A LIMNOLOGICAL STUDY OF AKKESHI LAKE WITH SPECIAL REFERENCE TO THE PROPAGATION OF THE OYSTER*

By

Tetsuo Inukai and **Shinroku Nishio**

(With 16 tables and 20 figures)

Introduction

In the early days of Hokkaido, then popularly called Yeso, there were found in Akkeshi lake fine native oysters in great abundance, making widespread natural beds, and the oysters, which are identified systematically as *Ostrea gigas* THUNBERG, characterised by their large size, once made Akkeshi very famous. At present we find a great number of shell heaps, consisting chiefly of oyster shells, in the neighbourhood of the lake, and it was said not so long ago that the Ainu who resided there made extensive use of the prolific natural beds. The prosperity of the oyster in the lake did not change as the population in the district was very small in the early days of the settlement of Hokkaido. Recently, however, wasteful catching and lack of care have inevitably brought about a disastrous consequence, reducing the production not a little. The greater part of the area where oysters were formerly produced is covered only with dead shell, and live oysters are found with great difficulty. Nevertheless attempts have been made repeatedly to restore them to the former state of prosperity. Sometimes propagation of the oyster by means of artificial cultivation was tried and sometimes transplantation of the young oyster spat from other localities. However, in spite of all efforts no noticeable results have yet been obtained and any hope of oyster culture in the lake is almost given up.

On the other hand we must not overlook the fact that the oystermen

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of the lake have sometimes been successful rather by chance in collecting the spats which are found occasionally attaching to the old shells in the lake and cultivating them. Moreover it is ascertained that in the laboratory artificial insemination and culture of oysters obtained from the lake can be performed without difficulty. Taking into consideration all these facts it is now highly probable that some limnological factors may be checking the propagation of the oyster. Therefore it is desirable first of all to examine the physico-chemical condition of the lake in relation to the life of the oyster. Again, from the point of view of the oyster life in the lake, only the limnological study during the breeding season of the animal, which lasts from June to August, is of primary importance. Apart from the food substance which is very abundant in the lake, we can enumerate the factors which exert an influence on the life of the oyster as follows: temperature, salinity, dissolved oxygen, hydrogen-ion concentration and turbidity of the water. The authors intend to investigate the above conditions of the lake precisely in connection to the oyster culture.

In the investigation the necessary laboratory work was done in the Marine Biological Station at Akkeshi attached to the Faculty of Science of the Hokkaido Imperial University. Most of the field work were done from June to October at intervals of 7–10 days at various levels of the tide. In addition some observations were made irregularly at different seasons.

The water sample was collected in a slightly modified KITAHARA's apparatus, consisting of a water bottle with a capacity of 700 cc. The temperature was measured instantly after collection in each case. For determination of oxygen content, salinity and hydrogen-ion concentration, the water was siphoned into a bottle of hard glass with a capacity of about 300 cc, carefully stopped to avoid air contamination, and brought into the laboratory. The dissolved oxygen was determined by means of WINKLER's methods and the result was recalculated according to KNUDSEN's hydrographical table (KNUDSEN 1901). The salinity was measured by using silver nitrate and chromic acid as indicators. KNUDSEN's table was also employed in this case for calculation. For determining the hydrogen-ion concentration the colorimetric method, using cresol-red, thymol-blue and brom-thymol-blue, was applied. However no correction for salt error was made.

In the study of the tides and the tidal currents which occur in the lake under the influence of the tide of Akkeshi bay, only the surface velocity of the current was measured, by floating a piece of wood for a certain distance for a certain length of time. From this we could obtain the relative velocity of the tidal current at any stage of the tide.

The observation was made chiefly by the junior author under the direction of the senior in 1933, and since then it has been continued by the latter. In carrying on the work the investigators were aided greatly by the staffs of the Akkeshi Marine Biological Station and by those of the Akkeshi Fishery Guild, Mr. HATTORI in particular. These are duly appreciated and it is hoped that this work may repay, at least in part, all who assisted the authors.

Physiography of the lake

Akkeshi lake is a kind of lagoon located on the south-eastern coast of Hokkaido, connected by a narrow canal of about 7 metres width to Akkeshi bay which opens to the Pacific.

