OYSTER CULTURE IN LONG ISLAND SOUND 1966-69

Clyde L. MacKenzie Jr.

The oyster industry in the Long Island Sound waters of Connecticut and New York (Fig. 1) is rapidly developing improved methods for raising oysters. Prospects are good for a return to production levels equaling or exceeding those of some earlier periods. The resurgence of the industry has resulted from determination of the causes of seed oyster mortalities, and the development and application of methods for preventing these mortalities. Future increases in production will probably be made through even more effective control of mortalities--and collection of much larger numbers of seed oysters as a result of better preparation of private setting beds and restoration of public seed areas.

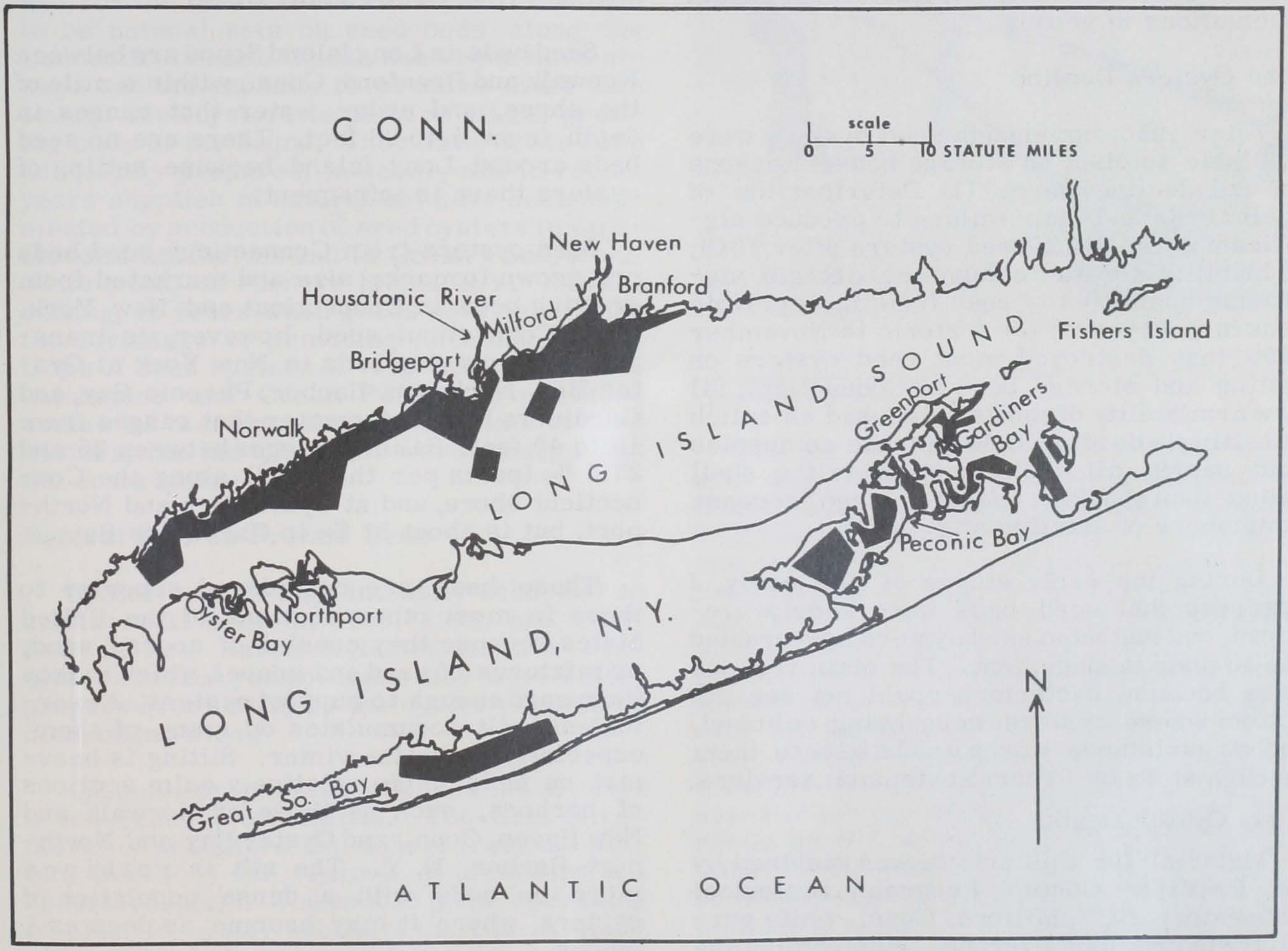

Fig. 1 - Chart of Long Island Sound showing coastlines of Connecticut and New York. Solid black areas show extent of oyster bottoms, only about 1 percent of which were actually planted with oysters in 1969.

The author is Fishery Biologist, BCF Biological Laboratory, Milford, Connecticut 06460.

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Production of oysters in the Sound declined sharply after the early 1950s from an average of about 1,300,000 bushels in 1950-52 to only 40,000 bushels in 1967 (Lyles, 1969). Traditionally, oyster companies held all their seed oysters on storage beds, totaling several thousand acres, under 30 to 50 feet of water in Connecticut. The quantity of these oysters was always several times larger than that marketed. Each year, a portion, depending on the size of beds and market demand, was transplanted to growing and fattening beds in Connecticut, but mostly in bays around Long Island. Companies merely filled vacant sections of storage beds when an oyster set occurred. Thus, the supply of market oysters did not fluctuate with annual fluctuations in setting.

Seed Oysters Decline

After 1950, not enough seed oysters were available to plant on storage beds. Reasons for the decline were: (1) Deterioration of public beds and their failure to produce significant quantities of seed oysters after 1948; (2) Inability of oyster companies to obtain significant quantities of seed from their private beds in most years; (3) A storm in November 1950 that destroyed most seed oysters on setting and storage beds in Connecticut; (4) Low availability of shells to be used as cultch on setting beds after 1950 because companies sold nearly all their oysters in the shell rather than shucked; and (5) A large increase in numbers of starfish after 1957.

During the early stages of this study, I observed that seed beds were poorly prepared, and that most seed oysters were wasted due to poor management. The main reasons were because oystermen could not see the bottom where oysters were being cultured, and no assistance was available to them through state or Federal extension services.

Study Oyster Deaths

Material for this article was obtained by the Predator Control Program, Biological Laboratory, BCF, Milford, Conn., while pursuing studies, long overdue, to determine the causes and patterns of mortalities of oysters on commercial beds.

The project involved: (1) Studying about 30 beds of oysters in Connecticut and New York by SCUBA diving once or twice a month; (2) Identifying causes of oyster mortality and determining the percentage killed by each cause at different periods; (3) Finding or developing methods for reducing the effects of these causes and other that limit production; and (4) Assisting oyster companies to fit better methods into their system of oyster culture.

