FACTORS INFLUENCING THE SPAWNING AND SETTING OF OYSTERS IN GALVESTON BAY, TEX.[1]

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CONTENTS

INTRODUCTION

The problems of oyster culture in the waters of the South Atlantic and Gulf coasts are decidedly different from those in the waters of the North Atlantic coast although the oysters are of the same species (*Ostrea virginica*). On the Gulf coast the bays and estuaries are very shallow, and so the waters are readily affected by heavy rains and freshets as well as by differences in air temperature. The natural oyster beds, or reefs, are generally confined to a relatively narrow place between high and low tide levels and slightly deeper, and seldom occur more than 2 or 3 feet below low-water level. In more northern waters natural oyster grounds may be under 30 or more feet of water.

Few actual oyster-cultural operations are carried on in Texas waters and the industry is limited chiefly to the removal and marketing of oysters from the public reefs. In the past this method has sufficed to supply the demand to a large extent, and the necessity for intensive oyster culture on private grounds has not been pressing. In recent years, however, the oyster production of Texas, like that of many other States, has diminished, and increasing thought has been given to the possibilities of oyster culture by private individuals or companies. The Texas Game, Fish, and Oyster Commission is strongly in favor of production of oysters by private interests and has been attempting to pass legislation to permit the leasing of portions of productive public reefs as a stimulus to private enterprise. (Burr, 1928.)

It was the purpose of this investigation to learn some of the more important facts concerning the reproduction of the oyster in Texas waters and on the basis of this information to make suggestions as to how best to develop ground for the production of oysters. Of greatest importance was the problem of finding means of obtaining seed oysters in abundance, and it was with this in view that these observations and experiments were made.

[1] Approved for publication Nov. 28, 1930.

It was not possible to make daily observations over the entire coast of Texas, and so the work was confined to certain portions of Galveston Bay, which is very similar to the other oyster-producing waters along the coast. The results are therefore considered to be typical and may apply to most of the bays along the Gulf coast.

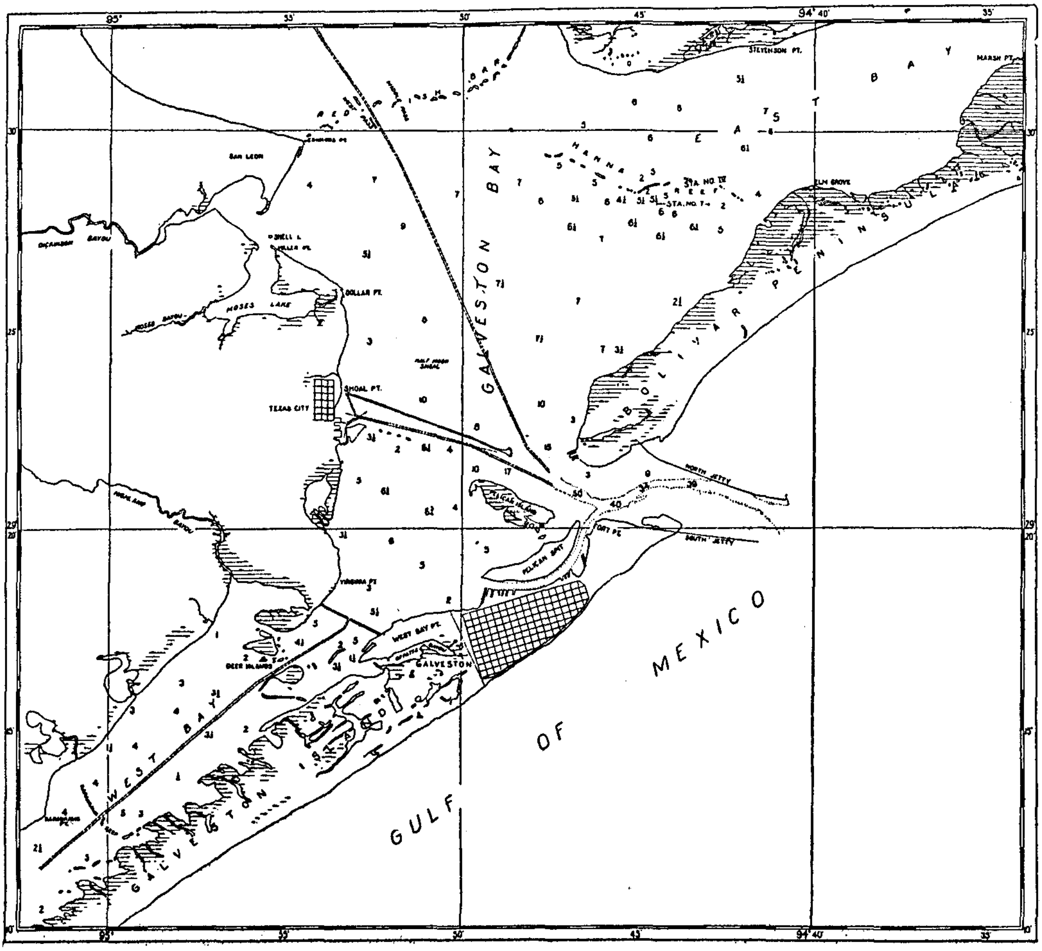

FIGURE 3.—Chart showing the major portion of Galveston Bay in which oysters are produced. Plankton collection station No. 7 and shell-planting station No. IV are indicated at Hanna Reef, in East Bay. See Figures 4 and 5 for West Bay and Offatts Bayou stations. (From U. S. Coast and Geodetic Survey Chart No. 1282)

A field laboratory[2] was built on the shore of Offatts Bayou (fig. 1), a portion of West Bay, and equipped with running sea water. This served as headquarters in which most of the observations were made.

METHODS

The most complete records were made in Offatts Bayou, for it is a small body of water and relatively calm even when the bay proper is rough. A pier extended out from the laboratory about 200 feet to the edge of the channel and on this the thermograph was placed. (Fig. 2.) The bulb was fixed slightly above bottom under about 2½ feet of water at low tide so as to give a fairly accurate record of water temperature without being exposed even at extreme low water. Continuous thermograph records

[2] The bureau is indebted to William J. Tucker, game, fish, and oyster commissioner of Texas, for furnishing the laboratory and equipment and a boat and boatman; also to W. A. Kelso for permitting the location of the laboratory on his property; and to Dolph Rogers for giving oysters as well as his time to assist in the investigation.

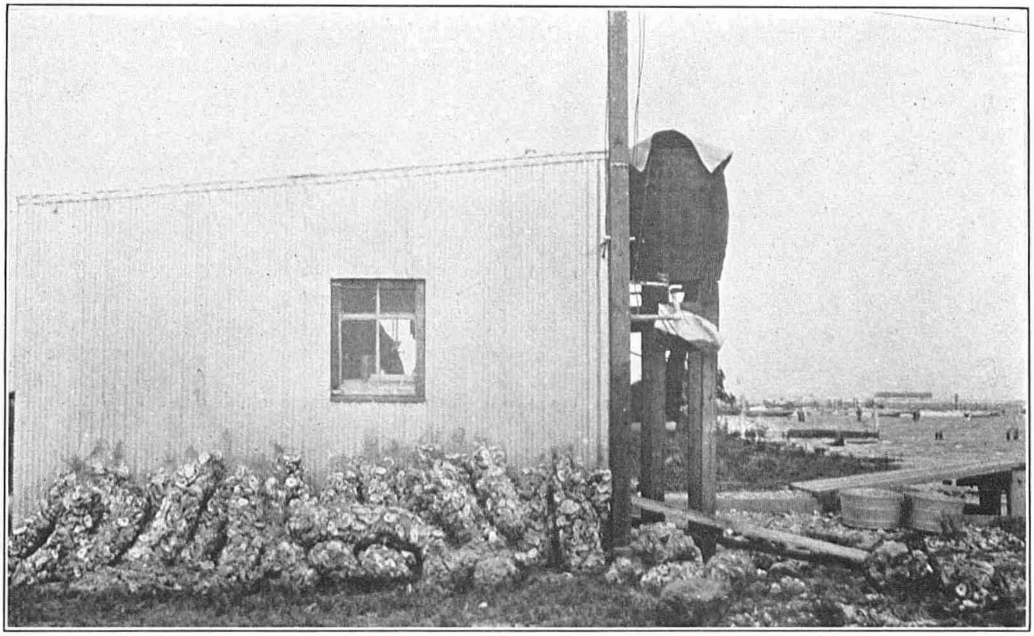

Figure 1.—Photograph of laboratory on the shore of Offatts Bayou near Galveston, showing a supply of shells in wire bags ready for planting

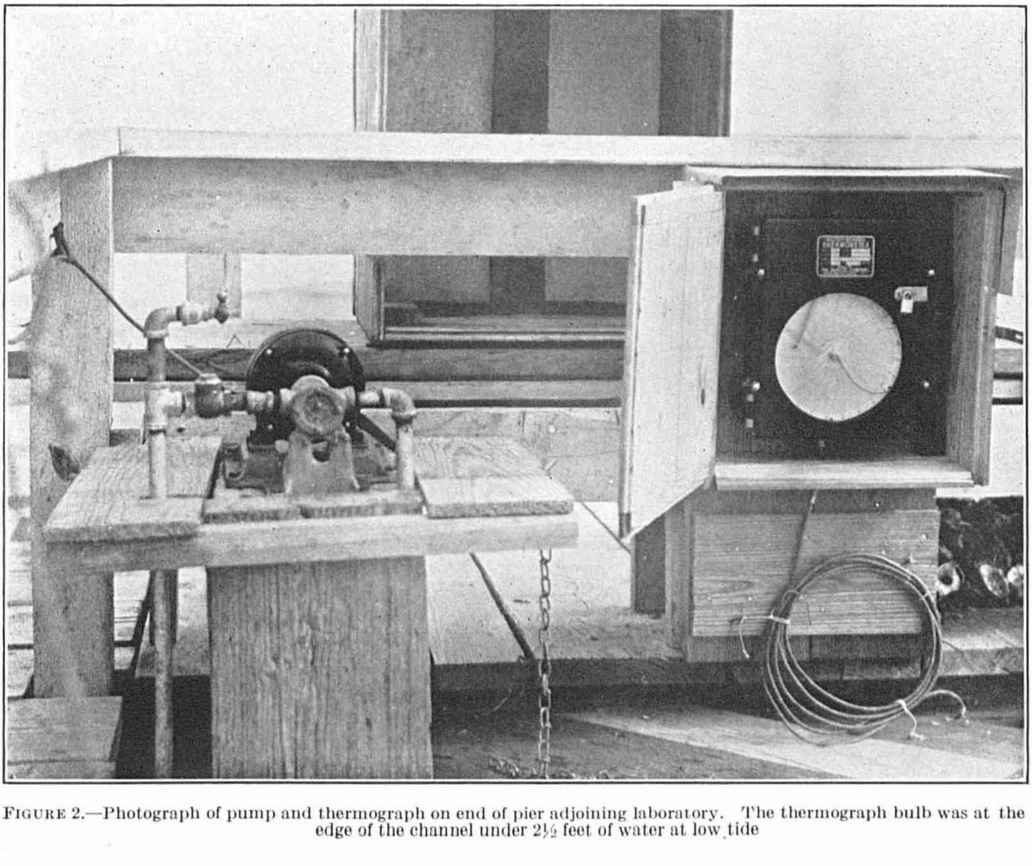

Figure 2.—Photograph of pump and thermograph on end of pier adjoining laboratory. The thermograph bulb was at the edge of the channel under 2½ feet of water at low tide

of water temperature were obtained over the period of six months from the end of February to the end of August, 1929.

