AN EXPERIMENTAL STUDY IN PRODUCTION AND COLLECTION OF SEED OYSTERS[1]

By PAUL S. GALTSOFF, Ph. D., *In Charge Oyster Fishery Investigations*

H. F. PRYTHERCH, *Assistant Aquatic Biologist*

H. C. McMILLIN, *Junior Aquatic Biologist*

United States Bureau of Fisheries

CONTENTS

I. OYSTER CULTURAL PROBLEMS OF THE NORTH ATLANTIC WATERS

By PAUL S. GALTSOFF

INTRODUCTION

Of the many bottom organisms inhabiting our inshore waters, the American oyster occupies the most prominent place. From Cape Cod to the mouth of the Rio Grande it grows in great abundance in nearly every protected inlet, bay, or sound, forming in the localities where bottom and water conditions are favorable

[1] Submitted for publication Apr. 15, 1930.

vast accumulations of live and dead shells, which cover areas of several square miles of sea bottom or extend for hundreds of miles along the tidal flats. In spite of such a striking abundance, many of the oyster-producing bottoms have become depleted, and the annual yield of oysters is declining. According to the statistics of the United States Bureau of Fisheries during the last 24 years, the annual production of market oysters has decreased 34 per cent. There may be several contributing factors that affect the annual crop of the oyster; but two of them—namely, the pollution of the inshore waters and the overfishing of the natural oyster bottoms—are undoubtedly the most important ones. Growth of cities along the Atlantic coast, accompanied by a tremendous development of industrial activity in the North Atlantic States, should be held responsible for the destruction of many natural resources of the ocean. With only a few exceptions, every city along the Atlantic and Gulf coasts has for years discharged untreated domestic sewage and trade wastes directly into the ocean. The effect of this deleterious and insanitary practice is that fish and shellfish in the vicinity of large cities have been either destroyed or made unfit for human consumption. Because of the present stringent sanitary regulations controlling the harvesting, handling, and marketing of shellfish, many thousands of acres of oyster-producing bottoms have been condemned, and formerly valuable grounds have become barren and worthless. On the other hand, intensive fishing on the natural oyster beds, coupled with the failure to return a sufficient number of shells to the grounds from which the oysters were taken, has resulted in the depletion of formerly productive natural bottoms. This decline in the productivity of natural oyster beds necessitated the introduction of various methods of intensive cultivation or oyster farming which at present are in operation in the North Atlantic States.

The oyster industry in the United States dates back to the early days when the first settlers on the Atlantic coast of America began to take oysters from the natural beds. They found oysters growing everywhere, and the supply of them seemed to be inexhaustible. For a long time no attempts were made to regulate or restrict the fishing for oysters, and no efforts were exercised to replenish the supply of shells taken from the bottoms. The predominating idea was that nature takes care of itself and that the productiveness of the beds could be kept on a constant level without exercising any care or consideration as to the time of fishing or number of oysters taken.

With the increase of population in the United States and corresponding increase in the demand for oysters, the beds and reefs yielded less, and some of them became entirely unproductive. Disastrous results of excessive fishing and lack of care were noticeable first in the northern parts of the country, where, because of the climatic and hydrographic conditions, propagation of oysters does not take place regularly and setting of young oysters is often affected by adverse weather. Oyster beds in the Gulf of Maine and on Cape Cod were soon almost completely depleted, while the grounds in Rhode Island, Connecticut, and New York began to suffer from overfishing and employment of wasteful methods. The first restrictive measure, as far as can be ascertained, was passed in October, 1766, when the Assembly of East Greenwich, R. I., passed an "Act for the preservation of oysters," forbidding dredging or other methods of taking oysters except tonging. In 1784 the State Legislature of Connecticut passed a law empowering the coast towns to regulate the oyster fishery within their respective limits. The main aim of the regulations adopted by different towns in accordance with this law was to restrict the fishery and prevent the depletion of the bottoms.

The first attempts to transplant oysters were made about 1810 in New Jersey, when small oysters were taken from crowded reefs and planted on private bottoms (Stafford, 1913). In 1845 planting of oysters gathered from natural bottoms was carried out rather extensively in Connecticut. The next step in developing a method of oyster culture, which originated in the United States independently of those in Europe, was made in 1855, three years before Coste began his experiments on the cultivation of the European oyster in France; in this year for the first time, shells for catching spat were planted in the harbors and bays of the Connecticut shore of Long Island Sound. In 1870 planting operations were extended to deep water of Long Island Sound, so that the latter date marks the beginning of the elaborate system of oyster culture which is now in operation in northern waters.

At present nearly all available grounds for oyster planting in the northern waters have been leased to private ownership, and the exploitation of public natural beds has been almost completely discontinued. South of Delaware, the oyster industry is still based primarily on the exploitation of the natural public beds carried out under the supervision of the respective State governments. There is no doubt, however, that the increasing depletion of the natural beds will eventually result in their total destruction. Efforts exercised by different States for maintaining the productivity of public oyster bottoms by planting cultch and seed oysters at present are inadequate to prevent their gradual destruction, and there is no doubt that in the future the sounder system of oyster farming will be introduced in these waters.

The main difficulty which the oyster industry experiences in the northern waters consists in the lack of seed oysters due to insufficient and irregular setting. The most important seed-producing areas are located in the harbors or at the mouths of the rivers, where they are greatly affected by pollution. Many of them are so badly depleted and the number of adult oysters on them is so small that no more setting takes place in their vicinity. With the diminished oyster population in the seed-producing areas and the destructive effect of pollution on spawning and setting of oysters, a reliable supply of young oysters has become of great importance; in many localities it is the key to the future success of the oyster industry.

Two possibilities of rehabilitation of the industry are open for experimentation: The artificial propagation of oysters and the development of a better method of production and collection of seed oysters under natural conditions.

ARTIFICIAL PROPAGATION OF OYSTERS

After the first successful experiments in artificial fertilization and development of the eggs of the American oyster made by Brooks (1879), many attempts were made by various investigators to rear the larvæ to adult marketable sizes. Rice (1883), Winslow (1884), Ryder (1883), and Nelson (1901, 1904, 1907) tried different methods to keep the oyster larvæ alive and to bring them to a setting stage. In the reports published by these investigators, one finds the description of many difficulties encountered in the attempts to keep the minute, free-swimming organisms in jars and to provide them with the necessary supply of food. Although Ryder (1883) and Nelson (1901, 1904, 1907) were enthusiastic and believed in the practicability of their methods, their experiments did not pass beyond the laboratory stage and the artificially raised larvæ failed to set.

Later on, Wells, in 1920 and in the following years, working under the auspices of the New York State Conservation Commission (1923–1927) developed a method based on the use of a high-speed centrifuge; briefly speaking, the method is as follows: Artificially fertilized eggs are allowed to stay in the containers and develop into larvæ which are immediately transferred into 50-gallon stoneware jars. Once a day the content of the jar is passed through a high-speed centrifuge (De Laval multiple clarifier) and all the larvæ, after being collected in the bowl of the centrifuge, are transferred into a new jar filled with fresh sea water. After the larvæ attain a sufficient size to be retained by the fine wire screen (200 mesh to an inch) which was used during the changing of the water, they are kept in larger tanks where they finally set.

In 1924 Prytherch reported the result of his experiments on artificial propagation of oyster larvæ which had been carried out in 1923 at Milford, Conn. His method consisted in obtaining natural spawn from the oysters brought from the harbor and in keeping the oyster larvæ in a system of tanks; the changing of water was accomplished by a slow filtration through the porous artificial stone known as filtros. When the larvæ were about 10 days old, they could be held by means of fine screens of monel metal, which permitted a good flow of water. By this method Prytherch was able to produce several thousand seed oysters, which at the end of the summer were planted in Milford Harbor.

The question of whether the methods of artificial propagation developed since 1920 have reached such a perfection that they can be instrumental in rehabilitation of the industry, requires careful consideration. We read in the Annual Report of the Conservation Commission of the State of New York (1926, p. 125) that "as to the artificial propagation of oysters, the State feels that the problem has been solved." Unfortunately, the data given in the reports of the New York Conservation Commission for the years 1923 to 1927 referring to the number of artificially propagated oysters, fail to support this optimistic view. The present annual production of seed oysters in Massachusetts, Rhode Island, Connecticut, and New York amounts, according to the data of the United States Bureau of Fisheries, to 586,443 bushels valued at $657,392, or $1.13 a bushel. The actual figure of production is several times higher, because seed oysters produced and replanted by the same company are not recorded by the statistics, which include only oysters bought or sold on the market. Every serious attempt to put artificial propagation on a commercial scale must take cognizance of the two main factors—the quantity of seed oysters required by the industry and the cost of production. If, under the present conditions, no large quantities of seed oysters can be raised artificially or should the cost of artificial propagation be too high, then the problem is not solved. The difficulty only begins when one attempts to produce hundreds of thousands of bushels instead of a few thousand individuals.

Present methods of artificial propagation are expensive; the reports of the New York Conservation Commission give no information as to the possible cost of production and fail to show the total number of oysters produced by Wells's method. In the report of 1923 Wells states (p. 46) "that it has been impossible to determine accurately the yield of the operation. Altogether, approximately 10,000 were planted as set in the open waters. This represents, however, only a small portion of the total number of larvæ developed in the jars." From a practical point of view, the number of larvæ raised in jars or tanks has very little significance; the real test of the method is in the production of seed oysters; and, as one can judge from the report of the conservation department of 1923, the quantity of set produced by artificial propagation was equal to approximately one bushel. The conclusion seems to be inevitable that the practicability of the artificial propagation of oysters has not yet been demonstrated. Apparently, the New York Conservation Commission later on reached the same conclusion, because in the report of 1927 on page 340 it states: "The New York State oyster growers suffer from the lack of oyster set. Most of the seed used is brought in from Connecticut or other States. This is a big handicap, and a remedy is eagerly sought for." It is the author's opinion that present methods of artificial propagation of oysters are very valuable for laboratory and experimental study of the life history of the oyster, and it seems possible that in the future, when the procedure is simplified and the market price of seed oysters is higher, they can be made applicable for the practical needs of the industry. The immediate problem, however, is to find out means and methods to increase productivity in natural areas rather than to experiment in the line of artificial propagation.

SPAWNING AND SETTING OF OYSTERS

It has been known for many years that setting in northern waters is subject to wide fluctuations. Oyster growers have attributed the failure of oysters to set to various factors: Adverse weather conditions before and after the time of spawning, tides, currents, sedimentation, natural enemies, etc. In spite of a great variety of opinions expressed, the problem has been very little studied and the scientific literature on the subject is surprisingly meager. In discussing spawning, fertilization, and development of the oyster, the earlier investigators (Brooks, 1905; Ryder, 1881, 1882, 1883, 1884; and Stafford, 1913) gave but little attention to factors which might affect these phenomena. Nelson (1920), studying oyster culture problems in New Jersey waters, states that adult oysters do not spawn in New Jersey waters until the temperature has reached 21.1° C. (70° F.) and has maintained it for some time. Nelson believes that free-swimming larvæ are very sensitive to temperature changes and that a fall of several degrees in water temperature may cause the death of a large number of them. He states (op. cit., p. 9) that "a sudden fall in temperature during the setting period may completely inhibit the obtaining of a set."

Churchill (1920) and Gutsell (1924) state that oysters may spawn when the water reaches a temperature of 20° C. (68° F.) but that spawning proceeds at normal speed only when the water is 21.1° C. or above. According to Galtsoff (1930), temperature is not the only factor that controls the discharge of the sex products. Working under laboratory conditions, he found that the presence of sperm in the water induces the female oyster to spawn, the reaction taking place at the temperature of 20° C. and above. The eggs discharged by the female in turn induce the spawning of the males, and the process once started in one place continues throughout the oyster bed. Thus, the mutual stimulation of the opposite sexes plays an important rôle in the propagation of the oyster.

The failure of oysters to set was attributed not only to low temperature of water but also to the presence of enemies destroying the oyster larvæ. Nelson (1925) thinks that the ctenophore, *Mnemiopsis leidyi*, which occurs in great abundance in the inshore waters, is responsible for the disappearance of oyster larvæ and the absence of set in certain areas of New Jersey waters.

Our present knowledge of the biology of the oyster is not sufficient, however, to explain the rôle of the other factors which may affect spawning and setting. It is interesting to note, for instance, that in certain localities having an established reputation as excellent growing grounds, setting does not take place, in spite of high temperature of the water and the presence of large numbers of ripe adult oysters. Such, for instance, is Cotuit Bay in Massachusetts, where, according to the observations made by the author in 1926, a few oyster larvæ were found swimming in the water but they failed to attach themselves to shells planted in the bay. This was probably due to the fact that every shell in this bay in a period of a few days becomes covered with a slimy film formed by microscopic algæ, rendering its surface unsuitable for attachment.

One condition prerequisite for obtaining a good set is the presence of clean cultch, which should be planted shortly before the time of setting. In 1884 Winslow wrote, "Thousands of dollars would be saved annually by the oystermen if they would determine with any approximate accuracy the date when attachment of the young oysters would occur." It has been shown by Prytherch (1929) that time and intensity of setting can be predicted one month in advance; his method is based on a study of temperature and tidal conditions in a given body of water, on the determination of the number of spawners, and on an examination of the fullness of their gonad development.

The knowledge of the exact location of the setting zone is as important to the oyster culturist as is the knowledge of the time of setting. Observations carried out by Galtsoff and Prytherch in Long Island Sound, in waters of Massachusetts, in Great South Bay, N. Y., and along the coast of South Carolina and Georgia show that setting is often restricted to a very definite zone. For instance, in the tidal waters of South Carolina (Galtsoff and Prytherch) and Georgia (Galtsoff and Luce, 1930), it is confined to the zone between the tidal marks, while in the Great South Bay, N. Y., setting takes place from top to bottom. Analyzing the factors controlling setting in Milford Harbor, Prytherch (1929) arrives at the conclusion that the distribution of the setting zones can be correlated with tidal changes during the time of setting. He finds that in Milford Harbor the zone of the heaviest setting coincides with the level of low slack water. Corroborating evidence is found in the fact that no oyster larvæ swim about in the water when the velocity of the current is more than 18.3 centimeters (0.6 feet) per second. Whether the setting at a definite level is due only to the changes in velocity of the current during the tidal cycle or can be correlated with the changes in the composition of the sea water at different stages of tide, is a problem for further research in which the authors are engaged.

METHODS OF SPAT COLLECTION

One of the most popular methods of collecting spat or seed oysters consists in scattering clean shells over the bottoms where setting is expected. This method was first introduced in Connecticut in 1855 when, according to Brooks (1905, p. 105), shells were planted among the islands off the mouth of Norwalk River; since that time this method has been extensively employed in northern waters. In certain localities—for instance, Wellfleet Harbor, and in some parts of Long Island Sound—gravel and crushed stone have been planted with very satisfactory results. It was soon discovered that the time of planting is of great importance, since the shells after being submerged for even a few weeks may become covered with a slimy film that prevents the attachment of the oyster larvæ. It is of great importance, therefore, to begin the planting just before the time of setting. In Long Island Sound this is always done between the 15th of June and 15th of August. Inasmuch as the method of planting was fully described in the literature (Brooks, 1905, and Moore, 1897) it is not necessary to go into a detailed discussion of it. It is sufficient to state that the bottoms over which the shells are scattered must not be shifting and must be firm enough to support the weight of the shells. Obviously, the sand bars and soft mud bottoms are not suitable for the purpose and are never used for planting of shells.

Very elaborate methods of seed collection are employed in Europe, Japan, and Australia. They consist in using various types of collectors such as brush, crates of tiles (France), bundles of hagel and ropes (Italy), bamboo (Japan), and stacks of rocks (Australia), which are placed over the bottoms and in the tidal areas. For a description of these methods, the reader is referred to the papers of Brooks (1905), Kellogg (1910), B. Dean (1892–93), and Roughley (1925). In this country experiments with artificial spat collectors were carried out in 1880–1885 by Ryder (1887), who used tile and slate coated with the mixture of lime, sand, and cement. All of these methods require considerable labor, and the cost of both material and operation is rather high. They can be used only in the countries where labor is cheap and the price of oysters is high. Under American conditions, where labor is expensive and the market price of oysters is low, the foreign methods of cultivation are not practicable. The problem for American oyster culturists is to find an efficient but inexpensive and simple method of collecting seed oysters which would require the minimum amount of labor.

BRUSH COLLECTORS

Of various types of collectors, brush is the least expensive. The first use of brush in America was made in 1868 (Collins, 1891, p. 477) in the Poquonock River, Conn., when a farmer, after trimming his orchard and throwing the branches of the trees into the river, found them in the succeeding autumn covered with oysters. This suggested the employment of the method by others, and for several years it was known as the "brush" or "Poquonock" method. It was, however, only moderately successful and later was discontinued.

During the last 10 years several attempts were made to plant brush in Great South Bay, but the results were not entirely satisfactory; setting was generally light and only a small number of young oysters were found attached to twigs.

In the waters of North Carolina and Georgia, where setting is heavy and occurs between the tide marks, brush can be easily planted by sticking it into soft mud on the flats. The experiments with brush carried out in 1926 and 1928 in North Carolina and Georgia (Galtsoff and Luce, 1930) have demonstrated both the possibilities and the limitations of this method.

WIRE BASKETS

Since the beginning of shell planting in 1855, only a few attempts were made to improve this method. In 1910 Belding (1911), studying the setting of spat in Wellfleet Harbor, Mass., used collectors consisting of from one-half to one bushel of shells placed between the tide lines and covered with galvanized wire netting of 1-inch mesh, securely fastened to the bottom by four short stakes. The height of the shell heap was 8 inches; the collectors were used only for a study of the intensity and distribution of setting; and the method was not tried on a commercial scale. In 1925 Capt. C. E. Wheeler, of the Connecticut Oyster Farms Co., suggested the use of wire baskets filled with oyster, clam, and mussel shells and placed on the flats. Experiments were carried out by Prytherch at Milford, Conn., and proved a success (Prytherch, 1930). Each of the shells on the top, bottom, and sides of the baskets was covered with from 100 to 200 spat; those in the layer just inside caught from 10 to 50 spat each, and those in the very center from 2 to 10 spat each. It was evident that the shape of the basket should be changed to enable the oyster larvæ to penetrate more easily and attach on the shells in the center.

CRATE COLLECTORS

In 1926 an inexpensive shell container was designed for this purpose. It is triangular in shape (fig. 1) and is constructed of spruce lath spaced 1½ inches apart. Three square sides, each 2 by 2 feet, are wired together after the bottom is put in place. The bottom is 6 inches above the ground, but the length of the legs can be increased, if necessary. The capacity of the container is 2 bushels, and it covers 2 square feet of bottom. To protect the wood from the attack of shipworms and other wood-boring organisms, the lath is coated with a mixture of quicklime and sea water, to which is added enough fine sand or mud to give the consistency of thick cream; after this treatment, the crate can be used several times.

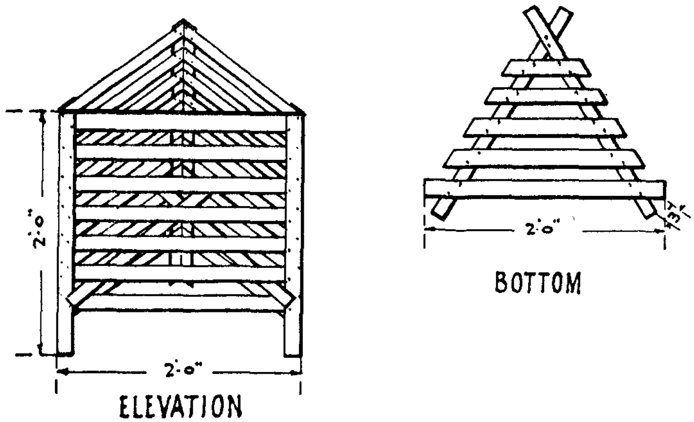

FIGURE 1.—Lath container (crate) for oyster shells. The three sides are constructed the same and are wired together after the bottom is put in place. Laths are spaced 1½ inches apart

Planting of the containers is a simple operation and can be carried out in different ways, depending on local conditions. Containers already filled with shells can be delivered at high tide on the grounds and thrown overboard; or in case of planting on tidal flats, the containers are stuck in the bottom and filled with shells afterwards. In the case of very soft bottom, the length of the legs can be correspondingly increased.

Experiments with lath containers were carried out in 1925 and 1926 in Milford Harbor, Conn., Wellfleet Harbor, and Wareham River, Mass. The results of these experiments have shown that, in order to insure better penetration of the oyster larva, the size of the container should be reduced. Some of the containers planted in Wellfleet Harbor and Wareham River, where they were exposed to strong wave action, were destroyed or washed away. At the same time, the experiments have demonstrated that by using the containers the catching of seed oysters over a given area of bottoms can be increased materially.

WIRE BAGS

At the suggestion of Prytherch, a new type of shell container was built and tested out in 1927. The container consisted of a bag of chicken wire having a mesh of 1½ to 2 inches and was filled with oyster, scallop, clam, and sea scallop shells. The wire bags had a capacity of 1 bushel and were cylindrical in shape, with a length of 36 inches and a diameter of 12 inches. The method employed in constructing the bags and filling them with shells is shown in Figure 2. The wire mesh was purchased in 24-inch rolls and then cut into pieces 3 feet long. (Fig. 2, Nos. 1 and 2.) Each piece of wire was then folded lengthwise and the ends closed either by twisting the wires together or by weaving a short piece of No. 18 annealed wire through them. (Fig. 2, Nos. 3 and 4.) The wire bags are now ready to be filled, and in this form they can be easily stored until it is time for shell planting. The filling of the bags was accomplished easily by placing them in an oblong wood box, 36″ by 8″ by 8″, and adding sufficient shells to fill them to the top. The bags were then closed tightly by drawing and weaving the edges together with galvanized, annealed wire No. 18. The bags of shells can be handled roughly without breaking open. They can be set out singly or can be stacked in tiers several feet high, thereby greatly increasing the quantity of cultch that can be planted on a given area of bottom.

The cost of the material for each bag at current retail prices was 5 cents for those of 2-inch mesh and slightly more for 1½-inch mesh. The oyster or scallop shells which were used cost 10 cents per bushel. The cost of the labor employed in making the bags, filling, and planting them averaged approximately 10 cents per bag, which gives a total cost of 25 cents for each bushel of shells that was planted. The method of making and filling the bags can be greatly simplified and the cost reduced when the operations are carried out on a commercial scale. Experiments with the shell bags were made at Onset, Mass., Milford, Conn., and Great South Bay, Long Island, in 1927 and 1928. The arrangement and position in which the bags were placed and other details of the experiments are given under each locality, together with the results that were obtained.

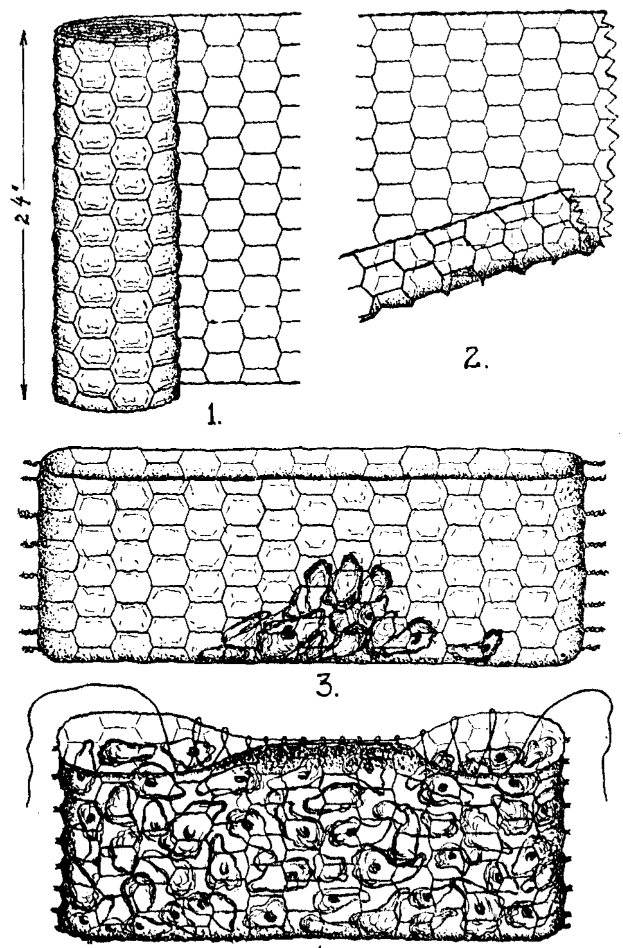

FIGURE 2.—Method of construction of wire bag collector. (Explanation in text)

The method of collecting spat in lath containers or in wire bags is based on the assumption that with the present method of scattering shells over the bottom only a small percentage of oyster larvæ present in the water finds a place of attachment, and that the majority of them perish. The main problem to increase the production of seed oysters is, therefore, to find the method whereby the natural supply of larvæ will be fully utilized. This can be accomplished by increasing the amount of cultch planted, thereby increasing the area suitable for attachment, and by utilizing the three dimensions of the setting zone by planting shells in bags or crates. A study of the distribution of the setting zones in various localities reveals the fact that there is always a level or zone where setting is the heaviest. The question of what causes the oyster larvæ to set in a definite zone is a very complex one and requires further investigations; but the determination of the zone of setting in any given locality presents no difficulty, as in most of the cases a careful examination of the bottoms and various submerged objects or structures allows one to determine it very accurately. (Fig. 3.) Obviously this zone should be utilized to its maximum capacity.

It is known that setting in northern waters is rather irregular; good years are followed by blank ones when there is no setting at all or when it is so light as to be of no commercial value. Examination of the setting regions discloses, however, the fact that there are certain localities where setting occurs regularly every year. Such are, for instance, Onset Bay and Wareham River in Massachusetts. It is logical that these areas should be more thoroughly utilized for the production of seed oysters. In the localities where setting continues for a period of 2 or 3 weeks, the collectors which had already caught a sufficient number of spat can be replaced by new ones, and in this manner the productivity of the given area may be increased and the intensity of setting on the cultch can be regulated.

One important factor governing the propagation of oysters is frequently forgotten or overlooked. It is the presence of a sufficient number of adult oysters (spawners) in the vicinity of the setting grounds. It is obvious that the abundance of spat is primarily dependent on the quantity of eggs discharged into the water. Inasmuch as the fertilization of the oyster egg takes place outside of the organism and is a matter of chance, there must be a sufficient number of ripe males and females to insure the abundance of the oyster larvæ in a given body of water. It is estimated that the spawning bed should contain not less than 500 bushels of spawners per acre.

Spawning and setting of oysters are controlled by a great number of environmental factors of which the temperature, salinity of the water, and the tidal currents are of great importance. Hence, knowledge of these conditions is essential for the success of an experimental study of oyster culture. In the following papers considerable space is given to the description of the localities where the experiments were carried out, together with the records of temperature, salinity, and velocity of tidal currents. These experiments were carried out under the general direction of P. S. Galtsoff in Wareham River, Mass., in Onset Bay, Mass., in Milford Harbor, Conn., and in Great South Bay, N. Y. These localities represent the different ecological conditions which one encounters in the northern section of the Atlantic coast. It was the author's intention to give a fair trial to the new method of spat collecting and to determine by a comprehensive study both its advantages and limitations.

The experimental work was greatly facilitated and in many instances made possible by the excellent cooperation given by the oystermen. It is a pleasure to express our thanks and to acknowledge the help rendered by W. H. Raye, president, and Capt. C. E. Wheeler, manager, of the Connecticut Oyster Farms Co., and to Messrs. Schroeder and Besse, of Onset, Mass.

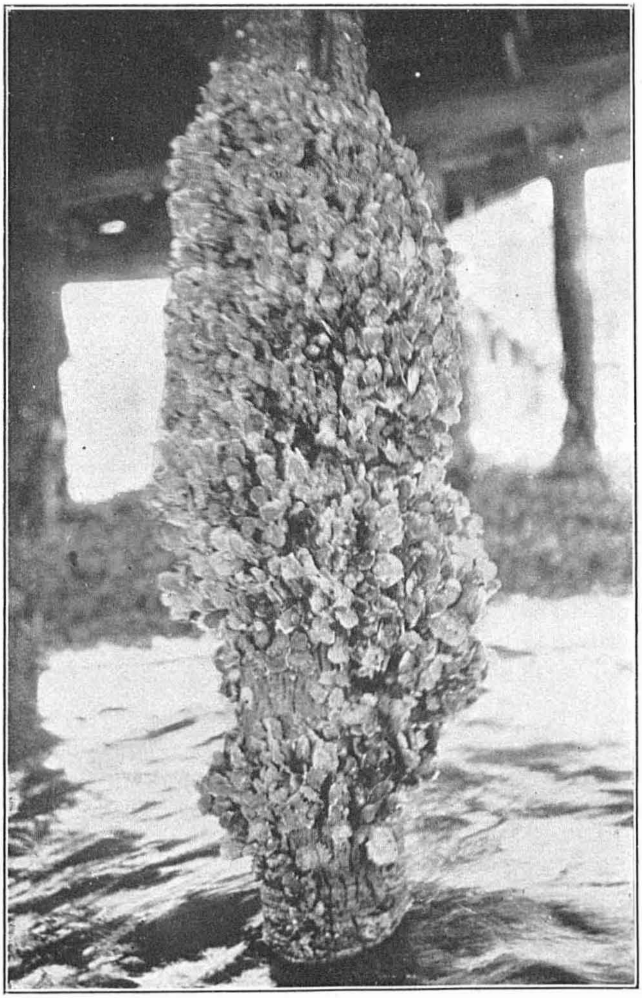

FIGURE 3.—Zone of heaviest setting. Wharf at low tide, Beaufort, S. C

II. OBSERVATIONS AND EXPERIMENTS IN SEED-OYSTER COLLECTION IN WAREHAM RIVER, MASS., 1926

By PAUL S. GALTSOFF

INTRODUCTION

The body of water known as Wareham River is a small oyster-producing area in the State of Massachusetts, where the oyster industry has been carried on since colonial days. Oyster production in this region has never attained large proportions, and in the early days consisted in the exploitation of the natural beds. Apparently they were soon depleted, because in 1775 the town meeting of Wareham voted that there should be no shellfish nor shell sold or carried out of town (Ingersoll, 1881). Later on, planting of shells was introduced, and it is known from the court records that in 1840 oyster cultivation was carried on in Wareham River. At present, the oyster industry in Wareham consists mainly in the production and selling of seed oysters, only a small number of which are grown locally. The operations are carried out by individual oystermen, who receive small grants from the town. The average size of the grant is about 2 acres. Unfortunately, the grants are not well described and for the most part unsurveyed. According to Belding (1909, p. 155), in 1909 the total area of grants approximated 1,000 acres, but only 196 acres were under cultivation. The annual production of seed oysters is around 20,000 bushels (Belding, 1909; Division of Fisheries and Game, 1925, p. 58).