Material was also obtained from extensive interviews with commercial oyster growers. Limited literature is available on any recent phase of oyster culture in Long Island Sound; most of this article consists of original material gathered from these sources.

LOCATION AND PHYSICAL CONDITION OF OYSTER BEDS

Seed beds in Long Island Sound are between Norwalk and Branford, Conn., within a mile of the shore, and under water that ranges in depth from 5 to 28 feet. There are no seed beds around Long Island because setting of oysters there is infrequent.

Seed oysters from Connecticut seed beds are grown to market size and marketed from growing beds in Connecticut and New York. Most Connecticut seed, however, is transported to growing beds in New York at Oyster Bay, Northport Harbor, Peconic Bay, and Gardiners Bay, under water that ranges from 10 to 40 feet. Salinity ranges between 25 and 27.5 ‰ (parts per thousand) along the Connecticut shore, and at Oyster Bay and Northport, but is about 31 ‰ in Gardiners Bay.

These beds are considered superior to those in most other sections of the United States because they consist of coarse sand, or mixtures of sand and gravel, which makes them hard enough to support oysters. Nevertheless, silt accumulates on many of them, especially during the winter. Silting is heaviest on beds in the relatively calm sections of harbors, such as those at Norwalk and New Haven, Conn., and Oyster Bay and Northport Harbor, N. Y. The silt is retained more on beds with a dense population of oysters, where it may become as deep as 2 inches.

Water temperatures over oyster beds are 32.5° to 33.5° F. from mid-January through mid-March. In Milford Harbor, Conn., average temperatures are:

Month	Temperature (°F.)[1/]
Mid-January through mid-March	32.5 - 33.5
April	38.0 - 40.0
May	52.0 - 60.0
June	65.0 - 67.0
July	66.0 - 73.5
August	72.0 - 74.0
September	61.0 - 72.0
October	52.0 - 61.0
November	46.0 - 53.0
December	38.0 - 42.0

1/BCF records.

SOURCES OF SEED OYSTERS

The principal source of seed oysters in the Long Island Sound area has always been and, for the foreseeable future, will continue to be natural sets on seed beds along the Connecticut coast. These seed beds have always had the capacity to produce more than enough seed oysters to plant on all the growing beds of the Sound. They have never been adequately prepared, however, and in recent years supplies of natural set have been augmented by production of seed oysters in commercial hatcheries and in Ocean Pond, a salt water pond, on Fishers Island, N.Y. Natural setting, in years when goods sets occur, has the advantage of providing enormous quantities of seed oysters at very little cost. The hatcheries and Ocean Pond have produced somewhat more predictable supplies of seed oysters, but the quantities were smaller and the costs higher.

Natural Sets on Private Beds

Oyster sets of high intensity occurred on commercial beds in 1966, 1968, and 1969. Beds in New Haven collected the most seed oysters in each year because they were better prepared for setting by the oyster companies controlling them.

Optimum preparation of a seed bed involves a sequence of operations. The first is removal of predators and debris from the bottom (methods for removal of predators are described later). The second is the spreading of cleaned oyster shells at the rate of 1,500 or more bushels per acre, when ready-to-set oyster larvae become abundant in the water. In some areas, where silt begins to cover shells immediately, the third procedure is the removal of this silt, which can greatly reduce the number of spat obtained. To remove silt, oyster companies can use starfish mops, consisting of a metal frame about 12 feet long from which waste cotton bundles are strung, or cutting boards, measuring 15 feet long and 1 foot wide (Fig. 2). By use of these boards, which lift the silt when towed rapidly, a boat can flush silt from 25 to 50 acres of planted shells during each tide (MacKenzie, in press, 'a'). Companies employed starfish mops to a limited degree during 1968-69, but use of cutting boards for this purpose is a new development.

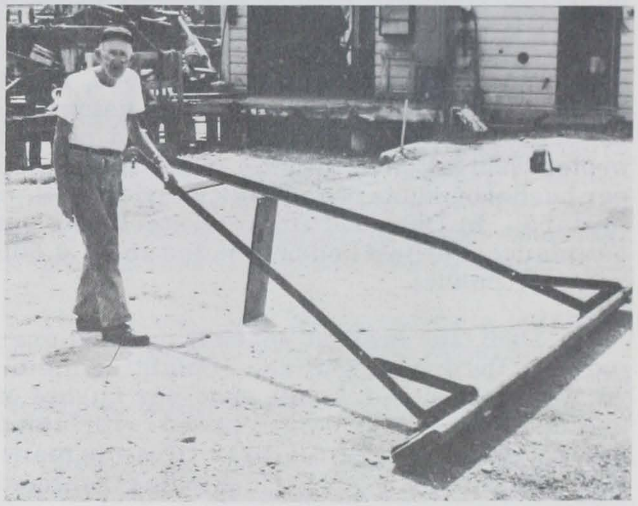

Fig. 2 - Cutting board, or vane, is towed rapidly over bottom, at angle shown, to scour silt off shells. Currents carry suspended silt off bed.

The old procedure of spreading all available clean shells on several beds along the Connecticut coast each year was wasteful. This was because from 1958-69, for example, oyster sets were of commercial significance in 6 of 12 years (1958, 1959, 1962, 1966, 1968, and 1969). In the other 6 years, plantings of shells did not collect a commercial set. Furthermore, in the years of significant sets, setting often occurred in only 1 or 2 areas, such as Bridgeport and New Haven. Each year, oyster companies spread from 150,000 to 200,000 bushels of clean shells on about 175 acres of setting beds. They obtained clean shells by storing on their docks shells that either were gathered from unused beds by suction dredging or saved when market oysters were culled. The cost of clean shells planted on a seed bed obtained by section dredging was about 30 cents per bushel; that of culled shells was much less. So 200,000 bushels of planted shells cost about $55,000.

A common, but less effective, method for collecting seed is the dredging up and respreading of shells, covered with living organisms, that have been on a bed for a year or more. Since this method does little more than expose small clean portions of shells that were laying against the bottom, it presents little additional clean surface where oyster larvae can set. During 1966-69, companies prepared about 100 acres of setting beds by this method.

In 1966 and 1968, several beds prepared with clean dock-stored shells caught as many as 15,000 spat per bushel of shells; in 1968, one bed (on which about 1,500 bushels of clean shells per acre had been planted) collected 50,000 spat per bushel. From this bed, about 2,500 bushels of seed per acre were harvested in spring 1969. At that time, the count of seed oysters had fallen to slightly more than 6,000 per bushel because of mortality and growth of oysters. In 1969, setting of oysters was not as intense; the best beds collected about 8,000 spat per bushel.