Over the same period samples of water were taken at noon daily from the end of the pier and tested for salinity and hydrogen-ion concentration. Salinity was determined by means of specific gravity hydrometers, and hydrogen-ion concentration was tested colorimetrically by means of LaMotte comparators using phenol red, cresol red, and thymol blue as indicators. These results were not corrected for the small error due to salt variation.

Samples of plankton were taken as frequently as possible at 3 stations (fig. 5, stations 1, 2, and 3) in Offatts Bayou, 3 (fig. 4, stations 4, 5, and 6) in West Bay, and 1 (fig. 3, station 7) in East Bay. A plankton net of No. 20 bolting silk was towed at slow speed for five minutes at each station and the sample preserved in formalin for

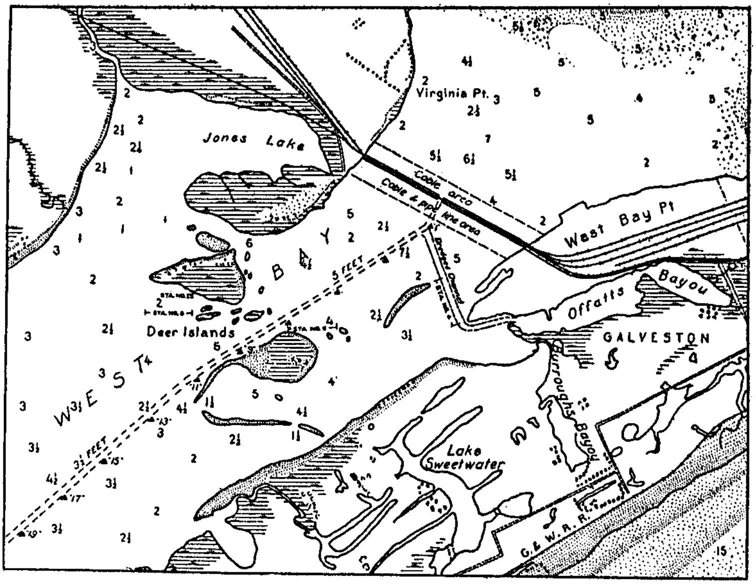

FIGURE 4.—Chart showing a portion of West Bay including plankton and shell-planting stations at the Deer Islands and near the mouth of Offatts Bayou. For stations in the bayou see Figure 5. (From U. S. Coast and Geodetic Survy Chart No. 1282)

analysis in order to establish the relative abundance of oyster larvæ and of diatoms. Whenever possible water samples were brought from the vicinity of Deer Islands (station 5) and Hanna Reef (station 7) and tested for pH and salinity. In this manner records were obtained which showed the physical characteristics of the water as well as the abundance of oyster larvæ and diatoms throughout the major part of the spawning season.

As a means of determining when setting of oyster larvæ takes place, oyster shells were planted periodically on the reefs at stations 1 and 2 in the bayou, station 3 at the Deer Islands, and station 4 on Hanna Reef. The shells were placed in bags, which were made of ½-inch mesh poultry wire and held about a half bushel of shells each. (Fig.1.) Descriptions of such bags have been published by Prytherch (1930a). Shells from the Bolivar cannery were used because they were thoroughly clean. By planting these bags of shells periodically in favorable places it was possible to determine when setting occurred. There was no possibility of the shells becoming slimy, for they were frequently exchanged.

DESCRIPTION OF OFFATTS BAYOU

Since many of the observations reported in the following pages were made in the bayou some description of this small body of water is essential. (Fig. 5.) It is about 2 miles long and varies from less than a quarter mile to about a half mile in width, and extends from West Bay into Galveston Island toward the Gulf. It is said that it is what remains of an old inlet connecting the bay and the Gulf. Though formerly shallow like most other such bayous along this coast, a few years ago extensive dredging was done for the purpose of filling in low land on the island. An irregular channel (fig. 5) now extends throughout most of the length of the bayou and is 30 feet or more deep. Portions of the bayou, however, still remain shallow and on these are excellent private oyster grounds which produce well-shaped, fat oysters. The deep channel insures a fairly rapid exchange of water with West Bay and would not be expected to suffer great changes in salinity due to local rainfall. Three regular

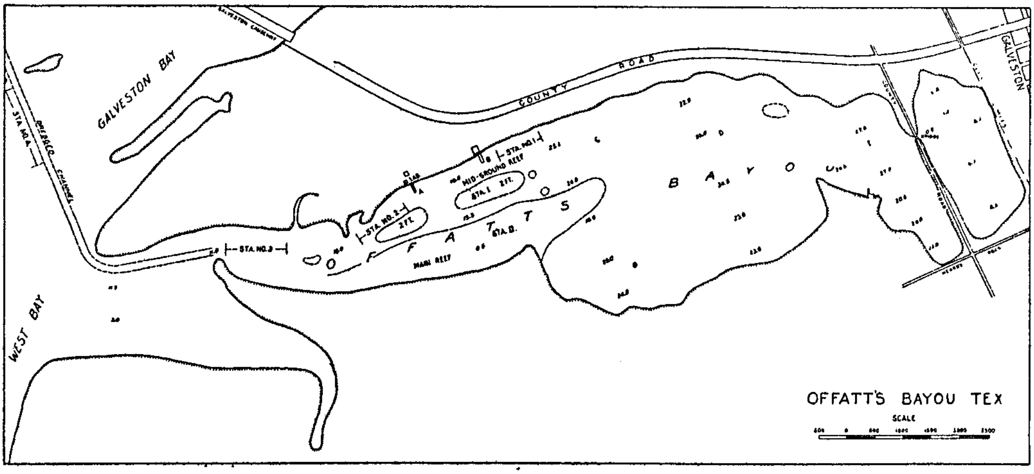

FIGURE 5.—Chart of Offatts Bayou showing oyster reefs, channels, and stations where shells were planted and plankton samples collected. See description in text. The laboratory was on the bank opposite the point marked A. Chart is based on preliminary survey by United States Engineers. Locations of oyster reefs indicated by Dolph Rogers, Galveston

stations for plankton collections and two for the planting of bags of shells are indicated on the chart.

THE SPAWNING SEASON

It has long been known that the spawning season of oysters in southern waters is very long, as compared to the short season in Long Island Sound, for example. (Prytherch, 1929.) Moore (1907) concluded from a study of Matagorda Bay that the major spawning in Texas waters takes place between May and early August. Later Moore and Danglade (1915) said that most of the spawning season was limited between May 1 and October 1. These conclusions were drawn largely from observations on the setting season, which, as will be shown, need not be closely similar to the spawning period.

It has been established that oysters do not spawn until after the water temperature reaches 20° C. (Churchill, 1920; Nelson, 1928; Prytherch, 1929; Galtsoff, 1930), and that the length of the spawning season is limited, therefore, by temperature. Oysters from Galveston Bay were examined frequently during February and March (1929) in an attempt to locate as nearly as possible the exact time of appearance of well-formed eggs and active sperms in the gonads.

The first oysters which were found to be somewhat "milky" were taken on March 18 in the bayou. Only an occasional specimen, however, contained either well-formed eggs or active sperms. On March 23 a similar condition was found in

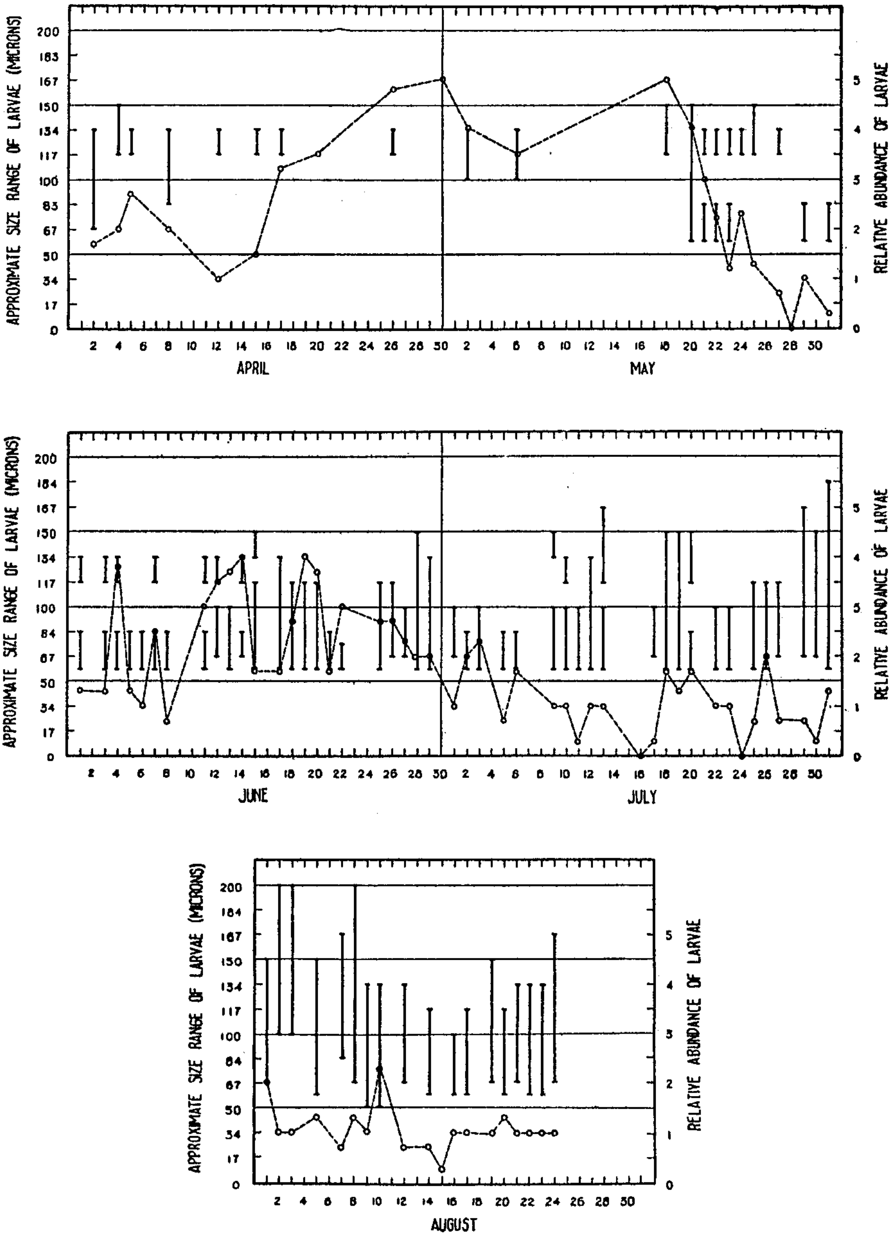

FIGURE 6.—Showing approximate size and relative abundance of oyster larvæ in plankton samples taken in Offatts Bayou, April to August, 1929. Size range of larvæ in microns of shell length is shown as vertical lines corresponding to values of ordinates shown on left of graphs. Relative abundance of larvæ was estimated as follows: 0, none; 1, very few; 2, few; 3, fair number; 4, many; 5, very many. Larvæ 150 microns or more in length are in umbo stage and closely approaching maturity

oysters taken from both East and West Bays. On the 29th all specimens from the bayou which were examined contained mature eggs or sperms, and some appeared to have spawned partially. On April 5 specimens from East and West Bays also appeared to have started spawning.

Oyster larvæ were taken for the first time in plankton collections on March 28 in the bayou. These were not numerous and were of the late straight-hinge stage, or presumably 2 to 3 days old. This is in substantial agreement with the observations on the gonads of the oyster and establishes the initiation of spawning on about March 25.