Two reasons influenced the selection of this locality for the experiments with spat collectors. First, the character of the oyster business consists mainly in producing seed oysters which are sold during the fall before the onset of cold weather; second, as could be ascertained from local oystermen, setting occurs here very regularly, and during the last 25 years there were only a few years when the oysters failed to set. The possibility of increasing the productivity of seed oysters per acre is of great importance for localities like Wareham River, where the area of bottoms suitable for shell planting is very limited. On the other hand, the regularity of setting affords opportunity for an experimental study with spat collectors.

DESCRIPTION OF THE LOCALITY

Wareham River forms the extreme northwestern corner of the head of Buzzards Bay (fig. 4); the town of Wareham is located on its west bank, approximately 2 miles above its mouth. The entrance to the river from the bay is obstructed by a sand bar known as Long Beach, extending for about 700 yards in a WNW. direction, and by extensive shoals and numerous ledges through which a dredged channel 12 feet deep and 100 feet wide leads to the town. The channel ends at the railroad bridge, where the river is about 75 yards wide. Above the bridge the river expands again and is joined by the shallow Agawam River, partially surrounded by marshes.

The depth in Wareham River, excluding the 12-foot channel, between Long Beach and the railroad bridge, varies from 1 to 11 feet at mean low water. The areas having a depth from 5 to 11 feet are, however, very small, the greater portion of the river being formed by shoals and bars from 1 to 4 feet deep. The bottom is generally hard in the southern half of the river between Barneys Point and Long Beach Point (fig. 4) and sticky and soft mud along both sides of the channel north of the line connecting Barneys Point and the mouth of Broad Marsh River. All over the bottom, excepting the shoals that are exposed at low water, eelgrass grows prolifically.

Shifting bottoms are found on the western shore of the river along Swifts Beach, around Long Beach Point, and at the entrance to the river.

Excepting the sand bars and flats exposed at low tide, oysters are found scattered all over the area. There was a continuous oyster bed in the upper part of the river,

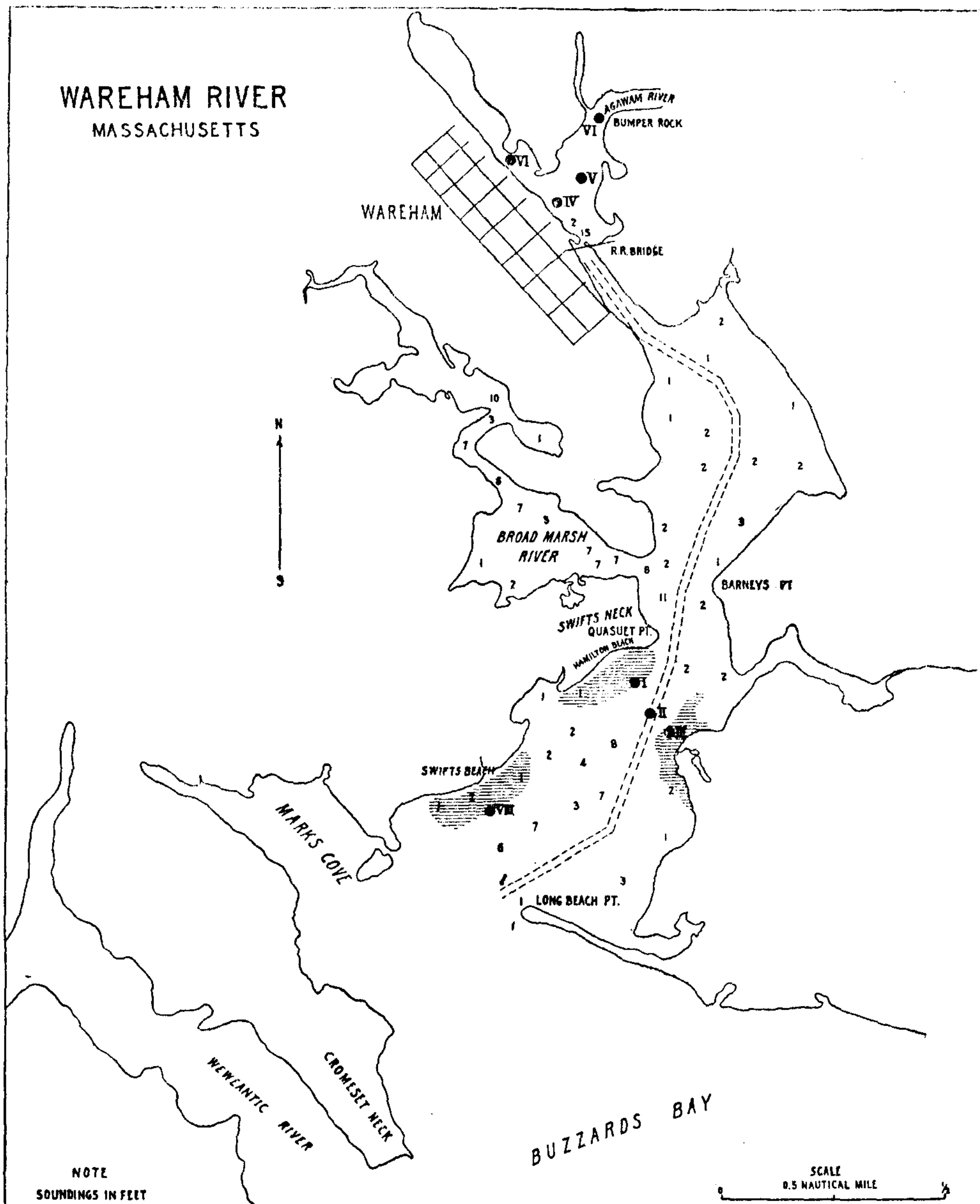

FIGURE 4.—Wareham River, Mass. Shaded areas indicate locations where crates were planted. Roman figures denote stations

above the railroad bridge, which at present is greatly depleted, but scattering oysters can be found in this portion of the river as far as Bumper Rock. (Fig. 4, Station VII.)

Setting in Wareham River takes place in the area between the tidal marks on both shores of the river. Planting of shells usually begins in the latter part of June and is completed before the 10th of July. The flats exposed at low tide are carefully cleaned from accumulations of eelgrass and other débris, and scallop shells are distributed evenly over the exposed areas. The shells are deposited very densely and raked in such a manner that they stand on the edges, thus affording the greatest surface for the attachment of the larvæ. Planting of shells never extends below low-water mark.

For the experiments with spat collectors the locations indicated as Stations I, III, and VIII (fig. 4) were chosen. Station III was located on the grounds where scallop shells were planted; Stations I and VIII were located along the western shore where no planting was done in 1926, although a certain amount of shells was left from previous operations. Field observations at Wareham were carried out during the summer of 1926 by R. W. Crozley, under the direction of the author.

TEMPERATURE OF THE WATER

Present observations cover a period of 40 days (July 9 to August 17, 1926) when temperature readings were made at 8 different stations in the river. (Fig. 4.) Before discussing the results of these observations, it is interesting to note that there were only slight differences between the temperatures in the upper part of the bay and at its mouth; in other words, that the horizontal distribution of temperature along the whole area of Wareham River was nearly uniform. This is clear from an examination of Figure 5, where temperature readings taken at the surface of the water between 9.50 a. m. and 11 a. m. of August 25 are shown with the figures of salinity. One will notice that the temperature in the upper part of the river above Barneys Point was approximately 0.5° C. higher than that in the lower part of the river. These observations were made on a calm, warm day.

In a shallow body of water with a considerable range of tide, the hourly fluctuations of temperature may be quite large. The best method to study them is by installing a thermograph and obtaining a complete record for a given period of time. Unfortunately, because of the local conditions this was not feasible, and our records of hourly fluctuations of temperature refer only to three days, August 14, 28, and September 28, when readings were made at Station II every half hour between 5.20 a. m. and 6.30 p. m. The results of these observations are presented in Tables 1, 2, and 4. As can be seen from an examination of these tables, the greatest fluctuation in temperature (1.7° C.) was observed on August 28.

TABLE 1.—*Hourly fluctuations in the temperature and salinity*[1] *of water in Wareham River, August 14, 1926*[2]

Time	Station II		Station VIII[3]	Time	Station II		Station VIII[3]
	Temperature, °C.	Salinity, per mille	Salinity, per mille		Temperature, °C.	Salinity, per mille	Salinity, per mille
12.30 p. m.	26.0	28.31	28.36	4 p. m.	26.0	26.06	26.68
1 p. m.	26.0	28.49	28.69	4.30 p. m.	26.0	26.25	27.72
1.30 p. m.	26.1	28.53	28.85	5 p. m.	26.2	26.58	27.25
2 p. m.	26.5	28.36	28.98	5.30 p. m.	26.3	26.98	27.30
2.30 p. m.	27.0	24.66	27.00	6 p. m.	26.0	28.26	28.26
3 p. m.	26.0	25.39	26.00	6.30 p. m.	25.7	27.07	27.23
3.30 p. m.	26.2	25.33	26.20	7 p. m.	25.6	27.03	27.23

[1] Temperature and salinity readings given in this table were taken at the surface.
[2] High water at 11.55 a. m.; low water at 4.51 p. m. Range of tide, 2.8 feet.
[3] Observations at Station VIII were made 5 minutes after time shown.

Daily fluctuations of water temperature observed during July and August, 1926, are shown in Figure 6, together with the maximum and minimum air temperatures

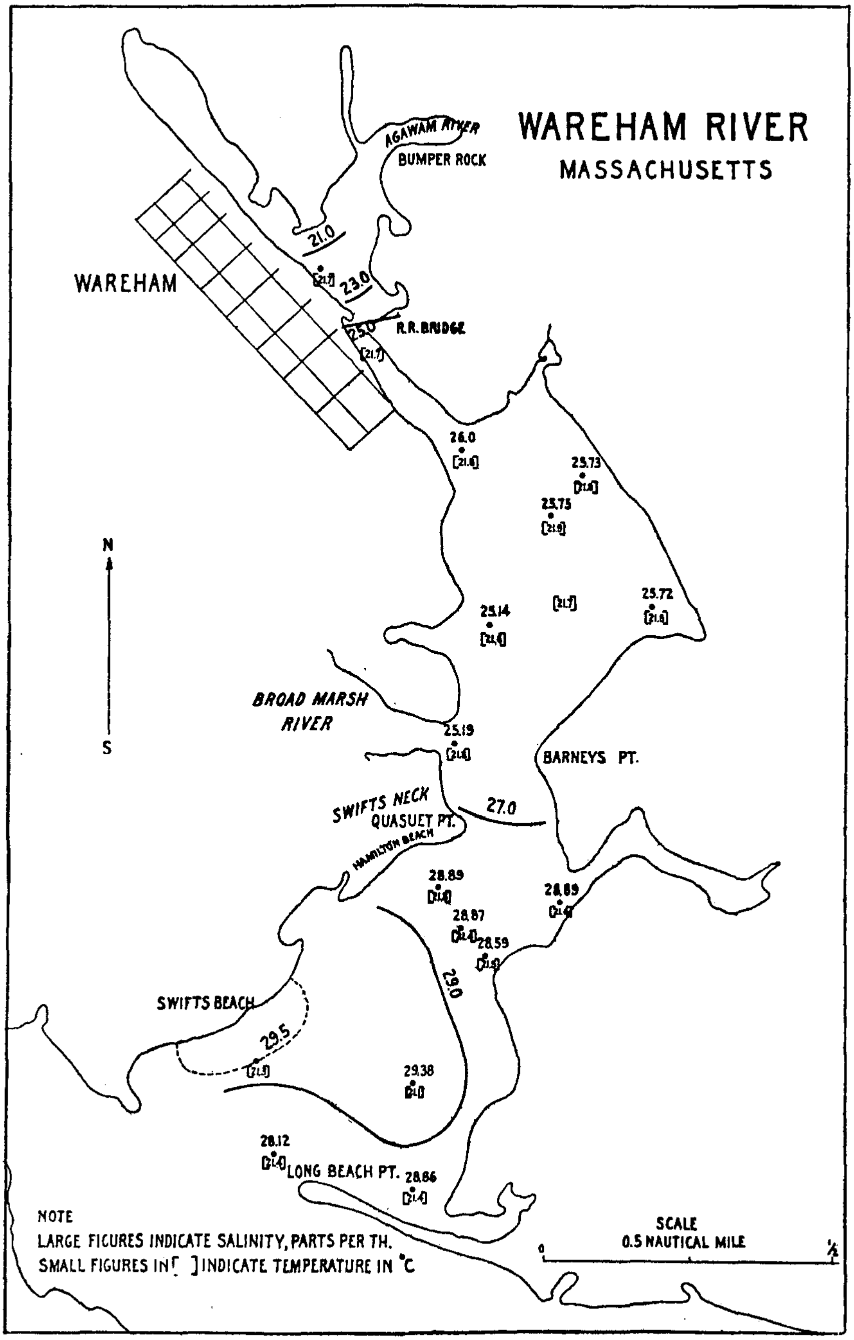

FIGURE 5.—Horizontal distribution of temperature and salinity in Wareham River, August 25, 1926, at low water. Isohalines are shown in heavy line. Large figures indicate salinity, per mille; small figures are degrees C.

recorded by the United States Weather Bureau station at East Wareham. By examining Figure 6, one can see that there were two distinct temperature maxima, the first on July 23 and the second on August 4, when the temperature of the water reached 27.0° C. and 28.0° C., respectively. The general rise and fall of the water temperature followed the fluctuations of the air temperature. It is interesting to note that the curve of water temperature approaches the curve of the maximum air temperature, although, as one should expect, the fluctuations in the temperature of the water are not so pronounced as those of the air temperature. The vertical

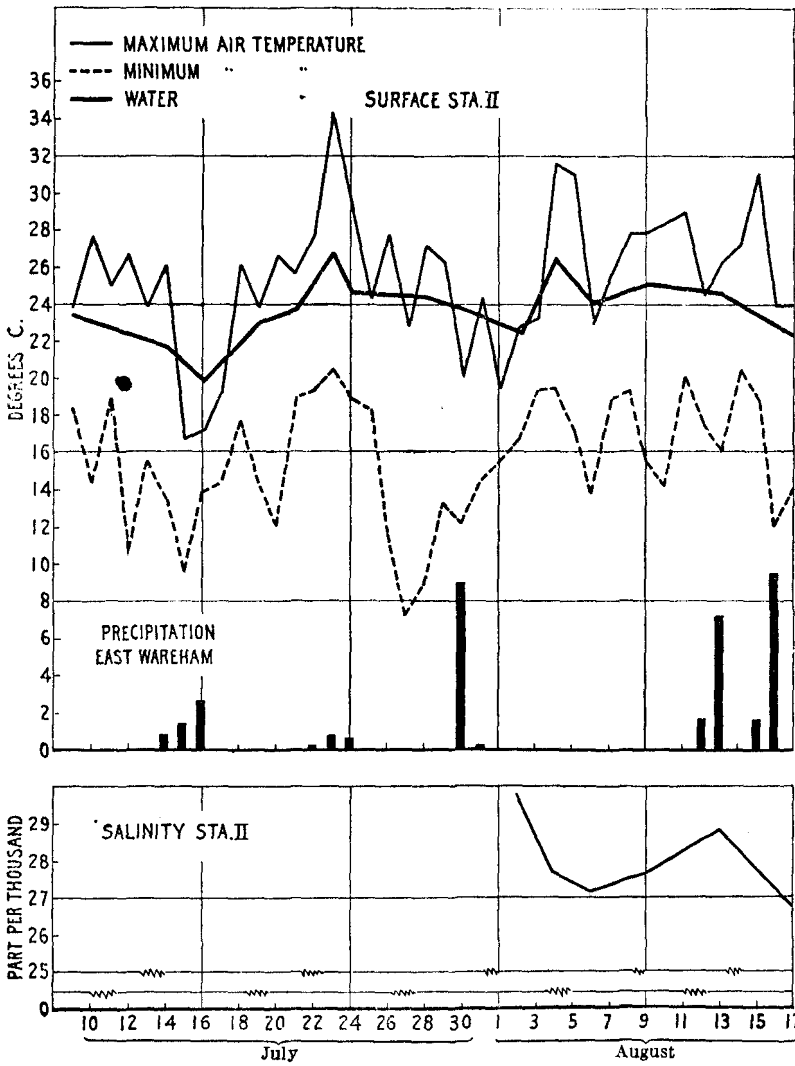

FIGURE 6.—Maximum and minimum air temperature, precipitation, temperature, and salinity of water in Wareham River, July–August, 1926

distribution of water temperature was rather uniform; slight differences between top and bottom temperatures, not exceeding 1.5° C. (July 23), were noticeable only in the channel.

SALINITY OF THE WATER

The salinity of water in Wareham River gradually decreases from about 30 per mille at its mouth to about 21 per mille in the upper part of the river near the railroad bridge. After rainy days, August 13 to 16 (fig. 6, Table 3), the salinity dropped to 7 per mille in the upper part of the river (Agawam River) and 26 at its mouth.

TABLE 2.—*Hourly fluctuations in the temperature and salinity of water in Wareham River, August 28, 1926* [1]

Time	Station II			Station I [2]		Time	Station II			Station I [2]	
	Temperature, ° C. (surface)	Salinity, per mille		Temperature, ° C. (surface)	Salinity per mille (surface)		Temperature, ° C. (surface)	Salinity, per mille		Temperature, ° C. (surface)	Salinity, per mille (surface)
		Surface	Bottom					Surface	Bottom		
9.30 a. m.	20.3	28.30	29.13	20.6	28.77	2 p. m.	21.6	26.56	29.74	21.1	29.56
10 a. m.	20.4	28.59	28.96	20.7	28.82	3 p. m.	21.7	27.06	28.55	21.2	28.80
10.30 a. m.	20.3		29.42			3.30 p. m.	21.7		28.24		
11 a. m.	20.3	29.57	29.46	20.5	29.37	4 p. m.	21.7	27.81	28.17	21.2	29.17
11.30 a. m.	20.6		29.75			4.30 p. m.	21.7		27.85		
12 noon	20.8	29.90	29.97	21.2	29.22	5 p. m.	21.7	27.36	27.39	22.0	28.96
12.30 p. m.	21.2		29.91			5.30 p. m.	21.8		27.81		
1 p. m.	21.3	29.52	29.90	21.0	29.45	6 p. m.	22.0	27.59	29.90	22.4	29.78
1.30 p. m.	21.3		29.96			6.30 p. m.				22.4	29.51

[1] High water at 12 (noon); low water at 5.23 p. m. Range of tide, 4.2 feet.
[2] Observations at Station I were made 5 minutes after time shown.

The horizontal distribution of the water of different concentrations of salt does not remain constant but is subject to fluctuations, depending on the stage of the tide and river discharge. A good idea of the distribution of salinities in relation to the stage of the tide can be gained by examining Figures 5, 7, and 8, showing the results of the observations made on the calm days of August 25 and September 27, when there was no mixing of water caused by the action of wind. All the observations were made within 1 hour and 10 minutes at high or low water. By comparing Figures 7 and 8, one can notice that in the upper part of the river the difference in the salinity due to the stage of the tide was 3 per mille, and that at high tide the salinity of 30 per mille extended over the entire lower half of the river.

TABLE 3.—*Temperature and salinity of the water at the surface of Wareham River, July to August, 1926*

Date	Station I		Station II		Station III		Station IV		Station V		Station VI		Station VII		Station VIII	
	Temperature, ° C.	Salinity per mille	Temperature, ° C.	Salinity per mille	Temperature, ° C.	Salinity per mille	Temperature, ° C.	Salinity per mille	Temperature, ° C.	Salinity per mille	Temperature, ° C.	Salinity per mille	Temperature, ° C.	Salinity per mille	Temperature, ° C.	Salinity per mille
July 9	24.2		23.5		24.0											
July 14	22.1		21.8		21.8		22.0		22.1							
July 16	19.8		19.9		20.1		20.1		19.0							
July 19	23.0		23.0		23.0		23.2		23.0							
July 21	24.6		23.7		23.7		23.8		23.4						23.6	
July 23	27.0		26.8		27.8		26.7				26.2		26.6		28.3	
July 26	24.0		24.7		25.2		24.7		25.3		24.4		24.7		25.0	
July 28	25.2		24.4		25.0		23.6		25.9		24.0		24.1		24.8	
July 30	22.0		22.8		22.6		22.3	21.18	23.4		22.3		22.3		22.6	
August 2	22.2	28.04	22.5	29.76			22.2	25.28	22.2	25.30	22.3	13.70	22.1	10.72	22.0	
August 4	28.0	27.14	26.5	27.70	27.5	26.88	26.7	17.13	28.2	14.72	28.0	9.83		18.51		
August 6	24.0	28.82	24.0	27.17			24.3	22.44	24.2	24.60	24.3	21.02	24.2			
August 9	25.3	28.16	25.0	27.66	25.2	28.94	25.8	21.26	25.2	27.93	25.2	21.28	25.3	18.22	26.0	27.81
August 13	24.8	29.58	24.5	28.86	24.3	29.18	26.0	23.17	26.0	23.15	25.7	20.25			25.2	29.32
August 17	22.3	26.87	22.2	26.77	21.5		23.0		23.0	7.12	23.0	7.12			22.3	

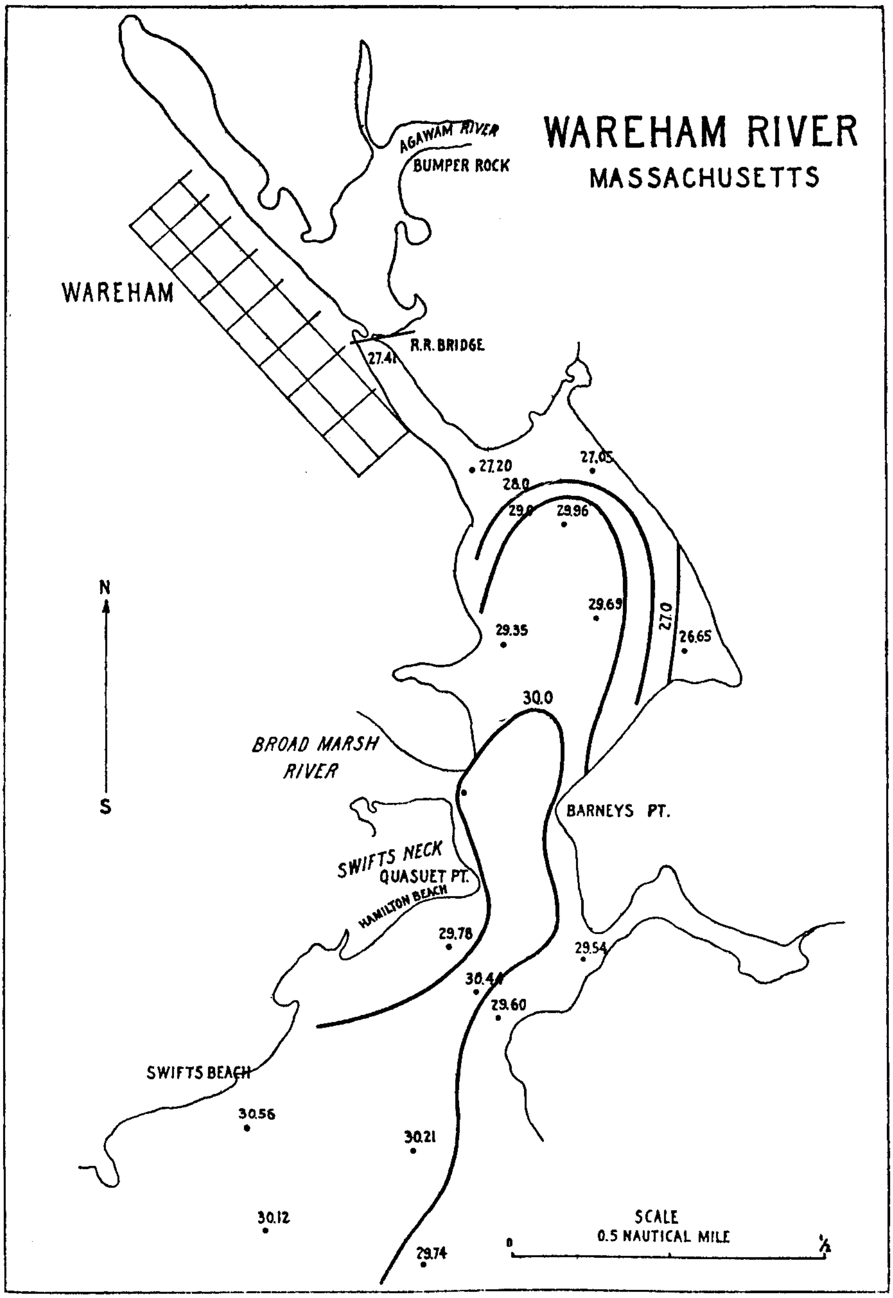

FIGURE 7.—Horizontal distribution of salinity (per mille) in Wareham River, September 27, 1926. High water, 12.05 p. m. to 1.10 p. m.

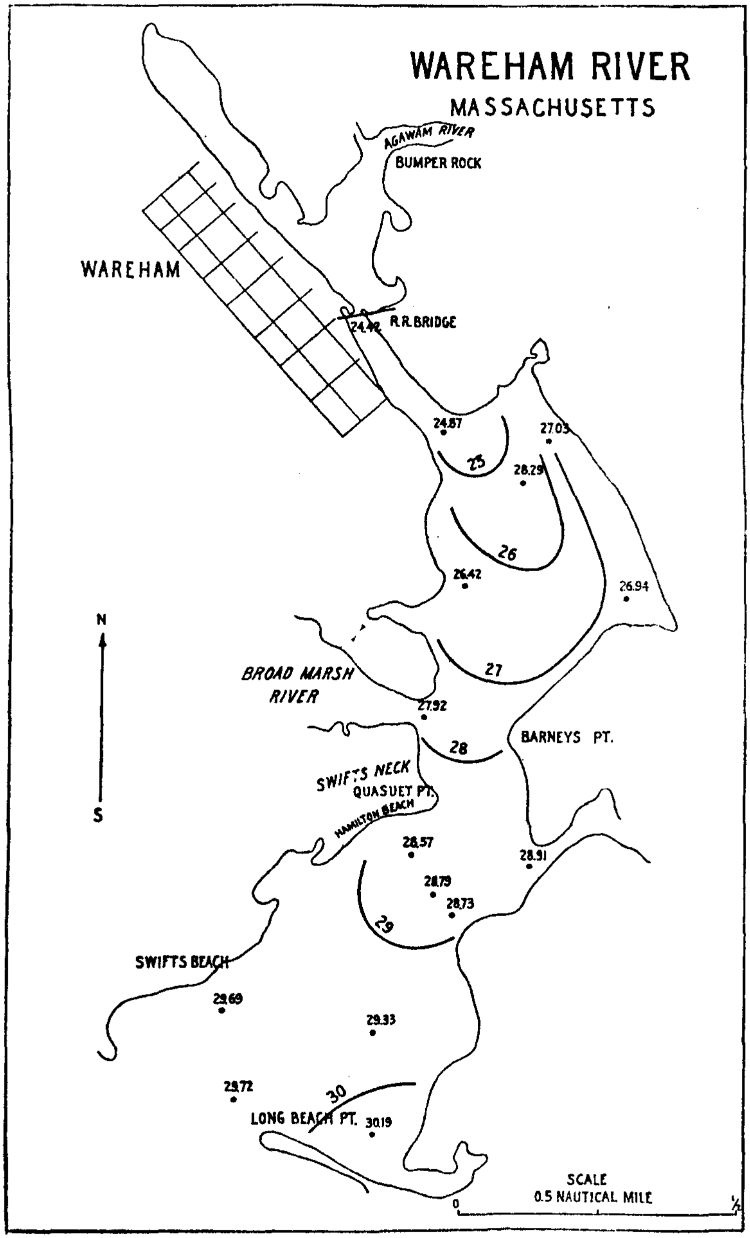

FIGURE 8.—Horizontal distribution of salinity (per mille) in Wareham River, September 27, 1926. Low water, 6.00 p. m. to 7.05 p. m.

