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FISH AND WILDLIFE SERVICE

USE OF LIME IN CONTROLLING STARFISH

RESEARCH REPORT No. 2

UNITED STATES DEPARTMENT OF THE INTERIOR
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By

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ABSTRACT

THE STARFISH (*Asterias forbesi* Desor) is one of the most destructive enemies of shellfish on the Atlantic coast of North America, the extent of its damage to the oyster industry of Long Island Sound alone being estimated at $500,000 a year. Efforts to eradicate this pest, though made for at least a century, have been largely unavailing.

The method here presented of combating starfish suggests the use of quicklime, the destructive effect of which is produced by direct contact. Particles of the chemical spread over oyster beds quickly sink to the bottom, and, falling on the starfish, are imbedded in the delicate skin. The caustic action of slaking lime disintegrates the membrane, and the lesions rapidly increase in size. After several days the wounds penetrate the body wall and expose the internal organs. Death usually follows in a short time.

Once spread over the oyster beds, the lime retains its effectiveness for some time. Starfish not hit directly by the descending particles will eventually come in contact with them when crawling along the bottom. In the course of time their lower surfaces will become affected and disintegration will begin. The cheapness of lime, the simplicity of its application, and its comparative harmlessness to oysters and many other commercial species all indicate that it is a practical weapon for use against the inroads of starfish on oyster beds.

USE OF LIME IN CONTROLLING STARFISH

By VICTOR L. LOOSANOFF, *Director, Fishery Biological Laboratory, Milford, Conn.*, and JAMES B. ENGLE, *Oyster Culturist, Fish and Wildlife Service*

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INTRODUCTION

The common starfish (*Asterias forbesi*) has long been regarded as one of the most destructive enemies of shellfishes on the Atlantic coast of North America. The greatest part of the loss caused by this pest is borne by the oystermen, who often find their stock depleted or entirely destroyed. Beds populated with seed oysters are especially vulnerable. Regardless of constant efforts in combating them, starfish continue to be very numerous, destroying annually several hundred thousand bushels of oysters in Long Island Sound alone. The extent of the damage caused to the oyster industry of Long Island Sound by starfish is estimated to be approximately $500,000 a year. In addition to the direct loss caused by the destruction of seed and marketable oysters, the industry spends large sums for operating starfish boats, handpicking starfish on dredge boats, and eliminating them by other methods. It is estimated that the oystermen of Connecticut expend $100,000 to $150,000 a year for this purpose.

The scallop, another valuable mollusk of the Atlantic coast, also suffers greatly from attacks by starfish. In spite of its swimming habits, the scallop often becomes a prey of the sluggish starfish. In 1931 the population of the natural scallop grounds of Buzzards Bay was seriously depleted through starfish depredations. The Massachusetts Division of Fisheries and Game reported that the value of the scallop industry in Buzzards Bay decreased from $795,000 in

1929 to $142,000 in 1931. State authorities attributed the greater part of this decrease to the gradual increase in the starfish population (Galtsoff and Loosanoff 1939).

The voracity of starfish can easily be observed under laboratory conditions if the animals are kept in a favorable environment. Experiments conducted at Milford Laboratory have shown that a medium-sized starfish may destroy as many as 5 one-year-old oysters in 1 day. In one experiment 2 starfish destroyed 25 one-year-old oysters in 3½ days, and in another a small starfish, 1.7 cm. in diameter, destroyed 25 oyster spat in 3 days. These examples indicate the extent of damage that may be caused to beds of young oysters by invading hordes of starfish.

Studies of the conditions existing on the oyster beds of Long Island Sound in the summer and fall of 1937 provided certain quantitative data, which showed that under natural conditions the heavy mortality and quick disappearance of the oyster set were due largely to starfish activities. Simultaneously with the studies of setting of oysters (Loosanoff and Engle 1940), observations were conducted on the setting of starfish. Comparison of the density of oyster and starfish sets in 8 different areas of Long Island Sound showed that the total number of starfish set was only about one-fourth less numerous than that of oysters. The distribution of starfish set according to depth corresponded closely to the oyster set. The areas that produced large numbers of young oysters produced almost equally large numbers of their enemies. At some stations, however, young starfish were found to be much more abundant than oysters. Observations on the setting of starfish indicate that it begins about 2 weeks prior to the setting of oysters. Thus, by the time the first oysters set a great many starfish are already crawling on the bottom in search of food.

Under natural conditions several species of mollusks and other small animals are available as food for starfish, and, therefore, oysters do not constitute their only diet. Nevertheless, estimating very conservatively that 1 young starfish destroys but 1 oyster spat in 1 week's time, it is possible that the majority of oyster set can be eaten by starfish within the first few days of their existence.

Efforts to eradicate starfish have been made for at least a century, but these attempts have been mostly unavailing. The method so far used consists of gathering the starfish from the bottom by use of dredges or special starfish mops and destroying the captured animals by immersion in hot water. This method, however, is slow and the unabated depredations of starfish on the oyster beds attest its inefficiency (Loosanoff 1936).

Since mechanical control of starfish on oyster beds is not very effective, the possibility of employing some toxic substance for their eradication suggested itself. Although the body of the starfish is enclosed in a skeleton of articulating calcareous plates set with rows of blunt spines, or ossicles, and appears to be rigid and well protected, its surface is covered with a delicate membrane. Between the ossicles protrude the thin contractile branchiae which, when fully extended, provide for a gaseous exchange between the sea water and body fluids. The delicate membrane covering the branchiae can easily be affected by various chemicals. These anatomical features make the starfish much more vulnerable than the oyster and some other shellfishes, which, by keeping their shells closed, protect their bodies from the injurious effects of poisons.

Experiments leading to the development of a method for chemical control of starfish have been conducted for several years (Galtsoff and Loosanoff 1939). In early experiments substances such as copper sulfate were used. Although this chemical proved lethal to starfish, several disadvantages attended its use. Large quantities were needed to create a lethal concentration; a procedure too expensive to be practical. A further disadvantage was the fact that in using it many other marine organisms also were killed.

METHODS

Experiments on the destruction of starfish by the use of calcium oxide, or quicklime, have been carried on since 1937 at Milford Laboratory (Loosanoff and Engle 1938). The possibility of using calcium oxide for combating starfish was first suggested by Wood (1908), who recommended the building of a barrier around the oyster beds by placing lime on the bottom in paper bags. In the course of time the water would disintegrate the bags, thus exposing the lime. The caustic nature of lime would prevent starfish from crawling over the barrier. Wood's method was primarily devised to restrict the movement of starfish from one area to another, but not to exterminate them.

The new method consists of spreading the lime uniformly over the starfish-infested bottoms. As demonstrated by observations of Loosanoff (1937), starfish are slow-moving animals, staying in approximately the same places for long periods. Therefore, starfish on the treated areas cannot move to untreated areas rapidly enough to avoid contact with the lime.

At present, various devices are being developed by oystermen and by lime-manufacturing companies for releasing the lime near the bottom and for its uniform distribution over the treated areas.

Figure 1 shows in detail the apparatus suggested by the authors, which is based upon features taken from several different devices. Granulated lime is placed in the hopper (A) which is capable of holding several bags of material. By opening the trap door (B) dry lime enters the mixing chamber (C) where a strong stream of water produced by the pump (D) keeps the falling lime particles in sus-

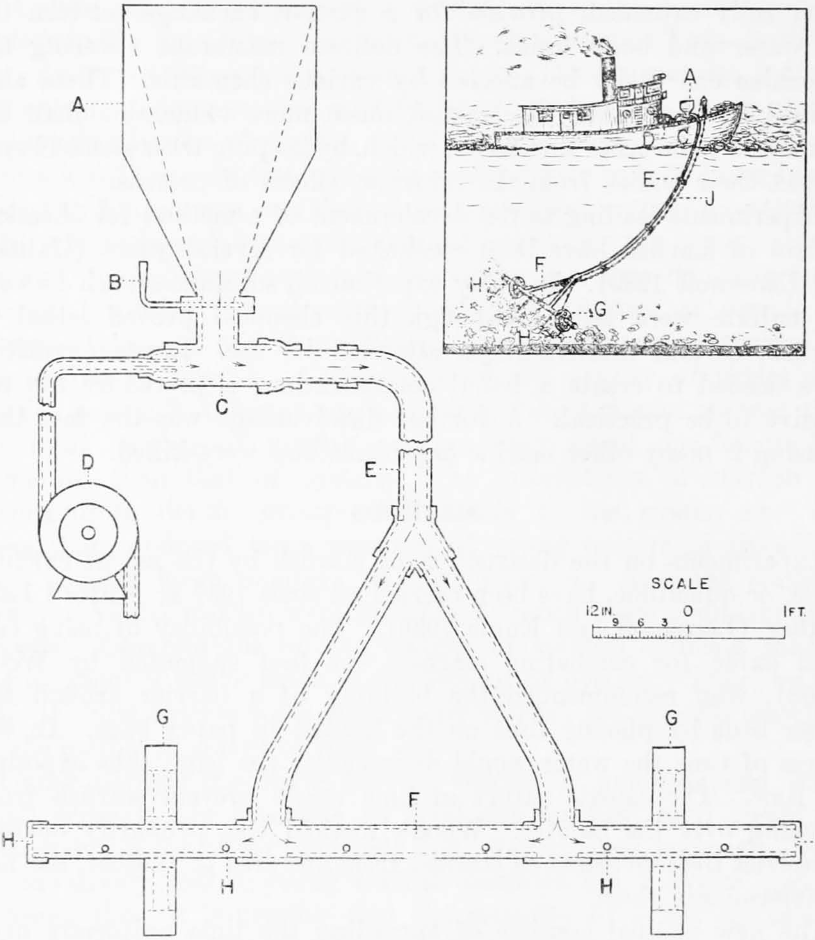

FIGURE 1.—Diagram of apparatus for spreading lime on starfish-infested bottoms.

