surface of all the bays were virtually alive with mullet. It would be impossible to estimate the number or weight of mullet, most of which are *M. cephalus*, in bays of the survey area, but the figures would undoubtedly be extremely large. Despite the inefficiency of the otter trawl in collecting mullet, *M. cephalus*, with 1380 caught, ranked fifth, after *D. cepedianum*, *M. undulatus*, *L. xanthurus*, and *B. patronus*, in number of specimens of fishes collected in the study (Table 10). It was taken at all stations and under a wide range of hydrographic conditions.

The mullet was taken over the entire chlorinity range of the bay trawls while the majority were caught in water below 4.0 ppt chlorinity. Only three successful catches of mullet were made out of 19 trawls in May, June, and July. Since temperature apparently affects the susceptibility to capture of this species, trawl samples cannot be used as indices to the actual population. The catch by month is indicated below:

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
Bay Trawls	10	12	13	17	8	9	8	5	3	11
Trawls With Catch	7	10	11	17	7	7	7	2	1	0
Number Per Catch	4.4	24.0	2.3	37.9	17.6	9.5	4.4	0.4	2.7	0
Temp. Range of Catch Trawls	66–73	55–65	44–60	44–54	44–60	56–64	65–78	78–80	86	

Whether the variations are real or due to interaction of temperature upon the catch per trawl is not certain.

TABLE 10

Abundance of shrimp, crabs, and the 20 most abundant species of fish in trawl collections from October, 1957 through July, 1958

		Total numbers caught
Dorosoma cepedianum	gizzard shad	6,903
Micropogon undulatus	croaker	3,960
Penaeus setiferus	white shrimp	3,123
Brevoortia patronus	gulf menhaden	2,935
Leiostomus xanthurus	spot	2,330
Penaeus sp.	commercial shrimp	2,199
Leiostomus and *Micropogon*	spot and croaker	1,748
Penaeus aztecus	brown shrimp	1,746
Callinectes sapidus	blue crab	1,535
Mugil cephalus	striped mullet	1,380
Dorosoma petenensis	threadfin shad	742
Palaemonetes sp.	grass shrimp	489
Cynoscion arenarius	sand trout	262
Pogonias cromis	black drum	86
Cyprinodon variegatus	broad killifish	69
Fundulus grandis	Gulf killifish	50
Galeichthys felis	sea cat	32
Lepisosteus spatula	alligator gar	22
Anchoa mitchilli	bay anchovy	19
Lagodon rhomboides	pinfish	18
Bagre marina	gafftopsail catfish	16
Aplodinotus grunniens	freshwater drum	15
Stellifer lanceolatus	star drum	14
Dormitator maculatus	sleeper	14
Pomoxis nigro-maculatus	black crappie	13
Menidia beryllina	gulf silverside	10

Mugil curema Cuvier and Valenciennes: The white mullet was rare in the survey area, only two specimens being taken on October 10, 1957.

Polydactylus octonemus (Girard): The eight-fingered threadfin was collected only once when six specimens were taken on May 15, 1958, in the Houston Ship Channel (Station VII).

Trichiurus lepturus Linnaeus: A single specimen of cutlass fish was collected in each of three trawls at Station VII in the Houston Ship Channel. Chlorinities at the time of the collections were 7.4 ppt, 4.5 ppt, and 5.2 ppt.

Pomoxis nigro-maculatus (LeSueur): In the present study the black crappie was collected on 10 occasions, with a total of 13 specimens taken. It was found in Burnett Bay, Crystal Lake, and Scott Bay and in the Houston Ship Channel at Station III and as far down the channel as Station VII from December through April. It was found at chlorinities as high as 6.8 ppt.

Lepomis microlophus (Günther): A single redear sunfish was captured on January 9, 1958, between Stations 4 and 5 in Burnett Bay at a chlorinity of 3,180 ppm.

Chaenobryttus gulosus (Cuvier): On December 12, 1957, and April 24, 1958, a warmouth bass was collected from Burnett Bay at chlorinities of 5.9 ppt and 5.0 ppt.

Roccus chrysops (Rafinesque): One specimen of white bass was collected between Stations 6 and 7 in Burnett Bay on December 26, 1957, at a chlorinity of 6.2 ppt.

Roccus mississippiensis (Jordan and Evermann): Yellow bass were collected on three occasions in Burnett Bay, October 10, December 12, and January 30 where chlorinities ranged from 2.9 ppt to 5.2 ppt and the temperature from 44°F to 73°F.

