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For a number of reasons it has become desirable to know the effects of oily and tar-like wastes on marine life of economic importance. Damages have been claimed for pollution of oyster beds by wastes from the manufacture of gas. A report to the Rhode Island shellfish commission has attributed to water-gas tar harmful effects to oysters in Narragansett Bay.[a] Tar of various sorts is used for coating piles or stakes, which might be in proximity to shellfish. Oily wastes are constantly escaping from passing craft in inland waters.

The present investigation does not cover the entire subject, but is confined to one important phase—the effect of water-gas tar on oysters. The experiments made during the summer of 1912 at the laboratory of the Bureau of Fisheries at Woods Hole could not then be carried further.

The tar was obtained from the separator at the works of the Providence Gas Co. on October 25, 1910, and was a mixture of the heavier and lighter tars as obtained in the manufacture of water gas, using an average temperature of 1,450° F. An analysis of tar taken under comparable conditions from the same separator at another time showed, according to the records of the Providence Gas Co., the following analysis:

Specific gravity at 65.5° F., 1.050.	Per cent by volume.
Water	7.65
Light oil at 200° F	13.95
Dark oil at 400° F	42.20
Medium pitch	36.20
Free carbon	2.70

Three series of experiments were made. In the first, oysters were exposed to water-gas tar in stagnant sea water; in the second series they were exposed to the tar in running sea water; while in the third small amounts of water-gas tar were introduced inside the shells of oysters.

SERIES I.

Experiment 1.—An oyster, marked with a file for identification, as were all the oysters used in these experiments, and weighing 83.2 grams, was put into a battery jar with 40 c. c. of water-gas tar and 2,500 c. c. of sea water. On the following day the water was changed by the method used in all the experiments of this series. A siphon delivered sea water from an aquarium to a point about 2 inches from the bottom of the jar, while another siphon at the same time drew off water from the middle of the jar. Water was allowed to run thus 10 to 15 minutes. As the tar stuck to the sides

[a] Field, G. W. In Annual Report of the Commissioners of Shell Fisheries, Rhode Island, 1906, appendix D, p. 46–64.

and bottom of the jar, or, in the case of the lighter more oily portions, floated on the surface of the water, none, or very little of it, was removed while the water flowed through the siphons. The water, therefore, was almost completely changed without removing the tar. Shortly after the water had been changed the oyster was seen to be slightly open, but could close at the slightest jar. The water was changed in this manner once or twice daily for 10 days, The oyster was often seen partly open during this time, but would always respond to a mechanical stimulus by closing. After 10 days the water was no longer changed, but was left entirely stagnant. At the end of two weeks under these conditions the oyster seemed to be affected. It now remained continuously open, and appeared unable to close when stimulated. A few days later it showed signs of putrefactive disintegration.

Experiment 2.—An oyster weighing 63.7 grams was treated exactly as in experiment 1. The results were quite the same, except that when the water was left entirely stagnant disintegration set in after five days.

Experiment 3.—An oyster weighing 71.6 grams was treated as in the preceding experiments, except that the tar was smeared all over the inside of the jar and on the oysters. After 24 hours the oyster was found wide open and unable to close when stimulated. It was removed from the jar, and was seen to have its mantle greatly retracted. It would spring open when closed by hand. It was washed and put into an aquarium in running sea water. Two days later it appeared to be entirely recovered, as it would close normally when stimulated. It was then put back into the jar of sea water and tar in which it had been at first. It was now kept in this jar during six days, with the water changed once or twice daily. At the end of this time it had again lost the ability to close normally, but when put in the aquarium once more it again apparently recovered. About three weeks later, however, it became disintegrated.

Experiment 4.—An oyster weighing 95 grams was arranged exactly as in experiment 3. The results were quite the same, that is, after 24 hours it refused to close, but recovered when put in the aquarium of running sea water. Some weeks later, however, it died. That its death was due to the tar is not certain, because at that time other oysters in the same aquarium died without any previous exposure to tar.

Experiment 5.—An oyster weighing 78.7 grams was treated exactly as in the preceding experiment. It, too, became unable to close after 24 hours, and when put in running sea water entirely recovered. At the end of the summer, nine weeks later, it seemed entirely normal and had a normal appearance when opened.