pension and forces the mixture through the hose line (E) to the distributing pipe (F). The efficiency of the apparatus may be increased further by placing a second pump on the other side of the mixing chamber. The hose line (E) is attached to the towing chain (J) by a series of metal rings that keeps the line from forming sharp bends, or kinks, which would interfere with the normal flow of the lime and water mixture. The towing chain is attached to a regular dredge hoist by means of which the chain and hose line can be paid out to a desired length. The distributing pipe (F) is perforated with several holes (H), ¾-in. in diameter, through which the lime suspension is forced upward and backward in geyserlike jets. In some cases it may be advantageous to perforate the distributing pipe with horizontal slits several inches long and about ¾-in. wide in lieu of the round holes. The holes (H) of the distributing pipe (F) should be so situated that they can direct the jets of lime upward and backward. Such position of the holes will permit a more uniform dispersion of lime particles before they settle to the bottom. A pair of wheels, or skids (G) are attached to the distributor to keep it between 1 and 3 feet off the bottom.

ACTION OF LIME ON STARFISH

The effectiveness of the method depends upon the direct contact of lime with the body of the starfish. Particles of lime fall upon the surface of the starfish and imbed themselves in the membrane covering the animal. The action of lime disintegrates the delicate membrane and creates lesions. The lesions increase rapidly in size, involving the branchiae and other structures on the dorsal surface of the starfish. After several days the lesions penetrate the body walls. When this stage is reached the internal organs of the animal become exposed and death usually follows very shortly.

Starfish which are not hit directly by the lime during application will eventually come in contact with it when crawling over the bottom. Since the chemical retains its effectiveness for some time, very few starfish will escape its action. In the course of time the lower, or oral surface of these animals will become affected, and disintegration will then set in.

HEALING OF WOUNDS

It was noted that not all the starfish affected by lime died. On the contrary, cases were recorded when the wounds healed and injured structures regenerated. To observe the recovery of starfish from wounds caused by lime, several experiments were performed. One experiment was conducted to determine whether a starfish will autotomize a ray affected by lime. In this experiment 5 starfish were placed in an aquarium with running water, and a small piece of lime was placed on 1 ray of each animal. After several hours the lime was removed. Burned spots had formed on each ray treated. Soon after the beginning of the experiment 4 of the starfish displayed shallow wounds, and the fifth animal had a deep wound that penetrated the body wall. Parts of the digestive gland protruded from this wound. The starfish were kept under observation for a period of 2½ months. During that time none of them died, and not a single case of autotomy occurred. About 3 weeks after the beginning of the experiment, wounds on several starfish began to show signs of healing. The healing process, however, was very slow. Scar tissue that formed over the affected areas persisted for a long time.

Another experiment with 6 starfish was begun on Feb. 1, 1938. As in the previous experiment, 1 ray of each starfish was treated with lime. In this case, however, larger quantities of the chemical were used. Within 2 days after treatment large wounds were formed on the rays touched with lime. Several days later the wounds penetrated the body walls, exposing the internal organs. Soon 3 starfish disintegrated and died. The other 3 survived and began to show signs of healing after a period of several weeks. Regeneration proceeded quite slowly. By the end of August, almost 7 months after the beginning of the experiment, the wounds healed, but microscopic examination revealed that the areas affected possessed smaller numbers of spines, pedicellariae, and branchiae than the corresponding normal areas. Some of the newly formed spines showed definite deformities.

Many cases of healing of wounds and of recovery were noted on the starfish brought to the laboratory from the natural oyster beds where the lime treatment was tried. It appeared that recovery depends upon the number and character of wounds suffered by each individual, as well as upon escape from attack by other animals. Numerous observations made in the course of this work showed that affected starfish, especially those having their internal organs protruding through the body walls, were attacked and eaten by healthy starfish and by other animals, chiefly crabs.

It was also noted that seriously affected starfish stopped feeding and moving, while lightly affected individuals continued to move and feed quite normally. In several instances wounded animals also were observed in the act of spawning.

ERADICATION EXPERIMENTS

LABORATORY STUDIES

To test the efficiency of lime treatment, laboratory studies were carried on in large outdoor tide-filling concrete tanks and in laboratory aquaria of 15-gallon capacity. Experiments in the tanks were begun in winter, when the water temperature was at or near the freezing point, and were continued until summer. Experiments in the aquaria were usually carried on at room temperature, ranging from 17 to 20° C. Unless otherwise stated, the water in the aquaria was not changed during the run of an experiment. Because the lime was obtained in barrels, each containing 280 pounds, the experiments were conducted on the basis of a certain number of barrels per acre, with correspondingly small quantities used in the tanks and aquaria.[1]

The first series of experiments was conducted to establish the relative effectiveness of finely granulated and coarse grades of quicklime, and to determine the concentration of lime needed to kill starfish. One experiment was begun on Dec. 17, 1937, in a tank 10 feet wide and 20 feet long in which 20 starfish were placed. A quantity of lime corresponding to 3 barrels (840 pounds) per acre was then spread over the bottom. The lime used in this experiment was of a coarse grade, the bulk of which consisted of lumps ranging in size from 0.5 to 5.0 cm., but also containing finer particles resulting from crumbling.

Examination 48 hours after the beginning of the experiment showed that the membranes of the animals hit by lime particles were disintegrating, numerous large and small lesions having formed on the aboral surfaces. In the parts affected many pedicellariae and tubular branchiae were destroyed, and spines were devoid of membrane covering.

At the end of the experiment the tank was emptied and the condition of starfish noted (table 1). Of the original 20 starfish, 10 were dead and decomposed (pl. 1, upper). All these animals had large lesions on their aboral surfaces which were inflicted by particles of lime imbedded in the membranes. The 10 starfish which survived were either slightly affected or not affected at all. The slightly affected animals had only a few small lesions on their aboral surfaces, the extent of injury depending upon the number and size of lime particles which had touched them. In some cases the ends of the rays and lower surfaces of the starfish were burned (pl. 1, lower). Apparently these starfish came in contact with the lime while crawling on the bottom. The healthy animals which were not hit by falling bits of lime crawled up the walls of the tank soon after the beginning of the experiment and remained there throughout its duration, thereby avoiding contact with the chemical.

The temperature of the water in the tank during the experiment was near 2.0° C. Before the addition of lime the pH of the water was 8.0. After the addition of lime it rose to 8.2 and remained at that level for 24 hours, after which it decreased to 8.0.

From the above-described experiment it can be concluded that only those starfish that came in contact with the lime were affected. A coarse grade of lime, when used at a concentration of 840 pounds per

[1] Lime used in most of the experiments was furnished through the courtesy of the New Brunswick Laboratories, Inc., New York City. When delivered, it contained about 93 percent of available calcium oxide.

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acre, did not cover the bottom evenly, permitting many starfish to escape. All starfish injured in the experiments were affected by particles of lime falling on their aboral surfaces or by coming in contact with the lumps lying on the bottom. The change in pH produced by adding a large quantity of lime to the water was not radical enough to create conditions which would kill starfish.

Simultaneously, a similar experiment was conducted in an adjacent tank in which granulated lime was used. After placing 20 starfish in the tank, the lime was spread over the surface of the water at a concentration of 840 pounds per acre. The particles of lime covered the entire bottom of the tank, and therefore fell on every starfish. Examination of starfish 24 hours after the beginning of the experiment showed many small fragments of lime imbedded in their aboral surfaces, causing disintegration of the membrane. Numerous small wounds were already visible. On the oral surfaces all the structures, including the tube feet, were seriously injured by crawling over the lime. The tube feet were abnormally slimy and their epidermal covering was disintegrating and peeling off. A few individuals had moved a short distance, but the majority remained in the same position as at the beginning of the experiment.

