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STARFISH AND OYSTERS.

Report on work during 1933.

by

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BIOLOGICAL BOARD OF CANADA

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Scope and significance. The destruction of young oysters by starfish is one of the most serious obstacles to oyster culture. It has appeared from the results of planting spat that the chief losses from this source occur during the first and second years of the oyster's life, and the problem is being attacked by attempts to rear oysters on trays and floats out of reach of the starfish to a relatively safe size. These experiments are reported elsewhere and in this report an account is given of a number of observations and experiments on various aspects of the starfish and the damage they cause. There are three chief subjects touched upon. The first is the relation between the sizes of oysters and the sizes of starfish which can destroy them. This is of importance in predicting the damage which would result in planting oysters of a known size on grounds where starfish occur. The second subject is that of the size frequencies in the naturally occurring stocks of starfish, rate of growth and general life history. Knowledge of the sizes attained, the rapidity of growth and length of life and of the times when the larvae settle are of great importance in predicting the starfish populations on grounds and in arranging operations to destroy or remove the starfish so as to be most effective, The third subject is the possibility of some form of trapping being a better method of removing starfish than mopping especially in small areas and with limited financial means.

A. Experiments on size relations of oysters and the starfish which can destroy them. A number of experiments were carried out in 1933 which consisted essentially of caging oysters of certain sizes and starfish of certain sizes and watching the success or failure of the starfish to destroy the oysters. They served to open the subject and to indicate some general size relations. Some other interesting observations on the method of attack, etc., were also made.

Results of individual experiments. At first a number of experiments were started using hatchery jars in which oysters and starfish were placed. Although the starfish remained active and apparently healthy and the oysters were apparently unharmed, it became evident that significant results could not be obtained with the apparatus. In spite of fairly rapid circulation of water the starfish tended to climb the sides of the jars and were seldom to be found on the oysters. In four jars over a period of three weeks only one spat was killed (just under 1" in length; killed by starfish 1½" in "diameter").

The other experiments used boxes about 8" x 12" x 12" made of galvanized wire cloth with four square meshes to an inch, which were suspended from floats or from the end of the landing stage. These insured as much circulation of water as on most of the oyster bottoms. In them active destruction of oysters by starfish occurred which yielded observations of comparative value at least, although it is doubtful whether the absolute rate of destruction of oysters by starfish in these wire cages is a safe indication of the rate of destruction on oyster beds, owing to motion of the boxes, etc., which might hinder the starfish.

In the experiments oysters of average shape were used - neither extreme "long" or "round" shape. The lengths are the total length of the oyster from the tip of the projection past the hinge on the concave shell to the edge of the "lip". The "diameter" of the starfish is the diameter of the circle which would pass through the tips of the arms.

1. Placed in box, August 3, 3 starfish 3" to 3⅛" in diameter and 5 oysters 2⅛" to 3" long (spawned in 1931). On August 4 all starfish and oysters were alive and apparently healthy and the same was found on August 10.

2. Placed in box, August 3, 3 starfish 3" to 3⅛" in diameter and 9 oysters 1⅛" to 2" long (spawned in 1932). On August 4, 2 oysters were found killed. On August 10, 1 starfish was dead and disintegrating and of the 9 oysters, 5 were dead and one had part of the edge cleaned and broken.

3. Placed in box, August 3, 4 starfish 2" to 2⅛" in diameter and 5 oysters 2" to 2⅛" long (spawned in 1931). On August 4 all oysters were alive and 1 starfish had made its way from the next box making now 5 starfish 2" to 2⅛" in diameter. On August 10, 1 oyster was found dead. On August 14 the remaining 4 were still alive and apparently vigorous though 2 were marked by the starfish.

4. Placed in box, August 3, 3 starfish 2" to 2⅛" in diameter and 5 oysters 1⅛" to 2" long (spawned in 1932). On August 4 all oysters were alive; 1 starfish had escaped to 3./above. On August 10, 1 oyster was dead and 2 marked. On August 14, a second starfish was found dead.

5. Placed in box, August 3, 5 starfish about 1½" in diameter and 10 oysters about 1" long (spawned in 1932). On August 4, one oyster was found dead. On August 10, all the oysters were dead and 3 of the starfish had escaped.

