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RAFT CULTURE OF OYSTERS IN MASSACHUSETTS

By WILLIAM N. SHAW

FISHERY BULLETIN 197

From Fishery Bulletin of the Fish and Wildlife Service

VOLUME 61

UNITED STATES GOVERNMENT PRINTING OFFICE • WASHINGTON • 1962

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C. – Price 20 cents

Library of Congress catalog card for the series, Fishery Bulletin of the Fish and Wildlife Service:

U.S. *Fish and Wildlife Service.*
Fishery bulletin. v. 1–
Washington, U.S. Govt. Print. Off., 1881–19

v. in illus., maps (part fold.) 23–28 cm.

Some vols. issued in the congressional series as Senate or House documents.
Bulletins composing v. 47– also numbered 1–
Title varies: v. 1–49, Bulletin.
Vols. 1–49 issued by Bureau of Fisheries (called Fish Commission, v. 1–23)

1. Fisheries—U.S. 2. Fish-culture—U.S. I. Title.

SH11.A25 639.206173 9—35239*

Library of Congress [59r55b1]

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ABSTRACT

The harvest of oysters in Massachusetts has dropped more than 50 percent in the last 50 years. The possibility of growing oysters attached to rafts was tested as a method of culture that might be useful in reviving the declining oyster industry.

Oysters suspended from rafts grew about twice as fast as oysters growing on the bottom. Survival of raft oysters was about 6 times greater than that of bottom-grown oysters. This study showed that oysters can reach market size in 2½ years, if they are first suspended from a raft for 14 months. During the final year, raft-grown oysters should be placed on the bottom to let the shells thicken. Normally, wild oysters take from 4 to 5 years to reach market size in Cape Cod waters.

A gross profit of $3.75 per bushel was earned from the raft-grown oysters. This amount compares favorably with the present gross profit of $4.50 per bushel earned by local oystermen who grow oysters on the bottom.

This experiment demonstrates that raft culture is commercially feasible in Massachusetts.

RAFT CULTURE OF OYSTERS IN MASSACHUSETTS

By William N. Shaw, *Fishery Research Biologist*

BUREAU OF COMMERCIAL FISHERIES

The harvest of oysters in the United States has dropped more than 50 percent during the past 50 years. For the decade 1893–1902, the annual harvest of oyster meats averaged 164.9 million pounds, but for 1943–52 it was only 76.8 million pounds (Galtsoff, 1956). An even greater decrease has occurred in Massachusetts. Figure 1 shows

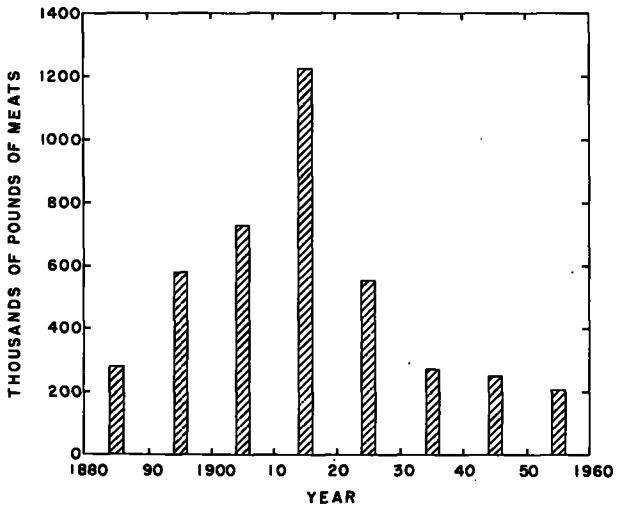

FIGURE 1.—Ten-year annual average of oysters marketed in Massachusetts, 1880–1960.

that in this State the annual average harvest of 1,222,500 pounds of oyster meats during the ten year period 1910–19 has fallen to the present low level of 204,700 pounds (1950–59), a decline of 83.3 percent. Since 1952 this trend has continued at a substantially higher rate and only 113,000 pounds were harvested in 1958, an all-time low for the State (fig. 2).

I wish to thank Dr. Paul S. Galtsoff for assistance in organizing the project and for suggestions in preparing the manuscript; J. C. Hammond, commercial oyster grower, whose help in construc-

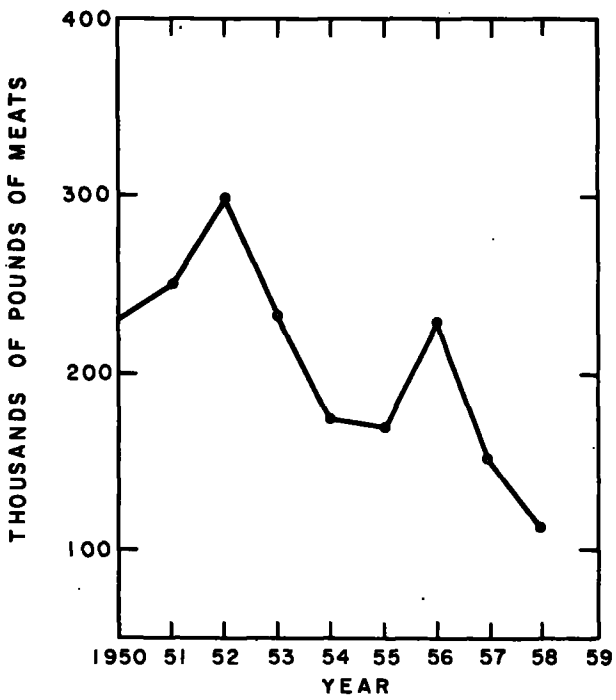

FIGURE 2.—Annual harvest of oysters in Massachusetts, 1950–58.

tion and maintenance of the raft made this project possible; Gilbert Covell, commercial oyster grower, who donated young oysters for the observations. The late Charles Jones, former Chatham shellfish warden, gave permission to use certain areas where oyster spat could be caught. Without the cooperation of local oyster growers and officials the project could not have been carried out. Robert K. Brigham furnished the photographs and Frank A. Bailey made the drawings.

NOTE.—Fishery Bulletin 197. Approved for publication June 30, 1961.

HISTORY OF MASSACHUSETTS OYSTER INDUSTRY

The Massachusetts oyster industry is centered around Cape Cod. When the first settlers came to this area they found many natural oyster beds in the tidal rivers emptying into Buzzards Bay, Cape Cod Bay, and Nantucket Sound. Since most of the beds were easily accessible at low tides it was not long before the Cape's natural supply of oysters was greatly reduced. Many towns recognized the value of oyster-beds and for fear of their destruction passed laws intended to protect the oyster fishery. As early as 1772 the town of Wellfleet regulated the taking of oysters in Billingsgate Bay. By 1775 Wareham invoked a law, "that there should be no shellfish nor shell sold or carried out of the town." Other restrictions pertaining to the taking of shellfish were inaugurated, but in most cases the laws were passed too late or provided only temporary relief; the destruction of many natural beds had already taken place.

The next phase in the history of the industry began during the early 1840's with the planting of Virginia oysters on leased grounds at Wellfleet. By 1850, 100,000 bushels were planted (Ingersoll, 1881). Because of the Civil War (1861–65) there was a sharp decline in the shipping of oysters. After the war, the decline continued until in 1880 only 6,000 bushels of Virginia oysters were planted in Wellfleet.