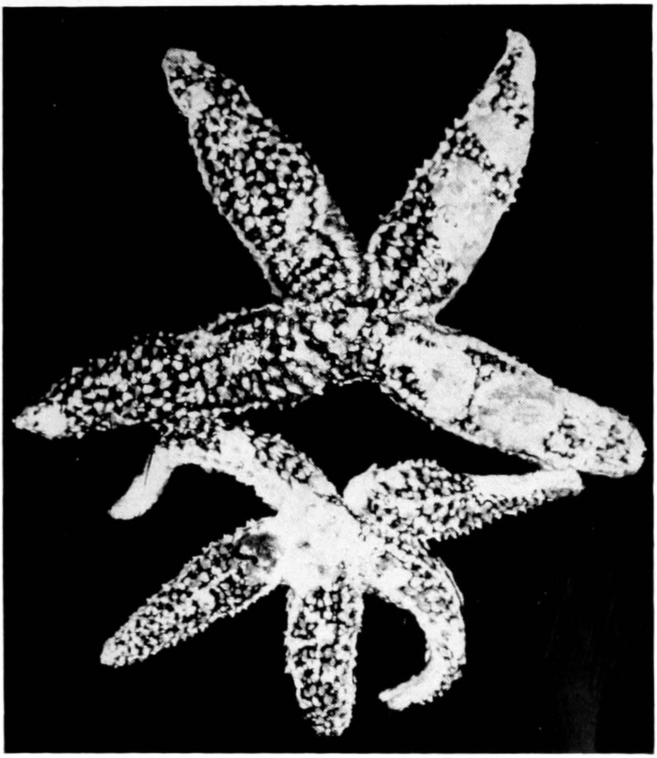
TABLE 1.—*Effect of lime upon starfish; number and day of death*

[20 starfish were used in each experiment]

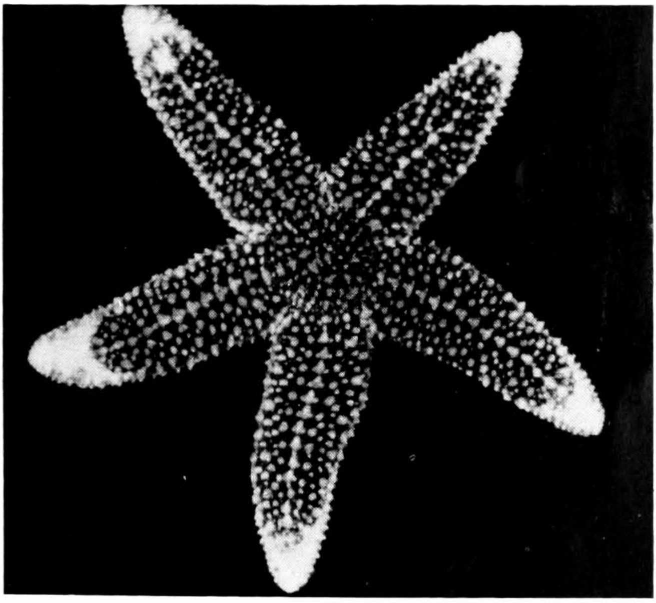
Concentration (pounds per acre) and grade of lime	Condition of test specimens								
	First day	Second day	Third day	Fourth day	Fifth day	Sixth day	Eighth day	Tenth day	Twelfth day
840 pounds [1]					2	1	2	4	1
840 pounds [2]	(3)	(4)	6	7	3	4			
560 pounds [2]	(3)	(4)	3	4	10	2	1		
280 pounds [2]	(3)	(4)	1	2	9	8			
Control	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)	(5)

[1] Coarse. [2] Granulated. [3] All injured. [4] Many disintegrating. [5] Alive

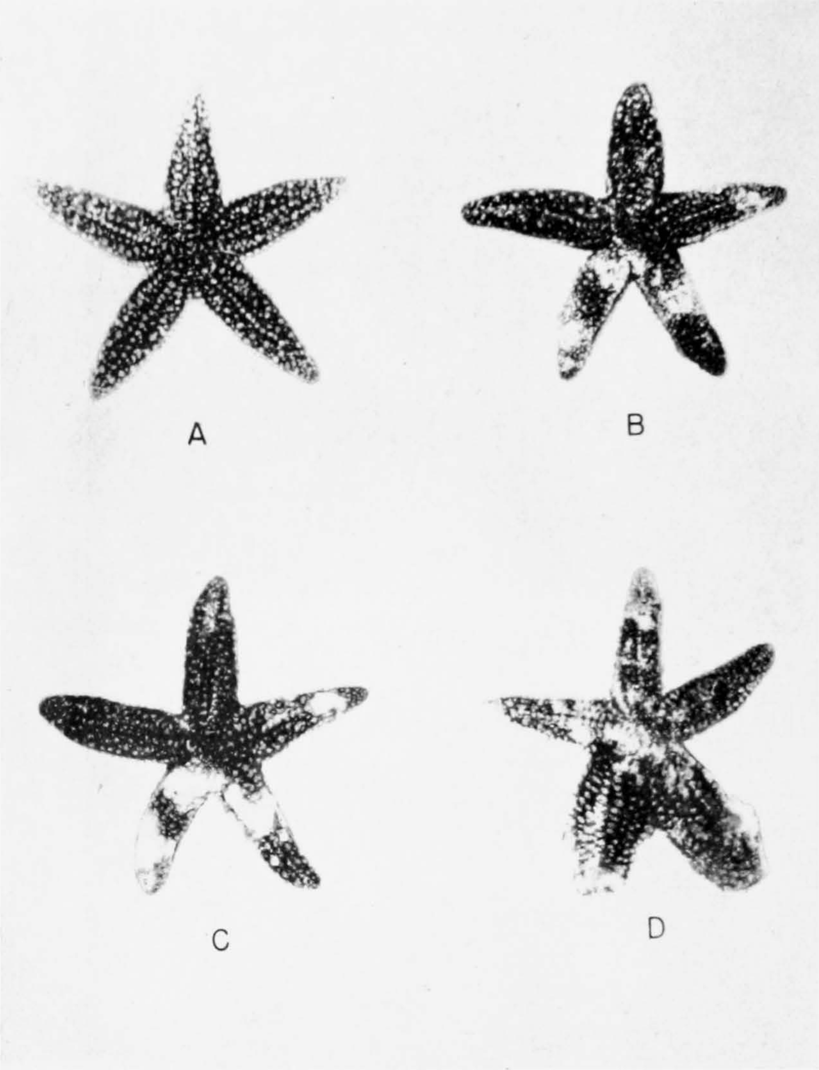
At the end of the second day the color of the starfish had changed to pale red, resembling that of a cooked lobster, and the aboral surfaces showed many destroyed pedicellariae and branchiae. The ambulacral grooves and spines on the oral surfaces were covered with white spots caused by contact with the lime. The tube feet were severely burned. Many animals began to disintegrate while still alive, and disintegration progressed still further the next day (pl. 2). At the end of 5 days 16 starfish had disintegrated completely and died, while the 4 others died on the sixth day. This experiment demonstrated that finely granulated lime covered the bottom more evenly than the coarse grade and was, therefore, more effective in exterminating starfish.



Starfish in advanced stages of disintegration, showing aboral surfaces affected by lime. Note large wounds penetrating the body walls and exposing internal organs.



Starfish with tips of rays affected by crawling over lime-covered bottom.



Effect of granulated lime on a starfish. A, normal animal; B, immediately after being touched with lime particles; C, same animal 1 day later; D, same animal (3 days after beginning of experiment) in advanced stage of disintegration.

The water temperature in the tank during this experiment was near 2.0° C. Before the addition of lime the pH of the water was 8.1 and it rose to 8.5 after the addition. A day later it decreased to 8.3, as compared with 7.9 of the control tank. Two days later the pH of the water in the experimental tank decreased to 7.9.

The experiments outlined above were repeated several times, and the results were similar to those described.

Having established the fact that lime will kill starfish, and that under the conditions of the experiment granulated lime is more efficient than coarse, a series of experiments was run to determine the minimum quantity of lime necessary to kill starfish.

Several experiments in which the lime concentration corresponded to 2 barrels (560 pounds) per acre gave results essentially the same as in the experiments in which 3 barrels per acre were used (table 1).

In the next series of experiments a concentration equal to 1 barrel per acre was employed (table 1). Twenty starfish were placed on the bottom of the tank and lime was spread evenly over the entire water surface. Examination of the starfish 24 hours after the beginning of the experiment showed that all animals were hit by particles of lime. Their aboral surfaces were badly burned, but they were still alive. At the end of the second day the starfish began to disintegrate. One animal died during the third day. After 5 days 12 starfish were dead and the others were either near death or seriously injured and partially disintegrating. When the tank was emptied 3 days later all starfish were decomposed. This experiment demonstrated that even as light a concentration as 280 pounds per acre is very effective, provided the lime is uniformly distributed over the entire area of the infested bottom.

A number of check-ups on these experiments were conducted in the laboratory, using aquaria of 15-gallon capacity. Quantities corresponding to 1, 2, and 3 barrels per acre of finely granulated lime were tried. In all these tests the starfish were quickly killed. Even when the lightest concentration was employed starfish began to disintegrate within 24 hours, and were dead by the third day.

The rapid disintegration and death of starfish in the aquaria experiments can be attributed to the two following factors: First, because the lime was very evenly distributed over the bottoms of the aquaria, all starfish were covered with the chemical; and second, the water temperature in the aquaria was near 20.0° C., and the process of disintegration of starfish progressed more rapidly than in the outside experimental tanks where a much lower temperature prevailed.

As previously mentioned, the experiments performed indicate that the contact of lime with the surface of the starfish's body was necessary to cause injury. It appeared that lime in solution was virtually harmless to starfish. To solve this question definitely, new experiments were devised and conducted under laboratory conditions. Five starfish were placed on the bottom of an aquarium and immediately covered with powdered lime at a concentration of 1 barrel per acre. As soon as the lime settled on the bottom another group of starfish, confined in a wire cage, was placed in the aquarium. The cage was suspended in the water about 3 inches from the bottom. In this way the caged animals, while exposed to lime in solution, were kept from direct contact with the solid particles.

