CONTROL OF OYSTER DRILLS, EUPLEURA CAUDATA *AND* UROSALPINX CINEREA, *WITH THE CHEMICAL POLYSTREAM*

BY CLYDE L. MACKENZIE, JR., *FISHERY BIOLOGIST*
BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORY
MILFORD, CONN. 06460

ABSTRACT

Five experimental and 10 commercial treatments of oyster beds in four States were made with Polystream. On a typical bed, where water currents were less than 2.7 km. per hour, Polystream killed about 85 percent of the thick-lipped drill, *Eupleura caudata*, and 66 percent of the Atlantic oyster drill, *Urosalpinx cinerea*. A significantly higher percentage of oyster drills was killed by treatments made in late April and early May rather than later in the summer. Oyster drills that survived did not feed for several months. The number of drills remained low for at least 2 years. Polystream treatments killed only small percentages of fish, small clams, *Mercenaria mercenaria*, crabs, and other invertebrates. After a treatment, oysters, *Crassostrea virginica*, clams, and other organisms had small residues of Polystream in their tissues but gradually lost these residues. Growth of oysters was normal on treated beds.

Boring gastropods, known as oyster drills, and starfish, *Asterias forbesi*, are the most serious predators of oysters in Long Island Sound. The drills prey heavily on oysters, *Crassostrea virginica*, along the entire Atlantic Coast, from Canada to Florida, and in certain areas of the Pacific Coast. Where they are extremely numerous, oyster drills destroy nearly all oysters on commercial beds. In Long Island Sound, however, drills usually reduce the number of oysters to such a level that most beds are of marginal value commercially.

This article summarizes laboratory and field experiments made during the development of a control method of oyster drills for use on commercial oyster beds in southern New England and New York; it includes the results of 15 treatments during 1961–67.

HISTORY OF DEVELOPMENT OF METHOD

All early phases of work on the development of a method of control of oyster drills by use of Polystream, including the initial testing of chemicals, was done by the biological laboratory at Milford, Conn. Field tests and commercial applications of Polystream were made under the inspection of the author in the States of Connecticut, New York, Rhode Island, and Massachusetts. Additional independent laboratory and field studies were later made in Virginia.

EXPERIMENTAL WORK AT MILFORD

In 1946, the Fish and Wildlife Sèrvice biological laboratory, Milford, Conn., began a program of screening organic chemicals with the goal of eventually developing a method to control oyster drills (Loosanoff, 1960). A method was sought that would kill oyster drills, but would not harm oysters, clams, *Mercenaria mercenaria*, and other organisms on a shellfish bed, and also would not leave residues in tissues of shellfish that would be harmful to man. Tests were made in the laboratory and the field.

Laboratory Tests

Loosanoff, MacKenzie, and Shearer (1960a, 1960b) reported that chlorinated benzenes, such as monochlorobenzene, orthodichlorobenzene, paradichlorobenzene, trichlorobenzene, tetrachlorobenzene, and their mixtures, are toxic to several species of marine gastropods, including the thick-lipped drill, *Eupleura caudata*, and the Atlantic oyster drill, *Urosalpinx cinerea*. These chemicals were selected for further tests because they were toxic to snails, virtually insoluble in sea water, and of sufficient density to settle to the bottom of the Sound. The last two characteristics reduced the chance of damage to any but bottom-dwelling organisms whose soft parts contact the chemicals directly. Small quantities of Sevin (1-naphthyl-

Published May 1970.

N-methylcarbamate) were added to the chlorinated benzenes to increase their killing effect on the snails. In laboratory experiments, orthodichlorobenzene mixed with dry sand in the ratio of 1 to 19, by volume, and then spread over shallow pans killed most oyster drills; and when used to form a barrier in small troughs it prevented them from crossing the barrier for several months.

Loosanoff, MacKenzie, and Davis[1] stated that for 14 months small barriers consisting of orthodichlorobenzene and sand continued to affect oyster drills on contact but were not toxic to larvae and juveniles of sea squirts, *Molgula manhattensis*, common shipworms, *Teredo* sp., Atlantic oyster drills, eastern white slippers, *Crepidula plana*, and mud blister worms, *Polydora* sp., which set and grew within 2.5 cm. (1.0 inch) of the barriers. These observations showed that orthodichlorobenzene was only a contact poison. In large outdoor troughs siltation reduced the effectiveness of chlorinated benzenes by forming a covering layer that kept the oyster drills from touching the chemicals.

Field Tests

Loosanoff (1961) reported that oyster drills can be greatly reduced in numbers by spreading chemically treated sand over shellfish beds. The combination that gave good results consisted of 95 percent dry sand and 5 percent orthodichlorobenzene containing 1 to 3 percent, by weight, of Sevin. The chemicals were mixed with the sand in large commercial cement trucks. The treated sand, loaded on the deck of a boat, was then spread over the oyster bed by a high-pressure stream of water.

Davis, Loosanoff, and MacKenzie[2] reported the results of treatments of several small oyster beds. They emphasized the effects of chemical treatments on organisms other than oysters and clams. On July 16, 1961, a bed of about 1.6 ha. (4 acres) in Great South Bay, Long Island, N.Y., was treated with 9.5 kl. per hectare (5 yards per acre) of sand mixed with 1.9 hl. (50 gallons) of orthodichlorobenzene containing 6 kg. (13 pounds) (2 percent by weight) of Sevin. As the sand descended, several small fish were killed and common jellyfish were carried to the bottom. Shortly after the sand reached the bottom, sea squirts were found partially contracted; oyster drills and other snails were greatly swollen; and a number of hermit crabs, *Pagurus* sp., and mud crabs, *Neopanope texana*, were dead. They did not determine whether this experimental treatment eventually killed the oyster drills. Another bed, which was off the east end of Long Island in 9 m. of water, was treated in like manner. Because of strong water currents over the area, little sand actually reached the bottom that was to be treated and, as a result, the treatment was not effective. This failure indicated that in an area with strong currents it was very difficult to control oyster drills with sand treated with a chlorinated benzene.

In treatments along the Connecticut shore the effects of the chemicals on animals inhabiting the bottom varied somewhat depending on location of the bed. In open waters, divers noticed only a small effect on fish, hermit crabs, mud crabs, and annelids. In areas where waters were shallower and currents slower, however, the effect was greater. In all tests, fish, hermit crabs, and mud crabs fed and moved normally in an area within a few days after a treatment. Fish, perhaps attracted by the exposed white feet of swollen gastropods, were more numerous after a treatment. Most pelagic common shrimp that were in the immediate area at the time the treated sand was spread were apparently killed. Once the chemicals were on the bottom, however, shrimp moved in again and remained uninjured. Oysters and mussels, *Mytilus edulis*, when present, were pumping normally within an hour of the treatment. Starfish, *Asterias forbesi*, were irritated by treated sand falling on their aboral surface, and small sores soon appeared. In a number of treated areas starfish consumed swollen oyster drills and northern moon shells, *Polinices* sp. Davis et al.[3] also reported that the treatment did not reduce the intensity of setting of oyster and starfish larvae in the area.

