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journal or publication title	Tohoku journal of agricultural research
volume	5
number	4
page range	251-268
year	1955-03-05
URL	http://hdl.handle.net/10097/29143

ECOLOGY OF OYSTER BED
I. ON THE DECLINE OF PRODUCTIVITY DUE TO REPEATED CULTURES

By

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(*Received January 20, 1955*)

Introduction

Oysters are commonly cultured by the hanging method in Japan :** the brood oysters are suspended vertically under either raft or rack which are located in shallow waters. New seed oysters are brought into the bed every year after harvesting. Having a plentiful supply of seed oysters in Japan, we seldom experience such depletions of beds due to inadequate spatfalls as are reported in European countries (2) and the United States (3).

Japanese growers state that when hanging culture is repeated in the same spot for some years, the production will gradually decline. Indeed, some of the old beds were actually abnadoned both in Matsushima Bay and other bays, and the establishments have been moved to new grounds because of poor crop after several years of good harvest.

In the hanging method, the intermediate stratum of water is used for culturing. Therefore it is hard to believe, at first thought, that repetition of planting in the same spot should interfere in the production of oyster. One possible explanation can be found in the increase of fouling organisms such as sea mussel and compound ascidia which compete with oyster in feeding. Another important reason seems to be the organic pollution of the bottom under the bed mainly caused by the bulky deposits of fecal discharge of the oyster. In the tank, we observed that an individual oyster of 90 gr. discharged, in average, 0.03 gr. (dry weight) of feces daily at 9°C. This is probably the minimum value of fecal discharge because the experiment was carried in cold tank water with poor suspension of food. Even such a minimal figure will give an estimate of the total quantity of fecal dischage of all the oysters suspended under a single raft as 0.6–1.0 ton per year on a dry basis.*** It equals to 6–10 tons on a wet

* Contribution from Onagawa Fisheries Laboratory.

** For the details of Japanese method of oyster culture, Cahn (1) should be referred.

*** Culture raft of standard size of 10×6 m^2 holds from 60,000 to 100,000 oysters.

basis. Chemical analysis showed that the feces contained 9.1 percent of humus and 0.8 percent of total nitrogen. Considering the amount of feces deposited on the bottom of about 60 m^2 in area, it can be expected that the bottom sediment will be polluted heavily by organic matters.

So far as we know, no systematic analysis has ever been made to determine how the oysters in hanging culture modify the bed bottom and in turn how, and to what extent, the modified bottom interfers with the lives of oysters. The present research was planned to answer these questions.

Oyster farm in Matsushima Bay was chosen for field observation. Physical and chemical characteristics of the bottom sediment in old and new beds were compared in detail and the difference in their productivity was examined statistically. Experimental culture was also carried in the oyster farms of Mangoku-ura Inlet to confirm the influence of bottom sediment on the crop of oysters. Finally laboratory experiments were carried on at the Onagawa Fisheries Laboratory on the phsiological action of bottom sediment on the activity of oyster. This paper reports the results of these observations and experiments.

Observations on the bottom characteristics of oyster beds and their relation to the size of crop in Matsushima Bay.

Field observations were made at a Katsurashima oyster farm in Matsushima Bay. It is situated on the northern coast of Katsurashima Island. Average water depth of the area was about 4 meters at mean tide. Distribution of culture rafts at the time of observation, Dec. 25, 1950, is shown in Fig. 1 and 2. In the Figure, group A include 40 rafts which were used for 6 years, group B are 150 rafts of 3 years and group C (20 racks) are in the second year of culture. The rafts were floated nearly 50 meters apart. Three rafts, one from each age group, were chosen for sampling. They are indicated as *a* (6 years), *b* (3 years) and *c* (2 years) in the Figure. From each raft, three clusters of oysters were sampled from 2 and 4 meters depth respectively. They were shucked and their dry meat weights (dried at 100°C) were measured. Results of analysis of dry meat weight of oyster samples are summarized in Table 1. In the table, the results of significance test of difference among oysters of the rafts of different ages are also shown. Among oysters of middle layers, no significant difference was observed, while the difference was apparent in oysters of bottom layers. Namely, the older the culture raft, the lower the dry meat weight of oysters.

Bottom sediments from each raft and control group were sampled by an Eckman-Birge bottom sampler and brought to laboratory in a rubber stoppered