Lagodon rhomboides (Linnaeus): In August and September, 1957, 250 pinfish were collected, mostly in Crystal Lake. The species disappeared from the area by the first of November and was not taken again until the latter part of June, an absence of almost seven months.

Gunter (1945) found *L. rhomboides* to be absent from Copano from December to March inclusive.

Larimus fasciatus Holbrook: Two banded croakers were collected on August 20, 1957, in Burnett Bay.

Stellifer lanceolatus (Holbrook): Star drum were collected during October and November, 1957, but were not taken from November 14, 1957, until July 10, 1958. The chlorinity at which it was collected ranged from 370 ppm to 6,000 ppm and the temperature varied from 63°F to 85°F.

Sciaenops ocellata (Linnaeus): Four redfish were taken during the study.

Leiostomus xanthurus and *Micropogon undulatus*: The two species of commonly found croakers are discussed together because of the similarity of their life history and the difficulty in distinguishing the smaller juveniles.

The spot is one of the most common fishes found in the survey area. It was abundant at the time of the preliminary sampling during August and September, 1957, and continued to be found in small numbers in Burnett, Crystal Lake, and Scott bays during October. It was absent from the end of October until the first of May, except for large numbers of very small fish which were difficult and often impossible to separate from the young of *Micropogon undulatus*. A total of 1,748 of these mixed young were collected between January 9, 1958, and April 24, 1958.

After the young became large enough to be readily identified, the numbers of spot collected increased greatly, with large numbers being taken at all bay stations and in the lower ship channel. A total of 2,330 spot were collected and identified during the study.

Reid (1956) found this to be one of the most abundant fishes in East Bay. Gunter (1945) caught large numbers of *L. xanthurus* in Copano and Aransas bays within wide ranges in temperature and salinity, but caught few specimens during the winter months.

In the present study 3,960 croakers were caught and identified as *M. undulatus*, and as discussed, large numbers of young were collected but not distinguished from *L. xanthurus*. Recognizable *M. undulatus* were absent from the area during the latter half of November and all of December and January. Fish identifiable as *M. undulatus* appeared in the bays in February and became numerous in April. Large populations were present through the end of July, 1958.

The monthly catch of spot and croaker, as tabulated, illustrates the decline of the population in the fall, absence from November 14 to January 16, and an increase in the spring. Thousands of small croakers were seen in the channel as early as December 16. They were undoubtedly also present in the bays by this time but were too small to be taken by otter trawl. Size ranged from about 11 to 200 mm for croaker and 16 to 100 mm for spot.

	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
Bay Trawls	16	10	12	13	17	8	9	8	5	3	11
Catch Per Trawl	5.2	1.9	0.1	0.0	0.7	1.6	10.9	231.1	287.2	66.0	140.4

The last *L. xanthurus* to be taken in the fall was on October 31, while some two weeks later on November 14 the last *M. undulatus* was taken.

There is some evidence that the D.O. requirements for the two species may be different. The spot was found at lower concentrations of D.O. than the croaker. The ratio of spot to croakers for the bay trawls and two of the channel trawls for the months of May, June, and July are given below:

Ratio of Species	Location	May	June	July
L. xanthurus/M. undulatus	Bay	0.01	0.83	0.51
L. xanthurus/M. undulatus	VII	0.93	0.36	5.37
L. xanthurus/M. undulatus	III	4.72	(11/0)	(0/0)

The higher ratio of spot to croaker in the channel as compared to the bays for May and July and the difference in the ratio between the channel trawls for May and June indicate a difference in D.O. requirements for the two species.

Th spot and croaker were usually taken in the channel when the D.O. content was above 3.7 ppm. Of the 40 trawls made during this period the fish were taken in 17 out of 18 trawls when D.O. was above 3.7, but when the D.O. was lower than 3.7 ppm, fish were taken only once in 22 trawls. At 2.0 ppm only *L. xanthurus* were caught.

Pogonias cromis (Linnaeus): Drum were found in small, but consistent, numbers through November until April when the species disappeared completely from the collections. *P. cromis* was taken at chlorinities from 370 to 6,780 ppm.