Polystream[4] (trademark of Hooker Chemical Corporation for a mixture of polychlorinated benzenes containing a minimum of 95 percent total of active trichlorobenzene, tetrachlorobenzene, and

[1] Loosanoff, V. L., C. L. MacKenzie, Jr., and H. C. Davis. 1960. Progress report on chemical methods of control of molluscan enemies. Bur. Commer. Fish. Biol. Lab., Milford, Conn., Bull. 24 (8), 20 pp.

[2] Davis, H. C., V. L. Loosanoff, and C. L. MacKenzie, Jr. 1961. Field tests of a chemical method for the control of marine gastropods. Bur. Commer. Fish. Biol. Lab., Milford, Conn., Bull. 25 (3), 9 pp.

[3] See footnote 2.

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

pentachlorobenzene, and having a last crystal point of 18° C. ± 3° C.), a less expensive product than orthodichlorobenzene, was used for the first time on experimental beds in New Haven Harbor, Conn., in the summer of 1961. I made field tests to compare the effectiveness of orthodichlorobenzene and Polystream and to determine the minimum quantity of chemically treated sand needed to control oyster drills. Sevin was added to both types of polychlorinated benzenes at the rate of 2 percent by weight, and a total of 1.9 hl. of either orthodichlorobenzene or Polystream was mixed with each 9.5 kl. of sand. The two chemical-sand mixtures were spread over eight 0.4-ha. beds at rates of 1.9, 5.1, 9.5, and 19 kl. per hectare. Drill traps were used to estimate the effects of treatments on populations of oyster drills and mud crabs.

SCUBA divers studied the effects of these treatments. Their observations indicated that treatments of 9.5 and 19.0 kl. per hectare of either orthodichlorobenzene and Sevin or Polystream and Sevin caused all visible gastropods, including thick-lipped drills, northern moon shells, knobbed whelks, *Busycon carica*, channeled whelks, *Busycon canaliculatum*, and New England nassas, *Nassarius trivittatus*, to become swollen (snails listed in order of importance as shellfish predators; the New England nassa is not a predator). Apparently, the latter three species of predators were compelled to emerge from their usual position buried in the bottom. A number of pipefish, *Syngnathus fuscus*, mud crabs, and shrimp were either partially paralyzed or behaved abnormally. Small flounders, *Pseudopleuronectes americanus*, however, swam around apparently unharmed. Three days later these effects were more evident; all visible gastropods were either swollen and being eaten alive by starfish or they had already died. The pipefish, mud crabs, and shrimp, nevertheless, had either recovered or had been replaced by others from surrounding areas. Subsequent observations revealed that starfish were gradually consuming the remaining swollen gastropods. Thus, the area was left with a large number of empty gastropod shells which gradually disappeared; a lot with 42 shells of the northern moon shell per 50 m.^{2} of bottom on July 3, for example, had none by July 18. Presumably, the shells had been occupied by hermit crabs and carried away.

Catches of oyster drills on traps indicated that applications of 9.5 and 19.0 kl. of treated sand per hectare had killed nearly all drills and that the mixture of Polystream and Sevin was more effective than the mixture of orthodichlorobenzene and Sevin. The numbers of mud crabs on traps before and after treatments indicated that they were not harmed by the treatments. As a result, we thereafter used Polystream exclusively, abandoned orthodichlorobenzene, and standardized the treatment rate at 9.5 kl. per hectare.

Increased catches of drills, along the borders of lots several weeks after the treatment, indicated that drills were migrating into the lots from surrounding areas. This observation suggested that to ensure protection of an oyster bed from oyster drills, a zone perhaps 25 or more meters wide outside the bed, as well as the bed itself, should be treated, and that treatment of a single large bed would be more efficient than treatment of a number of small beds.

Polystream was used to treat beds inhabited by oysters and clams that are later consumed by humans. It was necessary, therefore, to determine whether these shellfish retained any residues of this chemical. In practice, however, only those beds with seed oysters on them are treated with Polystream. These oysters are transplanted to untreated beds at least 4 months before harvest. It was also desirable to know whether other organisms inhabiting treated beds, particularly those that might be taken by sport or commercial fishermen, retain residues of Polystream.

To determine whether oysters, clams, or other animals or plants accumulated and then lost residues of Polystream, I studied specimens that were collected from treated beds by divers or by dredging. I also studied northern lobsters, *Homarus americanus*, in cages to determine whether residues would be lost after a period of time in water free of Polystream. The U.S. Testing Company of Hoboken, N.J., determined the quantity of Polystream in tissues of the plants and animals through use of a technique developed by Schwartz, Gaffney, Schmutzer, and Stefano (1963).

In 1961 and 1962, I determined the quantities of Polystream in oysters and clams from a 0.4-ha. lot, treated with 1.9 hl. of this chemical. In oysters the residue was 1.8 p.p.m. (parts per million) 8 days after the treatment. It diminished slowly until none was detected 119 days later. Residues in clams

417-060 O - 71 - 8

TABLE 1.—*Residues of Polystream in oysters and clams on a 0.4-hectare bed in New Haven Harbor, Conn., after it was treated with Polystream-sand, June 27–29, 1966*

Time after treatment	Residues	
	In oysters	In clams
Days	*P.p.m.*	*P.p.m.*
8	1.8	1.1
14	2.3	1.7
28	0.2	0.6
56	0.3	0.3
77	0.7	0.7
119	<0.1	<0.1
336	<0.1	<0.1
455	0.1	0.1

were at similar levels and were lost at similar rates (table 1).

Oysters removed from a treated bed and replanted on an untreated area lost any residue of Polystream within a week. Nevertheless, the first few times oysters that had once grown on a treated bed were to be harvested, they were analyzed for any possible residue of Polystream before clearance for marketing. None of these oysters had residues.

