SPAWNING AND SETTING OF OYSTERS IN LONG ISLAND SOUND IN 1937, AND DISCUSSION OF THE METHOD FOR PREDICTING THE INTENSITY AND TIME OF OYSTER SETTING.[1]

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CONTENTS

INTRODUCTION

Oyster farming as practiced now in Long Island Sound and adjacent waters represents the highest type of oyster cultivation on the Atlantic coast of North America. The present methods are the outgrowth of many years experience of oyster farming in northern waters.

The perpetuation of the industry depends largely upon an ample supply of seed oysters. From the available records (see table 1) it appears that during the second half of the last century the annual setting of oysters in Connecticut waters was very regular and usually quite heavy. Seed oysters, obtained from the harbors, shallow bays, and mouths of rivers, were used for planting on offshore beds of the Sound. Large quantities of Connecticut seed oysters were also sold to other States where the locally produced supply of seed was insufficient to meet the demand. The high survival rate of Connecticut seed oysters transplanted to other waters, as well as their rapid growth in a new environment, established a good reputation and created an extensive demand for them. Seed producing became an established and rather profitable industry in Connecticut. Virtually unfailing and heavy sets supplied more than sufficient quantities of seed oysters for both local needs and out-of-State markets.

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At the beginning of the century rather abrupt changes in the production of oysters occurred in Long Island Sound waters. Oyster sets, instead of being heavy and regular, became either light or resulted in complete failure (see table 1). During the last 37 years heavy setting occurred only 4 or 5 times. Complete failure of set was recorded for 20 seasons. As a consequence of these irregular and insufficient settings the local oyster industry soon began to feel the lack of seed oysters. At present the scarcity of seed constitutes one of the main difficulties of Long Island Sound oyster growers.

TABLE 1.—*Oyster sets in Connecticut waters from 1882 to 1937* [1]

Year	Set	Year	Set	Year	Set
1882	Heavy.	1901	Light.	1920	Failure.
1883	Do.	1902	Do.	1921	Do.
1884	Do.	1903	Failure.	1922	Light.
1885	Do.	1904	Heavy.	1923	Do.
1886	Do.	1905	Light.	1924	Failure.
1887	Do.	1906	Failure.	1925	Heavy.
1888	Light.	1907	Do.	1926	Medium.
1889	Do.	1908	Light.	1927	Failure.
1890	Heavy.	1909	Failure.	1928	Heavy.
1891	Do.	1910	Do.	1929	Light.
1892	Do.	1911	Light.	1930	Heavy.
1893	Medium.	1912	Failure.	1931	Failure.
1894	Heavy.	1913	Do.	1932	Do.
1895	Do.	1914	Light.	1933	Do.
1896	Do.	1915	Failure.	1934	Medium.
1897	Medium.	1916	Do.	1935	Failure.
1898	Failure.	1917	Do.	1936	Do.
1899	Heavy.	1918	Do.	1937	Medium.
1900	Medium.	1919	Light.		

[1] Compiled from State of Connecticut Biennial Reports of the Shell-Fish Commissioners.

PURPOSE OF INVESTIGATION

Since frequent failure of oysters to set in Connecticut waters requires an explanation, this investigation was initiated to obtain a broader knowledge of the spawning and setting of oysters in Long Island Sound and its tributaries. Aside from the purely scientific interest, the information obtained in the course of this work should be valuable to the oyster industry. If, as a result of these and future studies, it will be possible to keep the oystermen informed regarding the time when spawning of oysters in different areas of the Sound begins, the time and intensity of setting, and the probable rate of survival of set, then oyster growing would be a less uncertain and hazardous enterprise and become better planned aquatic farming.

Under the present methods the Long Island Sound oystermen continue to plant shells every summer, hoping that the setting will be of commercial importance. According to the information received from the Director of the Oyster Growers and Dealers Association of North America, Inc., the oyster industry of Connecticut alone spends approximately $200,000 annually in preparing setting grounds and planting shells. Often large quantities of shells are planted in the years when virtually no setting, or a very light one, occurs. In such cases serious monetary losses are incurred. In the years when setting takes place the oystermen, not knowing when to expect its peak, may plant shells either too early or too late to secure the best results. If the information on the time and intensity of setting were available, such mistakes could probably be avoided.

GENERAL DESCRIPTION OF REGION

Long Island Sound is a large body of water partially inclosed between the New York–Connecticut shore along its northwestern boundary, and Long Island along its southeastern line (see fig. 1). The length of the Sound is approximately 80 nautical miles. Its greatest width of 17 miles coincides with a line extending from Branford, Conn., to the Long Island shore. From this line the Sound decreases gradually in both directions, reaching a width of less than 1 mile at its western extremity, and about 8 miles at its eastern end. The average depth of the Sound is approximately 60 feet. The greatest depth of 306 feet is recorded in its extreme eastern part, a few miles southwest of Fishers Island. The middle and deepest part of the bottom is a comparatively level plateau with an average depth of about 90 feet. The eastern part is somewhat deeper than the western part.

Throughout the entire length of the Connecticut shore the slope of the bottom is very gradual, but along the Long Island shore it is quite steep. A 50-foot depth curve drawn along both shores of the Sound extends several miles away from the Connecticut shore, but lies rather close to Long Island.

The outline of the Connecticut shore of the Sound is quite irregular. Numerous harbors, bays, and mouths of creeks and rivers form an almost continuous row of indentations of various shapes and sizes. The Long Island shore line, with the exception of a few bays in its western part, is virtually unbroken along the largest part of its extent. While there is no river of any size entering the Sound on its Long Island shore, several streams, of which the Connecticut, Housatonic, Quinnipiac and Poquonock Rivers are the largest, flow into the Sound from the north.

Comparatively shallow water, the presence of numerous well-protected bays and harbors, and the large quantities of fresh water flowing into the Connecticut side of Long Island Sound explain why natural oyster grounds, as well as cultivated ones, are largely confined to that part of the Sound. The cultivated oyster beds of the Connecticut shore extend in a strip, approximately 3 to 5 miles in width, from Stamford to Branford. According to figures received by the authors from the State of Connecticut Commission of Shell-Fisheries, there are 47,708 acres of bottom used for cultivation of oysters.

METHODS AND EQUIPMENT

The United States Bureau of Fisheries Laboratory, situated on the western shore of the Wepawaug River, at Milford, Conn., served as headquarters during this investigation. Because the lower part of the Wepawaug River is locally called Milford Harbor this term will be used in the present discussion. The area below the junction of Milford Harbor and Indian River will be called Milford Bay (see fig. 2).

The State of Connecticut Shell-Fish Commission's boat *Shellfish* and the U. S. Fisheries' *Launch No. 30* were used continuously in the course of this work.

In the Sound, the temperature of the water was recorded with Negretti and Zambra reversing thermometers certified by the United States Bureau of Standards. Usually only the bottom-water temperatures were taken. A regular surface thermometer was used at shallow stations on the tidal flats of Milford Harbor.

For studies of the salinity of water, samples were collected with a Greene-Bigelow water bottle and titrated in the usual way according to Knudsen's method.

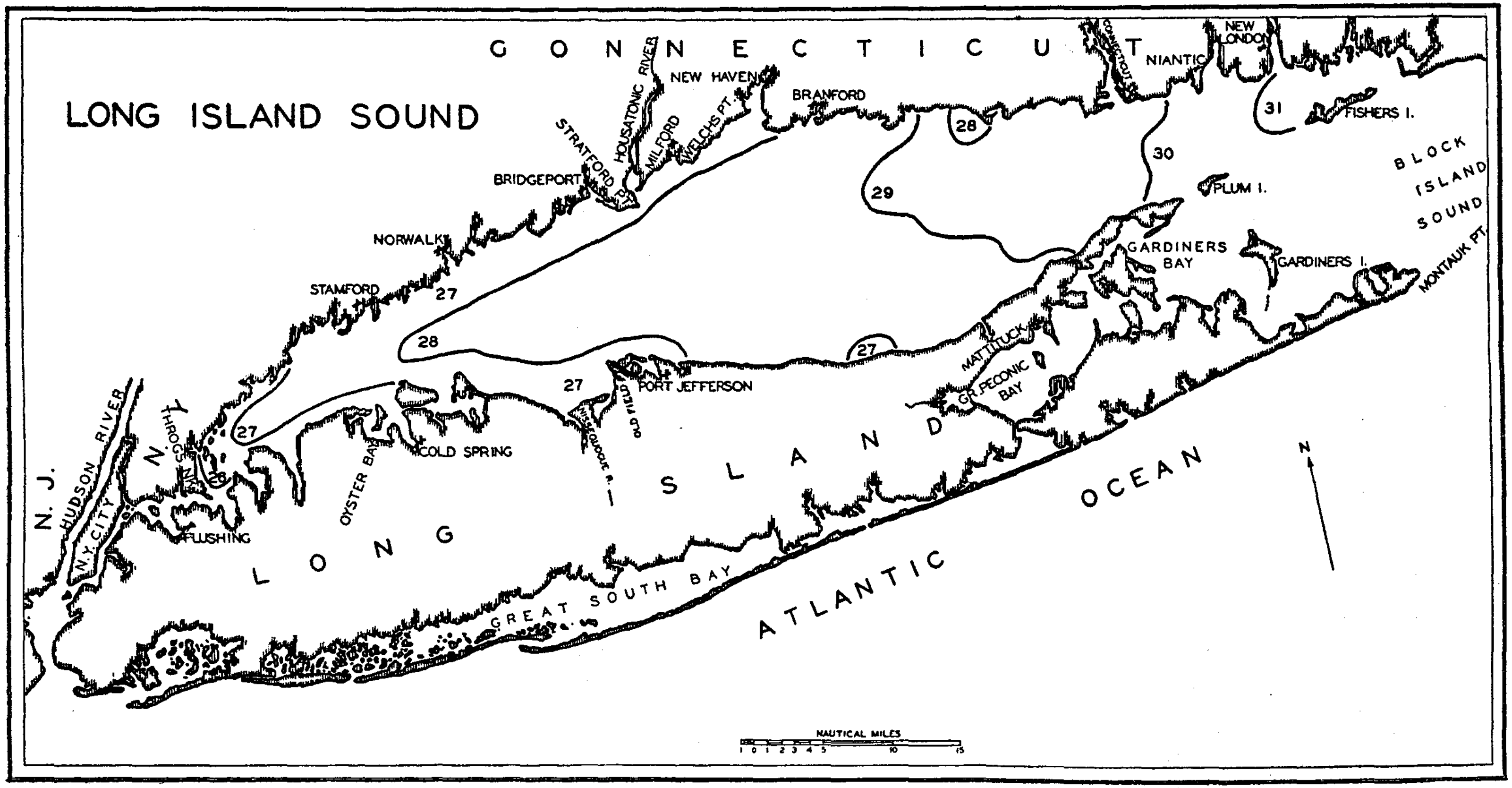

FIGURE 1.—Chart of Long Island Sound. Distribution of bottom salinity, as determined in the summer of 1935, is shown by isohalines.

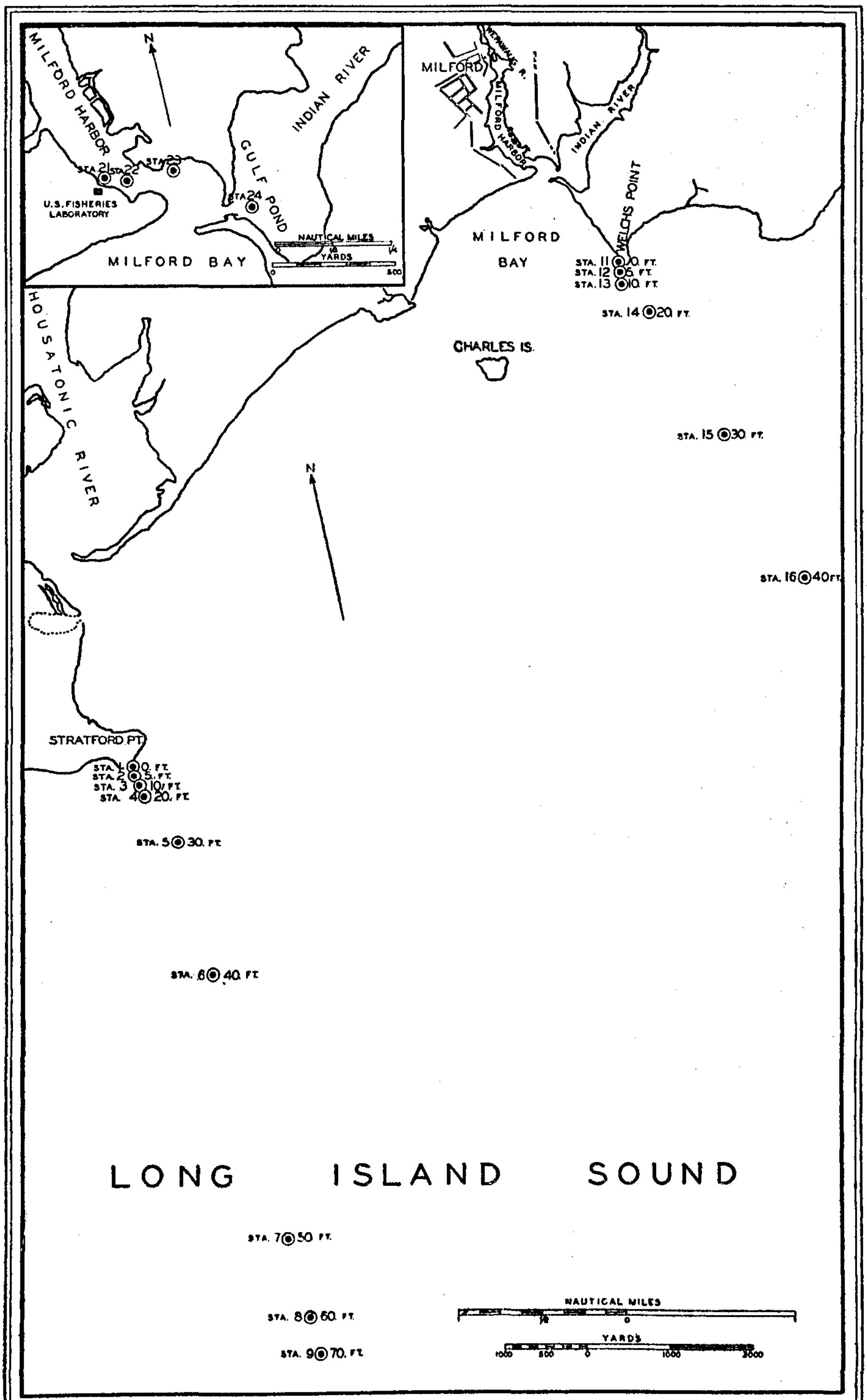

FIGURE 2.—Locations and depths of stations established for observations on oyster setting in Long Island Sound and Milford Harbor.

Samples of plankton were collected either by drawing a plankton net through the water, or, if quantitative data were needed, by means of a plankton trap of known capacity.

For observations on gonad development and spawning of oysters, 19 stations were established in Long Island Sound proper (see fig. 3), and 4 stations in Milford Harbor (see fig. 2). The location of each station was chosen with the purpose of obtaining information relative to the spawning and setting of oysters for each of the most important seed-oyster producing grounds along the Connecticut shore. Each station represented the conditions existing in the general vicinity of its location. All these stations were visited every week during the peak of the spawning and setting seasons, and every 2 weeks at other times throughout the summer.

Regardless of the fact that much work on the biology of the oyster has been carried on in local waters, no attempt has ever been made to conduct a systematic study of setting in Long Island Sound proper. To fill this gap it was decided to determine in 1937 the beginning and end of the setting period, the intensity of setting in time, the intensity of setting in relation to depth, the existence or lack of correlation between periods of setting and the temperture and salinity of water, and, finally, the rate of survival of recently set oysters in different parts and depths of Long Island Sound. For these studies two seed-oyster producing areas located about 5 miles apart were chosen (see fig. 2). The Stratford Point area represented the natural oyster beds where little or no cultivation of oysters is carried on. Welchs Point, on the other hand, is located in the center of cultivated grounds. In the studies of setting, wire bag collectors of uniform size and containing approximately the same number of shells were used. The bags were placed off Stratford Point at depths of 0, 5, 10, 20, 30, 40, 50, 60, and 70 feet, at mean low water, and at Welchs Point at 0, 5, 10, 20, 30, and 40 foot depths. The bags were removed at semiweekly intervals and each time replaced by a new unused duplicate. Recovered bags were brought in moist condition to the laboratory where the shells were examined for the presence of oyster set.

