BIOLOGY AND METHODS OF CONTROLLING THE STARFISH, Asterias forbesi (DESOR)

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INTRODUCTION

The starfish has long been regarded as one of the most destructive enemies of shellfish on the Atlantic coast of North America. The greatest part of the loss caused by these pests is borne by the oystermen, who often find their stock depleted or entirely destroyed. Beds populated with young oysters are especially vulnerable.

Even in the old days, when the purchasing power of the dollar was much higher, the direct damage caused by starfish to the Connecticut oyster industry was assumed to be $463,000 in 1887; $631,000 in 1888; and $412,000 in 1889. Now, according to the estimates of biologists and practical oystermen, the value of oysters destroyed by starfish in Long Island Sound alone may reach several million dollars in some years.

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For example, in 1958 starfish almost entirely destroyed one of the heaviest oyster sets in the history of shellfish cultivation in Connecticut. The monetary loss that year was considered to be between $10,000,000 and $15,000,000 and, perhaps, even greater because of the present high price of oysters.

Starfish also kill large quantities of oysters in the States of New York, Rhode Island, and Massachusetts. Scallop beds, as in Buzzards Bay, are often invaded and their population partially or completely destroyed by starfish. One phase of depredation, the extent of which is very difficult to estimate, is the heavy destruction of oyster spat caused by newly set starfish. In regions where heavy setting of these pests immediately precedes or coincides with setting of oysters, the latter may be devoured in a short time.

DISTRIBUTION AND OCCURRENCE

Of the several species of starfish found on oyster beds only two are serious predators of commercial mollusks. These are *Asterias forbesi* (Desor), the common starfish (fig. 1), and *Asterias vulgaris* (Verrill), known as the purple starfish. The range of distribution of the first species extends from Maine to Florida and to the Gulf of Mexico. This form, however, is most abundant between Cape Cod and Virginia. It is found at all depths ranging from the low water mark to 250 feet, but the majority of these animals live near the shore in comparatively shallow water. *A. vulgaris* is found from Labrador, Canada, to Cape Hatteras, North Carolina, and from the shoreline to a depth of 170 fathoms. This species, however, is most common in water of moderate depth, preferring deeper and cooler water than *A. forbesi* and, consequently, is rarely found in shallow places where oysters are grown. Only *A. forbesi*, the species causing the most damage to oyster beds, is discussed in this article.

Surveys by the U.S. Fish and Wildlife Service have disclosed great concentrations of starfish in Buzzards Bay, Mass.; Narragansett Bay, R. I.; in the waters of Long Island Sound; and, at times, in Chesapeake Bay. In all cases the majority of the animals were found to live in comparatively shallow water not deeper than 40 feet, their number decreasing with increasing depths. Usually, large concentrations were found near the shore where natural and cultivated oyster beds are located. Starfish appeared to be equally abundant on hard and soft bottoms, wherever food was available. In Chesapeake Bay they were concentrated chiefly in areas where an abundant supply of the small clam, *Mulinia lateralis*, was found.

It has been reliably established by semiannual surveys that the number of starfish in Long Island Sound varies tremendously in different years. Although there are no definite cycles in its population density,

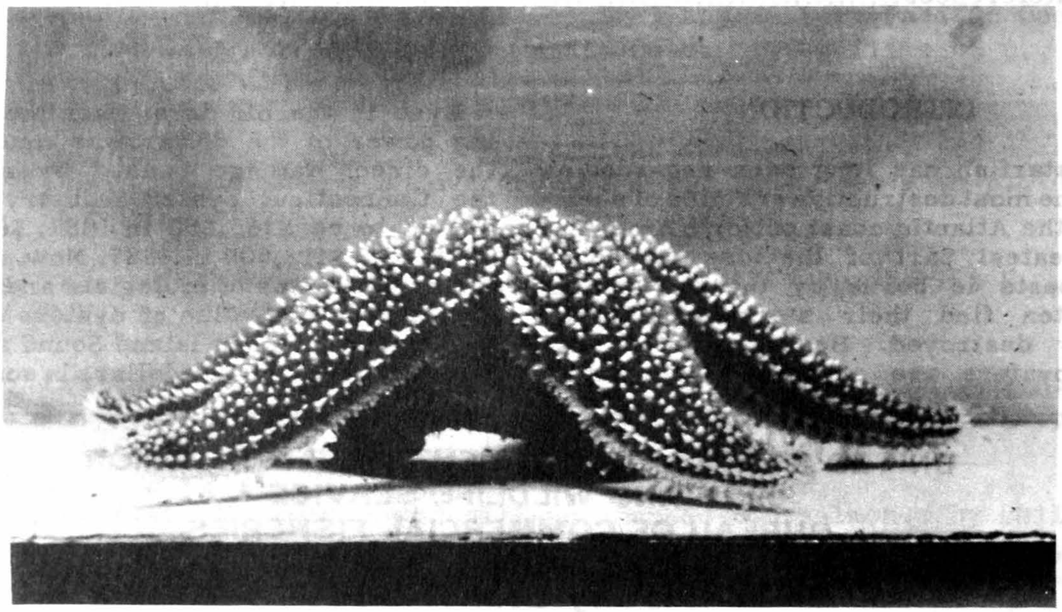

Figure 1.--Common starfish, *Asterias forbesi*, moving on bottom.

there are periods when starfish are extremely numerous and, also, periods when they are comparatively scarce. For example, pronounced increases in the starfish population were observed during the years of 1934-35, 1939, 1948-50 and, especially, in the fall of 1957. The starfish set of 1957, although not unusually heavy, survived well, increasing the number of starfish in Long Island Sound about tenfold. Since then, because of the preponderance of starfish and the difficulty of combatting them, many sections of Long Island Sound that were formerly very productive as oyster grounds have been completely abandoned.