In 1968, the highest spatfall on beds prepared by the dredging up and replanting method was only about 2,000 spat per bushel of shells. Beds nearby prepared with clean shells collected from 3.5 to 12 times as many spat (MacKenzie, 'a'). Companies realized few seed oysters from these beds because they did not control starfish and oyster drills. In 1969, spatfalls on beds prepared in this manner were not of commercial intensity.

In 1968, MacKenzie observed that black shells obtained from muddy bottoms could be planted immediately and, being free of fouling organisms, would catch about as many spat as clean dock-stored shells.

Between 1966-69, more than 95 percent of formerly productive seed beds received no preparation. In those years, a small number of unprepared beds received light sets of only 100 to 200 spat per bushel of shells (MacKenzie).

The total quantity of seed oysters obtained from all privately owned beds was about 200,000 bushels in 1966, 300,000 in 1968, and 200,000 in 1969. About a third of the 1968 spatfall occurred on 2-year-old oysters (1966 generation).

Natural Setting on Public Beds in Connecticut

The decline of the Long Island Sound oyster industry was partly due to the relatively few seed oysters produced on public seed beds. The states of Maryland, Virginia, and Louisiana, which produce the largest quantities of oysters in the United States, depend on public beds as the source of most of their seed.

The once-famous Bridgeport-Fairfield public seed bed, 4,500 acres in size, has not collected a significant quantity of seed oysters since 1948 because it has not been adequately prepared. During 1966-69, the few shells on it were completely covered with fouling organisms, and oyster larvae could not set on them. Observations of oyster sets on clean shells in test bags placed on this bed by the BCF Laboratory at Milford indicate that the bed would have received commercial set in more than half the intervening years had it been properly prepared. In 1969, some interest was aroused to restore the bed's productivity.

The only commercial sets on public seed beds were in the Housatonic River in 1966 and 1968. The river had about 65,000 bushels of seed oysters in fall 1968, when about 4,000 bushels of mixed 1966 and 1968 seed were harvested from the river with hand tongs; this was only about 6 percent of the river's total quantity. One of my studies showed that about 75 percent of the remainder were suffocated by silt during spring 1969.

In 1969, a law was passed in the Connecticut Legislature that allowed the use of power to tow hand dredges on public beds. In the past, dredging could be done only by sailboats.

Hatchery Production of Seed

In 1968, 4 commercial hatchers on Long Island and 1 in Connecticut were producing seed oysters (Fig. 3). In the hatcheries, abult oysters are induced to develop ripe eggs and sperm before the normal spawning season by

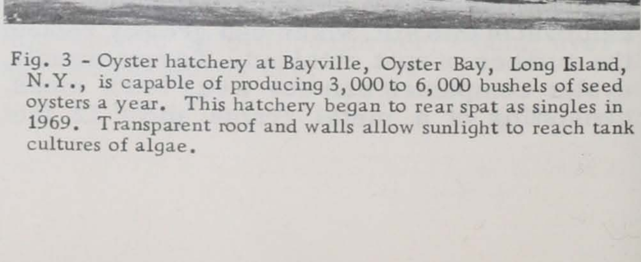

Fig. 3 - Oyster hatchery at Bayville, Oyster Bay, Long Island, N.Y., is capable of producing 3,000 to 6,000 bushels of seed oysters a year. This hatchery began to rear spat as singles in 1969. Transparent roof and walls allow sunlight to reach tank cultures of algae.

keeping them in warm sea water for several weeks. When the oysters have developed ripe eggs and sperm, they are induced to spawn, and the fertilized eggs are placed in 100-gallon, conical-bottom tanks. These eggs develop into straight-hinge larvae within 48 hours and can be caught on fine Nitex[1/] screens as the water is drained from the tanks. Water is changed every 24 or 48 hours, and the larvae are resuspended in fresh sea water. When the larvae reach setting size, 10 to 20 days after fertilization, they are transferred to setting tanks in which a layer of shells has been placed as cultch.

When they were built during 1960-65, the hatcheries depended entirely on the algae present in raw sea water to feed oyster larvae. This water was pumped through centrifuges that removed silt, zooplankton, and the larger phytoplankton--but allowed smaller algae to pass through to large shallow tanks in a warm, lighted room with translucent roof. The water was held there for 24-48 hours to allow the small algae to increase in numbers before it was used to feed the larvae. Most commercial hatcheries now grow algae in special culture units (Davis and Ukeles, 1961) to supplement the natural algae of raw water, and they sometimes use cultured algae exclusively.

By using these techniques, each hatchery can produce 1,000 to 6,000 bushels of seed oysters with a count of 2,000 to 15,000 spat per bushel.

In 1968 and 1969, hatcheries developed techniques to produce single spat. To do this, they placed ready-to-set oyster larvae in 12-inch-diameter cylinders with a bottom of Nitex screening and a continuous flow of water. After 24 hours most larvae had attached to the sides and bottom. These post-set larvae were then washed off as singles, 1/70th of an inch long. These had to be grown in trays, with a fine screen bottom, suspended from rafts until oysters were large enough to be planted on the bottom (Butler Flower, personal communication).

The minimum size of single oysters to be planted on the bottom has not been established. MacKenzie made two observations of planted singles: If they are less than 1 inch long, they are washed about by currents as slow as 2 knots; they are susceptible to predation by the abundant mud crab, Neopanope texana, which does not prey on attached spat greater than $\frac{1}{4}$-inch.

Growing single oysters avoids problem of crowding oysters in clusters and of misshapen oysters; culling of market oysters will be easier because they will all be single.

Production of seed oysters in hatcheries has two major advantages: (1) A somewhat more predictable supply of seed oysters is available each year; and (2) New genetic strains of superior quality oysters can be propagated by hatchery methods if and when they are developed.

The two major disadvantages are: (1) Production of oysters (1,000 to 6,000 bushels per hatchery per year) is small compared to that from natural sets in good years (300,000 bushels in 1968); and (2) Cost of hatchery seed ($1.00 per 300 spat) is much higher than that of natural seed ($1.00 per 50,000 spat).

The annual cost of operating a hatchery ranges from 50,000 to 70,000 dollars.

Setting in a Salt Water Pond

Ocean Pond on Fishers Island produces about 10,000 bushels of seed oysters a year, about half sold to 2 oyster companies in Connecticut.

Clean scallop shells strung on wires hung from rafts collect the spat. Each raft holds 400 strings, and each string holds 75 shells. Just before the setting season, the water is sampled daily to determine the presence of ready-to-set oyster larvae. When they have become abundant, the shells are lowered into the water to receive them.

The rafts remain in the Pond until the following spring, when the number of oysters per shell averages between 10 and 30. In May, when the oysters are about 9 months old, companies remove the strings from the Pond, load them onto boats, strip off the oysters, transport them to the beds, and plant them.