6. Placed in box, August 3, 5 starfish about 1½" in diameter and 5 oysters 1½" to 2" long (spawned in 1932). No oysters were killed up to August 24. 2 starfish had escaped.

7. Placed in box, August 10, 5 starfish 3" to 3½" in diameter, 5 oysters 2½" to 3" long (spawned 1931) and 4 oysters 1½" to 2" long (spawned 1932). August 14 all the smaller oysters were dead and none of the larger. August 24 all the larger oysters were still alive; 1 starfish gone to 8./

8. Placed in box, August 14, 6 starfish 2" to 2½" in diameter, 4 oysters 2" to 2½" long and 3 oysters 1½" to 2" long (spawned in 1931 and 1932 respectively). August 24, 1 3½" starfish entered from 7./ All the larger oysters alive; two of the three smaller oysters killed.

9. Placed in box, October 3, 3 starfish 3" to 3½" in diameter and 20 oysters 1½" to 2" long, spawned in 1932. Experiment interrupted by heavy storm October 9 when all the starfish were in good condition and one oyster only had been killed.

10. Placed in box, October 3, 3 starfish 6" to 7" in diameter and 25 oysters 1½" to 2" long (spawned in 1932). Experiment interrupted on October 9 by heavy storm. At that time all the starfish were in good condition and 5 of the 25 oysters were killed.

11. Placed in box, October 3, 6 starfish 1½" to 1⅝" in diameter and 12 oysters 1⅜" to 2" long and 12 oysters about 1" long (both spawned in 1932). On October 9 three starfish had escaped (too small for mesh?), 1 spat 7/8" long was dead and some others were marked.

12. Placed in box, October 3, 4 starfish 2" to 2½" in diameter and 18 spat 1⅜" to 2" long (spawned in 1932). On October 9, 1 oyster (1⅜") killed, and 3 strongly marked by starfish.

13. Placed in box, October 3, 2 starfish about 5" in diameter, and 26 oysters from 1 to 2¼" long (spawned in 1932). On October 9, 2 oysters (2½" and 1⅝" long) killed.

14. Placed in box, October 3, 2 starfish 3" to 3½" in diameter and 25 oysters from 1" to 2¼" long (spawned in 1932). On October 9, two of the oysters were dead (1⅜" and 1½" long) and one strongly marked by the starfish.

15. Placed in box, October 13, 3 starfish 3" to 3½" in diameter and 19 oysters 1⅜" to 2" long (spawned in 1932). On October 24, 4 oysters were killed and 4 strongly marked. On November 10 no more oysters were killed and two of the starfish were recently dead.

16. Placed in box, October 13, 3 starfish 4⅜", 5¼" and 6" in diameter and 20 oysters 1⅜" to 2" long (spawned in 1932). On October 24, 10 oysters were dead and on November 10, 2 more were dead and 2 of the remaining 8 were strongly marked.

17. Placed in box, October 13, 6 starfish 1½" to 1⅝" in diameter, 9 oysters 1⅝" to 2" long and 10 about 1" long (all spawned in 1932). On October 24, 3 of the starfish had escaped and none of larger oysters had been killed; six of the smaller had been killed.

18. Placed in box, October 13, 4 starfish 2" to 2½" in diameter and 20 spat 1⅝" to 2" long. On October 24, 2 starfish had escaped and 2 oysters were dead, many others being marked.

19. Placed in box, October 13, 3 starfish about 5" in diameter and 24 oysters from 1" to 2⅛" long. On October 24, 16 oysters had been killed irrespective of size. On November 24, 5 oysters were still alive of which 2 were marked.

20. Placed in box, October 13, 3 starfish 2½" to 3" in diameter and 23 oysters ⅝" to 2⅛" long. On October 1 dead oyster (15/8") was removed. On November 24, of the remaining 22 oysters 3 had been killed (⅝", 2", 1⅛"), one (1 1/4") was still alive but was weak and had much of the margin of the upper valve removed, 5 were alive and strongly marked (2⅛", 2", 2", 2", 2½"), and 13 were alive and unmarked (1⅛", 1⅛", 1½", 1⅝", 1⅝", 1⅝", 2", 2", 2", 2", 2", 2⅛" and 2⅛").