With the decline of the importation of Virginia stock, a system of grants was developed. In 1874 the towns of Swansea and Somerset were given the privilege of issuing grants for the propagation of oysters. Four years later, in 1878, the Massachusetts oyster laws were amended giving the mayor, aldermen, or selectmen of each city and town the right to issue grants "for a term not exceeding 20 years to an inhabitant thereof, to plant, grow, and dig oysters."

The oyster industry of Massachusetts has not changed significantly since the first grants were issued. Under this system the oysterman leases from a town a certain area of suitable offshore bottom. In the spring he plants fully grown oysters obtained from the waters of other States, mainly from Connecticut. The majority of these oysters are sold in the late fall and winter; only those under the 3-inch minimum legal size are left on the bottom for another year.

Because of the recent scarcity of oysters in Long Island Sound, the Connecticut and New York growers can no longer supply Massachusetts with enough bedding stock; therefore, many Bay State oystermen have gone out of business. For example, in Oyster Pond River, Chatham, where 20 men were once in the oyster business, only 3 are working at present. Since the oyster industry of Massachusetts can no longer afford to rely on obtaining bedding stock from other States, new and more effective methods of oyster culture are needed, if the industry is to prosper.

UTILIZATION OF THE POTENTIAL SEED RESOURCES

At present the potential seed resources of the Cape are not utilized. Wild oysters are found in the tidal waters of Cape Cod indicating that natural reproduction is taking place. Waters around Wareham River and Onset Bay are capable of producing thousands of bushels of seed oysters if proper spat-collecting methods are used. Failures of setting in this area are rare (Galtsoff, Prytherch, and McMillin, 1930). Good setting regions are also found along the south shore of Cape Code where many wild oyster sets occur nearly every year. By taking advantage of these resources, the local oyster industry could be made self-sustaining instead of depending on the importation of out-of-State bedding stock; by raising seed a true oyster culture would be practiced.

The basic reason for the present lack of utilization of Massachusetts natural seed is its slow growth. Local production is hampered by high mortality from predation, and difficulty in obtaining grants for the culturing of seed oysters. Massachusetts is near the northern limit of the range of distribution of the eastern oyster, *Crassostrea virginica*, which according to Abbott (1954), extends along the coast of the United States from the Gulf of St. Lawrence to the Gulf of Mexico. In Cape Cod waters wild oysters reach market-size (3-in. or greater) in 4 to 5 years, although fishermen report that in Wellfleet oysters grow to market size in 3½ years. During this time they are the prey of enemies. Our records show that of 400 bushels of seed oysters planted in Oyster Pond River in the fall of 1956, nearly 100-percent mortality had occurred by the end of 1958 due mainly to drills and whelks. Many growers throughout the State report similar experiences in attempting to raise oysters from spat.

Oystermen, who are willing to utilize the State seed resources, experience difficulty in obtaining new grants. At present, each coastal community has jurisdiction over the shellfisheries of its tidal water and restricts the issuing of grants to the residents. Furthermore, the officers of coastal municipalities are reluctant to make available any new grounds to private individuals for oyster cultivation. Finally, an oysterman has no assurance that his grant will be renewed at the expiration of the lease. Slow growth of oysters, high mortality, and the difficulty of obtaining permanent grants discourage him from investing his time and money in growing oysters by the present slow methods.

GROWING OYSTERS OFF BOTTOM

Experiments successfully tried in the United States, Canada, Australia, and Japan have shown that oysters grow faster when lifted off the bottom. In Elkhorn Slough, Monterey Co., Calif., Bonnot (1935) obtained remarkably rapid growth of Japanese seed oysters, *Crassostrea gigas*, which reached market-size in only 8 months. Some Eastern (U.S.) oysters in this experiment grew well but at a slower rate than the Japanese species. Similar studies were conducted at Ladysmith, British Columbia, Canada. One-year-old Japanese oysters were hung from rafts in March and by November were large enough to harvest. Quayle (1956) reports that by this method oysters can be harvested in two years instead of three.

In Japan and Australia, oysters are cultured off bottom on a commercial scale. In the Inland Sea of Japan, 20 million pounds of oyster meats are harvested annually using bamboo rafts (Wallace, 1959). Australian oystermen grow many of their oysters in wooden trays kept above the bottom (Kesteven, 1947). Despite the success of off-bottom culture in Japan and Australia, this method had not been adopted to any extent by commercial growers in the United States.

PURPOSE OF THE STUDY

To develop a method of oyster culture which might be useful in reviving the Massachusetts oyster industry, and at the same time utilize the State seed resources, the U.S. Bureau of Commercial Fisheries at Woods Hole began studies on the growth and survival of oysters kept on rafts in Oyster Pond and Oyster Pond River, at Chatham (Mass.). The present paper summarizes the observations made between 1956 and 1959. Particular attention was given to whether the benefits obtained from the cultivation of raft-grown oysters would justify the possible additional cost of production.

LOCALITY AND DESCRIPTION OF THE AREA

Oyster Pond (fig. 3) is approximately three-fourths of a mile long and one-quarter of a mile wide. Its bottom along the shore is hard sand which changes to soft mud in deeper water. Records show that natural oyster beds once existed in the pond, but by 1877, all had disappeared (Belding, 1909).

Oyster Pond River (fig. 3) begins at the outlet of the pond where it runs SW. for seven-eighths of a mile and then bends to a SE. direction for another three-quarters of a mile before emptying into Stage Harbor. The width of the river is fairly constant throughout its entire length, averaging about 165 yards. The depth varies from 1 to 9 feet at mean low water except for a 10-foot channel. Tidal currents recorded with a Gurley current meter are about 2 feet per second during flood tide. The bottom is generally hard-packed sand, but in deeper water away from the shore and in areas where tidal creeks flow into the river, the bottom is soft with a high percentage of silt and clay. High cliffs are found along the entire length of the north side of the river, and for the first seven-eighths of a mile on the south side, but for the remaining three-quarters of a mile only tidal flats appear.

TEMPERATURE, SALINITY, OXYGEN CONTENT, AND pH OF WATER

Surface water temperature in Oyster Pond River was recorded during each visit to the site. In addition, a thermograph was installed from April 1 to November 20, 1958. During 1958 the average monthly temperature fluctuated from 1.2° C. in February to a high of 22.3° C. in July, and then to a low of 0.8° C. in December (fig. 4). The water temperature was also found to vary during the day. For example, on April 24, 1958, a low of 11.8° C. was recorded at 6:00 a.m. By 12:00 noon the temperature had climbed to 16.2° C. In the