A quantitative method of measuring the abundance of oyster larvæ in plankton collections was not employed, for while such a measure might be feasible during a few weeks it would be too time consuming over a period of several months. A crude method of approximation of abundance was devised which gave values of relative significance. After immediate examination to determine if larvæ were present the

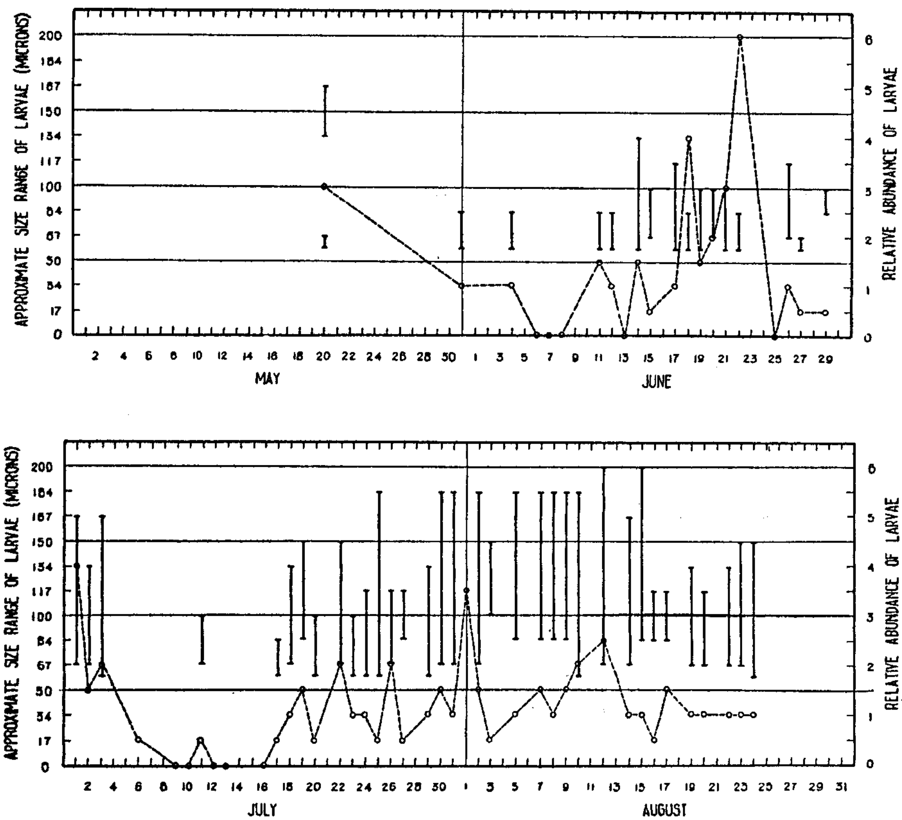

FIGURE 7.—Charts showing the relative abundance (circles) and approximate size (vertical lines) of oyster larvæ taken in plankton collections at Deer Islands from May to August, 1929. Size refers to length of larval shell in microns. Relative abundance was estimated as follows: 0, none; 1, very few; 2, few; 3, fair number; 4, many; 5, very many; 6, extremely abundant

samples of plankton were preserved and kept until the end of the summer. Then, over a relatively short period, to insure accuracy, the abundance of larvæ in each sample was estimated by an arbitrary standard. Numbers from 0 to 6 were employed to designate from none to extremely abundant and were defined as follows: 1, very few; 2, few; 3, fair number; 4, many; 5, very many; and 6, extremely abundant. All collections were made in the surface 12 to 15 inches of water and these figures refer only to the presence of larvæ at this level. However, since larvæ were taken in nearly every collection after the end of March it is probable that the collections represent a reasonable estimate of the abundance of larvæ in the water, or the intensity of spawning.

The general size range of the larvæ in each sample was determined by measuring the length of a number of specimens with a micrometer scale. The purpose was primarily to obtain an idea of the age, or growth stage, of the larvæ. In Figure 6 graphs are presented to show both the relative abundance and the size range of larvæ taken in plankton collections in Offatts Bayou from April 1 until the end of August. Collections during the latter part of April and the beginning of May were infrequent, but the results of these samples are entirely consistent. It will be observed that during early April larvæ in the collections were not abundant, indicating that spawning had not reached its maximum. After the middle of April, however, the curve is very high showing the great abundance of oyster larvæ. This abundance of larvæ continued until the middle of June and from then until the end of August, when collections were discontinued, the number of larvæ taken became constantly less numerous.

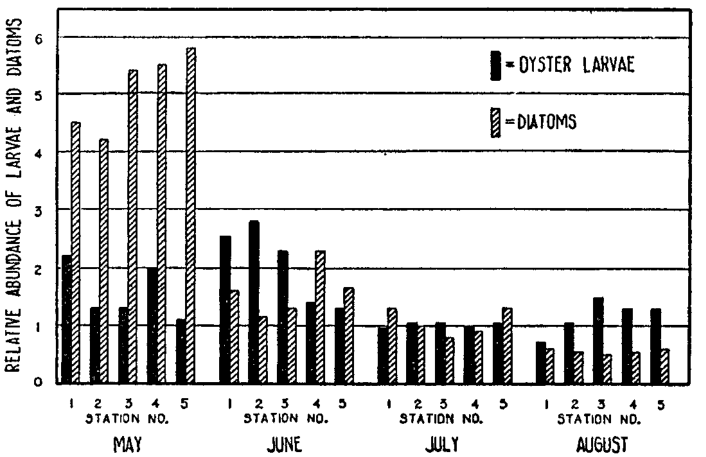

FIGURE 8.—Chart showing the relative abundance of oyster larvæ and diatoms, in plankton samples taken at stations 1 to 5 (figs. 4 and 5), as averages of all collections during each month from May to August. Relative abundance is designated by ordinates as in Figures 6 and 7. The rapid disappearance of diatoms is contrasted with the relatively slow reduction in number of larvæ taken

The period of greatest abundance of larvæ in the water appears to have been from the middle of April to the middle of June. Since these larvæ were predominantly in the straight-hinge stage, or within about 3 days old presumably, the records may be considered to indicate the period of most profuse spawning. However, in July and August spawning continued, as shown in Figure 6, at a diminished rate, and almost every collection contained larvæ. The collections made at the Deer Islands (fig. 7) were essentially similar to those made in the bayou, as described above, though few samples were taken before the end of May.

Figure 8 is presented to show the monthly average abundance of larvæ taken in collections at stations 1 to 6. The abundance of diatoms is also given in this figure. (See section on diatoms.) Stations 1, 2, and 3 were in the bayou; station 4 in West Bay outside the bayou inlet; and stations 5 and 6, which are averaged as of one station numbered 5, at the Deer Islands. (See charts, figs. 4 and 5.) The relative abundance of larvæ at each station was determined by averaging the figures designating the abundance of larvæ in all collections taken at each station during each month, from

May to August. April was not included in this because of the relative infrequency of the collections. The figure shows that the peak of spawning occurred in May and June, particularly the latter. The August collections at stations 4 and 5–6 in West Bay and station 3 in the bayou inlet contained somewhat more larvæ than in July, indicating a possible acceleration of spawning at this time.

Observations were brought to a close at the end of August, and it is not known how much longer spawning continued. From the records, however, it may be concluded that the spawning season was far from complete at this time. (See figs. 6, 7, and 8.) It may be assumed that the season continued for at least another month and possibly even longer. From the end of March until the end of August—a period of five months—spawning occurred apparently continuously, and it is reasonable to assume that the usual spawning period covers at least six months. During the time after spawning started only very occasional samples were taken which contained no larvæ, and these were taken in stormy weather when the silt in the water clogged the net and rendered the collections of little significance.

On the graphs showing daily abundance of larvæ in the bayou (fig. 6) and at Deer Islands (fig. 7) the size range of the larvæ taken is also indicated. Larvæ in the straight-hinge stage are less than about 150 microns in length, while those 150 microns or more long are in the umbo stage. At about 200 microns length the larvæ are close to the setting stage. Most larvæ taken throughout the season were in the straight-hinge stage, and only at certain periods did umbo larvæ appear. It would seem that the larvæ either did not develop rapidly or else died before becoming mature, for the presence of large larvæ in the water was closely associated with the appearance of spat. This is discussed more fully in the section on setting and need not be described further here.

SEX OF OYSTERS

While making examinations of oysters during the spring and summer, records were kept of the number of specimens of each sex. At irregular intervals small lots of unselected oysters were brought in from various reefs for the purpose of determining whether mature eggs were present in the gonads. The records showed, incidentally, a great predominance of females. Determinations made by Dr. Paul S. Galtsoff as well as those by the author are given in Table 1. In a few cases some specimens were either too completely spawned out or immature to permit ready determination of sex. In the table these are recorded as *doubtful.* Out of 252 oysters examined 178 were females, 51 were males, and 23 were of doubtful sex. More than three times as many females were taken as males, although the samples were taken in small lots at different times from different places. In each lot examined, males were outnumbered by females. Even if all of the specimens considered doubtful were males there would still be more than twice as many females.

It hardly seems possible that these results do not indicate the presence of more female than male oysters in this vicinity, although it has generally been found on the Atlantic coast that the two sexes are equally numerous.

TABLE 1.—*Sex of oysters in Galveston Bay*

Date	Place	Males	Females	Doubtful[1]
1929				
Apr. 15 [2]	Bayou, main reef	1	11	0
Apr. 16 [2]	do	3	21	0
Apr. 17 [2]	do	2	18	0
Apr. 29	do	6	12	2
	Bayou, middle ground	7	9	0
May 7	Bayou, main reef	2	12	6
	Bayou, middle ground	1	8	3
May 9	Bayou, main reef (top)	7	11	0
	Bayou, main reef (south side)	1	5	0
	Bayou, main reef (north side)	2	6	0
	Bayou, middle ground	2	12	0
June 12	do	5	12	5
June 13	Deer Island reef	2	10	1
June 14	Bayou, main reef	5	10	3
July 11	Deer Island reef	2	7	3
July 12	Bayou, main reef	3	14	0
Total		51	178	23
Percentages		20.24	70.63	9.13

[1] Specimens which were either spawned out or immature, the sex of which was not readily determined.
[2] Counts made by Dr. Paul S. Galtsoff.

WATER TEMPERATURE IN RELATION TO SPAWNING

The daily temperature of the water in Offatts Bayou is given in Figure 9 as the average of readings from the thermograph chart at each of the 24 hours daily. The bulb of the thermograph was under about 2½ feet of water at mean low tide.

At the end of February and the beginning of March (fig. 9) the temperature was between 14° and 15° C., from which it rose, by the middle of March, to 18° to 19° C. The major spring rise in water temperature, however, took place in the latter half of March. The temperature passed 20° C. on March 21, and six days later was over 25° C. The initiation of spawning as a response to rise in temperature is well illustrated here, for the first larvæ were found in the water on the 28th. However, instead of appearing immediately after the temperature reached 20° C., their appearance is more closely coordinated with the 25° C. level. This indicates that there is considerable lag between the time the water temperature reaches 20° C. and the time spawning begins. In fact it is very probable that the surface water, in which the oyster reefs are located, reached 20° C. well in advance of the time that the average temperature of the deeper water, as shown in the figure, attained this level.

The thermograph records show that even at a depth of 2½ feet the temperature was maintained for several hours at 20° C. as early as March 7. For 13 hours on March 9 it was between 20° and 22° C. On the 10th it was for 8 hours between 20° and 21° C. From the 10th until the 20th the maximum temperature shown on the charts was well over 19° C. Since the spring rise in temperature, beginning early in March, was due naturally to air temperature and sunshine it is probable that throughout the early part of the month the temperature of the water at the level of the oyster beds was 20° C. or above during most of the daylight hours, yet no larvæ were found in the water and the oysters appeared to be mostly unready to spawn.