We might also record here a single trial conducted late in 1932. On November 10 of that year several shells with spat were placed at one end of a wire tray about 2' x 3' and 4 starfish about 2" in diameter were placed among the shells and 4 at the other end of the tray. On November 12, 3 of the latter starfish were dead and only 2 starfish were found among the shells, 2 small mussels and one spat (about 1") were found to have been killed. The tray was on the bottom and it is believed that wave action may have caused damage.

Discussion

1. Size relations. For convenience in reference the above experiments are summarized in table I. It will be seen that in 7 instances (Nos. 1, 3, 6 and parts of 7, 8, 11 and 17) in which oysters were exposed to starfish, none of which had a diameter as much as 1½ times the length of the oysters, only one oyster was found dead, and it was only in these instances that failure of starfish to kill any of the oysters are to be found. In all other instances some oysters were killed. In experiments (Nos. 7, 2, 10, 13, 14, 15, 16, 19) in which the diameters of the starfish were definitely more than 1½ times the lengths of the oysters a relatively high mortality of oysters occurred allowing for the brief duration of some of them. In the remaining cases in which some of the starfish had diameters larger than 1½ times the lengths of some of the oysters but in which the average ratio of diameter to length was close to 1½ a great variation occurred in the mortality, but some oysters were killed in all cases. Where the average diameter drops below 1½ times the average length (as in 12, 18 and 4) mortalities are low. It appears that in cases where the ratio is close to 1½ the mortality is higher where both oysters and starfish are small.

The experiments indicate that starfish must be about 1½ times greater in diameter than the lengths of the oysters they are attacking if a high mortality is to occur among the oysters, and that this ratio tends to be somewhat lower when both oysters and starfish are small, than among large oysters and starfish.

2. Method of attack. In the course of the experiments it was observed that a successful attack of a starfish on an oyster was always accompanied by the dissolving away of a considerable amount of the edge of the upper (flatter) valve of the oyster and the cleaning of the neighbouring area. This bears out the observations of Prytherch and others who maintain that the starfish overcomes the oyster by the influence of its acid secretions from the stomach which weaken the edge of the shell and anaesthetize the oyster. They have found that oysters can be anaesthetized in vitro by a great variety of acids. In cases where small oysters (1½" long) were killed by starfish, in the above experiments most of the edge of the upper valve was dissolved away - sometimes more than ¼ of an inch in oysters of that size. Unsuccessful attacks of starfish could be recognized by a partial dissolution of the shell and cleaning of its surface. These "starfish marks" were observed on large numbers of oysters especially in instances where the oysters were apparently too big for the starfish to kill. The part of the shell actually dissolved away was that thin part of the flatter valve which bends when the oyster closes making a very tight fitting of the valves.

3. Rate of consumption and seasonal differences. The highest rate of consumption of oysters by starfish observed was just over 3 oysters per starfish per week. It must be remembered, however, that this has no significance as a maximum as more extreme differences between the sizes of the starfish and of the oysters will occur than those tried and the conditions of the experiments may not be as favourable as is usual in nature to the

action of the starfish. No definite differences in rate of consumption in August and in October can be deduced from the experiments but there was indication of a reduction in the activity of the oysters late in October and in November as the temperature approached 0°C.

4. Other aspects of the problem. Experiments are planned to check the above results and to throw light on other aspects of the starfish problem. These include extension of experiments on the rate of consumption of oysters by starfish and its seasonal variations, and experiments on the preference of starfish for one or more of various available prey. One of the possibilities which is in mind in the latter connection and which is of considerable practical significance is that the presence of mussels or other prey of the starfish may be of protective value to oysters. The presence of considerable numbers of small mussels may be an effective factor in reducing the consumption of small oysters from, let us say, lengths of 2" up and possibly even of smaller oysters. Casual observations made during the above experiments show that the starfish may attack large oysters which they cannot kill even in the presence of oysters which they can easily kill, but it was also seen that when unsuccessful they would leave one oyster and attack another and it may be that the presence of animals which the starfish can easily kill may lessen the frequency of attacks on oysters which are on the boCrderline. It may also, of course, be found that they exhibit definite preference for other species.