The lake is nearly ovoid in shape, being about 7 kilometres(km) long, 6 km wide, 35 sq. km in area, and 25 km in circumference. Except for the western side the lake is surrounded by a terrace which rises to an elevation 100–200 metres above sea level. Of the inflowing rivers the Bekanbeushigawa is the largest, entering from the north-western side, draining the vast area of the Kushiro plain, which was formerly impassable woodland in its upper section, and a wilderness of marsh and moorland in its lower regions. In the early days of the settlement of Hokkaido the large tracts of the upper reaches of the river became waste after several woodfires and reckless deforestation. This has modified the limnological condition of the lake greatly. The next largest river is the Oborogawa, which flows parallel to the sea-coast and enters the lake with the same mouth as the Bekanbeushigawa. There are several small insignificant inlets draining from the southern side of the lake.

It is a characteristic of the lake that by the tidal action of the bay the sea water from the open sea enters the lake and flows out with a strong and rapid current, making the lake water salty, especially at the connecting channel. The average depth of the lake does not exceed 2 metres at low tide. Where the current is strong, namely in the radial stretch from the mouth of the lake, the water is 2–7 metres in depth. Especially in the estuary of the Bekanbeushigawa there are several points which are more than 5 metres deep even at low tide. As a particular feature of the lake there exists a great number of natural oyster beds of varying size forming reefs, situated in the south-eastern section. At the present time they consist mostly of old oyster shells and mud containing rich vegetable debris. They are called popularly as Kakijima, meaning oyster islets. About 40–50 reefs are visible at low water, while most of them disappear at the flood tide, except 10 which are comparatively large and a little elevated. On the larger reefs there grow several kinds of seashore plants such as *Elymus mollis* TRIN., *Senecio pseudo-arnica* LESS., *Ammodenia oblongifolia* RYBD. var. *maxima* NAKAI, *Salicornia herbacea* L. etc. and even the land plant like *Artemisia Shikotanensis* KITAMURA safe from the flood tide (Fig. 2).

Where the basin is shallower than 1 metre, it is covered with soft mud in which an aquatic plant, *Zostera marina* L. grows densely. The vegetation in the deeper parts is very poor. However it is interesting to find some seaweed like *Laminaria longipedalis* OKAM. growing in the deeper part of the lake. The general bottom consists mostly of vegetable debris containing a small quantity of sand and fragments of shell.

The north-eastern and southern beaches of the lake are composed of deep mud and the swamp is overgrown by reeds. Only the western beach is composed of fine sand being made probably under the influence

Fig. 1. Low tide showing a vast field of oysters of Kakijima at about 35 years ago.

Fig. 2. One of the recent reefs (Kakijima) with seashore plants.

of the wave action of Akkeshi bay.

The colour of the lake water is in summer yellowish brown and is indicated by No. 10–12 in FOREL's xanthometer. The transparency is mostly less than 1.5 metre.

Off Akkeshi the warm current from the south, Kuroshiwo, and the cold current from the north through the Bering Strait meet each other, and make the meteorological condition of this district very complicated.

Temperature of the lake water

There is no need to exaggerate the importance of the water temperature for the life of the oyster. It exerts an influence, not only directly on the various physiological activities of the animal, but also indirectly, by controlling the amount of the food plankton. In the eastern district of Hokkaido where Akkeshi is situated, we generally experience bad weather throughout the year, having no real summer and meeting with extremely cold winters.

Climatic influence on the water temperature

Generally speaking the condition of the climate in Akkeshi is by no means good for the life of the oyster. The water temperature is too low for the latitude, being affected by the unfavourable climate, parti-