On the basis of these observations, it would be impossible to state that 20° C. is the critical temperature for spawning of oysters on the Gulf coast. However, Galtsoff (1930) showed experimentally that spawning will not occur below 20° C. but at this or higher temperatures it will take place when the specimens are adequately stimulated. From field observations on the Atlantic coast it was concluded by Churchill (1920), Nelson (1928), and Prytherch (1929) that spawning begins shortly after the water attains 20° C. While in Galveston Bay the temperature was sufficiently high during part of the time early in March, no spawning took place because the germ cells in the gonads had not reached maturity. No well-formed eggs or active sperms were found in the oysters before March 18. Because of the very rapid spring rise in water tem-

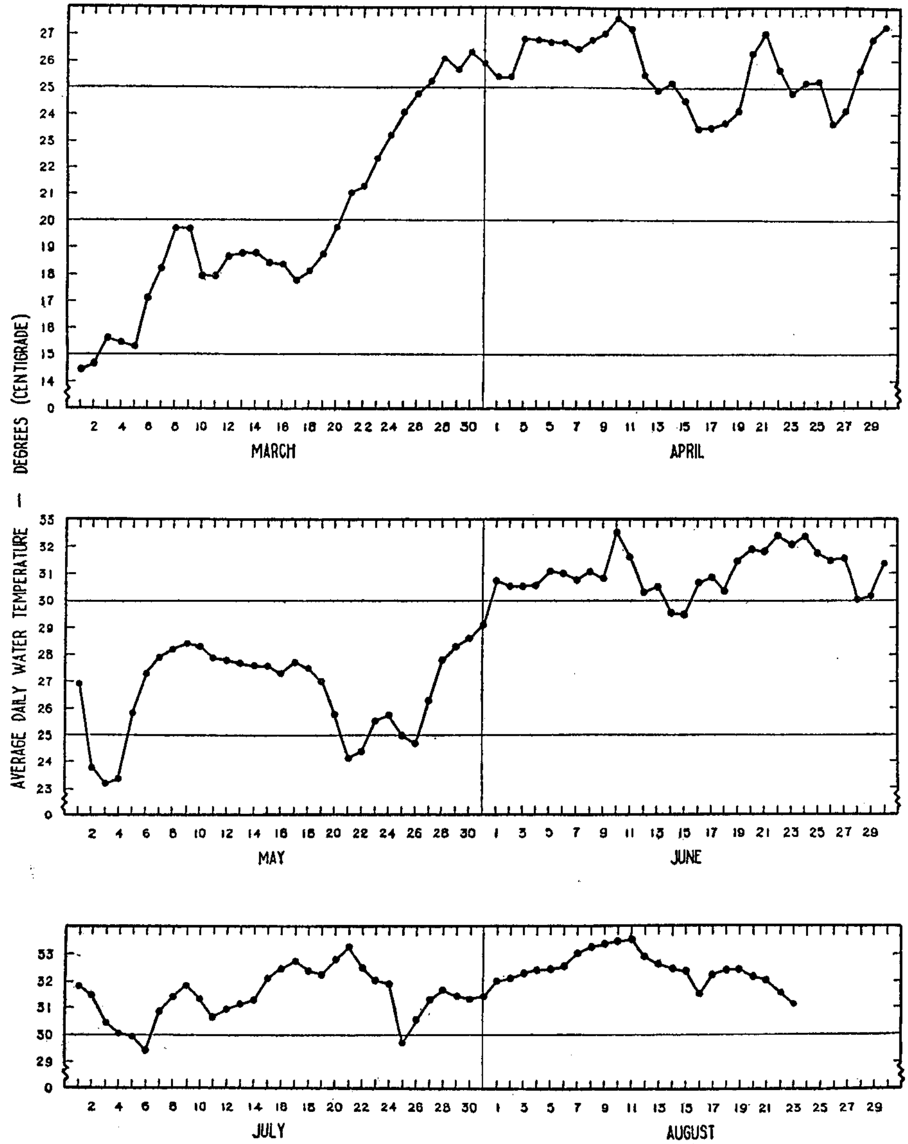

FIGURE 9.—Charts showing daily temperature of water in Offatts Bayou, Galveston, from March to August, 1929. Daily temperature was calculated as the average of the 24 hourly thermograph readings. The thermograph bulb was about 2½ feet below low tide level at the edge of a 30-foot channel

perature the critical temperature for spawning was reached in advance of maturation of the gonads.

The maximum of the spawning period occurred in May and June, during which time the water temperature was usually well above 25° C. and had been so since the end of March. This is strikingly in contrast to the observations of Prytherch

(1929) in Long Island Sound, where the entire season's spawning takes place within less than one month and can be predicted on the basis of water temperature. In that place the oysters spawn completely within a short time, while in the Gulf waters the spawn is ejected slowly over long periods of time. About a month and a half was required for spawning to reach its maximum, while in Long Island Sound and similar waters the maximum is reached within a few days after the water reaches 20° C.

TABLE 2.—*Temperature in °C. of surface water, Galveston Bay, in summer, 1929*

Date	West Bay near mouth of bayou	West Bay near Deer Island Reef	East Bay near Hanna Reef	Date	West Bay near mouth of bayou	West Bay near Deer Island Reef	East Bay near Hanna Reef	Date	West Bay near mouth of bayou	West Bay near Deer Island Reef	East Bay near Hanna Reef
June 19	27.9	27.8	30.3	July 15	----------	----------	28.9	Aug. 7	29.7	30.0	----------
20	28.7	28.5	28.9	16	29.7	30.4	----------	8	30.0	30.7	----------
21	28.9	29.4	----------	17	30.0	29.1	----------	9	29.4	30.5	----------
22	31.3	31.1	----------	18	29.3	29.4	----------	10	30.5	30.8	----------
25	28.9	29.4	----------	19	30.0	30.0	----------	12	30.3	30.3	----------
26	28.4	28.7	----------	20	30.5	30.3	----------	13	----------	----------	31.6
27	28.9	29.4	----------	22	29.4	30.5	----------	14	30.0	30.0	----------
28	28.1	28.5	----------	23	29.7	30.2	----------	15	30.0	30.3	----------
29	27.5	27.2	----------	24	28.9	29.3	----------	16	29.4	29.7	----------
July 1	29.2	29.3	----------	25	27.5	27.2	----------	17	30.0	29.4	----------
2	29.4	28.9	----------	26	27.2	27.2	----------	19	29.7	30.0	----------
3	28.1	28.1	----------	27	28.3	28.3	----------	20	29.4	29.4	----------
5	27.8	----------	----------	29	28.3	28.3	----------	21	29.4	29.4	----------
6	27.3	27.2	----------	30	28.5	28.9	----------	22	29.6	29.4	----------
9	28.9	29.2	----------	31	28.9	28.9	----------	23	28.3	28.3	----------
10	29.4	29.7	----------	Aug. 1	28.9	29.2	----------	24	27.2	27.2	----------
11	28.3	28.9	----------	2	29.4	29.4	----------	26	28.6	28.6	----------
12	28.5	28.3	----------	3	29.5	29.7	----------	27	----------	----------	28.3
13	29.8	27.9	----------	5	30.4	30.5	30.5	28	29.2	28.9	----------
14	----------	----------	29.4	6	----------	----------	28.3				

The water temperature in the bayou fluctuated around 25° C. during April and May, and during June, July, and August seldom dropped below 30°. Temperatures between 30° and 33° C. are extremely high, as compared with the North Atlantic waters, but probably are not much above average during the summer for the bays on the Gulf coast. The high temperature of the water throughout a large part of the year is probably responsible for the rapid growth of oysters, which attain marketable size in two years.

In the open bay the temperature did not rise quite as high as in the bayou. In Table 2 records of separate readings of the temperature of surface water in both East and West Bays are given. Because of the exposure of these waters to wind the temperature in general ranged slightly below 30° C. during the summer.

SALINITY AND HYDROGEN-ION CONCENTRATION

Galveston Bay is subject to changes in salinity due to discharge from the San Jacinto and Trinity Rivers and innumerable small bayous which drain the mainland as well as to the direction and strength of the wind. Being a shallow bay it would be expected to exhibit marked changes in salinity, particularly as a result of swollen rivers.

Samples of bayou water, from the surface 6 inches, were tested daily for salinity and pH. Frequent tests were also made with samples from the Deer Islands in West Bay and Hanna Reef in East Bay. A brief description of the changes taking place in the water during spring and summer is necessary to show what is perhaps a semitypical example of the variation in the bay waters of most of the Gulf coast.

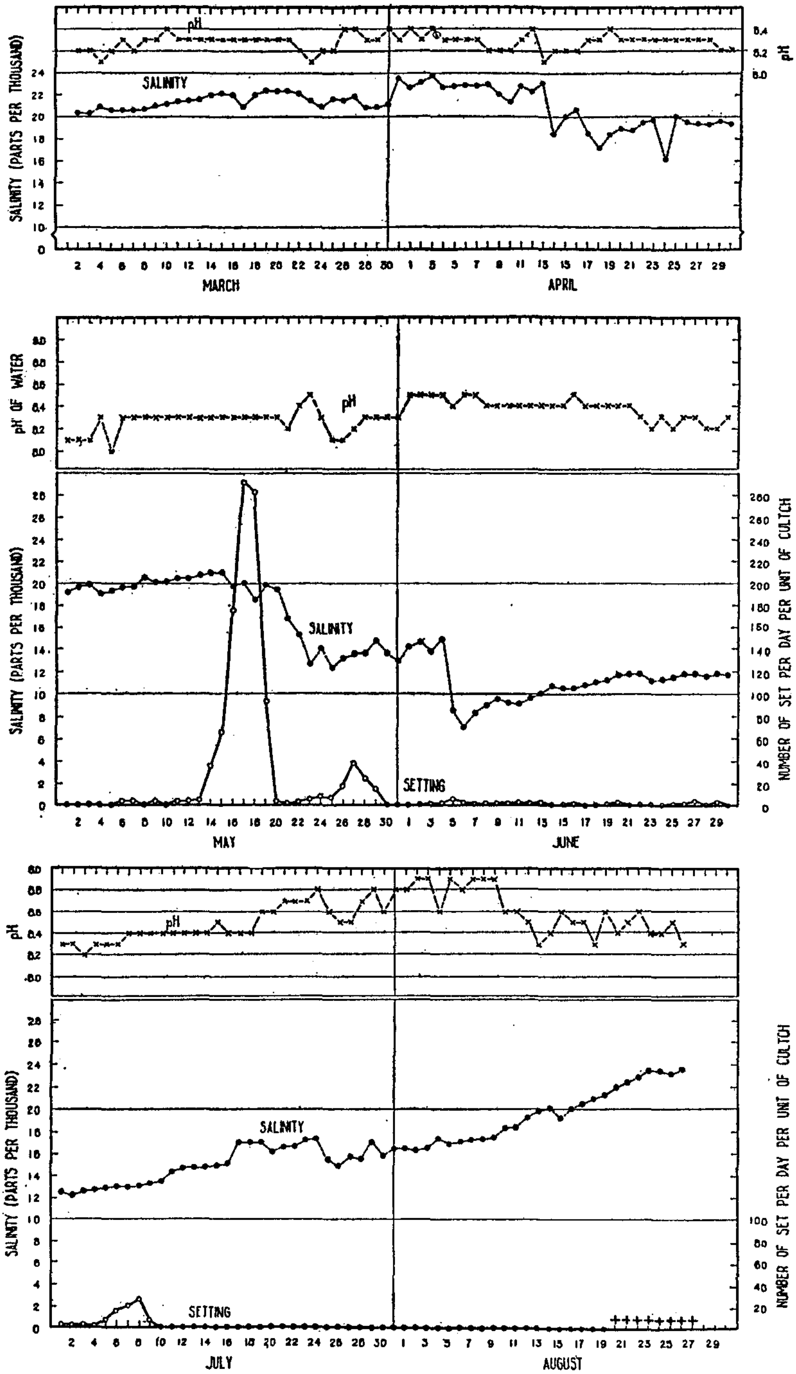

FIGURE 10.—Charts showing the daily salinity and pH of water (surface) in Offatts Bayou from March to August, inclusive, and the daily set from May to August in the same place. The period of heavy setting at the middle of May took place on both reefs, while the light setting at the end of May and early in July occurred on the middle ground reef only. Shells placed on reefs August 19 were examined on the 27th and found to have a fair set of small spat, though counts were not made (points marked +)