It is important to recognize that in 1957 a comparatively good setting of starfish occurred although the population of adult starfish, at that time, was one of the lowest recorded since systematic surveys of their occurrence and distribution were begun in the middle 1930's. This and similar observations clearly demonstrated that in the case of starfish there is no direct correlation between the numbers of parents and the intensity of setting.

Starfish cannot exist in water containing less than 1.8 percent of salt. However, they are capable of withstanding, without serious injury, sharp reductions in salinity provided that the low salinity periods are of short duration. Prolonged exposures eventually result in death of the starfish. Because of the inability of these animals to adjust themselves to water of low salinity they do not penetrate far into harbors and bays where the water is too brackish.

Surveys on the occurrence and distribution of starfish conducted semi-annually in Long Island Sound during the last 22 years fail to support the opinion prevalent among oystermen that seasonal migration occurs regularly from shallow to deep water, and vice versa. Results of these surveys indicate that the distribution of these animals in relation to depth is fairly constant and that in many instances large groups of starfish found in inshore areas remain there for a period of several years. Studies of movements of starfish, stained blue with the harmless dye, Nile Blue Sulphate, and then released at a definite point in Long Island Sound showed that the greatest distance any of the animals traveled in 10 months was about 5,000 feet. The stained starfish dispersed in all directions. Laboratory observations also showed that movements of starfish are irregular and quite slow, usually not exceeding a few inches per minute. In the winter, when the temperature of the water is near the freezing point, locomotion is slowed considerably or ceases entirely. However, severe storms or hurricanes, which cause strong movements of water near the bottom, may carry masses of starfish from one area to another over considerable distances in a short time.

FOOD AND FEEDING

The heavy damage to the shellfish industry from starfish predation has caused great interest in the method employed by starfish to open shells of bivalve mollusks. In general, all the suggestions offered in the past may be reduced to two probable alternatives. One of these is a "toxin" theory. It proposes that starfish release a chemical substance which produces relaxation of the adductor muscles of the bivalves. The second, the so-called "mechanical" theory, maintains that starfish are able to pull open the valves of molluscan shells by means of their tube feet. At present, the second or "mechanical" theory is accepted by most biologists. There is evidence that the opening of the valves is a rapid process involving overwhelming, discontinuous forces. In experiments with mollusks it was found that the tube feet did pull the valves open, and forces of over 3,000 grams were recorded.

In addition to bivalves, such as clams, oysters, and mussels, the food of starfish also consists of sea snails, small crustaceans, worms, and various dead marine animals. However, the small size of the starfish mouth, which in adult animals is only about one-fourth of an inch in diameter, does not permit taking in large pieces of food. To compensate for this handicap, nature provided starfish with a very unique method of feeding. After the shells of the attached mollusk are open, the starfish extrudes its stomach, inserts it between the shells, and digests the soft meat of its prey in situ. As soon as the mollusk is eaten, the stomach of the starfish is withdrawn. It has been found that a single, medium-sized starfish may destroy as many as five 1-year old oysters per day (fig. 2). Older and stronger mollusks are better equipped to withstand the attack. However, even large oysters, if in a weakened