TABLE 4.—*Temperature, velocity of the current, and salinity during flood tide in Wareham River, September 28, 1926* [1]

Time [2]	Station II, channel				Station I	Station III		Time [2]	Station II, channel				Station I	Station III	
	Temperature, ° C. (surface)	Current [3]		Salinity, per mille (surface)	Current [3] (surface)	Current [3] (surface)	Salinity, per mille (surface)		Temperature, ° C. (surface)	Current [3]		Salinity, per mille (surface)	Current [3] (surface)	Current [3] (surface)	Salinity, per mille (surface)
		Surface	Bottom							Surface	Bottom				
5.50 a. m.	17.5	3.0	15.2	28.69	------	------	28.91	11.20 a. m.	17.4	15.2	15.2	29.78	6.1	3.0	29.75
6.20 a. m.	17.5	6.1	18.3	28.73	0	0	28.86	11.50 a. m.	17.5	24.4	18.3	29.80	6.1	3.0	29.96
6.50 a. m.	17.5	0	12.2	28.86	0	3.0	28.87	12.20 p. m.	18.0	21.3	18.3	29.85	0	3.0	30.26
7.20 a. m.	17.8	18.3	18.3	28.84	3.0	0	28.87	12.50 p. m.	18.0	15.2	9.1	30.04	0	0	------
7.50 a. m.	17.5	18.3	18.3	28.96	3.0	0	28.71	1.20 p. m.	17.6	3.0	3.0	30.07	0	0	29.98
8.20 a. m.	17.5	6.1	12.2	29.33	3.0	3.0	28.82	1.50 p. m.	17.0	15.2	3.0	29.74	6.1	9.1	29.85
8.50 a. m.	17.5	6.1	12.2	29.01	6.1	6.1	29.15	2.20 p. m.	17.5	12.2	9.1	29.69	9.1	9.1	29.75
9.20 a. m.	17.5	18.3	15.2	29.51	6.1	3.0	29.46	2.50 p. m.	17.5	21.3	18.3	29.63	6.1	9.1	29.61
9.50 a. m.	17.5	30.5	24.4	29.46	6.1	3.0	29.52	3.20 p. m.	17.5	24.4	18.3	29.60	3.0	6.1	29.61
10.20 a. m.	17.5	12.2	9.1	29.63	6.1	3.0	29.66	3.50 p. m.	17.5	------	------	29.43	9.1	3.0	29.52

[1] Time of low water, 5.47 a. m.; high water at 1.02 p. m. Range of tide, 2.7 feet.
[2] Observations at Stations I and III were made 5 and 10 minutes, respectively, after time shown in column 1.
[3] Velocity of current is shown in centimeters per second.

TABLE 5.—*Velocity of the current and salinity of water during ebb tide in Wareham River, September 22, 1926* [1]

Time [2]	Station II, channel				Station I	Station III		Time [2]	Station II, channel				Station I	Station III	
	Current [3]		Salinity, per mille		Current [3] (surface)	Current [3] (surface)	Salinity, per mille (surface)		Current [3]		Salinity, per mille		Current [3] (surface)	Current [3] (surface)	Salinity, per mille (surface)
	Surface	Bottom	Surface	Bottom					Surface	Bottom	Surface	Bottom			
9.20 a. m.	------	------	------	------	------	3.0	30.18	12.20 p. m.	62.7	45.7	29.63	------	15.2	9.1	29.75
9.50 a. m.	48.8	33.5	29.78	------	6.1	6.1	30.08	12.50 p. m.	62.7	45.7	29.45	29.34	0	3.0	29.98
10.20 a. m.	54.9	33.5	29.81	30.12	12.2	12.2	30.01	1.20 p. m.	42.7	30.5	29.36	29.36	0	------	29.81
10.50 a. m.	61.0	42.7	29.80	------	12.2	12.2	30.10	1.50 p. m.	15.2	24.4	29.51	------	------	------	------
11.20 a. m.	61.0	42.7	29.70	------	15.2	12.2	29.96	2.20 p. m.	21.3	27.4	29.45	------	------	------	------
11.50 a. m.	62.7	45.7	29.64	29.75	15.2	9.1	29.85								

[1] Time of high water, 7.42 a. m.; low water at 1.38 p. m. Range of tide, 5.3 feet.
[2] Observations at Stations I and III were made 5 and 10 minutes, respectively, after the time shown in column 1.
[3] Current velocity is shown in centimeters per second.

Hourly fluctuations in the salinity of water were studied on August 14 and 28, and September 22 and 28. The results of the observations presented in Tables 1, 2, 4, and 5, and Figure 9, show that the maximum salinity occurs at the time of high water and that the salinity decreases with the receding tide. It is noteworthy that at Station II (fig. 9) there was a marked drop in salinity approximately 2 hours after the time of high water, followed by an increase in salinity at the time of low water. Similar changes, but occurring one hour later, were noticed at Station VIII (Table 1), located half a mile south of Station II. The sudden drop in salinity during ebb tide, followed by its sharp increase, can be explained by the influx of brackish waters from Broad Marsh River (fig. 1) which at high tide are held in check by the heavier waters of Wareham River. As soon as the water in Wareham River during the receding tide reaches a certain level, the water from Broad Marsh River begins to flow, lowering the salinity at Stations II and VIII and temporarily impounding the saltier waters farther up the Wareham River. These conditions account for unusual fluctuations in salinities observed at Stations II and VIII. During the changes from low to high water, the salinity rises gradually, reaching the highest figure at the time of high water.

TIDES

The mean range of tide in Wareham River is 4.1 feet; the spring range of tide is 4.9 feet.

The velocity of the current in the channel and on the bars was measured with the Price electric current meter. The results are shown in Tables 4, and 5, and Figure 10.

The highest velocity, 62.7 centimeters per second, was observed at two-thirds ebb on September 22 (spring tide). At flood tide on September 28, the changes in the current velocities were rather irregular (fig. 10). As can be noticed from an examination of Figure 10, the maximum velocity of the tide occurred between the times of high and low water, and the time of slack water nearly coincided with them.

The strength of the current running over the bars and oyster beds is much less than in the channel, its maximum velocity not exceeding 12 centimeters per second.

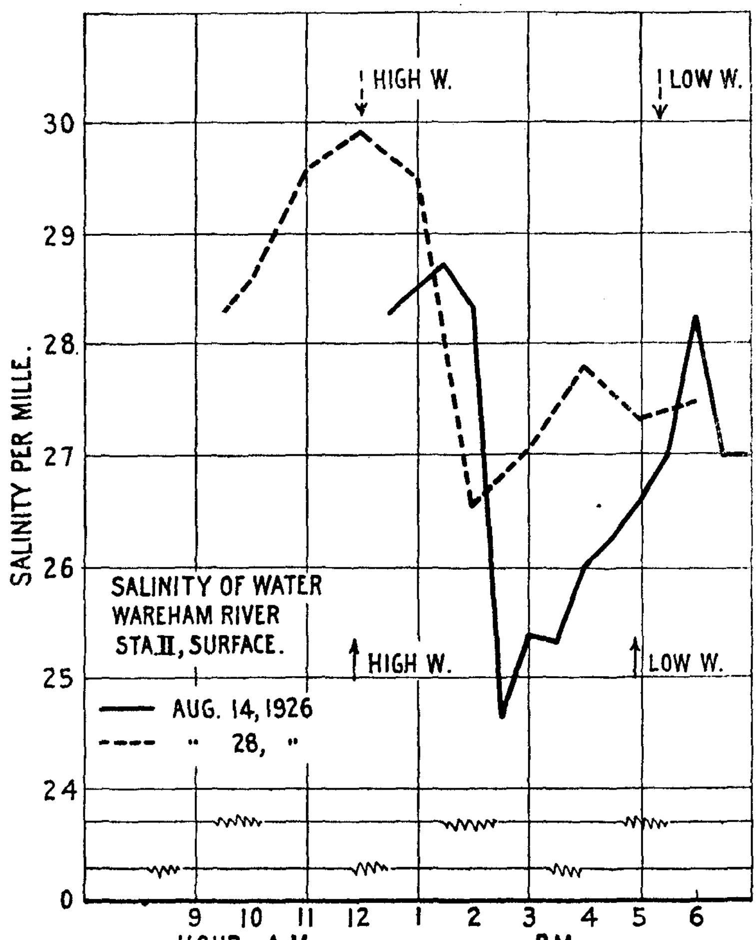

FIGURE 9.—Hourly fluctuations of surface salinity (per mille) during ebb tide, Station II, Wareham River, August 14 and 28, 1926

SPAWNING AND SETTING OF OYSTERS

Beginning July 9, plankton collections were made every other day at different stations by towing a plankton net made of No. 20 silk for 5 minutes; samples were preserved in formalin for further examination. The first occurrence of straight hinge oyster larvæ was recorded on July 21, and on the same day examination of oysters taken from the nearest bed showed that part of the oysters had spawned. Judging by the size, the larvæ were not over 2 days old; it can be concluded therefrom that spawning occurred on July 19 or 20, when the temperature of the water was about 23° C. The first spat (not over 1 day old) was noticed on the shells on August 6—15 days after the first appearance of the oyster larvæ in plankton. It is interesting to note that during July and August the oyster larvæ were very scarce in the plankton samples, although later on the setting in the harbor was heavy.

EXPERIMENTS WITH SPAT COLLECTORS

Crates filled with scallop and oyster shells were planted in three different localities in the river. On July 9, 24 crates containing oyster shells were placed at the north edge of the shell bed east of buoy S–20 (Station III) (fig. 4). On July 19, 13 crates filled with scallop shells were planted along the south side of Hamilton Beach, and 13 crates also containing scallop shells were planted at Swifts Beach. Scallop shells were used because no oyster shells were available at Wareham. The crates at Station III were planted 3 feet apart on the slope of the bar in four rows (figs. 11, 13) in such manner that the first row was always below low-water mark, the fourth row was entirely exposed at every low water, and the second and third rows occupied intermediate positions. One crate, placed on the top of the bar, was covered with water only at high tide. The difference between the levels corresponding to the top of the crate on the bar and the bottom of the crates in the first row was approximately 4 feet. Over the bar near which the crates were planted, scallop shells were scattered by the oystermen. The approximate dimension and shape of the area covered with scallop shells is shown in Figure 13. Because of the objection raised by the owner, who was afraid that planting of crates might affect setting on his bar, out of 24 crates only 1 was planted directly on the shelled area, the other 23 were set on the bottom where no planting was done. The crates were left undisturbed until the end of August, when they were examined and the number of spat in them counted. In order to make a comparison with the number of spat contained in the crates and on the bar, the latter was divided into 7 areas comprising 50 squares, from each of which a representative sample of shells was taken and the number of spat counted.

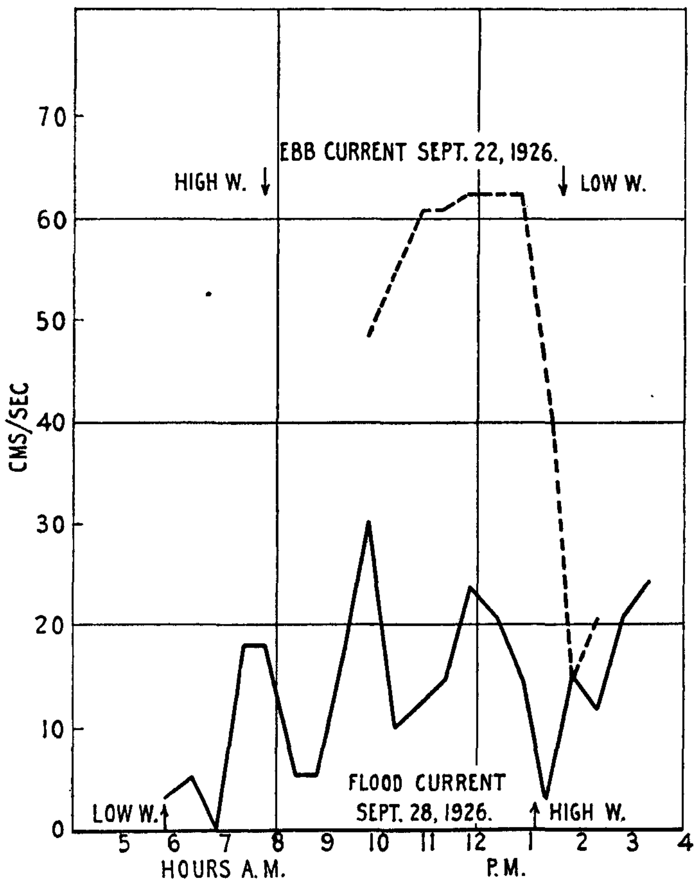

FIGURE 10.—Velocity of tidal currents in Wareham River, Station II, September, 1926

On the western side of the river, along Hamilton and Swifts Beaches (fig. 4), the crates were set between the tidal marks. During the period of 6 weeks that the crates were in the water, 11 of them were broken and carried out by the tide. All losses occurred in the crates planted on the western side of the river, where they were exposed to the action of waves. Those on the eastern side were well protected from heavy seas and sustained the test successfully.

Examination of the crates disclosed that scallop shells were not suitable for planting in the crates. In many of the crates a considerable portion of them was washed out, while those in the center were so ground up by the action of waves that they formed a solid mass of débris, which prevented the penetration of the larvæ. Much better results were obtained with oyster shells.

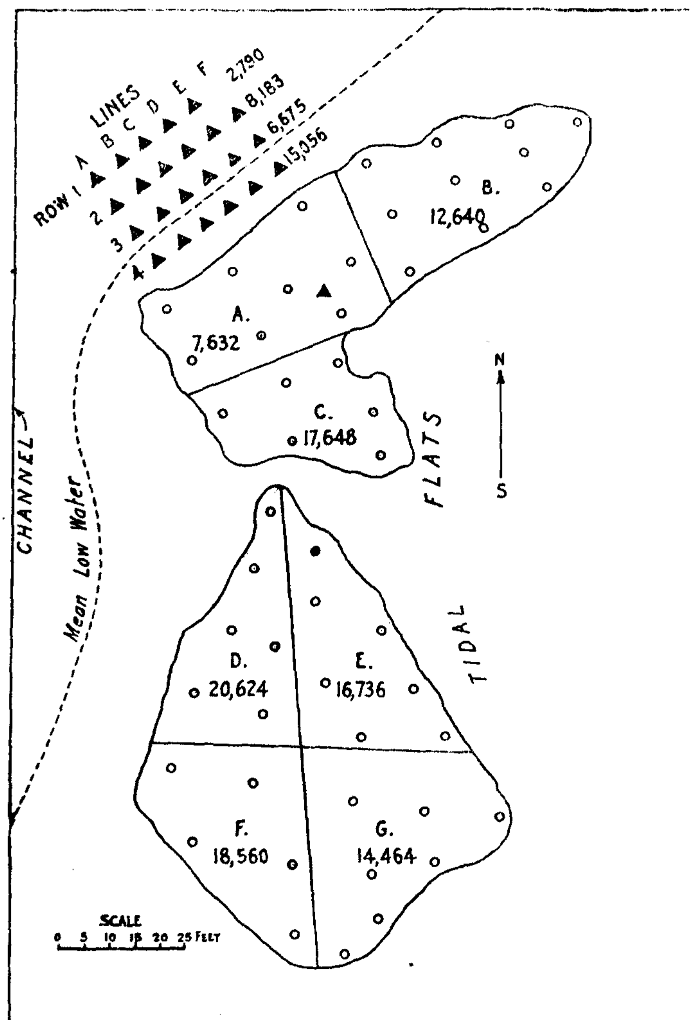

FIGURE 13.—Shelled beds and planted crates at Station III, Wareham River. Places from which samples of shells were taken are shown by o. Figures indicate average number of spat per bushel of shells. Location of crates is shown by triangles

When the counting of spat was begun on August 24, the spat had reached one-fourth of an inch in diameter and were easily noticeable on the surface of the shells.

The first problem to be studied was the distribution of spat within the crate. For this purpose the crate was divided into four horizontal zones or levels (fig. 14), and the abundance of spat in each zone was determined. In some of the crates a portion of the shells was washed out, and the remainder could be divided into three zones only. At every level shells touching lines *A*, *B*, and *C* (fig. 14, *A*) drawn from the center to each corner of the crate, were numbered from center outward and counts were made of the average number of spat per square inch of both shell surfaces. The results of the count of spat in one of the crates are presented in Table 6. The distribution of spat in various crates shows some variation, but it was noticeable that in all cases the concentration of spat at the top of the crate and in its corner was considerably greater than in its inner parts. From examination of shells taken from different portions of the crates, it was apparent that the oyster larvæ do not pene-

FIGURE 11.—Planting of crates in Wareham River

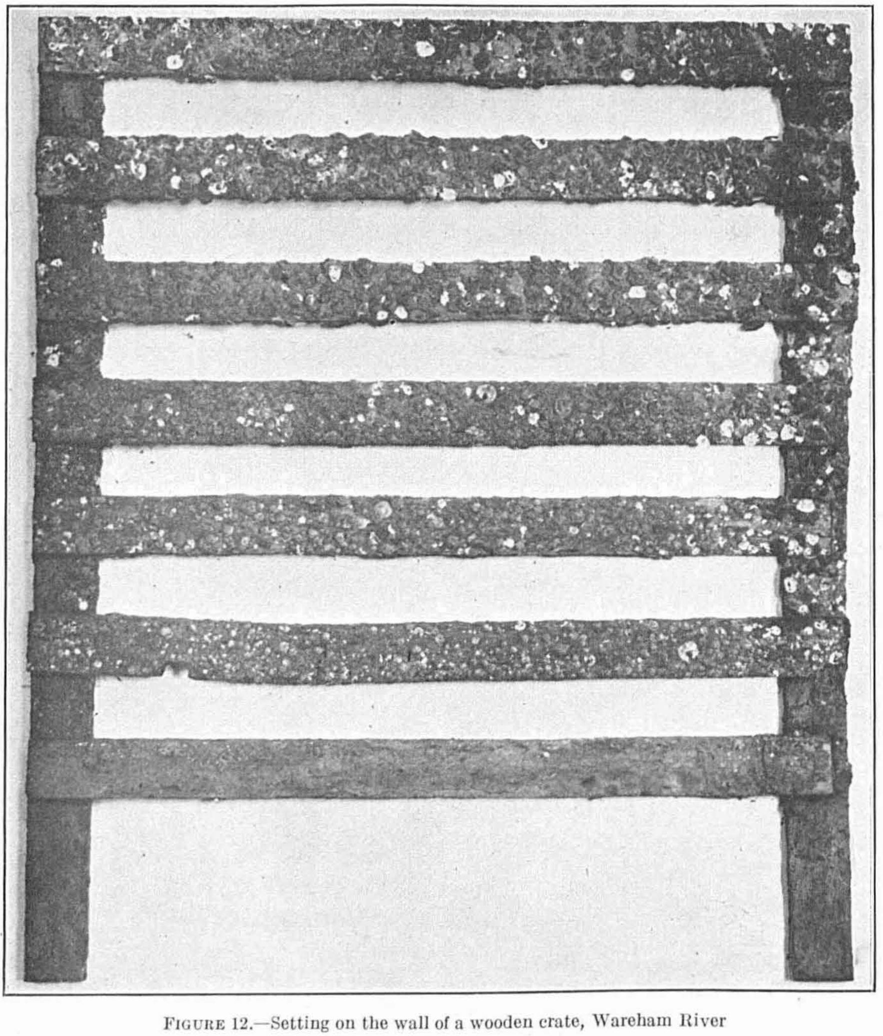

FIGURE 12.—Setting on the wall of a wooden crate, Wareham River

trate deeper than 6 inches from the surface and that the central portion of the crate had little value as a collector. This, however, can be easily improved by changing either the size or the shape of the crate. A more detailed analysis of the distribution of spat in the crate is given by Prytherch on pages 255 and 256.

TABLE 6.—*Distribution of spat within the crate* [1]

Shell No.	Level I			Level II			Level III			Level IV		
	A	B	C	A	B	C	A	B	C	A	B	C
1	1	6	4	4	1	0	0	0	0	0	0	0
2	26	8	9	1	1	1	0	0	0	0	0	0
3	24	9	7	0	0	9	1	0	0	0	0	0
4	20	6	1	0	0	1	5	0	1	0	4	0

Shell No.	Level I			Level II			Level III			Level IV		
	A	B	C	A	B	C	A	B	C	A	B	C
5	16	18	5	1	8	1	17	4	1	0	11	0
6	11	25	6	12	4	8	----	9	2	1	----	1
7	----	25	10	19	----	18	----	----	4	3	----	4

[1] The figures indicate the average number of spat per square inch of both shell surfaces. (For meaning of letters *A*, *B*, and *C* and levels I to IV, see fig. 13.)

In order to determine the number of spat caught in the crates, they were emptied the shells well mixed, and a number of them were taken at random and thrown into

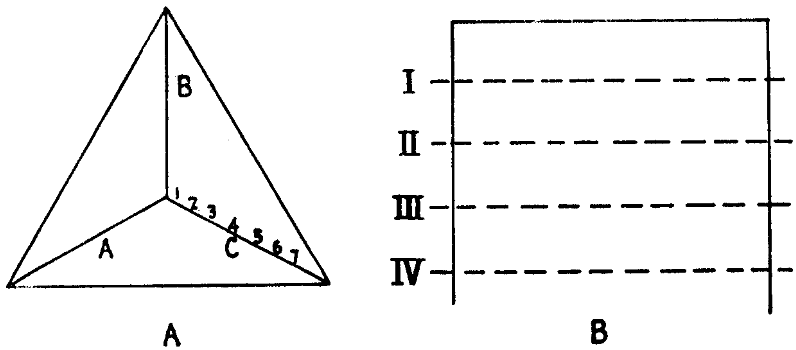

FIGURE 14.—Diagram showing the method of determination of the distribution of spat within the crate. *A*, Top view; *B*, side view

a 2-quart container. Then the number of spat on all the shells of the sample was counted. The results of the counts are presented in Table 7.

TABLE 7.—*Total and average numbers of spat caught in the crates*

Location	Number of crates	Total spat in crates	Average number of spat—	
			Per crate	Per bushel
Bar east of buoy S-2, Station II	24	436,500	18,188	9,094
Hamilton Beach	6	230,300	38,383	19,191
Swifts Beach	9	248,100	27,567	13,784
Total	39	914,900		
Average			23,459	11,729

All together in 39 crates there were obtained in round numbers 915,000 seed oysters. On the average there were 23,459 seed oysters per crate, or 11,729 per bushel.

Inasmuch as the crates were set in different localities and at different depths, and as some of them were filled with oyster while others were filled with scallop shells, it is of interest to analyze the results of the experiment in a more detailed manner.

We begin our discussion with the crates planted in front of Hamilton and Swifts Beaches. Thirteen crates were planted at each locality between the tidal marks. All the crates were partially exposed at low water and were set about 10 feet apart. A number of them were destroyed during the summer; only 6 crates remaining at Hamilton Beach and 9 at Swifts Beach. The wood of the crates was badly damaged by the shipworm and hardly was able to sustain the weight of the shells. The difference in the average number of spat per crate obtained in each locality was insignificant, 38,383 at Hamilton Beach and 27,557 at Swifts Beach; the variations in the number of spat in different crates (Table 8) were, however, very large.

TABLE 8.—*Number of spat caught in the crates*

Crate number	Spat per crate	Crate number	Spat per crate
HAMILTON BEACH		SWIFTS BEACH	
25	94,000	31	20,700
26	56,800	32	28,300
27	10,000	33	30,800
28	2,200	34	25,800
29	3,800	35	11,700
30	65,000	36	11,500
		37	21,800
Total	230,000	38	87,500
Average per crate	38,383	39	10,500
		Total	248,100
		Average per crate	27,567

The low figures in crates 27, 28, 29, 35, 36, and 39 were due to the fact that a considerable number of shells were washed out from these crates and the remainder represented what, at the time of setting, constituted the central portion of the crate.

The crates planted at Station II were less attacked by the shipworms, and none of them was lost during the season. They were filled with oyster shells, which, owing to the action of the waves, became by the end of the season more tightly packed, but none of which was either washed out or ground up, as happened with the scallop shells. On August 31 a representative sample of shells was taken from each crate and the number of spat was counted. The results of counting are given in Table 9.

The highest average intensity of setting, amounting to 30,117 spat per crate, was found in row 4, which was entirely exposed at low water; the lowest setting, averaging 5,580 per crate, took place in row 1, which was at all times submerged; while in rows 2 and 3 the setting averaged 16,366 and 13,350 per crate respectively. Counting the averages for every group of four crates in the lines *A* to *E*, we find no significant variations in the number of spat. This shows very conclusively that the zone of the most intensive setting was above the low-water mark. The maximum number of spat (50,100) was found in the crate set on the top of the bar above all other crates. (Fig. 13.)

TABLE 9.—*Spat caught in the crates planted at Station III, Wareham River.* (*See fig. 13.*)

Row No.	Line A	Line B	Line C	Line D	Line E	Line F	Average— Per crate	Average— Per bushel
1	14,100	2,300	5,200	1,900	3,900		5,580	2,790
2	21,800	8,200	5,000	20,100	15,700	26,800	16,366	8,183
3	16,100	9,100	17,400	6,300	15,700	15,500	13,350	6,675
4	16,700	48,500	18,000	47,100	24,000	26,400	30,117	15,058
Average per crate	17,175	17,025	11,850	18,850	14,825	22,900		

It is interesting to compare the setting in the crates with the setting on the shells (beds *A* and *B*, fig. 13). The beds are separated by only a few feet; they were mapped and divided into 7 areas comprising 50 squares, from which samples of shells were taken. The number of spat on the bed was determined by counting them on both surfaces of 10 shells taken at random from the top layer and from 10 shells at a deeper layer of the bed. It was noticed that there were many more spat on the upper layer of cultch than there was in its deeper layer. This can be seen in Table 10.

TABLE 10.—*Number of spat in top layer and in deeper layers of shells on shell beds*

Square No. 6	Average number of spat per square inch of shell		Square No. 6	Average number of spat per square inch of shell		Square No. 6	Average number of spat per square inch of shell		Square No. 6	Average number of spat per square inch of shell	
	Top layer	Deeper layer		Top layer	Deeper layer		Top layer	Deeper layer		Top layer	Deeper layer
Shell No. 1	13	0	Shell No. 4	4	2	Shell No. 7	3	0	Shell No. 10	14	1
Shell No. 2	12	1	Shell No. 5	12	0	Shell No. 8	8	0			
Shell No. 3	9	1	Shell No. 6	9	3	Shell No. 9	8	0			

In order to facilitate comparison, all the squares from which samples were taken were grouped in 7 large sections (fig. 13, *A–G*), and the average number of spat per bushel of shells was computed for each section separately. The intensity of setting over the beds varied from 7,632 spat per bushel in section *A*, located close to the fourth row of crates, to 20,624 in section *D*. The average intensity for both beds was 15,472 seed per bushel, approximately the same as that obtained in the fourth row of crates (15,058 per bushel). It should be borne in mind that oyster shells were planted in the crates, while scallop shells were scattered over the beds. The number of scallop shells per bushel is about 2½ times that of oyster shells; hence, because of the greater surface area exposed for the attachment of larvæ, the setting should be heavier on the former than on the latter. For practical purposes there is no advantage, however, in increasing the intensity of setting. In the case of oyster shells, a uniform set amounting to 3,000 spats per bushel can be regarded as an acceptable minimum. For fragile scallop or jingle shells, the figure should be higher.

The problem consists in increasing the productivity of seed oysters without increasing the intensity of setting. The comparison of setting in the crates with that on the bed should refer, therefore, not to the volumes of shells used, but to the unit of area over which shells or crates are planted. Each crate covers an area of 2 square feet, and a comparison of the number of spat found over this area on the bed with the number of spat in the crates gives us a true idea of the efficiency of the crate method. In order to make such a comparison, it is necessary to know the number of scallop shells planted over a unit area of the bed. It was found that on the average there were 86 scallop shells on each square foot of the bed and that 318 scallop shells formed one peck. Taking these figures as representative of the size of shells and the density of planting in Wareham River, we find that there were 0.27 pecks of shells planted on each square foot of the bed, or 0.54 pecks on each 2 square feet. Calculated on this basis, the number of spat per unit of 2 square feet in different sections of the bed is given in Table 11.

TABLE 11.—*Number of spat per bushel and per unit of area on shelled bed, Wareham River, Mass.*

Section	Spat per bushel	Spat in each 2 square feet	Section	Spat per bushel	Spat in each 2 square feet
A	7,632	1,030	F	18,560	2,506
B	12,640	1,706	G	14,464	1,953
C	17,648	2,382			
D	20,624	2,784	Average	15,472	2,089
E	16,736	2,259			

As has been shown above, the average setting in the crates of the fourth row, which was nearest to the bed, was 30,000 over 2 square feet, or about fifteen times greater than the average setting over the whole bed. If we compare the setting in the fourth row of crates with the setting in the nearest section A of the shelled bed, we find that seed production in the crates was nearly thirty times greater than that of the adjacent portion of the bed.

It is apparent from the results of the present experiment that the production of seed oysters over a given area of bottom can be greatly increased by the planting of shells in crates, thus utilizing three dimensions of the setting zone instead of only two. Furthermore, the setting area can be considerably enlarged by planting the crates on sand bars or soft mud flats, where ordinary scattering of shells is impossible. If necessary, the legs of the crates can be made longer to prevent their sinking into the soft bottom. As has been shown by the present experiments, the most intensive setting in Wareham River took place about 2 feet above the highest point on the bar where shells were planted. It is obvious that many more seed oysters could be obtained by planting cultch at this particular level. One would expect that more intensive planting might reduce the concentration of spat on shells, but as had already been mentioned, a great intensity of setting is not wanted, and for practical purposes 3,000 spat per bushel uniformly distributed can be regarded as a fair commercial set. For the successful growth of oysters, uniformity in distribution is of far greater importance than intensity of setting.