The records of Offatts Bayou water are shown in Figure 10, while those of the water at Deer Islands and East Bay are given in Figures 11 and 12. In the bayou during March and up until about the middle of April the salinity was 21 to 22 parts per thousand. It then fell slightly (fig. 10) to about 18 parts per thousand, slowly rising to 21 parts per thousand at the middle of May, before falling sharply to around 14 parts per thousand at the end of the month. Early in June it fell to 8 parts per thousand, and at the end of August it steadily rose to about 24 parts per thousand. Records for Deer Islands were not made until June (fig. 11) but after this time the

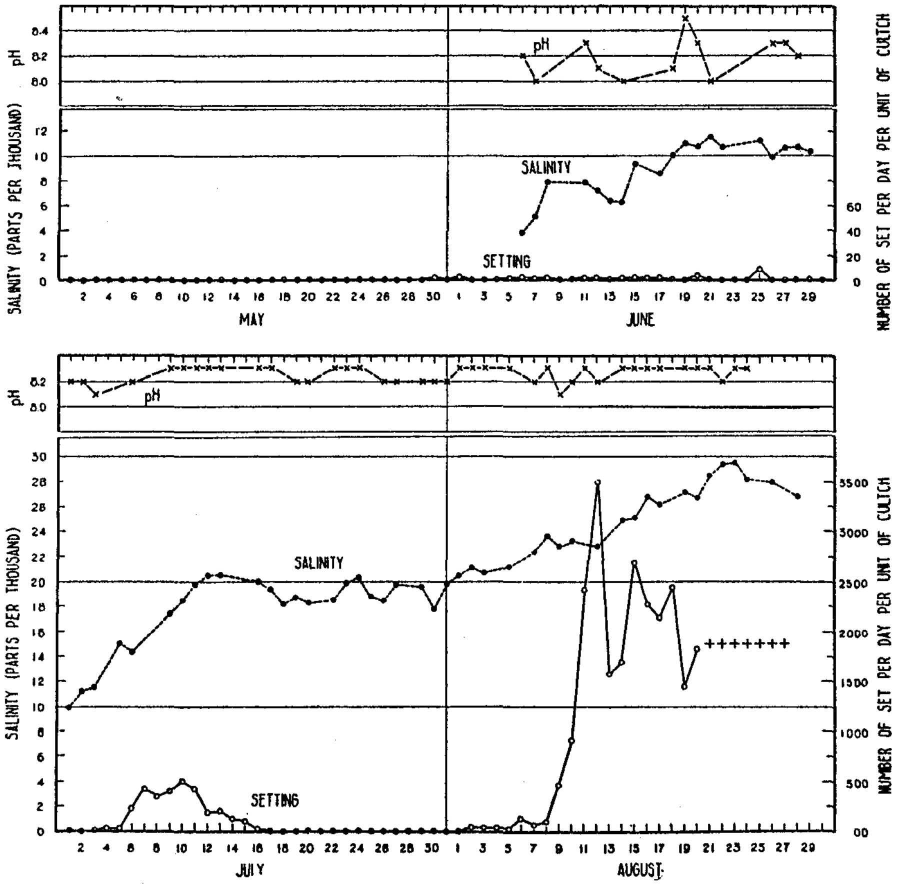

FIGURE 11.—Showing records of salinity and pH of surface water and intensity of oyster larvæ at Deer Islands from May to August, inclusive. After August 20 setting was occurring but counts were not made

salinity variations were essentially similar to those in the bayou save that, due to the larger size of West Bay and the free sweep of winds and tides, there is greater fluctuation. Early in June the salinity was below 4 parts per thousand and the water was almost fresh. In East Bay few tests were made, and these were as low as 2 parts per thousand in June. (Fig. 12.)

A more detailed description of the salinity variations is made in the section on setting.

The pH of the water, both in the bayou and in West Bay, appears to be characteristically between 8.1 and 8.4. Readings were found to agree closely when different indicators were employed. During the time that tests were made the pH was seldom below 8, but in the bayou in August it rose to nearly 9, due probably to algal growth. The pH of the water was not observed to have any particular significance with regard to the spawning and setting of oysters.

OBSERVATIONS ON SETTING

It has been established by Prytherch (1929) that the usual period of larval development, from the time of spawning until the larvæ set, is about 15 days. By means of this knowledge he was able to predict in Long Island Sound the beginning of setting by determining the time when spawning started. Where conditions remain constantly favorable, such a method of obtaining set economically may be employed, but in Galveston Bay no such relationship between the times of spawning and setting

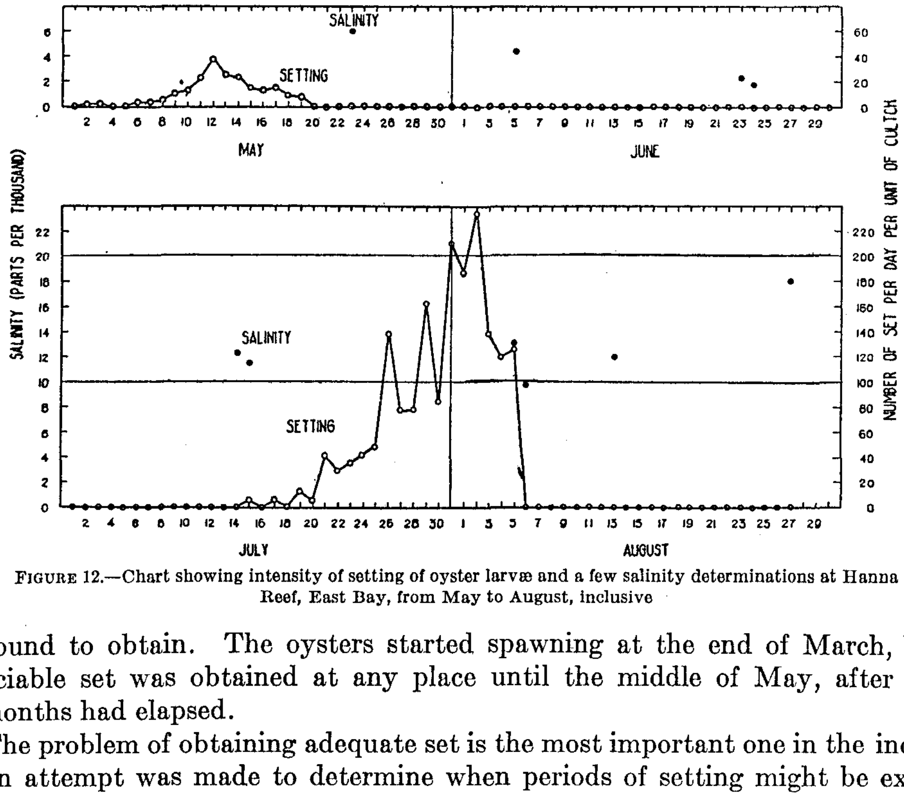

FIGURE 12.—Chart showing intensity of setting of oyster larvæ and a few salinity determinations at Hanna Reef, East Bay, from May to August, inclusive

was found to obtain. The oysters started spawning at the end of March, but no appreciable set was obtained at any place until the middle of May, after nearly two months had elapsed.

The problem of obtaining adequate set is the most important one in the industry, and an attempt was made to determine when periods of setting might be expected in order that they be taken advantage of to procure seed oysters. Obviously the time of spawning had little bearing upon the setting time in Galveston Bay, for factors other than the normal length of the larval period appeared to influence the maturation of the larvæ.

In order to determine as closely as possible the time when setting takes place, wire bags of shells were placed in favorable positions in the bayou (fig. 5, Stations I and II), in West Bay (fig. 4, Station III), and in East Bay (fig. 3, Station IV). At each station bags were placed both on top of the natural reef at approximately low-tide level or a few inches above and at the edge of the reef in 2–4 feet of water at low tide. Each bag of shells was numbered and the time and position of planting recorded. At intervals of one to three weeks new bags were planted in each place and representative ones of those that had been exposed in the water were brought to the laboratory and examined carefully for spat. By constantly placing fresh, clean bags of shells on the beds adequate cultch was always available for larvæ of the setting stage. In this manner the possibility of the shells becoming too slimy to act as suitable setting places was eliminated. As a further control the oysters and shells of the natural reefs were examined from time to time in order to be sure setting was not taking place on those instead of on the planted shells. Bags of shells were periodically planted from early in March until late in August and examined for spat.

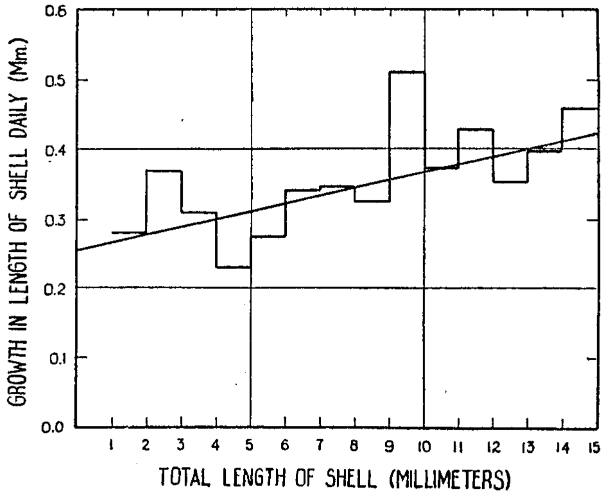

FIGURE 13.—Showing average daily growth in length of shell of oyster spat in relation to total length. The growth rate increases slightly with size. An ideal line is drawn to serve as a basis for calculations

When it was found that the bags of shells bore spat, several such bags from the same place were examined to see roughly if the spat were of the same approximate size and abundance. Then all of the shells in one bag, or in two from the same place, were carefully examined and counts made of the total number of spat on the inside surfaces of the shells. Since this method requires the counting of young and minute spat it was not possible to make counts for more than a half bushel of shells in each case. Only those on the inside surfaces of the shells were counted because the outside surfaces of the shells were too rough to permit accuracy. The counts made are comparable, however, and refer to the number of spat on the inside surfaces of a half bushel of shells. The counts were more accurate for spat several days old than for those only one or two days after setting, because the latter were readily sloughed off in handling, especially after the shells had become dry.