Examination of the starfish 24 hours after the beginning of the experiment revealed that all those on the bottom of the aquarium and in contact with lime were badly affected, whereas those in the cage were healthy and normal in appearance. At the end of 48 hours, the starfish on the bottom of the tank showed signs of disintegration. They all died between the fourth and fifth days after the beginning of the experiment. The caged animals, on the other hand, were healthy and feeding upon seed oysters placed in the cage. In a final examination made 1 week after the beginning of the experiment the caged animals showed no ill effects from the treatment.

The water temperature during the experiment fluctuated from 17.5 to 20.0° C. Before the addition of lime the pH of the water was 7.9. It rose to 8.5 after lime was added and remained at this point for 2 days, dropping to 8.3 after 5 days.

Several other experiments of a similar nature were conducted and gave virtually the same results. In one of these experiments starfish were exposed to a lime solution for a period of 20 days and came out alive, though somewhat weakened. It may be concluded that a strong lime solution does not kill starfish exposed to it, even if the period of exposure is as long as 20 days. It is apparent, therefore, that the method of combating starfish with lime will be effective only if there is an actual contact between the particles of lime and the body of the starfish.

To learn how long the lime retains its efficacy in the water, the following experiments were performed: Quicklime at a concentration of 3 barrels per acre was placed in the tank on Dec. 17, 1937, and left there until Dec. 28. The chemical was quite evenly distributed on the bottom. Of course, the lime was soon changed into slaked lime, or calcium hydroxide. The water in the tank was partly renewed at each high tide. During the experiment a thin layer of organic deposit was formed over the layer of lime. At the end of the 11-day period the tank was carefully drained without losing any lime, and then refilled on the next high tide. The old lime was agitated to distribute it evenly over the bottom of the tank. After it had settled, 25 starfish were placed in the center of the tank.

The first examination of these starfish was made on Jan. 1, 1938, 4 days after the beginning of the experiment. All starfish were still alive but showed slight injuries, especially on their oral surfaces. The second examination, conducted 2 days later, revealed that 2 starfish were seriously injured. On Jan. 5, 8 days after the beginning of the experiment, 6 starfish were dead. Two more starfish died within the next 2 days, and all starfish were dead at the end of 18 days.

During this experiment the temperature of the water in the tank was between 0.0° and 2.0° C. At times a thin layer of ice formed on the surface of the water.

This experiment showed that granulated lime retains its effectiveness after being in the water 11 days. However, its action is weaker than that of unslaked lime.

A similar experiment was conducted using a coarse grade of lime. After being in the water for several days the lime was agitated and the large lumps were broken into small pieces to cover the bottom of the tank. The results of this experiment were substantially the same as when granulated lime was used, although the coarse lime was found to retain its effectiveness somewhat longer than the finer material. In both experiments the injuries to starfish were confined largely to the oral surface.

In another experiment the lime was retained in the tank for a period of 25 days. At the end of this period the lime was stirred, and while it was still in suspension 20 starfish were placed in the tank. This step was taken in order to determine the effect of old lime on the oral surface of starfish, as was done in the two previous experiments, and also on the aboral surface. The temperature during the experiment was near the freezing point and the pH was between 7.9 and 8.0, the same as the control tank. Starfish examined 4 days after the beginning of this experiment were alive, but showed small lesions on their oral and aboral surfaces. Gradually the wounds increased in size, and after 2 weeks many starfish were in advanced stages of disintegration. The first few starfish died after several days. At the end of 30 days the tank was emptied and starfish examined. Of the 20 animals, 11 were dead and decomposed, and most of the remaining 9 were seriously affected and near death. This experiment demonstrated that lime kept in the water for 25 days was still injurious to starfish, in some instances causing their death.

That a thin layer of lime putty spread on the bottom upon which starfish are crawling may injure them was ascertained under several laboratory conditions. Almost immediately after coming into contact with the putty the starfish displayed pronounced signs of distress. They attempted to elevate themselves on the tips of their rays but soon tipped over, began to bleed profusely, and died within 3 or 4 days.

In another series of experiments small quantities of putty were smeared on the aboral surfaces of starfish, and the animals were immediately returned to tanks filled with untreated sea water. Examination of starfish 24 hours later showed that the areas of their bodies touched with putty were slowly disintegrating, exposing the internal organs.

A suspension of hydrated lime poured over the surface of the water-filled tank can also be used in killing starfish. It was found that under this condition the particles of lime slowly settle down, covering the starfish with a thin layer. The majority of the starfish thus treated died within a few days.

According to the results obtained from the above experiments, hydrated lime will injure starfish if it comes in contact with them. Apparently the caustic action of the hydroxide is strong enough to produce a wound and cause disintegration of the affected tissues and adjacent parts of the body.

FIELD EXPERIMENTS

Field experiments in starfish eradication on natural oyster beds of Long Island Sound were carried on during the spring of 1938. Unfortunately no proper equipment for uniform spreading of lime was available at that time. The lime was either shoveled, or washed overboard with a strong jet of water. In this way the distribution of lime over the areas treated was far from uniform. Another difficulty in using such primitive methods was that tidal currents carried the lime particles quite a distance away before they reached the bottom. This was overcome in some instances by spreading lime during slack-water stages. However, because slack water in Long Island Sound is of short duration, this practice could be followed only when small areas were treated. Regardless of adverse conditions, however, all field experiments revealed that by using lime starfish can be successfully attacked.

In the first series of experiments 2 lots, A and B, each 1 acre in area and located 500 feet apart, were chosen. These lots constitute a part of the Stratford natural oyster bed, located in 25 feet of water. On Mar. 11, 1938, 840 pounds of granulated lime were spread on lot A, and the same quantity of coarse material was deposited on lot B.

Samples of starfish collected the day after treatment (table 2) showed that although many animals of both lots were affected, their wounds were still very small and difficult to see. The animals were rigid and comparatively healthy. Seven days after the treatment 58 percent of starfish retrieved from lot A, and 84 percent from lot B were found to be affected. By that time the lesions were large, covering the greater part of the aboral surface. The wounds penetrated the body walls, and the internal organs of many protruded. Many starfish were dying or were already dead. Samples collected 13 days after the treatment showed 78 percent of animals from lot A, and 71 percent from lot B affected. Again the majority of animals were badly wounded, many of them disintegrating and dying. On the eighteenth day after the treatment 50 and 52 percent of starfish with wounds were found at lots A and B, respectively. However, the majority of animals had only small wounds. Apparently the starfish that were seriously affected had already died, and thereafter a further decrease in the percentage of injured animals was noted. This was due partly to the invasion by new starfish from the adjacent untreated grounds, to the death of some of the wounded animals, and, also, to recovery of the slightly injured animals. Starfish with scars caused by contact with lime were found as late as May 10, 2 months after the lime was used.

TABLE 2.—*Temperature and pH of water, and numbers and percentage of affected starfish on lots A and B, Stratford natural bed, treated on Mar. 11, 1938, with 840 pounds of lime per acre*

[Granulated lime was used on lot A, and a coarse grade of lime on lot B]

Date	Temp. °C.	pH	Lot A			
			Number examined	Number affected	Number not affected	Percent affected
Mar. 11	1.4	[1] 8.3				
11	1.4	[2] 8.5				
12	1.5	8.3	32	16	16	50
18	2.4	8.3	26	15	11	58
24	3.3	8.3	23	18	5	78
29	3.6	8.3	48	24	24	50
Apr. 6	3.8	8.3	50	21	29	42
16	6.1	8.2	45	11	34	24
26	8.3	8.1	69	15	54	22
May 10	11.9	8.3	40	6	34	15

Date	Temp. °C.	pH	Lot B			
			Number examined	Number affected	Number not affected	Percent affected
Mar. 11	1.4	[1] 8.3				
11	1.4	[2] 8.5				
12	1.5	8.3	13	5	8	38
18	2.4	8.3	13	11	2	84
24	3.3	8.3	35	25	10	71
29	3.6	8.3	52	27	25	52
Apr. 6	3.8	8.3	85	22	63	26
16	6.1	8.2	52	16	36	31
26	8.3	8.1	40	6	34	15
May 10	11.9	8.3	39	8	31	21

[1] Before addition of lime. [2] Fifteen minutes after addition of lime.

The results of the experiment are somewhat different from those carried on under laboratory conditions in that the treatment with a coarse grade of lime affected about the same percentage of starfish as did granulated lime. This discrepancy can be explained by the fact that under the conditions of the test a large quantity of fine particles were carried far away by the tide before they reached the bottom.

Thus, much lime intended for lot A was lost. On the other hand, coarse particles of lime used for lot B sank rapidly to the bottom, causing a much heavier concentration than that obtained on lot A.