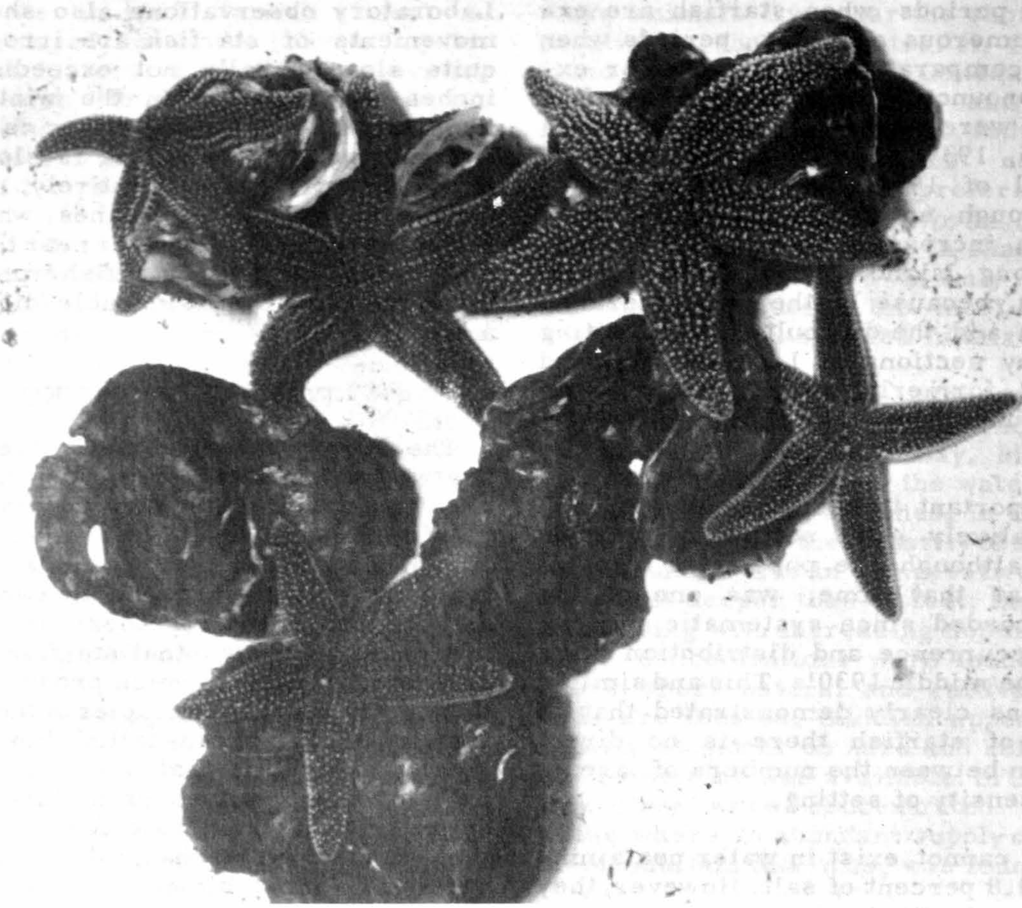

Figure 2.--Starfish feeding on young oysters. Two oysters recently opened and eaten by starfish can be seen in upper left hand corner.

condition, become easy prey to starfish.

The starfish of Long Island Sound manifest decided seasonal differences in their feeding habits. Indifference to food is shown throughout the pre-spawning period, extending from the end of May until July. Active feeding begins again after spawning, and starfish become voracious eaters during the period from August to December. The low temperature of the water during winter and early spring almost entirely suppresses their feeding activities.

REPRODUCTION

The sexes of starfish are separate. If the animals spent their first year in a favorable environment, they are able to breed when only 1 year old. They become ripe during late spring, and in the summer the sexual products of males and females are discharged into the water, where fertilization of eggs occurs. The spawning period may vary in different localities. It usually begins soon after the water temperature reaches 60° F. and continues throughout the summer, ending some time late in September. Recent experiments conducted with starfish of Long Island Sound have shown that in adult *A. forbesi* sex reversal from male to female may occur.

Fertilized starfish eggs develop into very small, delicate, free-swimming organisms called larvae, which subsist upon algae and other microscopic forms. The change from larval to juvenile stage occurs 2 or 3 weeks after fertilization, depending upon the water temperature and food supply. The young starfish, about four one-hundredths of an inch in diameter, sets on the bottom where it begins to feed upon small oysters, clams, and other animals. In Long Island Sound setting of starfish occurs at all depths, from the mean low water mark to 100 feet, being most intense in water less than 40 feet deep. Setting may begin late in June and continues until late September or even early October.

If food is abundant, young starfish may grow very rapidly reaching the size of 3 inches by the end of November. Generally, however, the rate of growth is slower. Old, fully grown starfish are known to reach the size of 11 inches in diameter.

METHODS OF CONTROL

Eradication of starfish on oyster bottoms has been practiced ever since cultivation of oysters was begun. Various methods of cleaning oyster beds of starfish are now employed by oystermen but the following are most commonly used:

Mechanical Methods

Starfish mop.--At present the most common device for destroying starfish is the mop (fig. 3). It consists of an iron bar 8 to 10 feet long to which are tied 12 to 16 light chains, and attached to each light chain is a large bundle, about 5 feet long, of rope yarn. A boat usually carries two mops which are raised and lowered from the side of the deck. As the mops are dragged over the oyster beds, the starfish, the bodies of which are covered with numerous spines, are entangled in the yarn and brought to the deck, where the mops are dipped into wooden vats of hot water. After the starfish are killed and removed from the mops the latter are again lowered overboard and the process repeated.

Oyster dredge.--During the regular dredging for oysters many starfish are also caught and later destroyed. In some instances oystermen prefer to use dredges instead of mops (fig. 4).

Suction dredge.--The suction dredge is a comparatively new implement placed in operation about 20 years ago. The dredge is designed on the principal of the ordinary suction vacuum cleaner. Starfish and other