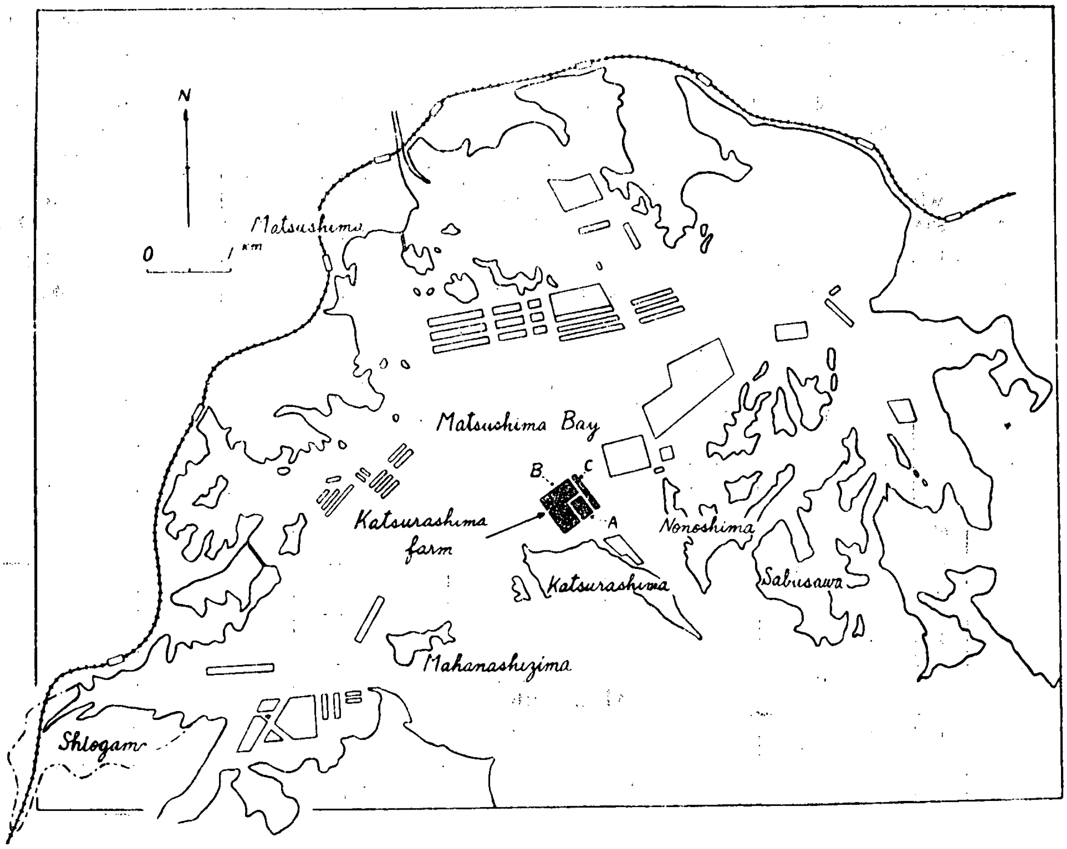

Fig. 1. Map of Matsushima Bay showing the distribution of oyster farms.

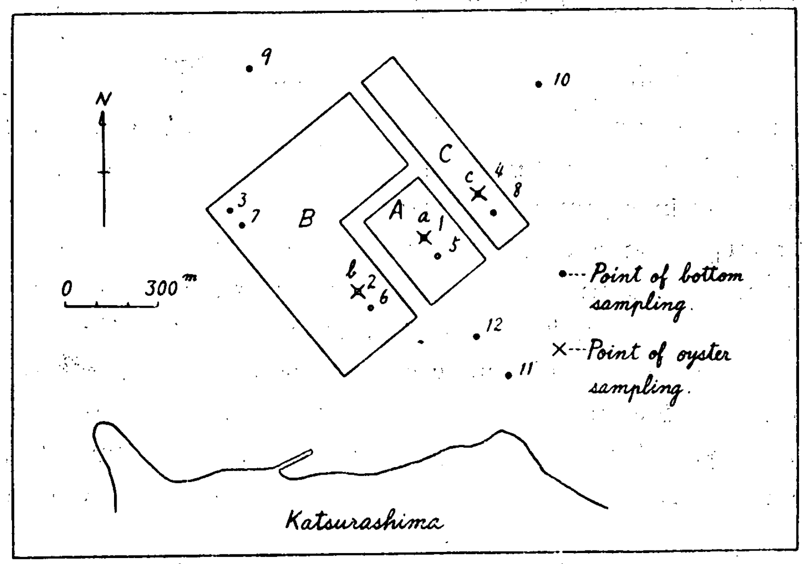

Fig. 2. Distribution of culture establishments in Katsurashima farm, grouped by age and sampling points of oysters and bottom sediments.

Table 1. Comparison of dry meat weight of oysters sampled from culture racks and rafts of various ages in Katsurashima farm, Matsushima Bay.

Kind of establishment and its age	Raft, 6 years old (A)		Raft, 3 years old (B)		Rack, 2 years old (C)	
The depth of water from which the oysters were sampled	Middle layer (1)	Bottom layer (2)	Middle layer (1)	Bottom layer (2)	Middle layer (1)	Bottom layer (2)
No. of oysters sampled	28	26	33	32	42	33
Mean dry meat weight in gr.	0.754	0.422	0.725	0.578	0.834	0.713

Test of singificance of difference

		(A)		(B)		(C)	
		(1)	(2)	(1)	(2)	(1)	(2)
(A)	(1)						
	(2)	P<0.1% (significant)					
(B)	(1)	P≒20%	P<0.1% (significant)				
	(2)	P≒0.8% (significant)	P≒0.4% (significant)	P≒2% (significant)			
(C)	(1)	P≒21%	P<0.1% (significant)	P≒9%	P<0.1% (significant)		
	(2)	P≒51%	P<0.1% (significant)	P≒7%	P≒6%	P≒6%	

glass tube. From the fresh bottom samples, total sulfide content was measured by Tomiyama and Kanzaki's method (4). Grain analysis was made by sieves. Humus content was measured by Tyurin's method and total nitrogen by the Kieldahl method.

The result of analysis of bottom sediment is summarized in Table 2. Comparison of bottom sediments immediately under the raft with that of a control area 100 to 300 meters from the farm, reveals that the former had a higher content of finer grains (less than 0.1 mm in dia.) than the latter. Humus and total nitrogen content under the rafts, were nearly twice as much as in the control areas. The former was black in color, while the latter brown. The average content of total sulfide was 4.00 ‰ against 0.72 ‰. The bottom sediment of the area between the rafts showed intermediate characteristics in physical composition as well as in the content of humus, total nitrogen and total sulfide. It can also be seen that as the rafts were used for a greater number of years, the bottom deposit became finer grained and the contents of humus, total nitrogen and total sulfide increased.