It has been shown that some of the crates were badly damaged by the shipworm and other wood-boring organisms and that the crates can be protected by dipping them into a solution made of 2 parts of lime and 1 part of cement. In 1928 several crates coated with this mixture were planted at the mouth of Crooked River near Wareham. They were not attacked by the boring organisms and sustained the experiments very well. It is interesting to note that wooden lath coated with a mixture of lime and cement affords a wonderful surface for the attachment of oysters. (Fig. 12.) In one of the crates the number of spat attached to the lath was counted by determining the number of spat over 1 square inch at 60 different places taken at random on the sides and bottom of the crate. The number of spat varied from 0 to 50 to a square inch, averaging 14.2. As the outside and inside surfaces of the crate have a total area of 1,730 square inches, the estimated number of seed oysters attached to this crate was 24,566. In determining the area of the crate, the surface of the edges of the lath, which was ¼-inch thick and was covered with seed oysters, was not taken into consideration. The market value of seed oysters which could be easily detached from the coated surface of the crate would pay completely for the cost of the crate, shell, and labor.

Experiments carried out in Wareham River proved 'hat the crate method has many advantages over ordinary planting, and that it particularly suitable for localities where setting is regular and where the production of seed osyters is the main business of the industry.

III. OBSERVATIONS AND EXPERIMENTS IN SEED-OYSTER COLLECTION IN ONSET BAY, MASS., 1927, 1928

By PAUL S. GALTSOFF and H. C. McMILLIN

BRIEF DESCRIPTION OF THE LOCALITY

Onset Bay is a small indentation of the northern end of Buzzards Bay, about 2 miles west of the entrance to the Cape Cod Canal. (Fig. 15.) The bay is about 2½

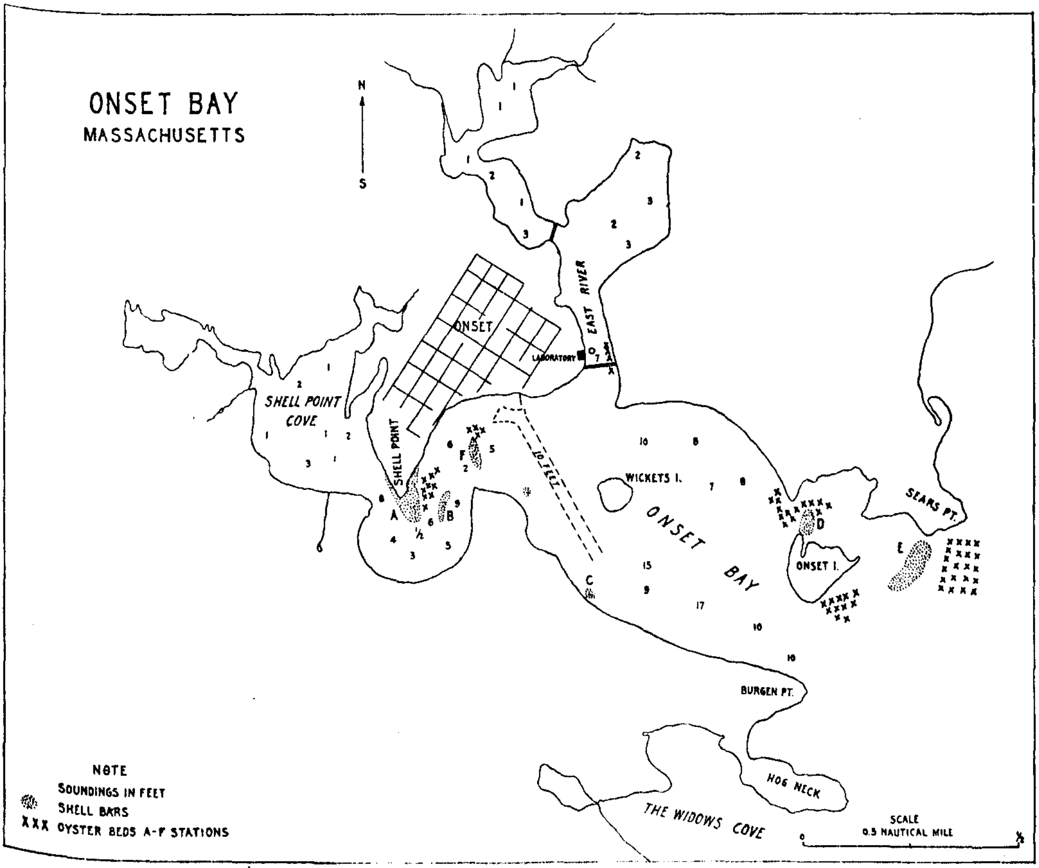

FIGURE 15.—Onset Bay, Mass.

miles long, not over half a mile wide, and has two islands—Onset Island at the entrance to the bay and Wicket Island in the middle of it. Numerous sand bars obstruct navigation in the bay. Outside of a dredged channel the depth of the water is from 1 to 17 feet at low tide. The shore line is very irregular, forming several points and coves. The bottom of the bay is generally hard and covered with a prolific growth of eel grass. A small amount of fresh water enters the bay through several mall creeks draining the surrounding low and marshy land.

At present there are no natural oyster bottoms in Onset Bay. Adult oysters and 3 years old are brought in every year from Long Island Sound, Delaware, and other places and planted here on hard and gravelly bottoms a few feet below low water. The general distribution of the beds is shown in Figure 15. According to local oystermen, there are only 12 acres in the bay that are considered good growing grounds and capable of supporting the growth of 500 bushels of oysters to each acre. The adult oyster population in the bay is changeable and varies depending on the commercial operations of the industry. Hence, it was impossible to ascertain accurately the number of oysters present at the beginning of the spawning season; it was estimated, however, that in July, 1928, there were at least 15,000 bushels of adult oysters in various sections of the bay.

The principal business of oystermen in Onset Bay is seed production, only a few native oysters being grown locally, as nearly all the crops of seed oysters is sold the first fall, before the onset of cold weather, which would kill the spat above the tide lines. The area devoted to catching of spat is rather small; it comprises 7 bars having a total area of about 8½ acres confined to the tidal land entirely exposed at low water. About 2,000 bushels of scallop, quahaug, or oyster shells are usually planted to each acre of bar.

Onset Bay has a well-established reputation as an excellent seed-producing area, where setting is usually very good. On the other hand, the area utilized for the production of seed is very small and the possibility of extending it has great importance to the local industry. These facts were the main reasons for selecting the place for the experiments with spat collectors.

The work in Onset was carried out during the summers of 1927 and 1928. Through the courtesy of the Schroeder & Besse Oyster Co., a space in the office building of the company was given for a temporary laboratory, and valuable assistance was rendered in supplying boats and equipment and in giving practical information concerning the oyster industry of the region. Under the general direction of P. S. Galtsoff, field observations were carried out in 1927 by Dr. E. B. Perkins and in 1928 by H. C. McMillin.

TEMPERATURE OF THE WATER

Temperature readings were taken daily at various stages of the tide at station A, off Shell Point (fig. 15), which was selected because Shell Point bar is the most important seed-producing area of the bay. On account of the shallowness of the place, only surface temperature was recorded. The results of the observations made in July–September, 1927 and 1928, presented in Figure 16 and Tables 12 and 13 show that except for five days in August, 1927, the temperature of the water during the 2-month period (July–August) was above 20° C., and that in both years the maximum temperature, 26.5° C. in 1927 and 26.1° C. in 1928, occurred in the second half of July.

An attempt to obtain a continuous record of the temperature of the water was made in 1928 when a thermograph was installed on a float anchored in East River just above the bridge. (Fig. 15.) Unfortunately on July 14 the thermograph was lost in a gale which swept Cape Cod and produced strong waves even in a well protected harbor. The thermograph records obtained for 13 days from June 29 until July 13, show that during this period the maximum fluctuation of the temperature within each 24-hour period was 4°.

TABLE 12.—*Temperature and salinity of the water at the surface of Onset Bay near Shell Point, July–September, 1927*

[Observations were made between 10 a. m. and 5.30 p. m.]

Day of the month	July		August		September		Day of the month	July		August		September	
	Temperature, ° C.	Salinity, per mille	Temperature, ° C.	Salinity, per mille	Temperature, ° C.	Salinity, per mille		Temperature, ° C.	Salinity, per mille	Temperature, ° C.	Salinity, per mille	Temperature, ° C.	Salinity, per mille
1	20.5	28.28	23.3	27.11	20.0	------	17	22.8	28.40	21.7	26.58	------	------
2	20.8	27.75	23.3	27.05	21.1	26.31	18	22.8	29.27	20.5	26.42	------	------
3	21.7	28.55	23.3	26.38	21.7	27.00	19	21.1	27.83	18.9	26.44	------	------
4	21.1	28.03	24.4	26.00	22.2	------	20	21.1	28.55	18.3	29.65	------	------
5	21.1	28.35	24.4	26.58	22.2	------	21	21.7	27.83	18.3	26.49	------	------
6	21.7	27.63	24.2	26.62	22.8	26.26	22	21.4	28.03	19.4	26.11	------	------
7	20.5	29.87	25.0	26.02	22.5	25.30	23	21.4	28.82	21.1	26.56	------	------
8	21.1	28.55	23.9	26.02	22.2	24.44	24	22.2	26.35	21.7	27.16	------	------
9	21.1	27.43	23.9	26.56	22.2	------	25	22.5	28.13	20.5	25.01	------	------
10	21.1	26.91	23.3	26.06	------	------	26	24.7	28.28	21.1	27.27	------	------
11	22.2	27.39	23.9	26.82	------	------	27	23.3	27.86	20.8	26.18	------	------
12	21.7	27.01	24.4	26.62	------	------	28	23.3	27.88	20.5	------	------	------
13	22.2	27.86	24.2	25.30	------	------	29	26.5	27.57	20.5	------	------	------
14	23.9	28.17	------	26.82	------	------	30	26.2	27.25	19.4	24.99	------	------
15	------	28.62	22.2	26.67	------	------	31	23.3	27.94	20.3	26.38	------	------
16	23.3	29.22	22.3	25.90	------	------							

TABLE 13.—*Temperature and salinity of the water at the surface of Onset Bay, near Shell Point, July–August, 1928*

Date	Time	Temperature, ° C.	Salinity, per mille	Date	Time	Temperature, ° C.	Salinity, per mille	Date	Time	Temperature, ° C.	Salinity, per mille
July 2	1.45 p. m.	24.4	27.36	July 17	10.11 a. m.	24.1	28.03	July 30	3.10 p. m.	23.9	28.01
3	11 a. m.	25.0	27.64	18	1.45 p. m.	26.1	27.84	31	11.07 a. m.	23.7	27.99
5	12.05 p. m.	24.0	28.24	19	10.40 a. m.	25.1	28.16	Aug. 2	9.55 a. m.	22.9	28.31
6	1.51 p. m.	21.3	27.77	20	12.03 p. m.	24.6	28.16	3	10.05 a. m.	24.1	28.45
7	3.06 p. m.	20.4	28.30	21	8 a. m.	21.8	28.16	6	10.46 a. m.	23.1	28.77
9	10.46 a. m.	22.7	28.51	23	9.50 a. m.	21.7	27.70	9	2.43 p. m.	23.9	28.73
10	8.50 a. m.	22.8	27.97	24	8.20 a. m.	22.0	27.21	10	9.55 a. m.	24.3	28.73
12	5 p. m.	23.1	29.17	25	9.16 a. m.	26.1	27.17	13	11.35 a. m.	24.5	29.11
13	9.45 a. m.	22.3	27.84	26	7.19 a. m.	21.9	27.72	20	8.45 a. m.	24.4	29.85
16	10.15 a. m.	23.4	26.83	27	8.15 a. m.	22.9	27.72	31	3.07 p. m.	25.7	29.66

A study of the horizontal distribution of the temperature of the water was made in 1928 with the view of determining whether there were any significant differences in the temperature at different sections of the bay. Observations were carried out on calm and warm days of June 17 and 26, August 20, and September 4. Twenty-nine stations were distributed uniformly over the whole area from the head of the bay to its mouth, and surface temperature readings were taken within less than 90 minutes. On June 17 observations were made at half flood; on June 26 records were taken both at low and high water; on August 20 at high water; and on September 4 at low water. The results of these observations, presented in Table 14, show no significant differences in the temperatures of the water in various sections of the bay. It can be noticed that on June 26 the temperature of the water in the lower section of the bay (stations 25–29) was less than 1° cooler than it its upper part. On August 20 the lowest temperature (23.7° C.) was observed in the middle of the bay (station 13) and the highest (25.6° C.) close to the sand flats (station 22); the temperature in the upper part of the bay (station 1) was 25° C. On September 4, observations made at low tide early in the morning (between 4.40 a. m. and 5.54 a. m.) show that the temperature of the water in the upper part of the bay (station 2) was 1.2° C. less than in the middle part.

The nearly uniform horizontal distribution of the temperature and the fact that there is but slight change in the temperature of the water during one complete tidal cycle (June 26) indicate that the comparatively cool water of Buzzards Bay, which enters Onset Bay with the flood tide, warms up when passing through the shallow channels at the entrance of the bay and by coming in contact with the exposed and warm tidal flats.

TABLE 14.—*Horizontal distribution of temperature and salinity at the surface of Onset Bay, summer 1928*

Station number	June 17, 1928			June 26, 1928						Aug. 20, 1928			Sept. 4, 1928		
	High water at 7.00 a. m.			Low water at 7.51 a. m.			High water at 3.16 p. m.			High water at 10.05 a. m.			Low water at 3.53 a. m.		
	Time	Temperature, ° C.	Salinity, per mille	Time	Temperature, ° C.	Salinity, per mille	Time	Temperature, ° C.	Salinity, per mille	Time	Temperature, ° C.	Salinity, per mille	Time	Temperature, ° C.	Salinity, per mille
UPPER SECTION															
	a. m.			*a. m.*			*p. m.*			*a. m.*			*a. m.*		
1	8.37	19.3	28.60	8.27	19.2	27.05	3.31	19.7	28.84	11.56	25.0	29.72	5.51		27.64
2	8.41	19.5	28.21			26.98	3.28	19.8	28.48	11.54	24.9	29.79	5.52	20.8	26.97
3	8.45	19.7	27.92			27.57	3.25	19.8	28.41	11.53	25.0	29.66	5.49		27.23
4	8.49	19.0	27.65			27.78						29.66	5.47		27.77
5	8.52	19.3	28.19			28.13	3.17	19.6	29.13			29.72	5.45		28.78
6	8.57	19.6	28.31			28.33			28.78	11.44	24.6	29.05	5.49		28.39
7	9.00	19.1	28.71			28.73			28.93			29.72	5.40	21.1	28.78
8	9.04	19.4	29.58	8.53	19.0	28.66	3.09	19.4	29.05			30.05	5.39		28.31
9	9.08	19.1	29.33			28.73			29.13	11.36	24.8	29.85	5.37		28.26
MIDDLE SECTION															
10	9.12	19.2	29.27			28.86			29.13	11.34	24.4	29.92	5.34		28.65
11	9.14	19.3	29.40			28.89	3.00	19.0	29.38			30.12	5.30		27.50
12	9.25	19.0	29.38	9.00	19.0	28.13	2.55	19.2	28.98			30.12	5.28		27.17
13	9.35	18.8	29.67			28.59			29.23	11.25	24.3	30.12	5.27		27.70
14	9.38	18.9	29.98			29.13	2.52		30.71			30.05	5.25	22.0	27.14
15	9.41	18.8	29.85			28.60	2.50	19.2	29.45	11.22		30.32	5.22		28.85
16	9.45	19.0	29.52			28.46	2.48	19.4	29.58			30.12	5.20		29.02
17	9.47	19.0	29.17			28.21	2.44		29.09			30.12	5.18		28.45
18						28.66	2.41	19.4	29.45	11.15	23.7	30.12	5.17		29.11
19				9.22	18.8	28.79	2.39		29.65			30.18	5.12		28.85
20						29.10			29.98	11.10	23.4	30.44	5.10	21.1	29.38
21				9.27	18.6	29.20			29.93	11.07		30.18	5.08		30.01
22				9.30	18.5	29.33			29.92	11.03	25.6	30.25	5.05		29.01
23				9.42	18.6	29.33	2.27		30.05	11.00	24.6	30.25	5.03	21.2	29.40
24						29.72	2.24	19.5	29.85	10.37	24.2	30.18	4.53		29.33
LOWER SECTION															
25						29.99			30.05			30.44	4.50		29.88
26						30.13			30.13	10.52		30.70	4.46	21.3	29.88
27						30.19			30.12	10.43		30.44	4.44		29.72
28				10.04	18.5	30.07			30.12			30.44	4.43		29.46
29				10.07	18.4	30.07	2.14	18.9	30.12	10.57	24.2	30.50	4.40		30.05

SALINITY

Daily observations of salinity made in the summers of 1927 and 1928 (fig. 16) by means of hydrometer readings show that during the first summer the concentration of salts varied from 24.99 to 29.07 per mille; during the second summer, the fluctuations were from 27.65 to 29.85. By examining Figure 16 one can see that the lower salinities of the summer of 1927 were apparently due to the higher precipitation during that year.

A study of the horizontal distribution of salinities was made in 1928 on the days when the distribution of the temperature was studied. It is clear from the examination of Table 14 and Figure 17 that the salinity increases from 27.05–29.72 at the head of the bay to 30.05–30.50 at its entrance. At low tide the differences in the salinities at the head of the bay and at its entrance were 3.02 per mille on July 26

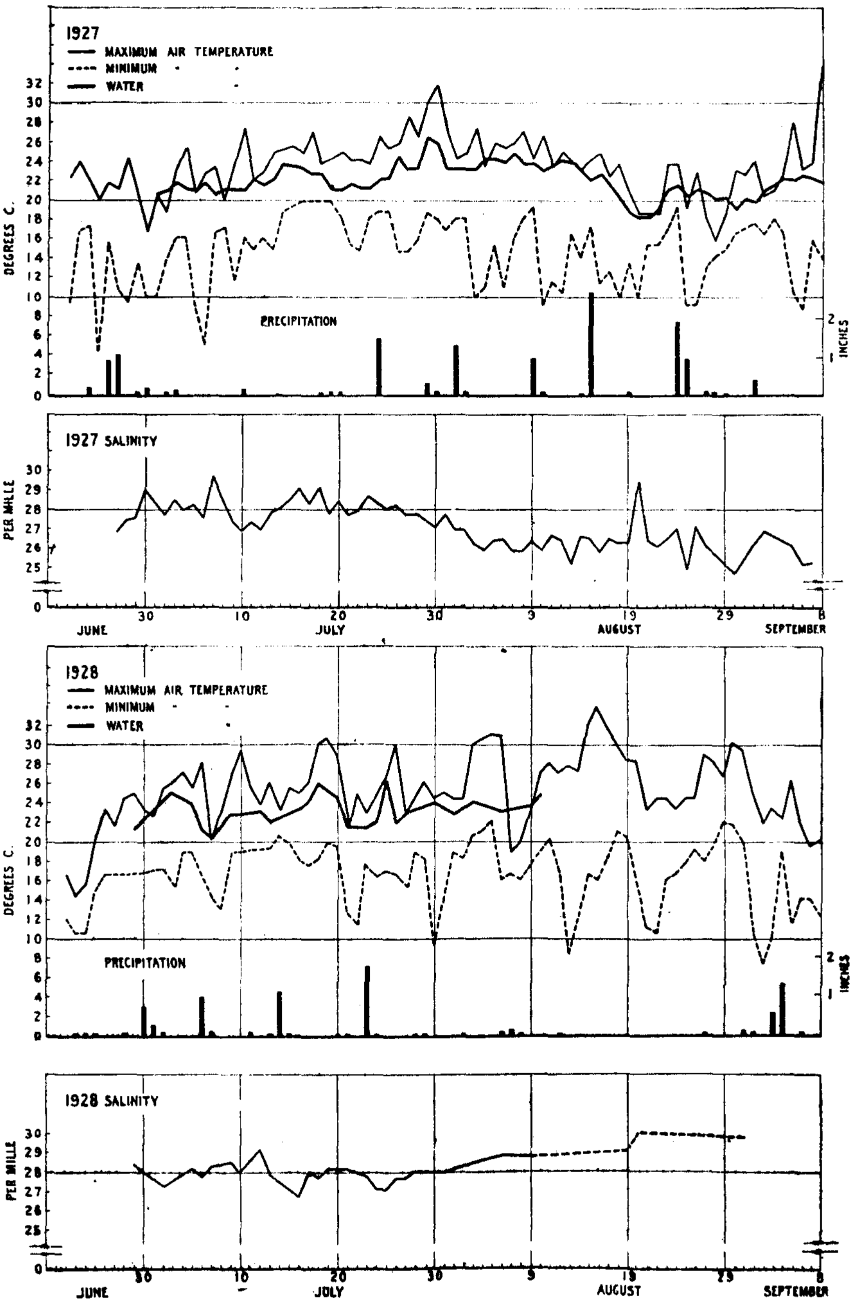

FIGURE 16.—Maximum and minimum air temperature, precipitation, water temperature, and salinity (per mille) in June and September, 1927 and 1928. Onset Bay, Mass.

and 2.41 per mille on September 4. At high water the salinity throughout the bay was higher, the difference between the head of the bay and its lower section being only 1.28 (June 26) and 0.78 (September 4).

TIDES

The mean range of tide in Onset Harbor is 4.1 feet and the spring range is 4.9 feet. The observations of the rise and fall of the tide were made on the tidal gage set up at the end of Shell Point. One of the points of interest in a study of tidal phenomena is the determination of the time of slack water in relation to the stage of tide. It has been shown by Prytherch (1929) that oyster larvæ in Milford Harbor were most abundant during the low slack water periods when the current velocities were from

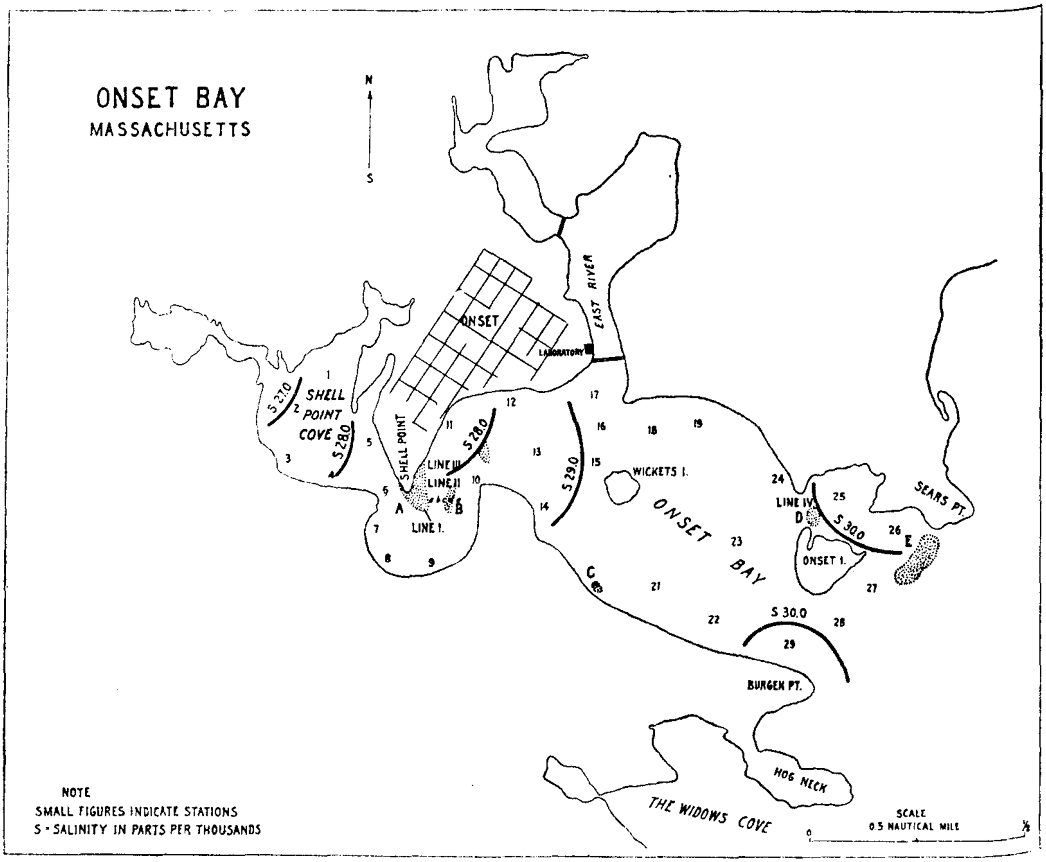

FIGURE 17.—Horizontal distribution of salinity in Onset Bay, September 4, 1928, at low water. Small figures indicate stations; large figures indicate salinities (per mille)

0 to 18.3 centimeters (0.6 foot) per second, and that they ceased swimming when the current velocity exceeded this figure. Hence, the determination of the exact time of slack water and of its duration in relation to the stage of tide may have some bearing on the understanding of the factors which cause the aggregation of the larvæ during the setting period in a definite zone. The determination of the time of high slack water was made on a very calm day, August 3, 1928, when the rise of the water and surface tidal currents were observed at very brief intervals by watching the tidal gage and noticing the movement of small floats thrown on the surface of the water.

TABLE 15.—*Observations of the height of the tide and the time of slack water, Onset Bay near Shell Point, August 3, 1928*

Time	Height of tide	Current	Time	Height of tide	Current	Time	Height of tide	Current	Time	Height of tide	Current
a. m.	′ ″		a. m.	′ ″		a. m.	′ ″		a. m.	′ ″	
8.03	4 4.7	Flood.	8.43	4 7.3	Slack water.	8.54	4 7.5	Ebb.	9.55	4 3.7	Ebb.
8.15	4 5.4	Do.	8.49	4 7.6	Do.	9.30	4 4.2	Do.	10.15	4 0.2	Do.
8.30	4 7.2	Do.	8.50	4 7.6	Ebb.	9.45	4 4	Do.			

It can be noticed from the examination of Table 15 that the maximum height of tide occurred 6 minutes after the slack water and that the period when there were no surface currents lasted only 7 minutes. On account of slow currents which can not

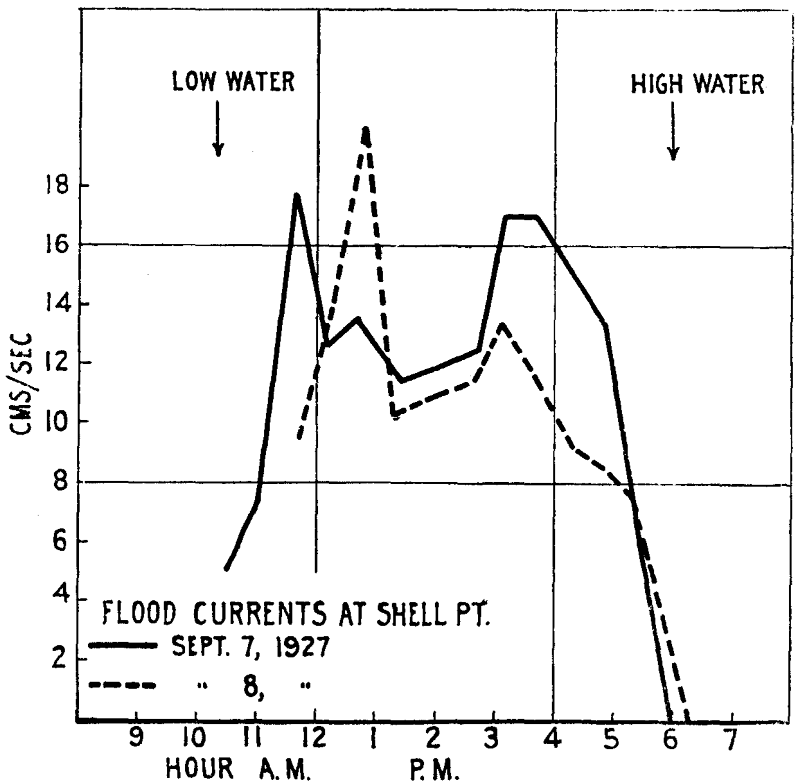

FIGURE 18.—Surface flood currents in the channel at Shell Point, September 7 and 8, 1927

be recorded with the current meter, such observations are possible only on very calm days. It is unfortunate that weather conditions did not permit repeating them several times and determining the time of slack water at low tide; the latter, however, is of less significance, because the zone of the heaviest setting in Onset Harbor is above low-water mark.

The velocity of tidal current in any inshore body of water is determined by two factors: The volume of water that flows through the channel past a given point, and the cross sectional area at this point. In a shallow bay like Onset Bay with an irregular shore line and numerous bars obstructing the free passage of water, the tidal movements do not conform with the comparatively simple motion that takes place in an unobstructed channel or in a wide, deep river. On account of changes in the cross sectional areas due to the slope of the bar the irregularity in the horizontal movements of water flowing over the bar is more pronounced than it is in the channel.