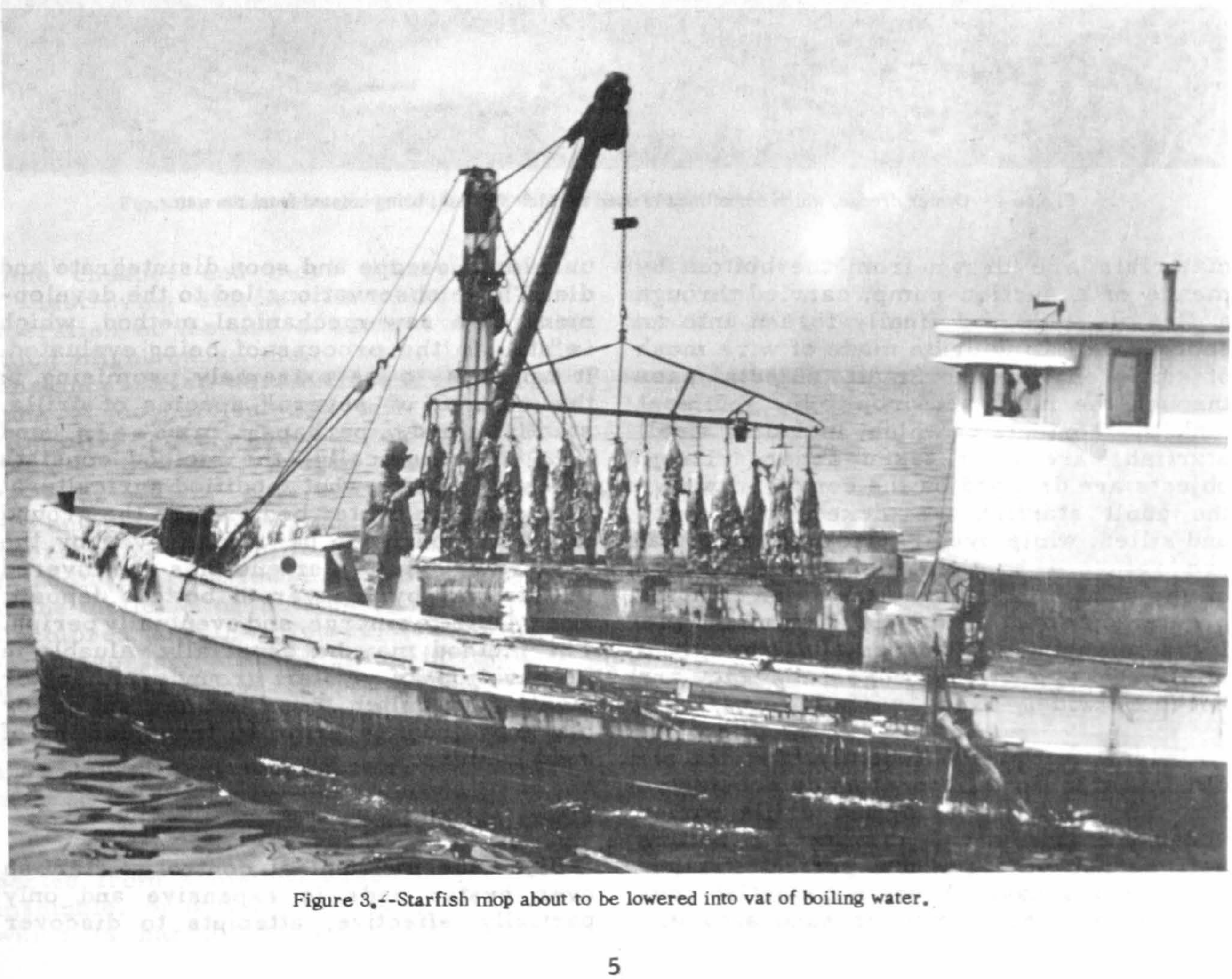

Figure 3.--Starfish mop about to be lowered into vat of boiling water.