From the results obtained, it is strongly suggested that repeated culturing of oysters in the same spot gives rise to organic pollution of the immediate bottom and such pollution in turn will interfere with the growth of oysters, particulary in the water layers near the bottom. Observations on the benthic organisms showed that the bottom which had been polluted by repeated culturing

Table 2. Analysis of bottom sediment sampled from several stations of Katsurashima farm

Stations			Result of analysis				
No.	Description of the station sampled	Depth in m.	Color	Percentage of fine grain less than 0.1mm in diameter	Humus in %	Total nitrogen in %	Total sulfide in ‰
1	Immediate bottom of 2-years-old raft	4.1	Black	93	4.95	0.281	1.32
2	Immediate bottom of 3-years-old raft	3.4	Black	89	5.79	0.286	5.48
3	Immediate bottom of 3-years old raft	3.4	Black	93	5.95	0.326	2.39
4	Immediate bottom of 6-ysars-old raft	4.1	Black	89	5.97	0.314	6.80
Average				91.0	5.67	0.302	4.00
5	Point between the racks of 2-years-old	4.1	Grayish black	80	3.87	0.179	0.33
6	Point between the racks of 3-years-old	4.1	Grayish black	77	4.87	0.205	0.56
7	Point between the racks of 3-years-old	3.4	Grayish dark	73	4.29	0.130	0.58
8	Point between the racks of 6 years-old	4.1	Grayish black	66	3.49	0.159	1.39
Average				74.0	4.13	0.168	0.72
9	300m north-west off the farm	3.2	Brown	27	2.24	0.095	0.68
10	300m north-east off the farm	4.0	Brown	30	4.33	0.201	0.92
11	300m south-east off the farm	4.0	Brown	39	3.07	0.133	0.45
12	100m south-east off the farm	3.9	Brown	55	3.19	0.149	0.84
Average				37.8	3.21	01.45	0.72

of oysters was unfavorable to most of them. Even oyster pests, such as starfish and drills, did not flourish on such polluted bed.

Culture experiments in Mangoku-ura Inlet.

The conclusion given above was based on the observations made on growers' rafts. In order to confirm the conclusion, an oyster culture experiment was carried at Harinohama and Sawada farms of Mangoku-ura Inlet in 1951. Harinohama farm is in the innermost part of the inlet and is about 4 meters in depth at mean tide, while Sawada farm is in the middle part of the inlet and is only 2.6 meters in depth (Fig. 3 and 4). Ecological characteristics of Mangoku-ura Inlet was reported in detail by Imai et al (5). In the Harinohama farm, two culture racks were used for comparison, one being a new rack and the other 2 years old. In Sawada a new rack and an old one (in use for 15 years) were selected. For the culture experiments, 5 collectors (Pecten shell) each bearing 5 seed oysters, were strung on wire. Two of these wires were suspended horizontally by ropes at two levels, one in the middle depth and the other a little above

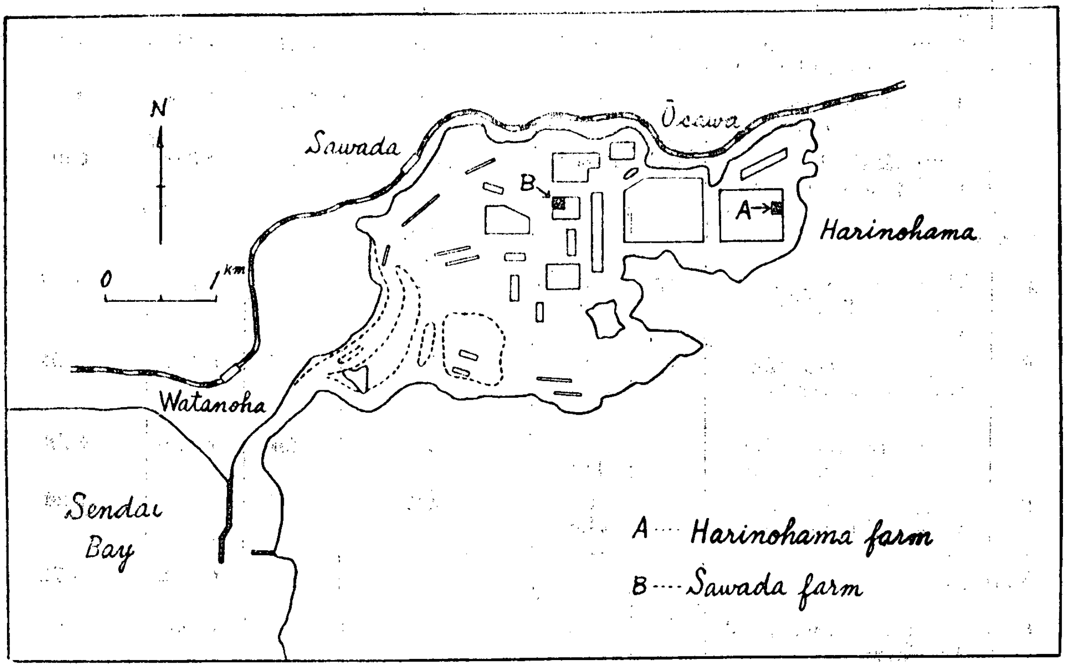

Fig. 3. Map of Mangoku-ura Inlet showing the location of farms.

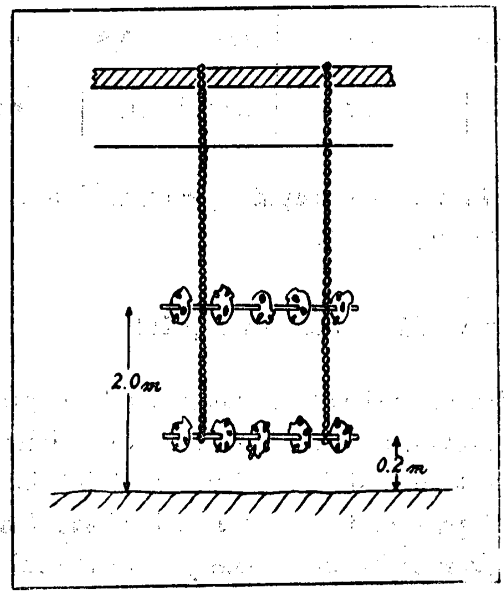

Fig. 4. Method of experimental culture in Harinohama farm.

the bottom, as shown in Fig. 4. Two sets were hung under each rack.

