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CAUSES OF OYSTER SPAT MORTALITY, CONDITIONS OF OYSTER SETTING BEDS, AND RECOMMENDATIONS FOR OYSTER BED MANAGEMENT

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ABSTRACT

As part of a study of mortalities of American oysters, Crassostrea virginica, *I identified the causes of mortality of oyster spat between setting and age of 6 months and compared their relative importance. The causes were complex and varied widely from bed to bed. They were a result of predation by various species, overgrowth by others, mechanical breakage during transplanting, suffocation by silt, early post-setting mortality (cause unknown), and deaths apparently from starvation and, in one location, from poisoning by a bryozoan.*

Two factors prevented much larger sets of oysters on commercial beds: (1) a small supply of clean oyster shells available for commercial oyster companies to plant and (2) layers of fouling organisms and silt that accumulate on shells planted for any length of time.

Between 1966-68, nevertheless, the total quantity of oysters in Connecticut was greatly increased by additional care given to seed oysters. From the mid-1950's through the mid-1960's the quantity had been no more than 35,000 hl (hectoliters) (100,000 bushels). By the spring of 1968 it had increased to about 350,000 hl. The additional care consisted of overcoming, to a large extent, the 3 main causes of mortality of seed oysters, namely, predation by starfish, predation by oyster drills and smothering by silt.

INTRODUCTION

The identification and relative importance of causes of mortality of American oyster spat, *Crassostrea virginica,* on commercial beds in Connecticut have received scant attention. Galtsoff and Loosanoff (1939), Engle (1940) and Loosanoff and Engle (1940) made preliminary studies on mortality caused by starfish, *Asterias forbesi,* and oyster drills, *Urosalpinx cinerea,* and Loosanoff and Engle (1941) indicated that overgrowth by other molluscan species may cause mortality.

In other areas it has been reported that crabs destroy oyster spat (Ryder, 1884; Lunz, 1947; McDermott and Flower, 1952; McDermott, 1960) and that silt interferes with either setting or survival of oysters (Lunz, 1955; Engle, 1956; Galtsoff, 1964).

As part of a long-overdue study that was begun in 1966 to determine the causes and patterns of mortalities of oysters throughout their life span on commercial beds, I identified the causes of mortality of oyster spat between setting and 6 months of age and compared their relative importance. The objectives of this study were to identify significant factors which limit production of oysters, find and develop methods to reduce their limiting effects, and help companies incorporate these methods into their system of oyster culture. In this article I list and compare the relative importance of the causes of oyster spat mortality, describe the conditions of oyster setting beds, and recommend methods for reducing mortalities and for preparation of setting beds.

METHODS

I made a number of preliminary observations on mortality of oyster spat in 1966 and 1967 which aided in identifying the causes of mortality and also provided data on causes of mortality that did not occur in 1968. In the laboratory I examined dead spat collected from setting beds and studied the characteristic markings of the valves of oysters killed by various predators. I confirmed them by noting markings made by various predators isolated in aquaria. Extensive, detailed observations of setting beds were made from late July to mid-October, 1968 (during a period of intense setting), when I examined commercial beds visually twice a week between Norwalk and New Haven. During that time observations of spat mortality were made about once a week, and until January 1969, an overall period of 6 months.

A day of diving consisted of detailed visual inspections of 5 to 10 oyster beds, which ranged from 8 to 40 ha (20 to 100 acres) in size. Visibility of the water ranged from 0.10 to 8 m, average about 2 m (6 feet). Inspections were made by slowly swimming over the bottom, noting: (1) condition of spat, (2) occurrence and behavior of any possible predators and competitors, and (3) degree of siltation. Once every 2 weeks I gently collected about 30 shells randomly from each bed without breaking off the top valves of any dead spat. Later I examined them in the laboratory to determine the number of live and dead spat, the cause of mortality of each dead spat, and the average number of spat killed by each cause for each bed.

The identification of causes of mortality was usually certain. It was determined by knowledge of the condition of a bed when shells were collected, by markings on valves left by predators, by position of spat in relation to competitors or to some physical characteristic, such as under a deposit of silt, and by knowledge of commercial oyster culture operations. In some instances, when the valve markings were common to more than one cause of mortality, a cause could be established by knowledge that only one of them was present on the bed. In a few instances, mortality of spat was apparently due to a specific cause, but the cause could not be definitely established.