Table I. Summary of caging experiments.

No.	Dates.	Starfish No.	Starfish Sizes.	Oysters No.	Oysters Sizes.	Oysters killed.	Remarks
1.	Aug.3-10	3	3"-3⅛"	5	2⅛"-3"	0	
2.	Aug.3-14	3	3"-3⅛"	9	1⅝"-2"	5	Another marked
3.	Aug.3-14	4	2"-2⅛"	5	2" -2⅛"	1	Starfish entered
4.	Aug.3-14	3	2"-2⅛"	5	1⅜"-2"	1	1 star.at end.
5.	Aug.3-10	5	ca.1⅝"	10	ca. 1"	10	3 stars.escaped
6.	Aug.3-24	5	ca.1⅝"	5	1⅝"-2"	0	2 " "
7.	Aug.10-24	5	3"-3⅛"	5	2⅛"-3"	0	
				and 4	1⅜"-2"	4	by Aug. 14.
8.	Aug.14-24	6	2"-2⅛"	4	2" -2⅛"	0	
				and 3	1⅜"-2"	2	3⅛"star.entered
9.	Oct. 3-9	3	3"-3⅛"	20	1⅝"-2"	1	
10.	Oct. 3-9	3	6"-7"	25	1⅝"-2"	5	
11.	Oct. 3-9	6	1⅜-1⅝"	12	1⅝"-2"	0	
				12	ca. 1"	1	3 stars.escaped
12.	Oct. 3-9	4	2"-2⅛"	18	1⅝"-2"	1	3 strongly marked
13.	Oct. 3-9	2	ca. 5"	26	1" -2⅛"	2	2⅛" & 1⅝"
14.	Oct. 3-9	2	3"-3⅛"	25	1" -2⅛"	2	1⅝" & 1⅝"
							1 strongly marke
15.	Oct.13-24	3	3"-3⅛"	19	1⅝"-2"	4	4 marked.
	Oct.24-						
	Nov.24	3	3"-3⅛"	15	1⅝"-2"	0	
16.	Oct.13-24	3	4⅛"-6"	20	1⅝"-2"	10	
	Oct.24-Nov.24	3	4⅛"-6"	10	1⅝"-2"	2	2 marked.
17.	Oct.13-24	6	1⅛"-1⅝"	9	1⅝"-2"	0	3 stars.escaped
				and 10	ca. 1"	6	
18.	Oct.13-24	4	2" -2⅛"	20	1⅝"-2"	2	Many marked.
19.	Oct.13-24	3	ca. 5"	24	1" -2⅛"	16	
	Oct.24-Nov.24	3	"	8	"	3	
20.	Oct.13-24	3	2⅛"-3"	23	⅝"-2⅛"	1	
	Oct.24-Nov.24	3	"	22	"	4	5 marked.

Experiments omitted. Two caging experiments were omitted above. They were as follows:

21. Placed in box, November 10, 1 starfish 3⅛" in diameter and 9 oysters 1⅝" to 2" long, spawned in 1932. On November 21 all were still alive.

22. Placed in box, November 10, 3 starfish ca. 5" in diameter and 18 oysters 1" to 2⅛" long, spawned in 1932. On November 21 all were still alive.

These experiments are further evidence of a reduction in the activity of starfish in cold water. Temperatures were from about 2½C to 0°C. during the period November 10 to 21.

B. Size frequencies and rate of growth. In table II are given the "diameters" of three complete catches of starfish made by mops of cotton waste on two beds in the upper part of Bideford river.

Table II. Diameters of mopped starfish.

Diameter	Mud-digger point bed.		Totten bed
cm.	Oct. 3	Oct. 13.	Oct. 28.
1	0	0	4
2	6	3	253
3	25	11	805
4	34	36	520
5	18	11	154
6	14	7	38
7	5	1	26
8	8	2	19
9	2	3	8
10	0	0	5
11	1	1	2
12	2	5	1
13	1	3	1
14	0	0	3
15	1	0	3
16	0	1	4
17	5	0	1
18	0	0	1
19	0	0	0
20	0	0	1
21	1	0	0
22	0	0	1
23	0	0	1

The high proportion of small starfish 6 cm. in diameter or less is evident in the above table. In the Totten bed catch only 4.3% were 7 cm. in diameter or more, and in the Mud-digger point bed catches combined 20%. These catches were made by the usual mopping procedure and there is some doubt regarding possible

selection by the method. Casual observations of the sizes obtained by other methods indicate that the sizes obtained by mopping are at least nearly representative but further investigations are planned to test this, and to extend the observations to a greater variety of time and conditions.