The culture experiment was started on the 31st of August, 1951 and the oysters were sampled on the 17th, Jan., 1952 at Harinohama and on the 9th of April, 1952 at Sawada. Analysis of oyster meats and bottom sediments was made in the same manner as in the previous study. Reuslts of the culture experiment are summarized in Table 3 for Harinohama and in Table 4 for Sawada farm.

Table 3. Comparison of dry meat weight of oysters exprimentally cultured under the racks of different ages in Harinohama farm in Mangoku-ura Inlet.

Racks	New rack (A)		Rack of 2 years old (B)	
Depth in water	Middle layer (1)	Bottom layer (2)	Middle layer (1)	Bottom layer (2)
Number of oysters surviving	40	44	34	30
Mean dry meat weight in gr.	0.320	0.313	0.357	0.241

Significance test of difference of mean dry meat weight

		(A)		(B)	
		(1)	(2)	(1)	(2)
(A)	(1)				
	(2)	P≒73%			
(B)	(1)	P≒13%	P≒5% (significant)		
	(2)	P<0.1% (significant)	P<0.1% (significant)	P<0.1% (significant)	

Table 4. Comparison of dry meat weight of oysters experimentally cultured under the racks of different ages in Sawada farm in Mangoku-ura Inlet

Racks	New rack (A)		Rack of 15 years old (B)	
Depth in water	Middle layer (1)	Bottom layer (2)	Middle layer (1)	Bottom layer (2)
Number of oysters surviving	47	26	44	31
Mean dry meat weight in gr.	0.887	0.512	0.651	0.228

Significance test of difference of mean dry meat weight

		(A)		(B)	
		(1)	(2)	(1)	(2)
(A)	(1)				
	(2)	P<0.1% (significant)			
(B)	(1)	P<0.1% (significant)	P≒1.2% (significant)		
	(2)	P<0.1% (significant)	P<0.1% (significant)	P<0.1% (significant)	

In the tables, the results of the significance tests as to the difference in meat weights of oysters under various conditions are given. Table 3 shows that, in Harinohama, the meat weight of oyster of the bottom layer in old rack was much less than that of middle layer of the same rack. The difference was significant. Among those in the middle and the bottom layers of the new rack and also in the middle layer of the old rack, no significant difference was observed. In Sawada farm (Table 4), the difference was more striking. Namely, even the oysters of the middle layer of the old rack were found to be significantly smaller than that of the same layer in the new rack. And the oysters in the bottom layer of the old rack were considerably smaller than those in any other layers.

The results of analysis of bottom sediments are summarized in Table 5 and 6 for Harinohama and Sawada respectively. The sampling was done on the 10th & 12th of September, 1952. In the tables, the color, the percentage of fine grains less than 0.1 mm in diameter, the content of humus and the total sulfide of sediment samples from the immediate bottoms under the racks are shown, with the results of analysis of samples collected from the control area (which is free from direct pollution by oyster discharge).

It can be seen from the tables that as the culture racks are used repeatedly, the bottom deposit gradually showed an increase of organic pollution by their

Table 5. Analysis of bottom sediment sampled from several stations of Harinohama farm in Mangoku-ura Inlet

Station			Result of analysis			
No.	Description of the station	Depth in m.	Color	Percentage of fine grain less than 0.1mm in dia.	Humus in%	Total sulfide in‰
1	Immediate bottom of 2-years-old rack	4.1	Black	99	4.88	1.73
2	Immediate bottom of 2-years-old rack	4.1	Black	100	5.01	2.01
Average				99.5	4.95	1.87
3	Immediate bottom of new rack	4.2	Dark brown	89	4.10	0.80
4	Immediate bottom of new rack	4.2	Dark brown	98	4.37	0.92
Average				93.5	4.24	0.86
5	Point between the racks	4.1	Brown	55	3.84	0.48
6	Point between the racks	4.1	Brown	58	4.10	0.53
Average				56.5	3.97	0.51

Table 6. Analysis of bottom deposits sampled from several stations of Sawada farm in Mangoku-ura Inlet

Station			Result of analysis			
No.	Description of the station	Depth in m.	Color	Percentag of fine grain less than 0.1mm in dia.	Humus in%	Total sulfide in‰
1	Immediate bottom of 15 years-old rack	2.6	Black	90	4.32	1.94
2	Immediate bottom of 15 years-old rack	2.6	Black	93	4.50	2.01
Average				91.5	4.41	1.975
3	Immediate bottom of new rack	2.6	Grayish brown	40	3.18	0.46
4	Immediate bottom of new rack	2.6	Grayish brown	32	2.75	0.33
Average				36.0	2.97	0.395
5	Point between the racks	2.7	Grayish brown	37	3.07	0.47
6	Point between the racks	2.6	Grayish brown	43	3.15	0.48
Average				40.0	3.11	0.475

color, the high percentage of fine grain and high content of humus and total sulfide. Old racks of Sawada farm, however, showed a relatively less organic pollution than was expected. This can be explained by the fact that the oysters of the raft was less densely populated, and the farm is in a channel in shallow water, and the bottom is exposed to rather strong currents of water during the ebbing and flooding of the tide.

The evidences found in Matsushima Bay as well as the results of experiment in Mangoku-ura Inlet seem to indicate clearly that as the culture racks are used repeatedly over the years the immediate bottom will become polluted to an extent that will interfere with the life of the oyster, particularly in the layer near the bottom.

Observations and experiments on the influence of bottom sediment on oyster.

In hanging culture, oysters are suspended in the intermediate stratum of water. Therefore, the problem of how the bottom sediments interfere the life of oysters remains to be solved. The interference may be either physical or chemical in nature. Loosanoff and Engle (6) showed in *O. virginica* that there was a certain limit of the density of suspended matter in the water, beyond which the feeding activity of oyster was inhibited. Seisi and Tomiyama (7),

Table 7. Comparison of sea water of Harinohama farm sampled on calm and rough weather conditions.