In 1966, I determined the rates of loss of Polystream in oysters at several distances from lot 42, Norwalk, which was treated on August 24, 1966, and where strong currents had washed many granules off the lot. After 8 days, residues were as high as 0.3 p.p.m. in oysters 150 m. from the lot and were higher in oysters closer to the lot. On October 13, however, only those oysters 15 m. or closer to the lot showed any residue. At this distance the level had dropped from 1.7 p.p.m. in September to 0.2 p.p.m. On December 8, 106 days after the treatment, no residues were detected in any oysters outside the treated lot (table 2).

To determine the quantity of Polystream in tissues of other organisms inhabiting an oyster bed,

TABLE 2.—*Residues of Polystream in oysters collected at various distances from lot 42, Norwalk, Conn. Lot was treated on August 24, 1966*

Distance from lot 42	Date of collection (1966)		
	Sept. 1	Oct. 13	Dec. 8
M.	*P.p.m.*	*P.p.m.*	*P.p.m.*
15	1.7	0.2	<0.1
30	0.4	<.1	<.1
75	0.2	<.1	<.1
150	0.3	<.1	<.1

I made periodic collections from treated beds. All species of animals or plants collected within a year had accumulated a small quantity of Polystream. Residues of Polystream eventually diminished in those species, namely, the bay scallop, *Pecten irradians*, hermit crab, and sea lettuce, *Ulva* sp., where comparisons between time intervals were made (table 3).

By holding northern lobsters in a cage for a week in the center of a bed 45 days after it was treated, I found that they do accumulate a small residue of Polystream (1.4 p.p.m.) when retained in a treated area. A group of lobsters held on the treated lot for a week and then held on an untreated area for another week did not have any residue. Thus, lobsters may accumulate a small quantity of Polystream while they inhabit a treated bed, but they lose it soon after they leave the bed.

To determine mortality rates of oysters because of possible predation by oyster drills on treated beds, divers collected oysters periodically on several beds. The divers either swam across the center of beds for a distance of perhaps 150 m., gathering about 30 clusters of oysters randomly, or they collected oysters and all other material from within a metal ring enclosing either 1 or 1.5 m.[2] of bottom from 10 different sections.

TABLE 3.—*Residues of Polystream in animals and plants inhabiting oyster beds in Conn. and N.Y. treated with Polystream*

Animal or plant	Location	Time after treatment	Residue
		Days	*P.p.m.*
Northern puffer (*Sphaeroides maculatus*)	New Haven (State spawning bed)	31	5.9
Sea robin (*Prionotus carolinus*)	New Haven (State spawning bed)	25	8.4
Sand shark (*Carcharias taurus*)	New Haven (lot 152)	8	5.0
Starfish (*Asterias forbesi*)	New Haven (lot 15)	30	1.8
Bay scallop (*Pecten irradians*)	Sag Harbor (lot S)	6	13.6
Bay scallop	Sag Harbor (lot S)	250	0.9
Northern moon shells (*Polinices* sp.)	Northport (lot 1)	1 hour	50.0
Hermit crab (*Pagurus* sp.)	New Haven (lot 152)	1	12.3
Hermit crab		25	2.2
Mud crab (*Neopanope texana*)	New Haven (lot 152)	1	20.5
Red sponge (*Microciona prolifera*)	New Haven (lot 13)	25	2.3
Spaghetti grass (*Codium fragile*)	Sag Harbor (lot S)	250	0.1
Sea lettuce (*Ulva* sp.)	New Haven (lot 152)	1	8.9
Sea lettuce	Sag Harbor (lot S)	6	0.3

EXPERIMENTAL RESULTS IN OTHER AREAS

Wood and Roberts (1963) reported that in the laboratory Polystream alone killed 50 to 78 percent of large Atlantic oyster drills from the Eastern shore of Virginia and that a mixture of Polystream and Sevin killed 66 to 77 percent. Thus, they felt that Sevin was not needed. They also indicated that if oyster drills are in poor condition, they are more easily killed by Polystream. Therefore, they recommended that treatments should be made in the early spring when oyster drills are emerging from winter dormancy.

Haven, Castagna, Chanley, Wass, and Whitcomb (1966) reported the results of a field test in Hog Island Bay, Va. A 0.4-ha. section of bottom was treated with 9.5 kl. of sand mixed with Polystream containing 2 percent of Sevin. The oyster drills were not killed by the treatment, they deposited egg cases at a normal rate, and they destroyed as many oysters on the treated plots as on untreated control plots. I believe the reason for the ineffectiveness was that the treated sand soon sank as deep as 4 cm. into a layer of silt on the bed; thus, the drills could move over the bottom without contacting significant quantities of the chemicals. Haven et al. (1966) also reported that the Polystream-Sevin treatment had a deleterious effect on other living organisms and that growth of oysters and clams was apparently retarded.

RESULTS OF COMMERCIAL TREATMENTS

I used several methods to evaluate the effectiveness of treatments in killing oyster drills and their effects on organisms inhabiting oyster beds. Ten commercial treatments of oyster beds are described.

METHODS USED IN EVALUATION

Oyster companies used a standard rate of 1.9 hl. of Polystream per hectare (50 gallons per acre) of oyster bed. In early treatments, they mixed Sevin with Polystream at the rate of 2 percent by weight. The Polystream was mixed with either dry sand or a granular clay [the mixture is termed Polystream (Granular)] which carried it to the bottom and dispersed it.

Several techniques were used to evaluate the effects of treating commercial oyster beds with Polystream and Sevin. On numerous occasions SCUBA divers examined each bed carefully for 20 to 30 minutes to determine the gross effects of the chemicals on all visible living animals and plants. Often they made the first examination within an hour of a treatment and followed it by many subsequent periodic examinations during the next 2 to 3 years. They examined certain beds once a month during collections to determine survival rates of oysters.

In 1961–63, drill traps were used to estimate the effectiveness of treatments in controlling oyster drills. Because mud crabs enter drill traps in large numbers, I estimated the effect of treatments on these populations.

From 1964–67 I made quantitative determinations of the number of drills per unit area with a hydraulic sampler, which pumps through a mesh bag all bottom material from within a ring enclosing areas of 1 or 1.5 m.^{2} All coarse material is retained within the bag, carried to the surface, and sorted. This sampling method, which is carried out by divers, provides an accurate measure of the density of oyster drills and other mollusks on a shellfish bed if enough samples are taken. I took about 25 random samples on beds 2 to 6 ha. in size a few days before and again about a month after a treatment. I determined the percentage of oyster drills killed by comparing their densities before and after treatments. Actually, the Atlantic oyster drills on many beds were too few in number for me to determine the precise percentage of this species killed.

EFFECTS OF TREATMENTS IN DIFFERENT AREAS

Ten commercial treatments in four States were made with Polystream. Each treatment will be described separately by areas.