Current-meter readings were made on calm days when there was only slight interference caused by the wind. The results of the observations are presented in Figures 18, 19, 20. It is obvious from an examination of Figures 18 and 19 that the periods of slack water in the channel near Shell Point occur about the times of the tide, and that the strength of the tide comes between the times of high and low water. In this respect tidal conditions at Onset Harbor, like those of Long Island Sound, present the characteristics of stationary wave motion. An interesting feature of the tidal currents at Shell Point is the appearance of two velocity peaks during the flood tide, which are probably due to a temporary piling up of water in a

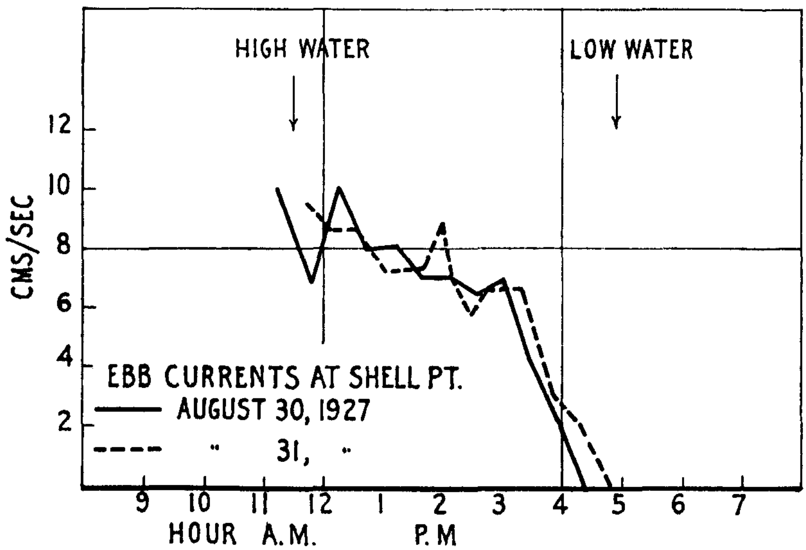

FIGURE 19.—Surface ebb currents in the channel at Shell Point, August 30 and 31, 1927

narrow entrance at Shell Point (see fig. 15) and blocking the horizontal movement of water on the bar. The maximum velocity (20 centimeters per second) was observed during flood tide. As can be noticed from Figures 18 and 19, flood-tide currents in Onset Harbor are stronger than ebb currents, and the changes in the velocities during the receding tide are more gradual than they are during the flood tide.

From a biological point of view, it is of interest to determine the current velocities on the bar which is exposed at low water and where, as had been determined by previous observations, the setting of oysters is usually good. Because of the gravelly bottom over the bar, the receding tides leave no pools of water; hence the oyster larvæ that set on the bar are undoubtedly brought in with the incoming or outgoing tide. Observations made on July 30 (fig. 20) show that flood-tide currents on the bar are rather irregular and reach higher velocities (73 centimeters per second) than in the channel, and that the difference between the velocities at flood and ebb currents is even more pronounced than it is in the channel.

SPAWNING OF OYSTERS AND OCCURRENCE AND DISTRIBUTION OF OYSTER LARVÆ

The time of spawning of oysters in Onset Harbor was ascertained by studying the plankton and noting the first appearance of the oyster larvæ and by examining the gonads of the adult oysters. In the summer of 1927 plankton was collected with a small plankton net made of bolting silk No. 20, and weighted on its under side which bore a protecting strip of linen, so that the net could be dragged over the bottom or towed at any desired level. Five-minute tows were made every day at the surface, along the bottom, and at a level midway between. By towing at the same speed each time a fair estimate of the relative abundance of the larvæ could be

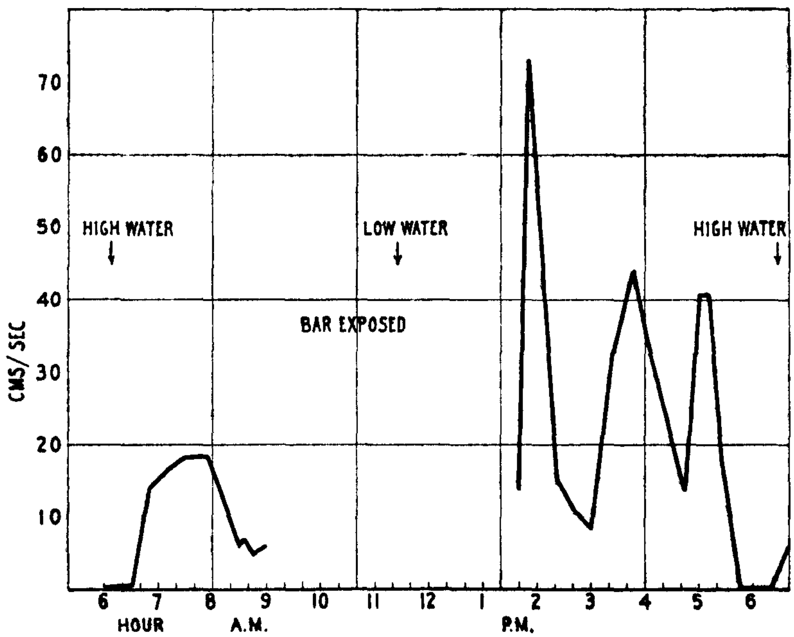

FIGURE 20.—Surface tidal currents at Shell Point bar, July 30, 1928

obtained. In 1928 quantitative plankton samples were taken by means of a rotary pump and a hose lowered to the desired level. Each time 50 liters of water were pumped and filtered through bolting silk No. 20. In 1927 the first straight hinge oyster larvæ were observed on July 14; the spawning probably occurred a day or two before when the temperature of the water was about 22° C. A few straight hinge larvæ, varying in number from 1 to 8 in a sample, were found in daily plankton samples collected during the second part of July. On July 29–30 their number increased, and from 35 to 80 young larvæ were found in some of the samples. This can be regarded as an indication of a second spawning, which coincided with a second rise of temperature. (See fig. 6.) Small numbers of larvæ were found in plankton during the first half of August; after August 15 they disappeared completely.

TABLE 16.—*Occurrence of oyster larvæ in plankton samples collected in Onset Bay during the period July 20–August 28, 1927* [1]

	Surface	Middle	Bottom
Number of samples in which oyster larvæ were found	16	19	14
Maximum number of oyster larvæ found in the sample	75	80	35
Minimum number of oyster larvæ found in the sample	1	1	1
Total number of oyster larvæ found in all the samples	143	298	102
Average number of oyster larvæ per sample	9	15	7

[1] 74 samples that contained no oyster larvæ are not included.

The results of the examination of plankton samples made in 1927 are presented in Table 16, which shows the number of samples containing the oyster larvæ and the maximum and minimum number of the larvæ in the sample. All the samples are grouped in three groups according to the level of water from which they were taken. Of 123 samples collected by Perkins during the period from July 20 to August 28 and examined by the senior author, oyster larvæ of various sizes were found in 49 samples. Altogether, only 543 oyster larvæ were found in all the samples—the maximum number in one sample being 80. It is interesting that, in spite of the scarcity of the larvæ in the plankton samples, setting, as will be shown later, was fair and in the zone between 0.5 and 2 feet above low water varied from 4,200 to 8,000 spat on a bushel of shells. Because of the small number of the larvæ found in plankton, it was impossible to study their vertical distribution and to correlate their occurrence with the physical or chemical factors of the environment. An examination of the table shows, however, that the greatest number of larvæ was found in the middle zone.

Full-grown larvæ were very scarce; out of 48 of them collected between August 3 to 10, 34 were found in the bottom samples. (Table 17). The first spat was observed on shells on August 1, but setting continued until August 15. The heaviest setting apparently occurred on or about August 10.

TABLE 17.—*Occurrence of umbo larvæ in plankton samples taken between August 3–15, 1927*

Date	Number of umbo larvæ in sample				Date	Number of umbo larvæ in sample			
	Surface	Middle	Bottom	Total		Surface	Middle	Bottom	Total
Aug. 3		4		4	Aug. 12	2			2
Aug. 8	1	6	[1] 10	17	Aug. 13			14	14
Aug. 9			2	2	Aug. 15			7	7
Aug. 11	1		1	2					

[1] Large larvæ ready to set.

In the summer of 1928 quantitative plankton samples were taken by McMillin at different stations in the harbor. The first larvæ were noticed on July 2; they had already passed the straight hinge stage and probably were from 4 to 6 days old. On July 12, when the temperature of the water was about 23° C., a distinct change was noticed in the character of the gonads of the adult oysters, indicating that they had released part of their spawn, but very few oyster larvæ of various sizes were found in plankton until the end of July. A clear idea of the scarcity of the oyster larvæ in plankton samples can be gained from an examination of Table 18, which contains the results of the quantitative plankton collection made at frequent intervals at Shell Point. In spite of the scarcity of oyster larvæ the setting on this bar, as will be shown later, was very abundant, varying from 40,000 to 67,000 per bushel of shells. Throughout the spawning season the number of the larvæ collected in various sections of the bay amounted to 146 found in 49 samples. (This figure does not include 43 larvæ collected in 68 samples taken on July 17.)

TABLE 18.—*Occurrence of oyster larvæ in plankton at Shell Point, Onset Harbor, from June 29 until August 3, 1928*

Date	Time	Temperature °C.	Number of larvæ in 50 liters	Date	Time	Temperature °C.	Number of larvæ in 50 liters	Date	Time	Temperature °C.	Number of larvæ in 50 liters
June 29	2.05 p. m.			July 12	5 p. m.	23.8		July 21	8 a. m.	21.8	2
July 2	2.15 p. m.			13	9.54 a. m.	22.8		23	9.50 a. m.	21.7	
3	11.45 a. m.	25.5		16	9.30 a. m.	22.6	9	24	8.25 a. m.	22.0	
5	2.15 p. m.	24.0		17	10.11 a. m.	24.1	2	25	1.06 p. m.	24.8	9
6	2 p. m.	21.3		18	1.45 p. m.	26.1	9	26	7.19 a. m.	21.9	
8	3.06 p. m.	20.4	2	19	10.40 a. m.	23.1		Aug. 2	8.13 a. m.	22.0	
9	11 a. m.	22.7		20	12.03 p. m.	24.2	1	3	10.10 a. m.	24.1	
10	8.50 a. m.	22.8	2								

A study of the relation between the occurrence of larvæ in plankton and the stage of the tide was made on July 17 at the station located at the end of the shelled area off Shell Point. Observations, consisting in taking quantitative plankton samples from top and bottom, continued without interruption from high slack water at 6.25 a. m. until the beginning of ebb at 6.45 p. m. One can notice from an examination of Table 19 that few oyster larvæ were found only during the morning ebb tide. Unfortunately, the small number of larvæ found in plankton samples makes it impossible to draw a definite conclusion regarding the relation between their behavior and the stage of the tide.

TABLE 19.—*Occurrence of oyster larvæ in plankton at different stages of tide on July, 1928, Shell Point Bar* [1]

Time	Tide	Number of larvæ in 50 liters				Time	Tide	Number of larvæ in 50 liters			
		Straight hinge		Umbo				Straight hinge		Umbo	
		Surface	Bottom	Surface	Bottom			Surface	Bottom	Surface	Bottom
6.25 a. m.	Ebb	2	0	0	0	8.40 a. m.	Ebb	3	1	1	1
6.40 a. m.	do	3	0	0	3	9 a. m.	do	3	0	0	0
7 a. m.	do	3	0	3	0	9.20 a. m.	do	0	0	0	0
7.20 a. m.	do	2	0	1	0	9.40 a. m.	Low slack	0	0	0	0
7.40 a. m.	do	0	0	0	0	10 a. m.	do	0	0	0	0
8 a. m.	do	4	2	1	1	10.20 a. m.	Flood	0	0	0	0
8.20 a. m.	do	3	2	1	2	10.40 a. m.	do	0	0	0	0

[1] No oyster larvæ were found in 48 samples taken at 20-minute intervals from 11 a. m., until 6.40 p. m.

An attempt to study horizontal distribution of the larvæ in a limited area of the bay was made on July 30; plankton samples were taken from the surface, middle zone, and bottom at seven stations along the line between Shell Point and the point on the southern shore of the bay. (Fig. 15.) The result of the observations, presented in Table 20, show that there was a slight concentration of the oyster larvæ in the vicinity of Shell Point.

TABLE 20.—*Horizontal and vertical distribution of oyster larvæ near Shell Point, Onset Bay*

[Sample of 50 liters]

Depth	Stations [1]						
	A	a	b	c	B	d	e
Surface	9	14	8	3	2	1	2
Middle			4			3	
Bottom	21	2	2	3	9	1	

[1] For location of stations see Figure 15.

The failure to take large numbers of oyster larvæ in the plankton during the two consecutive summers can be explained by either a faulty method of collecting or the behavior of the larvæ. Experiments carried out by the bureau in Great South Bay, where many thousands of oyster larvæ were collected by pump or in plankton tows, show that in this body of water, with very small range of tide, larvæ are easily obtainable by either method. It is, therefore, permissible to assume that the failure to collect oyster larvæ in plankton in Onset Bay was due to their behavior. The fact that at Shell Point the velocity of flood current is greater than the velocity of the ebb current may explain the absence of larvæ from plankton during the flood tide. It is quite probable, however, that besides the velocity of the current other conditions govern the behavior of the larvæ. The problem calls for an experimental study that should be carried out under controlled laboratory conditions. It is doubtful that it could ever be solved by field observations where on account of the complexity of conditions and the impossibility of eliminating various factors, the results obtained are often contradictory and their interpretation is difficult.

The conclusion can be drawn from the examination of plankton collections that the small number of larvæ, or even their absence in plankton samples taken in the inshore waters with strong tidal currents, does not necessarily show the failure of oysters to spawn in this locality and can not be regarded as indicative of ensuing poor setting. In the attempt to predict setting in such a region, more weight should be given to the conditions of the gonads of oysters and to the temperature of the water over the oyster bottoms than to the presence of free swimming larvæ.

After the 15th of July, shells from each bar were examined daily to determine the exact time of setting. On July 23 full grown larvæ were found in the bottom sample taken at Stony Bar. (Station *G*, fig. 15.) The following day a few spat were found on shells at Manoman Bar. (Station *C*, fig. 15.) On July 25 spat appeared on the shells all over the bay, and on July 26 the setting was complete, or at least the larvæ that attached after this date were not numerous enough to make themselves evident.

EXPERIMENTS WITH SPAT COLLECTORS

The commercial seed catching areas in Onset Bay are located on flat bars between mean low water and 2 feet above that level. The oystermen have learned by practice to restrict their shelling operations to these limited sections of the bay and to scatter the shells over the bars only in the zone which is exposed at low tide. No cultch is planted beyond low-water mark, where, according to the opinion of local oystermen, no setting takes place.

A series of experiments with wire-bag collectors was devised to determine the extent of the setting area and to find out the effect of elevation (with the reference to the low-water mark) upon the density of setting. In 1927, 950 bags were planted at 9 stations; they were placed either singly on the bottom, stacked in a group of 6 or 8 (fig. 21, 22), or piled irregularly on the bars. In order to determine the level of maximum setting, 400 bags were arranged in 8 rows at Shell Point extending across the bar from 1 foot below low-water mark to 4 feet above. After September 1, 10 bags were taken at random from every row, emptied, the shells were well mixed up, and 1 peck of them taken for counting the spat. The results of the counts are presented in Table 21. Although there was a considerable variation in the number of spat in the bags of the same row, it is evident from an examination of Table 21 and Figure 23 that the maximum density of setting occurred in the zone of from 1. 5 to 2 feet above low-water mark. No setting was found at high-water level (4 feet). It has been noticed also that the spat was well distributed throughout each bag, only about 10 per cent of shells being blank. From a commercial point of view, the setting in the bags planted in various sections of the bar was fair; in the zone between low-water mark and 2 feet above, it averaged 5,898 spats to a bushel. Setting on shells thrown on the bar averaged 6,990 spats to a bushel and was more uniform than it was in the individual bags. (Table 22.) This shows that both loose shells and those in the bags have approximately the same concentration of spat, but taking into consideration the area of the bottom covered by one bushel of scattered shells and by one bag, the productivity in the bags was much higher. On the surface of Shell Point bar in the zone between 0. 5 and 2 feet above low water, there was on the average 86 scallop shells over each square foot, or about 0. 6 bushel of shell to a square yard (there were about 1,300 scallop shells to one bushel) bearing about 4,200 spats. Three bags laid horizontally over the area of 1 square yard at the same level caught on the average 5,900 spats to a bushel of shells or 17,700 spats per square yard. Thus the productivity in the bags was four and two-tenths times that of the shells scattered over the same area. By stacking the bags in various formations it is possible to put 8 or 10 of them over one square yard of the surface of the bar, thus utilizing the whole height (4 feet) of the setting zone and increasing its productivity materially.

TABLE 21.—*Vertical distribution of setting (number of spat per bushel) in Onset Bay, near Shell Point, 1927*

[Wire-bag collectors]

Bag No.	Position of the bag in relation to low water							
	−1 foot	Low water	+0. 5 foot	+1 foot	+1. 5 feet	+2 feet	+3 feet	+4 feet
1	2, 000	3, 100	2, 200	4, 700	12, 200	6, 700	2, 500	No set.
2	3, 100	6, 900	2, 800	3, 400	7, 800	7, 000	1, 400	Do.
3	2, 000	2, 700	6, 000	3, 700	3, 200	9, 400	1, 200	Do.
4	1, 300	3, 100	6, 800	4, 200	7, 900	12, 900	1, 100	Do.
5	3, 500	5, 300	7, 500	5, 900	8, 200	4, 800	1, 100	Do.
6	2, 300	4, 500	6, 200	3, 600	8, 400	4, 400	3, 500	Do.
7	2, 200	4, 000	6, 900	3, 000	6, 200	12, 600	3, 000	Do.
8	1, 900	4, 900	6, 600	5, 100	4, 200	6, 000	2, 200	Do.
9	900	5, 800	6, 800	4, 500	10, 700	4, 000	1, 600	Do.
10	1, 400	4, 800	6, 100	4, 000	6, 200	2, 000	4, 000	Do.
Average	2, 050	4, 510	5, 790	4, 210	8, 000	6, 980	2, 160	

TABLE 22.—*Number of spat per bushel of scallop shells taken between 0.5 and 2 feet above low-water mark at Shell Point Bar, Onset, 1927*

Sample number	Spat per bushel	Sample number	Spat per bushel	Sample number	Spat per bushel	Sample number	Spat per bushel
1	6,800	4	7,500	7	6,400	10	6,600
2	7,700	5	7,200	8	7,200		
3	6,100	6	6,600	9	7,800	Average	6,990

The results of setting experiments on Middle and Stony Bars are shown in Table 23. From each bar 10 bags were taken at random from an area just above low water and the number of spat was counted. The results show that setting in the bags was heavier than on loose shells, although the difference was not great. Several bags filled with oyster shells and lowered to 5 or 6 feet below low-water level at the side of the main channel in Onset Bay caught a set averaging 8,000 to a bushel. These observations show that although the zone of heaviest setting occurs above low-water mark on the exposed bars, certain areas under water can be successfully utilized by planting bags filled with oyster shells.

TABLE 23.—*Setting on Middle and Stony Bars, Onset Bay, 1927*

Location	Number of spat per bushel (bags)			Number of spat per bushel (loose shell)		
	Average	Maximum	Minimum	Average	Maximum	Minimum
Middle Bar (station F)	11,200	19,300	5,600	7,700	9,700	6,100
Stoney Bar (station E)	8,400	11,800	5,200	6,300	10,500	3,700

Experiments carried out in 1928 were the repetition of those made in the summer of 1927 and were undertaken with the purpose of checking up the results obtained in the previous year. Over 100 wire bags filled with oyster or scallop shells were planted on Shell Point and at Sherman Bar (fig. 15, *A*, *D*); over 700 bags were planted also on Shell Point by Schroeder & Besse Co. All the bags were examined by McMillin in August and the setting on them was recorded. At Shell Point 21 bags were placed in 3 lines (fig. 15) extending from the middle of the area devoted to commercial seed production (about 1.5 feet above low water) to 3 feet below low water. The bags on line 1 which ran lengthwise of the bar and off the end of the point in a southeasterly direction were placed about 12 feet apart. Along lines 2 and 3 which ran at right angles to the eastern side of the bar the bags were about 4 feet apart below low water and 6 feet apart above low water. Bags on lines 1 and 3 contained oyster shells; those of line 2 were filled with scallop shells. One line (No. 4) comprising 8 bags filled with oyster shells was placed on Sherman Bar, Onset Island. In August, when the set was large enough to be easily seen with the naked eye, the bags were taken up and the number of young oysters was counted. In 3 bags the spat on every shell was counted but it was found that 1 peck of well-mixed shells gives a representative sample, and that by this way the number of seed per bushel could be calculated with an error of less than 5 per cent. The results of the experiments are presented in Table 24 and Figure 23. The maximum setting at Shell Point occurred about 1 foot above low-water mark where the number of spat per bushel varied from 41,800 to 68,700 spat per bushel. Setting below low-water mark was less heavy, varying from 2,000 to

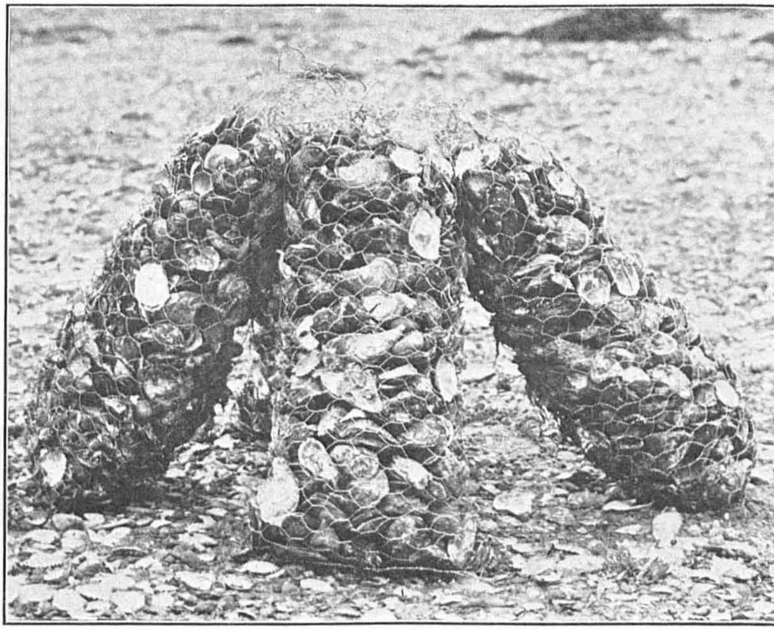

Figure 21.—A group of four wire bag collectors, Shell Point, Onset Bay

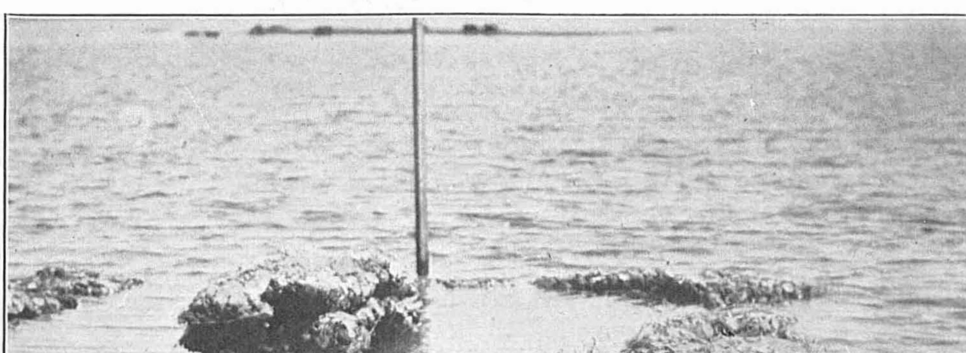

Figure 22.—Wire bag collectors planted at Shell Point, Onset Bay

27,700 spat per bushel. No significant differences were observed in setting along the three different lines.

TABLE 24.—*Vertical distribution of set in Onset Bay, 1928*

[Wire-bag collectors]

Height in relation to low water (feet)	Spat per bushel				Height in relation to low water (feet)	Spat per bushel			
	Shell Point Bar			Sherman Bar		Shell Point Bar			Sherman Bar
	Line 1	Line 2	Line 3	Line 4		Line 1	Line 2	Line 3	Line 4
+2.0				1,900	−0.5		27,700		11,900
+1.5				5,700	−1.0	11,400	2,300		
+1.3			41,800	12,400	−1.5	8,600	5,100	14,700	7,400
+1.0	44,800	68,700	64,400	10,800	−2.0		3,800	11,600	
+0.5	48,300	61,200	55,400	17,300	−2.5	10,500		19,200	
Low water	33,700				−3.0	4,800	2,000		

At Sherman Bar (line 4, Table 24) the largest number of seed (17,300 per bushel) was found at 0.5 foot above low water. This level is about 1.5 feet below the area

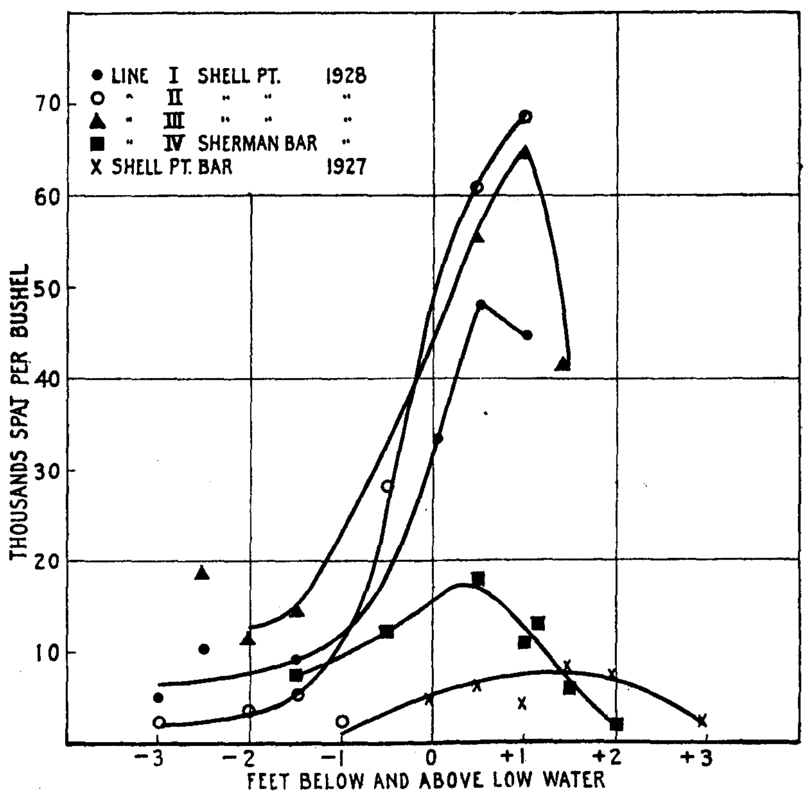

FIGURE 23.—Vertical distribution of setting in wire bag collectors planted in Onset Bay, 1927 and 1928

upon which shells were scattered by commercial oystermen. It is obvious that the productivity of this bar would be materially increased by grading it down until its entire surface is 1.5 below the present planted area. In most of the bars the areas upon which shells are planted by the oystermen do not extend beyond 1.5 feet below low water; yet, as the observations show, a fairly good set can be obtained at 3 feet below low water and probably deeper. Thus the productivity of all the bars can be greatly increased by extending the shelled areas below low water and by planting bags on muddy bottoms where loose shells would be lost.

An attempt was made to catch set in a very shallow body of water known as Shell Point Cove, located just above Shell Point. The cove, which is locally known as Sunset Bay, has never been used for collecting of seed. There is a general opinion, based on the experiments made several years ago by local oystermen, that the bay is unsuitable for catching of seed and that the shells thrown over its bottom never will catch any spat. Several bags planted there in July 1928, 1 and 2 feet below low water, caught however, from 6,800 to 7,900 spat per bushel.

It appears that the whole area of Shell Point Cove, comprising several acres of barren bottom, can be utilized for catching seed oysters and can be converted into productive ground.

In 1928 the number of blank shells (having no spat) in the bags was not over 1 per cent as compared to 10 per cent of blanks found in the previous summer. The smaller percentage of blank shells in 1928 is undoubtedly due to much heavier setting during that year. An exception to this was found in the bags planted 3 feet or more below low-water mark; 75 per cent scallop shells and 5 per cent of oyster shells from these bags having no spat. In the localities where setting was poor, all the spat in the bags was found on the outer shells only.

It is interesting to note that in the summer of 1927 the zone of the most intensive setting was about three-fourths of a foot higher than in 1928. The exact cause of this difference is difficult to ascertain, yet it seems probable that it was due to a range of tide during the time of setting. In 1927 setting took place between August 1 and 19 with the probable maximum around August 11–12 when the height of the tide was 4.2 to 4.4 feet. In 1928 setting occurred about July 26 when the height of the tide was only 3.3 feet. Unfortunately lack of knowledge of the conditions governing the behavior of the larvæ during their setting does not justify any further speculations as to the possible causes of the variation in the zone of setting.

IV. EXPERIMENTS IN SEED-OYSTER PRODUCTION AND COLLECTION IN MILFORD HARBOR, CONN., 1925–1928

By H. F. PRYTHERCH

INTRODUCTION

Milford Harbor is one of the typical oyster producing inshore areas of the State of Connecticut. When the town of Milford was settled in 1639, oysters and clams were found in abundance along its shores, and the fishing of oysters, which was free to everyone, soon lead to depletion of the beds and the passage of the first oyster legislation in 1784. This law gave to the towns in the State the power to regulate the fisheries of oysters and clams within their respective limits and resulted in various regulations restricting the quantity to be taken and the season when oysters could be harvested. These measures prevented overfishing to some extent and were followed in 1845 by legislation which allowed for the first time the transplanting and laying down of oysters from other States. In 1855 an important law known as the two acre law was passed which granted to any citizen such an area of bottom for the cultivation of shellfish, which at the time was considered to be all that one man could attend to. For the next 10 years oyster cultivation was confined to the shallow waters of the rivers and harbors and consisted in the transplanting and growing of seed from the natural beds and the planting of shells for the collection of set or spat.

