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Recent Advances in the Control of Shellfish Predators and Competitors

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THE PURPOSE OF THIS ARTICLE is to describe briefly several methods of control of shellfish enemies that either came into practical use during recent years or are on the threshold of being employed on a large scale by shellfish industries.

As is well known, the methods of controlling shellfish predators and competitors may be of three basic types, namely, biological, mechanical or chemical. Biological methods, being more natural than those of the other two categories, are preferable in many respects. However, in aquatic environments they are difficult to develop and, perhaps, even more difficult to execute. An example of this was when a ciliate, *Orchitophyra stellarum*, was discovered in gonads of male starfish, *Asterias forbesi*, which were made sterile by the activities of this parasite (Piatt, 1935). Unfortunately, regardless of persistent efforts, we failed to spread the infection among starfish kept in the laboratory aquaria and tanks or in Long Island Sound.

Mechanical methods have been mainstays of shellfish cultivators for many years. Most of us are familiar with starfish mops and dredges, drill traps and, more recently, suction dredges that are in use in this country. The principles of these methods have already been described (Galtsoff *et al.*, 1937; Galtsoff and Loosanoff, 1939). In Europe, for over a century, several types of fences have been in use against crabs and rays. All these methods are partially helpful but none is adequate in itself. As a result, to cite one example, the recent prevalence of drills in Long Island Sound compelled the oyster industry to give up virtually the entire area of Milford Bay, where only a few years ago highly productive beds existed. Almost total extermination by starfish of the extremely heavy 1958 oyster set in Long Island Sound is another example of the inability of oystermen to protect their crops with the methods presently available.

Since it has always been realized that mechanical methods of control are expensive and usually only partially effective, the possibility of using chemical substances to combat starfish and predatory snails, such as oyster drills, was considered on many occasions. During the early 1930's biologists experimented widely with copper sulfate to eradicate starfish (Galtsoff and Loosanoff, 1939). A few years later an effective chemical method, consisting of spreading quicklime over starfish-infested bottoms, was perfected at Milford Laboratory and has been used ever since by several oyster companies in Long Island Sound (Loosanoff and Engle, 1938). This method, unfortunately, has its limitations also, principally because quicklime becomes slaked upon contact with sea water and, therefore, soon loses a great deal of its efficacy.

As often occurs in nature, an oyster or a clam faces its enemies from the very beginning of its existence. Predation begins as soon as the eggs are shed and continues through larval, juvenile and even adult stages. In addition to direct enemies, such as plankton eaters are to early stages of developing bivalves, and as, later on, bottom predators, such as gastropods, starfish, crabs and the flatworms, *Stylochus,* are to recently set bivalves, competing organisms are often of paramount importance. We are all familiar with tunicates, *Crepidula,* barnacles, hydroids, and algae, not to mention mussels, which often set so heavily that they smother recently set oysters by competing with them for space, food and oxygen. Some of these forms, including barnacles and tunicates, act as direct enemies of oysters by eating their larvae and, also, as competitors of more advanced stages when living in the same environment. Because direct and indirect enemies of shellfish are important in mariculture, control measures should be developed for both groups.

As far as I am aware, there is virtually nothing new to report as to recent achievements in the field of biological control of shellfish enemies. Several laboratories are experimenting along such lines, but these experiments have not progressed far enough to give us any assurance that successful methods will be developed. At our laboratory, on the suggestion of our British colleagues, we experimented with the Sun-star, *Solaster papposus,* brought from the waters of New Brunswick, Canada, as a form that would attack and feed upon our common starfish, *A. forbesi.* The results were discouraging because usually the latter acted as the predator.

Contrary to the lack of progress in biological methods, a new mechanical method, which seems to show considerable promise, is now under trial at Milford Laboratory. It consists of burying drills under a thin layer of bottom material (Loosanoff and Nomejko, 1958). Laboratory experiments demonstrated that when buried at a depth of 3 centimeters, approximately 40 per cent of drills, *Urosalpinx cinerea,* could not reach the surface and died. If covered with a layer 6 cm deep, about 92 per cent of drills perished. Later, we discovered that the method is also quite effective against starfish. When buried under 1 inch of mud these pests died within 24 hours and in sand, within 48 hours. Only about 10 per cent of starfish buried with one or two rays protruding from sand could emerge, while the others died and decomposed within three days. F. Mansfield & Sons Company of New Haven is presently under contract with our Bureau to develop mechanical details of an underwater plow to be used for extermination of drills and starfish on bottoms composed of comparatively soft material (Figure 1).