GROWING OYSTERS FROM SEED TO MARKET SIZE

Culture Operations

In Connecticut, young-of-year seed oysters are sometimes transplanted from setting beds to growing beds in October, November, or December--but usually not until the following March, April, or May. Ordinarily, they are transplanted in the fall if the quantity of oysters is too large to move the next spring,

1/Mention of commercial products does not imply endorsement by BCF.

or if it is necessary to move them to beds more protected from starfish invasions or winter storms.

Growing beds are cleaned of predators, such as starfish and oyster drills, competitors, such as slipper shells and mussels, and silt before seed oysters are spread. Seed oysters may be transplanted each spring thereafter, or, if not transplanted, thinned out. Companies that do not transplant or thin out growing oysters each year find that they become much too dense on the bottom--in some instances, more then 3,000 bushels per acre. If a significant percentage of seed oysters is covered by silt, which accumulated during the winter, or by sand during winter storms, they must be transplanted during the following March or early April before water temperature reaches about 43° F. (the level at which most begin active pumping), or the buried ones suffocate (Fig. 4). When seed oysters are in clusters, repeated transplanting each year also breaks these apart so that almost all oysters are "singles" by the time they reach market size. A portion of market oysters may be attached in clusters, however, if the original set of seed oysters was very heavy. Most oysters are transplanted 3 or 4 times before they reach market size.

During 1966-69, oyster companies spread seed on growing beds at lower concentrations than they had in the past. They spread 1-year-old 1968 set on growing beds at rates of 175 to 300 bushels (750,000 to 1,000,000 oysters) per acre, depending on number of individuals per bushel. In the past, the rate of spreading of 1-year-olds was 500 to 800 bushels per acre. But survival rates of oysters became much higher, so spreading rates had to be lowered to accommodate growth of the

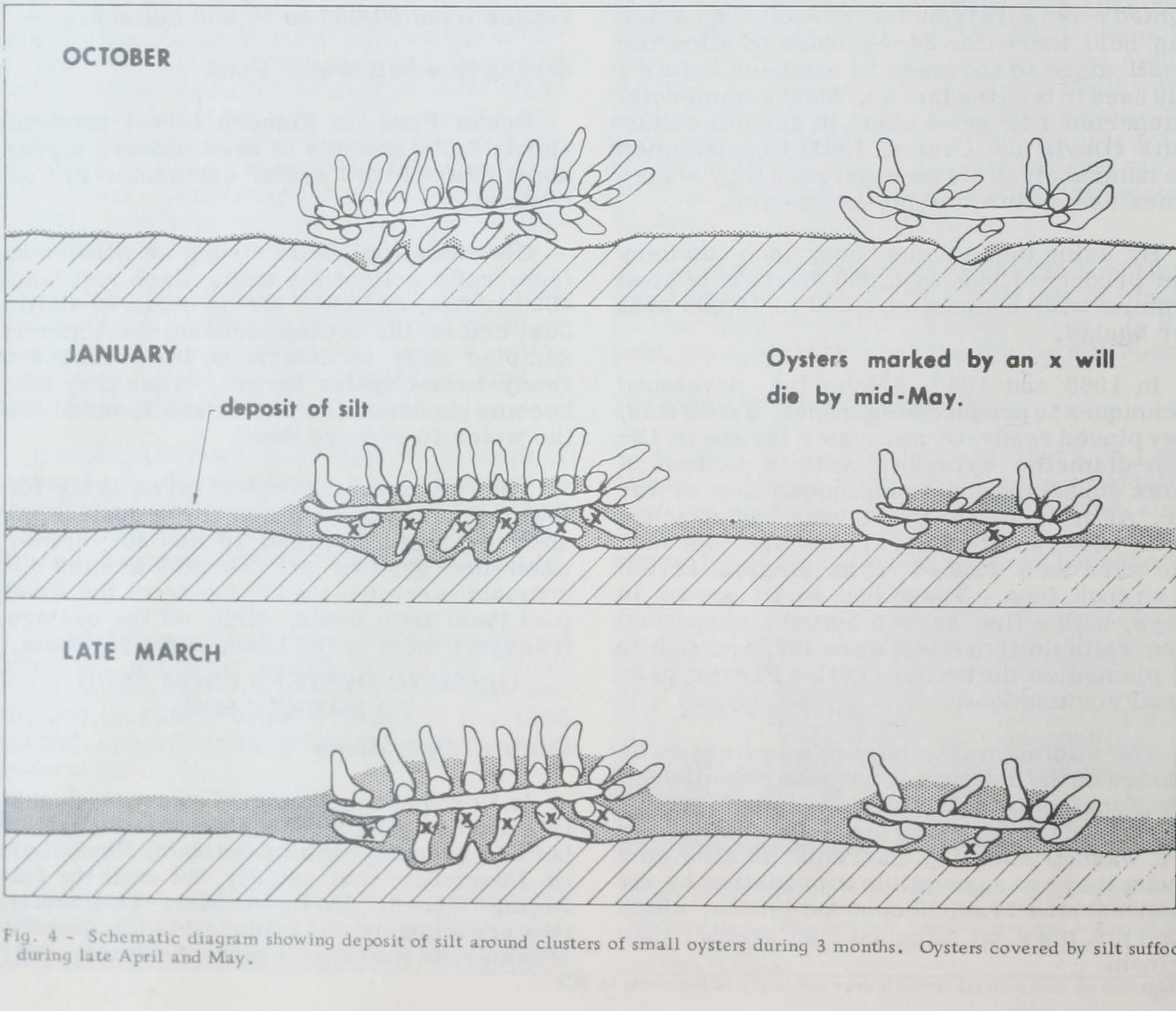

Fig. 4 - Schematic diagram showing deposit of silt around clusters of small oysters during 3 months. Oysters covered by silt suffocate during late April and May.

oysters. A planting of oysters of this age increases 4 to 7 times between April and December. At higher rates of spreading, the concentration of oysters by December, when growth ceased because of cold water temperatures, was greater than 1,500 bushels per acre--too many for high survival and good growth. When the oysters were 2 years or older, they were spread at rates of 300 to 500 bushels per acre. Even though spreading rates of oysters were lower, most growing beds had too dense a population of oysters in 1968-69.

Oysters are usually marketed at 4 to 5 years when 200 to 250 constitute a bushel. During 1966-69, companies sold many oysters 3 years old. Older oysters were in short supply. In fall 1969, however, about 2,000,000 bushels of oysters of various ages were growing on 2,000 acres of bottom in Connecticut and New York.