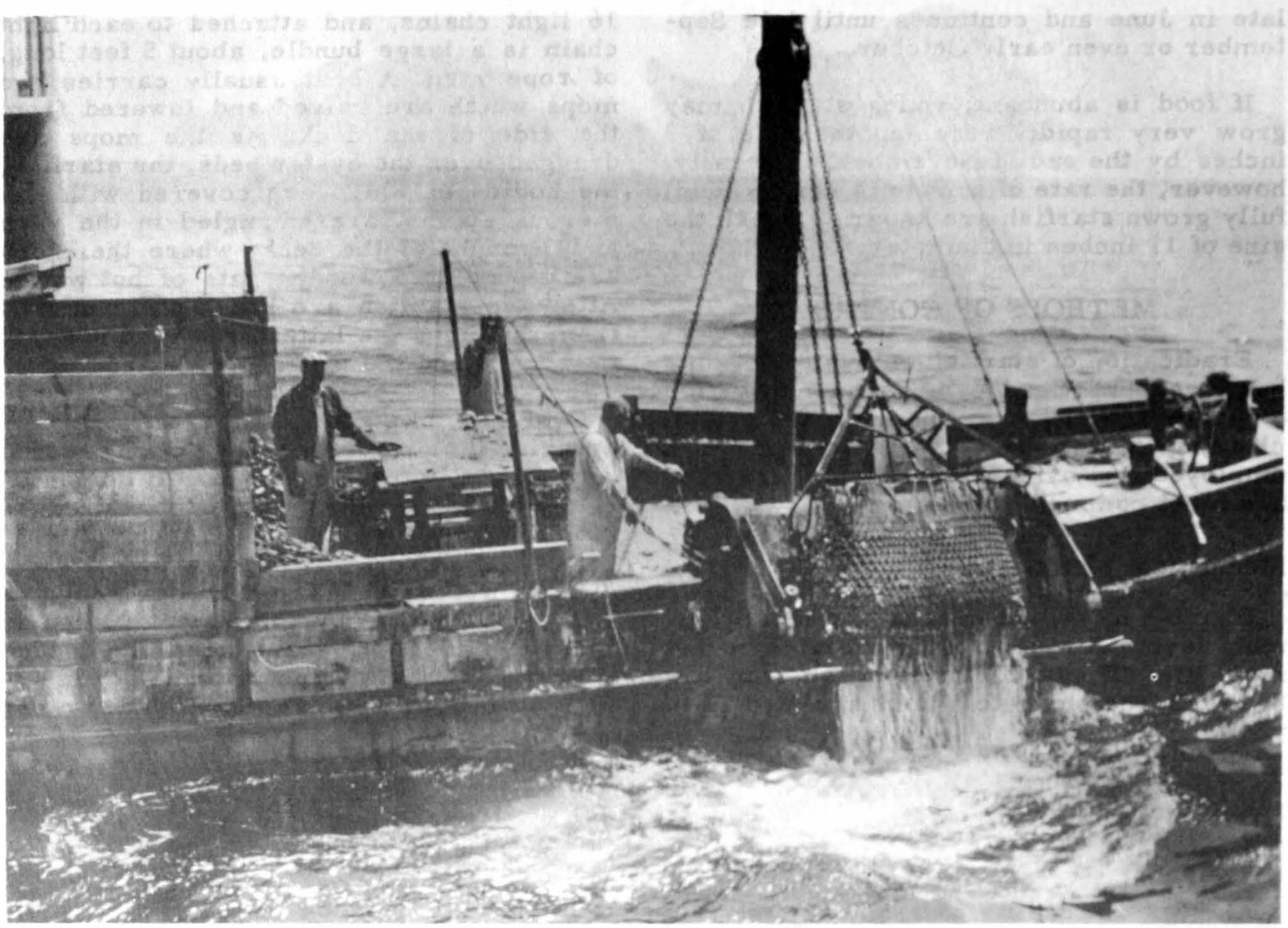

Figure 4.--Oyster dredge, which sometimes is used to catch starfish, being hoisted from the water.

materials are drawn from the bottom by means of a suction pump, carried through a flexible pipe and finally forced into an enclosed rotating drum made of wire mesh of different sizes. Small objects pass through the mesh and drop to the sediment tank the contents of which, including small starfish, are later taken ashore. Large objects are dropped on the conveyor, where the adult starfish are picked off by hand and killed, while oysters and other material are returned to the beds. The efficiency of the dredge is high and the catch is much greater than that of a regular starfish boat. It is unfortunate, in view of the great efficiency of suction dredges, that they are not more widely used.

Underwater plow--Recently, Service biologists at Milford Laboratory demonstrated that the majority of oyster drills buried under a comparatively thin layer of bottom soil cannot emerge, and perish. Further experiments have shown that starfish covered by a layer of mud or sand also are unable to escape and soon disintegrate and die. These observations led to the development of a new mechanical method, which is still in the process of being evaluated. It appears to be extremely promising in the control of several species of drills, starfish and, perhaps, mussels and *Crepidula*. Basically, the method consists of using a somewhat modified agricultural disc plow on oyster beds where the ground is soft enough to be turned over by the blades (fig. 5). Oyster enemies are covered in this way by a layer of bottom deposit, are unable to emerge, and eventually perish. The method may be especially valuable in preparation of oyster grounds either for planting of cultch to collect new set or for cleaning grounds prior to transplanting of seed oysters.

Chemical Methods

Since the mechanical control of starfish over oyster beds is expensive and only partially effective, attempts to discover