Area 1: Lewis Gut, Bridgeport, Conn., 1962

Lewis Gut is a long narrow arm of Bridgeport Harbor. The water is about 1 to 3 m. deep at low tide, and maximum currents run at about 4.5 km. per hour (2.5 knots). On June 27 and 29, 1962, an oyster company treated 12 ha. of this area with a mixture of Polystream-Sevin and sand.

Effect on gastropods.—Divers observed that within an hour after the treatment nearly all thick-lipped drills, Atlantic oyster drills, northern moon shells, and both knobbed and channeled whelks were swollen; a few weeks later most of these gastropods, as well as mud snails, were dead.

To evaluate the number of oyster drills killed, I used drill traps. The catch per trap per week fell from 16 drills before the treatment to 0.4 drill afterwards. One year later the average catch of oyster drills increased, primarily by recruitment of young drills, to about two per trap per week. In 1964, the average catch rose to about 5 per trap per week, again as a result of recruitment by young oyster drills; by July 1965 it rose to 13 per trap per week (fig. 1).

Effect on associated animals.—During 1961, divers observed that only a small number of fish—primarily sea robins, *Prionotus carolinus;* pipefish; flounders; mummichogs, *Fundulus heteroclitus;* and eels, *Anguilla rostrata*—were present in Lewis Gut before or after the treatment. Immediately after the application of chemicals only the pipefish appeared to be affected, i.e., more sluggish than usual. A few hours later, however, mummichogs were dying along the shore as some of the finer sand coated with Polystream was churned up in the water by wave action.

This treatment had a slight effect on several organisms. Hermit crabs were affected to some degree. A number of them had no shells; apparently, a small quantity of treated sand entered the shell and caused enough irritation to compel them to leave. The abdomens of a number of these crabs had been bitten off. Most mud crabs were unaffected, but between 5 and 10 percent were twitching abnormally immediately after the treatment. The treatment also compelled many nereids and nemerteans to emerge from their burrows. A few weeks later all animals not killed by the initial treatment appeared to be normal.

Catches on drill traps indicated that the treatment did not reduce the population of mud crabs. The weekly catch of these crabs on drill traps followed the same pattern each year: Each trap caught an average of about 15 crabs per week in May, June, and July; about 10 crabs during August; and (because of recruitment of young crabs) 18 to 23 crabs in the fall (fig. 2).

Effect on predation.—In midsummer of 1962 an oyster company planted 3,500 hl. (10,000 bushels) of seed oysters in Lewis Gut. Periodic examination of the oysters through early winter showed little loss from predation by oyster drills.

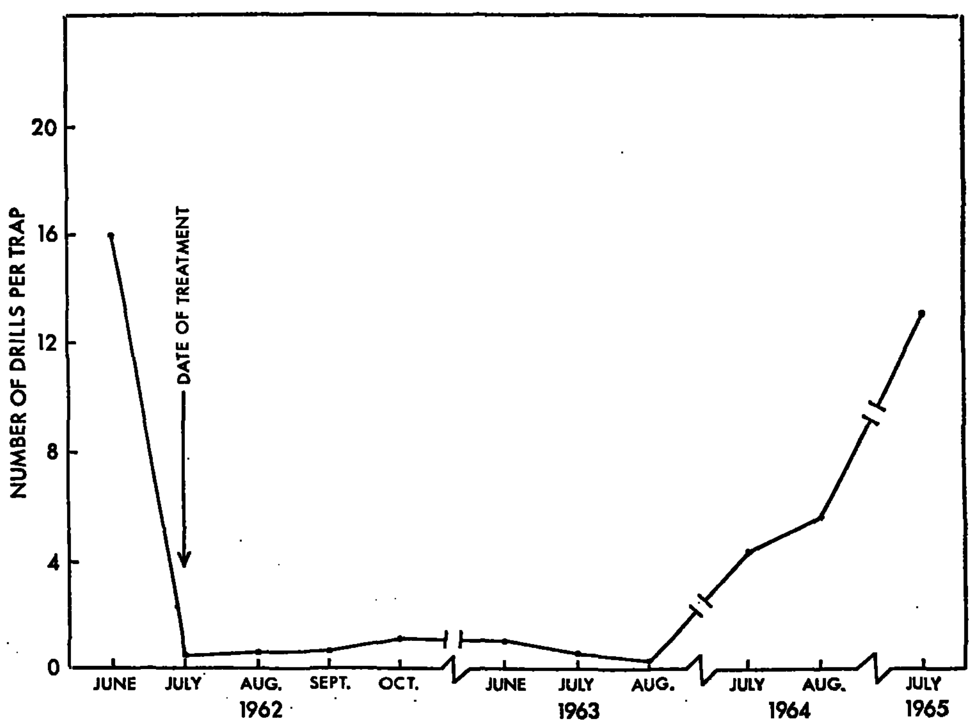

FIGURE 1.—Catches of oyster drills on traps in treated area of Lewis Gut, Bridgeport, Conn.

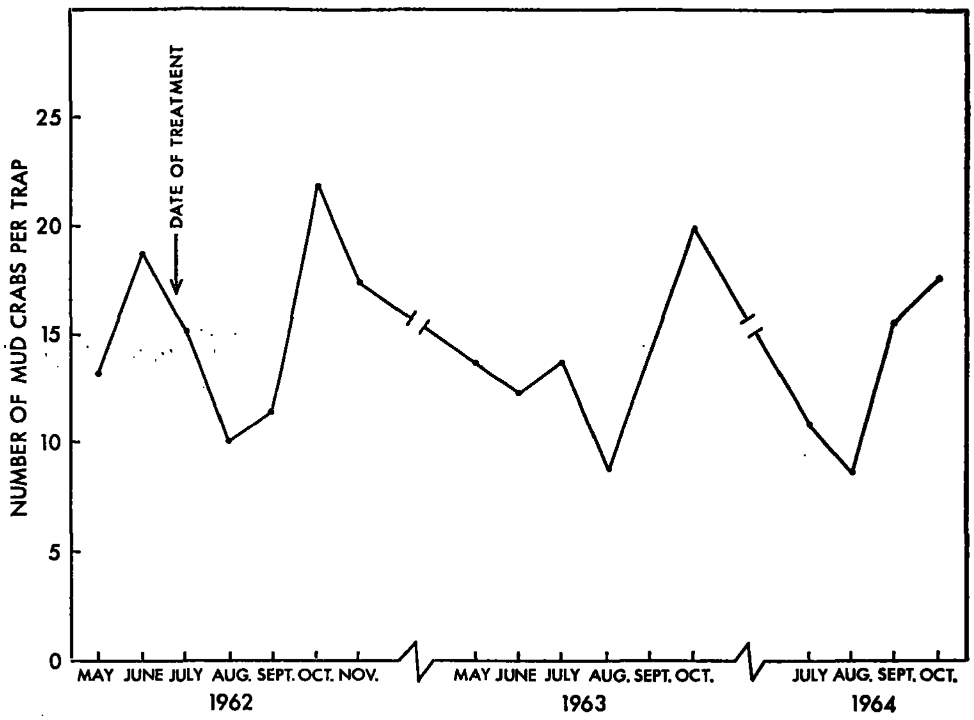

FIGURE 2.—Catches of mud crabs on traps in treated area of Lewis Gut, Bridgeport, Conn.