Milford Harbor was also included in this study because it resembles in general character numerous other shallow, sheltered areas of the Connecticut shore line. There were 4 stations established for observations on setting (see fig. 2) and spawning of oysters. Methods similar to those used in the studies of setting in the Sound were employed.

Previous experience in handling wire bag collectors showed that finding and recovering them in the open Sound was quite difficult, especially if the weather was foggy or rough. The bags, placed some distance away from the shore, were often lost. An arrangement which greatly facilitated their recovery is shown in detail in figure 4. To a wire bag filled with stones and serving as an anchor, a regular wire bag collector was attached by a short rope. From this anchor a strong rope extended to a rope buoy, the purpose of which was to float the rope. The length of rope extending from the anchor to the rope buoy was equal to the depth of water at the particular station at high water stage. Since, however, the long rope soon became waterlogged and covered with a heavy growth of algae, thus pulling the buoy under the surface, especially when the tidal current was swift, it was found necessary to have another rope of equal length extend from the rope buoy to the second or top buoy. Because of such an arrangement the top buoy was always found floating on the surface and could be seen from quite a distance. To facilitate

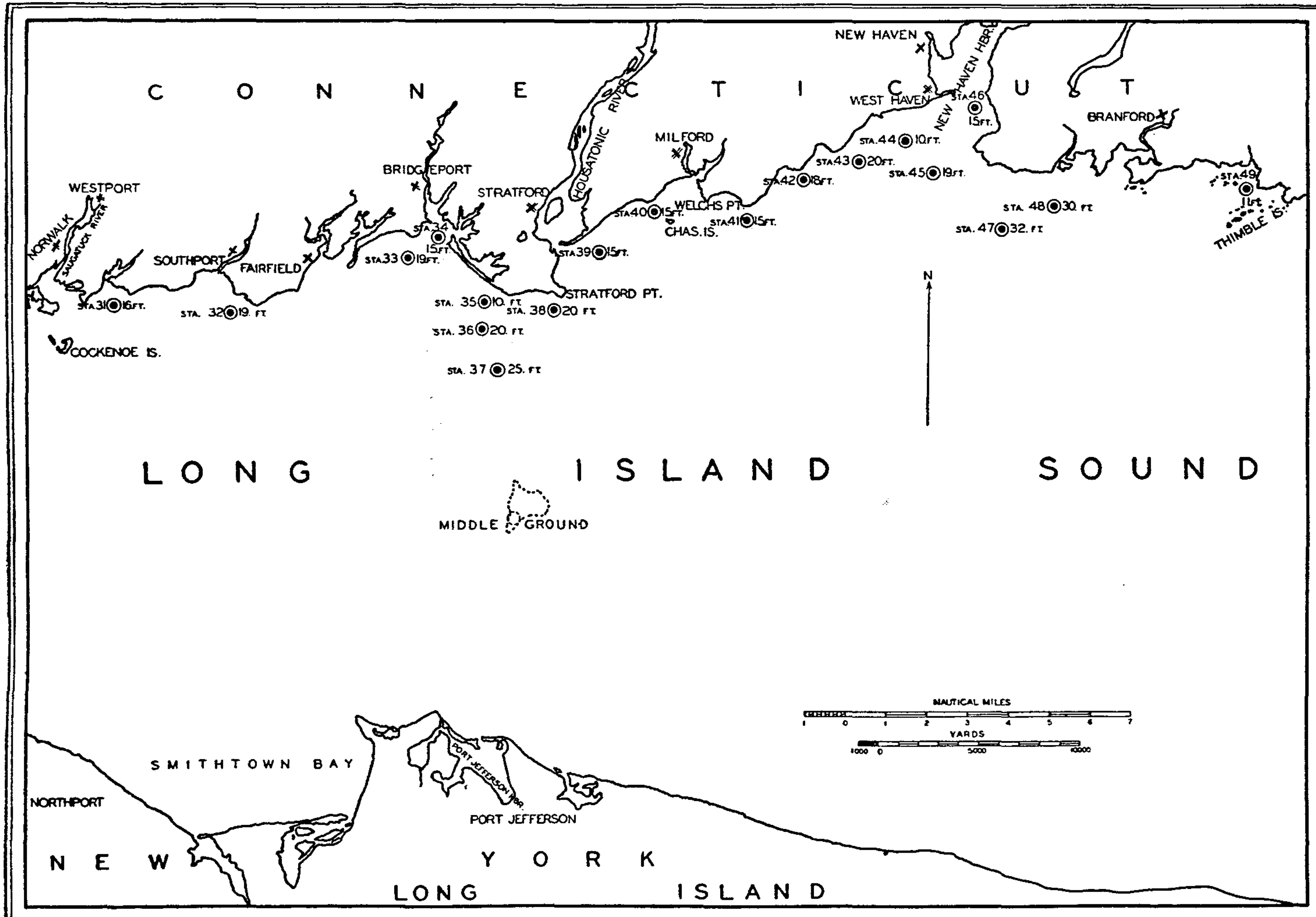

FIGURE 3.—Locations and depths of 19 stations established for observations on gonad development and spawning of oysters in Long Island Sound.

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the finding of collectors, regular oyster buoys, used by oystermen for designating the boundaries of their grounds, were set nearby.

For studies of vertical distribution of setting, a new type of collector was designed. It consisted of a 2- by 6-inch board wrapped tightly in chicken wire and covered with a layer of cement about one-fourth inch thick. The chicken wire kept the cement intact after it became dry. Such collectors were made of different lengths, depending upon the depth of water in which they were used. They were placed in a vertical position by pushing one of the ends into the bottom.

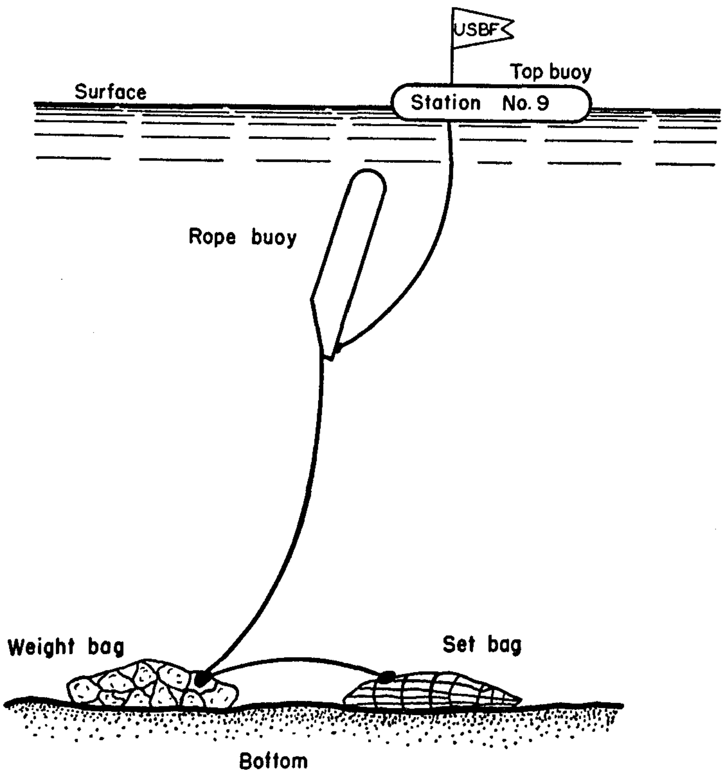

FIGURE 4.—Method of buoying collectors set in deep water.

PHYSICAL OBSERVATIONS

TEMPERATURE

The bottom-water temperature was recorded semiweekly at stations 3, 5, and 8 of the Stratford Point area, and at stations 13, 14, and 16 at Welchs Point. The period of observations extended from July 2 until Oct. 4, 1937. The location and depth of each station are shown in figure 2. Tables 2 and 3 give the data secured.

At the beginning of these studies the temperature at shallow stations was 2.0 to 3.0° C. higher than at the deepest ones. As the season progressed the difference became smaller. Finally, in August and early September, homothermal conditions were recorded in several instances. Late in September shallow water began to cool off more rapidly than the water of greater depths and, therefore, the temperatures recorded at shallow stations was somewhat lower than at deeper areas (see fig. 5).

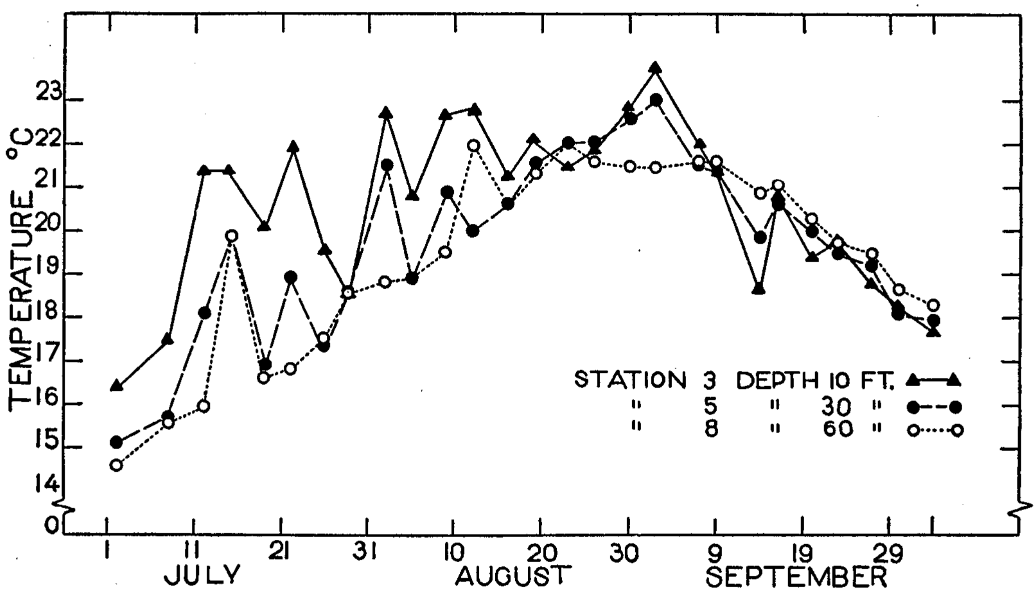

FIGURE 5.—Bottom-water temperatures recorded at semiweekly intervals at stations 3, 5, and 8 from July 2 to October 4, 1937.

TABLE 2.—*Bottom-water temperatures, in degrees centigrade, recorded semiweekly at 3 stations of Stratford Point from July 2 to Oct. 4, 1937*

Date	Station 3	Station 5	Station 8	Date	Station 3	Station 5	Station 8
	Depth 10 ft.	*Depth 30 ft.*	*Depth 60 ft.*		*Depth 10 ft.*	*Depth 30 ft.*	*Depth 60 ft.*
July 2	16.4	15.1	14.6	Aug. 23	21.5	22.0	22.0
July 8	17.5	15.7	15.6	Aug. 26	21.9	22.0	21.6
July 12	21.4	18.1	15.9	Aug. 30	22.9	22.6	21.5
July 15	21.4	19.9	19.9				
July 19	20.1	16.9	16.6	Sept. 2	23.8	23.0	21.5
July 22	21.9	18.9	16.8	Sept. 7	22.0	21.5	21.6
July 26	19.6	17.3	17.5	Sept. 9	21.4	21.4	21.6
July 29	18.6	18.4	18.6	Sept. 14	18.7	19.9	20.9
				Sept. 16	20.9	20.7	21.0
Aug. 2	22.8	21.5	18.8	Sept. 20	19.4	20.0	20.3
Aug. 5	20.8	18.9	18.9	Sept. 23	19.7	19.5	19.7
Aug. 9	22.7	20.9	19.5	Sept. 27	18.8	19.2	19.5
Aug. 12	22.8	20.0	22.0	Sept. 30	18.3	18.1	18.7
Aug. 16	21.3	20.6	20.6				
Aug. 19	22.1	21.5	21.3	Oct. 4	17.7	17.9	18.3

TABLE 3.—*Bottom-water temperatures, in degrees centigrade, recorded semiweekly at 3 stations of Welchs Point from July 3 to Oct. 1, 1937*

Date	Station 13	Station 14	Station 16	Date	Station 13	Station 14	Station 16
	Depth 10 ft.	*Depth 20 ft.*	*Depth 40 ft.*		*Depth 10 ft.*	*Depth 20 ft.*	*Depth 40 ft.*
July 3	17.6	17.0	15.5	Aug. 24	21.6	21.6	21.9
July 9	18.7	18.3	16.3	Aug. 27	22.8	22.2	22.0
July 13	20.2	21.6	18.5	Aug. 31	23.7	23.0	22.2
July 16	22.3	21.4	18.4				
July 20	20.6	19.6	17.6	Sept. 3	23.2	23.0	21.8
July 23	20.5	20.2	17.7	Sept. 7	21.1	21.2	21.6
July 27	19.4	18.4	17.5	Sept. 10	21.4	21.5	21.5
July 30	20.5	19.7	18.1	Sept. 14	19.9	20.1	20.4
				Sept. 17	20.0	20.2	21.0
Aug. 3	20.7	20.6	20.0	Sept. 21	18.4	18.5	19.5
Aug. 6	21.5	20.8	19.4	Sept. 24	18.4	18.6	19.3
Aug. 10	22.7	21.9	20.2	Sept. 28	18.5	18.5	18.7
Aug. 13	22.2	20.9	20.1				
Aug. 17	20.8	20.8	20.8	Oct. 1	17.8	17.9	18.3
Aug. 20	22.7	22.5	21.5				

Further information on bottom-water temperature in the Sound is given in table 4, showing the temperature changes from June until Sept. 1937, at 19 stations extending from west to east for a distance of over 30 nautical miles. This chain of stations embraced almost the entire seed-oyster producing area along the Connecticut shore (see fig. 3) and was established primarily for observations on gonad development and spawning of oysters. The depth of stations varied from 10 to 32 feet. Recorded within 36 hours of each other, the bottom-water temperature of these stations sometimes showed a difference of several degrees. Such differences, especially evident during the first part of the season, were due to the fact that some of the stations, for example stations 31, 33, and 48, were established in well protected harbors where the water temperature in the spring and summer was considerably higher than in the open Sound. As the season progressed the water temperature at all the stations of approximately the same depth became quite uniform.

As the records show, the bottom-water temperature of the western and eastern stations rather closely approached each other, thereby disproving the established opinion of many local oystermen that the western part of the Connecticut oyster-producing area is considerably warmer than the eastern part.

TABLE 4.—*Bottom-water temperatures, in degrees centigrade, at 19 stations of seed-oyster producing areas of Long Island Sound, June 10 to Sept. 2, 1937*

Station number	Depth in feet	June 10–11	June 24–25	July 7–8	July 14–15	July 22–23	Aug. 3–4	Aug. 16–17	Sept. 1–2
31	16	16.5	18.8	18.7	23.0	22.8	21.7	22.2	23.0
32	19	16.2	17.6	17.9	19.8	21.6	20.1	21.0	22.7
33	19	16.5	17.9	18.1	20.0	21.1	20.7	21.4	22.9
34	15	----------	17.9	18.5	21.3	21.3	21.7	23.2	22.8
35	10	14.0	16.8	17.2	20.4	21.7	21.1	22.2	22.3
36	20	13.7	16.7	17.2	19.8	20.3	20.7	21.2	22.6
37	25	14.3	15.9	16.3	20.7	19.4	20.3	20.2	21.9
38	20	13.2	16.9	18.4	21.6	20.7	21.4	20.7	22.9
39	15	15.7	18.0	18.0	21.8	21.7	21.2	21.8	23.0
40	15	15.6	18.5	18.4	21.8	21.7	20.9	21.2	23.0
41	15	15.1	16.5	17.9	22.1	20.5	20.2	20.7	23.2
42	18	14.6	17.4	18.9	21.9	21.5	21.7	21.2	23.2
43	20	15.4	17.6	19.3	21.9	21.8	21.5	21.7	23.2
44	10	15.5	18.5	19.3	21.7	21.0	22.2	22.2	23.4
45	19	14.5	18.2	19.3	21.8	21.7	21.5	23.0	22.8
46	15	17.0	18.8	19.8	22.2	21.8	21.9	23.5	23.2
47	32	14.2	17.2	18.2	20.5	19.6	20.7	21.0	22.2
48	30	14.6	17.2	18.3	21.7	19.7	21.4	21.1	22.1
49	11	15.7	17.8	19.7	21.2	20.4	22.9	23.7	23.2

NOTE.—Temperatures at stations 31–40, inclusive, refer to the first day of a 2-day period of observations indicated in the heading of each column; those at stations 41–49 refer to the second day of the same period.