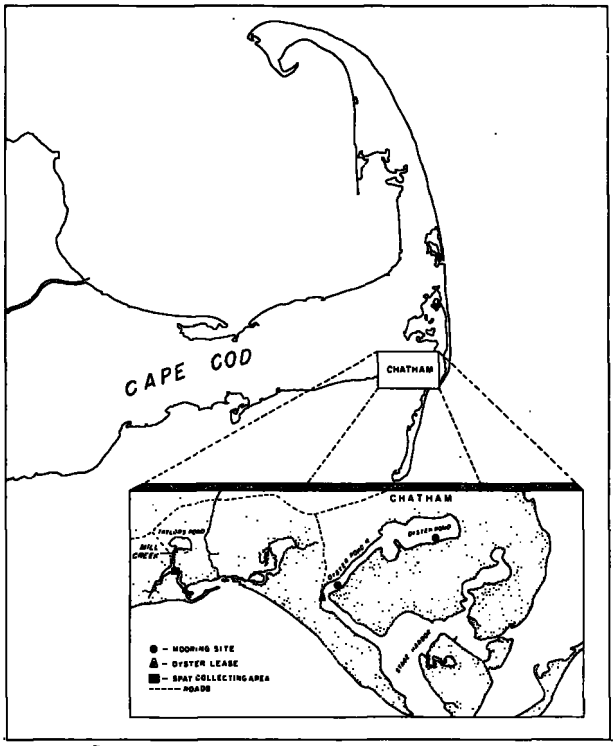

FIGURE 3.—Locations of mooring sites, oyster leased grounds, and spat collecting area near Chatham, Mass.

afternoon the temperature dropped slowly and by 6:00 p.m. it was down to 13.4° C.

During the 3 years of observations the salinity of the water in Oyster Pond River varied from 29.23‰ to 32.68‰. Since there is no major fresh-water drainage entering the river, a horizontal salinity gradient is absent. The salinity (fig. 4) was higher (31.00–32.68) from June 1956–October 1957 than for the period November 1957–December 1958 (29.23–31.00).

Dissolved oxygen (fig. 4) was highest during the winter and lowest in the summer. Most of the readings were at or near 100 percent saturation. The pH varied from 7.6 to 8.0.[1]

AQUATIC LIFE IN THE RIVER

The most conspicuous or most abundant animals and plants found on or near the oyster bottoms are various species of algae, Bryozoa, Arthropoda, and Mollusca. All the animals species listed in the table are permanent residents of Oyster Pond River with the exception of the horseshoe crab, *Limulus polyphemus*, which enters the river in early spring. After it spawns, *polyphemus* leaves the river for deeper water.

[1] Corrected for salt error.

The most common algae and invertebrates collected or recorded from Oyster Pond River (Mass.) are:

ALGAE:[1]
- Enteromorpha sp.
- Gracilaria confervoides
- Griffithsia sp.
- Ceramium rubrum
- Chondria sp.
- Champia parvula
- Scythosiphon lomentaria

PORIFERA:
- Microciona prolifera

BRYOZOA:[2]
- Membranipora tenuis
- Electra hastingsae
- Callopora aurita
- Schizoporella unicornis
- Schizoporella biaperta
- Cryptosula pallasiana
- Hippodiplosia pertusa
- Microporella ciliata
- Parasmittina trispinosa

ARTHROPODA:
- Libinia emarginata
- Carcinides maenas

ARTHROPODA—(Continued)
- Cancer irroratus
- Neopanopeus texana
- Panopeus herbstii
- Limulus polyphemus

MOLLUSCA:
- Littorina litorea
- Nassarius obsoletus
- Urosalpinx cinerea
- Eupleura caudata
- Busycon canaliculatum
- Busycon carica
- Polinices duplicatus
- Crepidula fornicata
- Aequipecten irradians
- Mercenaria (Venus) mercenaria
- Anomia simplex
- Crassostrea virginica
- Mytilus edulis
- Modiolus demissus
- Mya arenaria
- Gemma gemma

TUNICATA:
- Botryllus schlosseri
- Molgula manhattensis

[1] Algae identified by Dr. Paul S. Galtsoff from material collected on August 7, 1951.

[2] Bryozoa identified by Mrs. M. B. Lambert from a sample taken after dredging in 5 to 8 feet of water on July 14, 1953.

Several species of oyster predators are abundant. These include the oyster drills, *Urosalpinx cinerea* and *Eupleura caudata*, and two species

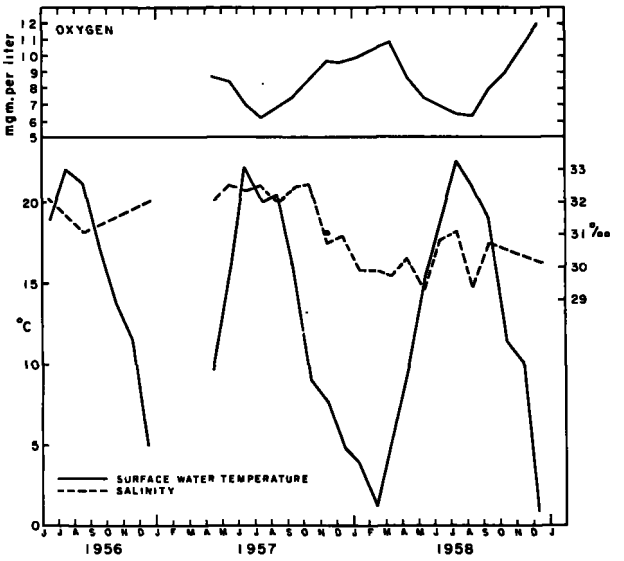

FIGURE 4.—The average monthly water temperature, salinty, and content of dissolved oxygen for Oyster Pond River.

of whelks, *Busycon carica* and *B. canaliculatum*. All four occur on the oyster grounds throughout the year and inflict a considerable amount of damage. Noticeably absent in the river is the starfish, *Asterias forbesi*. Only a few specimens were found in the lower stretches of the river during the three years of investigation.

It is of interest to mention the fluctuation in the abundance of the green crab, *Carcinides maenas*. In the spring of 1957, the crabs were found in such great numbers that they were caught by commercial fishermen for bait. By 1958 the population of crabs had so declined that commercial fishing became unprofitable and was terminated after the first day. In 1959, only an occasional green crab was observed in the river.

Two species of algae were conspicuous. *Gracilaria confervoides* was found on the oyster shells on the bottom, and *Enteromorpha* sp. was the principal fouling plant on the oysters attached to the raft. Other major fouling organisms included the compound ascidian, *Botryllus schlosseri*, the simple ascidian, *Molgula manhattensis*, and the barnacle, *Balanus balanoides*. The most abundant bryozoan was *Schizoporella unicornis*. Second in abundance were the peculiar nodular colonies of *Parasmittina trispinosa* found in soft mud in the channel and oyster bottom.

Throughout the tidal flats wild oysters grow attached to the stems of marsh grass, and often are found on exposed rocks; some set on ribbed mussels, *Modiolus demissus;* also many oysters are found on muddy bottom.

FIGURE 5.—Raft used in the study.

MATERIALS AND METHODS

CONSTRUCTION OF RAFT

The raft (fig. 5) used in the work was constructed of 25-foot cedar logs joined together by wooden crossbars which held it together and kept the logs sufficiently apart to permit free circulation of water. Logs were selected as floats because they were readily available and inexpensive. Each log was floated in the water and notched on the top with an axe. A row of 46 staples (3

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inches apart) was placed along the side of each log at right angles to the notches. The log was copper-painted for protection against various fouling and wood-boring organisms. In 1956 the raft consisted of two logs; two more were added in 1957. After storm-damage on January 7, 1958, the raft was reduced to the original two logs.