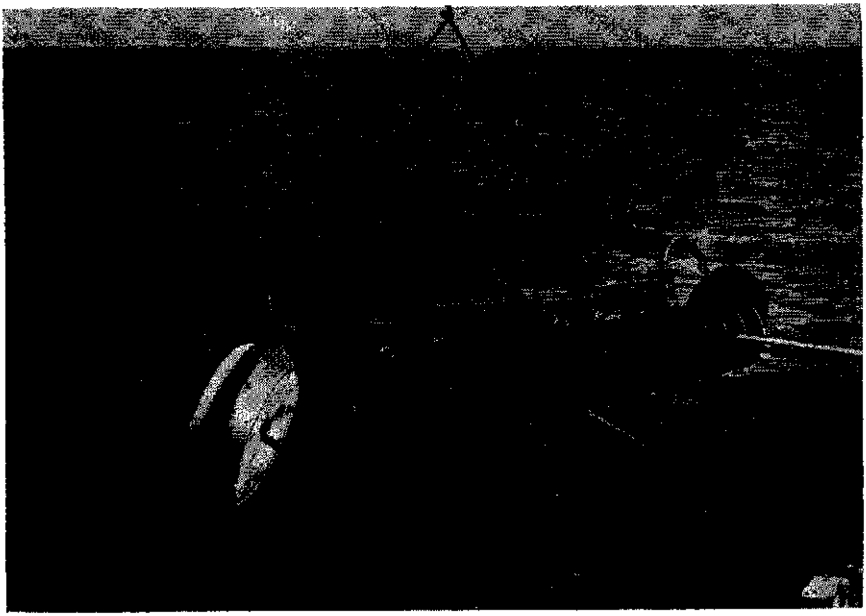

FIGURE 1. Underwater plow, used in control of oyster enemies and competitors, ready to be lowered.

The underwater plow method also appears to be promising in controlling the common mussel, *Mytilus edulis*, which at times occurs in a thick layer covering oyster beds of Long Island Sound. We have reason to believe that the same method will be effective against *Crepidula*, another important oyster competitor.

Probably the greatest progress in recent methods of controlling shellfish enemies has been made in the use of chemicals, especially insecticides. Many of these methods, several of which were developed at Milford Laboratory, are comparatively new and some of them are still undergoing a series of trials. In general, the use of chemical control measures can be discussed in two ways. The first consists of mentioning each enemy separately and then describing the method that is effective against it. The second approach offers, first, a general description of the method and then the names of all enemies that can be controlled by it. For this discussion the second approach has been selected as being more convenient and less time-consuming.

In controlling undesirable aquatic forms chemicals can be used in several ways. They may be (1) dissolved in water; (2) spread over large areas of the bottom as a thin layer which will repel enemies, such as drills, starfish, crabs, etc., or kill them or their larvae upon contact; (3) used in so-called barriers, or belts, made of chemicals mixed with materials of an inert nature, such as sand or fragments of old oyster shells, and laid as a continuous band to surround the oyster bed so that enemies, such as starfish and drills, will be stopped before penetrating into the protected area; (4) combined with shell material of living oysters, old oyster shells, or other spat collectors to make them either unsuitable for the existence of such forms as sponges, worms, and other shell dwelling organisms, or to prevent their fouling with tunicates, hydroids, barnacles, *Crepidula*, worms, algae, and others; (5) combined with shells of dead oysters, or other materials used as cultch, to repel drills or to kill larvae of other undesirable forms, such as flatworms, *Stylochus*, which may set on these shells and attack oyster set. A modification of the latter method may consist of using chemicals which will not only repel enemies but, simultaneously, attract oyster larvae to set in larger numbers on the specially-treated collectors; and (6) incorporated as poisons in foods that will be eaten by shellfish predators, such as horseshoe crabs, crabs, prawns, rays, drumfish, and others.

In addition to the above-mentioned uses, another method of employing chemicals may be suggested. It would consist, in general, of placing on an oyster bed, certain selected compounds, incorporated in organic solvents, that would gradually ooze into the water and create near the bottom, for desirable periods, light concentrations of chemicals that would be, nevertheless, strong enough to eliminate fungus, bacteria, hydroids, algae, and, perhaps, crustaceans and worms, without seriously endangering commercial mollusks or affecting their food value.

Water Solutions

Water solutions of chemicals should be used only under controllable conditions. Therefore, their use may be practical, as a rule, only in small volumes of water, such as laboratory and hatchery troughs and tanks, or in small lakes, ponds, claires, and dikes. Solutions can also be used advantageously for dipping into them, during transplanting operations, dredge-loads of oysters infested with boring sponges, worms, barnacles, etc. In still another case, placing infected bivalves in certain chemical solutions may free them of some internal parasites. We shall consider each of these uses separately.

Solutions of chemicals can be advantageously employed in controlling various forms of zooplankton, especially crustaceans of the sub-class Copepoda, which sometimes interfere with culturing of larval mollusks or invade mass cultures of phytoplankton, such as *Chlorella*, where they multiply rapidly and soon render the cultures worthless. In the past such invasions presented us with rather serious problems since it was virtually impossible to destroy the copepods, chiefly because of the viability of their eggs. Recently, however, we have been using a number of chemicals to prevent the invasions or terminate them (Loosanoff, Hanks and Ganaros, 1957). Several insecticides, which are known under the trade names of Guthion, Dipterex, Parathion, Lindane, TEPP and, more recently, Sevin, a carbamate, have been used for these purposes. The method is simple but effective. For example, in a 1.0 part per million solution of Guthion all crustaceans are killed within 2 hours at room temperature. Complete mortality is also caused by 0.05 ppm of Guthion or Lindane at the end of 20 and 53 hours respectively. The concentrations used, fortunately, do not noticeably affect the normal existence of algal cultures nor do they affect bivalves or their larvae which are fed treated *Chlorella*.