TABLE 5.—*Water temperatures, in degrees centigrade, at 4 stations in Milford Harbor from June 17 to Sept. 30, 1937. Temperatures were recorded during low-water stages*

Date	Station 21	Station 22	Station 23	Station 24	Date	Station 21	Station 22	Station 23	Station 24
June 17	22.2	21.1	21.7	24.4	Aug. 13	25.6	25.3	25.3	27.0
June 28	19.4	19.4	19.4	19.4	Aug. 17	26.1	27.0	27.2	28.3
					Aug. 20	25.6	27.0	27.0	28.9
July 2	21.7	22.0	22.8	24.4	Aug. 24	17.5	17.9	17.9	18.3
July 6	24.7	24.7	26.1	25.3	Aug. 27	21.7	21.1	21.4	22.2
July 9	22.2	22.5	22.2	23.3	Aug. 31	25.0	26.7	26.1	27.2
July 13	21.7	21.7	22.0	23.3					
July 16	26.1	24.7	26.1	27.8	Sept. 3	26.7	27.8	27.5	27.8
July 20	25.3	25.0	24.7	26.1	Sept. 7	17.2	17.2	17.8	17.8
July 23	23.3	22.5	21.7	21.7	Sept. 10	16.7	16.7	17.2	19.4
July 27	22.8	22.8	22.8	23.3	Sept. 14	20.0	22.0	18.9	20.3
July 30	21.4	21.1	21.4	21.4	Sept. 17	18.3	18.9	18.9	18.3
					Sept. 21	14.4	16.1	13.6	13.1
Aug. 3	25.3	25.6	27.2	27.8	Sept. 24	16.1	15.3	15.8	16.1
Aug. 6	28.3	27.8	26.7	27.0	Sept. 30	18.9	18.9	19.2	19.2
Aug. 10	24.4	25.0	25.0	25.0					

Temperature fluctuations at stations established in Milford Harbor were of considerable magnitude (see table 5). This, of course, is easily understood if it is remembered that at low-water stages, when the temperature was usually recorded, the shallow layer of water in the harbor was quickly affected by the prevailing air temperature. As a rule, however, with the exception of dark, cold days, these temperatures represent the daily maximum. The daily minimum temperatures usually coincided with high-water stages. The data secured with the recording thermometer show that in Milford Harbor the daily range of water temperature in summer may vary from 0.5 to 12.5° C., depending upon the stage of tide and weather conditions.

SALINITY

During the summer months the salinity of Long Island Sound varies from 25 to 26 parts per mille at its western end, near Throgs Neck, to 31 or 32 parts per mille at its

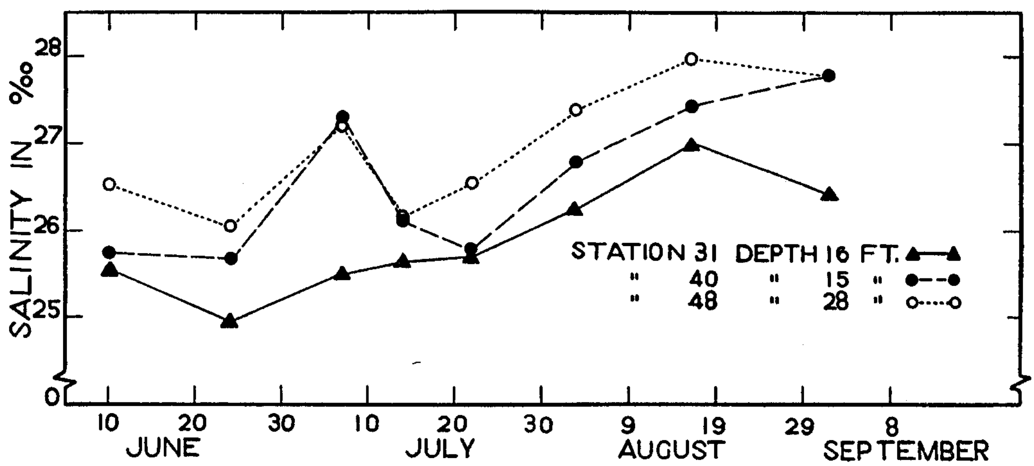

FIGURE 6.—Bottom-water salinity, in parts per mille, recorded at stations 31, 40, and 48 from June 10 to September 1, 1937.

extreme eastern portion, near Fishers Island. The salinity increases gradually from the western to the eastern end of the Sound (see fig. 1). As compared with the shore area, the middle part of the Sound contains water of somewhat higher salinity. However, such differences rarely exceed 1 or 2 parts per mille.

In the mouths of creeks and rivers entering the Sound the salinity of the water undergoes considerable fluctuation, depending upon the stage of tide and the quantity of fresh water brought down by the rivers. In Milford Harbor, for example, the salinity after heavy rains may be as low as 1 part per mille—June 19, 1936—whereas, at other times a salinity of 25–27 parts per mille prevails during high-water stages.

For observations on general salinity changes occurring in the water of the area extending from the Saugatuck River to Thimble Islands, stations 31, 40, and 48 were chosen. These stations represented the two opposite ends and the central part of the area under observation (see fig. 3). Samples were collected every week during the peak of the setting season, and every second week at other times. At all three stations the salinity showed a general increase as the season progressed (see fig. 6). The salinity at any two stations never differed from each other by more than 2 parts per mille. As could be expected, the most westerly station (station 31) showed a somewhat lower salinity than the other two, especially the easterly station. In general, however, the bottom-water salinity of the entire area under investigation was quite uniform throughout the summer months, showing neither great fluctuations at any one of the stations nor significant differences between the stations.

At the two series of stations established for observations on oyster setting, samples for salinity determination were collected at weekly intervals. For the Stratford Point series, samples were collected at stations 3, 5, and 8, established at depths of 10, 30, and 60 feet, respectively. Off Welchs Point the samples were taken at stations 13, 14, and 16, located at depths of 10, 20, and 40 feet. By following this method comprehensive data were obtained on the distribution and changes of bottom-water salinity at shallow, middle-depth and deep-water stations of both areas.

In both areas the salinity increased slowly throughout the summer (see tables 6 and 7). During the period of observation considerable fluctuation was noted in the Stratford Point area, especially at the shallow station 3 (see table 6). Between July 8 and July 15 the salinity at station 3 dropped from 26.64 to 22.41 parts per mille. A week later, however, it was again near 26.00 parts per mille. A small decrease amounting to about 1.5 parts per mille was noticed at the same time at a 60-foot depth where station 8 was located. The drop in salinity, especially of such a magnitude as noted at station 3, was due to a large quantity of fresh water brought down by the Housatonic River after a storm during which 1.5 inches of rain fell within 24 hours prior to collection of the sample. Another perceptible drop noticed at station 3 on August 12 was also due to an increased river discharge caused by a heavy rainfall. At all other times the salinity at the three stations remained comparatively uniform. This is especially evident in the case of the two deeper stations, 5 and 8. Thus, with the exception of immediate after-rain periods, the difference in salinity of the water at the three stations off Stratford Point was rather small, usually less than 1 part per mille.

At Welchs Point the salinity of the three chosen stations was remarkably constant throughout the season (see table 7). As a rule the difference between the shallowest and deepest stations lay within 0.5 part per mille, or often less. During the entire period of observation no considerable fluctuations were noted at any of the stations. Such uniformity in the salinity at the stations of Welchs Point is due to the fact that there is no large river entering the Sound in that vicinity. Therefore, conditions of this area differ somewhat from those of Stratford Point, where large quantities of fresh water are brought down by the Housatonic River.

TABLE 6.—*Bottom-water salinity, in parts per mille, recorded at weekly intervals at 3 stations of Stratford Point series during the period from July 2 to Sept. 30, 1937*

Date	Station 3	Station 5	Station 8	Date	Station 3	Station 5	Station 8
	Depth 10 ft.	*Depth 30 ft.*	*Depth 60 ft.*		*Depth 10 ft.*	*Depth 30 ft.*	*Depth 60 ft.*
July 2	26.29	26.67	27.12	Aug. 19	27.09	27.63	27.97
July 8	26.64	25.79	27.07	Aug. 26	27.54	27.61	27.81
July 15	22.41	26.18	25.79				
July 22	25.90	26.49	27.09	Sept. 2	27.43	27.09	28.13
July 29	26.60	26.74	27.56	Sept. 9	27.77	27.57	28.28
				Sept. 16	27.54	27.81	28.46
Aug. 5	27.12	27.47	27.70	Sept. 23	27.56	27.57	28.40
Aug. 12	25.95	27.61	27.90	Sept. 30	27.77	27.54	28.04

TABLE 7.—*Bottom-water salinity, in parts per mille, recorded at weekly intervals at 3 stations of Welchs Point series during the period from July 3 to Oct. 1, 1937*

Date	Station 13	Station 14	Station 16
	Depth 10 ft.	*Depth 20 ft.*	*Depth 40 ft.*
July 3	26.73	26.56	26.58
July 9	26.58	26.58	26.73
July 16	25.73	26.09	26.73
July 23	26.15	26.35	26.49
July 30	26.65	26.74	26.82
Aug. 3	27.29	27.38	27.41
Aug. 10	27.52	27.45	27.90
Aug. 17	27.75	27.77	28.01
Aug. 24	27.32	27.30	27.52
Sept. 3	27.54	27.75	28.06
Sept. 10	28.12	28.19	28.15
Sept. 17	27.68	27.94	28.13
Sept. 24	27.41	27.43	27.85
Oct. 1	27.56	27.90	28.08

HYDROGEN-ION CONCENTRATION

Observations on the hydrogen-ion concentration in Milford Harbor and Long Island Sound have been carried on since the summer of 1932. Because Milford Harbor contains a mixture of fresh water discharged by the Wepawaug River and brackish water of the Sound, the range of pH value fluctuates considerably, depending upon the stage of tide and the amount of river discharge. At high-water stages the pH of bottom-water ranges from 8.0 to 8.3. As a rule the pH value is lowest at low-water stages, when a pH as low as 7.1 may be recorded after heavy rains.

In Long Island Sound the changes of pH value of bottom-water were observed for a period of 2 years at 3 stations located near Charles Island at depths of 12, 23, and 45 feet. These observations were made at regular intervals throughout the year. During the last 6 years numerous additional observations in various other areas of the Sound were also made by the senior author. These observations indicate that the pH of bottom-water of the Sound, at a depth of 10 feet or more, is very uniform—ranging from 8.0 to 8.3. It shows virtually no fluctuation during the tidal cycle. There is no correlation between the time of the year and the increase or decrease of pH value. A possible exception to this rule may be found at the mouths of large rivers entering the Sound.

BIOLOGICAL OBSERVATIONS

GONAD DEVELOPMENT

For information on gonad development and spawning of oysters, a collection of samples was made at regular intervals from stations 40 and 48, and stations 23 and 24. The first two stations, located in Long Island Sound proper (see fig. 3), supplied representative samples of the population living at depths of 15 and 30 feet, respectively. The two other stations, 23 and 24 (see fig. 2), furnished oysters living in shallow, warmer water. The object of collecting specimens from different localities was to determine the rate of gonad development and the beginning, extent, and end of spawning activities of the oyster population in different parts of Long Island Sound. In addition to histological study, macroscopic examination of gonads and their thickness was made at frequent intervals during prespawning and spawning seasons on the oysters collected from the 19 seed-producing stations (31–49). For this the oyster body was cut transversely along a line extending through the stomach on a level with the lower edge of the palps. The thickness of gonad layer was then measured with a caliper. From 6 to 10 oysters were thus measured at each station and the average thickness of the gonad layer calculated. The results of these measurements are given in table 8.

TABLE 8.—*Average thickness of gonad layer of oysters collected at 19 sampling stations of Long Island Sound from June 10 to Aug. 17, 1937. Each sample was composed of 6 or more oysters*

Station number	Depth in feet	Average size of oysters, cm.	Average thickness of gonad layer in centimeters						
			June 10-11	June 24-25	July 7-8	July 14-15	July 22-23	Aug. 3-4	Aug. 16-17
31	16	7.0	0.45	0.4	0.2	0.1	0.25	0.2	0.0
32	19	13.0	.2	.25	.25	.15	.15	.25	.2
33	19	11.0	.6	.3	.25	.15	.1	.25	.05
34	15	11.0	----------	.3	.3	.2	.4	.2	0
35	10	11.5	.2	.45	.3	.1	.15	.15	.05
36	20	12.0	.1	.4	.3	.15	.25	.3	.1
37	25	11.3	.2	.3	.2	.1	.1	.2	.1
38	20	11.5	.1	.3	.35	.1	.2	.2	0
39	15	12.5	.25	.35	.3	.05	.2	.1	0
40	15	13.0	.3	.45	.2	.15	.1	.1	0
41	15	11.5	.2	.45	.3	.1	.3	.1	0
42	18	11.6	.2	.45	.4	.1	.1	.1	0
43	20	11.5	.4	.9	.2	.05	.1	.1	.05
44	10	8.5	.4	.5	.25	.1	.1	.25	.05
45	19	11.0	.4	.35	.25	.1	.3	.3	.05
46	15	11.5	.4	.5	.2	.1	.05	0	0
47	32	11.5	.4	.4	.25	.1	.3	.2	.05
48	30	12.0	.2	.4	.3	.1	.35	.1	.05
49	11	10.5	.2	.4	.15	.05	.2	.15	.2
Average	----------	----------	.29	.41	.26	.11	.19	.17	.05

Early in May most of the animals of both sexes possessed undeveloped gonads resembling the winter condition. In the middle of May, with the water temperature approaching 10° C., growth and ramification of gonads commenced. Ovocytes began to increase in size. Apparently ripe spermatozoa could be found in some males. From the middle of May on, gametogenesis proceeded at a very rapid rate. Simultaneously, the follicles began to proliferate and expand in all directions, largely toward the liver. At the beginning of June the development of gonads in the majority of oysters was very rapid. The gonad follicles ramified so fast that in a few days much of the space between the mantle and the liver was occupied by the gonad tissue. The thickness of the gonad layer in some instances already reached 2 mm. On the other hand, some oysters lagged behind in development and individuals with very unripe gonads were occasionally found. At that time of the year no perceptible difference in the degree of ripeness could be noticed among the oysters of different stations. Around June 10 a still further development of gonads was noted, especially in oysters of shallow waters.

Toward the end of June 1937, oysters at all stations reached a fully ripe stage. In males, ripe spermatozoa occupied the largest part of the follicles and streamed into the genital canals. In females, the gonad layer occupied all the available space between the mantle and the liver. The ova were fully grown and ripe.

SPAWNING

The first general spawning of the oyster population of Long Island Sound and Milford Harbor occurred on and about July 3. The date of the first spawning was ascertained by histological examination of gonads, by the presence and age of oyster larvae, by macroscopic examination of oysters collected from each station, and by establishing the date of the beginning of setting at all stations.

Plankton samples collected on July 7 and 8 at stations 31, 40, 44, and 49 contained oyster larvae of different ages; the oldest being 4 or 5 days old. This indicated that the first spawning occurred on July 3. Macroscopic examination of samples collected on July 7 and 8 at stations 31–49 (see fig. 3) also showed that in almost every instance the gonads were partly discharged. Dark liver tissue could be seen through the thinned layer of gonad, the average thickness of which was considerably smaller than that found at the previous examination (see table 8). In some cases, for example at station 43, it decreased from 0.9 to 0.2 cm.

Assuming that in Connecticut waters the free-swimming period of oyster larvae extends for about 14 days, the setting of larvae hatched from the eggs released on July 3 should occur about July 17. As will be shown later, our observations on the setting of larvae fully confirms this contention.