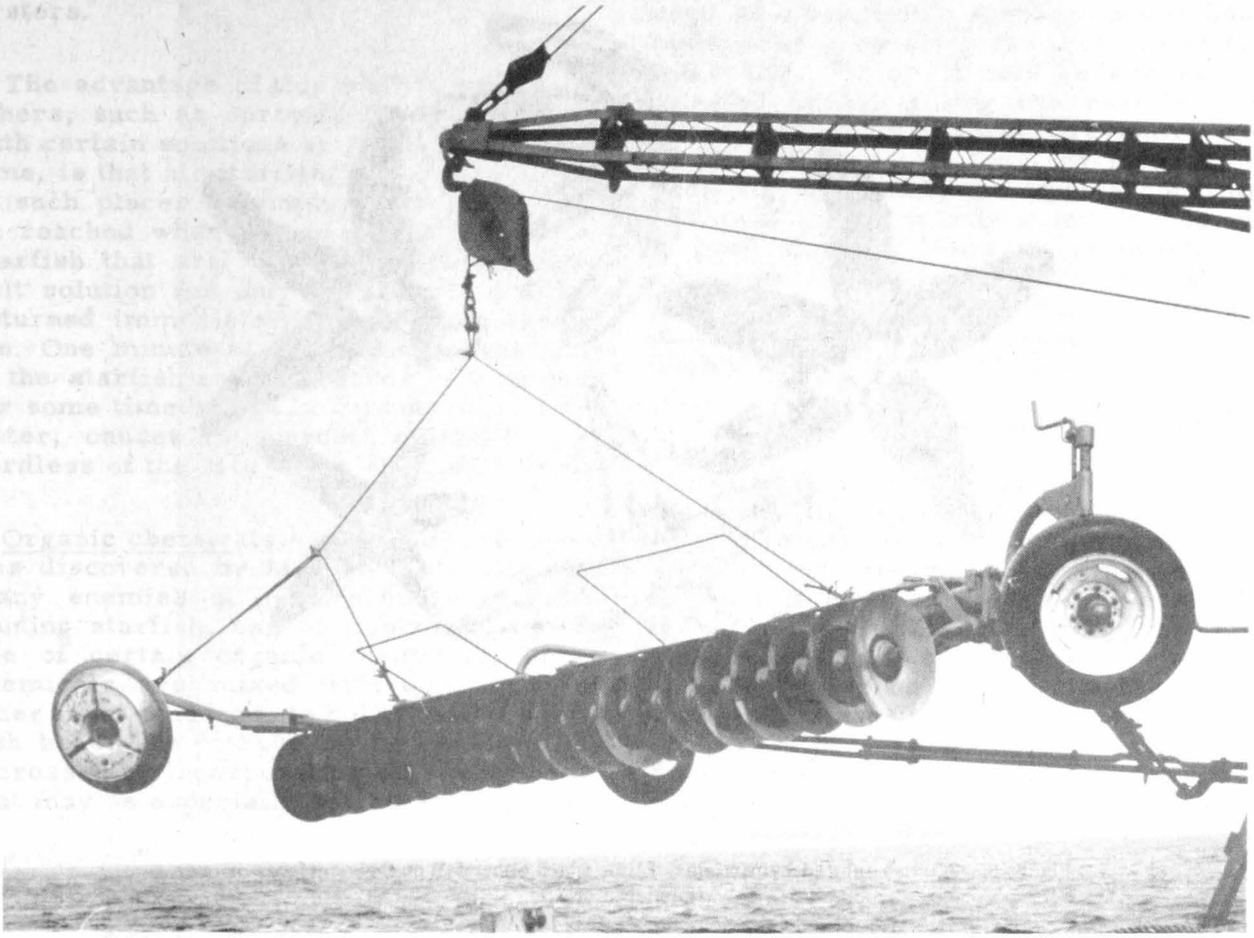

Figure 5.--Underwater plow, used in control of oyster enemies and competitors, ready to be lowered.

some cheaper and more efficient means of destroying starfish have led to consideration of the use of certain chemicals which might cause their death. Among the substances tried were different concentrations of copper sulphate and its mixture with nitre cake. The use of these substances, however, proved impracticable for beds of any size since only a small percentage of starfish was killed, while the others were driven to adjacent bottoms. In addition, in a few instances the shells of the mollusks of the treated area became discolored and the oysters were found to be unfavorably affected. Since introduction of metal salts over oyster bottoms may result in an accumulation which may eventually prove dangerous to aquatic animals and plants, this method was not recommended for the control of starfish.

Quicklime.--Better results can be expected from a method based on the use of insoluble, or only slightly soluble material which is harmful to the starfish when in direct contact with its body. Such a method was found by using calcium oxide, commonly called quicklime, which has the important property of causing an almost immediate effect upon the starfish body. Moreover, because of its low solubility, a comparatively small quantity of quicklime, in powdered or granular form, is sufficient to cover a relatively large area of oyster beds. When quicklime is spread over the oyster beds, its particles would fall and imbed in the upper surface of the starfish. This surface is covered with a delicate membrane which acts as the respiratory organ. The caustic action of lime causes surface lesions which quickly deepen and after a few days may penetrate throughout the bodywall of the starfish exposing the internal organs and finally causing death (fig. 6).

Once spread on the bottom, the lime retains its effectiveness for some time. Starfish which are not directly hit by the falling particles will eventually come in

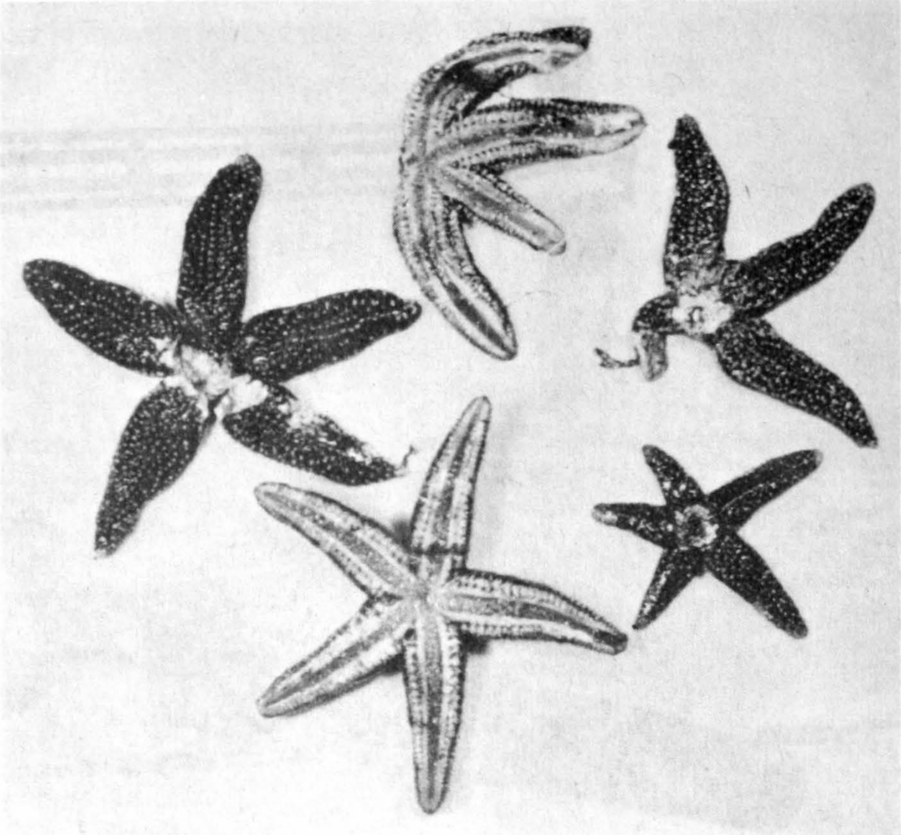

Figure 6.--Starfish injured by particles of lime which either fall on their surfaces or over which they crawl.

contact with them while crawling on the bottom. Thus, in the course of time the lower surfaces of the starfish also become affected and disintegration of their bodies begins. Starfish weakened by the wounds are attacked and eaten by crabs and other animals, a circumstance which adds to the number of starfish eventually killed.