CAUSES OF OYSTER SPAT MORTALITY

Mortalities of oyster spat during their first 6 months are nearly always high, and many heavy oyster sets can be reduced by predation or other causes to non-commercial levels during this period. I began observing small spat within 1 or 2 days after they had set to record all possible causes of mortalities. The causes were complex and they varied widely from bed to bed (Table 1). Many years of observation would be necessary to understand them thoroughly, but I believe that this short study has yielded valuable information.

Causes of mortality of oyster spat will be discussed in 2 sections: I. Established causes of mortality in which I shall discuss only those mortalities for which the cause could be definitely established, and II. Apparent causes of mortality

TABLE 1. *Percentages of oyster spat alive and dead from various causes on 4 beds at different dates during 1968-69. Lots 152, 143, and 1-C are in New Haven Harbor and lot 50 is at Norwalk, Connecticut. Characteristics of each mortality are discussed in text.*

	Lot, date, and percentage of oysters alive and dead			
	Lot 152 26 Sept.	Lot 143 27 Sept.	Lot 50 15 Nov.	Lot 1-C 30 Jan.
Live spat	28.0	60.0	86.5	70.8
Established causes of mortality				
Predation by:				
Adult starfish	0.0	17.0	0.5	0.0
Oyster drills	0.2	14.0	13.0	8.3
Overgrowth by:				
Slipper shells	58.0	0.0	0.0	4.1
Calcareous bryozoans	0.1	1.0	0.0	1.2
Other spat	0.2	0.5	0.0	0.0
Suffocation by silt	0.0	0.0	0.0	1.0
Apparent causes of mortality				
Post-setting mortality	6.3	5.0	?	9.0
Predation by mud crabs	7.2	2.5	0.0	5.6

in which I shall discuss mortalities which, at present, could be assigned only to probable causes.

I. Established Causes of Mortality

Predation by starfish

Predation of spat by young-of-year and adult starfish will be considered separately because the 2 groups behave differently and for this reason present different control problems. When spat and older oysters have been killed by either young-of-year or older starfish the valves gape and the top one appears to be filed to a blunt edge for at least a part of its circumference (Mead, 1901). No other predator leaves a similar mark.

Predation by young-of-year starfish. Young-of-year starfish were abundant on planted oyster beds from Norwalk to New Haven in 1966, but scarce in 1967 and 1968. They did not appear to be migratory; they remained on or close to the bed on which they set at least until the following spring.

I learned from laboratory and field studies that young-of-year starfish are very sensitive to light. In running water aquaria in a dark room, young starfish were on top of clusters of oysters, but when the room was lightened they crawled underneath the clusters. On Connecticut oyster beds under 2 to 7 m of water, they were on the bottom of shells and clusters of oysters and thus not visible from a position directly above. In contrast, in the dark turbid waters of Northport Harbor, Long Island, young starfish were on top of such clusters. Divers have not yet examined oyster beds at night to determine whether young starfish are on top of clusters at that time.

In 1966 young-of-year starfish killed significant numbers of oyster spat. For instance, in late November, on lot 152, New Haven, in a section where their uneven density was 50/m^2, these starfish killed 66% of spat which had once numbered about 40 per shell. I estimated the average mortality of spat over the entire bed at 28%. On lot 13, New Haven, each young starfish consumed an estimated 23 spat on various shells from 27 September to 9 November, a period of 6 weeks.

From 1968 to 1969 young-of-year starfish killed spat during the entire 6 months of this study, but they occurred in small numbers on only a few beds and caused small mortalities (Tables 2 and 3).

Predation by adult starfish. Adult starfish were numerous in all areas between Norwalk and New Haven. They migrate to some extent and appear able to travel several hundred meters within a few weeks.