The total cost of producing a bushel of market oysters, including rental of beds, procurement of seed, control of starfish and oyster drills, use of boats to clean beds and to transplant seed and harvest market oysters, and culling, averages about $2.50. The cost of culling, $1.25 average ($0.60 to $4.50 range) per bushel, is as high as all other expenses combined (Fig. 5). In 1969, oyster companies received as much as $18 per bushel for market oysters. Since the early 1950s, most oysters have been sold unshucked for the half-shell trade.

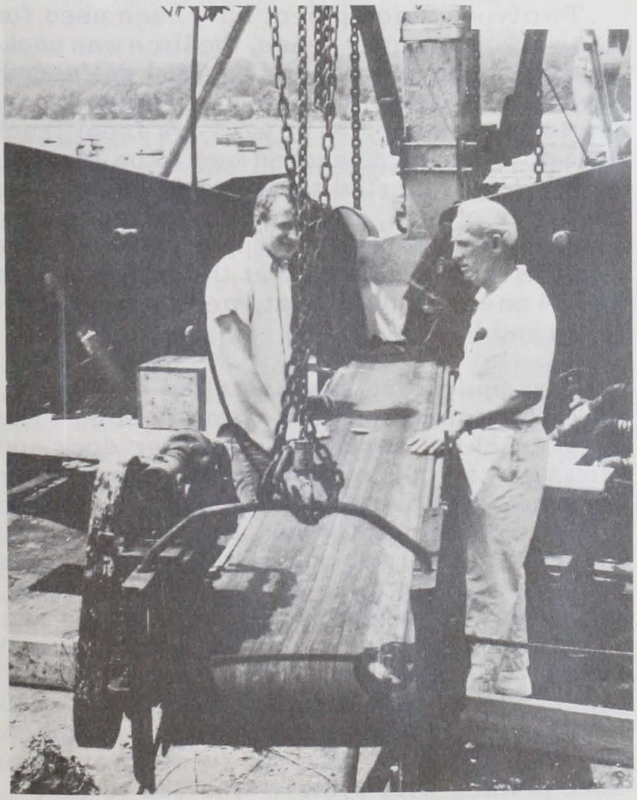

Fig. 5 - Oysters are culled faster and more cheaply from moving conveyor belt than from culling bench.

Equipment to Transplant & Harvest Oysters

A typical oyster boat in Long Island Sound is equipped with 2 standard oyster dredges: each can be lifted out of the water and over the boat's deck by a boom (Fig. 6). At the bottom of each dredge is a hinged door, which unlatches to empty the oysters on deck. The crew of a boat consists of a captain and usually 2 (sometimes only 1) deckhands. The boat plants, transplants, and harvests oysters. To plant seed oysters, two 4-inch-diameter hoses are used to wash them overboard while the boat travels at fairly high speed to ensure good spreading. The cost of operating an oyster boat is about $100 per day. Since a boat can transplant or harvest for market about 1,000 to 2,400 bushels of oysters per day, the cost is 4 to 10 cents per bushel.

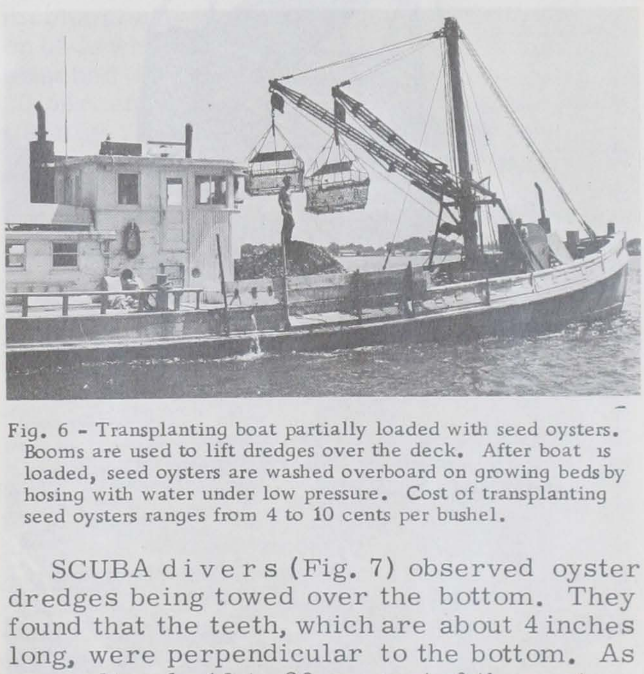

Fig. 6 - Transplanting boat partially loaded with seed oysters. Booms are used to lift dredges over the deck. After boat is loaded, seed oysters are washed overboard on growing beds by hosing with water under low pressure. Cost of transplanting seed oysters ranges from 4 to 10 cents per bushel.

SCUBA divers (Fig. 7) observed oyster dredges being towed over the bottom. They found that the teeth, which are about 4 inches long, were perpendicular to the bottom. As a result, only 10 to 20 percent of the oysters in the dredge's path were gathered. The dredge had to be towed rapidly to gather oysters because of the tooth angle. This caused the breaking and killing of a significant percentage of seed oysters (Medcof, 1961;

Fig. 7 - SCUBA diver entering water to inspect conditions on oyster bed. Depth of water is about 15 feet.

Fig. 8 - Oyster dredge with teeth angled forwards, to pass under oysters laying on bottom. Hinged door at bottom of dredge unlatches to release load of oysters.

Quayle 1969; MacKenzie). The dredges were modified.

The new dredges are built with the teeth pointing forward at a 15° angle in relation to the bottom (Fig. 8). These dredges have some advantages: (1) They can be towed at about half the speed used to tow old dredges, (2) They fill more quickly, (3) Less chain or cable is required to tow them, (4) Nearly all the oysters are gathered from the bottom during each pass, and (5) Apparently, they are less destructive to seed oysters.

Controlling Starfish

Some boats are equipped to control starfish. They are rigged with 2 mops and 2 tanks filled with water near the boiling point. Mops are dragged over the bottom for 10-minute periods and then dipped into the tanks to kill the starfish that have been collected. Boats so equipped can remove scattered starfish from beds more cheaply than by using lime. These boats are also equipped with either lime hoppers or tanks and water hoses to spread quicklime over beds infested with starfish.

Two types of equipment have been used for this work. For many years, the lime was packaged in 80-pound paper bags and delivered, perhaps 500 bags at a time, by cargo truck. The bags were carried by workers from truck to boat. When boat reached bed to be treated, the workers carried the bags to hopper on each side of boat, cut open bags, and poured lime into hopper. The hopper fed the lime into the stream of water at the bottom. Eight men, 4 on each side of boat, were often needed to spread lime.