Many oysters collected from the stations in Milford Harbor on July 7 were also found partially spawned. However, a considerable number of individuals were found with ripe but undischarged gonads. In no case was an animal with completely discharged gonads found at any station.

By the middle of July the majority of oysters at stations of moderate depths (15–25 feet) were found to be half, or more than half, spawned. In most instances the thickness of the gonad layer at the level of the stomach decreased to 0.1 cm. or even less (see table 8). In females, contraction of the follicles from which part of the eggs was discharged was very evident. In males, the lumina of many follicles were free of spermatozoa and the follicles themselves were contracting. The cells of connective tissue invaded the spaces between the contracting follicles, thus separating them from each other. At deep-water stations, oysters could be found in various stages ranging from virtually unspawned to almost completely spawned. The majority of animals, however, retained considerably more spawn than the population of stations located at moderate depths. Even so, individual differences among the oysters at each station were quite pronounced in that the quantities of spawn left varied considerably in different individuals. This may help to explain the fact that the average thickness of gonad layer of oysters collected on July 22 and 23 was somewhat greater than that observed in the samples collected on July 14 and 15. It is also probable that between these two dates a further accumulation of gonad material occurred in some individuals, especially in those of the deep-water stations. At the shallow-water stations of Milford Harbor the largest group of the oyster population was found to be with approximately half of the spawn already discharged. Peculiarly enough, some individuals with full, undischarged gonads were still found.

Late in July many oysters in medium-deep water were completing their spawning. Early in August many completely spawned animals of both sexes were already found. By August 15 the spawning activities of almost the entire population were finished. In both sexes resorption of gonads was in advanced stages.

At the deep stations the bulk of spawning material was discharged somewhat later than in the shallow places. On August 3 the majority of oysters of deep water still retained the largest part of their spawn. Four days later, however, much of this spawn was released. On August 17 many completely spawned oysters were found. At that date animals were found in all stages, ranging from partially spawned to a stage resembling that of the winter condition. Early in September the spawning of deep-water oysters was completed.

The oysters of Milford Harbor found late in July still contained large quantities of spawn. While a few animals were already in advanced spawning stages, the majority had less than half of their sexual products discharged, and many were found with gonads virtually undischarged. A few days later, however, during the first week of August, the oysters discharged the bulk of their spawn. Towards the middle of the month the majority of animals had completed their spawning.

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OCCURRENCE OF LARVAE

During the spawning season of 1937, numerous observations on the occurrence of larvae in plankton samples were made by the authors. Additional information on this matter was supplied by Mr. J. B. Glancy, of the Blue Point Oyster Co., who also studied the occurrence and distribution of oyster larvae in Connecticut waters.

Examination of plankton samples for the presence of oyster larvae, made by the senior author at frequent intervals during the 5 summers preceding 1937, showed that, as a rule, oyster larvae were very few in numbers. Often none could be found. Most of the larvae recovered were in the straight hinge stage. Larvae of early or late umbo stage were found only as exceptions. In the summer of 1936 young larvae were more numerous than in the other 4 years.

In 1937 the first few larvae were found on July 7 and 8 in samples collected at stations 31, 33, 40, 44, and 48. The oldest larvae were 4 to 5 days old.

Larvae were absent in most of the samples collected between July 8 and July 27. The absence of larvae in plankton samples during that period is very significant because, according to the data of the first and heavy setting which occurred on July 16–20, a great number of larvae existed in the water at the time of collection of plankton samples. This observation shows that, as Galtsoff (1930) pointed out in his paper on the behavior of oyster larvae in Onset Bay, the small number of larvae, or even their absence in plankton samples, does not necessarily show the failure of oysters to spawn in the locality studied and cannot be regarded as indicative of an ensuing poor setting. Explanations for the absence of larvae in plankton samples collected in the localities where the larvae are actually present in great numbers at the time of collection have already been advanced by Prytherch (1929) and by Galtsoff (1930) and therefore do not require any discussion in this paper.

During July 27–30 straight-hinge larvae were very numerous in samples collected between Bridgeport and New Haven. In some samples, for example one taken on July 29 near station 41, as many as 12,000 straight-hinge and 40 umbo larvae were found per 100 gallons of water. After July 30 the larvae disappeared, and until Aug. 9 were almost entirely absent in plankton samples collected at many different points of the Sound. On Aug. 10 straight-hinge larvae again appeared in large numbers in the area of the Sound confined between Milford and New Haven Harbors. They ranged from 1,600 to 13,000 per 100 gallons of water. Samples collected on that day near stations 41, 43, 45, 47, and at a point located about 1 mile south of station 40 in water 30 feet deep, contained approximately 6,000, 1,600, 13,000, 3,600, and 4,500 larvae, respectively. None of these were of umbo stages. Two or three days later samples collected in the same vicinities and approximately at the same tidal stages contained few or no larvae. During the rest of the summer larvae were seldom found in plankton samples. The last larvae seen were in the samples collected on Sept. 2.

Attempts to study vertical distribution of larvae in the waters of Long Island Sound produced but meager results. On several occasions systematic collections of plankton samples at different depths and at different tidal stages were made. Regular plankton traps were used in these collections. Very few, or no larvae at all were found in the samples, and therefore no conclusions could be formed relative to the vertical distribution of larvae in the open waters of Long Island Sound.

SETTING

In 1937 systematic observations on setting of oysters were made at 19 stations. Of these, 4 were located in the shallow inshore areas of Milford Harbor and 15 in Long Island Sound proper (see fig. 2). Additional, although not very frequent, observations were made at 19 other stations (31–49) established throughout the oyster-producing areas of the Sound (see fig. 3).

As described in the section dealing with the methods employed in studying the setting of oysters, wire bags containing oyster shells were used as spat collectors. Each bag contained approximately 70 large oyster shells. It was established, by numerous tests, that a count performed on 10 shells taken at random from a bag collector gave quite an accurate idea of the number of spat per bag. Therefore, the microscopic examination was limited to 10 shells per bag. Only those spat found on the clean inside surfaces of oyster shells were counted. Such a method was employed because the uneven and rough outside surfaces of the shells made the accurate counting of minute spat on them too difficult, if not entirely impossible. Counts made on the inside surfaces of 10 shells were later converted to a standard bushel basis, assuming that there are approximately 435 oyster shells per bushel. The latter figure was ascertained by counting the number of shells in each of 10 bushel baskets and determining the average.

TABLE 9.—*Oyster set per 10 shells and per bushel of shells. Semiweekly examinations of Milford Harbor stations, July 13 to Aug. 6, 1937*

Date	Station 21 (depth 0 feet)		Station 22 (depth 0 feet)		Station 23 (depth 0 feet)		Station 24 (depth 0 feet)		Total for all stations	
	10 sh.	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*
July 13	0	0	0	0	0	0	0	0	0	0
July 16	3	131	0	0	7	305	0	0	10	436
July 20	38	1,653	629	27,362	137	5,960	338	14,703	1,142	49,678
July 23	10	435	303	13,181	13	566	30	1,305	356	15,487
July 27	11	479	215	9,353	23	1,001	61	2,654	310	13.487
July 30	5	218	5	218	3	131	6	261	19	828
Aug. 3	9	392	5	218	3	131	1	44	18	785
Aug. 6	0	0	0	0	0	0	0	0	0	0
Total	76	3,308	1,157	50,332	186	8,094	436	18,967	1,855	80,701

Observations on setting in Milford Harbor were begun on June 12, when the first set of collectors was placed at each station. In Long Island Sound the first collectors were placed at 9 stations off Stratford Point on July 2. A day later 6 stations were established at Welchs Point. Observations on setting at Harbor stations were carried until Sept. 30; at Welchs Point until Oct. 1; and at Stratford Point stations until Oct. 4.

In Milford Harbor the first setting was recorded on collectors placed in the water on July 13 and removed at noon on July 16 (see table 9). Probably the latter date was the very beginning of setting because the set was extremely light, and only 2 stations out of 4 had any set present. Collectors removed from the Harbor area 4 days later, on July 20, showed that a medium or heavy set occurred at each station. The spat examined were of different ages—from individuals just completing metamorphosis, to spat about 4 days old. Thus, July 16 and 17 should be considered as the beginning of the setting season in Milford Harbor in 1937.

Collectors brought in from Stratford Point stations on July 15, and from Welchs Point the next day, showed no oyster spat (see tables 10 and 11). Four days later collectors brought from the Sound stations contained large numbers of spat. The spat was recorded at all stations except 7 and 8. Again, as was the case with Milford Harbor stations, the spat were of different ages—from just attached to 3 days old, thus showing that the initial setting in Stratford Point and Welchs Point areas occurred about July 17. The setting was in progress at the time of removal of the bags from the beds. These observations indicate that in 1937 the beginning of the setting season in shallow waters of Milford Harbor and in Long Island Sound took place at approximately the same date, namely, on and about July 16–17.

TABLE 10.—*Oyster set per 10 shells and per bushel of shells. Semiweekly examinations of Stratford Point stations, July 15 to Oct. 4, 1937*

Date	Station 1 (depth 0 feet)		Station 2 (depth 5 feet)		Station 3 (depth 10 feet)		Station 4 (depth 20 feet)		Station 5 (depth 30 feet)	
	10 sh.	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*
July 15	0	0	0	0	0	0	0	0	0	0
July 19	97	4,220	78	3,413	222	9,657	102	4,437	25	1,088
July 22	27	1,175	21	914	12	522	50	2,175	20	870
July 26	7	305	14	609	32	1,392	44	1,914	19	827
July 29	3	131	8	348	5	218	9	392	7	305
Aug. 2	2	87	66	2,871	2	87	7	305	20	870
Aug. 5	0	0	0	0	1	44	1	44	0	0
Aug. 9	0	0	0	0	0	0	-----	-----	0	0
Aug. 12	0	0	0	0	0	0	-----	-----	0	0
Aug. 16	0	0	0	0	0	0	0	0	0	0
Aug. 19	0	0	0	0	0	0	0	0	0	0
Aug. 23	0	0	0	0	0	0	0	0	0	0
Aug. 26	0	0	0	0	0	0	0	0	0	0
Aug. 30	0	0	-----	-----	0	0	1	44	1	44
Sept. 2	0	0	0	0	0	0	0	0	0	0
Sept. 7	0	0	0	0	0	0	0	0	0	0
Sept. 9	0	0	0	0	0	0	0	0	-----	-----
Sept. 14	0	0	0	0	0	0	6	261	-----	-----
Sept. 16	0	0	0	0	0	0	0	0	-----	-----
Sept. 20	0	0	0	0	0	0	0	0	0	0
Sept. 23	0	0	0	0	0	0	1	44	0	0
Sept. 27	0	0	0	0	0	0	0	0	0	0
Sept. 30	0	0	0	0	0	0	0	0	0	0
Oct. 4	0	0	0	0	0	0	0	0	0	0
Total	136	5,918	187	8,155	274	11,920	221	9,616	92	4,004

Date	Station 6 (depth 40 feet)		Station 7 (depth 50 feet)		Station 8 (depth 60 feet)		Station 9 (depth 70 feet)		Total for all stations	
	10 sh.	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*
July 15	0	0	0	0	0	0	0	0	0	0
July 19	10	435	0	0	0	0	1	44	535	23,294
July 22	3	131	2	87	0	0	1	44	136	5,918
July 26	-----	-----	2	87	0	0	0	0	118	5,134
July 29	3	131	73	3,176	0	0	2	87	110	4,788
Aug. 2	2	87	30	1,305	0	0	0	0	129	5,612
Aug. 5	0	0	0	0	0	0	0	0	2	88
Aug. 9	0	0	0	0	0	0	0	0	0	0
Aug. 12	0	0	0	0	0	0	0	0	0	0
Aug. 16	1	44	0	0	0	0	0	0	1	44
Aug. 19	0	0	0	0	0	0	0	0	0	0
Aug. 23	0	0	0	0	0	0	0	0	0	0
Aug. 26	0	0	0	0	0	0	0	0	0	0
Aug. 30	0	0	0	0	0	0	0	0	2	88
Sept. 2	0	0	0	0	0	0	0	0	0	0
Sept. 7	-----	-----	0	0	0	0	-----	-----	0	0
Sept. 9	0	0	0	0	0	0	0	0	0	0
Sept. 14	0	0	1	44	0	0	0	0	7	305
Sept. 16	0	0	0	0	0	0	0	0	0	0
Sept. 20	0	0	0	0	0	0	0	0	0	0
Sept. 23	0	0	0	0	0	0	0	0	1	44
Sept. 27	0	0	0	0	-----	-----	0	0	0	0
Sept. 30	0	0	0	0	0	0	0	0	0	0
Oct. 4	0	0	0	0	0	0	0	0	0	0
Total	19	828	108	4,699	0	0	4	175	1,041	45,315

TABLE 11.—*Oyster set per 10 shells and per bushel of shells. Semiweekly examinations of Welchs Point stations, July 16 to Oct. 1, 1937*

Date	Station 11 (depth 0 feet)		Station 12 (depth 5 feet)		Station 13 (depth 10 feet)		Station 14 (depth 20 feet)		Station 15 (depth 30 feet)		Station 16 (depth 40 feet)		Total for all stations	
	10 sh.	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*	*10 sh.*	*1 bu.*
July 16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July 20	92	4,002	181	7,874	63	2,741	118	5,133	29	1,262	41	1,784	524	22,796
July 23	109	4,742	75	3,263	32	1,392	85	3,698	12	522	3	131	316	13,748
July 27	7	305	6	261	40	1,740	7	305	3	131	14	609	77	3,351
July 30	6	261	0	0	1	44	-	-	1	44	17	740	25	1,089
Aug. 3	0	0	0	0	0	0	3	131	1	44	3	131	7	306
Aug. 6	0	0	-	-	0	0	0	0	0	0	0	0	0	0
Aug. 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug. 13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug. 17	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug. 20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug. 24	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug. 27	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug. 31	0	0	0	0	0	0	0	0	0	0	1	44	1	44
Sept. 3	0	0	0	0	0	0	1	44	1	44	0	0	2	88
Sept. 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sept. 10	0	0	0	0	0	0	0	0	0	0	4	174	4	174
Sept. 14	0	0	0	0	-	-	0	0	0	0	3	131	3	131
Sept. 17	-	-	0	0	-	-	0	0	0	0	1	44	1	44
Sept. 21	-	-	0	0	0	0	0	0	0	0	-	-	0	0
Sept. 24	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sept. 28	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oct. 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	214	9,310	262	11,398	136	5,917	214	9,311	47	2,047	87	3,788	960	41,771

The duration of the setting season in Milford Harbor was considerably shorter than in Long Island Sound (see tables 9, 10, and 11). In the Harbor it extended from July 16 until Aug. 3. In the Sound setting began on about the same date and ended about Sept. 23. These observations do not agree with those made by Prytherch (1929), who states that setting in Milford Harbor occurs from July 20 to Sept. 1, or, in other words, lasted almost 1 month longer than in 1937. Apparently the duration of the setting period in Milford Harbor is different in different years.

Studies of the intensity of setting in 1937 showed that, although the season extended for a period of more than 2 months, the peak of setting occurred at most of the stations at the very beginning of the season or soon after. In the Milford area the maximum setting occurred between July 16 and 20 (see table 9), or at the very beginning of the setting season. From that date until the first few days of August the intensity of setting decreased gradually. The setting in the Harbor ceased entirely on Aug. 3.

TABLE 12.—*Average daily set per 10 shells and per bushel of shells for all stations of Milford Harbor, July 13 to Aug. 6, 1937*

Date exposed	Days exposed	Set: Total per 10 shells	Set: Daily average per 10 shells	Set: Daily average per bushel of shells	Date exposed	Days exposed	Set: Total per 10 shells	Set: Daily average per 10 shells	Set: Daily average per bushel of shells
July 13–16	3	10	3.3	145	July 27–30	3	19	6.7	290
July 16–20	4	1,142	285.5	12,441	July 30–Aug. 3	4	18	5.0	218
July 20–23	3	356	119.0	5,177	Aug. 3–6	3	0	0.0	0
July 23–27	4	310	78.0	3,393					

Observations on Stratford Point stations showed that at all depths ranging from 0 to 40 feet, inclusive, the heaviest setting of the summer occurred within a few days after the beginning of setting (see table 10). At stations 7 and 9, located in 50 and 70 feet of water, respectively, the heaviest setting of the season took place about 10 days later than at shallower stations. There was no setting at station 8 during the entire season. The data secured from observations on Welchs Point stations fully agree with those of the Stratford Point series in the respect that the heaviest setting of the season at all depths ranging from mean low-water mark to 40 feet occurred at the very beginning of the setting season (see table 11).