Date of observation				21st of Sept., 1951					27th of Sept., 1951				
Weather condition				Rough. Wind: NW, grade 3–5. Wave: grade 3–5.					Calm. Wind: NW, grade 1. Wave: grade 1.				
Station No.	Description of the station	Depth in meter	Depth of the water sampled	Transparency of water in m.	Water temp. °C.	pH	O_2 in percentage of saturation	Free H_2S in ppm.	Transparency of water in m.	Water temp. °C.	pH	O_2 in percentage of saturation	Free H_2S in ppm.
1	Inside the rack of 2–years-old	4.2	Surface	0.85	19.5	8.0	78.5	0.15	over 4.2	18.4	8.0	95.8	0
			Bottom		18.2	8.0	80.3	0.40		18.2	8.0	93.9	trace
2	Inside the rack of 1–year-old	4.2	Surface	0.75	19.5	8.0	82.0	trace	over 4.2	18.4	8.0	96.4	0
			Bottom		19.0	8.0	84.2	0.30		18.4	8.0	95.3	trace
3	Point between racks	4.2	Surface	1.30	19.5	8.0	87.5	0	over 4.2	18.4	8.0	94.0	0
			Bottom		19.0	8.0	86.3	trace		18.4	8.0	93.3	0

in their study on the unusual mortality of oyster in the sowing beds in Hamana Bay, suggested the possibility of free hydrogen sulfide generated from sulfide under condition of high hydrogen ion concentration.

As the oyster farms in Matsushima Bay and Mangoku-ura Inlet are in shallow waters and are subject to strong northwest winds during fall and winter, the bottom sediment is often stirred up and becomes suspended in the water. In such case, the suspended fine grains are likely to interfere with the activity of oyster and moreover, under certain hydrographic conditions free hydrogen sulfide might be liberated and have ill effects on the oyster.

A series of observations and experiments were carried to analyse the character of the sediment suspension actually occurring in the oyster farms and also to determine its influence on the activity of oysters.

1) Observations on the sediment suspension in sea water found in oyster farms on the day of calm and rough weather.

Observations were made at Harinohama oyster farm. The observation of rough weather condition was made on the 21st of September, 1951, after two days of continued strong wind. Calm weather observation was made on the 27th of September, 1951, after two days of continued calm weather. Water samples were taken from the points inside of the racks of one and two years old and also from the point between racks. In the analysis, hydrogen sulfide was measured colorimetrically with methylene blue (8). The results are shown in Table 7.

On calm day, the water transparency as measured by Secchi's disc was high, and hydrogen sulfide could not be detected even in the bottom layer, while on the day of strong wind, the transparency was very low and free hydrogen sulfide was detected distinctly. The increase of turbidity as well as the liberation of hydrogen sulfide was most striking in the rack used for culture for the longer period of years.

2) Settling velocities of bottom sediments from racks of various ages.

Bottom sediments were sampled from the culture racks and control area outside of the bed and were analysed mechanically, and chemically. Grain size analysis was made by the hydrometer method (9). Settling velocity was measured by settling the mixture of mud (10%) in sea water in graduated cylinder and reading the height of turbid water at definite time intervals. The results are shown in Tables 8 (A–C). It can be seen from the tables that the bottom sediments from aged racks (Sample 1, 2 and 3) showed a high content of finer grains and their settling was much slower as compared to the samples from control ground (Sample 4, 5 and 6). The low settling rate of the sample from aged racks is partly due to its high content of finer grains but it seems to be also due to its low flocculation power in the sea water due to its high humus content. It is suggested from these observations that the sediment from the bottom of aged racks will float readily and stay longer as suspension in the water, having ill effect on oyster.

3) Liberation of hydrogen sulfide from the bottom sediment.

Samples of bottom sediments were taken from the culture rack of Ōsawa farm (sample 1) and control area (sample 2). 10 or 50 cc of the sample was

Table 8. 8–A Physical and chemical characters of bottom samples used for measurement of settling velocity.

Sample	Description of the station sampled	Depth in m.	Color	Water content in%	Humus in%	Total sulfide in‰
1	Immediate bottom of rack of 4-years-old	2.4	Black	75.3	4.33	4.88
2	Immediate bottom of rack of 3-years-old	2.4	Black	75.6	4.25	3.48
3	Immediate bottom of rack of 2-years-old	3.8	Black	71.2	2.87	1.95
4	50 meter off the rack	2.4	Grayish black	71.5	2.58	2.21
5	〃	2.6	Grayish black	73.7	2.02	1.44
6	〃	3.8	Grayish brown	66.2	1.05	0.13

8-B Percentage distribution of grain size of the samples

Sample	Grain size in mm.							
	Less than 0.01	0.01–0.05	0.05–0.1	0.1–0.2	0.2–0.4	0.4–0.6	0.6–0.9	0.8–1.0
1	25	24	11	9	6	8	8	9
2	24	21	8	20	4	7	7	9
3	17	25	11	2	4	4	0	37
4	18	17	8	7	3	7	14	26
5	18	8	5	6	5	8	18	32
6	4	7	4	2	3	10	22	48

8-C Settling velocity measurement of the samples.

Sample	Reading of the height of turbid water in cm.							
	At start	5 min.	10 min.	15 min.	20 min.	30 min.	40 min.	50 min.
1	30.0	30.0	29.8	29.2	28.4	24.2	22.2	20.7
2	30.0	30.0	30.0	28.4	26.8	23.0	20.8	19.4
3	30.0	29.9	27.3	24.8	22.7	21.0	20.1	19.4
4	30.0	26.0	20.4	17.0	15.7	14.5	13.7	13.1
5	30.0	24.4	20.8	19.2	18.5	17.7	17.0	16.6
6	30.0	13.5	9.5	8.3	8.0	7.4	7.0	6.7

shaken thoroughly in 100 cc of sea water (of various natures), in a glass stoppered flask and the liberated hydrogen sulfide was measured colorimetrically with methylene blue. Sample 1 was black in color and its total sulfide was 3.22‰ while sample 2 was grayish darkbrown and its sulfide content was 1.87‰. Normal sea water, oxygen-free sea water and oxygen-free sea water acidified with hydrochloric acid were used in the experiments. Oxygen-free sea water was prepared by shaking the sea water with bottom sediment in it. It was confirmed before the experiment that the sea water prepared was free from hydrogen sulfide.