TABLE 2. *Causes of mortality of oyster spat which set 1 August 1968, on 30 beds during different months. Approximate percentages of beds on which mortality occurred are shown under each month. Dashes indicate no mortality.*

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
Established causes of mortality						
Predation by:						
Young-of-year starfish	5	5	5	5	5	5
Adult starfish	a	a	a	a	a	a
Oyster drills	30	30	25	25	—	—
Overgrowth by:						
Slipper shells	20	20	—	—	—	—
Calcareous bryozoans	85	—	—	—	—	—
Barnacles	30	—	—	—	—	—
Other spat	30	30	30	30	—	—
Jingle shells	5	5	—	—	—	—
Mechanical breakage during transplanting	—	—	5	5	5	—
Suffocation by silt	—	70	70	70	—	—
Sinking into soft bottoms	5	5	5	—	—	—
Apparent causes of mortality						
Post-setting mortality	85	—	—	—	—	—
Predation by mud crabs	70	—	—	—	—	—
Starvation	—	15	15	—	—	—
Poisoning by fleshy bryozoans	5	—	—	—	—	—

a Approximately 80% of beds were invaded by random movements of starfish at least once during the 6-month period. Starfish caused most damage to spat along the borders of beds.

TABLE 3. *Approximate percentages of spat dead from various causes, between setting in 1968 and age of 6 months, on 15 commercial beds in Connecticut.*

	Percentage dead	
	Average	Range
Established causes of mortality		
Predation by:		
Young-of-year starfish	1	0 - 5
Adult starfish	25	0 - 90
Oyster drills	5	0 - 25
Overgrowth by:		
Slipper shells	5	0 - 58
Calcareous bryozoans	3	0 - 5
Barnacles	1	0 - 5
Other spat	1	0 - 2.5
Jingle shells	0	0 - 1
Mechanical breakage during transplanting	3	0 - 15
Suffocation by silt	1	0 - 5
Sinking into soft bottoms	1	0 - 1
Apparent causes of mortality		
Post-setting mortality	10	5 - 15
Predation by mud crabs	12	0 - 50
Starvation	8	0 - 50
Poisoning by fleshy bryozoans	1	0 -100

Oyster spat killed by adult starfish have the top valves with the same filed appearance as those killed by young-of-year starfish. Thus, mortality of spat by either of these groups of starfish can be distinguished only if the other group is absent. This was no real problem in my study because young starfish were scarce in 1968.

Oyster companies remove adult starfish from setting and growing beds before they spread shells or seed oysters. Starfish destroyed most spat, however, along the edges of setting beds when they invaded them from adjoining unplanted areas. For instance, they killed 77 and 94% of spat in a 5 to 7 m band along the edges of 2 beds.

Starfish consumed spat during the entire 6 months of this study (Table 2). They killed from 0 to 90%, or an average of about 25% of the spat on various setting beds (Table 3).

Predation by oyster drills, *Eupleura caudata* and *Urosalpinx cinerea*

In 1968 oyster drills were scarce on nearly all planted oyster beds between Norwalk and New Haven. Their densities averaged less than 1/m². On a few unplanted beds in Norwalk and New Haven, however, densities were as high as 20/m² (MacKenzie, in press). A small round hole through the top valve of a dead spat easily identifies an oyster drill as the predator.

In 1968 those oyster drills present consumed spat from the time of oyster setting until the water temperature fell below 10°C in late November (Table 2). Most planted beds, because of the very low densities of drill populations, showed virtually no mortality of spat by drills, but on one bed it reached about 25% (Table 3).

Overgrowth by slipper shells, *Crepidula plana* and *Crepidula fornicata*

Slipper shells were common on shells, oysters and other surfaces between Norwalk and New Haven. Their numbers varied widely from bed to bed, but lot 152 in New Haven, an excellent bed for collecting oyster sets, also received consistently heavier sets of slipper shells than most other beds. On 26 September 1969, shells which had been spread on this bed in late July had an average of 44 *C. plana* and 8 *C. fornicata* on their inner faces. By October the slipper shells covered three-fourths of these inner faces. Other setting on beds in New Haven Harbor ranged from 5 to 10 per shell; however, slipper shells were even less abundant on beds in Bridgeport.