At the Harbor stations there was but one period of setting. It extended from about July 16 until Aug. 3 (see table 12). At the Sound stations the first and heaviest setting was registered during the same period as in Milford Harbor (see tables 13 and 14). After the initial heavy setting at Sound stations its density sharply declined, and the setting ceased early in August. From then until the end of August, collectors brought in from the Sound stations showed no set (see tables 10 and 11). The only exception was recorded in the case of Stratford Point station 6, where a very light setting occurred on Aug. 12–16. Later in August, however, light setting was recorded at stations 4 and 5 of Stratford area and station 16 off Welchs Point. During Sept. 1–3 light and scattered set took place at stations 14 and 15. Between Sept. 7 and 14 light setting occurred at stations 3, 4, and 7 at Stratford Point and station 16 at Welchs Point. In the latter case setting continued from Sept. 7 to Sept. 17. As a rule, studies of loose oyster shells collected at the Sound stations corroborated the observations made on wire bag collectors.

TABLE 13.—*Average daily set per 10 shells and per bushel of shells for all stations of Stratford Point from July 15 to Sept. 27, 1937*

Date exposed	Days exposed	Set: Total per 10 shells	Set: Daily average per 10 shells	Set: Daily average per bushel of shells	Date exposed	Days exposed	Set: Total per 10 shells	Set: Daily average per 10 shells	Set: Daily average per bushel of shells
July 15–19	4	535	134.0	5,829	Aug. 23–26	3	0	.0	0
July 19–22	3	136	44.0	1,940	Aug. 26–30	4	2	.5	22
July 22–26	4	118	29.5	1,305	Aug. 30–Sept. 2	3	0	.0	0
July 26–29	3	110	37.0	1,610	Sept. 2– 7	5	0	.0	0
July 29–Aug. 2	4	129	32.3	1,403	Sept. 7– 9	2	1	.5	22
Aug. 2– 5	3	2	.7	29	Sept. 9–14	5	7	1.4	61
Aug. 5– 9	4	0	.0	0	Sept. 14–16	2	0	.0	0
Aug. 9–12	3	0	.0	0	Sept. 16–20	4	0	.0	0
Aug. 12–16	4	1	.3	11	Sept. 20–23	3	1	.3	14
Aug. 16–19	3	0	.0	0	Sept. 23–27	4	0	.0	0
Aug. 19–23	4	0	.0	0					

Observations of 1937 on the intensity of setting in time differ from those of Prytherch (1929), who states that in Connecticut waters the first set occuring is extremely light and is followed by a heavy and final set about 8 or 10 days later. He further states that although the setting has been observed to occur from July 20 to the beginning of September, it is generally most intensive during August; the peak occurring about the middle of the month. As can be seen from tables 12, 13, and 14, in 1937 the first setting in Milford Harbor, as well as in the Sound, was heavy rather than light. The peak of setting in 1937 occurred approximately 1 month ahead of the time found by Prytherch.

The setting of 1937 was general in character, occurring throughout almost the entire oyster-producing section of Long Island Sound. Examination of samples collected from 19 stations (31–49) established in different parts of the Sound showed that the setting took place at all but two stations (see table 15). The intensity of setting at different stations varied from 174 to 15,225 spat per bushel. Considering the fact that samples were collected at the beginning of the setting season, and that counts of spat referred to one side of shells only, the actual number of spat that set at each station during the entire season was much heavier than is shown in table 15. Therefore, the setting of oysters in 1937 can be regarded as medium or even heavy.

TABLE 14.—*Average daily set per 10 shells and per bushel of shells for all stations of Welchs Point from July 16 to Sept. 21, 1937*

Date exposed	Days exposed	Set: Total per 10 shells	Set: Daily average per 10 shells	Set: Daily average per bushel of shells	Date exposed	Days exposed	Set: Total per 10 shells	Set: Daily average per 10 shells	Set: Daily average per bushel of shells
July 16–20	4	524	131.0	5,699	Aug. 20–24	4	0	.0	0
July 20–23	3	316	105.0	4,568	Aug. 24–27	3	0	.0	0
July 23–27	4	77	19.0	827	Aug. 27–31	4	1	.3	11
July 27–30	3	25	8.0	348	Aug. 31–Aug. 3	3	2	.7	29
July 30–Aug. 3	4	7	2.0	87	Sept. 3–7	4	0	.0	0
Aug. 3–6	3	0	.0	0	Sept. 7–10	3	4	1.3	58
Aug. 6–10	4	0	.0	0	Sept. 10–14	4	3	.8	33
Aug. 10–13	3	0	.0	0	Sept. 14–17	3	1	.3	14
Aug. 13–17	4	0	.0	0	Sept. 17–21	4	0	.0	0
Aug. 17–20	3	0	.0	0					

TABLE 15.—*Number of oyster spat per 10 shells and per bushel of shells at each of 19 sampling stations on Long Island Sound, July 22–23, 1937. Spat on inside surfaces of shells only were counted*

Station number	Number of spat: Per 10 shells	Number of spat: Per bushel	Station number	Number of spat: Per 10 shells	Number of spat: Per bushel
31	50	2,175	41	4	174
32	300	13,050	42	20	870
33	62	2,697	43	40	1,740
34	350	15,225	44	119	5,177
35	4	174	45	271	11,789
36	10	435	46	240	10,440
37	35	1,523	47	222	9,657
38	23	1,001	48	110	4,785
39	0	0	49	27	1,175
40	0	0			

Placing collectors at depths ranging from mean low-water mark to 70 feet presented an opportunity for studying the intensity of setting in relation to depth. Figure 7 gives the distribution of oyster set in relation to depth at Stratford Point and Welchs Point stations for the entire season of 1937. At Stratford Point the heaviest setting occurred at a depth of 10 feet (station 3). The season's total for that station was 11,920 spat per bushel of shells. The intensity of setting gradually increased from the low-water mark to 10 feet, and then decreased. At a 50-foot depth, however, a set of 4,699 spat per bushel of shells was recorded, thus indicating that even at such a depth a setting of commercial magnitude may occur. No set was found at a 60-foot depth, whereas, at the deepest station, established in 70 feet of water, 175 spat per bushel of shells were counted during the season.

At Welchs Point the heaviest set of 11,398 spat per bushel of shells occurred at a 5-foot depth. It was closely approached in numbers by the sets at mean low-water mark and 20 feet, where over 9,000 spat per season per bushel of shells were recorded.

Similarly, as in the case of the Stratford Point series, the intensity of setting declined very sharply as soon as the depths of 30 and 40 feet were reached, where 2,047 and 3,788 spat per bushel were recorded during the season.

The observations on the intensity of setting in relation to depth indicate that in Long Island Sound the area of heavy setting extended from mean low-water mark to a 20-foot depth. At depths ranging from 30 to 50 feet, inclusive, setting was not

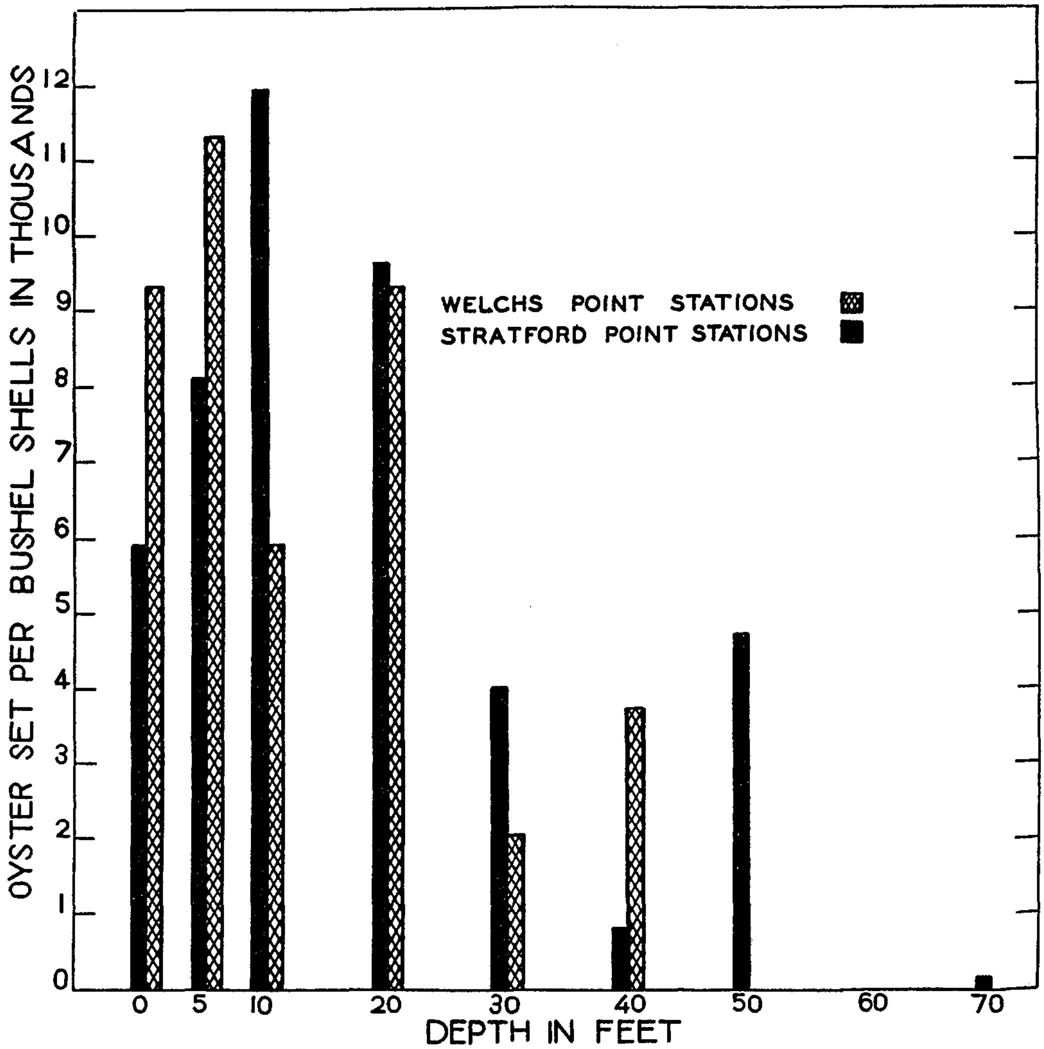

FIGURE 7.—Distribution of oyster spat in relation to depth at Stratford Point and Welchs Point stations for the entire season of 1937.

as heavy as in more shallow water, but still could have been of commercial magnitude, provided the rate of survival of spat was high.

To determine the depth at which oyster larvae set most readily, a series of observations was made using vertical concrete collectors described in the chapter dealing with methods. This type of collector was found preferable to a long wire basket filled with oyster shells and suspended in the water, because, in the latter case, the impossibility of measuring the exact area of individual shells rendered the results considerably less accurate. Unfortunately, collectors set in Long Island Sound soon became covered with a very dense growth of barnacles, and thus became unfit for the setting of oysters. On July 17 in Milford Harbor, where the mean range of tide is 6.6 feet, 3 vertical

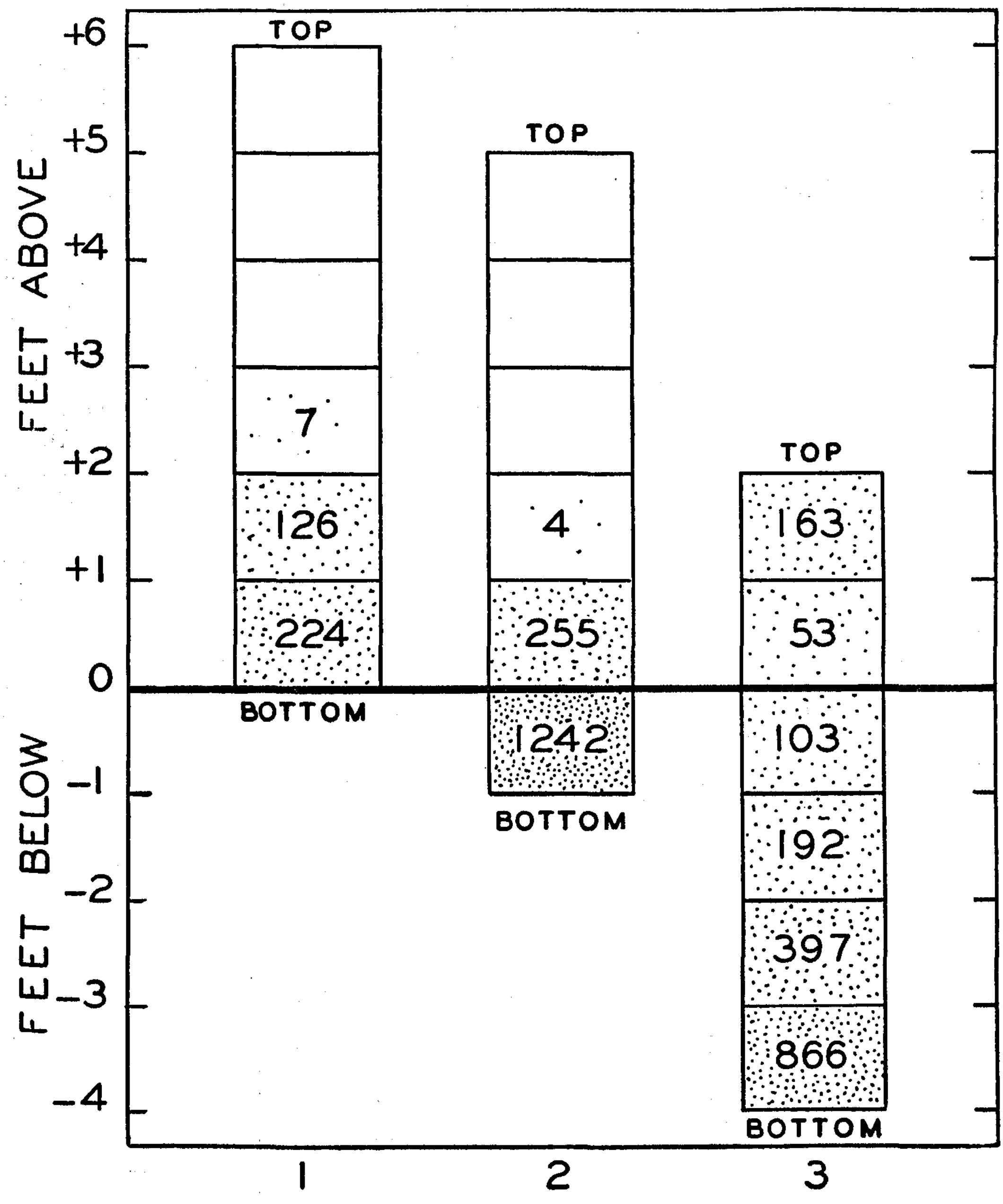

FIGURE 8.—Vertical distribution of oyster set in relation to mean low-water mark on three 6-foot concrete collectors in Milford Harbor from July 17 to Aug. 25, 1937.

collectors, each 6 feet long, were set in perpendicular positions. Collector No. 1 (see fig. 8), installed at station 23, was set at such a depth that its entire length was above low-water mark. Collector No. 2 extended 1 foot below low-water mark and 5 feet above. Collector No. 3 covered the zone from 4 feet below low-water mark to 2 feet above. The combination of all three collectors covered the zone from −4 to +6 in relation to low-water mark, which, in figure 8, is shown as 0.

On Aug. 25 all three collectors were brought in for examination. Each collector was divided into six 1-foot sections, each having a total area of approximately 216 square inches. The spat in every section was counted and recorded (see fig. 8 and table 16). Regardless of the depth at which a collector was installed, the heaviest setting occurred near the bottom. Usually the intensity of setting diminshed with an increasing distance from the bottom. In the zone extending from −4 feet to mean low-water mark good setting occurred, although the decrease in number from the bottom up to low-water mark was very evident. In the zone from mean low-water to +2 feet a good set was observed on 2 collectors. In the case of collector No. 3 such set took place 4–6 feet above the bottom. In no case did setting occur in the zone higher than 26 inches above low-water mark.