One of the most common offenders in hatchery trays and troughs is a bottom amphipod, *Corophium cylindricum*, which seriously interferes with recently set young clams, *Venus mercenaria*. This crustacean can also be easily exterminated by subjecting it for several hours to a solution of any one of several of the above-mentioned insecticides at a concentration of 1.0 ppm or even lower.

Sometimes, for example, during our experiments on propagation of oysters conducted in an artificial pond on Long Island, large numbers of free-swimming crustaceans become a problem because they compete with oyster larvae. We determined that a concentration of approximately 1.0 ppm of TEPP (tetraethyl phyrophosphate) killed crustaceans without causing serious injuries to oyster larvae. Many bottom crustaceans present in the same pond, which was approximately 1 square acre in area, also were killed, while none of the bivalves appeared to be affected.

Victoria Blue B, a biological stain, is another chemical compound, a solution of which will kill many undesirable forms, including common mussels, annelids, tunicates, certain gastropods, and hydroids. This chemical has been used routinely in our laboratory for over 5 years to check unwanted animal populations in hatchery troughs. The usual practice is to discontinue the flow of sea water through troughs and to create concentrations ranging from 1.0 to 2.5 ppm of the stain. As mentioned above, tunicates, annelids, mussels, and certain other competing bivalves, chiefly those that cannot keep their shells tightly closed, will be killed if subjected to this concentration for several hours. Hard shell clams, however, keep their shells closed and, consequently, remain unaffected. Some oysters, on the other hand, may open their shells during long immersion and receive a lethal dosage of the chemical. The Victoria Blue method, therefore, should be used with considerable care.

Still another modification of using chemical solutions is the so-called dip method. It consists of immersing a dredgeful of oysters, together with other bottom material, into a vat of the solution to destroy all predators and competitors that may be present (Figure 2). This measure prevents transplanting of undesirable forms from one bed to another by killing *Polydora,* boring sponges and other organisms that live within the shells of live oysters. Korringa (1951), using a solution of di-nitro-orthó-cresol at a concentration of 500 ppm, killed the majority of *Polydora* in shells of European oysters in this way within 3 hours. MacKenzie and Shearer (in press) repeated these experiments killing up to 90 per cent of the worms by exposing them from 1 to 3 hours to the above concentrations. However, when these workers used Victoria Blue B at a concentration of 200 ppm, they killed 97 per cent of the worms within only 15 minutes. MacKenzie and Shearer mentioned many other compounds that they found effective in the control of *Polydora* and other annelids inhabiting oyster shells.

The dipping of dredged oysters for different periods in Victoria Blue B and then leaving this material to dry in air also killed many undesirable forms, including tunicates and mussels. A detailed discussion of the use of Victoria Blue, as a practical method for killing oyster competitors, is offered in MacKenzie's article, which is now in press.

Copper sulfate is another compound that may be used advantageously to control oyster enemies and competitors by dipping them in a solution of this chemical. In the past we used this compound at Milford to kill drill embryos (Engle, 1941). Walne (1956) used different concentrations of copper sulfate to destroy fouling organisms on artificial oyster spat collectors. Glude (1957) showed that copper ions will effectively repel adult drills. Still more recently, MacKenzie (in press), in cooperation with local oyster companies, conducted

FIGURE 2. Experiments to develop dipping method to kill oyster enemies and competitors. Saturated solutions of common salt and weak dilutions of copper sulfate and Victoria Blue B are satisfactorily used for this purpose.

an extensive series of experiments in which copper sulfate was used to kill various oyster competitors. To kill mussels, MacKenzie recommends dipping them into copper sulfate solutions varying in strength from 0.5 to 1.0 per cent, if material is to be kept out of water for 24 hours or longer after dipping, and 1.0 to 2.0 per cent solutions, if it will be stored in air for only a few hours. This treatment kills mussels but does not affect medium and large oysters. However, young oysters, measuring less than 20 mm in length, should not be subjected to it even if the solution contains only 0.5 per cent of copper sulfate.

Another extremely simple but effective and versatile method to kill undesirable forms is the use of saturated or nearly saturated solutions of common salt (Loosanoff, 1958). By dipping the dredged material in a strong salt solution and then allowing it to dry on deck for some time, a wide variety of undesirable organisms can be destroyed. The method is extremely effective in killing shell-boring sponges of the genus *Cliona*. Complete mortality is achieved by immersing them in a saturated solution of common salt for only 30 seconds and then leaving them in air for at least 1 hour. Starfish, two species of *Crepidula*, several species of tunicates, the flatworm, *Stylochus ellipticus*, and many other undesirable organisms, including protozoa, hydroids, bryozoa, algae, and even small crustaceans, are killed by this method.