New equipment, now installed on 2 boats, makes it possible to handle lime in bulk. The cargo truck delivers lime to oyster dock and blows it by air through a pipe into large storage tank, capable of holding 30 tons, at edge of dock. From this tank, the lime is blown by pipe into the tank on the boat, which holds 12 to 15 tons (Fig. 10). When a bed is treated, only 1 worker is required on deck. All he has to do is start water pump and open doors at bottom of lime tank. This system works efficiently; the cost of lime is lowered from \$26 to \$21 per ton because no bagging is required. The annual cost of lime for treating average acre planted with oysters was \$21 to \$42.

Presently, about 15 oyster-dredging boats work in Long Island Sound. Four others are

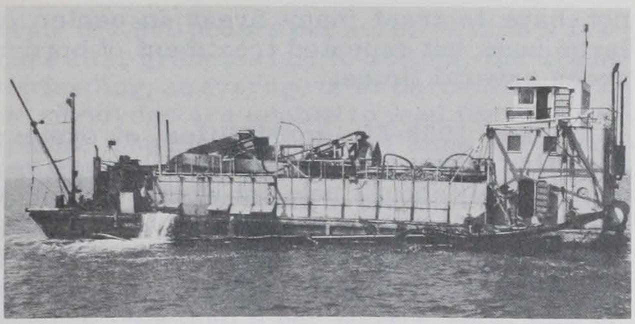

Fig. 9 - Suction dredging system mounted on barge is used to harvest shells to be used as cultch and to remove oyster drills from oyster beds.

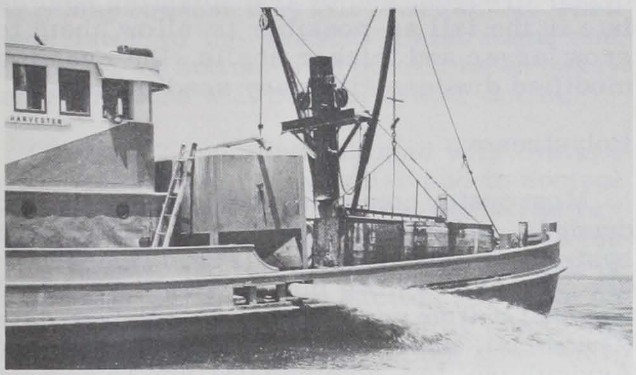

Fig. 10 - Spreading quicklime to kill starfish which invaded oyster bed. Tank on boat holds 15 tons of quicklime.

used exclusively to control starfish, and 2 boats and a barge are equipped with suction dredges. The boats are 55 to 85 feet long. The barge (Fig. 9) can dredge up 10,000 bushels of buried shells from the botttom, or remove oyster drills from 1 to 2 acres of bottom a day.

Causes of Oyster Mortality, 1966-69

The most important cause of mortality of oysters was starfish, Asterias forbesi. A single starfish can consume several oyster spat simultaneously. On beds where starfish were numerous, more than 1 per square yard, they reduced good sets of oysters to non-commercial levels within a few weeks; even on beds where good starfish control was practiced, up to 94 percent of spat were killed in bands 15 to 20 feet wide along borders of beds (MacKenzie). The rate of feeding on 1-year-olds has not been determined, but MacKenzie (1969) observed that a starfish can consume as many as five 2-year-old oysters per 28 days.

Silt

The second most important cause of mortality was silt. This settled over beds during winter, and suffocated seed oysters in late April and May when water temperatures rose above 43° F. (Fig. 4). Silt may accumulate to 2 inches by late March in areas where currents are low and wave action is slight. In open waters, where currents are strong or wave action generated by storms disturbs the bottom, silt deposit is usually negligible. In the Housatonic River, a protected area, 75 percent of about 65,000 bushels of 1- and 2-year-old oysters were suffocated by silt in spring 1969. In calm sections of harbors, such as New Haven, the mortality of 1-year-olds due to suffocation was 50 percent. In a more open area of that harbor, it was about 15 percent in spring 1968. Oystermen and biologists formerly termed this cause of mortality "winter kill." They believed it was caused by prolonged low temperatures.

Older-Type Oyster Dredge

The third most important cause was the use of the older-type oyster dredge in transplanting seed oysters. When 3-month-old spat were transplanted, about 15 percent were mechanically broken and killed. In addition, on beds where a large proportion of spat was attached to small fragments of shells, about 20 percent were left behind by the dredges. Usually, these were not protected thereafter and were killed by starfish (MacKenzie). Besides damage to young-of-year oysters, between 3 and 5 percent of 2-year-olds were killed by dredges during transplanting. MacKenzie estimated that if mortalities of seed oysters could be reduced to zero during transplanting, production of market oysters would increase about 50 percent.

Oyster Drill

The fourth most important cause was the oyster drill. In most sections of Connecticut (except for New Haven Harbor), in Oyster Bay and Northport Harbor, the thick-lipped drill, Eupleura caudata, is more common than the Atlantic oyster drill, Urosalpinx cinerea (MacKenzie, in press, 'b'). A single drill can consume at least 10 spat a month, and 18 to 20 one-year-old oysters, between late April and late November. Because drills were under good control by oyster companies, mortality of spat and older seed oysters caused by them was small during 1967-69. The heaviest mortality of spat by oyster drills observed on any bed in 1968 was 25 percent between setting and late November.

Mud Crab

The mud crab, Neopanope texana, was the fifth most important cause. It destroys spat up to $\frac{1}{4}$-inch long. In 1968, it appeared to me that 5 to 15 percent of spat were killed by mud crabs. On 1 bed, however, they killed more than 50 percent.

Mortality of oyster spat also resulted from other causes: overgrowth by slipper shells (double deckers), Crepidula plana and Crepidula fornicata; calcareous (lace) bryozoans, Schizoporella unicornis; jingle shells, Anomia simplex; and barnacles (species not identified). Mortalities from these causes were small--estimated at about 15 percent of spat on typical bed in New Haven Harbor in 1968. On 1 bed, however, where slipper shells were extremely numerous, they alone killed about 60 percent of spat before age of 2 months in both 1968 and 1969. Rock crabs, Cancer irroratus, may also kill small oysters.

I also found additional causes of mortality of older seed oysters: burial during winter storms, predation by whelks and, apparently, some very old oysters were killed by infestations of boring sponges. Also, 3 to 9 percent of oysters 2 years and older died after spawning in 1968.

There is no evidence that mortalities of oysters in Connecticut were attributable to MSX or other diseases.

Controlling Predators & Other Causes

Oyster companies have starfish under adequate control. They use mops to determine their location; if significant numbers (more than 10 starfish per mop frame per 3-minute tow) are found on the border of, or near a bed of oysters, they spread quicklime over bed during next period of slack current, at rate of about 2,000 pounds per acre. Starfish stop feeding instantly and die soon thereafter. Only those starfish protected underneath shells or algae survive liming treatment. During 1967-69, companies spread lime on beds planted with oysters on average of once or twice per acre per year. In practice, companies did not have to treat many areas in center of large beds, but repeated treatment of border areas several times.