Larvae of slipper shells and oysters set at about the same time on shells which companies spread on setting beds. Until the age of 2 months, slipper shells grow much faster than oyster spat, and can kill large numbers of spat by overgrowth. For example, on 8 August 1969 the largest slipper shells on lot 152 were 7 to 10 mm (1/4 to 1/3 inch), but the largest spat were only 1.5 mm, although both were about the same age. After about

2 months, growth of slipper shells becomes much slower. Dead spat or their scars (bottom valves) were observed under slipper shells.

Slipper shells killed spat from late July to late September (Table 2). I estimated the number of spat killed by the 2 species of slipper shells on lot 152 by determining the reduction in number of live spat on shells at regular dates. On 15 August the average number of spat per shell (both sides) was 143. Possibly, they had already killed many spat because shells in test setting bags on the bed had accumulated 233 by that time. These test bags with clean shells were placed on the bottom and recovered twice a week; hence, slipper shells did not have time to overgrow and kill spat. By 26 September the number of spat on shells on the bed had decreased to 36, whereas the number on shells in the test bags had accumulated an average of 453 (Table 4). Overgrowth by slipper shells was responsible for about three-fourths, or 80, of the 107 spat killed. Slipper shells killed more spat on the inner face of shells, where they were more abundant, than on the outer face. After 15 August it seemed possible that the large number of attached filter feeders, such as slipper shells, barnacles and spat themselves growing on cultch shells, may have prevented some setting of oyster larvae. Slipper shells did not kill significant numbers of spat on other beds (Table 3). A light set of oyster spat occurred on shells of both *C. plana* and *C. fornicata*, but I did not determine what percentage survived.

Overgrowth by a calcareous bryozoan, *Schizoporella unicornis*

Calcareous bryozoans were extremely common on shells, oysters and other hard surfaces between Norwalk and New Haven. They kill spat by growing either between their 2 open valves or completely over both valves and sealing them. Calcareous bryozoans killed only those spat that were less than a month old (Table 2), or 5 mm long. In 1968 they killed only 0 to 5% of spat (Table 3), and in a group of bagged shells, about 8%.

Overgrowth by barnacles (species not identified)

Barnacles were extremely abundant in New Haven but not as common in other areas. Barnacles kill adjacent spat by pushing up the top valve and growing over the bottom one, as the shell grows in diameter. Barnacles killed only those spat that were less than a month old (Table 2), or about 5 mm long. In 1968 they killed only 0 to 5% of spat (Table 3).

Overgrowth by other spat

Spat may be killed by overgrowth by larger spat especially when more than 25 spat are attached to one side of a shell. I saw dead spat, obviously killed by this cause, under shells of larger spat.

Mortalities from overgrowth of older spat took place mostly during the first 4 months (Table 2). In 1968 such mortalities were only 0 to 2.5% (Table

TABLE 4. *Average numbers of spat per shell on bottom and in test bag, lot 152, New Haven Harbor. Test bag was replaced twice weekly.*

Date (1968)		Setting bed	Test bag (per half-week)	Cumulative total in test bag
July	29	—	5	5
Aug.	1	26	50	55
	5	—	40	95
	8	94	14	109
	12	—	21	130
	15	143	103	233
	19	—	124	357
	22	112	31	388
	26	—	27	415
	29	77	8	423
Sept.	3	—	6	429
	6	44	6	435
	9	—	10	445
	13	—	4	449
	16	—	3	452
	19	—	0	452
	23	—	0	452
	26	36	1	453

3). Overgrowth might have been greater had not spat settled uniformly over a shell, thereby providing space between each spat for growth.

Overgrowth by jingle shells,
Anomia simplex

During 1966-68 the setting intensity of jingle shells was extremely light, and thus they caused little mortality of oyster spat (Tables 2 and 3). Jingle shells kill spat by overgrowth as do slipper shells. Scars of dead spat were observed under jingle shells. In one instance, 7 dead spat, all less than 5 mm long, were found under a single live jingle.

Mechanical breakage during transplanting

Oyster companies use the same heavy dredge for transplanting spat as employed for harvesting market oysters. Divers observed that this dredge collects only 10 to 20% of spat in its path during a drag and that it is very destructive. Many spat are broken and killed when the dredge passes over them, when they are tumbled about as they are picked up by the dredge, when they are dumped on deck, when they are walked on by deck workers, and when they are tumbled about while being washed overboard and planted on another bed.