Observations of 1937 on vertical distribution of oyster set in Milford Harbor fully agree with those of Prytherch (1929), who found that in local waters setting occurs in the zone extending from the bottom to a point 2 feet above low-water mark. Above this level to a high-water mark, a distance of about 4–5 feet, no setting took place. The lack of set in the zones higher than 2 feet above mean low-water mark was shown by Prytherch to be due to the fact that in Milford Harbor the larvae begin to attach at low slack water and continue to do so during the first 2 hours of flood tide until the current develops a velocity of one-third foot per second. With further increase in the current's velocity the setting of larvae is discontinued.

Studies on the vertical distribution of set in Milford Harbor provide the necessary knowledge for more efficient methods of catching oyster spat. It may be suggested that the cultch should not be planted on the flats higher than 2 feet above the mean low-water mark level and that the entire area of the bottom below +2 feet mark should prove suitable for catching spat. The area of the flats 1 foot below low-water mark should be most extensively utilized, because at this level oyster larvae set most abundantly.

TABLE 16.—*Vertical distribution of oyster set in relation to mean low-water mark on three 6-foot concrete collectors in Milford Harbor between July 17 and Aug. 25, 1937. Distances above* (roman type) *and below* (*italic*) *mean low-water mark* (*0*) *are shown in feet*

Tidal level	Number of oyster set		
	Collector 1	Collector 2	Collector 3
6–5	0	----------	----------
5–4	0	0	----------
4–3	0	0	----------
3–2	7	0	----------
2–1	126	4	163
1–0	224	255	53
0–*1*	----------	1, 242	103
1–2	----------	----------	192
2–3	----------	----------	397
3–4	----------	----------	866

SURVIVAL OF OYSTER SPAT

The rate of survival of newly set oysters is of paramount importance to the oyster industry. If mortality is high, an oyster bed having a very heavy original set early in the summer may be entirely devoid of spat 2 months later. Occasionally, a light set showing a high rate of survival will, in the end, show more living animals than a heavy set suffering a high mortality.

The rate of survival of oyster set living under natural conditions in Long Island Sound has never been studied experimentally. To obtain such information several experiments for ascertaining the mortality rate among oyster spat during the first few weeks of their existence were conducted in 1937. Wire bag collectors, of the type generally used in this work, were placed at stations 13, 14, and 16 at Welchs Point on July 20. Two days later, on July 22, collectors of the same type were placed at stations 3, 4, and 6 of the Stratford Point series. As far as depth was concerned, stations 3 and 4 of Stratford Point, located at 10 and 20 feet, respectively, corresponded to stations 13 and 14 of Welchs Point. Stations 6 and 16 were located at 40-foot depths. To differentiate between bags placed in the water for short periods and those left in place for long periods, the latter will hereinafter be referred to in this paper as seasonal collectors.

TABLE 17.—*Survival rate of oyster spat on the seasonal collectors placed at 2 stations at Stratford Point, and 3 stations at Welchs Point during the summer of 1937*

Station number	Depth in feet	Total set per season		Survival		Percent survival
		Per 10 shells	Per bushel of shells	Per 10 shells	Per bushel of shells	
Stratford Point:						
3	10	40	1,741	0	0	0
4	20	62	2,699	1.64	72	2.65
Welchs Point:						
13	10	73	3,176	0.33	13	0.45
14	20	96	4,178	13.39	581	13.95
16	40	42	1,829	4.42	190	10.52

The figures presented above may be criticized because of the assumption that shells of the seasonal, and those of the regular collectors possessed at all times the same efficiency as spat catchers. It may be maintained that shells of the seasonal bags remaining on the bottom for a period of about 6 weeks would lose much of their value. Under ordinary conditions such a criticism would be fully justified, because shells remaining in the water for a long time become covered with organic growth and silt. Such fouling may reduce their efficiency one-third in 9 days (Hopkins, 1936). Fortunately for the present study, the greatest bulk of set occurred within a few days after the seasonal collectors were placed in the water. Therefore, at the time of setting the shells in the seasonal bags were clean and their efficiency as spat collectors was approximately the same as that of regular collectors.

Bags from stations 3 and 4 were brought in for examination on Sept. 9, and from stations 13, 14, and 16 the next day. The bag from station 6 was lost. Thus, bags recovered from the Stratford Point area were in the water 52 days, and from Welchs Point 51 days. The number of surviving spat in each collector was found by counting living spat on the clean sides of all shells. The results were later recalculated as per 10 shells and per bushel of shells. By comparing these numbers with the total number of spat recorded from the corresponding stations during the same period of time, the survival could be determined. The figures giving the total set at any station for a given period of time could easily be computed by adding together the numbers of spat counted on the regular collecting bags removed from the water at semiweekly intervals (see tables 10 and 11). The total set for each seasonal collector was assumed to be equal to the total number of spat recorded on all regular collectors of the same station during the period of exposure of the seasonal collector.

The percent of survival at Stratford Point stations 3 and 4 was considerably smaller than at the two corresponding stations, 13 and 14, at Welchs Point (see table 17 and fig. 9). At station 3 the entire set perished, whereas, at station 13, 0.45 percent, or 13 spat per bushel of shells, were alive at the time of examination. Collectors removed from a 20-foot depth gave a survival value of 2.65 percent, or 72 spat per bushel for Stratford Point stations and 13.95 percent, or 581 spat per bushel for corresponding stations of Welchs Point (see fig. 10). The collector brought in from Welchs Point station 16 showed that 10.52 percent or 190 spat per bushel survived.

Although the data obtained in 1937 are not very extensive, the results of the observations indicate a very high mortality among the early spat. As can be seen

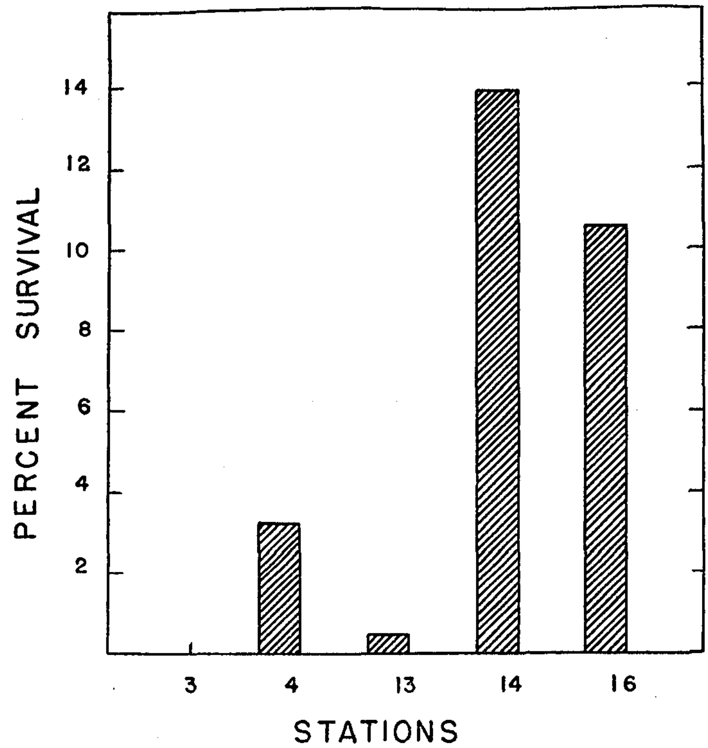

FIGURE 9.—Survival of oyster set on seasonal collectors at Stratford Point and Welchs Point stations.

by referring to table 17 and figure 10, the total set at each of the 5 stations was rather heavy, ranging from 1,741 to 4,178 spat per bushel. Local oystermen agree that 4 spat per shell counted late in September constitute a good commercial set. The set recorded on seasonal collectors, if alive, should have ranged from about 4 spat per shell at station 3 to about 10 spat per shell at station 14. Instead, the set proved to be either a complete failure (station 3) or too light to be of commercial importance.

The question naturally arises as to what factors are responsible for such a high mortality among young spat. Indirect observations for a number of years on the behavior of young spat strongly point to the conclusion that these animals can survive under very adverse physical conditions. It is common knowledge that oysters set on the flats above low-water mark are constantly subjected to abrupt changes of temperature, salinity, hydrogen-ion concentration, and other factors. Oysters on the mud flats may become exposed for hours to the drying rays of the sun, and to air temperatures over 100° F. Often they are left for hours in the tidal pools where

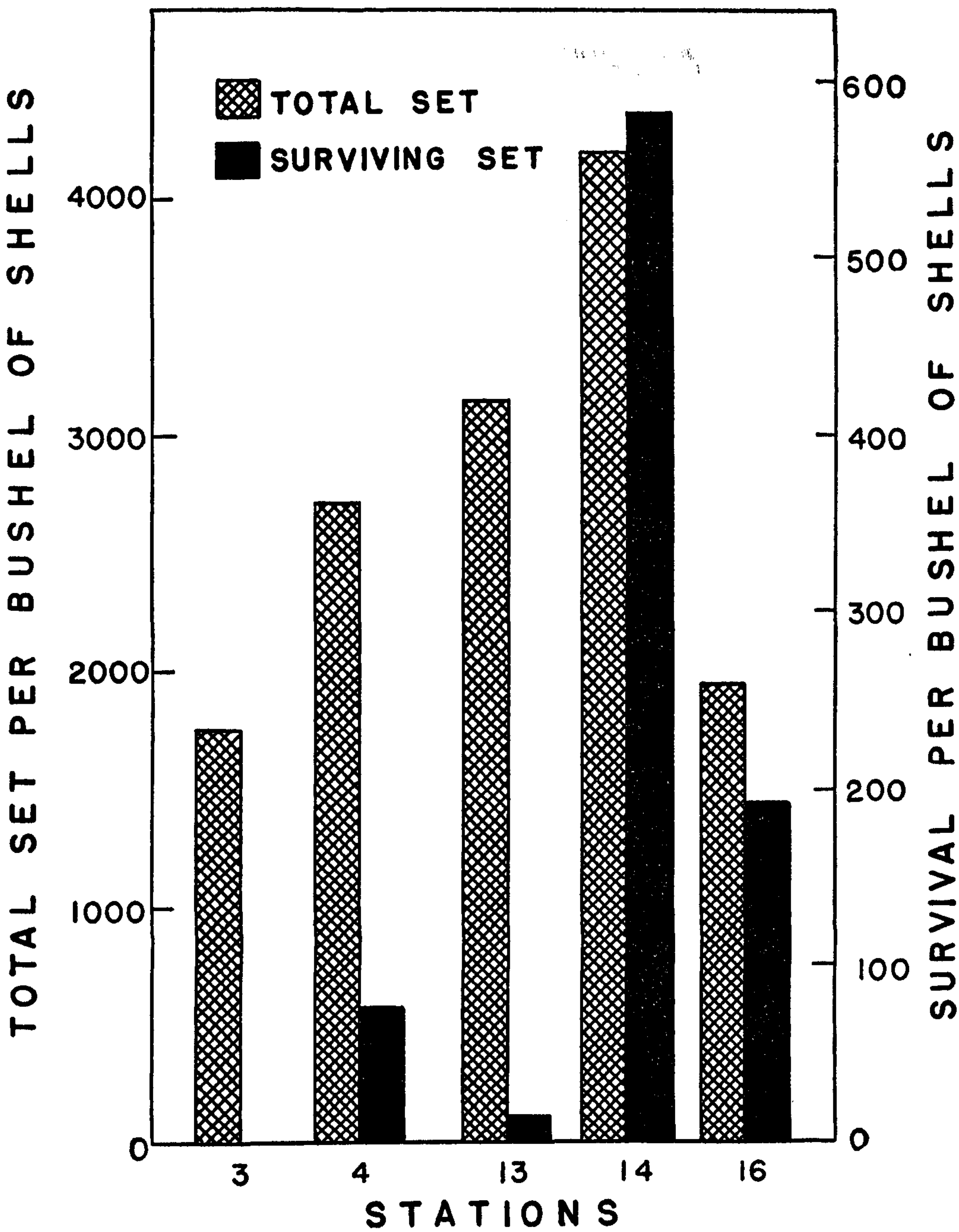

FIGURE 10.—Comparison of numbers of surviving set on seasonal collectors with the total number of spat set on regular collectors. Stratford Point and Welchs Point areas during the summer of 1937.

the temperature may be very high. For example, on the afternoon of Aug. 2, 1937, during low-water stage, the temperature of the water of shallow tidal pools of about

2 inches in depth was measured by the authors and found to be 37.2° C. (99.0° F.). To ascertain the body temperature of the oysters lying in the pool, their bills were carefully broken off and a thermometer inserted in the mantle cavity. The body temperature was 35.7° C. (96.5° F.). Twelve hours later, during the next low-water period, the temperature of the air and water of tidal pools may be fully 40° F. lower. The salinity of the water surrounding young oysters may sometimes be decreased in a few hours from 28 parts per mille to 5 or 6 parts per mille, and occasionally to

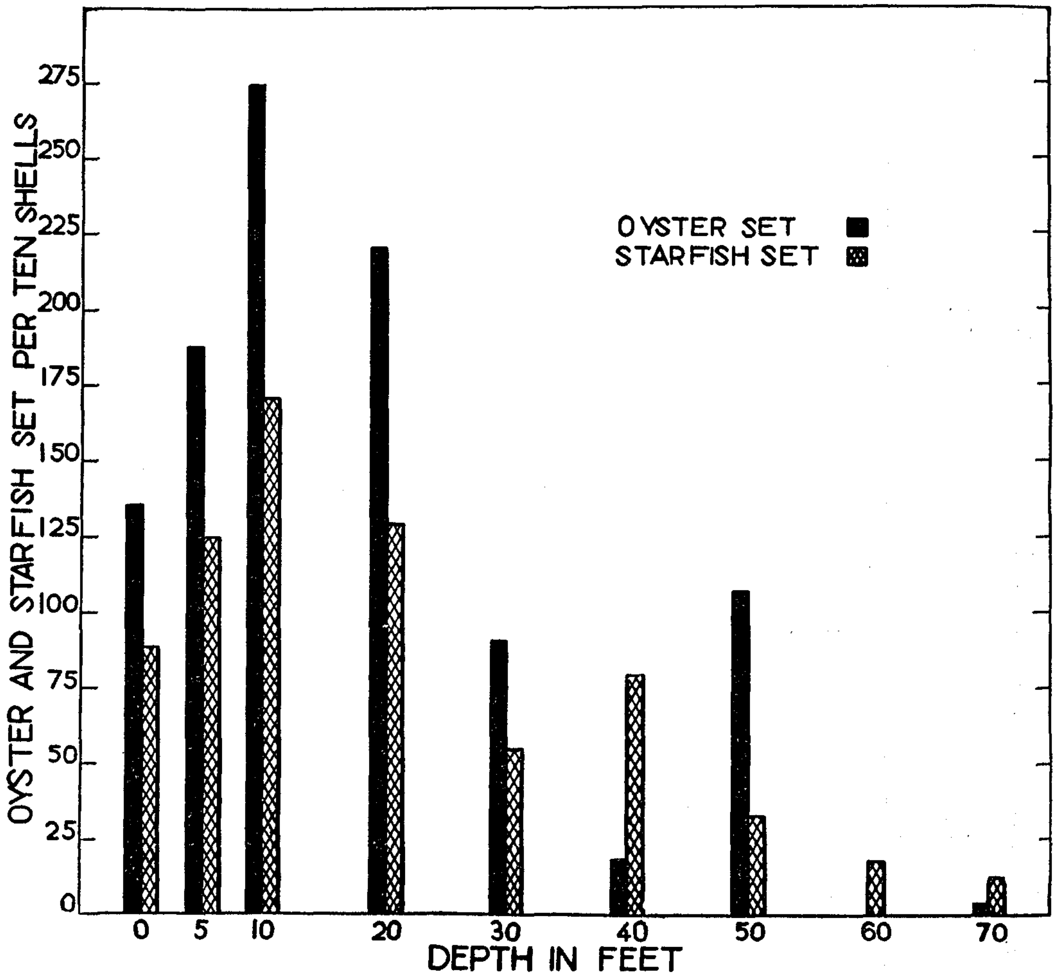

FIGURE 11.—Number of oyster and starfish set per 10 shells at each of the 9 stations in the Stratford Point area during the entire setting season of 1937.

almost zero. The concentration of hydrogen-ions in the water forming small pools during low-water stages may differ greatly from that normally found in the Sound. Regardless of all such radical changes the spat survive. It is obvious, therefore, that in Long Island Sound, where the set is always covered by several feet of water and is not subjected to rapid changes in environment, physical or chemical factors cannot be blamed for the heavy mortality among the spat. Other causes are responsible for the rapid disappearance of recently set oysters.