The raft was moored in Oyster Pond River from September through November 1956, and from April through November 1957 and 1958. During the winters of 1956 and 1957, it was moved and anchored in Oyster Pond to protect it from being damaged and carried away by floating ice which occurs in the river during this period. In November 1958 the raft was dismantled.[2]

ORIGIN OF OYSTERS USED IN THE EXPERIMENT

Oysters used in the 1956 experiment were obtained from a setting that took place during the last week of August between the outlet of Crooked River and Long Beach Point, Wareham River, Mass. Several bushels of cultch were transferred to Oyster Pond River, strung on galvanized wire, and placed on the raft by October 5. All but two strings of Wareham River oysters were destroyed in the storm of January 1958. The two remaining strings were kept attached to the raft until November 1958, when they were removed and taken to the laboratory for measurement.

The oysters used in the 1957 experiments came from Mill Creek, a tidal outlet of Taylors Pond in West Chatham, Mass., which runs for about one-half mile before emptying into Nantucket Sound. The creek bottom is hard sand changing to soft mud near the banks. Along the length of the creek are several sand bars exposed at low tide. Since 1955 a local oyster grower has been catching oyster spat by placing chicken-wire bags each containing one-half bushel of shells on these bars (fig. 6)[3]. In 1957 setting occurred around July 15. On August 12, samples of these oysters were transferred to Oyster Pond River, and by August 30 all were placed on the raft. Fortunately, only a few strings of oysters were lost in the 1958

[2] Shortly after the completion of this study a Fiberglas raft was designed, built, and successfully tested for growing oysters off the bottom. See: Shaw (1960).

[3] Recent studies at Mill Creek indicate that more spat are caught on shells strung on wires and hung horizontally from racks than on shells placed in chicken wire bags.

FIGURE 6.—Spat collectors in Mill Creek.

storm. In November 1958, the Mill Creek oysters were removed from the raft and planted on the bottom. Here they remained until November 1959, when most of them were sold.

ASSEMBLING THE STRINGS OF OYSTERS

To each staple on the log was attached a 5-foot, #14 galvanized wire that had been previously strung with scallop and oyster shells with 5 or more young oysters attached to each. Before stringing the shells, a hole was punched through each one using a tack hammer with a punch brazed to one end (fig. 7). Each string contained approximately 20 pairs of shells, the pairs being separated by a 3-inch piece of plastic tubing. A total of 191 strings were suspended in 1956 and an additional 192 were hung in 1957. After the 1958 storm the total number of strings was reduced to 182.

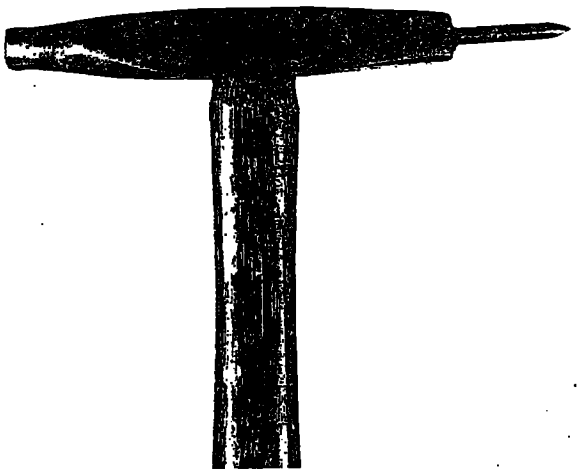

FIGURE 7.—Hammer used to punch holes in shells.

DETERMINING SHELL GROWTH AND OYSTER MORTALITY

Increments of shell growth were noted at monthly intervals. The shell dimensions selected were the height (greatest dorsoventral distance) and length (greatest anteroposterior distance); other measurements such as total volume, total weight, and weight of meat were not taken because the oysters could not be killed during this study without destroying the commercial aspects of the experiment, e.g., the determination of the total number of bushels that can be harvested from a log raft.

The procedure of measuring oysters was as follows: Approximately 100 oysters were taken from both the Wareham River and Mill Creek strings (fig. 8). The oysters were cleaned, taking care not to damage the new shell. They were then measured to the nearest 1.0 mm. with vernier calipers. The same oysters were selected each month in order to keep the cleaning process at a minimum. Immediately after the measurements were completed, the two experimental groups were

FIGURE 8.—Left, 1957 Mill Creek set grown on log raft for one year. Right, 1956 Wareham River set grown on log raft for two years.

restrung on wires and suspended side by side at a designated spot on the raft.

Just prior to planting the Mill Creek oysters on the bottom, a sample of undisturbed oysters was measured. Their mean height and length were compared with the mean height and length of oysters that had been disturbed and cleaned each month. Little difference between the two groups was found.

In our experiments the shell growth of oysters from Wareham River was observed from the time they were first attached to the raft in the fall of 1956 until the raft was dismantled in 1958. Similar observations of growth were made on oysters from Mill Creek which were attached to the raft in the fall of 1957, then planted on the bottom in the winter of 1958, and finally sold in the winter of 1959. No measurements were taken from mid-November to April because no appreciable shell growth occurred during this period. Oysters on the bottom of the same age and origin as those attached to the raft were measured once each fall. Since these oysters were on private grounds, their disturbance was kept at a minimum.

Monthly survival among the raft oysters was recorded by counting the total number of live oysters on one string. By selecting the same string each month, any decrease in the total number of live oysters from that counted the previous month could be considered natural mortality. A year after the raft oysters were planted on the bottom a random sample was collected and the number of live and dead (left valves only) oysters were counted. The ratio of dead to the total number in the sample was considered natural mortality.

ANALYSIS OF RESULTS

GROWTH

The shell growth rate of the eastern oyster of the Atlantic Coast increases southward and in the Gulf of Mexico. The average height of oysters at the end of the setting year in Connecticut is 19 mm. (Loosanoff, 1946). Moore (1897) found that by the end of the first season of growth oysters of Chesapeake Bay measured 38 mm. in height, whereas in North Carolina this size was reached in 3 months. Moore also observed that 7-month-old South Carolina oysters measured 63 mm. in height. Galtsoff and Luce (1930) working in Georgia, observed 1-year-old oysters ranging from 24 mm. to 69 mm. Ingle (1950) reported that Florida oysters reached 25.4 mm. in 5 weeks, while Butler (1954) found oyster set that grew to 51 mm. in height by the end of the year. The fastest growth was observed in Louisiana where 12-month-old oysters reached 71 mm. in height (Moore and Pope, 1910), although Butler (1954) observed under special conditions at Pensacola (Fla.), a growth of 76 to 101 mm. in 12 months.

Our study shows that the growth of raft oysters from Wareham River was fairly similar to that observed by Loosanoff (1946) for the oysters grown off the bottom at Milford Harbor (Conn.); the mean height in successive years of 11, 49, and 72 mm. for the former compared to 19, 59, and 78 mm. for the latter (table 1). In contrast, the raft oysters from Mill Creek grew faster; the mean height was 28, 67, and 88 mm.