Many spat killed during transplanting operations have broken top valves, but in others only the bottom valve remains. The mechanical handling of oysters destroys the markings on valves left by other causes of mortality, and thus I could not distinguish the spat killed by transplanting from those killed by other causes. Instead, I estimated the percentage of spat killed by comparing the number of live spat per shell before and after a transplanting operation.

Transplanting of spat was usually done in October, November or December, when they were 3 to 5 months old and 25 to 35 mm long (Table 2). In one transplanting operation, I determined the percentage of spat killed when they were transplanted during November from lot 804, Bridgeport, to lot 455, New Haven. The spat were 3 months old. In early October before being transplanted 79% of the spat were alive, while in early December, after transplanting, only 67% were still alive. Thus, as many as 15% of the transplanted spat may have been killed by the transplanting (Table 3). Nearly all this mortality seemed to be a result of mechanical breakage because the other causes were virtually absent. In addition to this mortality, counts of the number of live spat per unit area on lot 804 before and after the transplanting showed that about 20% of the spat, most of them attached to small fragments of shells which cannot be harvested by the standard oyster dredge, were left behind. Oyster companies rarely protect spat left behind on a bed after a transplanting operation, thus these spat are frequently lost to predation by starfish or destroyed by storms.

Suffocation as a result of siltation

Silt begins to accumulate on some setting beds after shells are spread. Besides interfering with the setting of oyster larvae, continuing siltation may suffocate spat, especially those at the bottom of a crevice between 2 shells.

Mortalities from suffocation can be identified by a covering of silt over the spat which have black, complete valves. This cause of mortality was distinguished from the post-setting mortality (see *Apparent Causes of Mortality)* if the dead spat had shown signs of growth. Suffocation of spat took place when they were 2 to 4 months old (Table 2). Mortalities of spat from this cause were 2.5 and 5% on 2 beds, but less on most beds (Table 3).

Sinking into soft bottoms

Spat were killed on a few beds when the shells to which they were attached sunk into soft mud. I listed buried spat with complete valves which had grown slightly (to distinguish the cause of death from post-setting mortality) in this category. In 1966 a company planted shells on 3 beds with soft bottoms in Stony Creek, Branford. By 23 September 1966, 17% of the spat were buried on one of these beds. The mortality may eventually have been much greater because the spat were not transplanted and shells may have sunk deeper into the soft bottom. In 1968, however, this cause of mortality was very low because companies planted almost all their shells on beds with hard bottoms (Tables 2 and 3).

II. Apparent Causes of Mortality

Post-setting Mortality

In this type of mortality the spat died within a few days after they had set and before displaying any growth (Table 2). The dead spat or scar which remained could be identified because it displayed no growth and the top valve was always complete. From 5 to 15% of spat on most beds died in this manner (Table 3).

Predation by mud crabs,
Neopanope texana

Mud crabs are extremely common on most oyster beds. *Neopanope texana* was the only species I recognized, though other species of xanthid crabs probably occur. At first, the identity of mud crabs as the cause of mortality was not certain because they usually leave no characteristic mark. In most instances, I found only a clean scar, but in others, a jagged top valve. After observing in laboratory aquaria that mud crabs do prey on spat, I listed them as the cause of mortality when they were present and when there was no other apparent cause for the mortality.

In laboratory aquaria mud crabs did not kill spat much larger than 10 mm, or after about 1 month of age, when the spat were attached to shells (Table 2). In contrast, they preyed on unattached spat up to about 25 mm long. On most beds mud crabs appeared to kill from 0 to 20% of spat. On lot 827, Fairfield, however, they apparently killed about 50% of the spat (Table 3).

Starvation

In 1968 I observed a mortality of spat apparently due to starvation or, possibly, to disease. This type of mortality occurred only on beds under 10 to 12 m of water in New Haven. About 50% of the spat that survived the early post-setting mortality became gradually pale and after about 2 weeks showed no further growth. The spat became increasingly pale until they died when 1 to 2-1/2 months old (Table 2). The remaining survivors were dark in appearance, however, and they lived and grew, but more slowly than spat on beds under shallow water. Mortalities due to this cause did not occur on any inshore beds; the average mortality from this cause on all beds was about 8% (Table 3).