Table 9. Tests on liberation of free H_2S from the bottom sediments.

A. Character of bottom samples used.

Sample	Description of the station of sampling	Color	Total sulfide in ‰
1	Immediate bottom of old rack	Black	3.22
2	Outside of rack	Grayish dark brown	1.87

B. Liberation of free H_2S from bottom sediment in normal sea water (O_2=6.3 cc/L, pH=8.3).

Sample	Amount (cc) of sample mixed in 100 cc of sea water	Free H_2S liberated in sea water, in ppm.
1	10	trace
	50	0.005
2	10	0
	50	0

C, Liberation of free H_2S from bottom sediment in oxygen-free sea water (O_2=0 cc/L, pH=8.0 H_2S=0 ppm.)

Sample	Amount (cc) of sample mixed in 100cc of sea water	Free H_2S liberated in sea water, in ppm.
1	10	0.05
	50	0.33
2	10	trace
	50	0.03

D. Liberation of free H_2S from bottom sediment in oxygen-free sea water acidified with hydrochloric acid (O_2=0 cc/L, H_2S=0 ppm.). (Concentration of bottom sediment = 10 : 100 cc).

Amount of 10% hydrochloric acid added to 100 cc of sea water in cc.		0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
pH		8.0	6.7	5.4	5.7	4.0	3.2	2.8	2.7	2.6	2.5	2.5
Free H_2S liberated, in ppm.	Sample 1	0.05	0.05	0.06	0.05	0.30	0.80	2.10	4.20	4.10	4.20	4.20
	Sample 2	trace	trace	0.01	0.01	0.08	0.20	0.50	0.80	1.10	1.10	1.10

The results of experiments are summarized in Table 9 (A–D). When normal sea water was used, hydrogen sulfide was hardly detected (Table 9–B). When oxygen-free sea water was used (Table 9–C), the liberation of hyrdogen sulfide appeared distinctly and its amount was much higher in sample 1 than sample 2. When acidified oxygen-free sea water was used (Table 9–C), it was shown that at the hydrogen ion concentration above pH 4, the liberation of hydrogen sulfide increased enormously.

From these experiments, it can be concluded that, when the bottom sediment is stirred by turbulence, the hydrogen sulfide in the sediment is liberated into sea water. If the oxygen content of sea water is high, the liberated hydrogen sulfide may be oxidized completely but if not, the liberated sulfide may be left unoxidized and will have an ill effect on oyster. As the reducing power of bottom sediment is high, it is expected that the water near the bottom tends to have a low oxygen tension. Accordingly, the liberation of free hydrogen sulfide may possibly occur in the farm under natural conditions. When the hydrogen concentration of sea water become very high with a pH value lower than 4, the sulfide is decomposed and a large amount of hydrogen sulfide is liberated. However, such low pH will never be met under natural condition in sea water in and above the bottom. Therefore, it is reasonably assumed that the generation of hydrogen sulfide from sulfide will hardly occur in the natural oyster bed.

Experiments on the effect of bottom sediment on the feeding activity of oyster.

In the above observations and experiments it was ascertained that the productivity of oyster beds tends to decline gradually as the rafts or racks are used repeatedly for greater numbers of years. Such decline might be due to interference by the bottom sediment which had been polluted mainly by the accumulation of oyster discharge. Only the problem of determining how the bottom sediment actually interferes the activity of oysters now remains. Therefore, in the following experiment, the effect of sediment on the rate of water pumping was studied. An apparatus devised by Loosanoff and Engle (7) was used for recording the pumping rate. The shell movement was recorded simultaneously on a kymograph. Two winter oysters of the average shell height of 9 cm. were used in the experiment. The oysters were kept in the oyster chamber where normal sea water was run at the rate of 500 cc per minute. Rate of pumping in normal sea water at 18–20°C is shown diagramatically in Fig. 5 with the record of shell movement.