These experiments also indicated that a saturated salt solution may be helpful in controlling a drill population by killing their eggs and embryos while they are still in egg cases (Loosanoff, 1958). Heavy mortality of drill embryos was observed even when egg cases were immersed for only 3 minutes and then kept in air for several hours before being returned to sea water. Further studies on applications of strong and saturated salt solutions were recently completed at our laboratory, indicating wide application of this method (Shearer and MacKenzie, in press). We think that the dreaded shell disease of European oysters can be kept in check by wide usage of this method.

There remains one more approach to using chemical solutions in control of oyster enemies. It is thought that certain dangerous internal parasites of oysters and European mussels, such as copepods of the genus *Mytilicola*, may be eliminated by placing infested mollusks into solutions of certain insecticides (Loosanoff, Hanks and Ganaros, 1956). The method can probably be made more effective by adding to the solutions a thick algal culture which, after absorbing some insecticide, will be ingested by mollusks and later passed through the digestive tract, certain sections of which harbor parasitic copepods.

Chemical Treatment of Shellfish Bottoms

During recent years it was found that many enemies of bivalves can be controlled by the use of chlorinated oils, such as orthodichlorobenzene (Loosanoff, MacKenzie and Shearer, 1960a; Loosanoff, MacKenzie and Shearer, 1960b). Further experiments indicated that the effectiveness of the treatment can be increased by incorporating in heavy oils other chemicals, such as Sevin, an

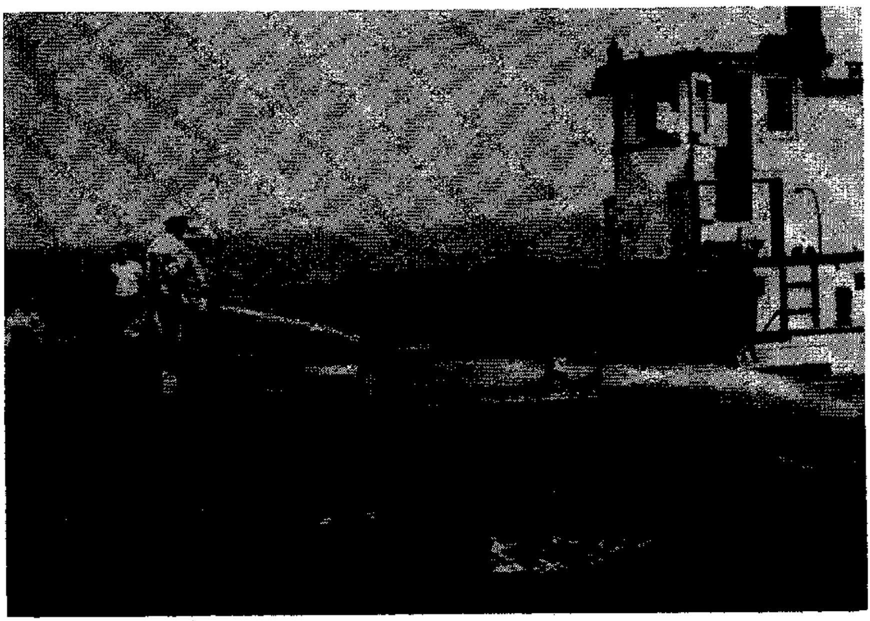

FIGURE 3. Chemically-treated sand being washed overboard with strong stream of water to destroy enemies on oyster beds.

insecticide which is relatively non-toxic to mammals. The oils are usually mixed with dry sand, broken oyster shells, or other inert materials to "anchor" them on the bottom undergoing treatment.

By spreading chemically-treated sand over shellfish beds, several enemies, including oyster drills, can be either almost entirely eliminated or their numbers greatly reduced. The formula that usually gives good results consists of mixing, by volume, 95 per cent of dry sand with 5 per cent of chlorinated benzenes containing from 1 to 3 per cent of Sevin. The sand is spread over the area either by a machine, such as is used when spreading sand on icy highways in winter, or by washing it overboard by means of a powerful stream of water (Figure 3). Several experiments of this nature conducted during the summer of 1960 in Long Island Sound and Great South Bay were quite successful. They will be described in detail later on in other publications.

This method of covering large bottom areas with chemically-treated sand may also be used to kill starfish already on the beds. Particles of sand falling on the upper surface of starfish will imbed in the delicate membrane covering these pests, quickly disintegrate it and eventually cause death.

The same method is also effective in stopping the re-invasion of shellfish beds with a new generation of those enemies that have swimming larval stages, such as starfish, crabs, and flatworms. Ready-to-metamorphose larvae will die soon after they settle on, or move over, the chemically-treated bottom.