Area 2: Northport Harbor, N.Y., 1963

Northport Harbor on the north shore of Long Island is about 6.5 km. long. The oyster beds are in water 4.5 to 7.5 m. deep at low tide, and water currents rarely exceed 1.8 km. per hour.

On May 21 and 28, 1963, I made a series of comparative treatments. The purpose was to determine whether Drillex (a mixture of Polystream and 2 percent by weight of Sevin) is more lethal to oyster drills than Polystream alone. The experiment had four 2-ha. lots. Two lots received an application of 11.5 kl. of treated sand per hectare. They were designated as 1 (for Polystream) and 1 x (for Drillex). The remaining two lots which received 19.0 kl. of treated sand per hectare were designated as 2 and 2 x.

Effect on gastropods.—The treatments had a very deleterious effect on gastropods. A few hours after the treatments, divers observed that nearly every visible gastropod on all four lots was swollen; on lots treated with Drillex, however, the drills expanded faster and sooner. Ten days after the treatments, most thick-lipped drills were drawn deeply into their shells but some were still swollen. Northern moon shells were observed in three conditions—partially expanded, dormant with their operculum flush with their aperture, and dead. Twenty-three days after the treatments divers noted that all visible thick-lipped drills were dead on lots 2 and 2 x, and only a small number were alive on lots 1 and 1 x. No northern moon shells were observed either dead or alive; even their shells were gone. Hermit crabs had probably carried them off the bed.

Because many flounders were swimming over the beds and crabs were numerous when the snails were swollen, these fish had ample opportunity to feed on the paralyzed drills. I observed no snails being consumed, however; instead, they appeared to die directly from the toxic effects of the chemicals.

Examination of the bottom showed that Polystream alone killed almost as many oyster drills as Drillex.

Effect on associated animals.—Divers observed that during the applications of Drillex-sand a small number of flounders, many hermit crabs, shrimp, and annelids were killed; however, 10 days later they saw a large number of healthy flounders (only about 1 percent were still affected) and mud crabs on the two treated beds.

Polystream was used in all later commercial treatments because these experiments showed it was much less toxic than Drillex to associated animals, particularly arthropods.

Effect on predation.—I made no careful quantitative determinations; however, periodic observations of the lot indicated that predation by oyster drills on oysters on the treated lots during 1963 was slight.

Area 3: Northport Harbor, N.Y., 1965

On April 28, 1965, which was 2 years after the initial treatment, lot 1 was treated again with Polystream-sand.

Effect on gastropods.—Eight days after the treatment divers observed that every snail was swollen.

The treatment killed 64 percent of the oyster drills (77.2 percent of the thick-lipped drills and 8.6 percent of the Atlantic oyster drills) and reduced their numbers from 31.5 to 11.4 per $m.^2$ (table 4).

Effect on associated animals.—Nine days after the treatment divers found 6 stunned adult flounders and one dead juvenile on the bed among about 50 healthy flounders of mixed ages. The only hermit crab they saw was healthy.

Before treatment the number of young clams (5–7 mm. long) on the bed was 158 per square meter; 28 days after the treatment the number of clams was 125 per square meter. Thus, apparently only about 20 percent were killed.

Effect on predation.—I made no quantitative determinations. Periodic observations of the lot indicated, however, that predation by oyster drills during 1965 was slight.

Area 4: Northport Harbor, N.Y., 1966

On May 9, 1966, 3 years after the initial treatment, lot 2 was treated again, this time with Polystream (Granular).

Effect on gastropods.—Three days after the treatment divers found that all thick-lipped drills, Atlantic oyster drills, northern moon shells, and New England nassas were swollen.

The treatment killed 92 percent of the oyster drills (94.5 percent of the thick-lipped drills and 71.7 percent of the Atlantic oyster drills) and reduced their numbers from 27 to 2.1 per square meter (table 4).

Effect on associated animals.—No observations were made by divers.

Effect on predation.—I made no careful quantitative determinations. Several observations of the lot indicated, however, that predation by oyster drills during 1966 was slight.

TABLE 4.—*Density of oyster drills, before and after treatments with Polystream and sand or Polystream (Granular), on oyster lots in N.Y., Conn., R.I., and Mass., 1965–67*

Lot no. and area [1] (hectares)	Date of treatment	Formulation	Drills per m.[2]				Killed [4]		
			Before treatment		After treatment				
			E. caudata	*U. cinerea*	*E. caudata*	*U. cinerea*	*E. caudata*	*U. cinerea*	Both species combined
			Number	*Number*	*Number*	*Number*	*Percent*	*Percent*	*Percent*
25 (3.2)	4/30/65	Poly-sand	3.3	0.9	0.0	0.5	100.0	46.6	88.7
1 (2.4–3.2)	4/28/65	Poly-sand	25.2	6.3	5.7	5.7	77.2	8.6	64.0
2 (2.0)	5/9/66	Poly (Gran.)	24.1	2.9	1.3	0.8	94.5	71.7	92.3
205 (1.6)	9/15/66	Poly (Gran.)	[3] 4.0		[3] 0.9				77.5
18 [2]	4/ ?/67	Poly (Gran.)	7.5	0.9	2.4	1.6	68.0		52.0
40 [2]	4/29/67	Poly (Gran.)	12.0	4.7	2.2	1.6	82.2	66.7	77.8
49 [2]	4/29/67	Poly (Gran.)	5.6	0.7	0.9	0.0	84.6	100.0	86.4
42 (2.8)	5/ 1/67	Poly (Gran.)	3.0	0.3	0.9	1.0	66.7		43.5
50 [2]	5/ 1/67	Poly (Gran.)	12.6	1.3	1.7	0.6	86.4	55.6	83.5
19	Control	None	18.8	0.7	19.5	1.7			
RI (0.8)	5/ 1/67	Poly (Gran.)	0.0	6.5	0.0	0.0		100.0	100.0
FP (0.08)	5/29/67	Poly (Gran.)	0.0	40.8	0.0	2.2		94.5	94.5
FP	Control	None	0.0	37.2	0.0	33.2			

[1] Lot 25, Oyster Bay, N.Y.; Lots 1, 2, Northport, N.Y.; Lots 205, 18, 40, 49, 42, 50, and 19, Norwalk, Conn.; RI, Charlestown Pond, R.I.; FP, Fresh Pond Mass.