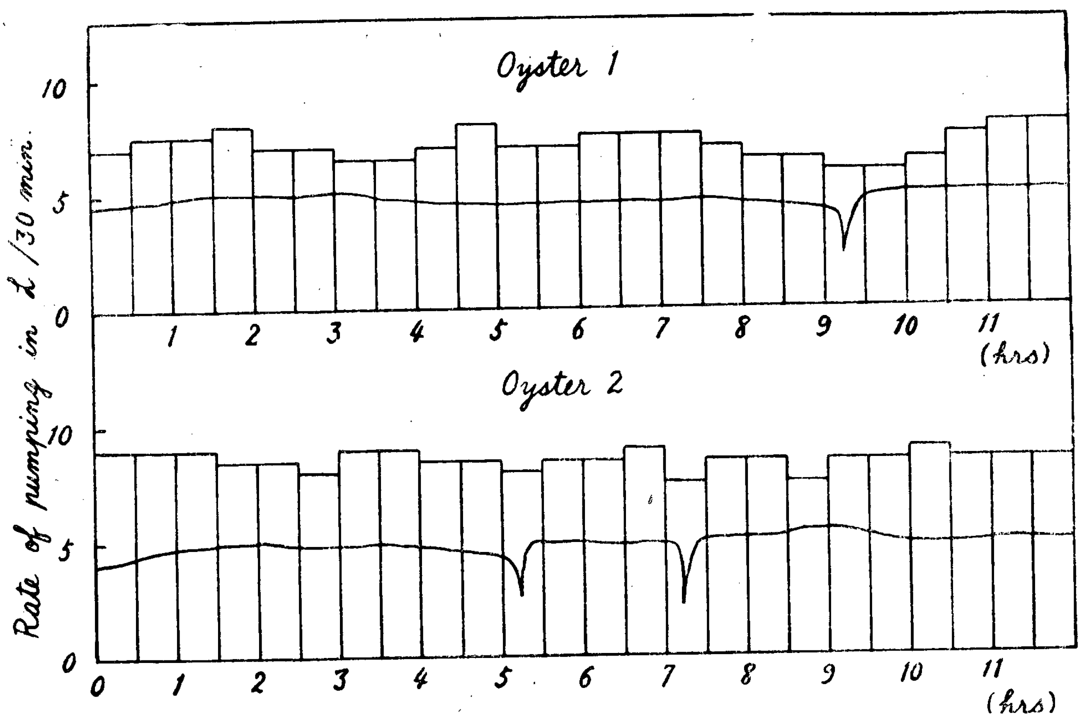

Fig. 5. Histogram showing the rate of pumping of two oysters in normal sea water with record of shell movement.

Though the individual variation was large, the oyster showed a uniform pumping rate for over 12 hrs. Sediment suspensions were prepared as follows; 20 kg of bottom samples from Harinohama bed and the control ground were shaken in 20 litres of normal sea water respectively. After allowing the mixtures to stand for definite periods of time, the supernatant fluid was decanted and used for the experiment. Physical and chemical characters of sediment samples and supernatant fluids prepared are summarized in Table 10.

Table 10. Supernatant fluid prepared from a mixture of bottom sediment in sea water

Bottom sample No.	Character of station	Characters of bottom sediment.				Analysis of supernatant fluid used for the experiment			
		Color	Percentage of fine grain less than 0.1 mm in dia.	Humus in %	Total sulfide in ‰	Settling period	Oxygen in cc/L	Content of sediment in gr/L	Free H_2S in ppm.
1	Rack of two-years-old	Black	97.0	4.10	1.80	10min.	0	1.88	trace
						30min.	0	0.80	0
						60min.	0	0.20	0
						24hrs.	0	0.01	0
2	Point off the farm	Grayish black	60.0	2.11	0.38	10min.	2.0	0.42	0
						30min.	2.0	0.30	0
						60min.	2.5	0.20	0
						24hrs.	2.9	0.013	0

In the experiment, the normal sea water was run at the rate of 500 cc per min. to begin with, then the supernatant fluid was added to it at the rate of 50 cc per minute and the change of pumping rate was recorded. The records are shown diagramatically in Fig. 6.

The fluid prepared from the sediment of the control area showed rapid settling. and on adding the fluid, the pumping rate was not greatly disturbed. But the fluid prepared from the sediment of rack lowered the rate considerably. It decreased to a half when the supernatant fluid of 30 min. settling was used. Fluid of 10 min. settling diminished the rate to one fourth of the normal. As is shown in the table, hydrogen sulfide was not detected in the fluid prepared. Therefore, the interference observed is likely to be due to physical action of suspended silt.

Among chemical substances dissolved into sea water from bottom sediment, the hydrogen sulfide is considered to be the one which has the most serious effect on oyster. Therefore, the effect of free hydrogen sulfide on pumping rate was studied in the following experiment. Hydrogen sulfide sea-water was prepared and various amount of it was mixed with normal sea water and was run into the oyster chamber to determine its effect on the pumping rate. The result is

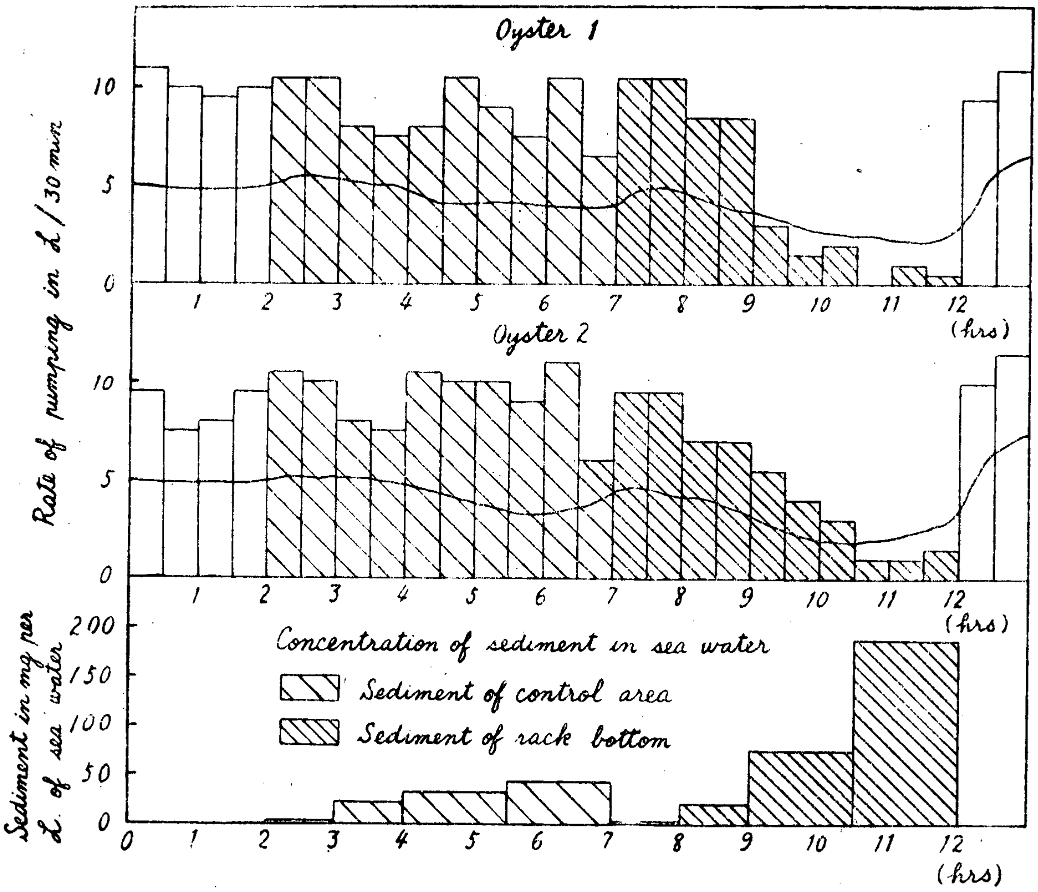

Fig. 6. Histogram showing the effect of sediment suspensions on the rate of pumping of two oysters.