Experiment 6.—An oyster weighing 62 grams was treated exactly as in the preceding experiment. The result was slightly different in that the oyster did not begin to show a tendency to remain open until after three days, and became entirely unable to close after five days in the tarry water with daily changing of the water. It was then put in running sea water and began to disintegrate a few days later.

Experiment 7.—An oyster weighing 70.8 grams was put into a battery jar with 20 c. c. of the tar not in contact with it and 2,500 c. c. of sea water. The water was changed daily during the next 10 days. It was then left stagnant during 8 weeks. The oyster was sometimes observed to be open, but would then close if jarred. At the end of that

time it was cleaned and dried and found to weigh 71.6 grams. It had formed new shell all around the edge. Opened it gave no smell of tar, the heart was beating and the mantle was normally sensitive to mechanical stimuli. Part of the heart and portions of the gills were discolored.

Control experiment.—An oyster weighing 72.4 grams was put in a battery jar with 2,500 c. c. of sea water. The water was changed during the next 10 days as in the preceding experiment and was then left stagnant during 8 weeks. Examination then showed no noticeable new shell, but the heart, gills, and mantle were quite normal.

The experiments of this series indicate that when considerable quantities of water-gas tar are in intimate contact with oysters in stagnant water serious or fatal effects are produced. Under these circumstances the oyster can not use its natural defense against a relatively or entirely insoluble substance. When the water is stagnant, there is little opportunity to eject such substances and free the organism from them. As will be shown later, the oyster can rid itself of water-gas tar when in running sea water. When the tar can not be ejected it seems to produce an effect similar to paralysis, so that the initial symptom is a failure of the adductor muscle to respond to stimulation of the sensory nerves. No conclusions as to the structures specifically affected can be drawn from these experiments. Whether the fatal effects produced in five of the above experiments were due to a direct toxic effect of water-gas tar, or to some indirect effect also, does not appear from these experiments.

SERIES II.

Method.—Two oysters were put in each of four battery jars. Each jar was arranged with two siphons, one bringing sea water from an aquarium to the jar with the lower end of the siphon about 2 inches below the level of water maintained by the other siphon, which carried water from the jar to a sink. The running water therefore tended to carry off the light floating oils but left the heavier tar sticking to the bottom and sides of the jar. The siphons were so arranged that each jar contained constantly about 2,500 c. c. of sea water. Into each jar there were put 30 c. c. of water-gas tar mixed with sand and thoroughly smeared over the bottom and sides of the jar and on the shells of the two oysters. From time to time during the following weeks small amounts of tar were added to replace that carried away by the siphons. After remaining in the jars as described during nine weeks the oysters were cleaned, weighed, and examined. Comparison of their weights at the beginning and at the end of the experiments is given in tabular form:

Jar.	Initial weight.	Final weight.
	Grams.	*Grams.*
1	98.0	99.0
	47.8	47.8
2	92.0	92.0
	52.4	52.3
3	96.8	94.0
	61.8	62.5
4	101.1	100.7
	45.2	44.3

That these variations in weight have no special significance is indicated by comparison with the variations in the weights of oysters kept in the aquarium during the summer but not exposed to tar.

Initial weight.	Weight after five weeks.
Grams.	*Grams.*
66.5	66.0
76.0	76.5
244.0	243.0
147.0	151.0

When opened all were found to be normal in appearance and function. No odor of tar was detectable in the shell contents of the oysters, although an abundance of tar was left in the jars at the end of the experiment. Smears of tar were also still present on the outside of the oyster shells.

These experiments indicate that even intimate contact with water-gas tar does not injure oysters in the course of nine weeks, provided facilities for defense in the form of moving water frequently renewed are available.

SERIES III.

Experiment 1.—A small oyster was first pried open and injected with 0.5 c. c. of water-gas tar. It was then put in a jar of running sea water. It remained tightly closed during the next two hours. On the next day it was found to be quite normal. It was open and apparently feeding, but closed when stimulated. Drops of tar near it indicated that the foreign material had been ejected. One week later it still appeared entirely normal. It was then again injected with 0.5 c. c. of tar, and was now put in stagnant sea water. Four days later it did not, when stimulated, close as readily and tightly as a normal oyster. It was then opened and found normal in its heartbeat and in contractility of the bivalve muscle, but the mantle was not normally responsive to mechanical stimulus.