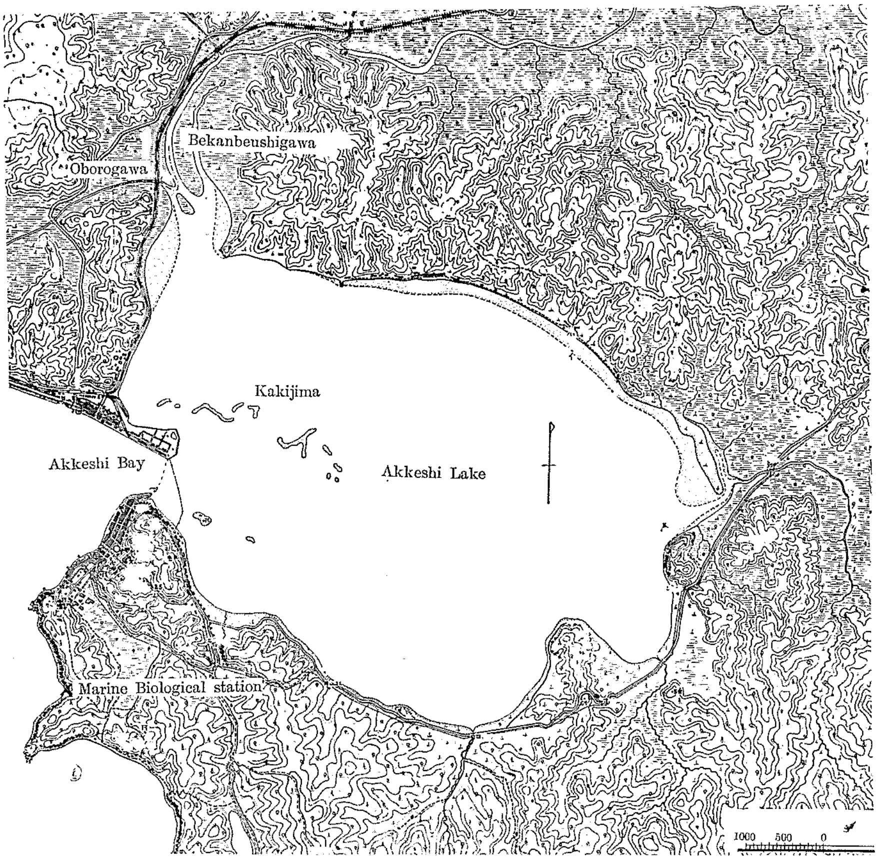

Fig. 3. Sketch Map of Akkeshi Lake.

cularly in summer, when the reproductive activity of the animal should be at its greatest. Severe winters with wind and ice which cover the lake to a depth of more than 1 metre, are also undesirable factors. Of the meteorological factors which affect the water temperature, the fog in summer is mostly responsible for lowering the air temperature, which in turn affects the water temperature and at the same time prevents solar radiation on the lake water. The fog appears most frequently from June to August on the south-eastern coast of Hokkaido, being caused by the cooling of damp air accompanying the warm Kuroshiwo flowing from the south when it meets the cold current coming from the north through the Bering Strait and along the Kuriles and partly from around the Okhotsk coast. The average number of foggy days in a month from 1930 to 1933 at Nemuro and Kushiro, between which Akkeshi is situated, is given below.

TABLE 1.

Average number of foggy days in a month in 4 years mean (1930–1933)

Month		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Number of days	Nemuro	1.0	2.4	4.5	9.3	13.1	18.5	20.5	19.1	8.2	3.1	1.8	1.5
	Kushiro	2.4	3.5	4.4	7.9	11.0	13.9	16.8	16.1	12.0	6.8	2.8	2.2

The fog occurs most frequently in July, next in August and then in June. It is worth noting that in this district the fog is more prevalent in fair weather and only several metres above sea level there is sun-shine, while below it the fog creeps on the ground. Generally the air temperature falls when the fog covers the place where there was

TABLE 2.

Date	Air temp. at noon	Weather condition
August 10	21.5	(light) foggy
11	23.5	fair
12	23.0	(dense) foggy
13	25.3	(light) foggy
14	22.0	(dense) foggy
15	21.8	rainy
16	19.7	cloudy
17	20.0	cloudy
18	16.3	cloudy
19	13.5	rainy
20	16.0	cloudy
21	20.7	cloudy
22	21.7	cloudy
23	22.6	cloudy
24	24.8	(dense) foggy
25	21.2	(dense) foggy
26	23.7	(dense) foggy
27	21.0	(dense) foggy
28	24.0	(dense) foggy
29	24.0	fair
30	22.0	fair
31	23.5	fair

sun-shine just a moment before. The observations made on Daikoku-jima off Akkeshi bay in 1933 explain the circumstances plainly (Table 2).