The success of oyster culture on this small scale and the discovery in 1865 that the deeper waters of Long Island Sound were suitable for growing oysters and collecting spat soon led to the development of extensive deep-water oyster farming in Connecticut. By 1880 the early method of oystering on 2-acre plots with dug out canoes and tongs was supplanted by a great system of deep-water oyster farms extending from Greenwich to Branford, on which were operated steam-driven vessels capable of dredging from 200 to 800 bushels of oysters a day. Thousands of acres of ground in the harbors and sound were leased to the enterprising oyster growers who converted these barren unproductive bottoms into valuable oyster growing areas. The acreage leased from the State for oyster culture in 1881 was 33,988; in 1910, 74,514; and since has declined to 54,212 in 1927. The production of oysters in Connecticut increased rapidly with the development of oyster farming, reaching a maximum of 3,948,100 bushels in 1908, which was valued at $2,582,940. Since then oyster production has shown a steady and alarming decrease, the chief cause of which has been the lack of seed oysters and the repeated failure of setting. This condition has led to the recent investigations conducted by the bureau at Milford, Conn.

One phase of this investigation dealt with the physical conditions affecting the spawning of the oyster and the distribution and setting of the larvæ (Prytherch, 1929). The second phase of the work, which is taken up in the present paper, deals with the experiments for increasing the production of seed oysters and improving methods for collecting them. The general plan of these experiments was to demonstrate the method of restoring inshore grounds to their former condition as prolific oyster setting areas through the establishment of spawning beds and the use of improved methods of spat collection. Various types of spat collectors were planted on the tidal flats and in the channel, arranged in different formations. Setting on the collectors was studied to determine the best setting areas and the zone in which the greatest numbers of spat could be collected, and the results obtained on each collector, the cost of material, handling expense, durability, etc., was compared to determine which type of collector is the most efficient, cheapest, most practicable, and best adapted for use on a commercial scale.

The experiments which are discussed here were made in 1925, 1926, 1927, and 1928 in cooperation with the Connecticut Oyster Farms Co., who generously supplied and planted oysters for a spawning bed and furnished men and boats for putting out the collectors. The spawning bed, containing approximately 1,000 bushels of oysters, was located in the harbor just below the laboratory and was situated partly on the tidal flats and partly in the channel. The harbor is practically unpolluted so that it was possible by its rehabilitation to study the oyster in an environment very similar to that in which it thrived in years past.

PHYSICAL CONDITIONS IN MILFORD HARBOR

Milford Harbor is located on the Connecticut shore of Long Island Sound and lies about half way between two great oyster producing centers, Bridgeport and New Haven. The general topographical and hydrographical features of the harbor are shown in Figure 24. This small body of water covers approximately 80 acres, about half of which consists of tidal flats which are exposed at low tide. The water in the harbor comes from two sources, from the Wepawaug and Indian Rivers which bring down fresh water from the surrounding country, and from Long Island Sound, from which brackish waters are carried into the harbor by the flood tides.

The potential value of any body of water for the propagation and growth of shellfish depends largely upon the physical conditions which exist there. The con-

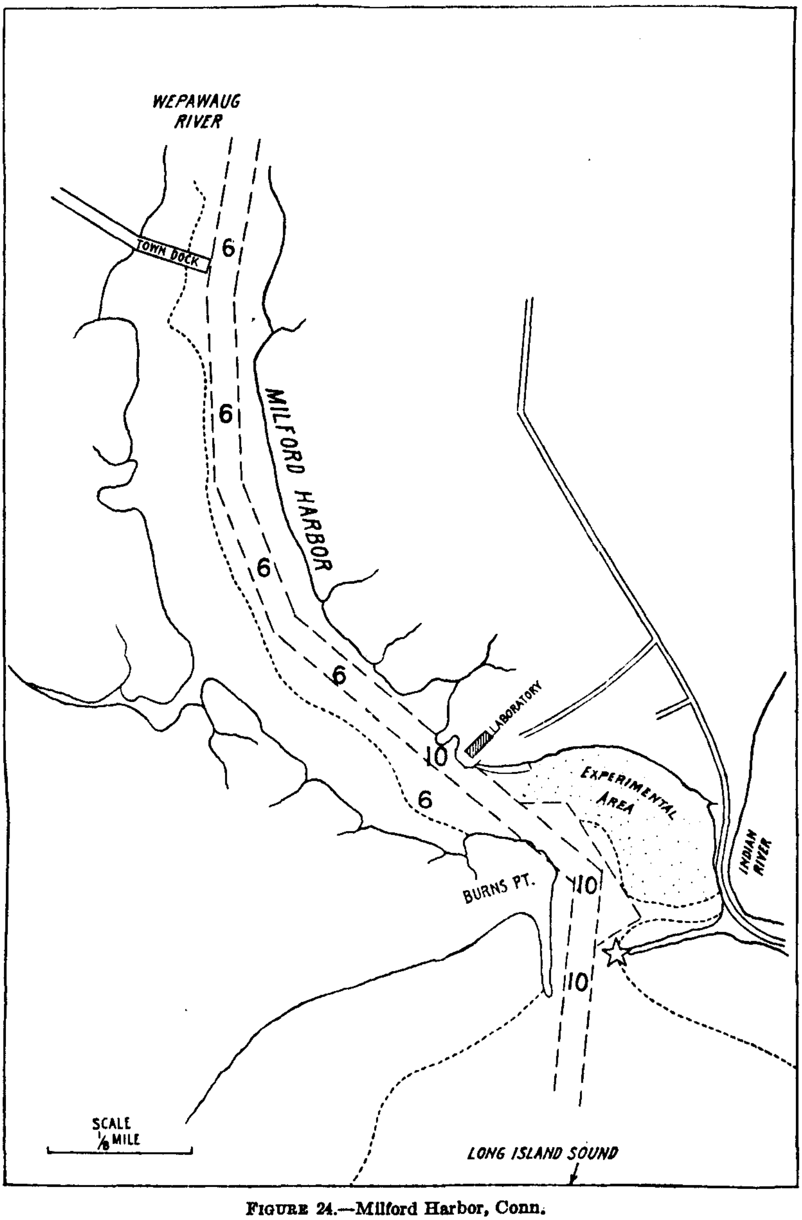

FIGURE 24.—Milford Harbor, Conn.

ditions found in Milford Harbor are characteristic of those found in most of the other harbors and estuaries which empty into Long Island Sound and which have been found to be very favorable localities for the reproduction and growth of the oyster, quahaug, and soft clam. A brief résumé is given here of the observations which were made in 1925 and 1926 regarding the physical conditions of the water:

for a more detailed discussion of the various factors the reader is referred to the author's previous paper (Prytherch, 1929).

TEMPERATURE

The temperature of the water in Milford Harbor was recorded continuously during the summer months by means of a thermograph set up at the laboratory. The daily variations in water temperature and its trend during the summers of 1925 and 1926 are shown in Figure 25. In 1926 and 1927 the mean water temperature for July and August was slightly lower than in 1925 as shown in Table 25. The average of the three years gives us a mean monthly temperature of 18.7° C. for July and 20.5° C. for August.

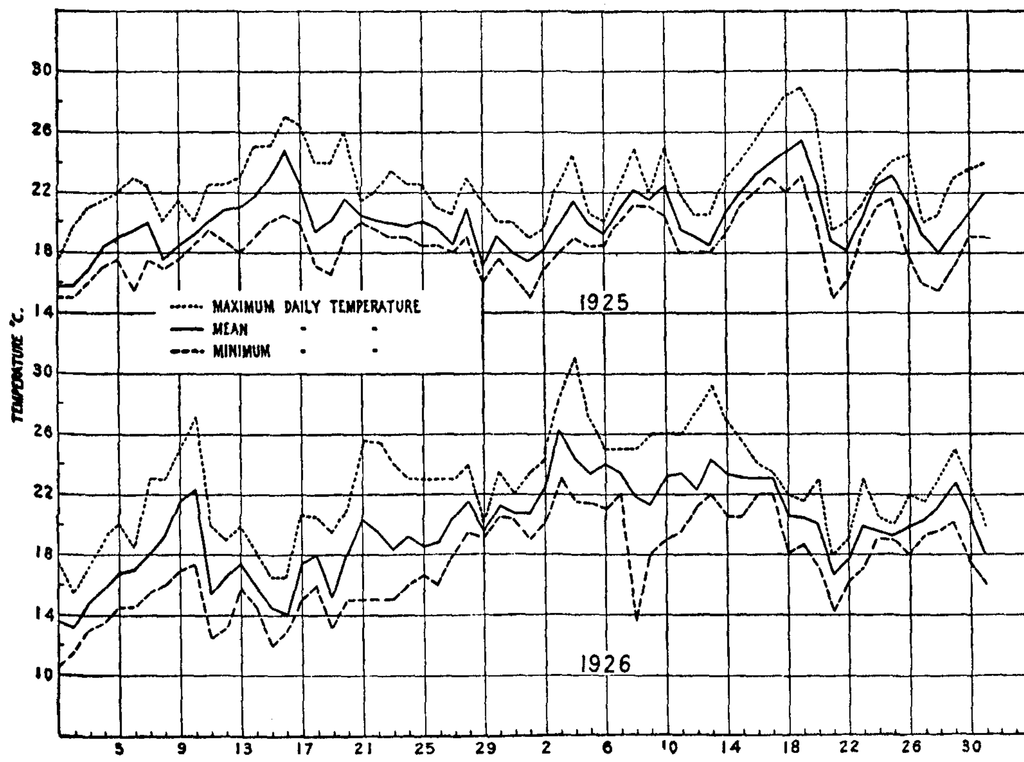

FIGURE 25.—Maximum, minimum, and mean daily temperature of the water, 1925 and 1926, Milford Harbor, Conn.

TABLE 25.—*Water and air temperatures in Milford Harbor during July and August, 1925 to 1927* [1]

Year	Mean monthly temperature, ° C.			
	July		August	
	Water	Air	Water	Air
1925	19.7	21.8	20.8	21.6
1926	17.8	22.0	21.6	21.8
1927	18.5	22.4	19.0	19.3
Average for 3 years	18.7	22.0	20.5	20.9

[1] The normal air temperature for this region is 22.2° C. in July and 21.1° C. in August, according to the records of the U. S. Weather Bureau at New Haven, Conn.

Considerable fluctuation in water temperature, characteristic of Milford Harbor and similar inshore waters is the result of changes in weather conditions and stage of tide. The daily and hourly fluctuations are at once apparent from Figure 25 which shows the maximum and minimum temperature for each day together with the mean. Variations in the daily range of temperature amounted to from 1° C. to 11.5 ° C. The highest temperature invariably occurred at the time of low water while the lowest temperatures were found near the time of high water when the greatest quantity of water had been brought in by the flood tide from Long Island Sound. The typical hourly changes in temperature that occur during a tidal cycle are shown graphically in Figure 26 for several days in 1926. The highest water temperature recorded by the thermograph during July and August was 31° C. and the lowest 10.5° C. In the studies of thermal conditions it was found that exposure and flooding of the tidal flats increase greatly the exchange of heat between the water, land, and air and are responsible for the large fluctuations in temperature of the water.

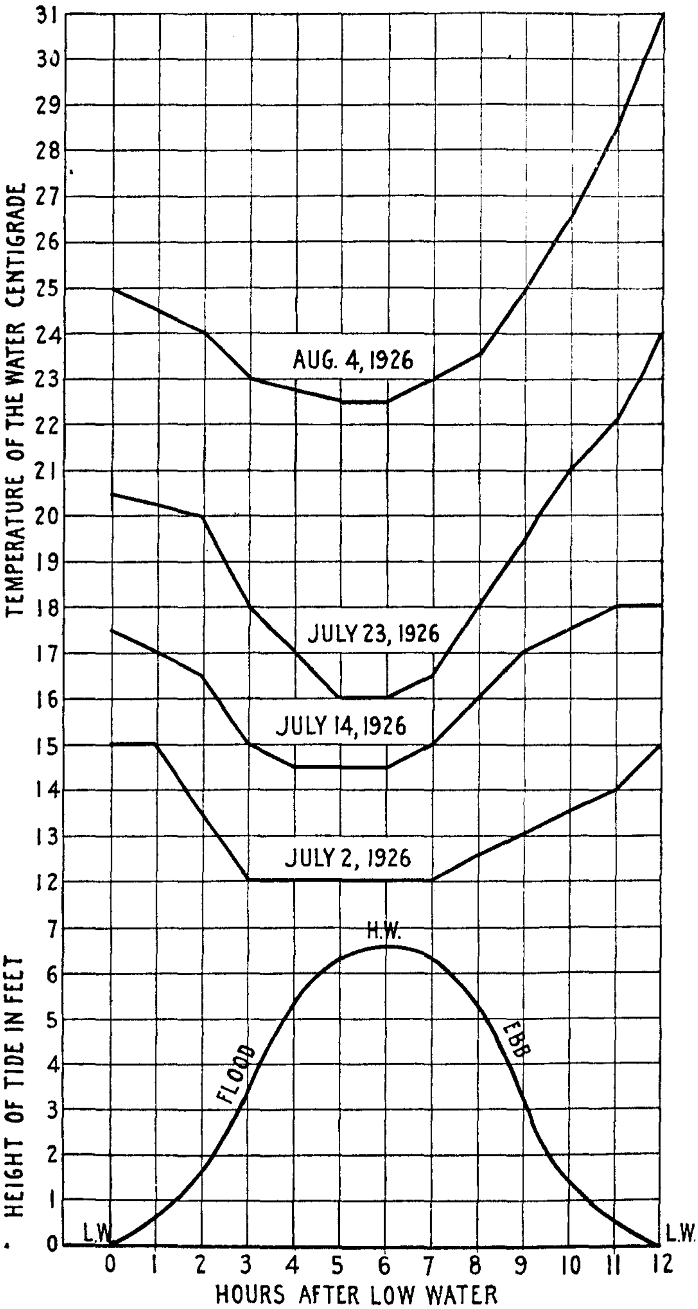

FIGURE 26.—Fluctuations in water temperature during tidal cycle, Milford Harbor

SALINITY

The salinity of the water in Milford Harbor depends upon two main factors, namely, the discharge of fresh water by the Wepawaug River and the inflow of brackish water from Long Island Sound. The distribution of salinity in the harbor is shown in Figure 27 for a series of observations that were made during flood tide on July 15, 1925. During the summer the range of salinity was from 4.50 to 28.66

per mille though as a general rule the daily fluctuation was from 25 to 28 per mille. The changes in salinity that occur during a complete tidal cycle are shown in Figure

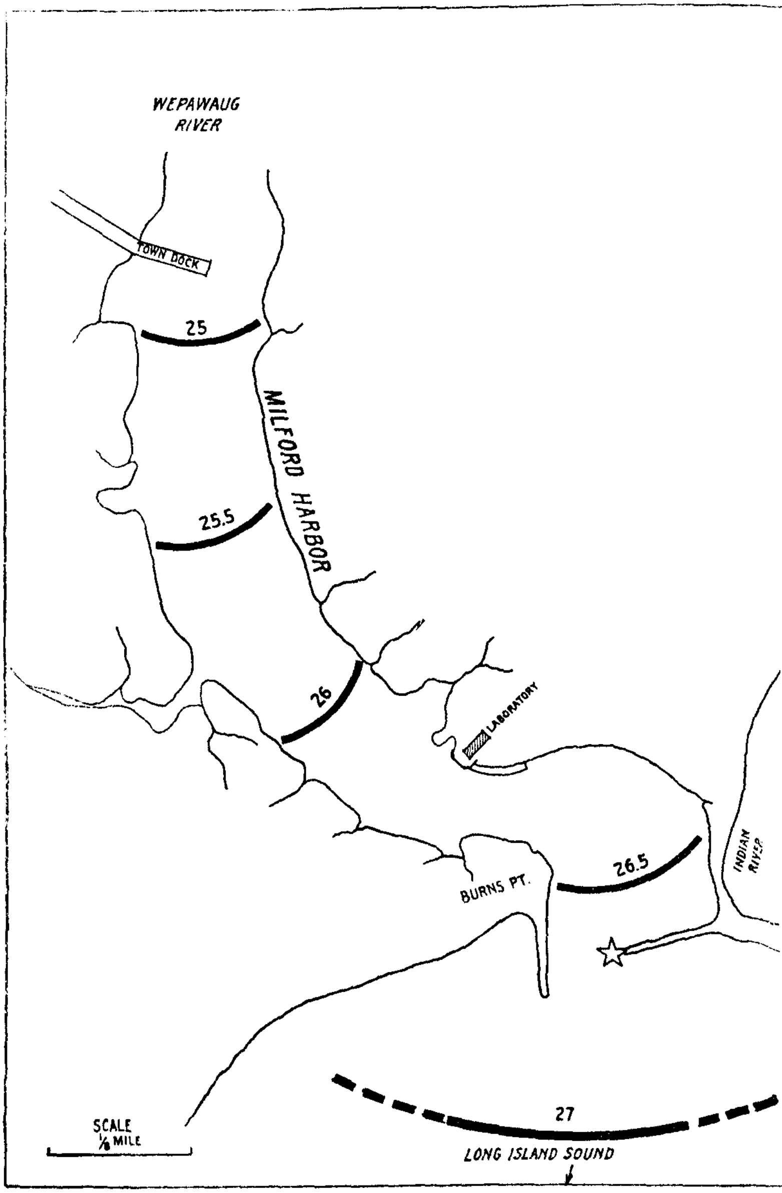

FIGURE 27.—Horizontal distribution of salinity, Milford Harbor, July 15, 1925

28 together with the observations on temperature and pH. The results obtained in this series of observations, which were made on August 24, 1925, from time of low water to high water and back again, are given in Table 26.

TABLE 26.—*Effect of tide on physical conditions in Milford Harbor, August 24, 1925*

Tide	Time	Depth, feet	Salinity, per mille	Temperature, ° C.	pH	Tide	Time	Depth, feet	Salinity, per mille	Temperature, ° C.	pH
Low water	8 a. m.	0	25.35	20.9	7.2	High water	2 p. m.	15	28.10	21.0	7.4
Do	do	10	27.66	21.8	7.4	Ebb	4 p. m.	0	27.66	23.3	7.6
Flood	10 a. m.	0	26.78	21.4	7.4	Do	do	13	28.12	22.0	7.4
Do	do	11	28.04	20.0	7.8	Last ebb	6 p. m.	0	26.18	24.2	7.5
Do	12 m.	0	27.88	21.9	7.8	Do	do	12	27.82	23.0	7.3
Do	do	13	28.10	20.2	7.6	Low water	8 p. m.	0	25.50	24.0	7.3
High water	2 p. m.	0	27.75	22.2	8.0	Do	do	10	26.75	23.0	7.2

Since the range of tide on this particular date is but 0.2 foot above the mean range, the changes in water conditions can be regarded as intermediate between those which would occur with extreme spring or neap tides. Changes in salinity are least at the time of neap tides and greatest with spring tides. The differences in the salinity between top and bottom samples were generally less than 1 per mille and naturally were greatest above the town dock, where fresh water entered the harbor from the Wepawaug River, and least at the mouth of the harbor. Occasionally, however, extreme differences were found following heavy rains or with the change of tide from low water to flood. An example of the first instance occurred on July 9, 1925, when the surface was covered with a layer of water from 6 inches to a foot deep which was practically fresh, or of a salinity of about 5 per mille, while that on the bottom was 25 per mille.

HYDROGEN-ION CONCENTRATION

The water in the harbor is naturally alkaline and ranges during the summer from pH 7.2 to 8.4. During July an average pH value of 7.8 was observed, while in August the readings became higher and ranged from 8.0 to 8.2. The lowest pH values were found in samples taken at low tide following heavy rains and the highest in afternoon samples taken near the time of high water. An example of the surface and bottom changes in pH during a complete tidal cycle is shown in Figure 28 and Table 26.

TIDES AND CURRENTS

The vertical and horizontal movement of the water as a result of the tide is important because it produces considerable variation in its temperature, salinity, and pH. In Milford Harbor the mean range of tide is 6.6 feet and the spring range 7.7 feet. During spring tides the maximum range recorded during the summer was 9 feet, while with neap tides the minimum range was 4.2 feet. The tide here is of the semidiurnal type with two high and two low waters occurring during each tidal day, with little difference between the morning and afternoon tides and their duration of rise and fall, each of which is about 6 hours.

From a biological point of view both the rise and fall of the water and the horizontal movement or tidal current are of considerable importance. In Milford Harbor the tidal movement is of the stationary-wave type, the strength of the current coming midway between high and low water while the slack of the current comes near the times of high and low water. The tide and current relationships for Milford Harbor entrance are shown in Figure 29. The tidal currents vary in strength from day to day in accordance with the regular changes in the range of tide. The strongest currents come with the spring tides of full and new moon and the weakest currents with the neap tides of the moon's first and third quarters. During the spring tides the flood current in Milford Harbor attains a maximum velocity of 33 centimeters (1.1 feet) per second and the ebb current 45.7 centimeters (1.5 feet) per second. With neap tides considerably less water passes in and out of the harbor and the velocity of the flood current at strength is 24.4 centimeters (0.8 feet) per second and the ebb current 40.6 centimeters (1.3 feet) per second. The tidal currents here are

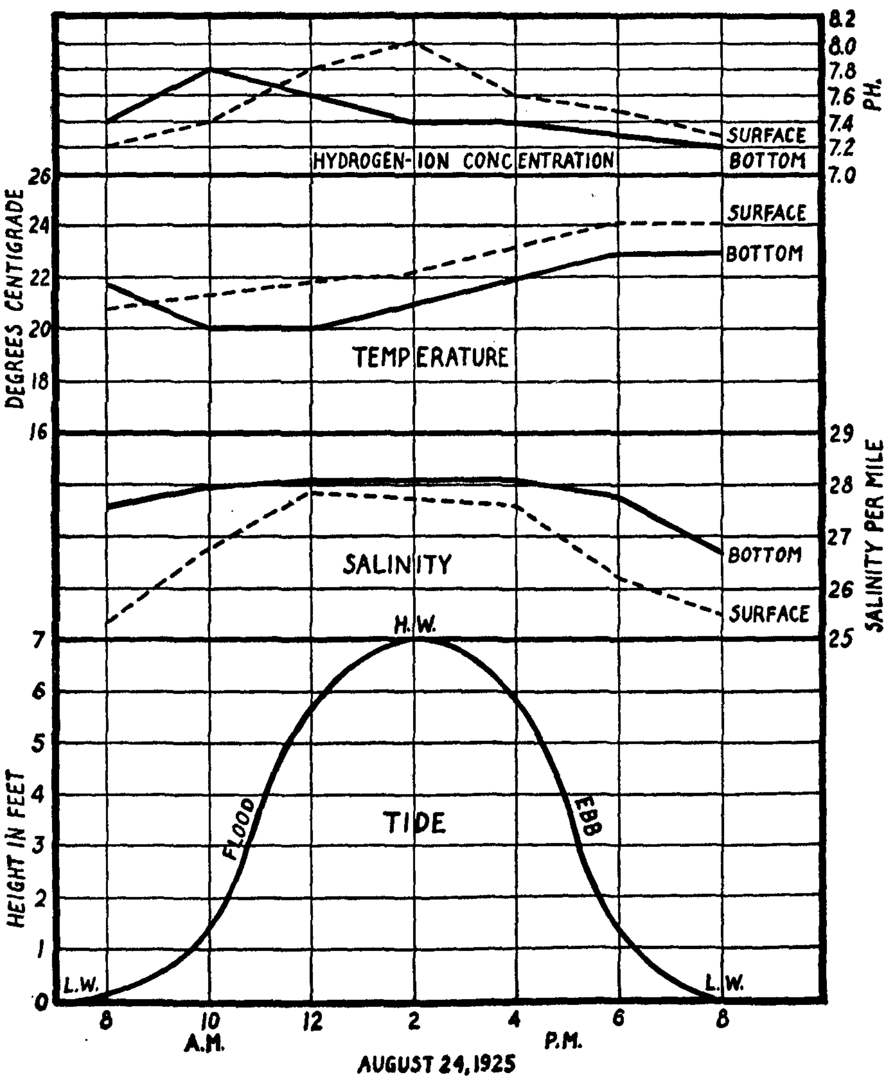

FIGURE 28.—Temperature of the water, pH, and salinity during tidal cycle, Milford Harbor

of the rectilinear or reversing type; that is, the flood current running in for a period of approximately 5 hours and 30 minutes and the ebb current running out for a period of 6 hours. The ebb current has a greater velocity and period of duration than the flood current because of the river water discharged into the harbor. Using the formula given by Marmer (1925) it is estimated that currents of such strength as those at the entrance of Milford Harbor would transport a floating object approximately 21,100 feet during the ebb flow of 6 hours and return it but 15,600 feet during the flood. Experiments with drift bottles demonstrated clearly the dominant drift of the ebb current and showed that an object floating freely in the water would be carried out of the harbor the first day by the tidal currents and would never be transported back to it. This condition has an important bearing on the distribution and occurrence of the oyster larvæ in the harbor which will be discussed later.

The most important effect of the tide was found to be in regard to its influence on water temperature. The movement of the water over the tidal flats increases greatly the effect of solar radiation and air temperature on water temperature and accelerates the exchange of heat between the air, land, and water. It was found that during full moon tidal periods in July the water temperature increased from approximately 15° C. to 25° C. in a period of 15 days. During these periods the range of tide is greater than the mean range, and a much larger area of tidal flats are brought into contact with the water. This condition combined with the intense solar radiation and the high air temperature that occurs at this time of year, is responsible for the heating of the water to a temperature of 20° C. and above, which is necessary for oyster spawning.

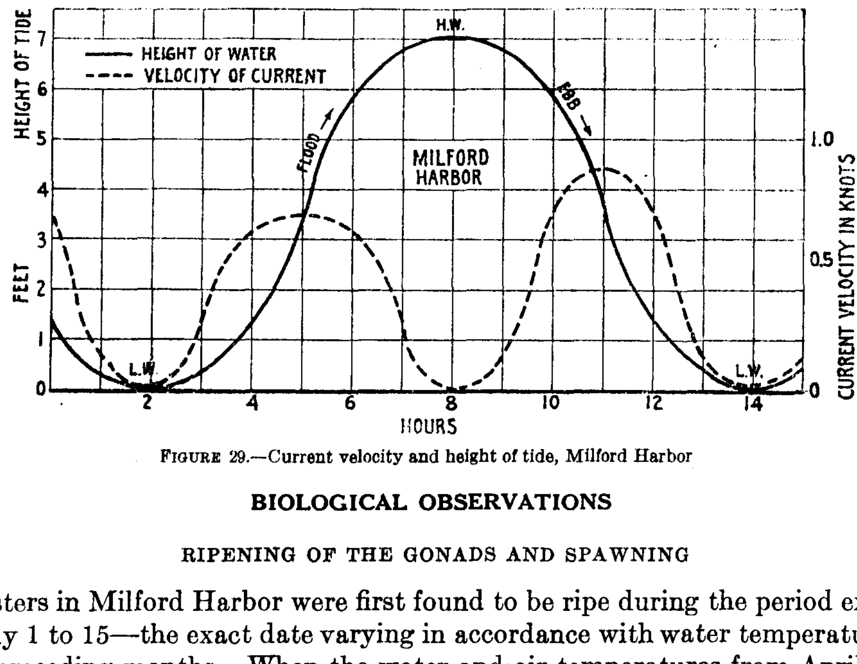

FIGURE 29.—Current velocity and height of tide, Milford Harbor

BIOLOGICAL OBSERVATIONS

RIPENING OF THE GONADS AND SPAWNING

Oysters in Milford Harbor were first found to be ripe during the period extending from July 1 to 15—the exact date varying in accordance with water temperatures during the preceding months. When the water and air temperatures from April to July were above normal, as in 1925, the oysters were found to be ripe much earlier and contained a greater quantity of spawn than they did in 1926 or 1927, when the temperature for the same period was below normal. The layer of reproductive tissue surrounding the liver was found to vary in thickness from 1.5 centimeter in 1925 to 0.5 of a centimeter in 1926 and 1927. The gonads of the oysters were found to be soft and ripe on July 1 in 1925, while this condition was not reached until the middle of the month during the other two years.

The time of oyster spawning depends largely upon the attainment of a water temperature of at least 20° C. In Milford Harbor there are generally two spawnings; the first being very light and occurring about the middle of July, while the second or heaviest spawning takes place about the 1st of August. In 1925, 1926, and 1927, the time of spawning was found to vary somewhat in accordance with water temperature and tidal conditions. Heavy and complete spawning of the harbor oysters occurred on July 13 in 1925, but not until August 1 in 1926, and July 22 in 1927. The spawning in 1925 was over two weeks earlier than the average time of spawning observed during the past seven years and was due to the higher water temperature and the early ripening of the oysters during July of that year. The heaviest spawning was found to occur after the water had reached and maintained a temperature of from 20° C. to 21° C. for a few days. During all three years the spawning took place at the end of the "full moon tidal period" or in other words from seven to eight days after the time of the July full moon. It was observed also that the oysters spawned near and at the time of high tide, when the water was found to be more alkaline and had a pH value of 7.8 and above. On the days when spawning occurred it was found that the water had attained for the first time (since ripening of the oysters) an average temperature of 20.7° C.

LARVAL PERIOD

Quantitative plankton collections were made regularly to study the occurrence and distribution of the oyster larvæ. In these collections the larvæ were found to be relatively scarce and in many cases were totally absent. The number of larvæ collected in the harbor was extremely small in proportion to the intensity of setting which occurred there later. For example, the total number of larvæ collected over the spawning bed in a period of several weeks scarcely reached a hundred, while in the same spot many hundred thousand were later found attached to the collectors. In a series of plankton collections made during several tidal cycles it was found that the oyster larvæ were most abundant at the time of low slack water and gradually disappeared as the tide began to run flood. The distribution of the larvæ in relation to the stage of tide on August 11 to 13, 1926 is shown in Figure 30. When the flood current had developed a velocity of 18.3 centimeters (0.6 foot per second, practically no larvæ could be found swimming in the water while samples from the bottom collected at the same time were found to contain an average of 14 larvæ per square foot of surface. The finding of the oyster larvæ on the bottom at certain stages of the tide shows that they are not passive planktonic forms and, therefore, are not subject to wide dispersal by the tides and currents. By remaining on the bottom during the greater part of the larval period and by limiting their swimming activities to the tidal periods when horizontal movement of the water is least, the oyster larvæ are able to remain and set on and near to the spawning bed which produced them.