Poisoning by a fleshly bryozoan, *Bowerbankia* sp.

In Bridgeport, fleshy bryozoans grew abundantly on shells on beds that had lain idle for 10 or more years. The few spat that had set on these shells grew only slightly and eventually all died. The bryozoans did not kill spat by overgrowth, as did calcareous bryozoans; instead, the strong acrid secretions they produce appeared to kill them, although confirmation was not made in the laboratory. The spat died before they were a month old, or 8 mm long (Table 2). The average mortality from this cause on all beds was about 1% (Table 3).

Undetermined causes of mortality

Doubtless, oyster spat are killed by other, still unrecognized causes. In laboratory aquaria rock crabs, *Cancer irroratus*, destroyed spat at least 25 mm long. I did not investigate mortalities of oyster spat by several other possible predators which are common in Connecticut, including: the tautog, *Tautoga onitis;* the summer flounder, *Paralichthys dentatus;* the hermit crabs, *Pagurus pollicaris* or *P. longicarpis*; the young-of-year mud crab; and the spider crab, *Libinia emarginata.* Field studies are needed to determine the importance of these fish and crabs as predators of oyster spat. The blue crab, *Callinectes sapidus,* which preys on spat in other areas, has been scarce in Connecticut in recent years.

CONDITIONS OF OYSTER SETTING BEDS

While studying setting beds in 1968, an excellent year for oyster setting, I observed that only a small percentage of available oyster beds in Connecticut were in condition to receive the many billions of eyed oyster larvae in the water. Clean shells in test bags placed in many areas by the Milford Laboratory staff indicated that thousands of acres of bottom would have received a set of oysters had they been properly prepared. Oyster companies spread clean shells on only a small number of beds with a total area of about 150 to 200 acres, or about 2% of the available seed beds, and they obtained heavy sets of oysters on them. On a smaller number of beds, whose area totaled about 100 acres, companies dredged up and immediately respread old shells, but because these shells were heavily fouled they collected only light sets. The remaining beds which received no preparation collected insignificant sets.

Shells on the unprepared beds were covered with live fouling organisms, consisting mostly of bryozoans and algae, and silt, which prevented oyster larvae from setting. The few shells and stones on the once-famous 1,800 ha public seed bed off Bridgeport and Fairfield which, until 1948, produced large quantities of seed oysters, were completely covered with live fouling organisms. While each clean shell in test bags placed on this bed by the Milford Laboratory staff accumulated an average of 150 spat during the setting season, each shell on the bed accumulated less than 1 spat, an insignificant number.

Deposits of silt on shells decreased the intensity of setting of oyster larvae. For instance, on lot 25M in Milford each clean shell in test bags placed by the Milford Laboratory staff had a cumulative average of about 1,000 spat, but silt-covered shells, that were otherwise virtually clean of fouling organisms, on the bottom collected an average of only 1 spat per shell. On lot 804, Bridgeport, shells at the north end where silting was negligible collected an average of 20 spat per shell, but those at the south end where silting was substantial had an average of only 5 spat.

It had always been difficult to explain the discrepancy between setting of oysters on shells planted by oyster companies and on clean shells in test bags placed in the same areas by the Milford Laboratory staff. Spread shells always had much lower sets than shells in test bags. The observation that spread shells become covered by live organisms and silt explains why they caught fewer spat.

In 1968 I compared the value of the following 3 types of oyster shells as cultch for setting oyster larvae: (1) shells cleaned by storage on land; (2) black shells obtained from muddy bottoms; and (3) shells "reconditioned" by being dredged up and respread immediately. This latter method of preparing shells has been used extensively in recent years by oyster companies, but it is not effective because it exposes only small clean areas of shells that were against the bottom. I placed bags of these 3 groups of shells together on a number of setting beds and also collected shells that had been spread on the bottom. Shells of the first 2 types were about equal as cultch, collecting from 3-1/2 to 12 times as many spat as the "reconditioned" shells.