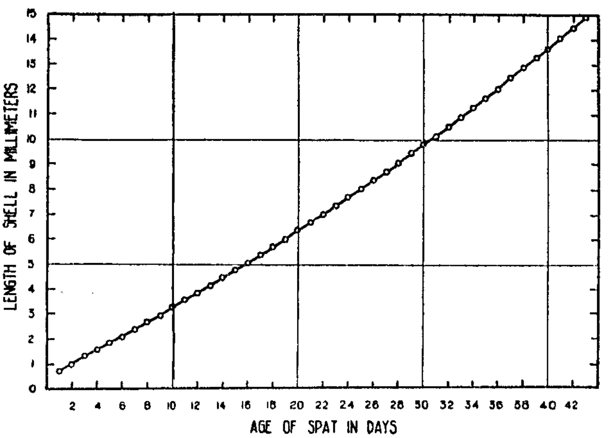

FIGURE 14.—Showing length of shell of oyster spat in relation to age, calculated from values on the ideal line in Figure 13. The curve, for growth of spat of the ages shown departs only slightly from a straight line

GROWTH OF SPAT

In the counts above described it would occur that the spat might range from less than 1 millimeter to 6 or 8 millimeters in length, the shells having been in the water for two or three weeks. It was considered desirable to attempt to define the intensity of setting more closely than over two or three week intervals. A roughly serviceable method was devised to give the number of larvæ setting daily at each station. While not accurate to the day these results may be considered significant within plus or minus two or three days. In order to obtain figures of the rate of growth of the shells of spat, measurements of the length of 128 living spat were made, and the shells to which they were fixed placed back in the water in wire bags. These spat were of diverse sizes at the start. After four to six days they were taken up and measured again, and the amount of growth divided by the number of days was taken as the growth per day. Since the original spat ranged from 1 to 15 millimeters in length, the method suffices to show the relative amount of shell growth per day with regard to the total size of the shell. The results are presented in Figure 13. The abscissæ represent the length of the shells of the spat at the beginning in groups of 1 millimeter range, while the ordinates show the average growth in length. The amount of growth daily increases with size of the spat. Because of the individual variation the graph is not perfect, so a theoretical line was drawn to represent the increment in length per day. While not intended to be mathematically accurate this is of use in making it possible to gain an idea of the day on which the spat actually set. Calculating from this theoretical line the length of spat at different ages, a curve (fig. 14) is obtained, which for the spat up to about 40 days old is to all practical purposes a straight line. Certainly in proportion to the entire growth period of the oyster this would not be the case, but we are concerned here chiefly with spat of 20 days old or less. For this purpose it is considered that the growth or daily increase in size is constant.

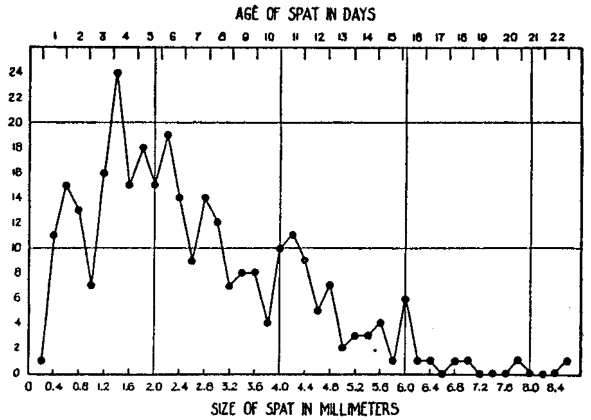

FIGURE 15.—Size distribution of 300 oyster spat on shells which were in water 22 days. At top of figure, divisions show age of spat with reference to size groups shown on lower axis

DETERMINING DATES OF SETTING

If a bag of shells bore a very heavy set, the spat were counted and then 300 of them were measured. To do this the shells were not selected and all spat on each shell used were measured. An adequate distribution was obtained therefore. One example is presented in detail below.

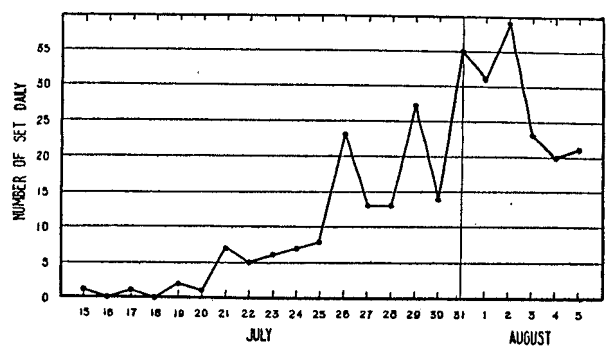

FIGURE 16.—Graph showing the data given in Figure 15, recalculated to indicate the date of setting of the 300 spat. Setting was rare in the middle of July but became more abundant up until the 1st of August

There were 1,800 spat on the half bushel of shells, and 300 of these were measured and their size distribution plotted. (Fig. 15.) The figure shows the predominance of the younger spat. The bag of shells had been in the water for 22 days, and the largest spat, therefore, could not be more than 22 days old. Some of the largest spat, according to the age curve (fig. 14) would appear to be older than this; but these are rare and grew faster than average, for the individual variation is large. Apparently the oldest spat set soon after the shells were placed in the water. Then, since the growth rate may be considered constant, the abscissal axis representing size was divided up into 22 equal parts, as shown in the figure, each representing a day.

On the basis of these divisions the size range of the spat for each day was recorded and the measurements regrouped according to the day of setting. These data were then plotted as in Figure 16, which shows the relative number of larvæ which set each day. This is the approximate distribution of the 300 which were measured. Since there were 1,800 spat altogether, by multiplying each value by 6 the total number of larvæ setting daily per half bushel of shells was obtained.

It would be simple if it were possible to establish the age readily simply by referring to the age and size curve (fig. 14); but this would be less accurate because the spat grow more rapidly at some times and at some places than at others, due to depth of water and consequent temperature, etc. The method above described appears to be much more serviceable in indicating the approximate times of most profuse setting.

Similar counts and calculations were made throughout the summer with samples of shells which received a set. These results are grouped in three series according to location of the reefs on which the shells were planted and are presented graphically on the charts (figs. 10, 11, and 12) which show also salinity and pH of the water.

SETTING PERIODS DURING SEASON

Shells in wire bags were planted at two stations in the bayou. (Fig. 5, Stations I and II.) The main reef, on which Station II was located, is on one side of the channel and is relatively free from the tidal currents which flow back and forth. The "middle ground," however, (Station I), is an isolated shallow plot directly in the path of the currents and might be expected to be subject to relatively rapid changes in the water which flows in from West Bay during flood tide and out from the upper end of the bayou during ebb tide. This difference between the locations of the two bayou stations is important, for, in some cases, shells at one of the places received set while those at the other did not.

It has been pointed out that spawning was taking place at the end of March. From the observations of Prytherch (1929) that the larval period is about 15 days, it was expected that small spat would be found by the middle of April. However, no set was obtained on any reef during the entire month of April. During about six days at the middle of May (fig. 10) a period of setting took place at both stations in the bayou, but not in West Bay (fig. 11). At about the same period, or a few days earlier, a light set occurred in East Bay on Hanna Reef. At the end of June a few days of light setting occurred in the bayou, on the middle ground reef, but not on the main reef. Neither in West Bay nor in East Bay did any setting take place at this time.

Early in July a short period of relatively heavy setting occurred in West Bay. (Fig. 11.) The scale of ordinates on this figure is different from the others, and each unit is 12.5 times as great, in order to show the heavy setting which took place later. At the same time young spat were not found on shells in East Bay. However, there was a light set on the middle ground reef in the bayou but not on the main reef. At the end of July and beginning of August a 2-week period of setting occurred in East Bay, followed after a few days by continuous heavy setting in West Bay, but not in the bayou. Observations were discontinued about August 20 and further counts were not made. However, shells put in the water on August 20 in both West Bay and the bayou collected spat, showing that setting had started again in the bayou and was continuing in West Bay. Up until the 27th there was no further set in East Bay.

These records, as shown in Figures 10, 11, and 12, indicate that whatever factors may have influenced the setting of the larvæ they were not equally effective in the three locations. Such natural variations as sunshine, temperature, and local precipitation would be virtually the same in all three places, and it is necessary to look further in order to obtain a suggestion of the factors controlling setting.

Table 3 gives a summary of the results of all counts of spat which were made. Except near the end of the season, in the case of the Deer Islands samples, setting was never extremely heavy. It was not a continuous process, as appears to have been true of spawning, but took place in isolated periods. It looks as if the time of major setting, during the season of 1929, was early fall, for at the end of August profuse setting was taking place both in West Bay and in Offatts Bayou, and in both places larvæ in the umbo stage were constantly found in the plankton collections. (Figs. 6 and 7.) According to local oystermen most of the set is often obtained early in the fall.

APPARENT INFLUENCE OF SALINITY ON SETTING

A comparison of the records of salinity with those of setting (figs. 10, 11, and 12) suggests the possibility that there may have been some connection between salinity of the water and maturation of the oyster larvæ. It has been pointed out that in Offatts Bayou the two reefs where bags of shells were planted were close together but that at times set was obtained on only one of them. This would indicate a difference in some respect between the water at the two places.

During March and up until April 13, the salinity of the water in the bayou was around 22 parts per thousand. However, on the morning of April 13 a heavy rain fell, and the next day the salinity was down to below 19 parts per thousand. This occurred at the time when the beginning of setting was expected. During the following four weeks the salinity rose very slowly and was about 21 parts per thousand at the middle of May for a few days. At this time and for a few days thereafter a fairly heavy set took place, amounting to about 1,000 spat per bag of shells. Spat were found on both reefs in the bayou, but not at the Deer Islands in the adjoining West Bay. The salinity then fell abruptly and setting ceased on the main reef.

A few days later, however, a light set occurred on the middle ground reef only. Since setting was not going on in West Bay this could not have been due to mature larvæ brought in from that place. Further, the marked lowering in the salinity of bayou water was due to the inflow of West Bay water, for the bayou is subject to almost no dilution by direct land drainage. It was observed consistently that changes in the salinity of West Bay water were only slowly transmitted to the water up in the bayou, so it would be expected that, following such a change, a salinity gradient would exist from end to end of the bayou. On June 6 a series of samples was taken from six places and tested for salinity. The first was at the Deer Islands, in West Bay, with a salinity of 3.73 parts per thousand. The others were taken from positions in the bayou indicated on the chart (fig. 5) by the letters *A* to *E*, extending from the laboratory dock to the head of the bayou. The salinity values in parts per thousand were as follows: *A*, 6.75; *B*, 7.25; *C*, 7.30; *D*, 7.43; and *E*, 8.57.

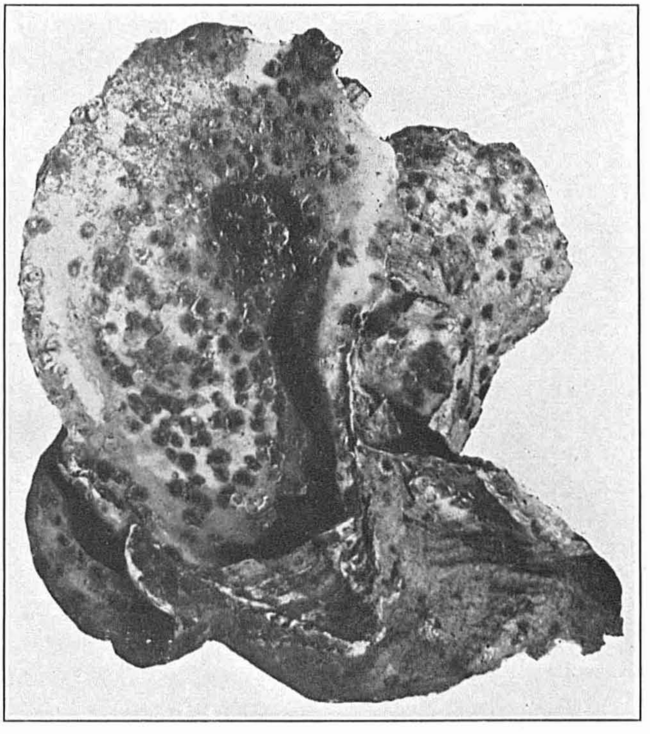

Figure 17.—Photograph of a clump of shells bearing young spat within 19 days old, for the shells were in the water only 19 days. Actual length of the main shell was 4 inches

This gradient of salinity in the bayou shows that the water least subject to change, as a result of the inflow of West Bay water, is that at the head of the bayou. These tests were made more than a week after the brief setting period on the middle ground reef took place, but yet show the presence of water of higher salinity at the inner end of the bayou.

The significance of this salinity gradient with regard to the light setting period which occurred at the end of May on the middle-ground reef is possibly that water of high salinity left in the inner end of the bayou moved outward along the channel at ebb tide and furnished adequate setting conditions along the main channel, in which the middle ground is located. Such water would not be expected to touch the main reef to the side, where no set took place. Such a condition would be expected when the salinity in West Bay is falling, and the bayou water is of a higher salinity.