This experiment indicates that when an oyster ingests tar and can not get rid of it because the surrounding water is stagnant, some impairment of the sensory apparatus in the mantle results. This interferes with certain activities of the oyster, prevents normal closure, and eventually causes degeneration of muscular and other tissues.

Experiment 2.—Three medium-sized oysters were each injected with about 1.5 c. c. of water-gas tar and then put in separate jars of running sea water. Some time after they were seen in each case to open slightly and in a few minutes close violently so as to eject masses of tar. This process was repeated a number of times in the course of one to three hours after injection. They then remained constantly closed for some time, but were found normally open on the following day. They were left in the running sea water for a period of eight weeks and behaved throughout that time like control oysters in the aquarium. As it was then necessary to terminate the experiments, the oysters were

opened and carefully examined. They were found to be normal in color, odor, heartbeat, responsiveness of the mantle, ciliary movement, and in short in every respect.

This experiment distinctly indicates that water-gas tar in considerable doses is harmless to an oyster in running sea water. The conditions of this experiment more closely resemble those of the native habitat of the oyster than do those of the preceding experiment, because tides and other currents over oyster beds maintain a constant movement and a continuous changing of the surrounding medium.

Experiment 3.—A medium-sized oyster was injected with 1 c. c. of water-gas tar, which was distributed all around the mantle. It was then put into about 1,500 c. c. of sea water and carefully observed. During the next five hours it did not visibly open and no tar escaped from it. On the following day, however, a few drops of tar were floating on the surface of the water. During the next two days the oyster was only infrequently observed and was not seen open, but on the third day it was found normally opened and able to close when stimulated. It was left in the same sea water during the next two weeks. It had then developed the usual symptoms of imperfect closure and when opened did not show a normally beating heart or a responsive mantle. This experiment confirms the first one of this series.

EFFECT OF WATER-GAS TAR ON THE DISSOLVED OXYGEN OF SEA WATER.

It seemed possible that tar and similar substances might in a measure reduce the oxygen content of water so as to affect shellfish. Mixtures of tar and sea water were, therefore, allowed to stand for varying periods of time and then tested by Winkler's titration method to measure the quantity of dissolved oxygen in the water. The experiments are summarized in the following table. Three liters of sea water were used in each case.

Amount of water-gas tar used.	Time mixture was allowed to stand at room temperature.	Oxygen remaining in water at end of the time.
Cubic centimeters.	*Hours.*	*Parts per million.*
200	20	6.61
200	24	6.10
200	45	.00
200	130	.08
50	40	2.71
50	45	1.10
50	130	.08
None.	40	[a] 7.10
None.	45	[a] 8.09
None.	130	[a] 8.26

[a] Control, sea water alone.

These experiments show that the tar can cause the disappearance of dissolved oxygen in sea water. How potent a factor this may be in causing the effects of the tar on oysters in stagnant water it is not, however, safe to say. Oysters, as the author has shown, are remarkably resistant to lack of oxygen and do not when deprived of it

show inability to close except in the advanced stages of oxygen starvation. That oxygen consumption by tar may help to account for the fact that oysters are injured by stagnant tarry water, while they are uninjured by the tar in running sea water, is quite probable. In the natural habitat of the oyster, however, it seems quite impossible that the slight reduction of dissolved oxygen which small amounts of tar could effect would alter the results of oyster culture.

CONCLUSION.

These experiments show no noticeable effects of water-gas tar on oysters in constantly renewed sea water. This is true in spite of the fact that large amounts of tar mixed with stagnant sea water, or small amounts injected into oysters which are kept in stagnant water, do cause serious or fatal effects. Considerable quantities (1.5 c. c.) may be put inside the shell of an oyster kept under conditions resembling those of its natural habitat without causing any effect. The harmlessness of the tar under these circumstances is due apparently to the ability of the oyster to rid itself of such foreign matter. In stagnant water the organism can not be effectively washed out, and effects involving a loss of sensitiveness in the mantle result. That consumption of the dissolved oxygen in the stagnant water by tar may have some effect on oysters is a possibility.