During 1968-69, mortalities of oysters resulting from suffocation by silt were reduced to only about 2 percent when companies transplanted oysters to growing beds during March and early April, rather than waiting until traditional May and June.

During 1968-69, mortalities of oysters from transplanting operations were reduced somewhat by modification of tooth angle of oyster dredges, and by transplanting spat as late in the fall as possible to allow them to grow larger and thicker shells. But even the modified dredges kill many seed oysters.

Polystream

Most oyster companies now employ suction dredges or Polystream (Granular) to keep oyster drills under control (Fig. 11). Suction dredges can remove most drills from 1 to 2 acres of bottom per 8-hour day. Polystream (Granular), approved by U.S. Department of Agriculture for commercial use to control oyster drills in Connecticut and New York, is spread evenly over surface of the water, with the same equipment used to spread lime,

Fig. 11 - Pouring clay granules saturated with Polystream into hopper from which they will be hosed overboard. As the granules sink, they spread evenly over the bottom and kill 85 percent of oyster drills within 4 weeks.

at rate of 1,600 pounds per acre. Within a few hours after granules fall to bottom, the drills stop feeding, an average of 85 percent die, and the survivors are unable to feed for several months. The cost of treating 1 acre of bottom is about $200. The bottom remains relatively free of drills for at least 5 years; a treatment averages no more than $40 a year. By using either suction dredges or Polystream (Granular), the number of drills on a bed can be reduced to less than 2 per square yard; this is a density which cannot cause significant damage to seed oysters. Polystream (Granular) treatments should be made in late April or early May because they kill fewer drills when made later in the season. I also found that treatment of bottom with quicklime in heavy concentrations will control oyster drills.

Of about 2,000 acres planted with oysters in fall 1969, oyster companies had to control oyster drills on about 400 acres. The remaining areas, not planted with oysters for many years, did not have drills. Control of drills was achieved by suction dredging on about half the infested area, and by treatment with Polystream (Granular) on the other half.

No specific attempt has been made to control mud crabs, but most are removed incidentally when beds are cleaned by suction dredges or by standard oyster dredges before cultch or seed oysters are planted.

The fouling organisms that cause spat mortalities are controlled partially by delaying planting of cultch on setting beds until oyster larvae are ready to set. This avoids the competitors and fouling organisms that set earlier.

ESTIMATES OF POSSIBLE OYSTER YIELDS

Development of new predator-control methods, avoidance of mortalities from smothering, and better surveillance of beds to detect invasion by predators and accumulations of silt--have resulted in large increase in survival rates of seed oysters and consequent yields, with promise of greatly increased production of market oysters.

In one example, a company planted 1,000 bushels of 1-year-old oysters, counting 6,000 per bushel, in May 1966. I counted a natural set of 9,000 spat which attached to each bushel of these 1-year-olds in July 1966. Oyster drills had killed 40 percent of these 2 groups by mid-August. The company treated bed with Polystream (Granular) on August 24, and this prevented further mortalities from drills. Some 6,000 bushels of oysters were transplanted off this bed in May 1967, a sixfold increase; these oysters had increased to 15,000 bushels by May 1968. I estimated the volume at 20,000 bushels by late fall 1969. Had the bed been treated with Polystream (Granular) earlier than August 24, the final yield would have been considerably larger. This production is far superior to past yields, which averaged only 1 bushel of market oysters from 1 bushel of 1-year-old oysters.

Since all phases of the much improved system of caring for seed oysters had not been practiced before 1966, no oysters that had this intensive care had reached market size by fall 1969. The following percentage survival estimates are based on studies of different beds of different ages that had the most intensive care during study period:

Age of Oysters[1]	Percentages of Survival Recorded		Number of Beds Studied
	Average	Highest	
Setting to 1 mo.	60	85	15
1 mo. to 9 mo.	75	90	18
9 mo. to 1 yr. 9 mo.	80	90	13
1 yr. 9 mo. to 2 yr. 9 mo.	85	94	7
2 yr. 9 mo. to 3 yr. 9 mo.	93	95	7
5 yr. to 6 yr.	90	90	1[2]

1/Oysters of age 3 yr. 9 m. to 4 yr. 9 mo. were not studied.
2/Estimate made from 100 oysters held in tray on bottom.

From these average percentages of survival, and assuming a 90 percent survival from 3 yr. 9 mo. to 4 yr. 9 mos., the following yields of certain ages can be expected:

One bushel of 1-month-old spat, counting 10,000 per bushel, will yield about 21 bushels of market oysters (200 oysters per bushel).

One bushel of 9-month-old seed (1-year-olds), counting 6,000 per bushel in April, will yield about 18 bushels of market oysters.

One bushel of 1 year 9-month-old seed (2-year-olds), counting 700 per bushel in April, will yield about 2.5 bushels of market oysters.

One bushel of 2 year 9-month-old seed (3-year-olds), counting 400 per bushel in April, will yield about 1.7 bushels of market oysters.

In summer 1969, many beds were planted with seed oysters maintained under intensive care. If, from time of 9 months, 40 to 50 percent should survive to market size, they will yield 5 to 30 bushels of market oysters for each bushel planted.

SIGNIFICANT DEVELOPMENTS SINCE 1966 THAT MADE HIGHER YIELDS POSSIBLE

The most important factors in bringing about the remarkable increase in yields, and the promise for much greater increases in yields and in total production in the future, were: (1) Systematic identification of causes that limited production; (2) Monthly counts of living and dead seed oysters on many beds, which established relative importance of these causes; (3) Use by most companies of superior methods, previously employed by only 1 or 2 companies; (4) Introduction of new methods; and (5) The speed with which oyster companies adopted these methods to overcome or minimize effects of these limiting causes.

The use of SCUBA diving techniques was instrumental in determining the causes of oyster mortalities and the effectiveness of remedies. Divers can observe conditions as they actually exist on a bed. By quantitative sampling techniques, they can determine precisely when predators, accumulations of silt, and burial by storms endanger a bed. Divers found that deposits of silt on shells significantly interfered with setting of oysters. They found that companies often planted seed oysters in scattered, too-dense patches, rather than uniformly over bottom. By using divers, incorrect estimates of the situation on beds are avoided, the efficiency of culturing oysters can be sharply upgraded, and oyster companies can avoid many management errors.

PROBLEMS THAT NEED TO BE SOLVED

It has been estimated that the enormous number of ready-to-set larvae in Connecticut waters from July to October 1968 would have yielded up to 500,000,000 bushels of market oysters if--sufficient shells of good quality had been provided to catch them; they had been protected from predators, competitors, and suffocation; enough equipment had been available to handle them; and sufficient space had been available to grow them. At most, only 0.4 percent of this potential will be realized since the total 1968 set saved will grow into about 2,000,000 bushels of market oysters.