Studies of the conditions existing on the oyster beds of Long Island Sound in the summer and fall of 1937 provided certain data which may help to explain the heavy mortality and quick disappearance of the oyster set. Simultaneously with the studies of the biology of oysters, observations were also conducted on the setting of starfish (*Asterias forbesi*), the chief enemy of oysters, in the waters of the North Atlantic. The methods employed in studying the frequency of setting of young starfish were precisely the same as those used in the studies of oyster setting and the same stations were chosen for observations. Counts of oysters and starfish set were made on the same shells, taken from the same collector.

Comparison of the density of oyster and starfish set for stations of the Stratford Point series showed that the total number of starfish set was only about one-fourth less numerous than that of oysters (see fig. 11). The distribution of starfish set according to depth corresponded closely to that of oyster set and the areas which gave large numbers of young oysters produced almost equally large numbers of their enemies. At some stations, however, young starfish were found to be much more numerous than oysters. Observations on the setting of starfish showed that it began about 2 weeks in advance of the setting of oysters. Thus, by the time the first oysters set a great many young starfish were already crawling on the bottom in search of prey (Loosanoff, in press).

Experiments carried out under laboratory conditions showed that young starfish are voracious feeders, capable of eating several oyster spat per day. Of course, under natural conditions several species of mollusks and other animals are available as food for starfish, and oysters do not constitute their only item of diet. Nevertheless, a very conservative estimate, namely, that one young starfish destroys one oyster spat per week will show that, on the basis of our figures, a great quantity of oyster set are eaten by starfish within the first few days of their existence. It is apparent that, to protect the oyster set from quick destruction, the extermination of starfish living on oyster beds is necessary. The killing of starfish early in the spring, before they discharge their spawn, would reduce their numbers during the summertime when setting of oysters is taking place. Recent studies by the authors have shown that the eradication of starfish can be successfully conducted by the use of quicklime spread over the oyster bottoms infested with these pests (Loosanoff and Engle, 1938).

In addition to the ravages caused to oyster set by starfish, a great deal of damage is also done by a common oyster drill (*Urosalpinx cinerea*), which in certain sections of Long Island Sound occurs in very large numbers. While not many quantitative data are at present available, a single example will, perhaps, illustrate the destructive activities of oyster drills. One of our collectors, accidentally lost in a shallow inshore area devoid of starfish, was recovered after being in the water about 50 days. Examination of the collector showed that there were 67 young oysters ranging in size from 0.5 to 1.0 cm. Of these animals only one was found alive. More detailed studies of the remnants of the 66 other animals revealed that each of 17 oysters, still having both their shells together, showed one or two drill holes in the upper shells. The remaining 49 animals had already lost their upper shells and, therefore, the cause of their death could not be established, although the presence of a large number of drills in the bag may sustain the assumption that many of them were also killed by drills. It was only a question of time when the single surviving oyster would also have been killed.

DISCUSSION

In the foregoing account a description has been given of the development of gonads and the spawning and setting of oysters in Long Island Sound and one of its tributaries in the summer of 1937. Since it was stated by a previous investigator (Prytherch, 1929) that in these waters annual fluctuations in the quantity of spawn accumulated by the oyster, spawning, the intensity of setting, and the production of seed oysters can be correlated with water temperature during the spring and early summer months, special attention was paid to this factor. The importance of temperature becomes immediately evident if it is assumed that its departure above and below normal should be used in predicting the intensity and time of oyster setting in Connecticut waters (Prytherch, 1929). Observations of 1937, together with observations of the previous 5 years, permit at the present time the discussion of these questions in the light of new information available.

TEMPERATURE AND GONAD DEVELOPMENT

As already mentioned, the spring development of gonads of oysters begins when the water temperature approaches 10° C. By the end of June or early in July gonads are usually ripe. Observations of the last 6 summers on the thickness of the gonadal layer of oysters of approximately the same size, and collected from the same bed, indicate that it varies from year to year. The layer of reproductive tissue was found to be thickest in the summer of 1936, when it averaged 0.8 cm. in the large (11.0–12.0 cm.) oysters. In all other years, including 1937, the average thickness of the gonadal layer prior to the beginning of spawning was from 0.39 to 0.5 cm. Prytherch (1929) states that in 1925 the layer of reproductive tissue surrounding the liver was over 1.5 cm.

The question arises as to what factors cause the difference observed in the quantity of sexual products accumulated by oysters in different years. The explanation advanced by some investigators postulates that thickness of gonad layers is influenced greatly by the temperature of the water during the most active period of gonad development, i. e., spring and summer. It was maintained that, since in oysters the process of feeding consists in filtering water through the gills and retaining the food particles, and since the amount filtered is controlled by temperature, the higher the temperature the more food should be consumed by the oysters. Therefore, in the years when the water temperature during spring and early summer was above normal, larger quantities of spawn should have been accumulated by oysters, with a correspondingly greater thickness of gonad layer than in other years when the temperature was lower.

Material collected and data available for the last 6 years permit an answer to the question as to whether or not the thickness of gonad layer and, consequently, the quantity of spawn developed by oysters each year, can be correlated with the deviation of temperature from normal for the period from Apr. 1 to Aug. 1. Gonads of oysters from Charles Island beds were collected at biweekly intervals, or more often, throughout a period of several years. They were prepared for histological studies, thus giving a permanent record of their condition at the time of collection. In addition to these samples, observations and measurements of gonads were performed each year on many other oysters. No definite correlation could be found between thickness of gonad and deviation of air and water temperatures from normal. Several examples will suffice to demonstrate this point. In the summer of 1925 the thickness of gonad layer in the oysters examined was 1.5 cm. (Prytherch, 1929). In the years 1933, 1934, and 1937, the gonad layer was only one-half to one-fourth as thick. This condition prevailed despite the fact that during those years the departure of temperature above normal was considerably greater than in 1925 (U. S. Weather Bureau, New Haven Station) and, therefore, a correspondingly larger quantity of gonad material should have developed. Another example of a similar nature is provided by comparing the temperature conditions and the quantity of spawn in 1932 and 1937. In 1937 the air and water temperatures in spring and early summer were much higher than in 1932. Regardless of this, the thickness of the gonad layer of oysters was virtually the same in both years. Conditions prevailing in 1936 provided the most conclusive evidence against the hypothesis that the higher the temperature the larger the quantity of spawn accumulated by oysters. By referring again to the Weather Bureau data, it can be seen that the deviation in temperature above normal for the period from Apr. 1 to Aug. 1, 1936, was smaller than for any like period during the preceding 5 years. Paradoxically, the quantity of spawn developed by the oysters that year was the largest. Evidently the departure of temperature from normal for the period from Apr. 1 to Aug. 1 cannot always be relied upon as a basis for drawing conclusions relative to the quantity of spawn to be accumulated by oysters.

While the importance of temperature in inducing oysters to filter through smaller or larger quantities of water cannot be denied, it should be remembered that it is the foodmatter suspended in the water that is important, and not the acutal amount of water filtered. A small quantity of water pumped by an oyster at low temperature may often contain a much larger quantity of food than a considerably larger quantity of water passing through the oyster at higher temperatures. It is more probable that the quantity of spawn developed by oysters in different years is controlled, not by departures of temperature a few degrees below or above normal, but by the quantity and quality of food available.

EFFECT OF TEMPERATURE ON SPAWNING AND SETTING

In 1937 the first general spawning of the oyster population of Long Island Sound occurred on and about July 3. The water temperatures prevailing in the Sound prior to and during this period are given in tables 2, 3, and 4, and in figure 5. The date of spawning was ascertained by the presence and age of oyster larvae in the water and by the time of the beginning of setting. Gross and histological studies of gonads provided additional information as to the approximate time of spawning.

In 1937 the spawning of oysters in Long Island Sound began at a temperature lower than 20° C., which, according to the opinion prevailing among biologists (Churchill, 1920; Gutsell, 1924; Nelson, 1928; Prytherch, 1929; Galtsoff, 1930, 1932) and shared by the authors, was the minimum temperature at which spawning occurs under natural conditions. Because of this opinion spawning in 1937 was anticipated much later than July 3.

Although no continuous records of bottom-water temperature were obtained at each of our stations during the beginning of the spawning period, ample evidence is at hand to prove that the mark of 20° C. was not reached at that time. A continuous record of water temperature obtained with a recording thermometer installed near the shore in 4 to 5 feet of water showed that the maximum water temperature registered on July 2 and 3 was 19° C. The average temperature for each of these 2 days was 18.3° and 18.5° C., and the minimum 17.2° and 17.7° C., respectively. By frequent comparisons of the water temperature in the area of the recording thermometer and a nearby oyster bed located at a depth of 15 to 20 feet, it was established that the water temperature of the latter was from 1 to 2 degrees lower. Therefore, even if the water temperature in shallow shore water approached the 20° C. mark, it was one or more degrees lower at depths of 15 to 20 feet where the majority of the spawning beds are located. As is shown in tables 2, 3, and 4, the temperature readings at station 3, taken on July 2 and 8, were 16.4° and 17.5° C., respectively. At station 13 the temperature on July 3 and 9 was 17.6 and 18.7° C. At station 40, during the same period, the temperature ranged from 17.0° to 18.4° C.

In addition to the temperature data discussed above, more information on the same subject is available from several large oyster companies engaged in the collection of seed oysters in Connecticut waters. According to Mr. Sweet, Manager of H. C. Rowe Co., the bottom-water temperature taken at noon of each day between July 1 and 7, inclusive, at four oyster beds located between East Haven and Stratford Point, varied from 65.0 to 66.5° F. The location of these beds almost corresponded with our stations 39, 43, 45, and 47. Information secured from the records of The Connecticut Oyster Farms Co. showed that the bottom temperature, measured at noon of July 1 and 2 near Charles Island, was 63° F. From July 3 to 7, inclusive, the water temperature taken at oyster lot No. 771, located near Stratford Point where our stations 4 and 38 were established, ranged from 63 to 64° F. Between July 7 and 10 the bottom-water temperature over lot No. 771 reached 67° F. Thus, in no case between July 1 and 8 was a bottom-water temperature of 20° C. (68° F.) recorded over the oyster beds located in 12 to 25 feet of water either by the Bureau's investigators or by oystermen.

It may be assumed, however, that while in each of the cases the temperature at the time of actual measurements was below 20° C., it might have reached that point at some time just prior to spawning. Such an assumption can be refuted on the following grounds: The water temperature of the Sound is influenced largely by air temperature. Prytherch (1929) has shown that changes of water temperature follow with short delay the changes of air temperature, but are less pronounced. In general, a rise in air temperature is followed, in a day or two, by a corresponding but much less prominent rise in water temperature. If such is the case, then to anticipate a sharp rise in water temperature sometime around July 3, a correspondingly sharp increase in the air temperature prior to and during that period should be expected. However, as is shown in table 18, the air temperature during that period was unusually low for this time of year, sometimes departing by as much as 7 degrees below normal, and giving an accumulated deficiency of 29° F. for the period under discussion. Overcast skies and an almost continuous fog which accompanied this prolonged drop of air temperature can hardly be regarded as favoring an abrupt or even slow rise in water temperature. Obviously, such an assumption should be disregarded as groundless.

Other evidence supporting the observation that spawning took place at a water temperature below 20° C. was the fact that oyster larvae 4 and 5 days old were recovered in the plankton samples collected on July 7 and 8. General setting of oysters, which occurred on July 17, also shows that spawning took place about 14 days earlier, on July 3, when the water temperature was below the so-called minimum critical temperature.

An argument may be advanced that the oyster larvae found in the plankton samples on July 7, and later on July 17, causing a heavy set at a depth ranging from shore line to 40 feet, came from spawn released by the oysters of shallow water and not from the oysters living on the beds where setting occurred. While there was no possibility of ascertaining the place of origin of the larvae, it is highly improbable that they were carried far away from the spawning beds and distributed throughout the Sound. Prytherch (1929), and Galtsoff and Prytherch (1930), state very definitely that oyster larvae are not distributed far from the spawning beds by currents. They found that the majority of larvae set within a radius of 300 yards from the center of the spawning beds. Finding many oysters on July 7, in water 15 to 25 feet deep, with the gonads almost completely discharged, gives additional weight to the conclusion that spawning occurred several days before, and that the larvae found in the plankton sample were of local origin.

TABLE 18.—*Maximum, minimum, and mean daily temperatures, June 26–July 3, 1937. From the records of the U. S. Weather Bureau Station, New Haven, Conn.*

Date 1937	Temperature, ° F.			Departure from normal
	Maximum	Minimum	Mean	
June 26	71	62	66	−3
June 27	66	58	62	−7
June 28	66	62	64	−6
June 29	75	62	68	−2
June 30	77	62	70	0
July 1	75	60	68	−2
July 2	74	55	64	−6
July 3	75	59	67	−3

Spawning of oysters in Long Island Sound at temperatures several degrees lower than 20° C. was again recorded by the authors and corroborated by Galtsoff in 1938 (Loosanoff, 1939).

Spawning of oysters at a temperature lower than 20° C. is not without precedent. Nelson (1931) observed a female *O. virginica* spawn at 19.1° C. This, according to Galtsoff (1938), throws further doubt on the validity of the view that 20° C. is the "critical" temperature in the spawning of this species. Orton (1920) found that the European oyster, *O. edulis*, breeds at a temperature of 59–61° F. (15.0–16.1° C.). Spärck (1925) stated that the breeding temperature of the same species varied from year to year depending upon the spring rise in temperature. The breeding temperature is higher after a cold spring and lower after a mild one. After a warm spring a temperature of only 55–57° F. (12.8–13.9° C.) is sufficient to induce breeding, whereas, after a cold spring a temperature of 61–63° F. (16.1–17.2° C.) is required. Observations of Nelson (1928a) on the American oyster are in agreement with those of Spärck on *O. edulis*, that is, the more rapid the rise in temperature the sooner the spawning begins. Another example of spawning of oysters at temperatures usually considered much lower than the minimum is given by Hopkins (1936) who observed that female *O. gigas* spawned at 8° C. instead of 25° C. which, according to Galtsoff (1930a), is the minimum temperature required to induce ovulation in this species under laboratory conditions.

Studies of the spawning behavior of oysters living under different environmental conditions provided additional interesting information on the relation of temperature to the beginning of spawning of oysters in shallow water. In 1937, parallel with observations on activities of oysters in deep water, similar observations were carried at 4 shallow stations of Milford Harbor. The water temperature of these stations reached a 20° C. mark early in June (see table 5). Although the water temperature fluctuated with the tides, it remained at 20° C. or over for considerable periods of time. Examination of oyster gonads collected at Milford Harbor stations at the end of June and during the first days of July showed that many individuals had not discharged any spawn. Some animals with full gonads were found in samples collected for histological studies as late as July 30, about 7 weeks after the water temperature first attained a 20° C. mark; reaching almost 28° C. at times (table 5). This supports previous observations of Hopkins (1931), and Loosanoff (1932), that in shallow waters there is a considerable lag between the time the water temperature reaches 20° C. and the time of spawning. The failure of oysters to spawn so late in the season cannot be attributed to the unripe state of gonads because examination showed that all oysters examined after the first of July were ripe and eggs fertilizable.

The failure of some individuals to spawn until very late in the season shows that a combination of two factors, namely, temperature and chemical stimulation in the form of sex products of other oysters, is not always sufficient to induce spawning under natural conditions. This is concluded from observations on the spawning behavior of oysters at four Milford Harbor stations. Although the temperature at those stations had been higher than 20° C. for about 7 weeks, and many of the oysters had their sexual products partly or fully discharged, unspawned individuals were not uncommon. Obviously, even though these unspawned individuals were subjected on many occasions to the effect of high temperature and chemical stimulation of sexual products discharged by nearby oysters, they did not spawn. Gonads of such individuals prepared for histological studies showed that they were ripe morphologically. When the eggs of such individuals were artificially fertilized by the addition of spermatozoa taken from males of the same late-spawning type, a normal development followed. Therefore, the physiological ripeness was also established.