Another experiment in this series was begun on Mar. 14, 1938, near Charles Island. Two widely separated lots, each 1 acre in area and located at a depth of about 18 feet, were treated with lime. Lot C received 840 pounds, and lot D 280 pounds of granulated lime. In treating these 2 lots extreme care was taken to distribute the chemical as uniformly as possible. To make sure that the lime would not be carried away by the currents while sinking to the bottom, the treatment was conducted during slack-water period. Samples collected 10 days after the treatment showed that 88 percent of starfish from lot C, and 74 percent from lot D, were affected (table 3). It should be borne in mind, however, that by the time the examination was made many starfish from adjacent untreated areas had crawled over to the experimental lots. Their presence in the collected samples undoubtedly decreased the percentage of affected starfish.

TABLE 3.—*Temperature and pH of water, and numbers and percentage of affected starfish on lots C and D, treated with granulated lime on Mar. 14, 1938*

[Lot C received 840 and lot D 280 pounds of lime per acre]

Date	Temp. ° C.	pH	Lot C			
			Number examined	Number affected	Number not affected	Percent affected
Mar. 14	2.0	[1] 8.3				
14	2.0	[2] 8.5				
18	2.5	8.3	8	6	2	75
24	3.3	8.3	8	7	1	88
29	3.6	8.3	15	12	3	80
Apr. 6	3.9	8.3	16	3	13	19
16	6.8	8.3	6	6	0	100
19	7.4	8.1	18	4	14	22

Date	Temp. ° C.	pH	Lot D			
			Number examined	Number affected	Number not affected	Percent affected
Mar. 14	2.0	[1] 8.3				
14	2.0	[2] 8.5				
18	2.5	8.3	6	4	2	67
24	3.3	8.3	23	17	6	74
29	3.6	8.3	11	4	7	36
Apr. 6	3.9	8.3	20	3	17	15
16	6.8	8.3	5	2	3	40
19	7.4	8.1	20	4	16	20

[1] Before addition of lime. [2] After addition of lime.

The third test in this series was conducted on a much larger scale on seed-oyster grounds located in New Haven Harbor. On Mar. 22, 1938, 3 oyster lots were treated with granulated lime. Lot No. 1, comprising an area of 25 acres, located at a depth of approximately

17 feet, received 320 pounds of lime per acre. Lot No. 2, of the same size as the first lot, and located at approximately the same depth, received 480 pounds of lime per acre. Lot No. 3, 15 acres in area, located in 25 feet of water, was treated with 640 pounds of lime per acre. The lime was applied by forcing it overboard with a strong stream of water. Because of limited time, the work of spreading the lime had to be carried on regardless of direction and velocity of tidal currents. Much of the lime, therefore, was carried by the currents beyond the areas intended for treatment.

TABLE 4.—*Temperature and pH of water, and numbers and percentage of affected starfish on lots 1, 2, 3, New Haven Harbor, treated with granulated lime on Mar. 22, 1938*

Date	Temp. ° C.	pH	Number examined	Number affected	Number not affected	Percent affected
			Lot 1, depth 17 feet, 320 pounds of lime per acre			
Mar. 22	3.6	8.3	----	----	----	----
29	3.8	8.3	178	103	75	58
Apr. 1	4.4	8.3	180	89	91	49
5	5.3	8.3	98	46	52	47
12	5.1	8.3	169	60	109	36
19	7.8	8.2	12	4	8	33
26	9.1	8.2	6	2	4	33
May 3	11.3	8.3	6	0	6	0
10	10.9	8.3	12	3	9	25
			Lot 2, depth 17 feet, 480 pounds of lime per acre			
Mar. 22	3.5	8.3	----	----	----	----
25	2.6	8.1	26	20	6	77
29	3.9	8.2	168	133	35	79
Apr. 1	4.5	8.3	146	100	46	68
5	5.5	8.3	149	69	80	46
6	----	----	113	91	22	81
12	5.1	8.3	146	84	62	58
19	7.8	8.2	69	36	33	52
26	9.2	8.3	98	58	40	59
May 3	11.2	8.3	15	8	7	53
10	11.0	8.3	24	14	10	58
			Lot 3, depth 25 feet, 640 pounds of lime per acre			
Mar. 22	2.7	8.3	----	----	----	----
25	3.2	8.3	115	75	40	65
29	3.8	8.3	72	46	26	64
Apr. 1	4.8	8.3	142	51	91	36
5	5.3	8.3	66	27	39	41
12	5.0	8.4	215	92	123	43
19	7.0	8.3	3	1	2	33

After the treatment all three lots were visited frequently, and samples of starfish were collected and the number of injured animals noted (table 4). The best results were observed at lot No. 2, where, in some samples, the percentage of affected starfish was as high as 81. Lot No. 3 was second best, with 33 to 65 percent of the starfish affected.

The percentage of starfish affected at lot No. 1 reached 58 in some samples.

Seriously affected starfish died within a few days after the treatment. Less seriously wounded animals could be found on the beds for a long time after the treatment. In some cases healing of wounds was observed. Experiments performed on Charles Island beds showed that even a small quantity (280 pounds per acre) of lime, if spread uniformly and under the proper tidal conditions, will destroy the majority of starfish present. On the basis of these and other field experiments it was concluded that lime is an effective agent for the eradication of starfish on natural oyster bottoms. The efficiency of the treatment undoubtedly depends upon the uniformity of distribution of the chemical over the bottom, and upon the quantities used.

Field studies of the authors were corroborated by several oyster-growing concerns. Joseph B. Glancy, of Bluepoints Company, Inc., West Sayville, Long Island, N. Y., in a letter to the authors, stated that the results obtained by him were distinctly encouraging. An oyster bed of about 40 acres in area, located in Huntington Bay, N. Y., was treated on Apr. 8, 1938. The depth of water over the bed varied from 10 to 40 feet. At the time the lime was applied, the bed had over 15,000 bushels of oysters ranging from 2 to 4 years of age. Prior to the application of lime, starfish were very numerous, comprising about one bushel out of every 25 bushels of material dredged from the bottom.

In treating the bed, 480 pounds of lime per acre were spread on the surface of the water. One week later 90 percent of the starfish captured were found to be affected, and many starfish, especially the larger ones, were disintegrating. Such results were apparent over the entire bed. The oysters and other bottom forms apparently remained unharmed and the mortality of oysters due to starfish activity had almost ceased. The second examination of the bed, 17 days after the application of lime, showed that the number of starfish had significantly diminished; only about 20 percent of the original population remaining. About 1 year after the lime treatment the oysters were dredged and marketed. According to Glancy, their meats were in excellent condition.

EFFECT OF LIME ON ANIMALS OTHER THAN STARFISH

The question naturally arises as to how lime used in large quantities on starfish-infested bottoms will affect other animals. Since oysters and other shellfishes constitute the most important branches of commercial fisheries in Long Island Sound, attention was directed mainly upon these animals, with a few additional observations on other forms.

SURVIVAL AND GROWTH OF OYSTERS

As a rule, in all laboratory and tank experiments with lime, marine forms, including oysters, were kept under the same conditions as the starfish. No unusually high mortality among oysters was noted during any of the experiments, nor after the experiments were concluded and the oysters were returned to a normal environment. In the field, oysters dredged from bottoms treated with lime always appeared healthy. Apparently the addition of lime in the quantities employed in our experiments did not cause serious injuries. However, to obtain some definite information on the survival of oysters when exposed to the effects of lime, and also on their growth, weight increase, rate at which water is pumped, and other physiological activities, several experiments were performed.

On May 16, 1938, 100 normal oysters about 3 years old were individually marked, measured, and weighed. The animals were divided into two groups of 50 individuals, and each group was placed in a separate outdoor tide-filled tank of several thousand gallons capacity. The water in the tanks was partly renewed at each high tide. During low tides the oysters in the tanks were covered by about 3 feet of water. At the beginning of the experiment, lime at a concentration of 5 barrels, or 1,400 pounds, per acre was added to the experimental tank. Each month throughout the experiment a new dose of lime was thrown in the tank. Such an excessive quantity of lime was used as to create a concentration greater than would probably ever be employed on the oyster beds. Unfavorable conditions in the tank were further aggravated by depriving the oysters of the beneficial effects of the rapidly running tide, which on the natural beds would soon dilute the solution of lime to a negligible concentration. Thus the animals in the experimental tank were subjected to much more severe conditions than they would be in open water treated with the same concentration of lime. Except for the addition of lime, the conditions in the experimental and control tanks were identical.

The experiment was continued from May 16 until Nov. 1, 1938. Every month all animals were measured and weighed. At the beginning of the experiment the average maximum length of animals in the lime tank was 72.17 mm., as compared with 73.10 mm. for those in the control tank, showing a difference of 0.93 mm. in favor of the control group (fig. 2). At the end of the experiment, 5½ months later, the average maximum length of lime-treated animals was 83.66 mm., whereas that of the control was 86.10 mm., or 2.44 mm. more. Thus, in this experiment the control animals showed a slightly better growth than the group subjected to lime treatment. It should be emphasized, however, that regardless of abnormal conditions existing in the lime tank, the growth of the oysters kept there was neither stunted nor considerably retarded. This is shown by the fact that the average maximum length of these animals increased during the experiment from 72.17 to 83.66 mm., or 11.49 mm. In the same time the control group showed an increase from 73.10 to 86.10 mm., or 13.00 mm. During a 5½-month period the lime-treated animals grew on an average only 1.51 mm. less than animals kept under normal conditions. The new shell growth of lime-treated oysters appeared normal and undistinguishable from that of control animals.