The difference in growth of our Wareham River and Mill Creek oysters was caused by the time of setting of the oysters. Setting in Mill Creek occurred in the middle of July 1957, and by November, when growth stopped, the mean height of these oysters was 28 mm. (table 1, fig. 9). Setting in Wareham River did not take place until late August 1956, and the oysters averaged only 11 mm. in height when growth stopped in November. After the setting year [4] shell growth of both groups was about the same. The total annual increment

[4] From time of setting to January 1 is the setting year; from January 1 to January 1 is the first year, etc.

TABLE 1.—*Measured mean height and length (mm.), and number of oysters from Wareham River, Long Island Sound, and Mill Creek at the end of growing periods*

[H=height; L=length; N=number]

Time of measurements	Wareham River stock (Grown off bottom in Oyster Pond River)				Long Island stock [1] (Grown off bottom in Milford Harbor)				Mill Creek stock [2] (Grown off bottom in Oyster Pond River)			
	Age	H	L	N	Age	H	L	N	Age	H	L	N
End of setting year	0	11	9	229	0	19	14	-------	0	28	24	105
End of first year	1	49	37	101	1	59	45	-------	1	67	48	103
End of second year	2	72	52	66	2	78	58	-------	2	88	56	50

[1] The information taken from: Loosanoff, Victor L., 1946, Growth of oysters of different ages in Milford Harbor. Proc. Nat. Shellfish Assoc., 1946, pp. 12-21.
[2] At the end of the first year the Mill Creek stock was planted on the bottom.

in mean height for the raft-grown Wareham River oysters at the end of the first and second year was 38 mm., and 23 mm., respectively, compared to 39 mm., and 21 mm. for the raft-grown Mill Creek oysters (fig. 9). From these observations it appears that the Mill Creek oysters do not grow faster, but had an earlier start.

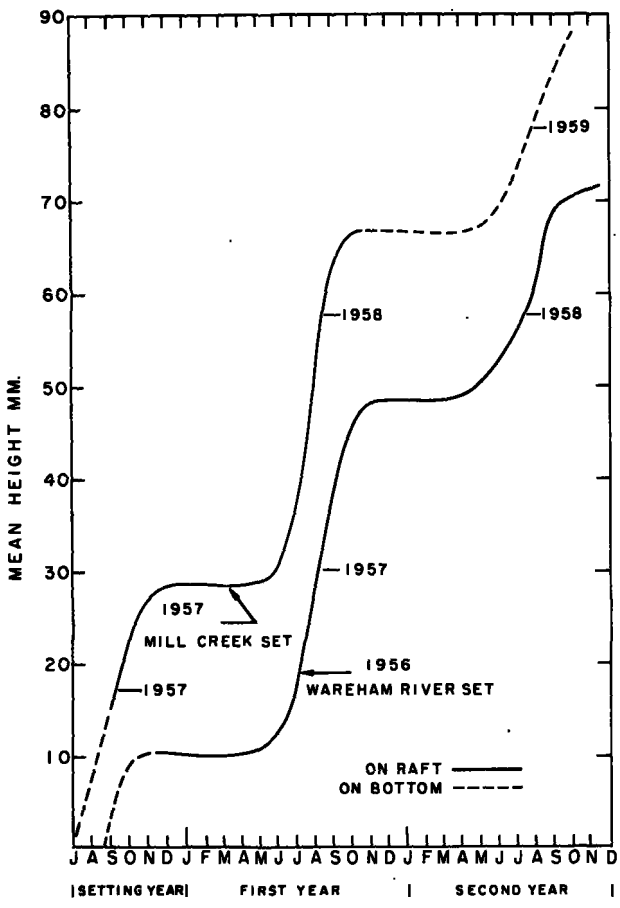

FIGURE 9.—Growth curves of raft-grown Wareham River and Mill Creek oysters.

Because of rapid growth of the oysters attached to the raft, their shells were thin and fragile; the average thickness along the principal axis of the right valve was only 1.4 mm. On November 13, 1958, the raft oysters were planted on the bottom in order to let their shells thicken. After a year on the bottom, the shells of these oysters thickened more than threefold, and averaged 4.6 mm., along the principal axis. The thickening of shell on the bottom is apparently the result of a slower rate of growth in height and length, consequently, larger amounts of calcium carbonate are deposited on the existing shell.

Figure 9 shows the growth curve of Mill Creek oysters from 1957 through 1959. By the end of 1959, following 14 months of attachment to the raft and 1 year on the bottom, the oysters averaged 88 mm., or 3½ inches in height. Market-size for oysters in Massachusetts is 3 inches or greater; therefore, the Mill Creek oysters had attained market-size in 2½ years instead of 4 to 5 years, which elapse when oysters are grown on the bottom in Cape Cod waters.

An actual comparison of raft-grown and bottom-grown Wareham River oysters was made from September 1956 to November 1958. As shown in figure 10 no difference in growth was observed at the end of 1956. By the end of 1957 the raft oysters measured 49 mm. in mean height, whereas those on the bottom were only 36 mm., a difference of 13 mm. The difference increased to 20 mm. by the end of 1958, the raft oysters measuring 72 mm. in height, and the bottom oysters 52 mm. It is of interest to note (fig. 10) that the bottom-grown oysters at the end of 2½ years averaged only 3 mm. larger than the size obtained by the raft oysters in 1½ years.

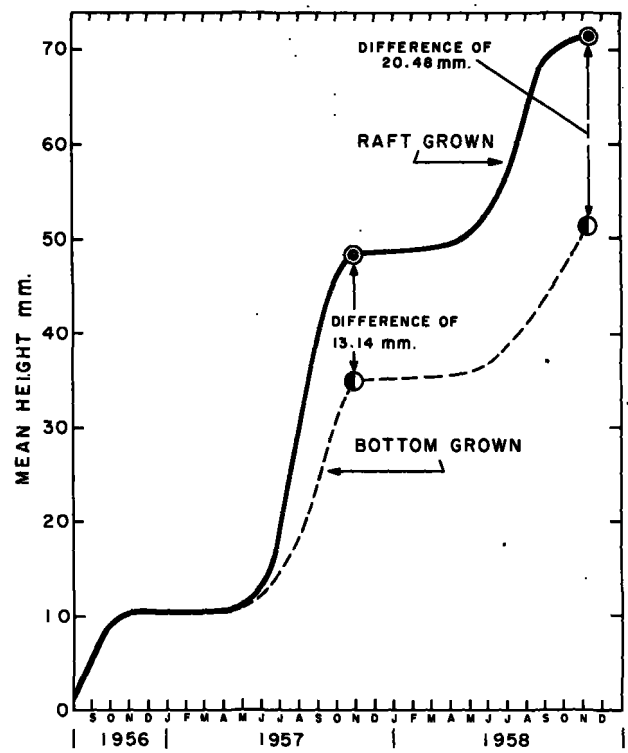

FIGURE 10.—Growth curves of raft-grown and bottom-grown Wareham River oysters. Symbols indicate when shell growth stopped for the year.

In 1957, 76.7, and 82.7 percent of the annual increment in height and length of raft-grown Wareham River oysters occurred during the months of July, August, and September; whereas in 1958, 77.7 and 84.3 percent of the annual growth in height and length occurred during the months of June, July, and August (figs. 11 and 12). For the raft-grown oysters from Mill Creek, 83.7 and 90.4 percentage of the annual increment in height and length occurred during the months of June, July, and August, 1958 (fig. 12).