Cynoscion arenarius Ginsburg: Sand trout were relatively abundant in all the bays until late November. No *C. arenarius* were taken during the months of December, January, February, and March as shown by the monthly catch below:

	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
Catch Per Trawl	6.5	2.7	0.5	0	0	0	0	0.1	0.2	2.0	16.0

It has been shown by Gunter (1945) and other workers that there is a decline of the bay population in the fall and winter and that the sand trout apparently migrates to the gulf at the onset of cool weather in the fall. The lowest temperature at which fish were caught by Gunter (1945) was 66.9°F (13.7°C). In this study, however, fish were taken in late October and November at water temperatures somewhat lower than 67°F. For example, in eleven trawls in the spring, trout were caught in a temperature range between 62° to 68°F.

Cynoscion arenarius were taken over a wide salinity range as shown below:

Cl Interval,	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5
ppt	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Bay Trawls	9	6	3	9	10	3	4	7
Catch Per Trawl	0.0	0.0	1.0	1.2	1.7	0.0	0.0	2.0
Cl Interval,	4.0	4.5	5.0	5.5	6.0	6.0	6.5	7.0
ppt	4.5	5.0	5.5	6.0	6.5	6.5	7.0	7.5
Bay Trawls	10	8	9	6	8	8	3	1
Catch Per Trawl	6.7	6.5	51.5	9.0	1.0	1.0	10.0	0.0

Sand trout were probably absent in the middle chlorinity range and below 1.0 ppt because all the trawls except one in these particular intervals were taken at a temperature lower than 62°F.

After the water temperature rose above 62°F, sand trout were taken in seven out of 15 trawls at Station VII while none were taken at Station III where 11 of 14 trawls made were in water below 4.0 ppm D.O.

Cynoscion nebulosus Cuvier and Valenciennes: The speckled trout was taken only once during the survey.

Aplodinotus grunniens Rafinesque: The fresh water drum was collected on 11 occasions with a total of 15 specimens taken sporadically during the months of October, November, January, March, and April. The chlorinity at which fresh water drum were taken in the bays ranged from 40 ppm to 6,500 ppm and the temperature varied from 49°F to 84°F. It was found on seven occasions at chlorinities above 1.0 ppt and on three occasions above 5.0 ppt.

Chaetodipterus faber (Broussonet): Spadefish were found in August and September, 1957, with a total of 18 collected. The species was not collected between September and July 31, 1958.

Dormitator maculatus (Bloch): The sleeper was first taken during the preliminary study in September, 1957, when 28 specimens were taken in all the bays in the area. Fourteen specimens were taken in the survey from October until the middle of December, 1957. It was not taken after December 12, 1957, at any station. Chlorinities varied from 0.19 ppt to 6.6 ppt; the temperature ranged from 44°F to 73°F.

Gobioides brousonneti Lacepede: The violet goby was collected on five occasions from Burnett Bay, Crystal Lake, and Scott Bay with a total of seven collected. Chlorinity ranges at the time of collection varied from 1.4 ppt to 6.6 ppt. This form was taken in October, December, and February.

Gobionellus shufeldti (Jordan and Eigenmann): Four specimens of this fresh water goby were collected during October, November, and December, in Crystal Lake on three occasions. Chlorinity varied from 1,950 ppm to 5,970 when they were taken. Neither Gunter (1945) nor Reid (1956) collected *G. brousonneti* or *G. shufeldti*.

Trinectes maculator (Bloch): The hog choker was taken on five occasions in the survey, all in Burnett Bay between October 31, 1957, and January 30, 1958. Chlorinities varied from 0.34 ppt to 5.2 ppt and the temperature range was from 49° to 66°F.

Variation in Trawl Catch Between Stations

To determine if a significant difference existed in the trawl samples at stations, the sign test was employed. The catch per trawl for each species at a particular station was compared during a two-week period, in most cases for each of the two weeks, to the catch per trawl at the other bay stations.

The results of such comparisons indicate no significant difference exists in the catch between the individual bay trawls except that, on occasion, the sample taken in the entrance of Burnett Bay (Station 2 to Station 3) was significantly different from the other bay trawls.

Scott Bay is much closer to the point of discharge of the Humble effluent than stations in Crystal or Burnett bays. Since trawl data in Scott Bay were not significantly different from that in the other bays, it is believed that Humble's effluent has little effect, if any, on the distribution of fish in the local bays.