It is interesting to note that the air temperature is higher on foggy days than on cloudy or rainy days. Though the air temperature influences that of the water not a little, in the shallow water like Akkeshi lake the radiation heat from the sun direct plays a great part in raising the water temperature. As a matter of fact we have noted occasionally that the water temperature in the lake temporarily rises more than 25°C in the sun-shine in summer. However on account of so many foggy days in summer (as seen in the table) there is little chance of keeping the water temperature raised.

Then we may turn our attention to the air temperature in this district. In Akkeshi bay the daily temperature of the sea water measured off the Marine Biological Station varies almost exactly with the air temperature as shown in the following figure.

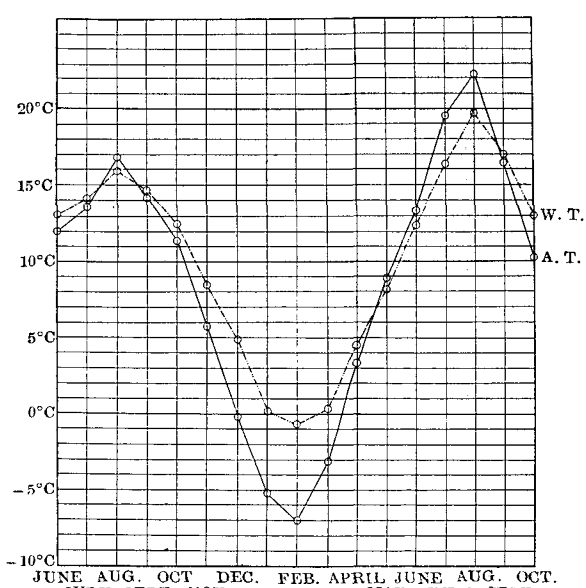

Figure 4.
W. T. means water temperature and A. T. air temperature.

When measured monthly (Fig. 4) the temperature of the sea water is higher by 5°C than that of the air in February while it is lower by 2°C in August. In general the temperature of the sea water varies from month to month according to the air temperature.

Now how is the seasonal range of air temperature in this locality? The 4 years average of the air temperature in this district from 1930 to 1933 shows that it does not exceed 20°C as seen in the table given below.

TABLE 3.

4 years average of air temperature in a month from 1930 to 1933 (°C)

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Nemuro	−5.2	−5.6	−2.6	2.8	6.5	9.9	14.3	19.1	15.2	10.5	4.4	−1.4
Kushiro	−7.0	−6.5	−2.4	2.8	6.7	10.6	15.3	17.9	13.2	9.8	3.6	−3.2

Therefore it is understood that the air temperature is not high enough to warm the water of the lake above the general level necessary for the reproduction of the oyster.

In addition the amount of precipitation is raised in summer, immediately causing the high water of the inlet rivers, and this provides another reason for lowering the water temperature of the lake. In the following table the 4 years mean of the monthly precipitation at Nemuro and Kushiro is given.

TABLE 4.

4 years mean of monthly precipitation (1930–1933) in mm^3

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Nemuro	37.3	27.1	53.6	76.9	96.5	90.8	97.7	129.0	144.1	101.3	83.9	57.5
Kushiro	89.8	36.1	70.0	85.1	93.3	107.0	110.0	144.0	163.5	119.0	76.6	48.2

The highest figure is shown in September and next in August, at which times otherwise the water temperature might be much warmed.

In short an examination of the meteorological factors which influence the water temperature of the lake show them to be by no means favourable.

Influence of hydrographical factors on the water temperature

Apart from the climatic factors the action of the tidal current which flows in and out of the lake and the river discharge are of great importance in regulating the limnological as well as the nutritional condition of the lake.

THE TIDAL CURRENT

Generally speaking, the form of the sea tide in this district belongs throughout the year to the semidiurnal type. The range of the tide in Akkeshi bay was surveyed by Lieut. Y. MIURA in 1892. According to him the range of the spring tide in the bay is 1.6 metre and that of the neap tide is 1 metre. In the lake the depth of the tide is different according to the place, the influence of the river discharge playing an important part. Observations were made in October, 1936, at 2 stations, one near Kakijima (A) which is influenced much by the water of the two great inlet rivers and the other (B) in the centre of the lake where neither the tidal current nor the river discharge exert much influence (A and B in Fig. 5). The table 5 shows the result.