Observations of the entire season failed to show a correlation between the fluctuation of water temperature and the intensity of setting of oyster larvae. It is significant, however, that in many instances setting occurred at temperatures lower than 20° C. At some stations, as, for example, stations 5, 16, and other deep-water stations, the water temperature during the entire period of the first wave of setting (July 16–Aug. 1) was below 20° C., sometimes reaching as low as 16.9° C. (see tables 2 and 3). Regardless of such low temperatures heavy setting occurred (see tables 13 and 14). Evidently, under natural conditions the oyster larvae may survive and set within a very wide temperature range.

PREDICTING THE TIME AND INTENSITY OF SPAWNING AND SETTING

On the basis of his observations, Prytherch (1929) expressed an opinion that the success or failure of setting and its intensity in Long Island Sound may depend largely upon the departure of temperature from normal. Successful settings should be expected in the years when the temperature for the period of April to August is above normal, and failures when it is below. Prytherch suggested a method for predicting, 1 month in advance, (1) the time when spawning will take place, and (2), the time and relative intensity of setting that will occur. Such predictions could be made from about July 1–10 of each year, after considering the following conditions:

1. Water temperature from April to July.
2. The quality of adult oysters on the beds.
3. The quantity and degree of ripeness of spawn.
4. The range of tide for July and August.

In suggesting this method Prytherch emphasized that it was new and far from being a statistical computation as to the probability of the time of spawning and intensity of setting, but by accumulating a number of physical and biological data the method might in the future be placed on a statistical basis, definite values given to each variable, and more accurate predictions made as to the yield of seed oysters each year.

New observations made and information secured during the last 6 years now permit a discussion of Prytherch's method.

That prediction of the time of the initial spawning can be made 1 month in advance, after considering conditions existing early in July, is not fully in agreement with observations of 1937. In that year spawning occurred around July 3, during the period when, according to Prytherch, the study of conditions for the prediction of spawning, approximately 1 month thence, should have been in progress.

Spawning of Long Island Sound oysters at such an early date is not, however, without precedent. Glancy reported that in 1931 the first spawning of oysters in the Sound occurred on July 2, virtually the same date as in 1937. In 1938 the first spawning of oysters in Long Island Sound occurred on June 28. In 1939 a few partially spawned oysters were found in New Haven Harbor on June 28, and 2 days later, on June 30, a general spawning of oysters took place in Long Island Sound. Spawning again occurred at a temperature lower than 20° C.

The assumption that success or failure of oyster setting depends upon the departure of temperature from normal also does not quite agree with the observations made in recent years. The data on the intensity of setting for the years 1932 to 1937 were obtained by observations of the senior author, from the managers of several of the largest oyster companies of the State, and from the records of the State of Connecticut Commission of Shell-Fisheries. The temperature data were obtained from the U. S. Weather Bureau, New Haven, Conn. As a rule, as Prytherch (1929) pointed out, there is a close relationship existing between the air and water temperature in coastal areas. In 1932 the average daily departure of air temperature from normal from Apr. 1 to Aug. 1 was +1.7° F. Setting in the Sound was exceedingly light. Since only a few spat survived until September, the set of 1932 was a complete failure from a commercial point of view. In 1933 setting was again a failure, both from a biological and commercial standpoint. It is of interest to note that in 1933 the setting was a failure regardless of the fact that the average daily departure of temperature from normal was 6.4° F. above normal, or, in other words, higher than in 1925 when an exceedingly heavy set was recorded (Prytherch, 1929). In 1934 the departure of temperature from normal from April until August was +9.6° F. and a comparatively good set occurred in many areas of the Sound. Unfortunately, many of the spat died soon after setting. Therefore, oystermen regarded the set as either light or medium. Sets of 1935 and 1936 were complete failures in every respect. This occurred regardless of the fact that in both these years the departure of temperature was above normal, being +3.3° F. for 1935 and +1.9° F. for 1936. In 1937 the departure of temperature from normal was +7.6° F., more than 2 degrees higher than in 1925, the year of very heavy setting. However, in the estimation of biologists, the set of 1937 was only medium. The heavy mortality of spat significantly reduced the numbers of initial set, and, therefore, commercial oystermen consider the set of 1937 medium or light, or even a failure, depending upon the areas under consideration.

Thus, during the period of 6 years, from 1932 until 1937, the temperature was above normal in every instance. In this period of time, failure of setting was observed for 4 years, and medium or light sets for 2 years. Apparently the departure of temperature above normal does not always signify that the oyster larvae will set in large numbers.

The contention of Prytherch that the number of adult oysters on the beds is of importance cannot be denied. It is evident that if other conditions are identical, the larger the number of oysters the more spawn is discharged during the spawning season.

That the quantity of spawn accumulated by oysters is a poor criterion for predictions of intensity of setting has been demonstrated by the events of recent years. A description of the thickness of gonad layers in the years from 1932 to 1937 has already been given in the chapter dealing with the effect of temperature upon the development of gonads. Here it will suffice to point out that in 1936, when the quantity of spawn accumulated was the largest since 1932, the setting of oysters was a complete failure. This was established by examination of spat collectors brought from the Sound at regular intervals. On the other hand, in 1937, when the average thickness of the gonad layer of oysters was about one-half of that in 1936, a much heavier set of oysters took place. In 1939 the average thickness of gonad layer of oysters, immediately prior to spawning, was only about 0.31 cm. Regardless of the small quantity of spawn accumulated, the setting of oysters was extremely heavy, far exceeding in numbers any of the sets in recent years. The oystermen considered the set of 1939 the best since 1925.

The fecundity of the oyster is remarkable. A single adult female may produce as many as 500,000,000 eggs in one summer (Galtsoff, 1930b). If all the eggs of only 1,000 females survived the larval period and metamorphosed, an excellent set would occur in Long Island Sound. Since the oyster population in the Sound is composed of billions of individuals it is evident that, regardless of the quantity of eggs discharged in different years, there is always enough of them to produce an exceedingly heavy set; provided the eggs develop and the larvae survive the free-swimming period. It is quite evident that the discharge of a large quantity of spawn does not insure a proportionally heavy setting of oysters. Obviously the intensity of set depends upon the rate of survival of oyster larvae, as well as upon the quantity of spawn discharged. During the long larval period, which in Connecticut waters extends from 12 to 21 days, these microscopic animals are eaten in large numbers by their enemies, or destroyed by other causes. Kincaid (1915) pointed out that in Puget Sound waters a ctenophore *Pleurobranchia* devours very large numbers of oyster larvae, and Nelson (1925) has shown that there is a distinct correlation between the abundance of *Mnemiopsis* and the intensity of sets of oysters in New Jersey coastal waters. Orton (1937) states that on the sea bottom barnacles, seasquirts, many bivalves, certain worms, lobsters and hydroids take oyster larvae as normal food. In the upper waters jellyfish, especially *Aurelia,* most kinds of young fish, and probably numerous larval and adult crustaceans, as well as arrow worms and even *Noctiluca,* feed upon oyster larvae. Apparently, heavy sets should be expected when larval enemies are few in numbers, and poor when enemies are numerous. At present there is no information available to enable biologists to predict the relative numbers of the larva's enemies to be expected in the water in the summertime. As long as such information is not available an accurate prediction of intensity of oyster setting cannot be made.

In suggesting his method for predicting the time of spawning and the time and intensity of oyster setting, Prytherch (1929) offered a new and very interesting problem in the field of oyster investigation. Because the influence of temperature on all biological phenomena is undeniable, Prytherch's method is theoretically on a sound foundation. If the method was not entirely satisfactory in practice, it is only because there are many other variables, in addition to those mentioned by Prytherch, that should be studied and incorporated in the method before it will be of practical value. Among the obstacles that prevent making reliable predictions on the intensity of setting is the comparative lack of knowledge of the habits of oyster larvae. For example, the question of what forms constitute the bulk of the food of larvae is not satisfactorily answered. It is clear, however, that if food is not available, the larvae will perish. At present no methods for the prediction of the relative abundance of larval food are known.

This investigation indicates that the oyster larvae will withstand rather drastic changes in temperature and salinity of the surrounding water. Abrupt changes of such a character are of frequent occurrence in the bodies of water of Milford Harbor type, yet sets of oysters are quite regular and usually heavy. In Connecticut waters, as the studies of 1937 have shown, the oyster larvae lived and set at temperatures ranging from 16.6° to 28° C. Almost equally good sets were obtained under such diverse conditions. Evidently, in predicting the time and intensity of oyster settings, observations on temperature and salinity changes can be of little practical value until their influence upon related biological phenomena, such as abundance or scarcity of oyster food and absence or presence of larval enemies, is better known.

SUMMARY

1. This investigation was conducted to obtain a broader knowledge of the factors governing spawning and setting of oysters in Long Island Sound and its tributaries.

2. The physical conditions of Long Island Sound and Milford Harbor, such as water temperature, salinity, and hydrogen-ion concentration, have been described.

3. Studies of gonad development of oysters living in different parts of Long Island Sound show that early in May both sexes possessed undeveloped gonads resembling the winter condition. Growth and ramification of gonads began in the middle of May and a fully ripe condition was reached toward the end of June.

4. The first general spawning of oysters of Long Island Sound and Milford Harbor occurred on and about July 3. By the middle of July oysters in shallow and moderately deep stations were half, or more than half, spawned. The majority of these oysters completed spawning early in August. Spawning of oysters in deep-water stations continued until September.

5. Occurrence of oyster larvae in Long Island Sound has been discussed.

6. In 1937 the setting of oysters in Milford Harbor and in Long Island Sound began at approximately the same date, on and about July 16 and 17.

7. The setting in Milford Harbor extended from July 16 until Aug. 3. In the Sound setting continued until Sept. 23.

8. The peak of setting at all stations occurred at the very beginning of the season or shortly thereafter.

9. In Milford Harbor there was only one period of setting, extending from July 16 until Aug. 3. In Long Island Sound the first and heaviest setting was registered at the same time as in Milford Harbor. The first wave of setting in the Sound was followed by light and scattered sets in late August and in September.

10. The first setting of 1937 was general in character, occurring throughout almost the entire oyster-producing section of Long Island Sound. The setting could be regarded as medium.

11. In Long Island Sound the area of heaviest setting extended from mean low-water mark to a 20-foot depth. At depths ranging from 30 to 50 feet, inclusive, the setting was not as heavy as in more shallow water, but was still heavy enough to be of commercial magnitude. The setting of oysters took place even at a 70-foot depth.

12. In Milford Harbor setting occurred in the zone extending from the bottom to a point 2 feet above low-water mark. Above this level to a high-water mark no setting took place.

13. The rate of survival of oyster spat in the waters of Long Island Sound was very low. By comparing the numbers of surviving spat on seasonal collectors with the total number of set on regular collectors at the same stations, it has been established that at the end of 7 weeks after the first setting the mortality among young spat ranged from 86.05 to 100 percent.

14. It has been shown that the heavy mortality and quick disappearance of oyster set in 1937 was caused by starfish (*A. forbesi*) and oyster drills (*U. cinerea*).

15. Comparison of the density of oyster and starfish sets for stations of the Stratford Point series shows that the distribution of oyster set according to depth corresponds closely to that of starfish set. The areas which gave large numbers of young oysters produced almost equally large numbers of starfish.

16. No definite correlation could be observed during the period 1932–37 between the thickness of the gonadal layer of ripe oysters and the deviation of temperature from normal during the spring and early summer months. Therefore, the departure of temperature from normal cannot be regarded as evidence upon which to base conclusions relative to the quantity of spawn accumulated by oysters in different years.

17. In 1937 oysters appeared to have spawned at temperatures lower than 20° C. The bottom-water temperatures several days prior to and during the first wave of spawning ranged from 16.4° to 18.7° C.

18. The setting of oysters took place at temperatures as low as 16.9° C.

19. The method advanced by Prytherch (1929) for predicting the time and intensity of spawning and setting of oysters has been discussed.

LITERATURE CITED

CHURCHILL, E. P., JR. 1920. The oyster and oyster industry of the Atlantic and Gulf coasts. Appendix VIII, Rept. U. S. Com. Fish., 1919 (1920). Bureau of Fisheries Doc. No. 890, 51 pp., Washington.

GALTSOFF, P. S. 1930a. The role of Chemical stimulation in the spawning reaction of *Ostrea virginica* and *Ostrea gigas*. Proc. Nat. Acad. Sci., vol. 16, pp. 555–559.

GALTSOFF, P. S. 1930b. The fecundity of the oyster. Science, vol. LXXII, pp. 97–98.

GALTSOFF, P. S. 1932. Spawning reactions of three species of oysters. Jour. Wash. Acad. Sci., vol. 22, pp. 65–69.

GALTSOFF, P. S. 1938. Physiology of reproduction of *Ostrea virginica*. II. Stimulation of spawning in the female oyster. Biol. Bull., vol. LXXV, No. 2, pp. 286–307.

GALTSOFF, P. S., H. F. PRYTHERCH, and H. C. MCMILLIN. 1930. An experimental study in production and collection of seed oysters. Bull. U. S. Bur. Fish., vol. XLVI, pp. 197–263.

GUTSELL, J. S. 1924. Oyster-cultural problems of Connecticut. Rept. U. S. Com. Fish., 1923. appendix X, pp. 1–10 (Document No. 960).

HOPKINS, A. E. 1931. Factors influencing the spawning and setting of oysters in Galveston Bay, Tex. Bull. U. S. Bur. Fish., vol. XLVII, pp. 57–83.

HOPKINS, A. E. 1936. Ecological observations on spawning and early larval development in the Olympia oyster (*Ostrea lurida*). Ecology, vol. 17, No. 4, pp. 551–566.

KINCAID, T. 1915. Oyster culture in Washington. Transactions of second annual meeting, Pacific fisheries, p. 4, San Francisco.

LOOSANOFF, VICTOR L. 1932. Observations on propagation of oysters in James and Corrotoman Rivers, and the seaside of Virginia. Va. Com. Fish., pp. 1–46. Newport News, 1932.

LOOSANOFF, VICTOR L. 1939. Spawning of *Ostrea virginica* at low temperatures. Science, vol. 89, No. 2304, pp. 177–178.

LOOSANOFF, VICTOR L., and J. B. ENGLE. 1938. Chemical control of starfish. Science, vol. 88, No. 2274, pp. 107–108.

NELSON, T. C. 1925. On the occurrence and food habits of Ctenophores in New Jersey inland coastal waters. Biol. Bull., vol. XLVIII, No. 2, pp. 92–111.

NELSON, T. C. 1928. Rept. Dept. of Biol., 1927, New Jersey Agr. Exp. Sta., pp. 77–83. New Brunswick, N. J.

NELSON, T. C. 1928a. On the distribution of critical temperatures for spawning and for ciliary activity in bivalve molluscs. Science, vol. LXVII, pp. 220–221.

NELSON, T. C. 1931. Stimulation of spawning in the American oyster by sperm of the Portuguese oyster. Anat. Rec., vol. 51, No. 1, p. 48.

ORTON, J. H. 1920. Sea-temperature, breeding and distribution in marine animals. Jour. Mar. Biol. Assoc., United Kingdom, vol. XII (N. S.), pp. 339–366.

ORTON, J. H. 1937. Oyster biology and oyster-culture. 211 pp. Edward Arnold & Co. London.

PRYTHERCH, H. F. 1929. Investigation of the physical conditions controlling spawning of oysters and the occurrence, distribution and setting of oyster larvae in Milford Harbor, Conn. Bull. U. S. Bur. Fish., vol. XLIV, pp. 429–503.

SPÄRCK, R. 1925. Studies of the biology of the oyster (*O. edulis*) in the Limfjord, with special reference to the influence of temperature on the sex change. Rep., Danish Biol. Stat., vol. 30, pp. 1–84.

UNITED STATES WEATHER BUREAU. Annual meteorological summary with comparative data. 1937. New Haven Station. New Haven, Conn.