Still another reason for spreading chemically-treated sand over oyster growing bottoms is to eliminate the mud shrimp, *Upogebia*, the ghost shrimp, *Callianassa*, and related forms which, by their continued digging activities,

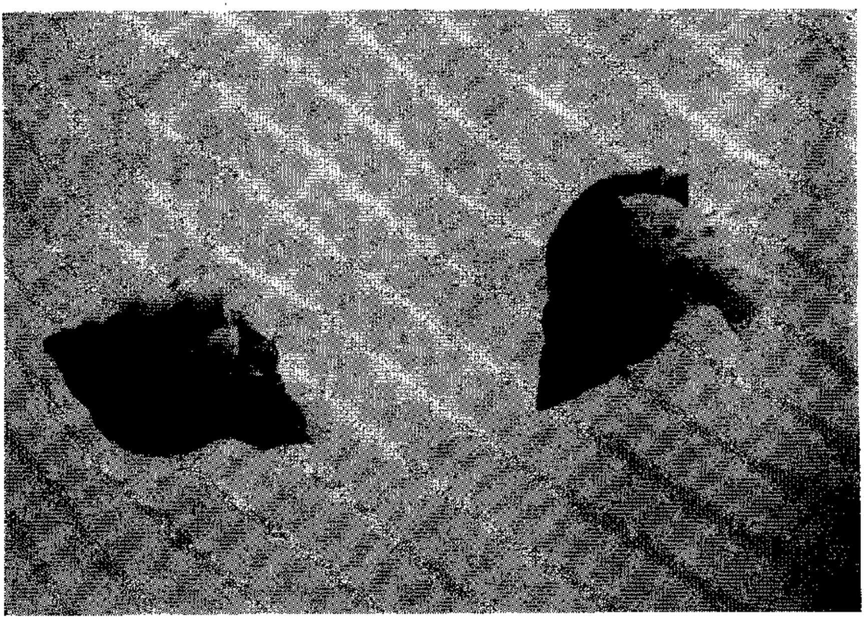

FIGURE 4. Oyster drills, *Urosalpinx cinerea,* swollen after contacting sand mixed with orthodichlorobenzene and Sevin.

render large bottom areas unsuitable for oyster culture (Loosanoff, MacKenzie and Shearer, 1960a). Preliminary experiments conducted on shrimp-infested bottoms of the State of Washington by Cedric Lindsay of the Department of Fisheries have indicated that these methods can be successfully used for this purpose (personal communication).

Chemical Barriers

Chemical barriers are made of a mixture of sand, such oils as orthodichlorobenzene, and other chemicals, depending upon what enemy or groups of enemies are to be controlled. We found that virtually all gastropods can be stopped by a barrier composed of only sand and heavy oils (Figure 4). However, as already mentioned, the efficiency of barriers can be increased by incorporating in them certain other compounds (Loosanoff, MacKenzie and Shearer, 1960a).

FIGURE 5. Starfish severely affected by chemical after contact with experimental barrier.

Several formulas have already been developed to arrest, under experimental conditions, movements of starfish, *Asterias forbesi* (Figure 5). Other formulas have been developed which seem to be effective in stopping, simultaneously, the movements of boring gastropods, starfish, and crabs. A promising combination for this purpose is orthodichlorobenzene containing small quantities of 2-chloro-1-nitro-propane and Sevin. However, since we do not know much about the toxicology of 2-chloro-1-nitro-propane and this material is expensive and difficult to obtain, another chemical, Rosin Amine D, manufactured by Hercules Company appears to be a good substitute. It will be tried next year on a large scale in Long Island Sound.

Because of recently acquired knowledge and quite extensive field experience, we can now create barriers wide enough and strong enough to stop movements of crabs. It should be remembered, however, that while this method may be safely applied in areas where crabs are of no commercial value, for example, in some waters of New England where the green crab is the chief enemy of the soft clam, in other areas, such as Chesapeake Bay, where the blue crab is an important commercial species, extreme care should be exercised. We hope, nevertheless, that by learning more about the application and special uses of chemical methods, life histories of different organisms populating aquatic basins, and by finding specific poisons that will affect only certain species of a large genus or family, we will eventually succeed in preventing unnecessary losses among useful animals.

We have experimented with barriers laid in laboratory troughs, in the intertidal zone of Milford Harbor, and finally in 20 feet of water on the bottom of Long Island Sound. In all cases we found that the barriers were effective as long as they did not become covered with a heavy layer of silt. During these experiments many interesting and important observations were made. For example, setting of oysters within the areas protected by barriers was just as good as on untreated bottoms. Furthermore, no noticeable mortality occurred among any forms within the barriers and, finally, growth of clams and oysters within the protected zones was just as rapid as in the outside areas established as controls (Loosanoff, MacKenzie and Davis, 1960).