TABLE 5.

Depth of water at different time in a day (1936)

Station A on Oct. 11–12		Station B on Oct. 16–17	
Time of observ.	Depth of water in metres	Time of observ.	Depth of water in metres
p.m. 1	2.5	p.m. 12.40	1.40
3	2.45	2	1.70
4.30	2.25	3.30	1.85
6	2.10	5	1.85 max.
7.30	2.05	6.30	1.60
9	2.10	8	1.30
10.30	2.25	9.30	0.95
12.20	2.40	11	0.9 min.
a.m. 1.30	2.45	a.m. 12.30	1.0
3	2.35	2	1.20
4.30	2-20	3.30	1.50
6	2.0	5	1.80
7.30	1.90 min.	6.35	1.80
9	1.97	8	1.55
10.30	2.30	9.30	1.33
12	3.53	11	1.28
1	3.65 max.		
Tidal diff.	1.75		0.95

From the above it is seen that at the neap tide the tidal difference attains 1.75 metre near Kakijima, while it is 0.95 metre at the centre of the lake. However in comparison with the sea the time of the slack in the lake is greatly shortened on account of its narrow opening. For example the period of slack water in the lake inside of the Kakijima circle lasts for 30–40 minutes at low water in the neap tide and only 10–20 minutes in the spring tide.

The flood current as measured in summer, 1933, enters the lake continuously for about 5½ hours, while the ebb current flows out for about 6 hours in the neap tide. The measurements made in October, 1936, also show that at the outside of the Kakijima and in the central part of the lake the tidal change occurs almost regularly every 6 hours.

The direction of the flood and the ebb tide in the lake as observed at different stations is shown in figures 5 and 6.

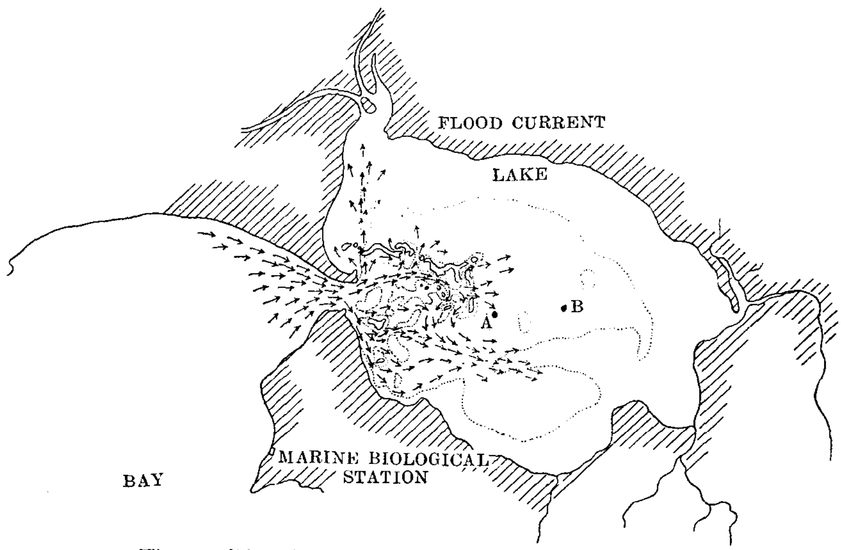

Fig. 5. Direction of flood current observed at neap tide on Aug. 21, 1933.

As seen in the figures the flood tide flows into the lake and spreads from the mouth to all directions into the interior of the lake. In the ebb current the water runs in an almost exactly reversed direction to the flood current. However after passing the entrance of the lake it flows out constantly alongside of the western coast in the bay. It is quite necessary to investigate how far the sea tide exerts its influence on the temperature as well as on the salinity of the lake water.