[2] Actual number of hectares treated on these beds is unknown, but I estimated that areas treated ranged between 1.2 and 6.0 hectares.

[3] Both species.

[4] If count increased, no percentage is given for this species

Area 5: Sag Harbor, N.Y., 1963

A 0.4-ha. lot along the eastern shore of Shelter Island in Sag Harbor was treated. The water over this lot is about 3 m. deep at low tide, and maximum currents are about 2.7 km. per hour.

On September 27, 1963, Polystream (Granular) was used for the first time to control oyster drills.

Effect on gastropods.—Within an hour of the treatment divers noticed that all visible snails were at least partially swollen. A week later divers observed many affected thick-lipped drills, Atlantic oyster drills, northern moon shells, and both knobbed and channeled whelks.

Ten drill traps were placed on the treated lot and an adjacent area before the treatment. The traps in each area collected between 200 and 300 oyster drills. After the treatment, traps were examined only once. They collected only 10 oyster drills on the treated area but gathered 127 on the control area. I did not count the two species of drills separately.

Effect on associated animals.—Divers observed that the treatment did not affect associated animals and plants, such as flounders, bay scallops, mud crabs, and sea lettuce.

Effect on predation.—No determinations were made.

Area 6: Oyster Bay Harbor, N.Y., 1965

Oyster Bay Harbor on the north shore of Long Island is about 8 km. long. The oyster beds are in water from 3.5 to 10 m. deep at low tide and water currents do not exceed 2.7 km. per hour.

On April 30, 1965, lot 25, 3.2 ha., was treated with Polystream-sand.

Effect on gastropods.—The divers made no observations. The treatment killed 89 percent of the oyster drills (100 percent of the thick-lipped drills and 46.6 percent of the Atlantic oyster drills) and reduced their numbers from 4.2 to 0.5 per square meter (table 4).

Effect on associated animals.—The divers made no observations.

Effect on predation.—Lot 25 was planted with small oysters in 1965, 1966, and 1967. Each year oysters were grown on the bed during their first summer of life and then transplanted to another bed the following spring. When first planted in June, July, August, and early September, the oysters were about 5 to 10 mm. long. By late November most of them had grown to 40 to 60 mm.

Predation on the oysters was light in each of the 3 years. On October 1, 1965, examination of the bed showed that less than 5 percent of the oysters had been killed by oyster drills and starfish combined. On July 22, 1966, divers observed that no oysters had been drilled. By October 9, 1967, oyster drills and starfish had killed 4.3 percent of the oysters on one section of the lot and 8.1 percent on another section. Predation by starfish was responsible for most of the mortality.

Area 7: Norwalk Harbor, Conn., 1966

Norwalk Harbor is interspersed with several small islands that protect oyster beds in channels and bays from storms. Water over the beds is from 2 to 6 m. at low tide, and the strongest currents run about 3.5 km. per hour.

Lot 42 in Norwalk Harbor was treated with Polystream (Granular) on August 24, 1966. Depth of water at mean low tide averages about 3 m.; maximum current is 3.5 km. per hour. Divers reported that strong currents carried off the lot a portion of the granules.

Effect on gastropods.—Before the treatment, divers counted up to five oyster drills of both species on each cluster of oysters. Within an hour after the treatment all visible thick-lipped drills and Atlantic oyster drills on clusters of oysters were swelling.

On September 8, 1966, 14 days after the treatment, divers observed that most oyster drills attached to clusters of oysters had fallen to the bottom. In a few instances, however, one or two oyster drills that were protected by being attached on the underside of clusters were unaffected and some were feeding on oysters.

On frequent inspections of the lot divers found that most oyster drills remained stunned, in a semiswollen condition, until November. A small number of drills may have recovered before the water dropped below 10° C., the temperature at which they normally become dormant.

As far as divers could determine, the treatment of lot 42 on August 24 did not kill many oyster drills but only immobilized them and prevented them from feeding. I suspected that a higher percentage would have been killed if the treatment with Polystream had been made in late April or early May.

To determine more precisely the effect of Polystream in the summer, however, an oyster company treated lot 205, in a more protected area. Tidal currents over this lot run at no more than 0.9 km. per hour and, therefore, did not carry off the Polystream (Granular). The water is about 2 m. deep at low tide. On September 15, when the lot was treated, the water temperature was about 21° C.

A month later determinations with the hydraulic sampler showed that the treatment killed 78 percent of the oyster drills (no separation of species was made) (table 4).

Effect on associated animals.—On lot 42, divers reported that a large number of pipefish, juvenile flounders, mud crabs, and shrimp were stunned by the chemical an hour after the treatment, but these animals appeared to be normal later. They made no observations on lot 205.

Effect on predation.—In early May 1966, lot 42 was planted with 350 hl. of 1-year-old oysters (5,000–6,000 individuals per bushel). On June 17, 7 weeks later, oyster drills had killed 4.3 percent of the oysters and had reduced the number of live oysters per cluster from 19 to 18.2.

By July 25, 12 weeks after the planting, the rate of kill by oyster drills had increased tremendously. For example, 34 percent of the oysters had been killed around the edges of the bed and 26 percent in the center. Thus, during the period of 5 weeks, from June 17 to July 25, the average kill was 4.8 oysters per cluster, or nearly one oyster per cluster per week.

On August 24, the day the lot was treated, a third sampling was made. In areas around the edges of the lot, where oysters were planted thinly, clusters averaged only two live oysters each. In the center of the lot the number of live oysters per cluster averaged between 9 and 10. Thus, even in the main portions of the lot about 50 percent of the oysters had been destroyed. Oyster drills caused almost all the mortality; starfish caused only a small amount.

The fourth sampling was made on September 8. In the main portion of the lot, clusters had an average of ten 1-year-old oysters and, in addition, 18.3 live spat had attached to each cluster. By counting small oyster scars I determined that the original 1966 oyster set had averaged about 30 per cluster. Thus, even in the center of the lot, oyster drills had destroyed more than a third of the 1966 oyster spat by the time of treatment, August 24.