Lime is also used when oyster set is transplanted. By spreading several handfuls of powdered quicklime over each dredgeload the majority of the starfish found among the oysters will be killed. This method prevents transplanting starfish from one area to another.

To cause injury to starfish it is necessary to create actual contact of particles of quicklime with the bodies of these pests. Therefore, the efficiency of the method depends primarily upon the uniform distribution of the lime over the area treated, and also upon the quantities used. An apparatus insuring uniform distribution of lime has been devised by biologists of the Fish and Wildlife Service and successfully tried on the cultivated beds of Long Island Sound. Whenever lime is used the direction and speed of the tidal currents should be taken into consideration. If properly applied, even small quantities of lime (500 to 750 lbs. per acre) will be sufficient to destroy the majority of the starfish present. Sometimes, however, larger quantities may be needed. Fortunately, the concentrations of quicklime required to kill starfish do not seriously affect many other commercially important forms of marine life. When used in the concentrations employed in these experiments, lime does not kill nor noticeably injure oysters, clams, or other mollusks commonly found on cultivated bottoms.

Salt solution.--Recently another extremely simple method was developed to kill starfish during transplanting of oysters from one area to another. The method consists of dipping dredgeloads of oysters, together with their enemies, in saturated or strong solutions of common salt. This simple method is extremely effective in killing small and large starfish, boring sponges, tunicates, hydroids, *Crepidula*, etc., without causing serious injuries to oysters.

The advantage of this method over some others, such as spraying loads of oysters with certain solutions or small particles of lime, is that all starfish, even those hidden in such places as empty conch shells, will be reached when dipped in the salt brine. Starfish that are immersed in a saturated salt solution for only 30 seconds and then returned immediately to sea water usually die. One minute of immersion, especially if the starfish are afterwards kept on deck for some time before being returned to sea water, causes 100 percent mortality, regardless of the size of the starfish.

Organic chemicals.--Several years ago it was discovered by Milford biologists that many enemies of oysters and clams, including starfish, can be controlled by the use of certain organic chemicals. These chemicals are mixed with dry sand, or other inert carriers, to hold them on shellfish beds. The potency can be considerably increased by incorporating other chemicals that may be especially selected for specific groups of enemies. The treated sand can be used as a barrier to surround the shellfish beds, thus preventing the entrance of enemies (fig. 7), or it may be spread over infested areas, killing the enemies and, under certain conditions, preventing even their pelagic larvae from re-invading the beds (fig. 8). Under experimental conditions chemical barriers only a few inches wide stopped starfish. However, in practice, to compensate for the fact that starfish may sometimes be carried by currents for long distances, the barrier should be considerably wider.

The first sign of distress shown by starfish that come into contact with a chemical barrier is usually a curling of the rays (fig. 9). Often a starfish acquired an arched position standing on the tips of its rays. In extreme cases, when the chemical formula is especially strong, the starfish may roll into a ball. After relatively short periods of contact with the barrier, the bodies of starfish begin to disintegrate and the pests soon die. The method, although extremely promising, is still under study to determine its safety to bivalves and to humans.