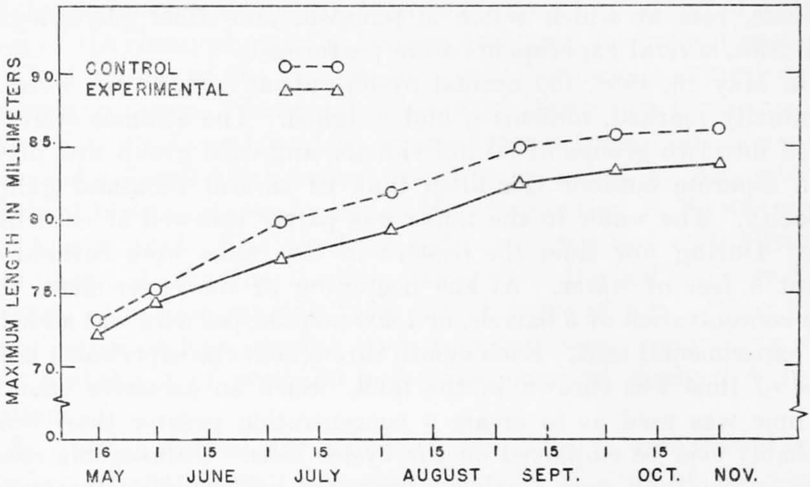


FIGURE 2.—Increase in size of lime-treated and control oysters. May 16 to Nov. 1, 1938.

Studies of changes in the weight of the two groups of oysters showed that the average total weight of lime-treated animals changed during the time of the experiment from 67.10 to 100.47 g., an increase of 33.37 g. (fig. 3). The average weight of the control animals increased during the same period from 69.24 to 112.91 g., giving an increase of 43.57 g.; or 10.30 g. greater than for the experimental group. Such a difference is quite significant, showing that conditions existing in the lime-treated tank interfered with the normal increase in weight of the oysters.

More detailed studies of changes in the size and weight of the two groups of oysters showed that the difference between the lime-treated and control animals became more pronounced as the experiment progressed (figs. 2 and 3). This can be attributed either to the cumulative effect of lime on the oysters themselves, or to the fact that the large quantities of lime always present in the experimental tank decreased the numbers of microscopic organisms normally present in the water, thereby depriving the oysters of their normal quota of food. During the experiment 2 oysters in the control tank, and 4 in the lime-treated tank, died.

At the end of the experiment all surviving oysters were killed and their meats and shells weighed. The average weight of the meat of lime-treated animals was 10.69 g., and that of their shells 78.9 g. Control animals gave 13.96 and 85.8 g. for meats and shells, respectively. For the lime-treated group the weight of meat constituted 10.6 percent, and the weight of shell 78.3 percent of the total weight. In the control group these percentages were 12.4 and 75.9.

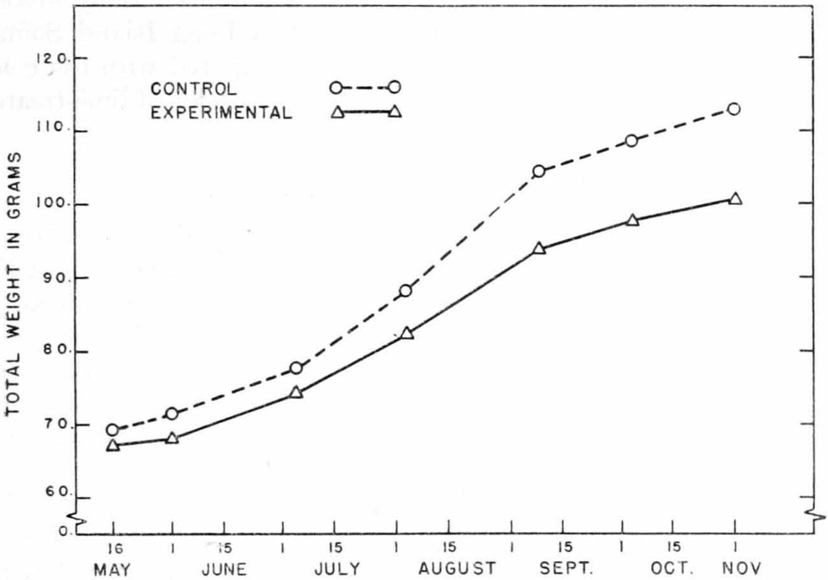


FIGURE 3.—Increase in weight of lime-treated and control oysters. May 16 to Nov. 1, 1938.

To summarize the above-described experiment, it may be stated that the majority of oysters subjected to a very strong concentration of lime for a period of 5½ months survived the treatment, but their growth and increase in weight was somewhat retarded. It should be remembered, however, that the concentration of lime in the tank was much greater than that to be expected on natural beds. Furthermore, such a strong concentration of lime persisted in the tank for months, whereas in a large open body of water a strong concentration could persist for only a few minutes because the tidal currents would soon dilute it. It is apparent, therefore, that the use of moderate quantities of lime in combating starfish cannot endanger the oysters on the treated area.

The experiment just described brought to light another fact which is of interest to commercial oystermen. It has been claimed that if green oysters, which are very common in Long Island Sound, are treated with lime simply by spreading it over the oyster bottom, they will lose their greenness and acquire a normal creamy color. Our experiments have shown that such statements cannot be supported. Oysters used in our experiments were brought from Stratford natural beds, known for its green oysters. After being kept in the tank containing lime for 5½ months, oysters were opened and their color noted. Of 46 animals examined, 27 were very green. Among the control group 25 showed green color. It is clear, therefore, that the spreading of lime upon the bottom will not whiten green oysters. This conclusion is also corroborated by our field observations. Many oysters collected at regular intervals from the beds of Long Island Sound, after treatment with lime, were green. As compared with the color of oysters of adjacent beds, the intensity of green color of lime-treated oysters was not altered.

SHELL MOVEMENT AND FEEDING OF OYSTERS

Hopkins (1932) has shown that oysters are highly sensitive to chemical changes occurring in the water. Sometimes, because of the presence of foreign substances, the number of hours the oyster keeps its shells open is reduced, and the water-pumping capacity and hence the rate of feeding are significantly decreased (Baltsoff et al. 1938). Because the new method of starfish eradication would require comparatively large quantities of lime to be introduced into the water, a possibility existed that this would seriously interfere with the normal physiological functions of oysters living on the treated beds. To establish definitely what effect the lime solutions would have upon the shell movements, feeding, and respiration of oysters, the following experiments were performed at Milford Laboratory.

Oysters used in these experiments were subjected to various concentrations of lime in sea water. The animals were mounted on small cement blocks. Their right shell valves were connected by a string to kymograph levers, which, in turn, recorded every movement of the shell on the kymograph drum.

To study the effect of solutions of lime upon feeding activities of oysters, a combination of the apron method described by Nelson (1936) and modifications of Galtsoff's constant-level-tank device were used. With such an arrangement it was possible to obtain a continuous record of the quantities of water pumped by the oysters.

To determine the normal behavior of experimental animals they were kept for long periods in running sea water before being subjected to the lime solution (table 5). To observe the recovery of oysters after their exposure to lime they were again returned to running sea water and their shell movements and other activities noted and recorded. A second group of oysters, designated as the control, was kept under conditions virtually identical to those of the experimental animals, except that no lime was added to the water.

Experimental oysters were subjected to a running saturated lime solution, to a running solution composed of 1 part of saturated lime solution and 1 part of sea water, and to a running solution of 1 part of saturated lime solution in 3 parts of sea water. Results of the experiments are summarized in table 5. Data for each of the first two concentrations represent the average of two observations. The averages for the 1:3 concentration are based upon 4 experiments.

TABLE 5.—*The effect of lime solution upon the shell movements and the quantities of water pumped by oysters*

Conditions	Duration of experiment	Average			
		Percent of time open	Water filtered, cc. per hour	pH	Temp. °C.
1. In sea water, before treatment	55 hrs. 15 min	97.5	98.8	8.1	14.5
2. In saturated lime solution	105 hrs. 10 min	18.0	6.9	9.5	16.2
3. Recovery in sea water	35 hrs	95.5	200.2	8.1	14.9
Control: 1. Sea water	43 hrs. 25 min	98.4	123.0	8.2	13.4
Control: 2. Sea water	101 hrs. 35 min	80.4	119.8	8.2	14.2
Control: 3. Sea water	48 hrs. 8 min	60.6	53.9	8.1	14.1
1. In sea water, before treatment	18 hrs. 46 min	92.5	1173.0	8.1	15.6
2. In 1 part saturated lime solution, 1 part sea water.	92 hrs. 43 min	79.5	367.0	8.8	15.3
3. Recovery in sea water	24 hrs. 17 min	68.0	1190.6	8.1	14.6
Control: 1. Sea water	17 hrs. 33 min	86.8	714.9	8.2	15.7
Control: 2. Sea water	91 hrs. 43 min	93.7	1003.4	8.1	14.4
Control: 3. Sea water	24 hrs. 15 min	81.9	654.2	8.1	14.8
1. In sea water, before treatment	59 hrs. 4 min	92.7	1355.7	8.1	15.0
2. In 1 part saturated lime solution, 3 parts sea water.	215 hrs. 41 min	82.1	1385.5	8.6	15.6
3. Recovery in sea water	109 hrs. 49 min	79.5	2019.8	8.1	15.3
Control: 1. Sea water	51 hrs. 56 min	92.4	1305.8	8.0	15.2
Control: 2. Sea water	216 hrs. 42 min	85.5	2048.4	8.2	15.4
Control: 3. Sea water	105 hrs. 17 min	71.5	2276.0	8.1	15.5

Oysters exposed to a saturated solution of lime kept their shells closed for a longer time and pumped much less water than before treatment. Whereas, before the treatment the oysters remained open 97.5 percent of the total time, during the treatment they were open only 18 percent. The average rate of pumping decreased from 98.8 cc. per hour before the treatment to 6.9 cc. during exposure to the concentrated lime solution.