By observing these oysters through the fall of 1966 and into the spring of 1967, I found that virtually no additional oysters were killed by oyster drills. On March 31, 1967, clusters in the main portion of the lot averaged 9.3 2-year-olds (in 1966 they were 1-year-olds) and 21.5 1-year-olds of the 1966 oyster set. No careful determinations were made on lot 205. Later periodic observations indicated, however, that predation by oyster drills was slight.

In the spring of 1967, when these oysters were transplanted to another lot, their volume had increased to 2,100 hl., a sixfold increase during one growing season. I did not determine the increase in size of individual oysters.

Area 8: Norwalk Harbor, Conn., 1967

Five lots in Norwalk were treated with Polystream (Granular) between April 29 and May 13, 1967. Lot 42 was treated again and two lots alongside, lots 40 and 50, were treated for the first time. Depths of water and current velocities are about the same over these three lots. Lots 18 and 49 were also treated for the first time. The depth of water over these lots at low tide is about 2.5 m. and current velocities do not exceed 0.9 km. per hour. Lot 19, adjacent to lot 18, was not treated and served as a control.

Effect on gastropods.—Divers made no observations during or immediately after these treatments.

On lot 18 the treatment killed 52 percent of the oyster drills (68 percent of the thick-lipped drills and apparently none of the Atlantic oyster drills—again, numbers of Atlantic oyster drills were too low for significant comparisons) and reduced their numbers from 8.4 to 4.0 per square meter (table 4).

On lot 40 the treatment killed 78 percent of the oyster drills (82.2 percent of the thick-lipped drills and apparently 66.7 percent of the Atlantic oyster drills—again, numbers of the latter species were too low for accurate appraisal) and reduced their numbers from 16.7 to 3.8 per square meter (table 4).

On lot 42 the treatment killed 44 percent of the oyster drills (66.7 percent of the thick-lipped drills and apparently no Atlantic oyster drills—numbers of Atlantic oyster drills were too low for reliable comparisons) and reduced their numbers from 3.3 to 1.9 per square meter (table 4). Because most oyster drills were killed on this lot by the second treatment and not by the first in 1966, I believe that treatments in early May are much more effective than those made later in the summer.

On lot 49 the treatment killed 86 percent of the oyster drills (84.6 percent of the thick-lipped drills and apparently all of the Atlantic oyster drills) and reduced their numbers from 6.3 to 0.9 per square meter (table 4).

On lot 50 the treatment killed 84 percent of the oyster drills (86.4 percent of the thick-lipped drills and 55.6 percent of the Atlantic oyster drills) and reduced their numbers from 13.9 to 2.3 per square meter (table 4).

Lot 19, which served as a control, was sampled at the same time as the other lots. The density of oyster drills per square meter was about the same on each date; on May 10 it was 19.5, and on June 30 it was 21.2 (table 4).

Effect on associated animals.—Divers did not examine these lots closely during or immediately after treatment. At intervals during the summer of 1967, however, they observed that healthy flounders, young starfish, mud crabs, and other animals were numerous on the beds. They saw no affected animals. In fact, most animals were more numerous on treated lots than on areas barren of oysters nearby. The divers did not count the young starfish on unplanted areas, but on October 6 they counted 8.8 young-of-year starfish per square meter on lot 18, and 35.3 per square meter on lot 40.

Effect on predation.—I carefully recorded mortalities of oysters on these lots from the time they were planted through November when oyster drills became dormant. In May 1967, 1- and 2-year-old oysters were planted on lot 40 and 1-year-old oysters were planted on lots 42, 49, and 50; and from June through early September, 1967-year-class hatchery-reared seed oysters about 5 mm. in length were planted on lot 18. Losses of oysters because of predation by oyster drills did not exceed 1.5 percent on any of these lots by late November (table 5). Because enough drills were present on some lots to cause higher mortalities—lot 40, for instance, had 3.8 oyster drills per square meter, and lot 50 had 2.3 per square meter—most live oyster drills must have been sufficiently "stunned" by the Polystream to prevent their feeding. This apparent "stunning" effect was also evident on lot 42 in 1966.

Oysters planted on these lots freshly treated with Polystream grew normally. For example, the 1-year-old oysters on lot 50 increased in volume from an average of less than 1 cc. to about 15 cc. each during the 1967 growing season. My determinations of growth of oysters planted on untreated bottoms show that this amount of growth is about normal.

Area 9: Foster's Cove, R.I., 1967

Foster's Cove on the south shore of Rhode Island, about 4 ha. in area, is a tidal pond connected to Charlestown Pond by a narrow inlet. Depth of water over the oysters ranges from 0 to 2 m. at low tide. There is little exchange of water between the two areas; thus, the principal water currents in the cove are caused by winds. Examination of three sections of Foster's Cove on November 10, 1966, indicated that oyster drills had killed about 75 percent of the oysters.

On May 31, 1967, two areas totaling 0.8 hectare were treated with Polystream (Granular).

Effect on gastropods.—Divers made no observations during or immediately after treatment. My later observations showed that the treatment killed all Atlantic oyster drills (no thick-lipped drills were present) in both areas and reduced their numbers from 9.5 and 3.6 to 0.0 per square meter (table 4).

Effect on associated animals.—On June 8, 8 days after the treatment, I examined the areas by walking along the shores and divers also examined them. Along the north shore, perhaps 15 m. from one of the treated areas, there were 4 dead toadfish, *Opsanus tau;* 50 dead silversides, *Menidia menidia;* 500 to 1,000 dead mummichogs; 4 dead blue crabs, *Callinectes sapidus;* 50 dead shrimp;

TABLE 5.—*Percentage of oysters killed by oyster drills and starfish in center areas of lots in Norwalk, Conn., 1967*

[Accumulated monthly totals [1]]

Lot number	May	June	July	Aug.	Sept.	Oct.	Nov.
			Percent				
18 [2]	0.0	0.0	0.0	0.6	0.4	1.0	0.2
40 [4]	.0	.0	0.0	1.0	0.0	0.0	.5
42 [3]	.0	.0	0.9	0.5	1.0	0.0	.5
49 [3]	.0	.0	0.0	0.0	0.3	1.5	.0
50 [3]	.0	.2	1.0	0.0	1.0	0.7	.0

[1] Sampling errors account for slight variation in numbers.
[2] Oysters raised in hatcheries in 1967.
[3] 1-year-old oysters.
[4] Mixture of 1965 and 1966 oyster set (1 and 2 years old).

and 10 dead polychaetes. On the inspections made along the shoreline, just inside the other treated section, there were only two dead toadfish and one dead blue crab. Undoubtedly, a high percentage of fish, blue crabs, and shrimp was killed at the time of treatment. Divers did not see any fish or shrimp, live or dead, either on or off treated areas.