One of the important questions that has presented itself in the development of methods for seed oyster production has been, "Where does the spawn, or larvæ, from a bed of oysters finally become attached or set?" The increased production of oyster larvæ and spat in Milford Harbor following its rehabilitation showed definitely during the past three years that the oyster larvæ are not distributed far from the spawning bed by the currents—the predominating drift of which is out of the harbor. The final distribution of the larvæ was determined easily by studying the relationship of the setting areas to the spawning bed. It was found that the majority of the larvæ set within a radius of 300 yards from the center of the spawning bed, and that the greatest number of spat per square inch or per shell was found on the bed and within a 100-yard radius. As indicated by setting, the larvæ were distributed both above and below the spawning bed and attached in greater numbers on the areas which were just below or in the direction of the sound. Though the intensity of setting varied from year to year the distribution of the larvæ was always found to have this same relation each year to the spawning bed.

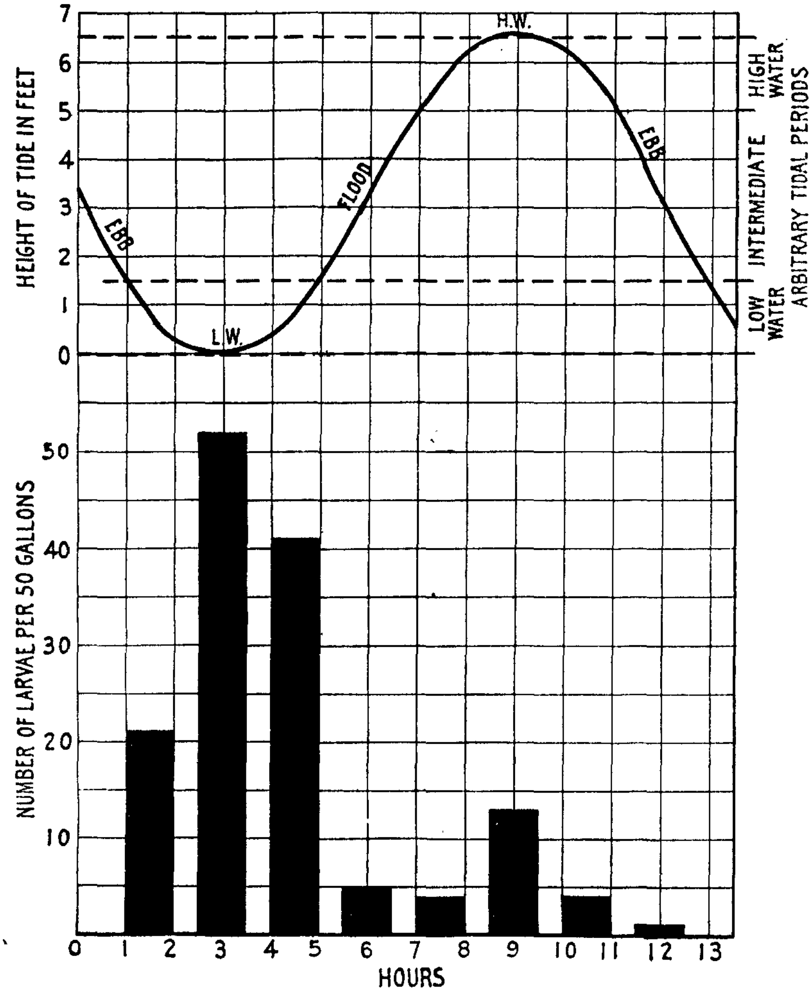

FIGURE 30.—Occurrence of oyster larvæ in plankton in relation to the stage of the tide

The duration of the larval period (from spawning to setting) was found to vary from 13 to 18 days. The variation in the larval periods observed during 1925, 1926, and 1927 is given in the following table.

TABLE 27.—*Duration of larval periods, 1925–1927*

Year	Length of period	Mean temperature of water, ° C.	Remarks
1925	13 days (July 7-20)	20.8	Following light spawning.
1925	16 days (July 13-29)	20.6	Following heavy spawning.
1926	16 days (July 21-Aug. 6)	21.3	Following light spawning.
1926	15 days (Aug. 1-16)	23.2	Following heavy spawning.
1927	18 days (July 1-Aug. 8)	20.0	Do.
Mean	15.6 days	21.2	

In many cases the failure of setting has been attributed to a mortality of larvæ as a result of sudden changes in temperature or salinity and to heavy rainstorms.

In the studies of the physical conditions in Milford Harbor during the periods when larval development was in progress, it has been found that extreme changes in water temperature, ranging from 5° C. to 11.5° C. in 24 hours, or in salinity from 5 to 25 per mille, produced no noticeable decrease in the numbers of larvæ present in the water. During the larval period in 1925 and in 1927, the precipitation was several inches above normal and there was a great amount of fresh water discharged into Milford Harbor. The changes in salinity and the increased velocity of the ebb current following these storms did not kill the larvæ or carry them out of the harbor. The studies at Milford show that the oyster larvæ can withstand wide changes in the temperature and salinity of the water and are not carried away by the tides and currents.

SETTING

The successful collection of oyster seed in any particular region or body of water is dependent upon a knowledge of when setting will occur, where it will be most intensive in relation to the spawning bed or depth of water, and how great the production of spat is likely to be during that season.

In the studies as to the time and distribution of setting in Milford Harbor, various types of spat collectors were used such as tiles, brush, tar paper, and containers filled with oyster, clam, scallop, and mussel shells. The collectors were arranged so as to cover the entire zone from the bottom of the channel to high-water mark—a vertical distance of approximately 17 feet, of which the upper 5 to 9 feet are exposed by the tides.

Setting in Milford Harbor has been observed to occur from July 20 to September 1 but is generally most intensive during August with the peak occurring about the middle of the month. The first early set is extremely light and is followed by a heavy and final set about 8 or 10 days later. For example, in 1925 there were 10 to 15 spat per shell at station No. 3 from the light set on July 20 and from 150 to 250 spat per shell from the heavy set on July 29. The daily examination of the shells showed that the setting period of the majority of the larvæ of a single spawning lasted but two days. In 1926 the heavy set occurred on August 16, which is representative of the average time of setting for this region.

The number of spat produced in the harbor each year varied considerably though the number of spawners was practically the same in each instance. It was found that the intensity of setting could be clearly correlated with the quantity of spawn in the oysters and the early water temperatures. In 1925 when the temperature was above normal and the oysters contained a large amount of spawn, the setting was heaviest, and an average of 15,000 spat were collected per bushel of shells. In 1926 and 1927 we had the other extreme—that is, water temperatures below normal and small amount of spawn in each oyster—with the result that the average number of spat collected per bushel was only 2,000 and 2,500 respectively. Such annual variations in the production of seed on both natural and cultivated oyster beds have long been observed and is largely the result of the fluctuations in the physical condition of the water which have been discussed previously.

The intensity of setting according to depth or in other words the vertical distribution of spat is quite peculiar in Connecticut waters. In Milford Harbor the spat were found to be attached in a zone extending from the bottom of the channel to a point 2 feet above mean low-water mark; while from above this level to high-water mark, a distance of about 5 feet, no setting takes place. In other bodies of water as for example in South Bay, Long Island, setting occurs from the bottom to nearly high-water mark, while in South Carolina and Georgia the set is found chiefly between low and high water marks and not below low-water mark.

On a given area of bottom in Milford Harbor the setting was found to be unevenly distributed and varied in intensity according to the distance from the spawning bed and the depth of water. In the harbor the set was found to occur on such areas as are covered with water when the tide is 2 feet above mean low-water mark, with the exception of a small portion above station No. 1, where setting rarely occurs because of the discharge of fresh water. In 1925 a set of commercial value was found principally within a radius of 300 yards from the spawning bed, the number of spat ranging from 5 or 6 spat per shell on the outside edge to 200 and 300 per shell in the central portion. The spat were most abundant on shells planted over the spawning bed and within approximately 100 yards of its center. The concentration of spat at the 100-yard circle averaged 50 per shell. Though setting occurred practically the same distance upstream or above the bed as it did below it was found to be of slightly greater intensity in the areas lying below or toward Long Island Sound. The horizontal distribution of the set in relation to the spawning bed clearly shows that the oyster larvæ remain close to the place where they were produced.

EXPERIMENTS IN SEED-OYSTER COLLECTION

Various types of spat collectors and materials suitable for the attachment of the oyster larvæ were used during the past four years in Milford Harbor. In 1925 birch brush, glazed tiles, and wire baskets filled with oyster and clam shells were used. In 1926 triangular crates made of lath were filled with shells and set out on the tidal flats in various formations. In 1927 and 1928 wire bags filled with oyster shells were used on a much larger scale and were tested out in Milford Harbor and several other localities in Connecticut. In 1929 experiments were conducted with partition type collectors. In order to simplify matters each summer's experiments will be discussed separately as to the methods employed and results obtained with each type of collector.

In 1929 a new type of collector was developed for the gathering of seed oysters in heavy setting regions. This device consisted of a series of waterproof cardboard partitions, similar to an egg case filler, which was covered with a thin coating of cement. It gave a total collecting surface of approximately 1,000 square inches. In Great South Bay, Long Island, 1,000 of these partitions were planted by the Bluepoints Co., and a similar number were set out by the Connecticut Oyster Farms Co., on the tidal flats in Milford Harbor.

In each region the partitions proved to be very satisfactory and collected from 2,000 to 25,000 spat on a single partition. The advantage of using seed collectors of this design lies in the fact that they are inexpensive and suitable for collecting large numbers of spat which can be separated easily when a few months old. The supply of oyster shells has been steadily decreasing each year and consequently the development of partitions as a practical substitute is significant.

The partitions are superior to shells principally because they can be broken up or separated thus saving the spat after they have grown for two or three months.

For full description of the preparation, use and planting of partitions for the collection of seed oysters the reader is referred to Bureau of Fisheries Document 1076, "Improved Methods for the Collection of Seed Oysters" by H. F. Prytherch.

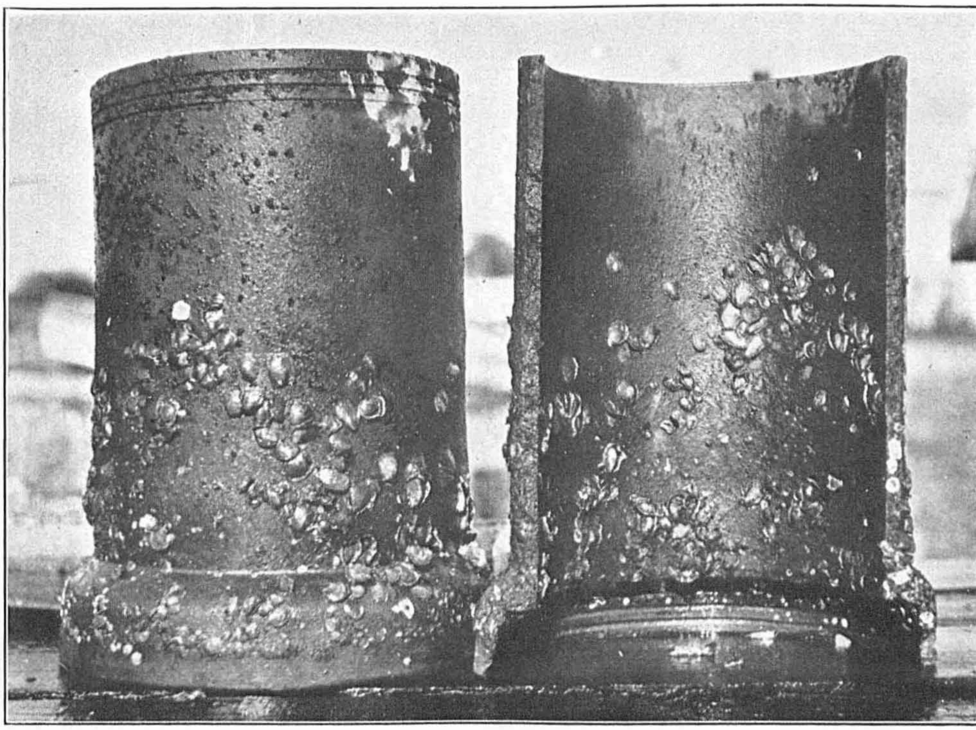

Figure 31—Set on tile collectors, Milford Harbor

Figure 32.—Wire baskets filled with shells, and brush collectors planted at Milford Harbor

EXPERIMENTS IN 1925

In the United States, brush spat collectors have been employed but very little chiefly because of the cheaper and better results generally obtained with oyster shells. Brush, however, is superior to shells in many respects and in certain regions has proved to be a very suitable collector for use on soft mud tidal flats which can not be utilized for any other purpose. In Connecticut the profitable utilization of soft muddy tracts by brush methods is described in the reports of the Connecticut Shellfish Commission for 1882 and 1883. At that time 50 acres of muddy bottoms in the Poquonock River near Groton were planted with white birch brush and yielded as high as 1,000 bushels of oysters per acre. The brush or really young trees which were used, measured around 4 inches at the butt and are said to have yielded as much as 25 bushels on one branch. The average yield, however, is said to have been approximately 5 bushels per branch.

For the experiments in Milford Harbor in 1925, white birch brush or branches were used having a length of approximately 6 feet and a diameter at the butt ranging from 1 to 2 inches. The branches were forced into the soft bottom areas at an angle of about 45° and were arranged in two different formations: (1) In rows at right angles to the direction of the tidal currents and (2) in conical stacks having a diameter at the base of about 8 feet. The branches were set out a few inches apart and were forced into the mud from 6 inches to a foot deep according to their size or length. The planting of the brush was carried on during the first two weeks of July, the operations being confined, of course, to the periods of low water. The areas selected for planting were flat and even and were located at a level corresponding almost exactly with that of mean low-water mark.

Two weeks after the brush planting was completed the setting of the oyster larvæ occurred and was the heaviest observed in this harbor in many years. Studies of the setting (from the standpoint of number per collector, etc.) were not made until the first week in September by which time the spat had attained an average diameter of one-half inch. The number, distribution, and size of the oyster spat on the branches was determined for samples taken from each planting formation and was compared with the results obtained in the baskets of shells and tile collectors which were planted on the same areas.

The number of spat per branch was found to vary in regard to the location of planted area in relation to the spawning bed, the diameter of each branch or twig, and the formation in which each branch was planted. On branches having practically the same diameter at the butt the number of spat ranged from approximately 25 to 300 spat per branch which is quite a low figure in view of the surface area offered for attachment of the oyster larvæ. The branches which were set out below the spawning bed collected nearly twice as many spat as those which were put out upstream or above the bed. Where branches of different size were planted under the same conditions it was found that those having the greatest diameter collected the largest number of spat and that twigs in the same zone having a diameter less than one-fourth inch rarely had spat attached to them. The same general condition was observed in comparing the brush planted in stack formation with that planted in rows. In the stacks the branches were massed closer together and offered greater resistance to the tidal currents with the result that it was easier for greater numbers of larvæ to become attached to branches under these conditions.

In addition to variations in the number of spat per branch it was also found that the distribution of spat showed marked differences according to the direction and velocity of the tidal currents, the height of the collector from the bottom, and the range of tide on the days when setting occurred. The setting of the oyster larvæ in Milford Harbor occurred chiefly at the surface at low slackwater and continued until the flood tide had risen approximately 1½ feet above mean low-water mark. This was clearly shown also by the distribution of the spat on the brush on which they were found to be located on all sides of the main branches in a zone from the bottom to 3 inches above, while above this level they were chiefly on the lee side of each branch and became less numerous as the current and height of water increased. The smaller twigs on the branches offered very little resistance to the currents and consequently no spat were found attached to them, except in a few cases where the twigs were very close to the bottom and in the low slack-water zone.

The experiments in Milford Harbor have shown, however, that brush collectors can rarely be used successfully in northern waters because of the comparatively light setting, slow growth of spat and necessity of transplanting and anchoring the branches in deep water before the first winter. However, satisfactory results have been obtained in southern waters or in regions where setting is heavy and growth of the spat rapid. This has been demonstrated by experiments made in South Carolina and Georgia in which branches 4 to 8 feet long, having a diameter of the butt of about 1-inch were found to be most suitable. (Galtsoff and Luce, 1930.) Where the tidal currents are strong it is best to plant the branches in conical stacks, so that the smaller twigs are closely bunched, to facilitate the attachment of the oyster larvæ by creating eddies. Oak brush was successfully used in Georgia and South Carolina and birch in Connecticut, though for this purpose almost any kind can be used.

The advantages of using brush are:

1. It offers considerable surface area for the attachment of the oyster spat.
2. Oysters growing on the convex surface of the branches are less crowded and have a better shape than those attached to shells.
3. The brush keeps the seed oysters above the bottom, thereby increasing their growth and protecting them to a certain extent from natural enemies.
4. It disintegrates in about a year or is destroyed by shipworms, so that the seed oysters attached to it break apart or can be separated as single specimens.
5. It can be used on mud flats that are useless for the planting of shells.
6. It is a cheap material for the collection of seed oysters and is easily obtained.

A series of experiments was undertaken to demonstrate the suitability of tiles as seed collectors. The tiles used were half-round glazed sewer pipe having a diameter of 12 inches and length of 2 feet. The surface of the tiles was approximately 1,000 square inches and the average number of spat collected per tile was 1,500 from the first set and 4,000 from the second or heaviest set. The setting on the tiles, of course, was not uniform but decreased in intensity from the bottom to the upper setting limit. The setting on tiles planted at low-water mark in vertical positions is shown in Figure 31. The spat, which were attached to them, were allowed to grow until late fall and were then detached from the tiles without the slighest injury and transplanted as single seed oysters.

The third type of seed collector used in 1925 was that suggested by Capt. Charles E. Wheeler, of the Connecticut Oyster Farms Co. It consisted of a round galvanized wire bushel basket which was filled with shells and then set out on the tidal flats. A dozen of these baskets were filled with either oyster, clam, or mussel shells, and collected on the average 15,000 spat per bushel of oyster shells and a few thousand less on the clam and mussel shells. The spat were not uniformly distributed throughout the baskets, but were most numerous on the bottom and outside edges and comparatively scarce on the shells in the middle. By actual count the oyster shells on the top, bottom and sides of the container were each covered with from 25 to 200 spat, those on the next inside layer from 12 to 50, while in the center from 2 to 10 spat were found per shell. The representative distribution of spat in these baskets is shown diagrammatically in Figure 33.

These initial experiments with wire baskets showed that the principle of putting shells into a comparatively open container was an efficient and practical means for collecting seed oysters and worthy of further development in future investigations.

The studies and experiments in 1925 brought out certain fundamental facts which should be summarized briefly as they have a direct bearing upon the development of methods for the production and collection of seed oysters in similar bodies of water. It was found:

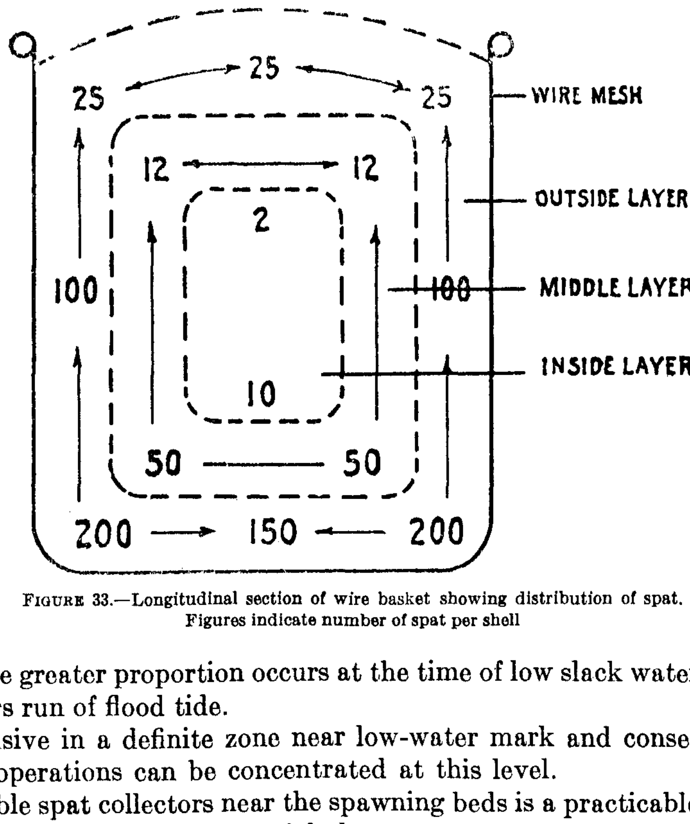

FIGURE 33.—Longitudinal section of wire basket showing distribution of spat. Figures indicate number of spat per shell

1. That inshore areas such as Milford Harbor can be rehabilitated as prolific oyster-producing regions by the establishment of spawning beds.

2. The optimum conditions for successful spawning and setting are to be found in Connecticut primarily in the harbors, bays, and river mouths.

3. Oyster larvæ will remain and set in the vicinity of the spawning bed in spite of adverse tidal currents and river discharge.

4. The attachment of the greater proportion occurs at the time of low slack water and during the first two hours run of flood tide.

5. Setting is most intensive in a definite zone near low-water mark and consequently the spat collecting operations can be concentrated at this level.

6. The planting of suitable spat collectors near the spawning beds is a practicable means of obtaining seed oysters and will be successful almost every year.

EXPERIMENTS IN 1926

The experiments in oyster seed collection during the previous summer indicated that a change in the shape of the shell container should be made that would facilitate the passage of the larvæ amongst the shells and thus produce more uniform setting. For this purpose triangular lath crates were employed, the design and construction of which has been previously described. (See fig. 1.) Three hundred of these crates were planted in various formations on the tidal flats so as to determine their efficiency as seed collectors and the effect of their position and arrangement on the uniformity and intensity of setting within them. The crates were set out during the last two weeks of July, and on August 15 were found to have collected a light set, the counting and distribution of which was not made until the early part of September when the spat were large enough to be easily seen. In analyzing the setting in the collectors, two crates were chosen as representative samples from each group and counts made as to the number of spat per bushel or per shell, and according to the position of the shells in the crate.

In Figure 34 the group formations in which the crates were planted are shown together with the location of the spawning bed and the direction of the tidal currents

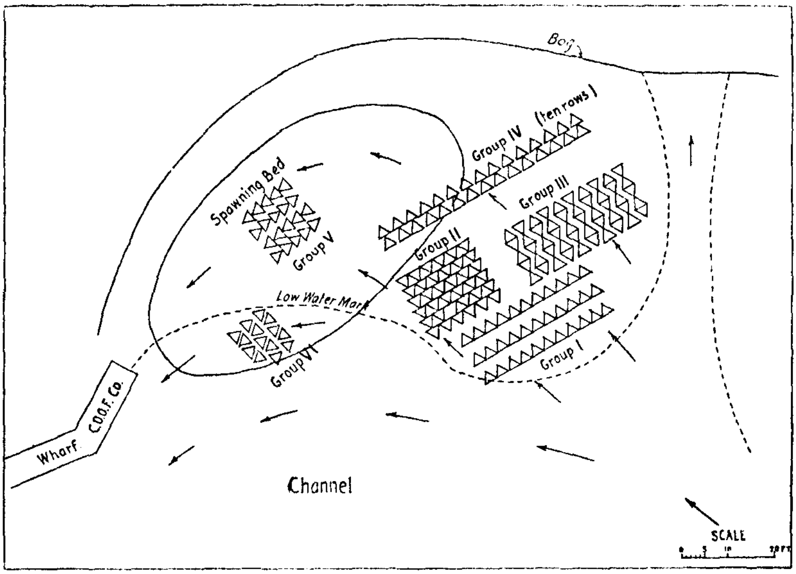

FIGURE 34.—Arrangement of crates on tidal flats, Milford Harbor, 1926

when setting occurred. The intensity of setting in each group varied somewhat as is shown in Table 28.

TABLE 28.—*Intensity of setting of oyster spat*

Group number	Crates	Spat per bushel	Total (approximately) spat collected per group	Group number	Crates	Spat per bushel	Total (approximately) spat collected per group
I	50	2, 264	226, 400	V	20	1, 275	51, 000
II	30	1, 407	84, 420	VI	14	1, 020	28, 560
III	36	2, 812	202, 464				
IV	150	1, 734	520, 200	Total			1, 113, 044

Each crate holds two bushels of oyster shells, so by computation we get an average of 3,710 spat per crate or 1,855 per bushel which corresponded to a light set and was, therefore, of commercial value, The shells which were used averaged 250 to a bushel so that the calculated intensity of setting was approximately 7.4 spat per shell. The setting in the crates was more uniform than in the wire baskets but still was found to vary from 0 to 35 per shell according to their position in the container.

In order to study the distribution of spat in the crates the shells in each crate were divided into three layers—top, middle, and bottom—and counts were made as to the number per shell and the distance each shell was located from the center of the container. The plan used in counting the shells is shown in Figure 35, together with the distribution of spat that was found in three crates planted in Group I. The spat were found to be most abundant on the shells in the corners of the crates while within a radius of 6 inches from the center or from the sides the setting was very light and unsatisfactory. To show this distribution and the typical variation in the num-

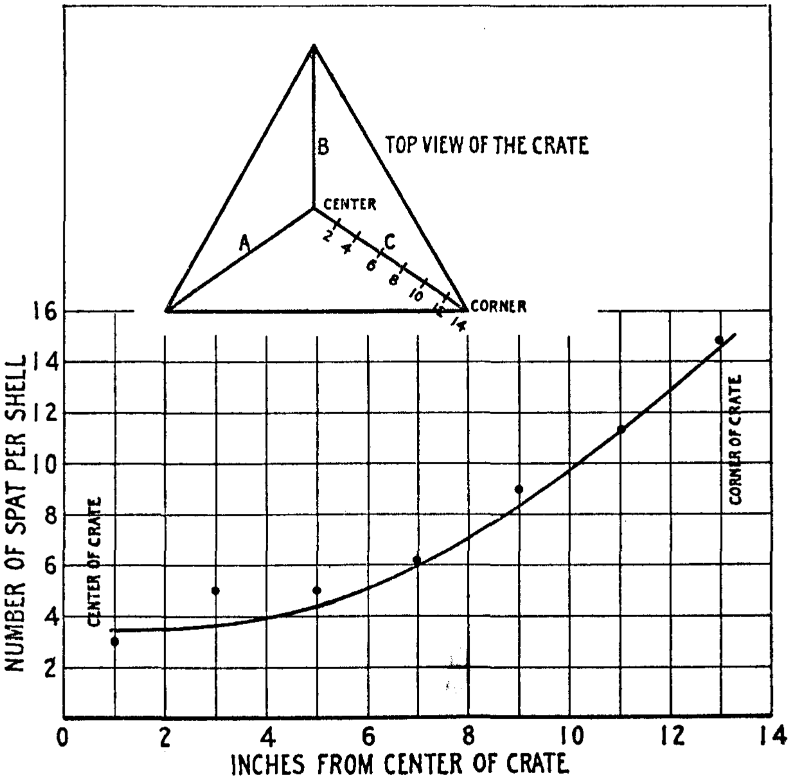

FIGURE 35.—Method of counting and distribution of set in crates. The figures are the averages of three crates in Group 1

ber of spat attached per shell, the following record is given for a representative crate taken from Group I. (Table 29.)

TABLE 29.—*Distribution of spat in a crate*

Inches from center	Top layer			Middle layer			Bottom layer		
	Line A	Line B	Line C	Line A	Line B	Line C	Line A	Line B	Line C
14	14	10	26	28	14	15	35	18	16
12	14	20	5	4	13	10	12	14	17
10	16	8	6	1	2	18	19	12	9
8	6	2	14	8	4	4	4	5	7
6	18	7	4	2	1	0	1	3	1
4	3	1	6	1	3	9	0	0	1
2	1	8	3	1	0	0	0	0	0
Total	72	56	64	45	37	56	71	52	51

In the samples taken in each layer we find a total of 192 spat in the top, 138 in the middle, and 174 in the bottom layer which shows fairly even distribution in each zone as a whole. The spat were not more numerous in the bottom layer in the crates because the close fitting of the lath on the bottom and lower side apparently interfered with the penetration and setting of the larvæ. However, if we take the shells in the corners or on the outside edges of the crate we find the usual decrease in setting above low-water mark from 69, at the bottom of the crate, to 57, at the middle or halfway up, and 50 at the top.

A study of the effect of close grouping of crates on the distribution of spat within them was carried out in Group III where the crates were set out within a few inches of each other. (Fig. 34.) The crates on the outside edges of this group collected an average of 1,600 spat per bushel of shells while those in the middle were even more efficient and contained from 2,500 to 3,500 spat on the same quantity of material. An increase in the intensity of setting in the middle portion of the group can be attributed to the decrease in the velocity of the tidal currents and the creation of eddies. In the crates as a whole, setting was invariably found to be most intensive on the lee side of the collectors where the larvæ apparently were able to attach with greater ease.

The setting in the crates placed more than a foot below low-water mark (Group VI) was extremely light as the shells planted there became foul and covered with silt in a very short time while those which are above low-water mark are kept clean by regular exposure to the sun and air. With the conditions existing in Milford Harbor the best results can be obtained by placing spat collectors on areas that lie in a zone extending from 1 foot below to 2½ feet above low-water mark. Such areas are rather limited in northern waters but by using the lath crates or a similar constructed device, supported by legs sufficiently long to hold them above the bottom, it is possible to use the same area for the planting of spawners and for setting out collectors.