There was an obvious difference in the total population of fishes, shrimp, and crabs at different localities in the ship channel and a significant difference in the species comprising fish populations (Table 11). In general, there was a decrease, both in the number of species and in the total population of fishes, from lower to upper channel, as shown by the results of progressive trawl samples up the channel. During the period between March and July, fish were taken in only one of thirteen trawls in the upper channel region (Station 137) as compared to 6 of the 16 trawls in the middle channel region (Station III) and 15 of the 16 trawls in the lower channel region (Station VII). The principal reason for these differences may have been the lack of adequate dissolved oxygen to support fish life in the upper channel. It was found that when the surface dissolved oxygen content was 4.0 ppm or above, fish were usually taken in the trawls.

The difference in species composition between the lower and middle regions of the channel was due largely to the presence of high salinity fishes in the lower region such as *G. felis*, *C. arenarius*, *S. ocellata*, *P. octonemus*, *T. lepturus*, and *Prionotus sp.* Although the salinity was often higher in the lower region (Station VII) than at the middle region (Station III), on a number of occasions species differences were found when the chlorinity was about the same at Station III and Station VII. The difference in species composition probably results from factors such as the reduced dissolved oxygen at Station III.

A resident population cannot be maintained in the middle region of the channel (Station III) because of environmental conditions. The fish taken here are transient populations that move in and out of the area as the environmental conditions fluctuate. Wide fluctations of D.O. occur seasonally, daily, and hourly.

The per cent of the catch for certain species of fish in the middle region of the channel was quite different from the bays and usually from the lower region as shown by the Data in Table 12. The per cent of the catch data shown in Table 12 and the dissolved oxygen content data for these days indicate that the dissolved oxygen requirements of *M. undulatus* are higher than *L. xanthurus*, and that menhaden prefer water containing more than 4.0 ppm D.O. The species representation in the bays and channel (Station VII), the first date of appearance of marine fishes, and the last for fresh water fishes

TABLE 11

Comparison of trawl collections in the ship channel. Figures are the number of fish or crabs caught per trawl (c/t)

Date		Upper region Station 137		Middle region Station III		Lower region Station VII		Number of species	
		Crab c/t	Fish c/t	Crab c/t	Fish c/t	Crab c/t	Fish c/t	Same	Different
March	20	0	0	0	0	8	33	....	....
	27	0	0	0	0	9	15	....	....
April	2	0	0	3	0	2	124	....	....
	10	0	0	0	0	29	0	....	....
	24	0	0	3	1	16	40	....	1
May	2	0	0	1	70	5	50	2	4
	8	1	27	3	311	12	276	3	4
	15	0	0	7	38	14	220	4	4
	22	0	0	0	0	14	313	....	....
	28	0	0	0	0	34	830	....	....
June	5	0	0	0	0	27	271	....	....
	12	0	0	15	21	28	333	3	3
July	2	....	....	1	1	99	269	....	1
	10	....	....	0	0	15	474	....	....
	17	....	....	1	0	10	137	....	....
	31	....	....	0	0	18	367	....	....

TABLE 12

Variation in percent of catch for certain species in the bays and channel

Date	Station	*Brevoortia* sp. including *B. patronus*	*Leiostomus xanthurus* percent	*Micropogon undulatus* percent	*Galeichthys felis* percent	Others percent	All fish catch per trawl
May 2	III	0	87	17	0	0	70
	VII	10	26	52	2	10	50
May 8*	III	1	82	17	0	0	311
	VII	1	85	12	0	2	276
	6–7	0.3	0.3	98	0	1	648
May 15	III	8	71	18	0	3	38
	VII	19	39	36	0.4	6	220
	4–5	2	2	84	0.26	13	386
	6–7	1	1	58	0	38	66
	8	13	1	72	0	12	282
June 12	III	48	52	0	0	0	21
	VII	78	9	13	0.3	0.9	333
	4–5	34	32	23	0	12	197
	8	4	22	62	0	12	94

* Station 137, *L. xanthurus*, 96%; *M. undulatus*, 4%.

between March 20, 1958, through July 31, 1958, are shown below. Certain species were not included as they occurred at all stations over the entire period.

Species	Marine or Fresh water	Present in Bay, Channel Or Both	Date of Appearance at Station VII	Date of Appearance at Bay Stations
Brevoortia sp.	M	both	April 2	April 2
G. felis	M	both	March 20	April 24
B. marina	M	channel	July 10	----------
C. faber	M	channel	July 31	----------
C. arenarius	M	both	June 5	April 24
T. lepturus	M	channel	May 15	----------
C. nebulosus	M	channel	June 26	----------
S. lanceolatus	M	channel	July 10	----------
A. grunniens	F	bay	----------	July 10
L. rhomboides	M	both	June 26	July 2
S. ocellata	M	channel	May 8	----------
L. productus and *L. platostomus*	F	bay	----------	March 20
A. mitchilli	M	both	May 2	April 2
P. octonemus	M	channel	May 15	----------

Most marine fishes migrating into the area in the spring and early summer were taken first at Station VII, the most seaward station, and some have been taken only at that station. Several of the marine fishes, however, were taken first in the bays due to immigration of the species between sampling periods.