Effect on predation.—No determinations were made.

Area 10: Fresh (Quahog) Pond, Falmouth, Mass., 1967

Fresh Pond, about 2.0 ha., is a tidal pond on the east shore of Buzzard's Bay. It is connected with the Bay by a long, narrow creek only about 1 m. wide and 0.3 m. deep at the entrance of the pond. The area for growing oysters is from 0 to 2 m. deep. Winds generate the principal currents in the pond.

On May 29, 1967, a 0.08-ha. section of the pond was treated with Polystream (Granular).

Effect on gastropods.—Within an hour of the treatment divers observed that all snails were beginning to swell.

By July 11, the treatment had killed 95 percent of the Atlantic oyster drills (no thick-lipped drills were present) and reduced their numbers from 40.8 to 2.2 per square meter (table 4).

An untreated area in another section of the pond that served as a control for the treatment had an average on May 29 of 37.2 Atlantic oyster drills per square meter. On July 11 this control plot had 33.2 drills per square meter.

Effect on associated animals.—Because the treatment extended to the shoreline of the pond, a number of observations could be made by walking along the shore. An hour after the treatment I observed 2 flounders (5 cm. long), 5 green crabs, *Carcinus maenas*, and 200 shrimp all dying, and 100 mummichogs stunned. I also observed three small schools of silversides swimming through the area; all these fish were healthy. New England nassas and mud snails, *Nassarius obsoletus*, were beginning to swell.

On July 11, 1967, divers examined the area again. The only animal affected other than snails was a tautog which weighed about 1.8 kg. All New England nassas and mud snails were dead.

Effect on predation.—The area had no oysters.

RECOMMENDATIONS FOR USING POLYSTREAM

During this study I made a number of observations on the use of Polystream (Granular), the form now most commonly used on commercial oyster beds to control oyster drills. These observations are listed below and should be emphasized for those who might wish to use this product:

1. The bed to receive a treatment should have a firm bottom, free of silt.
2. Treatments should be made in late April or early May when oyster drills first become active after a period of winter dormancy.
3. Polystream (Granular) should be spread at slack current.
4. Most successful treatments have been made in water less than 6 m. deep, where currents are less than 2.7 km. per hour. Where currents are stronger than this, planted oysters appear to prevent the Polystream (Granular) from being carried off a bed.
5. Polystream (Granular) treatments are successful on beds planted with seed oysters.
6. In certain shallow areas, where little or no current flows, a smaller quantity of Polystream (Granular) may be successful.

SUMMARY

1. Five experimental and 10 commercial treatments of oyster beds were made with Polystream in the States of Connecticut, New York, Rhode Island, and Massachusetts.
2. Immediately after a treatment, oysters, clams, and other organisms accumulated small residues of Polystream in their tissues. These residues, however, were gradually lost or greatly diminished. For instance, oysters and clams lost the residue of Polystream within 119 days. If they were transplanted from a treated to an untreated bed, however, they lost the residue within a week.
3. All oyster drills were killed in areas where water current velocities were low. On a typical bed, in an area where current velocities were between 0.9 and 2.7 km. per hour, however, about 85 percent of thick-lipped drills and 66 percent of Atlantic oyster drills were killed. Apparently, no oyster drills were killed where current velocities were strong.
4. On treated beds where current velocities were low, significant percentages of fish, small clams,

and other invertebrates were killed. On treated beds where current velocities were between 0.9 and 2.7 km. per hour, treatments killed only small percentages of fish, small clams, crabs, and other invertebrates. A few hours after the treatment the area appeared to be nontoxic to these animals.

5. A higher percentage of oyster drills was killed by treatments made in late April and early May than later in the summer.

6. Oyster drills were killed by the toxic action of Polystream, not by fish or crabs after they became swollen. In a small number of instances, however, they were consumed by starfish.

7. Oyster drills that survived a treatment appeared to be affected by the treatment to the extent that they did not feed significantly for a few months and, thus, did not kill many oysters.

8. The number of oyster drills on a bed where seed oysters were planted and removed each year remained low for at least 2 years.

9. Oyster drills killed less than 2 percent of young oysters during the first year on most treated beds.

10. Growth of oysters appeared to be normal on treated beds. For example, on one bed 1-year-old oysters increased in volume from less than 1 cc. to 15 cc. in one growing season.

ACKNOWLEDGMENTS

Barry Baiardi, Russell Clark, Otis C. Lane, John J. Manzi, and Nicholas Penchuck provided technical assistance. Hillard Bloom and the Bloom Brothers Oyster Company; J. Richards Nelson and the former F. Mansfield and Sons Oyster Company; Lester Johnson and G. Vanderborgh, Jr., of G. Vanderborgh and Sons Oyster Company; and Arnold Carr, Division of Marine Fisheries, Mass., also helped me.

LITERATURE CITED

HAVEN, DEXTER, MICHAEL CASTAGNA, PAUL CHANLEY, MARVIN WASS, and JAMES WHITCOMB.

1966. Effects of the treatment of an oyster bed with Polystream and Sevin. Chesapeake Sci. 7: 179–188.

LOOSANOFF, VICTOR L.

1960. Some effects of pesticides on marine arthropods and mollusks. Biological problems in water pollution. *In* Transactions of the 1959 Seminar, pp. 89–93. U.S. Dep. Health Educ. Welf., Public Health Serv.

1961. Recent advances in the control of shellfish predators and competitors. Proc. Gulf Carib. Fish. Inst., 13th Annu. Sess., pp. 113–127.

LOOSANOFF, V. L., C. L. MACKENZIE, JR., and L. W. SHEARER.

1960a. Use of chemicals to control shellfish predators. Science (Wash.) 131: 1522–1523.

1960b. Use of chemical barriers to protect shellfish beds from predators. Fish., Wash. State Dep. Fish. 3: 86–90.

SCHWARTZ, N., H. E. GAFFNEY, M. S. SCHMUTZER, and F. D. STEFANO.

1963. A method for the analysis of chlorinated benzenes in clams (*Mercenaria mercenaria*) and oysters (*Crassostrea virginica*). J. Ass. Off. Agr. Chem. 46: 893–898.

WOOD, LANGLEY, and BEVERLY A. ROBERTS.

1963. Differentiation of effects of two pesticides upon *Urosalpinx cinerea* Say from the Eastern Shore of Virginia. Proc. Nat. Shellfish. Ass. 54: 75–85.