Supposing for the present that the above sizes are fairly representative we have an explanation of the high mortality among spat planted as beds and the low mortality after the oysters reach a length of about two inches. In the preceding section of this report it was found that starfish must have a diameter approaching one and a half times the length of the oyster to attack it successfully, i.e. to attack oysters about 2 inches in length they must be about 3 inches in length or over 7 cm. in length. In the Totten bed samples only about 4% of the starfish would be sufficiently large.

In table III are given diameter of starfish produced in 1933 which settled on bags of shells suspended from floats on which were an abundance of small mussels. They settled from early in July until early August. The average diameter on

Table III. Starfish of the current year.

Diameter in cm.	Number Sample measured August 24	Sample October 5
0	1	0
½	15	0
1	57	1
1½	28	4
2	1	17
2½	0	34
3	0	39
3½	0	32
4	0	26
4½	0	22
5	0	15
5½	0	4
6	0	1
6½	0	0

August 24 was 1.1 cm.; on October 3, 3.4 cm. It is interesting to note that the length attained by these starfish by October of the year they were spawned coincides with the most frequent length in the samples of mopped starfish - i.e. 3 to 4 cm. This suggests that the starfish producing the peaks in the frequency curves in the samples were 1933 brood, and this means that the great majority (75% or more) were of that brood, and that only a few from earlier broods were present. As a similar high proportion of small starfish has been found as a general rule along shores and on the beds near the head of the inlet, it is suggested that there is either a very high death rate or a migration of the older starfish to deeper and colder (in summer) water.

These questions are of the highest importance in connection with the development of a procedure for rearing small oysters without damage from starfish and with the selection of grounds for the first planting of small oysters, or of spat. It is planned to continue the investigations to include a study of the growth of starfish in various conditions, the death rate and the migration of starfish and the time of spawning and settling of the larvae.

It is worthy of note in the latter connection that starfish settling in early July are large enough to kill the oyster spat of that same year as soon as they appear and for the remainder of the season. They are not, however, large enough to kill oysters from the previous year and do not reach such a size before winter. Many of the spat do not exceed 1.5 cm. at the end of the growing season while the current year starfish have reached an average of 3.4 cm. Spat from the previous year

reared on floats averaged over 4 cm. The starfish settling on cultch may be a serious problem especially when cultch is put out early as it appears that the starfish settle somewhat earlier on the average than the oysters.

C. Trapping starfish. The only method hitherto used in our waters to catch starfish on a large scale has been mopping. This method, which has been described several times elsewhere, consists essentially of towing mops of crinkly cotton wastes - "unsized slasher thrums" - over the bottom at a slow speed. It appears to be efficient to quite a degree, trials indicating that when mops are towed three times over the same place hardly any more starfish can be obtained there with mops at that time. A number of starfish are probably still there in crannies in the bottom.

The cost of a day's mopping with a small motor boat may be estimated as follows: Wages of men at $1.50, $3.00; 5 gals. gasoline 1.10; oil and grease .25; wear on mops (estimated on the basis of 1 lb. of cotton wearing off) .20;Total $4.55. This is a minimum cost based on low wages and price of gasoline and it does not include the upkeep of the boat, interest on capital, etc. A good catch for a day's mopping when the boat is provided with hot water trough for killing the starfish has been found to be 8,000. This would be a good catch, and represents a cost of 5½ cents per hundred starfish, a cost which would be a minimum. Mopping requires a capital investment of at least $150 in boat, engine, mops amd frames etc. When no hot water trough is used and starfish are nicked off by hand considerably more time is taken in that than in towing and the catch is little

more than half with a corresponding increase in price.