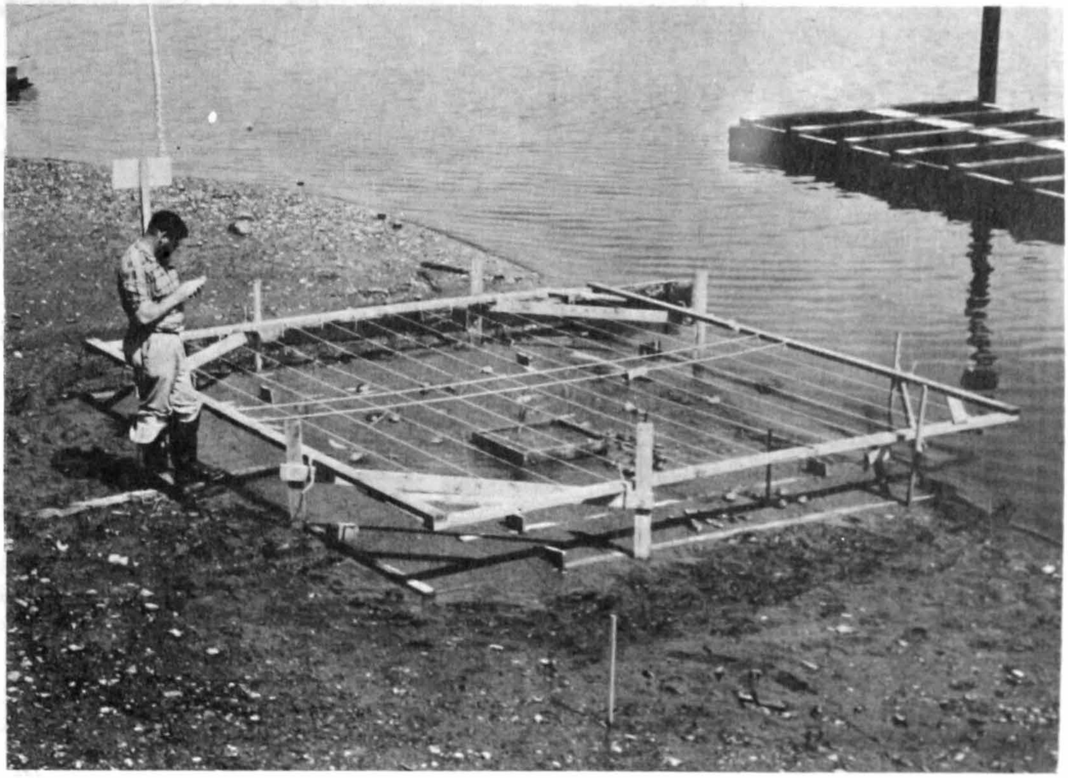

Figure 7.--Experimental chemical barrier constructed in intertidal zone in Milford Harbor. Strings over the bottom were needed to keep sea gulls away from the animals planted inside the barrier.

Figure 8.--Method of treating shellfish bottoms invaded by starfish. It consists of spreading chemically treated sand by means of a rotary spreader. Experiments are still in progress to determine the best formula to be used and quantity of material per acre of bottom needed to eliminate starfish.

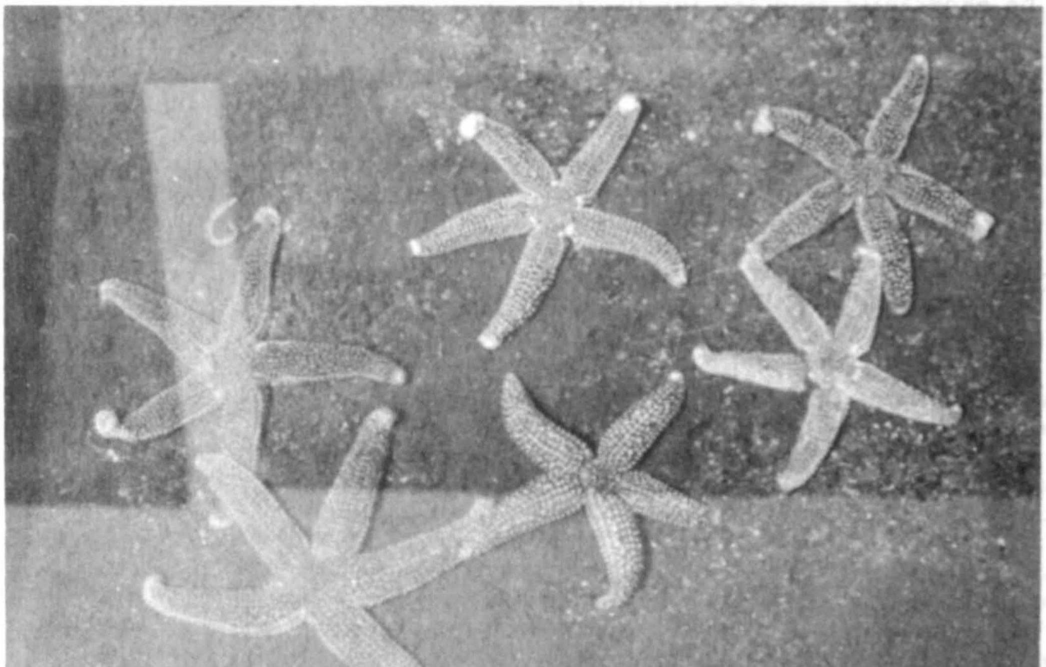

Figure 9.--Starfish curling their rays and some disintegrating at centers soon after contact with chemical barrier.

UTILIZATION OF STARFISH

Many attempts have been made to utilize starfish as fertilizer or chicken feed. Technological studies of this nature conducted in the pást by the U. S. Fish and Wildlife Service led to the conclusion that production of starfish meal was not practical because the oyster industry did not provide a reliable source of this material and because a separate fishery for starfish could not operate to yield raw material at a cost consistent with its value as a feed stock or as fertilizer. Furthermore, extreme fluctuations in the abundance of starfish promised a very poor source of supply of raw material. Finally, starfish meal had a low nitrogen content and high ash content and, therefore, was less desirable.

More recent studies have demonstrated, nevertheless, that protein concentrates prepared from starfish, either by pancreatic digestion or by washing with hydrochloric acid, have high protein-quality values that are comparable to good-quality fish meals. Defatted starfish meal was also shown to be approximately equal to fish meal, on a protein basis, when added at levels of 3 to 6 percent to purified or practical diets, while maintaining the same dietary calcium level. In general, these studies suggested that defatted starfish can compete nutritionally and economically with fish meal as a source of protein, calcium, and unidentified growth factors in poultry ration. Thus, modern techniques of processing showed new means of utilizing sea products, such as starfish, which until recently were considered virtually valueless. Because of the unreliable nature of the supply, however, it is doubtful that utilization of starfish meal offers much promise of aid to the oyster industry.

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