Literature Cited

Breder, C. M., Jr. 1929. Field book of marine fishes of the Atlantic Coast from Labrador to Texas. New York, Putman's Sons, XXXVII + 332 pp.

Carpenter, J. H. and D. G. Cargo. 1957. Oxygen requirements and mortality of the blue crab in the Chesapeake Bay. Chesapeake Bay Institute, Technical Reports, XIII: 1–21.

Chin, E. 1960. The bait shrimp fishery of Galveston Bay, Texas. Trans. Amer. Fish. Soc. 89(2): 135–141.

Dixon, W. J. and F. J. Massey, Jr. 1951. Introduction to statistical analysis. New York, McGraw-Hill, X + 370 pp.

Gameson, A. L. H. and M. J. Barrett. 1958. Oxidation, reaeration, and mixing in the Thames Estuary. Proceedings of a siminar on oxygen relationships in streams, October 30–November 1, 1957, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, 63–93.

Gunter, G. 1945. Studies on the marine fishes of Texas. Publ. Inst. Mar. Sci. Univ. Tex., 1(1): 1–190.

———. 1950. Seasonal population changes and distribution as related to salinity of certain invertebrates of the Texas coast, including the commercial shrimp. Publ. Inst. Mar. Sci. Univ. Tex., 1(2): 7–51.

Hohn, M. H. 1959. The use of diatom populations as a measure of water quality in selected areas of Galveston and Chocolate Bay, Texas. Publ. Inst. Mar. Sci. Univ. Tex., 6: 206–212.

Karchmer, J. H. and J. W. Dunahoe. 1948. Rapid determination of sulfides, thiosulfates and sulfites. Analyt. Chem., 20(10): 915–919.

Ludzack, F. J. and D. Kinkead. 1956. Persistence of oily wastes in poluted water under aerobic conditions. Industr. Engng. Chem., 48(2): 263–267.

Ludzack, F. J., W. M. Ingram, and M. B. Ettinger. 1957. Characteristics of a stream composed of oil refining and activated sludge effluents. Sewage Industr. Wastes, 29(10): 1177–1189.

Marmer, H. A. 1954. Tides and sea level in the Gulf of Mexico. Fish. Bull., U.S., 89: 101–118.

Murray, M. J. 1955. Total phenols in gasoline and in cresylic acid. Analyt. Chem., 21(8): 941–945.

Patrick, R. 1955. Catherwood Diatomer survey in the Gulf Coast. Academy of Natural Sciences of Philadelphia, Dept. of Limnology (unpublished).

Reid, G. K. 1955. A summer study of the biology and ecology of East Bay, Texas. Part I. Tex. J. Sci., 7(3): 316–343.

———. 1955a. A summer study of the biology and ecology of East Bay, Texas. Part II. Tex. J. Sci., 7(4): 430–453.

———. 1956. Ecological investigations in a disturbed Texas coastal estuary. Tex. J. Sci., 8(3): 296–327.

Simard, R. G., I. Hasegawa, W. Bandaruk, and C. E. Headington. 1951. Infra-red spectrophotometric determination of oil and phenols in water. Analyt. Chem., 23(10): 1384–1387.

Tyler, C. P. and J. H. Karchmer. 1959. Portable analyzer for determination of dissolved oxygen in water. Analyt. Chem., 31(4): 499–502.

Some Opisth

EVELI

A collection of marine slugs
eight species are new. All of the

The Opisthobranchs desc
ana coasts principally by Pr
Station, Dillon Beach, Cali
from life. The specimens ar
(P.O. Box 6994), São Pau

Apl

Occurrence: Texas, Mus
1947; one specimen.
Description: The preserv
is soft, hence it must have
black" (Dr. Hedgpeth), an
is a little denser and theref
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Seminal groove (d) and p
The tentacles form the e
Also, the very short rhin
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concrescence is one mm. T
rated by a distance of 8 mm
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condition frequently found
type. The purple gland (v
brownish secretion. The op
broad which open separatel