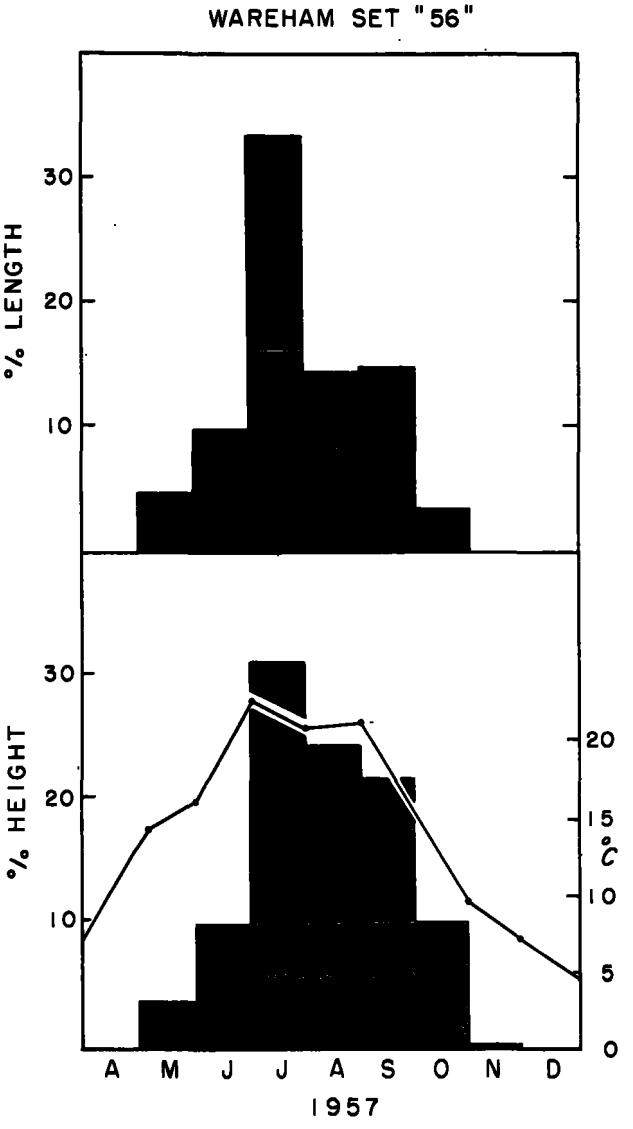

FIGURE 11.—Monthly increase in height and length of oysters as percentage of total growth during 1957. Temperature curve based on records taken at time of measurement.

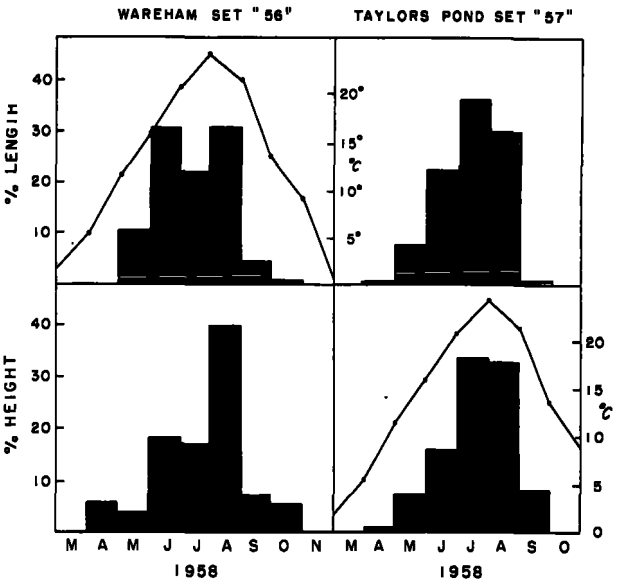

FIGURE 12.—Monthly increase in height and length of oysters as percentage of total growth during 1958. Temperature curve based on records taken at time of measurement.

EFFECTS OF TEMPERATURE, FOULING, AND SPAWNING ON GROWTH

Temperature

Shell growth did not occur when the water temperature was below 10° C. This observation is in agreement with the findings of Loosanoff and Nomejko (1949) and Walne (1958). In general the oysters in Oyster Pond River grew from April to October inclusive (figs. 11 and 12). During the years 1957 and 1958, approximately 20 percent of the total annual growth occurred when the water temperature was between 10° C. and 15° C., but more than 75 percent of the year's growth took place when the water temperature was above 15° C.

Fouling

The question arose whether the monthly removal of fouling organisms has any effect on the shell growth. On November 17, 1958, the heights and lengths of oysters from two strings were compared; one sample was selected from a string that had remained undisturbed, while the other sample was selected from the string that had been cleaned of fouling animals and plants each month. The results of this comparison are as follows: the average height and length of oysters on the undisturbed string were 65.9 mm. and 48.9 mm., respec-

tively; whereas the clean oysters were 68.6 mm. in height and 47.5 mm. in length. Since little difference was found between the two groups it appears that periodic removal of fouling material had no apparent effect on shell growth.

A year after the oysters were planted on the bottom a sample was collected to determine the extent of fouling. The oyster shells were almost barren of fouling organisms except for some colonies of *Microciona prolifera* and *Didemnum* sp., some Bryozoans, and algae. Most of the original fouling plants and animals had either died or been sloughed off. Noticeably absent was the algae *Gracilaria confervoides* which in other years was one of the principal fouling organisms on the bottom grown oysters.

Spawning

Observations by Loosanoff and Nomejko (1949) and Walne (1958) have shown that the growth of the Eastern oyster in Long Island Sound and the European oyster, *Ostrea edulis*, is not interrupted during the spawning season. In the years 1957 and 1958 the raft oysters were ripe during July. Examination made by the end of August showed that the majority of them had spawned although the actual act of spawning was not observed. Since nearly 60 percent of the total annual shell increment occurred during July and August (see: figs. 11 and 12), it is apparent that shell growth was not inhibited during this period.

MORTALITY OF RAFT OYSTERS

The greatest losses among the suspended oysters occurred when the raft was blown ashore during a winter storm in the early part of 1958. As mentioned, all but two strings of the Wareham River oysters were destroyed, although we were able to save almost all of the strings that contained Mill Creek oysters. In 1958, the mortality among the remaining Mill Creek oysters was determined. By the end of the year 17.7 percent were dead. The number of monthly deaths on one string was recorded from April to December 1958. The deaths per month ranged from 0 to 4 oysters, a total of 14 of the original 79 oysters (table 2). Since there is no known disease in these waters, it is unlikely that the deaths were the result of an epizootic.