It was thought that some method of trapping starfish might be devised which would be cheaper both in capital investment and in operating expenses. Only half a day with a dory would be necessary to haul a very large number of traps - cost of .75 only. If cheap traps could be developed which would catch 1500 starfish per day in this way the cost would be as little and the capital investment less than that involved in mopping. It might be possible to develop a method which was cheaper in operating as well as in capital.

With this end in view a number of preliminary trials were conducted in 1933. It is common knowledge that large numbers of starfish are found about the bait in lobster traps and the trials made this year were developments of such a method.

Small lath traps. A number of small lath boxes were made having solid ends about 6" x 6" and lath sides with three laths per side and spaces of about ½ to ¾" between the laths. In these boxes a small roll of galvanized wire cloth was used to hold bait - flattened and nailed to the wood at one end and with a wooden plug at the other. They were weighed with stones and placed on the bottom near the landing stage of the biological station. Two such traps put out with broken clams as bait at 5.00 P.M. August 3 had 0 and 5 starfish at 8 A.M. August 4 and 4 and 3 more by 5 P.M. i.e. a total of 4 and 8 starfish in 24 hours. In the next 24 hours 6 and 5 were caught. In the next 48 hours only 1 and 0, the bait having now disappeared. When re-baited 2 and 2 starfish were caught. It is indicated that

when baited these traps caught an average of about 5 starfish per trap per day, but that when not baited hardly any were caught. Starfish were quite abundant where they were placed.

Wire cylindrical traps. A number of traps were made by rolling a square foot (approximately) of hexagonal 1" mesh galvanized wire netting (the common "mink" wire) into cylinders with the overlapping inner edge rolled over slightly to hold bait. A number of these (12) were put out on August 8 with live mussels and clams as bait. On August 9 these 12 traps had 5, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0 - an average of 2/3 per trap, more being taken when the bait was clams. The line of traps had been set on muddy ground and it was changed to harder ground along the shore from the landing stage. Some of the mussels and all of the clams were broken. On August 11 the following catches were made: 1. in four traps with broken mussels 4, 15, 6, 8 (av. 7½), 2. in 2 no bait left 1,2 (av.1½), in 3 with live mussels 2, 1, 6 (av.3) and in 2 with broken clams 11,7 (av.9). The average catch in all those in which some bait was left was over 6½; in those with no bait 1½. 28 traps set on Fred England's bed baited with broken mussels on August 15 yielded an average of 4¼ per trap. Set again without re-baiting they yielded only 1 among the 28 traps on August 17 when all the bait was gone. Re-baited they yielded an average of just over .1 from the same ground on August 18. These and further similar trials show that catches of over 5 starfish per trap can be made, that the traps do not catch starfish when the bait is gone and suggest that this method if improved might be more effective than mopping. The cost of 300 of these traps would not greatly

exceed $15.00 and it is believed that 300 could be handled in half a day with a dory only. If a catch of 5 per trap could be made under conditions where the mopping would catch 8,000 per day the cost of the two methods would be similar with a much smaller capital expenditure for the trapping.

It is planned to try a number of other styles of traps and other kinds of bait. Herring were given only a very poor trial. It is also desirable to study the variation in the efficiency of the traps under different temperature conditions, as this will influence the time when they should be operated and should be correlated with the activity as indicated by the cageing experiments.

General Summary.

1. Experiments in cageing starfish and oysters of various sizes are summarized. They indicate that starfish to attack oysters effectively must have a "diameter" about 1½ times the length of the oysters, and that this ratio seems to increase slightly with the sizes of the oysters and starfish. It is also indicated that the activity of the starfish decreases as the temperature approaches 0°C. Further experiments are projected especially as regards the changes in activity of the starfish with season.

2. A study of the size frequencies of starfish caught by mopping in October showed a very high percentage with a diameter of 6 cm. or less and measurements of starfish spawned in the early summer of 1933 showed that they had reached a size corresponding with the mode on the two beds sampled. Further

investigations are projected to throw light on the rate of growth, death rate and movements of starfish.

3. Preliminary trials of catching starfish with baited traps gave results which indicate that this may be a method as efficient or more efficient than mopping. It is planned to try a greater variety of forms of traps and to find what variation occurs in their efficiency under different conditions including temperatures.

Toronto, January, 1934.