The following problems must be solved before oyster companies will be able to obtain larger percentage of the potential from a crop of larvae.

Seed Beds Need Better Preparation

Companies must prepare their seed beds better to increase the number of oyster spat obtained. They should store larger quantities of shells on their docks. These shells should be spread on beds only in years when oyster larvae set, and only in areas where the larvae are present (extensive sampling of larvae would be required to do this). After the supply of shells on their docks has been planted, black clean shells dredged from under the bottom should be harvested and planted on setting beds. Silt should be removed from setting beds. Also, larger quantities of shells per acre, perhaps up to 3,000 bushels, should be planted, experimentally at first. My recent observations indicate that filter feeders, such as clams, oysters, and mussels, should be removed from a setting bed because they may reduce setting by ingesting oyster larvae.

The Bridgeport-Fairfield public seed bed should be restored to full production as an additional source of seed oysters by a good management plan. Clean shells should be spread on the bed, and starfish should be controlled. Oyster drills are uncommon on the bed.

Seed Oysters Require More Care

To raise a higher percentage of seed oysters and to increase yields even further, companies need to give them more care. Accordingly, I am attempting to develop methods for reducing mortalities and to determine the optimum levels of care seed oysters require.

More Efficient & Specialized Equipment Needed

The standard oyster dredge is used to perform nearly all tasks in oyster culture, including: (1) Transplanting seed oysters; (2) Harvesting market oysters; (3) Recovering shells from setting beds to be replanted; (4) Sampling oysters to determine their condition; and (5) Even checking beds for the presence of starfish.

This dredge was used to harvest oysters since the 1800s and was still employed in the late 1960s with little significant change in design. It is grossly inadequate to perform any of these tasks for the following reasons: (1) It loads a boat at the slow rate of only 300 to 500 bushels per hour or, at most, 2,400 bushels a day. (Actually, it harvests oysters from the bottom only 5 to 7 percent of the time); (2) It kills too many spat and larger seed and leaves too many behind on a bed; (3) It takes inadequate biased samples of oysters from the bottom to determine their condition; and (4) It covers too little area when used to check beds for the presence of starfish.

Because of a short supply of boats, a great need exists for a harvester that will load a boat or barge with seed (with less breakage) or market oysters much faster. A harvester that could remove all spat from a bed probably would also remove enemies from the bottom--such as starfish, oyster drills, mud crabs, and slipper shells. The Bailey hydraulic-escalator oyster harvester used on the Pacific Coast (Quayle, 1969), or the Chesapeake Bay escalator clam harvester modified to harvest oysters in Eastern Canada (Medcof, 1961), would probably satisfy these requirements. But these harvesters would have to be modified to retain small predators and to function on beds under the deeper waters of Long Island Sound (MacKenzie).

Most seed beds have at least 1,000 and many more than 5,000 bushels of shells per acre buried under the bottom. A device such as a wide agricultural cultivator with deep-penetrating, curved, rigid tines could be towed to raise the buried, but clean, shells to the surface. Silt might have to be flushed off these raised shells afterwards. Uncovering these shells would greatly expand the area available for a set of oysters.

Many unused seed beds have more than 1,000 bushels of shells per acre on the surface of the bottom. These shells are virtually useless as cultch for setting oyster larvae, however, because they are covered with fouling organisms. BCF is trying to develop a method for killing these organisms before oyster setting. If this can be done, the area available for a set of oysters would be greatly expanded.

Silt can be removed from a setting bed effectively by use of starfish mops or cutting boards. The design of both, however, can be improved. The starfish mop could be constructed wider than 12 feet, and the cutting board could be constructed so not to disturb sediments under planted shells. I found that most silt on shells originates from the bottom directly beneath the shells. The quantity of silt in bottom sediments varies widely. For this reason, a cutting board that scours the bottom vigorously might stir up additional silt and worsen the condition of the shells on some beds. A cutting board that could be towed at predetermined distances above the bottom might remove silt from shells without disturbing the bottom, regardless of its consistency.

A device such as a wide agricultural cultivator with shallow-penetrating, curved spring tines needs to be used to recover oysters buried by storms. Divers have found that oysters are seldom buried more than an inch under the bottom; recovery should be easy. Oysters buried by storms have always died because companies have never attempted to recover them.

The cost of labor for culling oysters is much too high. A system such as a conveyor belt with holes, and with a side-to-side motion to separate oysters from small empty shells and stones, could be used to lower this cost.

CONCLUSION

The level of efficiency of oyster culture in Long Island Sound increased sharply during 1966-69. Undoubtedly, it will continue to increase because the differential between the cost of producing oysters and the selling price is extremely wide. Companies will make large profits on any oysters sold. New developments are needed to increase the quantities of oysters available.

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WHAT ARE ALGAE?

Algae are primitive plants ranging in size from a single cell, which can only be seen with a microscope, to the giant kelps, which grow to a length of 100 feet. Algae are dominant in the sea, both in number of species (approximately 6,600) and in number of individual plants. Although algal cells contain chlorophyll and other pigments, these plants do not have roots, stems, or leaves. However, some larger forms do have structures which resemble these organs.

Algae do not need roots, because they live in a solution of nutrients and the whole plant can absorb water and nutrients from this solution. Some algae have a holdfast that resembles a root. The holdfast is simply a structure that holds the plant in place; it does not absorb water or nutrients from the "soil"; therefore, it cannot be called a root. Since most of the plant can absorb materials needed for sustenance and growth, there is no need for an elaborate system to transport water, nutrients, and food; therefore, algae do not have stems. The supporting structure of kelp that resembles a stem is called a stipe; it does not serve a transport function and it does carry on photosynthesis.

Some algae have blades that resemble leaves, but these are extensions of the plant body and are not the primary site of photosynthesis as in terrestrial plants. Because the entire body of the algal plant carries on photosynthesis, the blades are adapted to increase the surface area to make absorption and photosynthesis more efficient.

Photosynthesis requires light, and, since the amount of light available in the water is limited by suspended particles, the blades with their larger surface area enable the algae to receive more of the available light. When the water is very turbid, light penetration is poor and plants grow only in shoaler areas. Plants with large surface areas have a better chance of survival.

Large plants do not usually grow in the open ocean, but are restricted to water less than 300 feet deep; one exception is the sargassum weed which floats in the surface layers of the Sargasso Sea. Algae in the open ocean are generally one-celled forms and are limited to the lighted zone (surface to approximately 600 feet). These algae are extremely numerous and are referred to as the "grass of the sea" because they are the very beginning of the food chain in the sea. ("Questions About the Oceans," U.S. Naval Oceanographic Office.)