TABLE 2.—*Cumulative deaths on one string of raft oysters from April to December, 1958*

Date	Number on one string	Monthly deaths	Sum of dead	Percentage dead
April 17	79	0		
May 2	79	0		
June 2	78	1	1	1.3
July 3	75	3	4	5.1
August 5	74	1	5	6.3
September 5	70	4	9	11.4
October 3	70	0	9	11.4
November 5	66	4	13	16.5
December 2	65	1	14	17.7

In the winter of 1958 the raft-grown oysters were transplanted on the bottom. A sample was collected a year later to determine the mortality that had occurred since planting. Of 87 oysters examined, 64 were alive and 23 were dead, an annual mortality rate of 26.4 percent. The total natural mortality rate for the years 1958 and 1959 was 39.4 percent.[5]

The mortality rate after two years is much greater when oysters are kept on bottom all the time. From a planting of 400 bushels of seed oysters, by a local fisherman in 1956, approximately 90 percent were dead by the fall of 1958. The poor survival of bottom grown oysters is believed to result from losses inflicted by predatory whelks and drills, which invade the oyster beds in large numbers. It appears that by suspending oysters from a raft for one year the number surviving is increased sixfold.

PRACTICAL ASPECTS OF RAFT CULTURE

One of the purposes of this experiment was to determine the commercial feasibility of raft culture in Cape Cod waters. The total cost of materials and labor to construct the 2-log raft, to prepare and attach the strings, and finally to market the oysters was estimated at $248 (p. 492). After one year on the raft and one year on the bottom 25 bushels of raft-grown oysters (averaging 250 to a bushel) were sold and 7 bushels were replanted. The wholesale value of these 32 bushels in 1959 at the Chatham price of $11.50 a bushel was $368, yielding a gross profit of $120 or $3.75 a bushel for this small-scale operation.

[5] Based on a progressive death rate; if there are 1,000 oysters and 17.7 percent die in the first year, 823 oysters are still alive. If 26.4 percent of the remaining oysters die during the second year, there are still 606 of the original 1,000 oysters alive, or a mortality rate for the two years of 39.4 percent.

A summary of the total cost of material and labor to construct a 2-log raft, to prepare the strings, and to market oysters follows:

Materials:	
Two 25-foot cedar logs	$30.00
Polyethylene tubing used for spacers ($23.75/1,000 feet)	16.00
Copper paint ($7.75/gallon)	15.50
Two 50-pound mud anchors ($18.50/anchor)	37.00
Miscellaneous (rope, peavie, staples)	10.00
Commercial spat ($1.50/bushel)	30.00
Total costs for material	$138.50

Labor: (Chatham $1.50 hourly wage)	
2 hours, cut and straighten wire	$3.00
8 hours, cut polyethylene tubing	12.00
4 hours, paint and staple logs	6.00
36 hours, assort, put in holes, and string shells	54.00
3 hours to moor raft and secure strings	4.50
4 hours to disassemble raft and plant oysters	6.00
16 hours to tong, cull, and pack oysters	24.00
Total costs for labor	109.50
Grand total (materials and labor)	$248.00

In 1959, the oystermen at Chatham were paying as much as $7 a bushel for Long Island oysters. These oysters were planted in the spring to grow and fatten during the summer, and were sold in the fall at $11.50 a bushel, with a gross profit of $4.50 a bushel. Approximately the same number of bushels of oysters planted are sold because natural mortality balances any increase in volume resulting from shell growth. The net profit is less because the labor costs, to plant, gather, and pack the oysters for market, are not known [6] and have not been deducted.

One cannot overlook the fact that the oystermen at Chatham are earning $4.50 a bushel each year, whereas the profit of $3.75 a bushel earned from raft-grown oysters require 2 years. Profits from raft culture could be earned on a yearly basis by suspending new strings of young oysters at the time when the 1-year-old raft-grown oysters are planted on the bottom, thus developing a continuous operation.

The cost of materials in raft oyster culture may be considerably reduced and the profit increased if the operation were conducted on a large and continuous scale.

DISCUSSION AND RECOMMENDATIONS

Our data show that raft-grown oysters grow faster and have a higher survival rate than those kept all the time on bottom. The question arises whether this faster growth and higher survival is enough to warrant the extra cost for materials and labor necessary for raft culture. From the findings of these preliminary observations it appears that raft-grown oyster farming may be feasible in Cape Cod waters. The study should now be repeated on a larger semicommercial scale. A pilot oyster farm should be tried to ascertain the true commercial practicability of raft-grown oysters in Massachusetts.

The raft used in our study was primitive and could only support the weight of 32 bushels of oysters. By increasing its buoyancy more oysters could be attached and the yield would, therefore, be greater.

Oyster Pond River was selected as the site for this study because the area was easily accessible by road. Though it proved a satisfactory site for our experiments, this river is not suitable for raft oyster culture on a commercial scale. Because the river is shallow, only 5-foot strings could be used. In deeper water longer strings could be attached and the yield would increase considerably. The danger of floating ice in the winter also makes the river undesirable for raft culture.

There are many salt-water ponds along the shore of Cape Cod were raft culture could be established. For example, Taylors Pond, West Chatham (Mass.) appears suitable for this purpose. Here the water is more than 9 feet in depth and there is little danger of floating ice. Additional research is necessary to locate the ponds on the Cape that are suitable for raft culture, and to determine their productive capacity.

The importance of suspending an early set should not be overlooked, if and when raft oyster culture is conducted on a commercial scale. Our observations show that marketable oysters are obtained in 2½ years when a July set is attached to the raft. On the other hand, when an August set is suspended the average oyster after 2½ years is less than the 3-inch legal minimum size. It would be necessary to carry these oysters for another season. Losses inflicted by predators during this time would reduce profits considerably.

[6] Oystermen working in oyster Pond River rarely employ hired labor.

The development of raft culture in Cape Cod waters would not eliminate the need for suitable planting grounds. As mentioned earlier the shells of the raft oysters are thin and fragile because their growth is rapid. It is, therefore, necessary to plant them on the bottom to thicken their shells. Since most oysters grown in Massachusetts are purchased to be served on the half-shell, restaurants and fish markets require an oyster with a reasonably thick shell. From our obsevations, it appears that such an oyster can be obtained by planting the raft-grown oysters on the bottom for one year.

It should not be forgotten that the oystermen of Cape Cod are almost entirely dependent on out-of-State bedding stock. With the present decline of oysters more and more Bay State growers are going out of business. To date the seed resources of Massachusetts are not being utilized. By developing the setting areas, the oyster industry of the State could become self-sustaining and independent of out-of-State bedding stock. The introduction of raft culture in local waters would be one way of utilizing the State's seed resources.

In conclusion, it must be realized that the study was conducted in Cape Cod waters where more than 75 percent of the annual increment of shell-growth occurs during three summer months and where no growth takes place during the winter. Other areas might give different results, especially in the South where shell growth is not interrupted by hibernation. It would be of interest to repeat the raft experiments in the more southern waters.

SUMMARY

1. The harvest of oysters in Massachusetts has dropped 83.3 percent in the last 50 years. In 1958, only 113 thousand pounds of oyster meats where havested, an all-time low for the State.

2. The objective of the experiment was to determine whether raft oyster culture is commercially feasible in Cape Cod waters.

3. A log raft was moored in Oyster Pond in the winter and in Oyster Pond River during the summer. Atttached to the logs were wire strings containing shells with oysters from Wareham River and Mill Creek. The mean height for raft oysters in successive years was as follows: Wareham River stock, 11, 49, 72 mm.; Mill Creek stock, 29, 67, and 88 mm.