When the situation is reversed, however, and the salinity of West Bay water is rising while that of bayou water follows, the water flowing into the channel at flood would be of higher salinity than that at ebb tide. This would also give opportunity for setting to occur on the middle-ground reef. This condition obtained early in July, when a fairly heavy set was obtained, at the Deer Islands, amounting to between 400 and 500 spat per day per bag of shells. At the same time a set of 15 to 25 spat per day per bag of shells was obtained on the middle-ground reef, but not on the main reef. After this no further set took place in the bayou until the week following August 19, when the bags of shells on both reefs received a fairly heavy set. The graph (fig. 10) shows that at this time the salinity was rising gradually from 20 to about 24 parts per thousand.

No set was obtained on the Deer Islands Reef (fig. 11) until early in July, and this occurred on a rapidly rising salinity, which, during this time according to the samples taken, rose from about 14 to over 20 parts per thousand. These measurements are necessarily rough for there is much variation in such a body of water as West Bay where the effect of tides and winds is great. The salinity then remained at a slightly reduced level until the first of August when it started upward and by the end of August was close to 30 parts per thousand. Coinciding with this rise came a period of very heavy setting during which up to 3,000 spat were obtained daily per half bushel bag of shells. Figure 17 shows a sample of one of the clumps of shells bearing spat up to about two weeks old. Setting was still continuing when observations were discontinued.

In East Bay at Hanna Reef (fig. 12) only a few salinity determinations were made, but the results are in harmony with those above described. A period of setting took place early in May, extending over about two weeks, with its peak a few days earlier than that in the bayou. It may be assumed that at this time the salinity was high in East Bay as well as in the bayou. On the 23d it was down to 6 parts per thousand, even lower than that in the bayou. The infrequent determinations, as shown in the figure, indicate that after June 24, when the salinity was less than 2 parts per thousand, it rose to 12 parts per thousand on July 14 and possibly higher at the end of the month, as was the case in West Bay. (Fig. 11.) Samples of shells brought in on August 5 showed that a fair set had taken place during the preceding two weeks. On this date the salinity was 13 parts per thousand and on the next day was down to less than 10 parts per thousand, and no more setting occurred. Previous to the setting period the salinity was rising, and afterwards it was falling, but the salinity at the time of setting is unknown. Following this the salinity gradually rose to 18 parts per thousand on August 27 but no set was obtained at this time. On the other hand, at the same time the salinity in the bayou (fig. 10) and in West Bay (fig. 11) was between 24 and 30 parts per thousand, and setting was going on.

These records are suggestive of a marked correlation between the salinity of the water and the setting of oyster larvæ. The results obtained in Offatts Bayou are the most significant because the small size and relatively great depth of the channels prevent a rapid exchange of water, and variations in salinity are not as frequent or extreme as in either West Bay or East Bay. Consequently the daily samples of water tested gave results more representative of actual salinity conditions than in the case of the open bays. Although less accurate the records taken at the Deer Islands are also valuable for they are reasonably consistent in spite of the exposure of the bay to the effects of tides and winds. The results indicate that setting periods followed rises in salinity above approximately 20 parts per thousand, although it is certainly impossible to state an exact limit.

It has long been recognized that very low salinity is unfavorable to the production of seed oysters. A number of investigations on the Gulf coast have indicated the harmful effect of freshets on oyster larvæ. Moore and Pope (1910, p. 19) found that shells planted in the Bayou St. Denis in Louisiana "remained barren during the period in which the crevasse water (from the Mississippi River) was pouring over the beds, but after this was stopped and the water grew more salt a small set appeared on these shells * * *," although their figures of salinity during this period were between 13 and 14 parts per thousand. In Mississippi, Moore (1913) found heavy setting in water, the average salinity of which was about 22 parts per thousand, as contrasted to the observation of Moore and Pope (1910) that in one bay in Louisiana not far away there was a very slow set throughout the summer in water ranging in salinity up to about 13 parts per thousand, though the figures represent very few determinations. Churchill (1920) stated that oysters seem to thrive best in waters of salinity between 14 and 28 parts per thousand, and pointed out that the production of spat is inhibited by freshets. He considered larvæ to be extremely sensitive, particularly to cold and rain.

Conditions of salinity in the Gulf coast waters are entirely different from those in the waters of Long Island Sound where Prytherch (1929) has been able to predict the peak of setting to occur close to 15 days after the peak of spawning. This investigator found that in Milford Harbor, Conn., the salinity ranged from 25 to 28 parts per thousand. On the other hand the salinity in Galveston Bay during the spring and summer varied from less than 2 to nearly 30 parts per thousand. It is probably this variability which is largely responsible for the discrepancy between the spawning and setting times in Galveston Bay and those in Milford Harbor.

If, as appears to be the case, a salinity of above 20 parts per thousand was necessary in Galveston Bay before oyster larvæ would set, the question arises as to how this factor produced such an effect. The effect may have been indirect, due to the abundance of the organisms on which oyster larvæ feed which in turn may depend upon a certain salinity in order to attain maximum abundance. It is possible, though hardly probable, that oyster larvæ require water of a certain osmotic pressure in order to mature. It is also suggested that salinity as such is secondary in promoting setting and that the most important factor is some specific ion or salt in the water, a certain concentration of which is essential to the larvæ. Wheeler (1910), for example, found that in the vicinity of Beaufort, N. C., there was considerable difference between samples of water with respect to the relative percentage of some of the salts. Analyses of Galveston Bay water showed similar and more striking variations in some of the salts. These data will be published at a later date. It is possible that oyster larvæ require a high concentration of some salt which in time of freshets is in concentration too low to permit the completion of larval development. If this is the case such a salt would be expected to be in high concentration in the pure Gulf water and lower concentration in the diluted bay water.

Prytherch [3] recently found that mature oyster larvæ may be caused to set by dissolving a small amount of a copper salt in the water. His evidence indicates that the copper in solution in the river waters emptying into Long Island Sound is instrumental in causing larvæ to set. The fresh water from the rivers, according to this worker, must be present in a high enough proportion to allow setting to take place; that is, a certain dilution, due to the river water, is conducive to setting. This is directly the opposite of the condition found to obtain in Galveston Bay, where setting appeared not to take place when the salinity was below about 20 parts per thousand. It may be that optimum conditions for setting are to be found when the sea water is diluted by land drainage only to a limited degree, and that when dilution is greater some necessary substance other than copper becomes reduced below the minimal required concentration. No conclusion can be drawn with respect to the actual cause of the phenomena observed in Galveston Bay, save that in some manner setting of oyster larvæ seems to be dependent either directly or indirectly upon salinity.

ABUNDANCE OF DIATOMS

The food of the oyster consists of the microscopic or semimicroscopic organisms which float in the water, particularly the diatoms and other algæ of comparable size and form. The richness of this plankton at different periods of the year determines in large measure the quality of the oysters, for without sufficient food oysters obviously can not fatten. It is important, therefore, to estimate the relative abundance of diatoms in the water near oyster grounds.

Plankton collections were made in the vicinity of Galveston during the spring and summer months, and these results show an interesting fluctuation in the relative abundance of diatoms during this time. Collections were made with a plankton net of No. 20 bolting silk, and hauls were made at the surface of the water. While the collections were made primarily for obtaining oyster larvæ, they served as well for diatoms. Samples were taken only infrequently during April and the first part of May, but after this they were taken almost every day.

The relative abundance of diatoms was estimated as in the case of oyster larvæ. Numbers from 0 to 6 were used to designate the relative number of diatoms from none to the maximum ever taken. The method is not strictly quantitative but serves well enough to show roughly the seasonal variation in abundance of diatoms. The numbers representing abundance were defined as follows: 0, diatoms totally absent, although this was never the case, for in every collection there would be at least one or two diatoms; 1, very few diatoms, representing scarcely enough to form a coating on the bottom of the bottle; 2, few; 3, fair number; 4, many; 5, very many; and 6, extremely abundant, so that the plankton net became clogged and the sample bottle was as full as possible of diatoms. The gradations in between the extremes are largely arbitrary, but since all estimates were made over a period of a few days, while the last of the samples were being taken, and by the author only, they represent a reasonable degree of accuracy.

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[3] Unpublished manuscript.

In Figure 18 all of these data are presented graphically. There are two main series, the samples from Offatts Bayou and those from West Bay. In the former each point represents the average of three samples taken at the three places designated in Figure 5 (stations 1, 2, and 3). This average is a fair estimate of the abundance of diatoms in the bayou, for the places where collections were made include not only the water near the mouth which is changed frequently by tides but also that farther up in the bayou where the water is only slowly exchanged. In the case of the points representing West Bay collections each point is the average of three determinations; two from near the Deer Islands and one from a short distance out in West Bay from the mouth of the bayou. (Fig. 4, stations 4, 5, and 6.) These points do not give as complete an idea of the abundance of diatoms in West Bay as do those referring to the bayou, for West Bay is much larger. In spite of this fact, however, it will be observed (fig. 18) that there is a striking parallel between the records in the two places.

Another series of samples is also represented in the figure, referring to East Bay near Hanna Reef. Samples were taken only infrequently, and many of those taken are not included because the water was muddy and clogged the net, making the samples of doubtful value. However, these few points are distinctly in agreement with those of the other two series, suggesting that the records constitute a fair estimate of the diatom content of Galveston Bay as a whole.

The most striking characteristic of these records (fig. 18), when minor fluctuations be overlooked, is the gradual reduction in abundance of diatoms in the water from the end of March, when the first samples were taken, to the end of August, when sampling was discontinued. In the former case the water was so full of diatoms that a haul had to be shorter than the standard time, due to clogging of the net. Toward the end of July and during August most of the samples contained little else save oyster larvæ. In most cases at this time very careful microscopic examination was necessary in order to find one or two diatoms. These samples were designated as halfway between none and very few and actually represent the virtual absence of diatoms of the sizes taken by the net.

Comparison of the graph of diatom abundance with those of temperature (fig. 9) and salinity (fig. 10) is of interest. The temperature rose rapidly toward the end of March to over 25° C. and after this time diatoms became rapidly less abundant. The diatom records for the end of April and beginning of May are too scattered to be particularly significant, but the few samples during this period showed extremely few diatoms in the water. The salinity during March, April, and half of May was in the neighborhood of 20 parts per thousand. However, following May 20 the salinity dropped quickly from 20 to about 14 parts per thousand, due to increase in river discharge. This was accompanied by a drop of a few degrees in temperature. At the same time there was a great increase in the diatom content of the surface water which lasted for about 10 days, and then abruptly the diatoms disappeared.

The variations in the average temperature of bayou water (fig. 9) after the middle of May appear to bear a definite relationship to the abundance of diatoms in the samples taken in this place. In nearly every case, between this time and late in the summer, whenever there was a marked fall in water temperature there was a rise in abundance of diatoms collected. When the temperature rose again the diatoms taken became less abundant. Even minor variations in temperature were accompanied by fluctuations in the abundance of diatoms taken. Whether the temperature variation is itself responsible for differences in the abundance of diatoms is not clear.