shown in Fig. 7. Though the effect of hydrogen sulfide on the pumping rate was hardly detectable at the concentration lower than 0.1 ppm. It became distinct as the concentration increased and finally at 0.7 ppm. the pumping come to a complete stop. In view of the fact that free hydrogen sulfide of the concentration of 0.4 ppm. was found in the water around the culture rack (see Table 7), it can be concluded that in the old racks, the oysters laid near the bottom will often be exposed to the liberated free hydrogen sulfide from the bottom.

Conclusion and discussion

It has been proved in this study that by repeating the cultures, the productivity of the oyster farm declines gradually. Decline shows itself as a poor crop of oysters, particularly in the water near the bottom. The bottom sediment immediately below the rack or raft is polluted readily with organic discharge of oysters. The polluted bottom sediment contains a high percentage of fine grains and is rich in humus, total nitrogen, total sulfide and free hydrogen sulfide. When the sediment of such a polluted bottom is stirred by wave

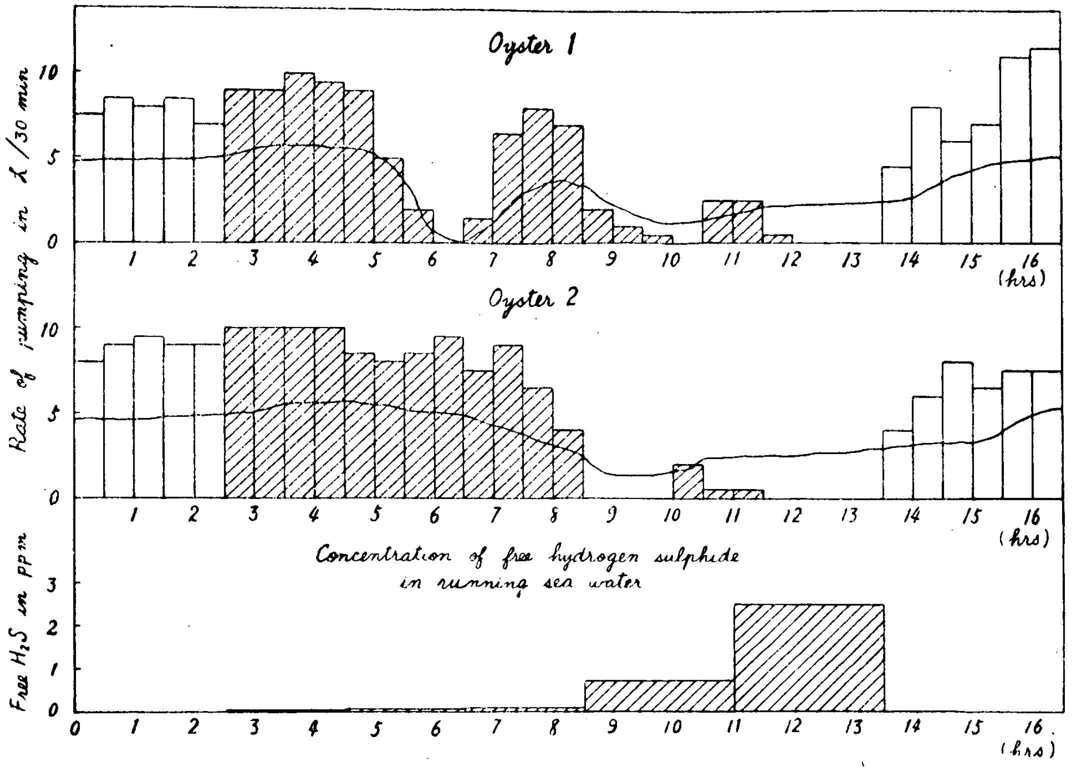

Fig. 7. Histogram showing the effect of free hydrogen sulfide on the rate of pumping of two oysters.

action it readily gives rise to silt suspension in sea water and often liberates free hydrogen sulfide which has a harmful effect on oysters. From the results of observations in the farms and physiological experiments, it is expected that such harmful effect of sediment suspension could occur in the oyster bed. Therefore it can be concluded that the decline of productivity in the oyster farms used repeatedly over the years is mainly due to the physical and chemical action of polluted bottom sediment.

As it has been shown that the decline of productivity in the oyster farm is caused by the organic sedimentation from oyster, the problem is how to prevent it. One possible means is to use the culture beds in rotation in order to slow down the organic pollution.

Alternative means is to remove the organic sediment from the bed or to accelerate the oxidation of organic matter in the sediment. The latter idea has been put into practice in the management of the clam bed by ploughing the bottom bed with farm cultivator. But the results are not so much promising, because infrequent ploughing does not oxidize the sulfide in the sediment thoroughly with sustaining effect. At any rate, a cultivator can not be used efficiently in the oyster beds which are not exposed to air even at low tide. In this regard, pumping air or suction dredging would be much more useful.

A light organic pollution of bottom sediment may be a common occurence in the densely populated beds of sowing oyster and clams. In the waters where the organic discharge from the land is added bottom pollution presents a serious problem, which demands proper means for its prevention and for the methods of reviving the prodcutivity of the polluted beds. This seems to be the point of greatest importance in the management of shellfish industry. Study will be continued toward this end.

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