Oysters exposed to the mixture of 1 part of lime water and 1 part of sea water remained open 79.5 percent of total time, as compared with 92.5 percent before exposure. Such a difference can hardly be considered as significant, because in the control experiment the percentage of time the shells remained open varied from 81.9 to 93.7, or about as much as in the case of lime-treated animals. Significant, however, was the observation that the average hourly quantities of water pumped by the oysters decreased from 1,173 cc. before the treatment to 367 cc. during exposure. A marked reduction in pumping activities was thus still evident.

In a concentration of 1 part of saturated lime solution to 3 parts of sea water, the oysters kept their shells open 82.1 percent of total time. This compared favorably with the observations on control animals which were open for about the same percentage of time (table 5). During exposure to the chemical, the rate of water filtration by oysters was somewhat greater than during the period before the treatment. This indicated that the ciliary activities of oysters were not depressed when the animals were exposed to a 1:3 dilution of lime water.

Generally, a quick and rather marked recovery of ciliary action was noted as soon as solutions of lime were substituted with the flow of fresh sea water. In the first series of experiments, where concentrated solutions of lime were used, the average quantities of water passed by oysters during the recovery period were more than twice greater than before the beginning of the treatment. In the second series there was also a marked increase in the rate of flow immediately after the treatment, being even slightly greater than before the oysters were subjected to the effect of the chemical. These observations suggest the attempt of oysters to cleanse themselves from the effect of the chemical. Increase in water flow produced by the oysters after exposure to lime solutions was also observed in the last series of experiments. There, however, the increase was not proportionally as large as in the two previous experiments.

As previously stated, a marked decrease in the time oysters remained open was noted as soon as they were exposed to a concentrated lime solution (table 5). Soon after the solution was replaced with running sea water, however, the shell movements of the oysters became normal. There was no definite change noted in the type of shell activity before and after exposure to the chemical. Similar observations were made in two other series of experiments where weaker concentrations of lime were used. The only exception noted in the latter cases was that during the recovery period the percentage of time the oysters remained open was somewhat smaller than before the treatment, or even during exposure period (table 5). These observations are not significant, however, because a corresponding reduction in the percentage of time open was noted in case of control animals.

The water temperature during experiments ranged from 13.0° to 16.5° C. Usually the difference in temperature of lime solution and sea water flowing over the control animals did not exceed 1 or 2 degrees, and the salinity of the water was maintained near 25 parts per mille. The pH of the sea water ranged from 8.0 to 8.25. In a saturated lime solution the pH rose to 9.5. In the second series of experiments the pH of lime water ranged between 8.7 and 8.8, while the pH of the weakest lime solution used was near 8.6 (table 5).

After the end of laboratory experiments all oysters exposed to lime solutions were transferred to large outdoor tanks for further observations. Fourteen months later many animals were still alive.

The physiological experiments described above demonstrated the relative safety of oysters inhabiting lime-treated areas. They showed that oysters exposed for long periods to such strong concentrations as 1 part saturated lime solution to 3 parts sea water behaved normally and displayed no ill effects. Oysters exposed to a saturated lime solution for several days survived and were alive 14 months after the end of the experiment. It should be remembered that in actual practice the strong concentrations of lime solutions used in our experiments will never exist in open water for any appreciable time. Therefore, the lime method for the extermination of starfish can be regarded as safe for oysters.

GONAD DEVELOPMENT AND SPAWNING

The effect of lime on gonad development and spawning of oysters was studied by keeping adult oysters in a tank to which large quantities of lime were added. This experiment was conducted in the same tanks used in the experiments on growth and survival of oysters subjected to lime, and was run simultaneously. Half a bushel of oysters was placed in each of the tanks on May 16, 1938. From then on, at biweekly intervals, a sample of 6 oysters was taken from each tank for histological examination of gonads. Throughout the experiment no difference between the control and lime-treated animals could be detected. In both cases gonad development proceeded normally. Both groups of oysters began spawning at approximately the same time.

SETTING OF OYSTERS ON LIME-COVERED BOTTOMS

To determine whether the oyster larvae would set on lime-covered bottoms, the following experiment was performed in July 1938. Ten bushels of oyster shells were spread on each of 2 lots, 150 square feet in area, located near mean low-water mark in Milford Harbor and separated from each other by a distance of about 10 feet. On top of the shells wire-bag spat collectors were placed. One of the lots was covered with enough lime to form a thick layer over the entire area. The other lot, designated as a control, was not treated. Lime was spread on the experimental lot during low tide, when the lot was exposed. Our observations showed that no lime had been carried by the currents onto the control lot.

The first setting of oysters took place on July 29, 3 weeks after the lime was put over the shells. At the end of the setting period, on August 16, 50 shells were collected at random from each lot, and 25 shells from each of the wire-bag spat collectors. These shells were examined and the number of set attached to them were counted. There were 144 spat found on 50 loose shells from the lime-covered lot, as compared with 324 spat attached to the same number of shells gathered from the control lot. Thus, the set on the untreated shells was more than twice that on treated areas. However, the number of spat on 25 shells taken from the wire-bag spat collector that came from the lime-covered lot was 74, whereas the number of spat from 25 shells of the control bag was 61, or 13 less.

The considerably smaller number of oyster spat found on the loose shells of the lime-treated lot indicated that large quantities of lime deposit on the shells interfered with the normal setting of oysters. This was probably due in part to the fact that the oyster larvae could not find clean, hard areas for their attachment. Apparently the thick layer of lime on the loose shells interfered mechanically, and probably chemically, with the setting of the larvae. The observation that the shells taken at random from the wire-bag spat collector treated with lime contained more spat than the shells of the identical collector of the control lot can be explained on the ground that, since only the upper layer of shells of the collector was covered with lime, there were enough clean shells inside of the bags to provide setting areas for the spat. It should be remembered that in connection with these experiments the concentrations of lime used were far greater than those expected to be used on oyster beds, and, as will be discussed later on, the lime treatments should be used only in autumn, winter, and early spring (p. 28). Obviously, the lime will disappear by the time the setting of oysters usually takes place. Furthermore, the planting of shells for catching spat is, as a rule, conducted during June and July, or during the time when the use of lime is not recommended.

Observations on survival of seed oysters subjected to the effects of lime showed that these animals survived the treatment very well. Seed oysters lived in the tank with lime for 6 months, and at the end of that time were apparently normal. No unusual mortality was noted among seed oysters collected from the natural beds where experiments were conducted.

MOLLUSKS OTHER THAN OYSTERS

Hard clams (*Venus mercenaria*), soft clams (*Mya arenaria*), and mussels (*Mytilus edulis*), kept in the tanks to which lime at the rate of 1,400 pounds per acre was added at monthly intervals, survived such an exposure for a period of about 6 months. The mortality among these animals ranged between 4 and 5 percent, being no higher than in the control tanks. Field experiments showed also that there was no mortality which could be attributed to the effects of lime among those mollusks dredged from the beds where experiments in the eradication of starfish were conducted.

TABLE 6.—*The effect of lime solution upon shell movements of hard clams* (Venus mercenaria)

Conditions	Duration of experiment	Average		
		Percent of time open	pH	Temp. °C.
1. In sea water, before treatment	19 hrs. 19 min	52.8	8.1	19.6
2. In 1 part saturated lime solution, 1 part sea water.	49 hrs. 8 min	52.4	8.8	19.2
3. Recovery in sea water	35 hrs. 49 min	90.9	8.1	18.8
Control 1. Sea water	18 hrs. 59 min	44.8	8.2	19.3
Control 2. Sea water	49 hrs. 8 min	81.9	8.1	18.5
Control 3. Sea water	35 hrs. 49 min	88.0	8.1	18.4
1. In sea water, before treatment [1]	53 hrs. 46 min	67.3	8.1	15.0
2. In 1 part saturated lime solution, 3 parts sea water.	200 hrs. 9 min	80.9	8.6	15.4
3. Recovery in sea water	80 hrs. 21 min	84.9	8.1	15.8
Control [1] 1. Sea water	53 hrs. 46 min	76.6	8.0	15.0
Control [1] 2. Sea water	199 hrs. 16 min	93.8	8.2	15.1
Control [1] 3. Sea water	80 hrs. 21 min	93.9	8.1	15.5

[1] Average of four experiments.