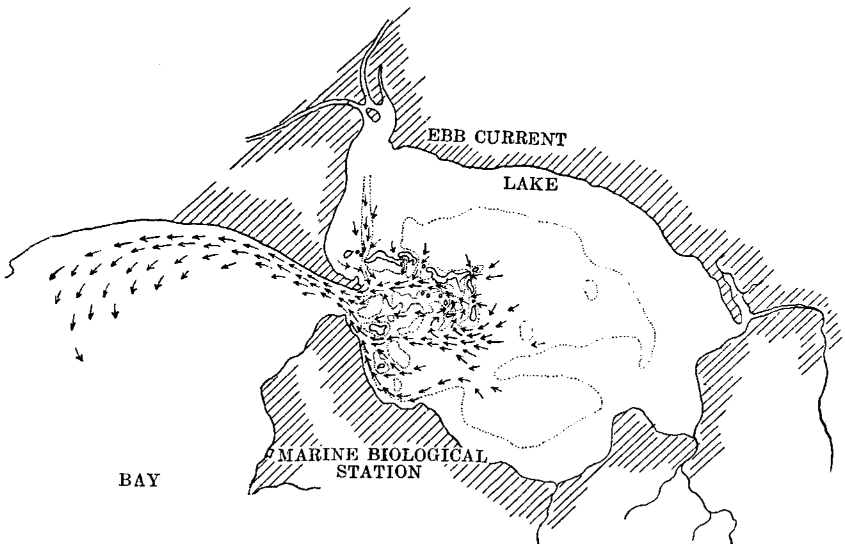

Fig. 6. Direction of ebb current observed at neap tide on Aug. 21, 1933.

First, the influence of the tidal current on the temperature of the lake water will be considered. The water temperature of the lake was measured occasionally at about 11 different stations as shown in the figure (Fig. 7). The results of the observation are given in the following table (Table 6). Station 2 is situated between 1 and 4.

Fig. 7.

TABLE 6.

Water temperature at different points in the lake measured in 1933

Date of observ.	May 17	May 27	July 2	July 21	July 27	Aug. 9
Station 1	9.0	14.5	18.2	18.8	18.5	22.0
2	8.5	14.5	18.5	17.3	20.0	23.0
3	11.0	14.5	18.3	18.2	21.0	22.7
4	11.5	14.8	19.0	17.5	20.6	23.5
5	11.0	16.0	19.5	—	21.2	23.7
6	11.5	15.8	19.4	18.3	—	24.5
7	11.0	18.0	18.5	16.7	22.7	24.5
8	10.5	16.7	19.5	—	22.5	24.7
9	12.0	17.2	19.5	16.0	22.0	24.3
10	12.5	16.0	—	15.0	20.7	23.2
11	12.5	15.0	19.5	18.0	21.0	23.0
Remarks	a.m., fair, high water	a.m., fair, low water	a m., cloudy, high water	p.m., foggy, high water	a.m., fair, low water	a.m., fair, low water

It is clear from the table, first, that in the interior of the lake where the influence of the tidal current is relatively small the water temperature is mostly higher than around the mouth part where the tidal influence is strongest; secondly, that the difference of the temperature between the interior part of the lake and the part near the opening of the lake is a little greater at low water than at high water. In short we can hardly get the water warmer than 20°C in the lake near the entrance of the bay. On the contrary in the interior a warmer temperature is easily obtainable. In this connection another investigation was made in 1936. The following table (Table 7) shows the results of observations made at the end of the flood tide in the lake. The temperature of the sea water was measured just in front of the Marine Biological Station where it is more or less exposed to the direct influence of the solar radiation.

TABLE 7.

Temperature measured in 1936. Stations A, B, etc. are shown in Fig. 7.

Station	A	B	C	D	E	Air temp. at noon	Temp. of sea water	Weather
Date								
June 8	14.2	15.2	—	14.9	16.2	10.4	9.0	fair
June 20	18.2	—	21.0	22.8	23.0	13.9	16.0	cloudy
June 28	22.6	24.5	—	—	—	21.3	15.0	fair
July 5	21.0	—	—	—	—	12.0	14.0	fair
July 8	23.6	—	—	—	—	15.1	16.1	fair

The figures in the above table confirm the general features clearly; for example, the temperature of the lake water is already raised up higher than 23°C on the 20th of June whereas the sea water measures only 16°C.