EXPERIMENTS IN 1927

In continuation of the work of finding a cheap, efficient, and practical spat collector, wire bags filled with shells, as shown in Figures 2 and 37, were tested out in 1927 in Milford Harbor and Great South Bay, Long Island. Six hundred collectors of this type were planted on the flats in Milford Harbor and in addition 300 bushels of shells were put out in a pyramidal wire collector having a wood base 12 inches square. This latter type of container was designed by Capt. Charles E. Wheeler of the Connecticut Oyster Farms Co., and proved to be suitable for the planting of shells on soft mud bottoms. One thousand bushels of oyster shells were scattered over the bottom between the bags in order to make a comparison between this usual method of seed collection and the wire bags.

Because the spring and early summer water temperature in 1927 were below normal, the oysters developed only a small quantity of spawn and were not fully ripened until near the middle of July. Spawning occurred on July 24 and the setting of the larvæ reached its peak on August 8. The setting was slightly heavier than in 1926 averaging 2,450 spat per bushel in the wire bags and 1,500 spat in the pyramidal type of collectors. The number of spat collected in the bags was found to vary from approximately 1,500 to 3,500 per bushel, according to the location in which they were planted in the harbor, or to their position in relation to low-water mark.

The distribution of spat within the bags was very satisfactory, the setting being fairly uniform and occurring on over 95 per cent of the shells. In making the counts

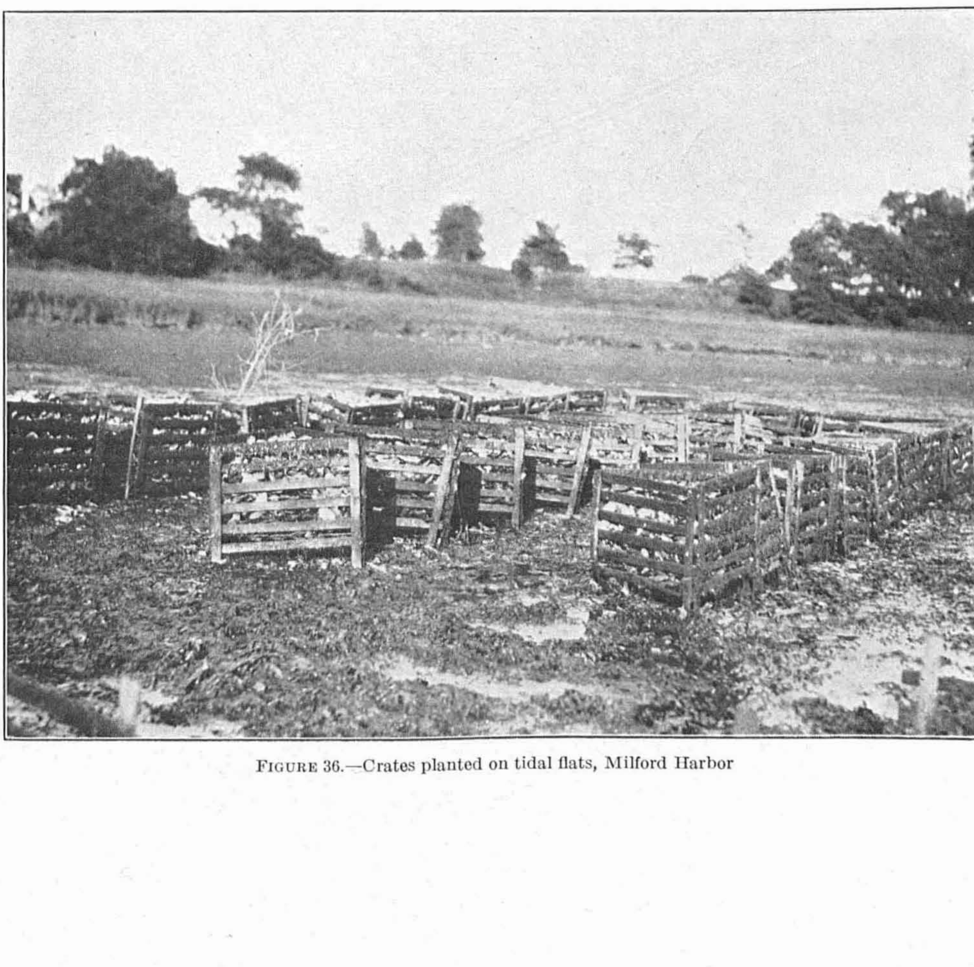

FIGURE 36.—Crates planted on tidal flats, Milford Harbor

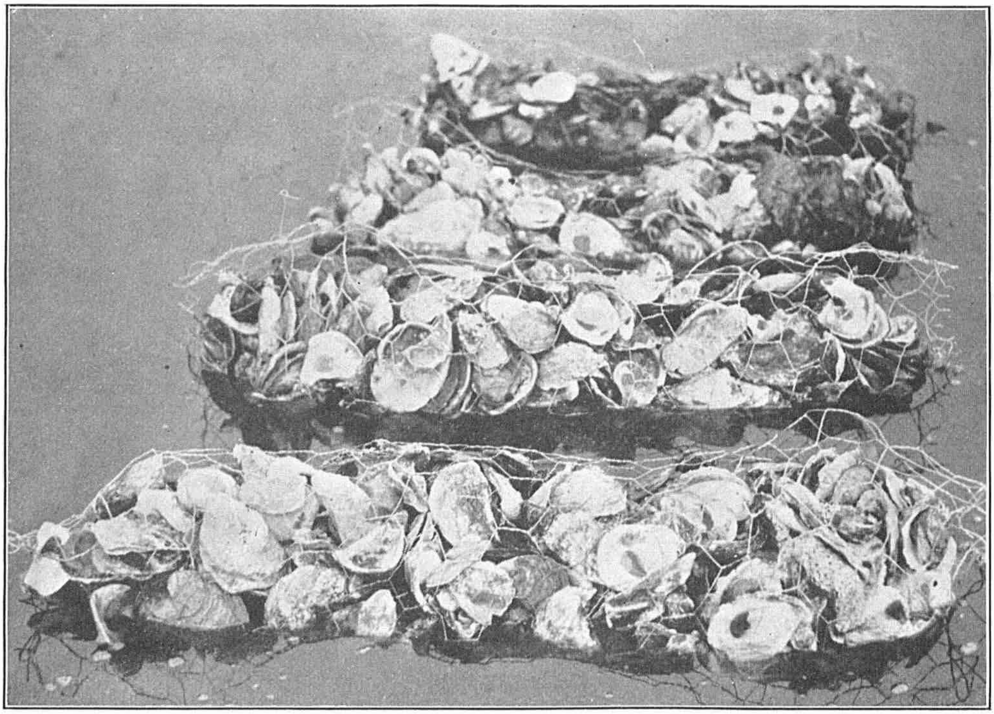

Figure 37.—Wire bag collectors planted on tidal flat, Milford Harbor

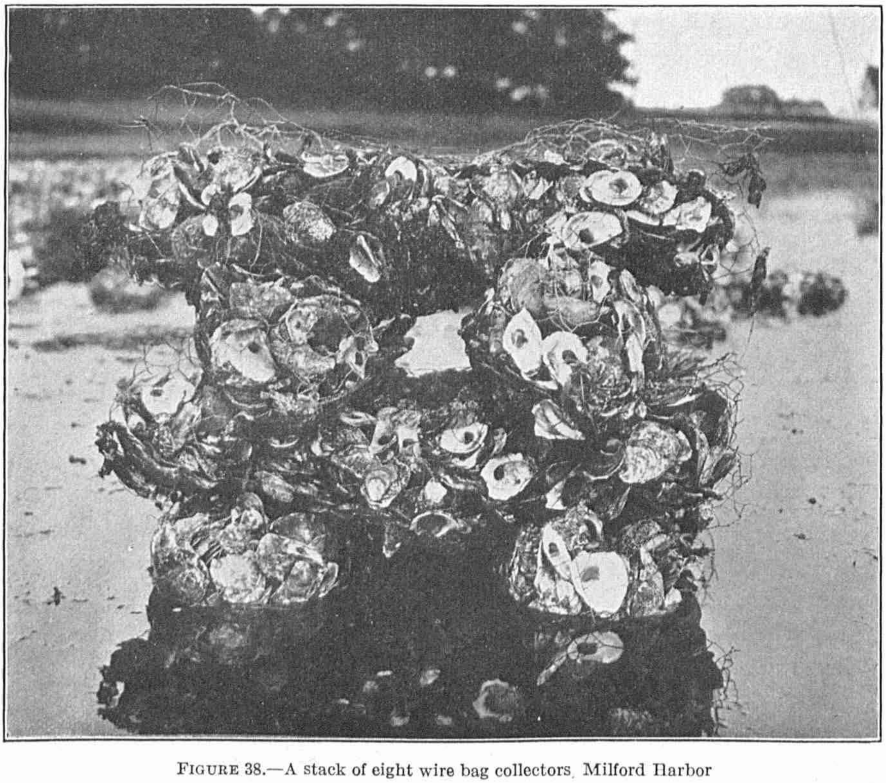

Figure 38.—A stack of eight wire bag collectors, Milford Harbor

a representative sample of one-half bushel of shells was taken from each bag and the number of spat per shell determined.

In Figure 39 the frequency distribution of spat on the shells is shown for three different bags in which the intensity of setting varied from 1,900 to 3,150 spat per collector. The bags were all planted under practically uniform depth and current conditions but were located at different positions in relation to the spawning bed,

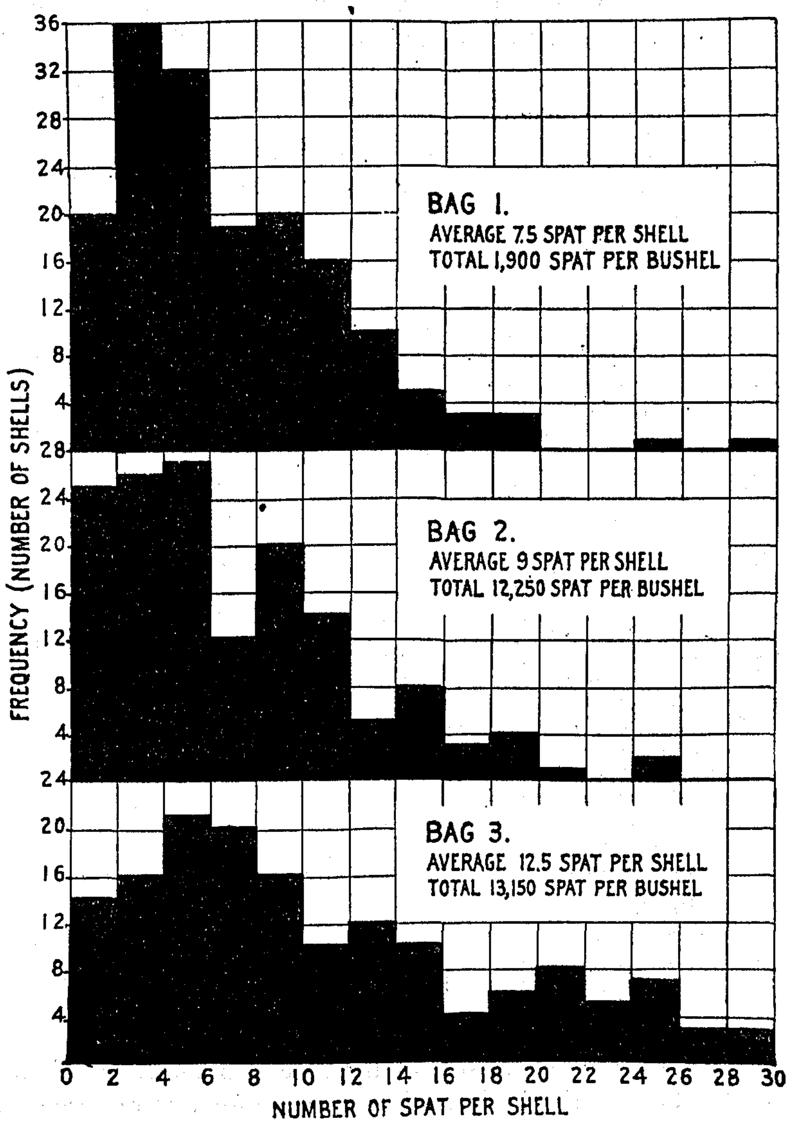

FIGURE 39.—Frequency distribution of spat on shells from wire bag collectors, Milford Harbor, 1927

Bag No. 1 was at the upper end of the bed, No. 2 in about the middle, and No. 3 just below the southern or lower limit of the bed where setting was the heaviest. The figure shows clearly that with an increase in the intensity of setting there is a greater uniformity of distribution of spat on the shells. In bags Nos. 1 and 2, where the setting was comparatively light, it was found that 66.5 per cent and 70 per cent of the shells, respectively, had collected a satisfactory set or more than 4 spat per shell. In bag No. 3 only two blank shells were found and 81 per cent of the shells were covered with sufficient numbers of spat. The variation in the number of spat per shell is really slight if we consider the different sizes of shells and the large number of positions in which they may become arranged in the wire container.

One of the advantages of the wire bags is that they can be stacked or piled up in tiers and thus increase greatly the amount of shells that could be planted on a given area. The shell bags were planted in tiers at several different points in the harbor and counts made as to the number of spat that were attached in the bags at each

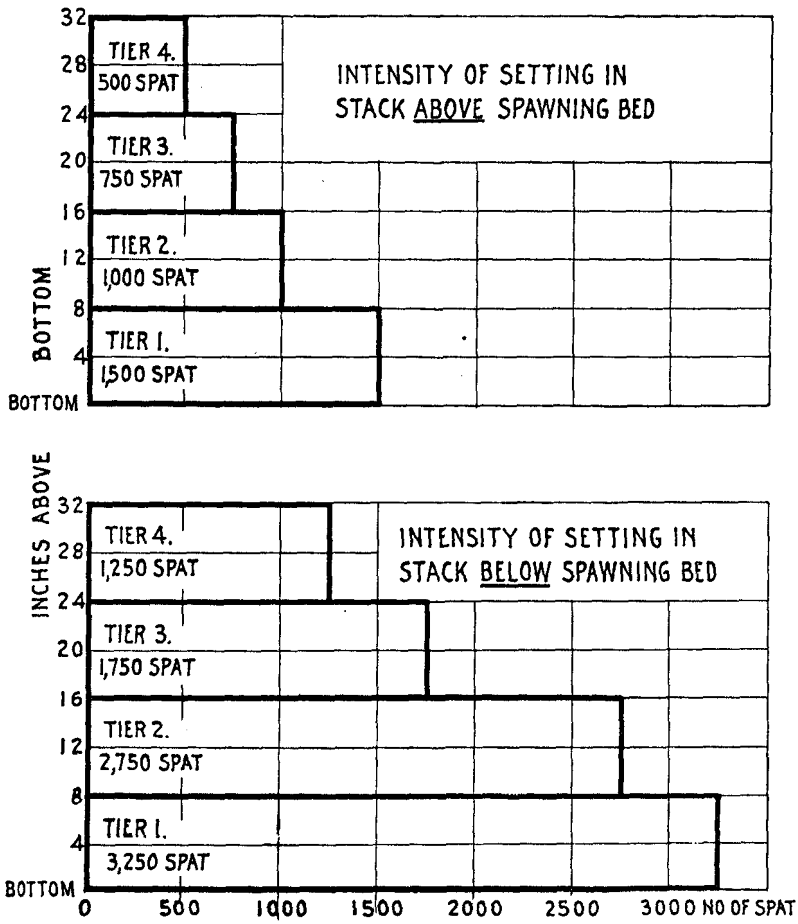

FIGURE 40.—Intensity of setting in stacks of wire-bag collectors

particular level. A photograph of one of the stacks is shown in Figure 38. The intensity of setting in each tier is shown in Figure 40 for two representative stacks, one of which was located at the upper end of the spawning bed and the other at the lower end. The figures given in this diagram are rounded off to the nearest 250 unit and show clearly how setting is of greatest intensity near the bottom or at low-water level and decreases gradually in the zone above. In each of these tiers there were two bags or eight in all in each stack which gives us a total collection of 7,500 spat for the upper stack and 18,000 for the lower. The area of bottom covered by one stack is approximately one square yard which gives us a unit for comparing this method of seed collection with the usual practice of scattering from 500 to 1,000 bushels of shells per acre. By the former method there is an efficient distribution of 8 bushels of shells per square yard (when 4 tiers are used) while by the latter, only 0.1 or 0.2 of a bushel are planted on the same area. Several samples of the scattered shells from the surrounding bottom were collected and counted and on these the setting ranged from approximately 1,500 to 2,000 spat per bushel. On one square yard of bottom in the best setting region in the harbor a production of 18,000 seed oysters was obtained in a single stack while on the scattered shells only 400 seed oysters were collected. The question naturally arises as to what the production would be on the scattered shells if they were planted more densely. This was tested out at a concentration of 2 bushels of shells per square yard in which the setting was found to be extremely poor and at best was less than 1,000 spat per bushel while in the wire bags only a few feet away over 3,000 spat were found on the same amount of shells. In the dense planting of shells, setting occurred almost entirely in the upper or exposed layer where the shells were much cleaner than those underneath.

The number of shell bags that can be planted successfully in a single stack will vary somewhat in each locality according to the depth of water, tidal conditions, and especially the zone in which setting takes place. Similar experiments were made in cooperation with the Bluepoints Co., at Great South Bay, Long Island, where the zone of setting extends from the bottom to nearly high-water mark. The bags were arranged on the deck of the oyster boat in tiers of six and the entire stack lowered over the side by means of the galvanized wires that bound them together at the corners. Twelve such stacks were set out in water 8 to 10 feet deep, and practically every shell caught a certain number of spat, most of them being well covered with from 50 to 100 per shell. The setting in the bags was decidedly heavier than it was on the shells scattered over the bottom and likewise the growth of the spat was much more rapid in the elevated collectors. In South Bay the setting is oftentimes extremely heavy (1,000 to 2,000 spat per shell) but for some unknown reason the spat invariably die during such prolific years unless they are elevated a few inches above the bottom. Therefore, the successful use of shell bags in this body of water is significant as it demonstrates not only a practical method of fully utilizing the heavy sets that occur but especially a means of keeping the spat alive.

EXPERIMENTS IN 1928

In 1928 the wire-bag method of seed-oyster collection was put into practice on a small commercial scale in four different harbor areas in Connecticut. The plantings were made in Milford Harbor by the Connecticut Oyster Farms Co., in New Haven and East Haven Harbors by F. Mansfield Oyster Co., in Branford Harbor by E. Ball & Co. In each locality the plantings were successful; the production of seed oysters ranging from 5,000 to 25,000 spat per bag. In Milford Harbor, where there were plenty of spawners, the setting was heaviest and varied from 9,000 spat per bushel, or an average of 30 per shell to over 25,000 per bushel or 85 spat per shell—the most intensive setting occurring in the bags that were planted just above low-water mark. The shells on the bottom and outer layer of the bag were covered with from 47 to 195 spat per shell while those further inside averaged approximately 25 per shell. Complete counts of the shells in many of the bags showed that the attachment of the larvæ within them had been exceedingly uniform and that less than 1 per cent of the shells had failed to collect spat. A summary of results obtained with wire-bag collectors in various localities of Connecticut shores and in Great South Bay, N. Y., is given in Table 32.

TABLE 32.—*Summary of results obtained with the wire-bag type of seed-oyster collector*

Observations	1927		1928	
	Milford Harbor	Great South Bay	Milford Harbor	Other Connecticut harbors
Average number of spat per bag	2,450	18,000	15,000	15,000-20,000
Maximum number of spat per bag	3,500	22,000	26,000	25,000
Minimum number of spat per bag	1,500	7,500	9,000	5,000
Average number of spat per shell	9	75	60	70
Maximum number of spat per shell	50	150	85	100
Per cent of shells covered with spat	95	90	99	90-98

V. CONCLUSIONS

By P. S. GALTSOFF and H. F. PRYTHERCH

Observations and experiments carried out by the authors from 1925 to 1928 along the coast of Cape Cod and in Long Island Sound indicate that there exist many thousands of acres of formerly productive bottoms which at present are depleted to such an extent that it is difficult to find a few live oysters on them. These areas can be rehabilitated by the establishment of spawning grounds and by employment of spat collectors for obtaining seed oysters. Since suitable bottoms for collecting the set are limited, it is necessary to employ such devices as crates, shell bags, or brush in order to present a greater area of surface for the attachment of the oyster larvæ.

It has been demonstrated that by means of the bags (3 feet long, 1 foot in diameter) made of poultry wire, filled with oyster shells, and stacked in various formations the number of seed oysters collected per a given area of bottom can be materially increased. In Wareham River from 15 to 30 times as many seed oysters were collected on a given area as by ordinary methods. In Onset Bay the number of spat, per a unit of area, in one layer of horizontally laid bags was 4 times greater than on the adjacent bar. Since it is possible to put 3 or 4 layers of bags over 1 square yard the productivity of seed oysters in that bay can be increased from 12 to 16 times as compared with the present method of planting. In the experiments at Milford Harbor 45 times as many seed oysters per given area were obtained in the stocks of bags as on loose shells scattered over the bottom.

A success with the wire-bag collectors depends on several conditions. There must be sufficient number of spawners (at least 500 bushels to an acre) in the vicinity of the collectors. The temperature of the water must be above 20° C. because no spawning takes place below that temperature. The surface of shells or other cultch must be clean since slime or overgrowth of algæ prevent the attachment of the larvæ. The bags must be planted in the zone of heaviest setting which could be determined either by preliminary experiments or by a careful examination of piles, wharves, and other underwater structures or objects.

Crates and wire-bag collectors can be successfully used either on soft bottoms or on sandy and shifting bars where ordinary planting of shells is impossible.

Though the production of seed oysters varies somewhat from year to year, the relative intensity of setting that will occur each season can be estimated a month or more in advance from the examination of the gonad development of the oysters and analysis of the daily temperature records. A full description of this method and its application can be found in the paper of Prytherch (1929).

The experiments with the shell bags carried out in several localities described in this paper show clearly that this method of seed collection can be successfully applied on a commercial scale in the inshore areas of North Atlantic States.

BIBLIOGRAPHY

BELDING, D. L.

1909. The shellfisheries of Massachusetts; their present condition and extent. The Commonwealth of Massachusetts, 1909, pp. 1–241, 50 pl. Boston.

1911. Observations on the set of oyster spat in Wellfleet Bay. Report, Commissioners on Fisheries and Game for the year ending December 31, 1910 (1911), Public Document No. 25, pp. 129–143. Boston.

BROOKS, W. K.

1879. Abstract of observations upon the artificial fertilization of oyster eggs and the embryology of the American oyster. American Journal of Science, Vol. XVIII, 1897, pp. 425–427. New Haven, Conn.

1905. The oyster. A popular summary of a scientific study, second edition, 1905, 225 pp., Pls. XVIII. Baltimore.

CHURCHILL, E. P., Jr.

1920. The oyster and the oyster industry of the Atlantic and Gulf Coasts. Appendix VIII, Report, United States Commissioner of Fisheries, 1919 (1921). Bureau of Fisheries Document No. 890, 51 pp., 29 pls., 5 figs. Washington.

COLLINS, J. W.

1891. Notes on the oyster fishery of Connecticut. Bulletin, United States Fish Commission, 1889 (1891), Vol. IX, pp. 461–497, Pls. CLIX–CLXVI. Washington.

CONSERVATION COMMISSION, STATE OF NEW YORK.

1923. Thirteenth Annual Report for the year 1923. Legislative Document No. 30, 1923 (1924), text figs. Albany.

1924. Fourteenth Annual Report for the year 1924. Legislative Document No. 29, 1924 (1925), pp. 1–251. Albany.

1925. Fifteenth Annual Report for the year 1925. Legislative Document No. 28, 1925 (1926), pp. 1–270. Albany.

1927. Seventeenth Annual Report for the year 1927. Legislative Document No. 38, 1927 (1928), pp. 1–371. Albany.

DEAN, BASHFORD.

1892. Report on the European methods of oyster culture. Bulletin, United States Fish Commission, Vol. XI, 1891 (1892), pp. 357–406, Pls. LXXV–LXXXVIII. Washington.

1892. The present methods of oyster culture in France. Bulletin, United States Fish Commission, Vol. X, 1890 (1892), pp. 363–388, 2 figs., Pls. LXVIII–LXXVIII. Washington.

DEPARTMENT OF CONSERVATION, THE COMMONWEALTH OF MASSACHUSETTS.

1925. Annual Report of the Division of Fisheries and Game for the year ending November 30, 1925. Public Document No. 25, 1925, pp. 1–58. Boston.

GALTSOFF, P. S.

1930. Biology and cultivation of shellfish. *In* Progress in Biological Inquiries, 1928, by Elmer Higgins. Appendix X, Report, United States Commissioner of Fisheries, 1929 (1930). Bureau of Fisheries Document No. 1068, pp. 732–737. Washington.

GALTSOFF, P. S. and R. H. LUCE.

1930. Oyster Investigations in Georgia. Appendix V, Report, United States Commissioner of Fisheries, 1930. Bureau of Fisheries Document No. 1077. Washington.

GUTSELL, J. S.

1924. Oyster cultural problems of Connecticut. Appendix X, Report, United States Commissioner of Fisheries, 1923 (1924). Bureau of Fisheries Document No. 960, 10 pp., 2 figs. Washington.

INGERSOLL, ERNEST.
1881. The oyster industry. *In* The history and present condition of the fishery industries. Department of the Interior, Tenth Census of the United States, 1881, pp. 1–250. Washington.

MOORE, H. F.
1897. Oysters and methods of oyster culture. Report, Commissioner of Fish and Fisheries, 1897 (1898), pp. 263–340, Pls. I–XVIII. Washington.

NELSON, JULIUS.
1901. Renewed studies in Oyster Culture. Report, Biological Department of the New Jersey Agricultural College Experiment Station, 1900 (1901), pp. 315–360, 5 plates. Trenton, N. J.
1905. Experiments in the artificial rearing of oyster fry. Report, Biological Department of the New Jersey Agricultural Experiment Station for the year 1904 (1906), pp. 413–445, Pl. IX. Trenton.
1907. Experimental studies in oyster propagation. Report, Biological Department of the New Jersey Agricultural College Experiment Station, 1906 (1907), pp. 313–354, Pl. XIV. Trenton, N. J.

NELSON, THURLOW C.
1920. The conservation of New Jersey's oyster industry. Report, Board of Shellfisheries of New Jersey, 1920, pp. 8–15. Trenton, N. J.
1921. Aids to successful oyster culture; procuring the seed. Bulletin 351. New Jersey Agricultural Experiment Stations, New Brunswick, N. J., pp. 1–59. Trenton, N. J.

PRYTHERCH, HERBERT F.
1924. Experiments in the artificial propagation of oysters. Appendix XI, Report, United States Commissioner of Fisheries, 1923 (1924). Bureau of Fisheries Document No. 961, 4 pp., 9 figs. Washington.
1929. Investigation of the physical conditions controlling spawning of oysters and the occurrence, distribution, and setting of oyster larvæ in Milford Harbor, Conn. Bulletin, United States Bureau of Fisheries, Vol. XLIV, 1928 (1929), pp. 429–503, 32 figs. Washington.
1930. Improved methods for the collection of seed oysters. Appendix IV, Report, United States Commissioner of Fisheries, 1930. Bureau of Fisheries Document No. 1076, pp. 47–59, 9 figs. Washington.

RICE, H. J.
1883. Experiments in oyster propagation. Transactions, American Fish Culturists Association, pp. 49–56. New York.
1885. The propagation of the oyster. Supplement to Report, Commissioner of Fisheries in charge Oyster Investigations, pp. 71–137. Albany, N. Y.

ROUGHLEY, T. C.
1925. The story of the oyster, its history, growth, cultivation and pests in New South Wales. Australian Museum Magazine, Vol. II, 1925, pp. 1–32. Sydney, Australia.

RYDER, JOHN A.
1882. Notes on the breeding, food, and green color of the oyster. Bulletin, United States Fish Commission, Vol. I, 1881 (1882), pp. 403–419. Washington.
1883. Rearing oysters from artifically fertilized eggs together with notes on pond culture. Bulletin, United States Fish Commission, Vol. III, 1883, pp. 181–194. Washington.
1884. An account of experiments in oyster culture and observations relating thereto. Appendix D. Report, United States Fish Commission 1882 (1884), Part XXIV, pp. 763–778. Washington.
1885. The oyster problem actually solved. Forest and Stream, October 22, 1885, pp. 249–250. New York.
1887. An exposition of the principles of a rational system of oyster culture, together with an account of a new and practical method of obtaining oyster spat on a scale of commerical importance. Appendix C, Report, United States Commissioner of Fish and Fisheries, 1885 (1887), Part XIII, pp. 380–423. Washington.

STAFFORD, J.
1913. The Canadian oyster, its development, environment, and culture. Commission of Conservation, Canada Committee on Fisheries, Game, and Fur-bearing Animals, 1913, 159 pp., 1 map, VII Pls. Ottawa.

WINSLOW, FR.
1884. Report of experiments in the artificial propagation of oysters conducted at Beaufort, N. C., and Fair Haven, Conn., in 1882. Appendix D, Report, United States Commissioner of Fish and Fisheries, 1882 (1884), Part XXIII, pp. 741–762. Washington.

WELLS, WILLIAM F.
1926. A new chapter in shellfish culture. Report, Conservation Commission, State of New York, 1925 (1926), pp. 93–126. Albany.
1927. Report of experimental shellfish station. Report, Conservation Department, State of New York, 1926 (1927), pp. 1–26. Albany, N. Y.