4. Oysters attached to the raft had a faster growth rate than those on the bottom; by the end of the first year the raft-grown oysters from Wareham River were 13 mm. greater in mean height than those growing on the bottom. The difference increased to 20 mm. by the end of the second year.

5. No measurable shell growth was observed when the water temperature was below 10° C. Seventy-five percent of the year's growth took place when the water temperature was above 15° C.

6. Greatest shell growth occurred when the oysters were in spawning condition.

7. Both fouled and cleaned oysters had the same growth rates.

8. Survival of raft oysters was about 6 times greater than for oysters growing on the bottom. The high losses of bottom oysters is believed to be due to predation by whelks and drills.

9. The experiment demonstrated that oysters can be grown from seed to market-size in 2½ years. Wild oysters take from 4 to 5 years to reach market-size in Cape Cod waters.

10. Thirty-two bushels of raft-grown oysters were harvested. Of these, 25 bushels were sold and 7 bushels were replanted. A gross profit of $120 or $3.75 a bushel was earned from the two-log raft. It is likely that costs for materials and labor would be reduced and profits correspondingly increased if raft culture were conducted on a larger scale.

11. The development of raft oyster culture in Cape Cod waters appears to be commercially feasible. It is recommended that raft culture on a larger scale be conducted for the purpose of ascertaining the true commercial value of this method.

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APPENDIX A

Mean height and length, standard deviation, and standard error of the mean for raft-grown oysters

TABLE A–1.—*1956 Wareham River oysters*

Date sampled	Mean height (mm.)	Standard deviation (mm.)	Standard error	Mean length (mm.)	Standard deviation (mm.)	Standard error	*N*
1956							
Oct. 11	9.9	3.6	.31	8.4	3.4	.28	140
Oct. 25	10.3	3.4	.23	9.0	3.5	.23	231
Nov. 8	10.4	3.6	.24	9.1	3.1	.21	229
Dec. 4	10.5	3.6	.23	9.0	3.1	.21	229
1957							
April 12	10.8	3.5	.35	9.5	3.2	.32	99
April 26	10.7	3.5	.33	9.0	3.2	.31	110
May 9	12.7	4.1	.39	10.9	3.6	.34	110
May 16	12.4	4.4	.39	10.4	3.9	.34	129
May 29	12.1	4.0	.35	10.2	3.8	.33	134
June 27	15.7	6.3	.57	13.0	5.6	.51	120
July 29	27.5	6.3	.61	22.7	5.6	.54	109
Aug. 29	36.6	6.9	.70	29.6	6.1	.62	97
Sept. 27	44.9	7.6	.78	36.8	6.8	.70	95
Oct. 29	48.7	8.0	.79	37.8	6.6	.65	102
Nov. 29	48.8	8.0	.80	37.1	6.8	.68	101
1958							
April 17	49.9	9.3	1.05	35.5	6.9	.78	79
May 2	51.1	9.0	1.02	34.9	7.1	.80	79
June 2	52.0	9.3	1.05	36.7	7.0	.79	78
July 3	56.0	9.4	1.09	41.9	7.5	.87	75
Aug. 5	59.9	9.2	1.07	45.8	7.7	.90	74
Sept. 5	69.1	11.7	1.40	51.2	8.9	1.06	70
Oct. 3	70.7	10.8	1.29	52.0	8.9	1.06	70
Nov. 5	71.9	10.6	1.31	52.1	7.7	.95	66

TABLE A–2.—*1957 Mill Creek oysters*

Date sampled	Mean height (mm.)	Standard deviation (mm.)	Standard error	Mean length (mm.)	Standard deviation (mm.)	Standard error	*N*
1957							
Aug. 29	15.2	6.8	.67	13.7	5.8	.57	103
Sept. 27	23.1	8.0	.73	20.6	6.8	.62	120
Oct. 29	27.5	7.8	.76	23.0	6.5	.63	110
Nov. 29	28.5	8.0	.80	23.6	6.8	.68	105
1958							
Apr. 17	27.3	7.6	.75	21.6	6.2	.62	102
May 2	27.5	7.6	.75	21.7	6.5	.64	103
June 2	30.4	7.4	.66	23.9	6.2	.56	124
July 3	36.7	8.9	.86	30.1	7.7	.74	108
Aug. 5	50.3	8.9	.88	39.9	7.7	.77	102
Sept. 5	63.4	11.1	1.09	48.1	8.3	.82	103
Oct. 3	66.7	11.9	1.17	48.4	8.8	.86	104
Nov. 5	66.6	11.4	1.12	48.2	8.5	.83	103
1959							
Oct. 6	88.5	12.0	1.70	56.5	6.8	.95	50

APPENDIX B

Total monthly growth and percentage of growth, 1957–58

TABLE B–1.—*Wareham River oysters*

Date sampled	Mean height (mm.)	Monthly growth (mm.)	Monthly growth in percentage of total increment during year (mm.)	Mean length (mm.)	Monthly growth (mm.)	Monthly growth in percentage of total increment during year (mm.)	*N*
1957							
Apr. 26	10.7	----	----	9.0	----	----	110
May 29	12.1	1.4	3.7	10.2	1.2	4.1	134
June 27	15.7	3.6	9.4	13.0	2.8	9.7	120
July 29	27.5	11.8	31.0	22.7	9.7	33.7	109
Aug. 29	36.6	9.1	23.9	29.6	6.9	24.0	97
Sept. 27	44.9	8.3	21.8	36.8	7.2	25.0	95
Oct. 29	48.7	3.8	9.9	37.8	1.0	3.5	102
Nov. 29	48.8	0.1	0.3	37.1	----	----	101
1958							
Apr. 17	49.9	----	----	[1] 35.5	----	----	79
May 2	51.1	1.2	5.5	34.9	----	----	79
June 2	52.0	0.9	4.1	36.7	1.8	10.4	78
July 3	56.0	4.0	18.2	41.9	5.2	30.2	75
Aug. 5	59.9	3.9	17.7	45.8	3.9	22.7	74
Sept. 5	69.1	9.2	41.8	51.2	5.4	31.4	70
Oct. 3	70.7	1.6	7.3	52.0	0.8	4.7	70
Nov. 5	71.9	1.2	5.4	52.1	0.1	0.6	66

[1] Original sample measured in 1957 was lost in a winter storm.

TABLE B–2.—*Mill Creek oysters*

Date sampled	Mean height (mm.)	Monthly growth (mm.)	Monthly growth in percentage of total increment during year (mm.)	Mean length (mm.)	Monthly growth (mm.)	Monthly growth in percentage of total increment during year (mm.)	*N*
1958							
Apr. 17	27.3	----	----	21.6	----	----	102
May 2	27.5	0.2	0.5	21.7	0.1	0.4	103
June 2	30.4	2.9	7.4	23.9	2.2	8.2	124
July 3	36.7	6.3	16.0	30.1	6.2	23.1	108
Aug. 5	50.3	13.6	34.5	39.9	9.8	36.6	102
Sept. 5	63.4	13.1	33.2	48.1	8.2	30.6	103
Oct. 3	66.7	3.3	8.4	48.4	0.3	1.1	104
Nov. 5	66.6	----	----	48.2	----	----	103