RECOMMENDATIONS FOR OYSTER BED MANAGEMENT

Control of mortalities of spat

In 1968 oyster companies controlled several causes of mortality of oyster spat to various degrees. Adult starfish and oyster drills were under reasonably adequate control, but the former still caused significant mortalities. Competitors for space on shells, such as slipper shells, calcareous bryozoans and barnacles, which cause mortalities of oyster spat, were partially controlled by delaying the spreading of dock-stored shells on setting beds until eyed oyster larvae appeared in the water. From 1966 to 1968 the total quantity of oysters in Connecticut was increased at least 10 times because companies gave much more care to seed oysters. By the spring of 1968 the quantity of oysters, which had been no more than 35,000 hl (100,000 bushels) from the mid-1950's through the mid-1960's, increased to about 350,000 hl. The additional care consisted of controlling the 3 main causes of mortality of oyster seed, namely, predation by starfish, predation by oyster drills and smothering by silt in April and May.

Mortalities of spat caused by: (1) competition for space on shells (except by slipper shells); (2) siltation; and (3) poisoning by fleshy bryozoans are not large enough to warrant attempts to control them. Oyster companies reduced mechanical damage of spat during transplanting to some degree by postponing this operation until late fall or the following spring when spat had larger and thicker shells. Nevertheless, mortalities from this cause were still too great. Suffocation after sinking into soft bottoms has been avoided on occasion by early transplanting.

What causes of mortality would be the most profitable to control? At present, the ones that appear to hold the most promise, in order of importance, are predation by (1) adult and (2) young-of-year starfish, (3) mud crabs, (4) mechanical breakage during harvesting, (5) starvation, and (6) overgrowth by slipper shells. Adult starfish can be controlled more effectively by checking oyster beds more frequently to determine their presence and by applying lime without delay. It may be that young-of-year starfish would be controlled most effectively by treatments with lime at night, if they are not protected beneath shells at that time. Mud crabs can be controlled before shells are planted on a bed by use of suction dredges, as recommended by McDermott and Flower (1952).

An improved system for transplanting spat is obviously needed. The present system in which a heavy oyster dredge is towed over the bottom, filled with oysters, pulled to the surface, emptied, and lowered to the bottom, is extremely destructive and inefficient. I estimate that employment of an ideal system, one which would harvest all spat and older seed from the bottom with negligible breakage, would bring an ultimate increase of about 50% in production of market oysters. Such a system would also remove pests from the bottom. The Bailey hydraulic-escalator oyster harvester or the Chesapeake Bay escalator clam harvester used on shallow beds in Canada (Medcof, 1961; Quayle, 1969) might satisfy these requirements, if they were modified to retain small predators and operate on beds under deeper water. The use of either harvester might permit spat to be transplanted earlier in the summer. This would avoid several causes of spat mortality, i.e., predation by starfish in some instances, starvation on beds under deep water, suffocation by sinking into soft bottom and destruction by storms.

Slipper shells can be controlled by treating shells with Polystream [1], as recommended by MacKenzie, Loosanoff and Gnewuch (1961).

Preparation of oyster setting beds

Oyster companies could obtain many times more spat on their setting beds in a number of inexpensive ways: (1) by preparing larger stocks of clean oyster shells; (2) by spreading shells only when and where setting size oyster larvae are present in the water (they would have to take plankton samples to determine this); (3) by spreading shells dredged from under the bottom on setting beds after the supply of clean shells is exhausted; (4) by keeping the setting beds free of silt by using devices such as starfish mops or cutting boards (vanes); and (5) by dipping fouled shells in hot water as they are harvested, making them suitable as cultch for oyster larvae.

CONCLUSION

Apparently, the 2 major limitations to oyster production in Connecticut are: (1) lack of sufficient shells in good condition for setting oyster larvae; and (2) very high mortality of young spat and older seed by various causes. The waters of Connecticut contained enough oyster larvae in the years of 1958, 1959, 1962, 1966 and 1968 (un-

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[1] Trade names referred to in this publication do not imply endorsement of commercial products.

published data, Biological Laboratory, Milford, Conn.) to support an annual production of several million bushels of market oysters if enough of the set had been caught and saved.

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CONTENTS