TABLE 7.—*The effect of lime solution upon the shell movements of mussels* (Mytilus edulis)

Conditions	Duration of experiment	Average		
		Percent of time open	pH	Temp. °C.
1. In sea water, before treatment	19 hrs. 9 min	95.2	8.1	19.6
2. In 1 part saturated lime solution, 1 part sea water.	49 hrs. 8 min	96.4	8.8	19.1
3. Recovery in sea water	32 hrs. 35 min	99.0	8.1	18.7
Control 1. Sea water	18 hrs. 59 min	59.9	8.2	19.3
Control 2. Sea water	46 hrs. 28 min	94.6	8.1	18.5
Control 3. Sea water	35 hrs. 44 min	96.5	8.1	18.4
1. In sea water, before treatment [1]	32 hrs. 23 min	99.7	8.1	14.5
2. In 1 part saturated lime solution, 3 parts sea water.	119 hrs. 51 min	99.5	8.6	16.4
3. Recovery in sea water	54 hrs. 8 min	96.6	8.1	16.6
Control [1] 1. Sea water	18 hrs. 3 min	99.8	8.0	14.8
Control [1] 2. Sea water	84 hrs. 39 min	99.7	8.2	15.8
Control [1] 3. Sea water	54 hrs. 8 min	99.3	8.1	16.6

[1] Average of two experiments.

Observations on the shell movements of hard clams exposed to very strong solutions of lime showed that the time these animals remained open was somewhat less than for those of the control (table 6). Judging by the fact that the percentage of time they were open during exposure to concentrations of from 1:1 to 1:3 was either almost equal to or in excess of that before treatment, however, it may be concluded that the experimental animals were not much affected by lime in solution. Observations on the shell movements of the mussels revealed that they were not disturbed by the presence of lime in the water (table 7). When exposed to 1:1 and 1:3 concentrations, mussels kept their shells open virtually the same percentage of time as did the control animals. The records of all shell movements were obtained with kymographs.

Other mollusks whose behavior was observed were two species of *Crepidula*, *Anomia*, two common forms of oyster drills, *Urosalpinx cinerea*, and *Eupleura caudata*, and two species of mud snails, *Nassa*. All these animals appeared to be unaffected after exposure to saturated lime solutions in outdoor tanks for a period of 2 weeks or longer.

TABLE 8.—*Effect of three different concentrations of lime in sea water, filtered and unfiltered, on the hatching of eggs of flatfish* (Pseudopleuronectes americanus)

Concentration	Condition	Exposure time	Quantity of eggs used, cc.	Quantity of eggs unhatched, cc.	Quantity of eggs hatched, cc.
1 : 250	Filtered	3 hrs. 30 min.	50	8.0	42.0
1 : 500	Filtered	3 hrs. 30 min.	50	7.5	42.5
1 : 1000	Filtered	3 hrs. 30 min.	50	9.0	41.0
Sea water (control)			50	7.0	43.0
1 : 250	Unfiltered	3 hrs. 0 min.	50	50.0	0.0
1 : 500	Unfiltered	3 hrs. 0 min.	50	50.0	0.0
1 : 1000	Unfiltered	3 hrs. 0 min.	50	50.0	0.0
Sea water (control)			50	8.0	42.0

EGGS AND FRY OF FLATFISH

Experiments performed at Milford Laboratory and the State hatchery at Noank, Conn., showed that the eggs and fry of flatfish (*Pseudopleuronectes americanus*) may survive in strong solutions of lime, provided they do not come into contact with solid particles. Samples consisting of 50 cc. of flatfish eggs were kept in strong concentrations of lime in sea water for several hours (table 8). In the first series of experiments the solutions were filtered to remove undissolved particles of lime before the eggs were placed in it. After exposure to lime water for 3½ hours the eggs were transferred to hatching jars through which sea water was circulated. Two days after the exposure the first few fry hatched, escaping from the jar into an aquarium, and within a few days hatching was finished. The volume of all unhatched eggs was then determined (table 8). In all cases the quantities of unhatched eggs were almost identical; closely approaching that of the control.

In another series of experiments, 1:250, 1:500, and 1:1,000 concentrations of lime were used. Undissolved particles of lime were left in the vessel, forming a thin layer on the bottom so that the eggs came into contact with them. All eggs died (table 8).

Flatfish fry survived for 1 hour in a filtered saturated lime solution. They died quickly, however, after coming into contact with solid particles of lime.

As these experiments indicate, the eggs and fry of flatfish may be seriously endangered by the indiscriminate use of lime. It is suggested, therefore, that this chemical should not be used in the areas thickly populated with flatfish during the time when their eggs and fry are present.

LOBSTER LARVAE

Observations on the effect of lime on lobster larvae were conducted at Noank Hatchery in June 1938. The first 3 larval stages were used. The first stage was composed of animals that were about 12 hours old, those of the second stage were 8 days old, and of the third stage 14 days old. In a dilution of 1 part of a filtered saturated solution of lime to 10 parts of sea water the larvae of all stages survived for 4 hours. The same results were obtained when a solution of 1 part of a saturated lime solution to 2 parts of sea water were used. In a solution of 1 part of lime water to 1 part of sea water, however, a mortality of about 25 percent was registered at the end of 4 hours exposure. All 3 larval stages appeared to be equally affected. In a saturated solution of lime, all animals died in 3 hours or less. The larvae of the first, or earliest stage, appeared to be the most resistant. Direct contact of lobster larvae with particles of lime resulted in the death of the animals. Again the animals of the first larval stage proved to be the most resistant, sometimes surviving as long as 40 minutes. Apparently the use of lime should be avoided during the time when lobster larvae are present in the water. Fortunately, the hatching of lobsters in Long Island Sound usually takes place in June, the time when the oystermen are preparing their beds for the new set of oysters, and lime will not be used at this time.

OBSERVATIONS ON OTHER FORMS

Barnacles were observed to live in a strong lime solution for periods of 6 months. They behaved normally and fed as if not disturbed. The local species of shrimp also withstood the lime treatment very well. On the other hand, crabs kept in tanks to which large quantities of lime were added soon died. No dead crabs were found, however, on the oyster beds treated with lime. Apparently, under natural conditions, crabs could always find small areas not covered with lime or could dig into the bottom mud, thus avoiding direct contact with lime. *Fundulus* were found to be very resistant. Flatfish, on the other hand, died within a few days after being placed in tanks with bottoms covered by a layer of lime. No dead flatfish were found on the natural beds where the concentration of lime was much lighter than in the experimental tanks, and where by flapping their fins, as is their habit, they could clean up a small area to rest on.

CONCLUSIONS AND RECOMMENDATIONS

Observations and experiments carried out by the writers under laboratory and field conditions indicate that the starfish living on oyster beds can either be eliminated entirely, or greatly reduced in numbers, by spreading common quicklime over the infested area.

The actual contact of the body of the starfish with the particles of lime is necessary to cause injury. Therefore, the efficiency of lime depends primarily upon its uniform distribution over the areas treated, and also upon the quantities used. The method of spreading lime over an area by shovels or by a stream of water should be discontinued as wasteful. Instead, methods insuring uniformity of distribution of the lime over the treated area should be employed. In all cases, the direction and speed of tidal currents should be taken into consideration. If properly applied, small quantities of lime (300 to 500 pounds per acre) will be sufficient to destroy the majority of the starfish present. Until more efficient methods of lime dispersal are developed, however, larger quantities, up to 1,000 pounds per acre, may be used. The cheapness of quicklime renders the method economically feasible. At the time of writing, the cost of 1 ton of quicklime delivered to oystermen ranged from $12 to $14. At this figure the cost of treatment per acre of bottom would vary from about $2 to $7, depending on the concentration used. At present, many oyster companies of Connecticut, New York, and Rhode Island are using lime regularly. Among these are Bluepoints Co., Inc., F. Mansfield & Sons Co., H. C. Rowe & Co., The Connecticut Oyster Farms, Inc., Warren Oyster Co., and Frank M. Flower & Sons.

It is fortunate that the concentrations of lime harmful to starfish do not seriously affect many other commercially important forms of marine life. When used in the concentrations employed in experiments, lime did not kill or noticeably injure oysters, clams, or other mollusks commonly found on cultivated bottoms. It was found injurious, however, to several pelagic forms, such as the larvae of flatfish and lobsters. By using lime at times when the larvae of commercially important species are absent, such injury can be avoided.

It is thought that lime can be advantageously used twice a year. The first treatment may be given in March, thereby killing starfish before the period of their spawning activities and thus reducing the numbers of their progeny, and the second in the fall or winter will protect the oyster set from being devoured by both young and adult starfish.

Frequent surveys of starfish distribution carried on during the last 5 years indicate that certain areas of Long Island Sound are always inhabited by very large numbers of starfish, consequently serving as centers of propagation and distribution of these pests. Such areas should be treated with lime, thus destroying large numbers of starfish and preventing them from spreading to adjoining bottoms.

The simplicity of application of lime, its comparative harmlessness to oysters and many other commercial species, and the cheapness of the product, all indicate that the method provides a practical weapon against starfish.

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