The chemicals composing the barriers retained their strength for a considerable period. For example, the mixture constituting the intertidal Milford Harbor barrier, which was laid on April 19, 1959, was still strong enough to cause swelling of gastropods when tested in October 1960. Our divers also observed that, regardless of several heavy storms and a hurricane, the barrier laid on the bottom of Long Island Sound in 1959 was intact after one year. These observations indicate that, because of their long-lasting effectiveness, the use of barriers may be practical.

Prevention of Fouling

One of several difficulties experienced by oyster growers in this country and abroad is the rapid fouling of cultch. This is especially true when, to collect a new set of oysters, cultch is suspended in water. For example, in Milford Harbor, oyster shells or artificial cultch will be converted into balls composed of numerous fouling organisms within two or three weeks after planting.

Efforts to combat fouling have been carried on at our laboratory for many years. We discovered, quite some time ago, that setting of barnacles on spat collectors can be prevented if they are treated with DDT (Loosanoff, 1947). Our British friends continued these studies using, in addition to DDT, other chemicals, including Lindane (Waugh *et al.*, 1956). Recently, our studies have been considerably expanded. Experiments conducted last summer, which consisted of dipping oyster shells in certain heavy oils and, later, planting them in Long Island Sound for periods of 2 to 3 months, gave encouraging results. Oyster spat were more numerous on shells treated with certain oils, particularly Polystream and Polychlor mother liquor, both of which contain large amounts of tetrachlorobenzene, than on control shells.

These experiments, which were duplicated in Milford Harbor, not only showed that oyster set was heavier on shells treated with Polystream, but also that these shells were virtually free of fouling organisms, including barnacles,

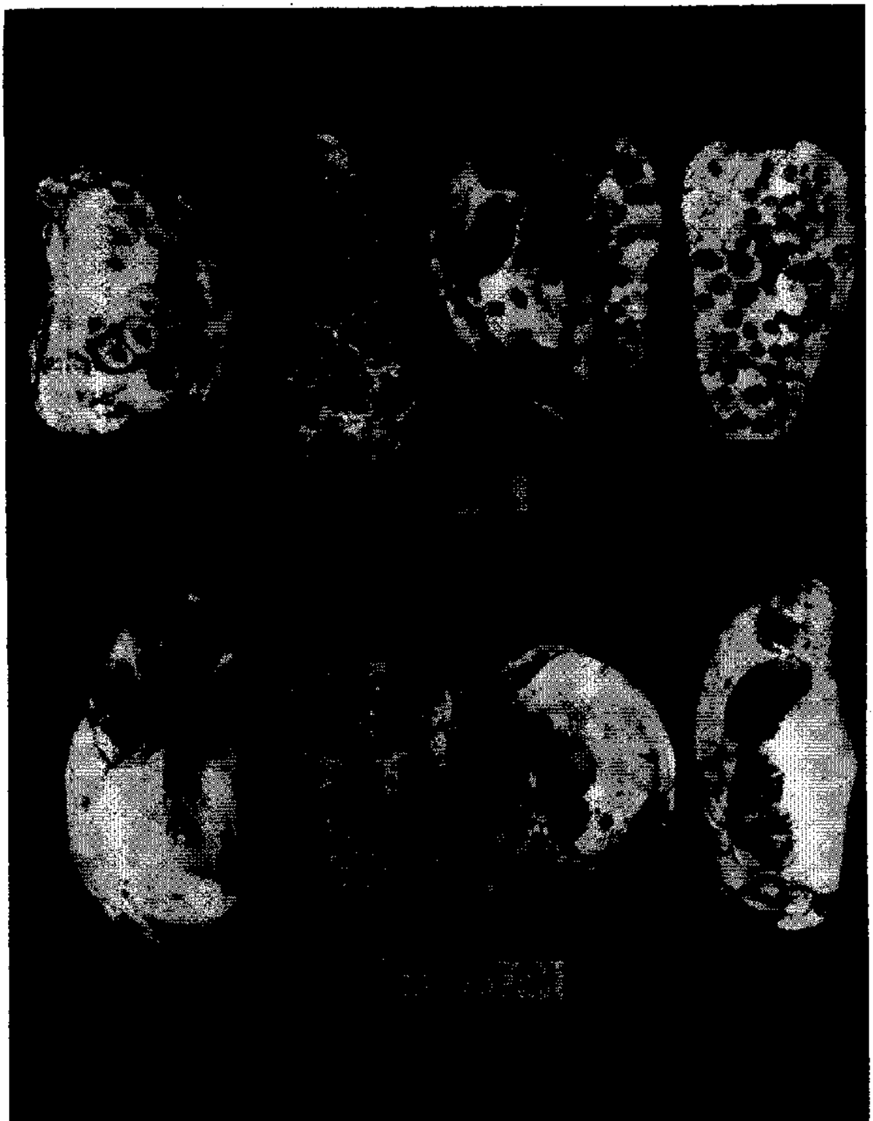

FIGURE 6. Photograph showing differences in intensity of setting of barnacles on Polystream-treated and control shells used as oyster set collectors.

tunicates, worms, hydroids, and the protozoan, *Folliculina* (Figure 6). What may be of special significance to the oyster industry of many areas is that shells treated with Polystream also repelled or killed the oyster leech, *Stylochus*, and its set. Extensive experiments to verify these conclusions are planned for next summer in the waters of several states.