It is possible that the diatoms sink into deep water when the water is warm and rise to the surface when the water is cooler; or else wind which cools the water also

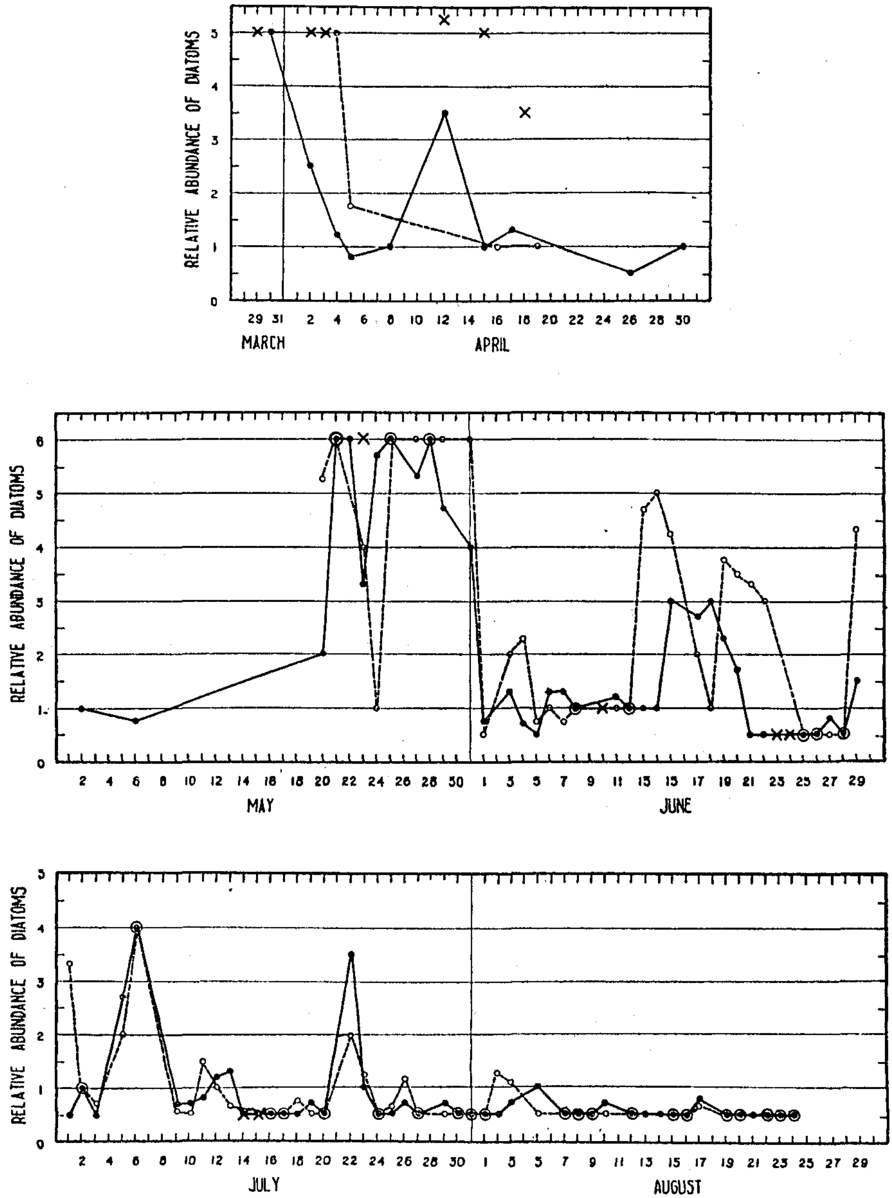

FIGURE 18.—Charts showing the relative abundance of diatoms, taken with plankton net of No. 20 bolting silk, in Galveston Bay. Solid points represent collections in Offatts Bayou, each point being the average of three or more samples. Circles refer to collections in West Bay near Deer Islands, representing usually three samples in East Bay, near Hanna Reef, are designated by X's. Abundance of diatoms was roughly estimated as follows: 0, none (although in no case were they considered to be absolutely absent); 1, very few; 2, few; 3, fair number; 4, many; 5, very many; 6, extremely abundant. The figures are only rough estimates but clearly show certain fluctuations, especially the disappearance of diatoms toward the end of the summer

stirs up the diatoms which may have settled to the bottom; that is, these minor variations may have been due to the method of sampling, for the net was effective only for the surface 12 or 15 inches of water. It is this surface water, however, which is of particular significance with regard to oysters in most of the Gulf of Mexico waters, since most oysters occur at approximately the low-tide level and few are found in deeper water.

Whatever may be the significance of the correlation between temperature fluctuations and the abundance of diatoms at the surface, the graphs (figs. 8 and 19) show distinctly the gradual disappearance of diatoms between March and August. This is entirely in harmony with the well-known seasonal variation in diatom growth. Steuer (1903) called attention to the fact that while in northern waters there are two maxima of diatom abundance, one in spring and one in the fall, in more southern waters the two maxima encroach more and more upon the winter months, thus tending to fuse together in warm regions to form a single winter maximum. This condition was found in the Adriatic. A secondary maximum was found to occur in June and July. Fish (1925) found essentially the same condition to obtain in Buzzards Bay.

Since this variation is a function of temperature, and since the warmer the water the greater the tendency to concentrate the maximum into the winter months, it would be expected that in the very warm water of Galveston Bay the maximum would be of relatively short duration, perhaps in mid or late winter, depending upon the time of minimum temperature. It would be of considerable importance in reaching a complete understanding of the differences between oysters of the North Atlantic coast and those of the South Atlantic and Gulf coasts to obtain systematic diatom collections throughout the year. It may well be that the short season during which oysters in the southern waters are fat or prime is due as much to a short period during which sufficient food is available as to the long spawning season. The observation of Battle (1892) on oysters in South Carolina waters is of significance in this respect. He wrote (p. 329): "As a rule the oysters do not attain their best condition in South Carolina until late in the winter and early in the spring." Yet the spawning season there, as in Texas, probably ends in late fall. It is very probable that the oysters do not become prime until relatively late because of the lack of food in fall and early winter, and that the period of maximum "fatness" of the oysters corresponds closely with the period of maximum abundance of diatoms.

USE OF WIRE BAGS OF SHELLS AS CULTCH

In South Atlantic and Gulf waters one of the major difficulties in obtaining seed oysters is due to the fact that silt and slime soon cover the cultch after it is placed in the water. As has been discussed in the preceding pages, the setting periods in Galveston Bay were scattered and of short duration, although setting might be expected at times during at least six months of the year. Had shells been placed in the water at the middle of April when a set was expected, the shells would have become silted and their value as cultch in this manner reduced before any setting took place. For this reason the simple method of spreading shells on suitable bottom is inadequate especially when the setting does not occur soon after the planting of the shells. One aim of the present investigation was to determine whether the method of using wire bags of shells as cultch is suitable in such a body of water as Galveston Bay. A complete account of experiments with these bags on the Atlantic coast has recently been published by Galtsoff, Prytherch, and McMillin (1930).

As has been described, the set obtained on shells in such bags in Galveston Bay was highly satisfactory. Table 3 shows the number of spat per bag of shells obtained at different places and during different periods of time. The heaviest set was obtained at the Deer Islands in August when the inside surfaces of the shells in each bag (one-half bushel) bore nearly 20,000 spat. The outer surfaces of the shells probably received as heavy a set, so it may be said that the set amounted to 40,000 spat per half-bushel bag of shells. In Figure 17 is a photograph of a clump of shells from one of these bags showing the great abundance of young spat.

In some cases the spat are too abundant for they would tend to grow into coon oysters unless broken apart while still relatively small. If left in the water longer even more would set on the same shells, resulting in considerable crowding. Shells which are merely spread on a reef as cultch can not readily be removed when the proper amount of set is obtained, but the bags may be removed when desired and transferred to beds in deeper water for growth where little or no further setting occurs. Also, after the shells in bags have become slimy and bear no set, the bags may easily be taken up and left in the sunshine for a few days, and then put back into the water as clean cultch on which larvæ will set. In this manner seed may be collected in desired abundance for planting on private grounds or for developing new public grounds.

TABLE 3.—*Number of spat on the inside surfaces of shells planted in Galveston Bay, 1929*

Date planted	Date removed	Place	Spat per half bushel of shells	Date planted	Date removed	Place	Spat per half bushel of shells
May 6	May 20	Bayou, main reef	975	June 25	July 10	Bayou, middle ground	67
Apr. 18	May 23	Hanna reef	212	Do	July 18	Deer Island	2,700
May 20	May 31	Bayou, middle ground	120	July 15	Aug. 6	Hanna Reef	1,800
May 28	June 25	Bayou, main reef	31	Aug. 3	Aug. 14	Deer Island	15,000
May 31	do	Deer Island	22	Do	Aug. 22	do	19,000
June 25	July 9	do	1,270	Aug. 20	Aug. 27	Bayou, main reef	(1)

1 Spat present, but not counted.

This method may be employed as an economical means of developing oyster ground in places not near the natural reefs. The removal of common coon oysters from reefs as seed is also advisable but this method involves more labor in culling and transportation than that above described. More recently the use of cement-coated egg-crate partitions (Prytherch, 1930) has been found to be highly efficient as a method of collecting seed oysters. This method might well be employed on the Texas coast. Such modern methods of oyster culture if applied extensively in the coast waters of Texas should increase the production of oysters tremendously. The survey by Galtsoff [4] in 1925 showed that the coastal waters comprise large areas which appear to be suitable for oyster culture.

SUMMARY

(1) The spawning season of oysters in Galveston Bay in 1929 was observed to begin at the end of March. At the end of August larvæ were still in the water and the oysters still milky, indicating a spawning season of at least six months.

(2) Spawning started when the average daily water temperature in Offatts Bayou was about 25° C. When 20° C. was reached the oysters were just beginning to develop mature eggs and sperms, causing them to appear milky.

4 Unpublished manuscript in the files of the Bureau of Fisheries.

(3) Thermograph records of water temperature in the bayou show that at the end of February the winter temperature was 14° to 15° C., while during the spring and summer it rose to between 30° and 33° C.

(4) Because of increased river discharge in spring and early summer the salinity of the water in Galveston Bay remained low for a considerable time. In early spring the salinity in the bayou was 22 to 24 parts per thousand, while early in June it was down to 7 parts per thousand. At the same time in West Bay it was only 4 parts per thousand. In East Bay late in June it was below 2 parts per thousand. During July and August the salinity rose to between 20 and 30 parts per thousand.

(5) The characteristic pH of the water in Galveston Bay was between 8 and 8.4, fluctuating between these levels. In August in the bayou it rose to 8.9.

(6) Setting was irregular and took place during short, isolated periods. The first spat were not obtained until a month and a half after spawning started.

(7) In Offatts Bayou two chief setting periods occurred, one at the middle of May, and the other beginning at the end of August. In addition two very light sets were obtained at one place in the bayou; at the end of May and at the beginning of July, respectively.

(8) In West Bay at the Deer Islands two setting periods were observed; a short one early in July, and a more prolonged one beginning at the first of August. At the latter time setting was very heavy and up to 3,500 spat were obtained daily per bag of shells.

(9) On Hanna Reef, East Bay, a light set was obtained at the beginning of May and a fairly heavy one at the end of July and first part of August.

(10) The setting periods appear to have been correlated with periods of high salinity, suggesting that in some manner the larvæ depend, either directly or secondarily, upon a salinity above about 20 parts per thousand, in order to develop to the setting stage.

(11) Most of the larvæ taken in the collections were in the straight-hinge stage, with the exception of short periods, until August when many umbo larvæ were taken. It is probable that setting was not more continuous because early in the season few reached the setting stage.

(12) Of 252 adult oysters from different reefs only 51 were males and 178 were females. The remaining 23 specimens were either too completely spawned out or immature to permit ready determination of sex.

(13) Diatoms in the surface plankton collections were most abundant in early spring and slowly decreased in numbers taken so that in July and August the water was almost free of them. It was observed that during periods of low temperature of the water more diatoms were taken than during times of high temperature. This was the case for temperature changes occurring over a few days as well as over the entire period during which collections were made.

(14) Use of wire bags of shells as cultch was tested in Galveston Bay waters and found to be highly satisfactory as a means of collecting spat for developing oyster grounds.

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