Repelling Drills from Set Collectors

In some instances it may be practical to collect oyster set in areas where drills are abundant, provided that drills can be kept from attacking young oysters. This may be achieved by chemical treatment of cultch before it is placed in the water. Experiments of this nature were undertaken last year on oyster beds of Long Island Sound and Milford Harbor, and in outdoor troughs with running sea water (Loosanoff, MacKenzie and Davis, 1960). The oyster shells were dipped in one of the following: (1) orthodichlorobenzene; (2) orthodichlorobenzene and kerosene in equal volumes; (3) orthodichlorobenzene, trichlorobenzene and tetrachlorobenzene in equal volumes; and (4) a mixture of equal parts of orthodichlorobenzene, trichlorobenzene and tetrachlorobenzene, to which an equal volume of kerosene was later added. The final mixture was composed, therefore, of 50 per cent of the 3 chlorinated oils and 50 per cent of kerosene.

The results of the experiments were gratifying because they showed that oyster larvae set on oil-treated shells and, what may be even more important, that some of the mixtures, for example, that of 3 chlorinated oils diluted with an equal volume of kerosene, were effective for some time in keeping drills from attacking recently set oysters.

In the summer of 1960 the experiments were expanded by using a much larger number of collectors, new kinds of oils, and conducting observations in more locations. Since, at the time this report is being written, many collectors are still overboard and because the examination of samples is still in progress, we cannot offer final conclusions about the effectiveness of the method. However, we have sufficient evidence to conclude that all groups of shells dipped in chlorinated oils collected oyster set. Furthermore, in several cases oyster spat on oil-treated shells showed better growth than on control shells although, on the basis of present evidence, the rate of growth on oil-treated shells is, in general, somewhat slower. Finally, observations made during the past summer again indicated that drills are reluctant to attack oyster spat attached to shells treated with chlorinated oils. On the basis of the experiments carried on thus far, Polystream and Trimix seem to be the most effective agents to counteract drill activities.

A series of critical experiments to verify these conclusions is already underway. It appears, nevertheless, that the method will prove to be effective because, as soon as drills crawl upon Polystream or Trimix-treated shells, many of them swell and become unable to move. Probably touching the crystals of these oils, which can be seen on shells removed from the water even after being overboard for several months, affects the drills soon after their bodies come in contact with them. The method does not offer complete protection because some drilled oyster spat were found even on the treated shells. We hope, however, that by adding certain other chemicals to Polystream this will be prevented.

Baits

Use of chemically-treated baits to poison undesirable aquatic species, such as crabs, horseshoe crabs, rays and drumfishes, occurred to biologists some time ago. Our observations that crabs feeding on barnacles dipped in a solution of DDT went into convulsions soon after feeding, and similar observations by Dr. F. Gross of England (personal communication) led us to believe that poisoning of crustaceans can be simply accomplished by using insecticides. In our screening of several thousand chemicals, which were tested on approximately 10 different species of oyster enemies, we found many that can be used either in bait or in solution to kill most crustaceans that have been exposed to these poisons. To determine the effectiveness of these substances on the group of marine arthropods that has presented or can present problems in shellfish conservation or in other aspects of mariculture, we used the following species:

Rock crab	*Cancer irroratus*
Blue crab	*Callinectes sapidus*
Lady crab	*Ovalipes ocellatus*
Mud crab	*Panopeus herbstii*
Green crab	*Carcinides maenas*
Hermit crab	*Pagurus pollicaris*
Spider crab	*Libinia emarginata*
Common sand shrimp	*Crangon vulgaris*
Mantis shrimp	*Squilla empusa*
Horseshoe crab	*Limulus polyphemus*
Copepods	(several species)

The results showed that all these forms can be quickly affected (Loosanoff, Hanks and Ganaros, 1956). A list of over 100 substances, which were found effective in our experiments against crabs, has recently been published (Loosanoff, 1960). We recommend Sevin, one of the insecticides that is least toxic to humans and fish, for incorporation in bait to kill crabs. Our colleagues at Boothbay Harbor, Maine, have made prolonged studies on the use of Lindane in control of green crabs and have recently reported results of their extensive and convincing experiments showing that control of these crabs can be easily accomplished by proper use of chemicals (Hanks, in press).

The use of poison bait distributed on the bottom, perhaps in the form of pellets composed of agar, clam meat and a poison and made heavy enough to sink by addition of sand, may also help us to solve a number of problems where crabs are intermediate hosts in transmission of diseases. For example, we are all familiar with the fact that the sporozoan, *Nematopsis*, quite commonly found in oysters, is transmitted by mud crabs. In the past, heavy mortalities of oyster populations have been ascribed to these gregarines. At present, another extremely serious mortality of epizootic nature is raging in the waters of several states along our Atlantic coast. The organism, which is suspected of being responsible for this mortality and which, at present, is called MSX, is also a sporozoan and, presumably, may pass the intermediate stage in the body of certain crustaceans, perhaps mud crabs or bottom shrimps. Because we now have several methods to exterminate crustaceans we may, in the near future, prevent spreading of several diseases by destroying intermediate hosts of parasites.

Other Uses of Chemicals

In many areas the oyster crab, *Pinnotheres ostreum*, is very common. This crab, living inside of oysters, usually causes considerable damage to their bodies and, in general, affects their quality, in some instances even causing death. These parasites, and they are true parasites, may be controlled or entirely eliminated by using various modifications of the chemical methods mentioned in this paper. A little experimentation along these lines will probably point towards a simple but effective approach. We suggest that it consist of placing on an oyster bed, where such crabs are prevalent, certain organic solvents in which other chemicals, probably such insecticides as Sevin, are incorporated. These chemicals will dissolve at a comparatively slow rate and create an extremely light concentration of the insecticide near the bottom. This concentration, nevertheless, will be strong enough to kill the crabs in a few days. Perhaps our method of covering bottom areas with chemically-treated sand, which we recommend for control of drills, will be applicable. Next summer we intend to ascertain its effectiveness against *P. ostreum*.

I could continue with further suggestions about what can be done to control shellfish enemies not mentioned in this article, but it would be impractical because of the large number of cases to be considered. This article cannot be terminated, however, without mentioning that chemical methods may also be useful in control of shellfish diseases due to bacteria or fungi, such as the widespread fungus disease of southern oysters caused by *Dermocystidium*. This may again be accomplished by incorporating certain fungicides in the heavy oils and, after mixing the oils with dry sand, spreading the mixture over an oyster bed or surrounding the bed with a belt of this material. The slowly dissolving fungicides will gradually leave the oils and spread in a thin layer over the oyster bed, possibly creating concentrations, which will be sufficient to kill fungus already infesting the oysters or to prevent infestation of healthy oysters by fungus. Similar methods can probably be applied to control other microorganisms responsible for heavy oyster mortalities, including bacteria and, perhaps, even viruses.

In conclusion I want to emphasize that we fully realize that any chemical entering the water becomes a pollutant. Fortunately, the organic solvents that we employ in our formulas are virtually insoluble in water and, therefore, are relatively safe to use in an aquatic environment. Nevertheless, we are concerned with the potential danger of indiscriminate usage of large quantities of chemicals in aquatic controls. We also think that any compound to be used on shellfish beds on a large scale should be thoroughly evaluated by experienced biologists in terms of its danger to aquatic forms and, of course, in relation to human safety.

In other words, before the use of any chemical is generally recommended, a critical evaluation of the desirability of its usage should be made by comparing its positive and negative values. In our case, it will be especially important to determine the effects of chemicals on commercial species of shellfish, especially whether these compounds accumulate in the bodies of these mollusks rendering them undesirable or dangerous as food. Therefore, regardless of what components are recommended for the final formulas, their safety to humans will be fully established in accordance with recommended procedures.

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Economic Aspects of Markets for Middle Atlantic Oysters

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AN HISTORICAL ANALYSIS of oyster production and consumption in the United States shows that within the past 25 years two anomalous supply-demand situations have existed. Perhaps the most striking anomaly has occurred during the 15 postwar years when the domestic production of oysters, unlike the domestic production of most consumer goods, failed to respond to increased demand as a consequence of the sharp increase in population and per capita income. Preceding World War II, oyster production increased by about 34 per cent in the years from 1933 through 1937, at a time when general economic conditions were not conducive to such expansion. This expansion, however, was dissipated by a decrease in production which began in 1941. The fact now appears, that despite the brief 4-year expansion, oyster production nationally has remained fairly steady since 1933, without responding as would be expected to supply-demand imbalances.

The consumption of oysters in the United States is involved in the foregoing supply-demand situation. For many years the national per-capita consumption of oysters has been skidding downward. Although the unprecedented population and income growth of the postwar years created an expanding market, it did not halt the downward slide of per-capita consumption which began in 1937. Consumption was a little over three-fourths of a pound per person in 1937, and last year reached a low of 0.36 pounds per person. This figure does not include imported oysters. Imported oysters, largely canned, have had only nominal effect in bringing the per-capita consumption to 0.40 of a pound per person. The downward trend, particularly in the postwar years, appears to be a consequence of static production and rapid population growth. Some of the downward trend may be attributable to changing tastes.

Generally speaking, static production, rapid population growth together with an expanding national market, and increasing per-capita income have created a condition in the postwar years wherein the demand for oysters has exceeded the supply. The level of national consumption has been established and limited by the available supply of oysters on the market. This is particularly true in the case of fresh and frozen oysters to which the studies reported herein were directed.

It is self-evident, under supply-demand conditions which have existed, that the price of oysters would increase. An index of prices received for oysters by