The circumstances explain the fact plainly that the tidal current acts as the cooling agent of the lake water which is warmed in the interior part. Therefore insofar as the temperature is concerned the effect of the sea water is the most important of the physical factors which dominate this district.

The river discharge

Similar to the tidal current which we have considered above, the river discharge into the lake is important also in regulating the water temperature as well as the salinity of the water necessary for the life of the oyster. In addition, it carries mineral salts and organic substances which in turn increase the amount of plankton available for the food of the oyster. In this respect the influence of the Bekanbeushigawa, which is the largest, is most conspicuous, bringing throughout the year, at the same time, into the lake a considerable amount of mud which is by no means favourable to the oyster. Particularly after heavy rain, which occurs often in summer, the condition of the lake is much changed by the inflowing water; sometimes the water near Kakijima becomes completely turbid for several days. Unfortunately, owing to the vast swampy area through which some part of the inflowing water passes, quantitative measurement of the running water is not available. Generally the amount of water discharged varies markedly from season to season, the

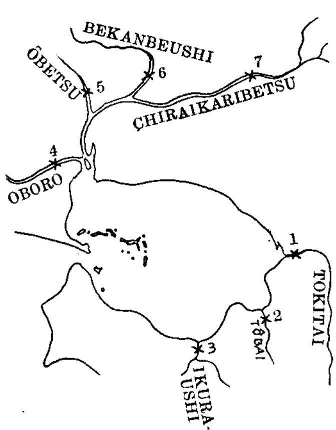

Fig. 8.

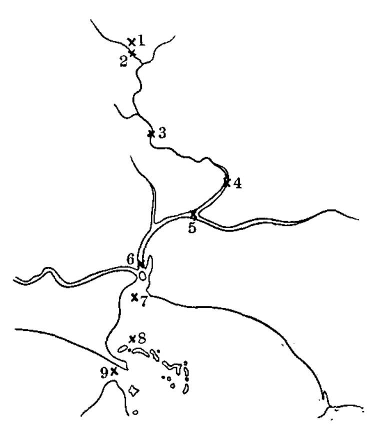

Fig. 9.

water level being at its highest in April and May because of the snow thawing in this district. The summer precipitation makes the river water reach its next highest level (refer Table 4). In February on the contrary there is the lowest water of the season, which is undoubtedly due to the freezing cold with snow and ice. It is noticeable that the water temperature of the river measured at the discharging spot is higher than that of the outer sea during the season from June to September while it is just reversed in winter. The measurements of the temperature, the salinity and the pH of the water, were made at different seasons at several stations. The figures 8–10 and the table 8 show the results.

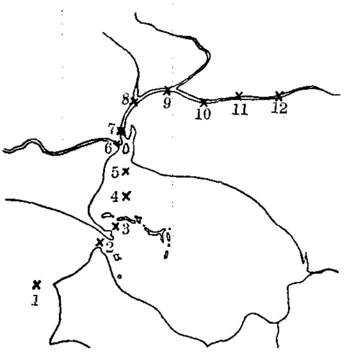

Fig. 10.

TABLE 8.

Date	Station	Time	A.T.(°C)	W.T.(°C)	Sal. ‰	pH
May 31	1	12.30 p.m.	16.5	15.7	6.71	7.1
	2	12.40 p.m.	15.0	16.2	2.30	7.2
Fig. 8	—	— —	—	16.0	19.69	7.6
	3	1.40 —	15.5	15.3	trace	7.5
	—	— —	—	15.2	12.50	8.3
July 6	4	9.00 a.m.	16.0	14.8	3.24	7.1
	—	— —	—	14.0	24.05	7.6
Fig. 8	5	10.10 —	16.5	12.7	trace	7.0
	6	11.00 —	17.5	12.5	—	6.8
	7	12.10 p.m.	21.0	14.8	—	6.8
Aug. 28	1	4.15 p.m.	20.6	20.0	—	6.20
	2	4.35 —	18.1	16.6	—	6.70
	3	4.55 —	18.9	16.6	—	6.75
	4	5.10 —	18.8	16.6	—	6.75
Fig. 9	5	5.25 —	17.9	16.6	trace	6.80
	6 L.W.	5.45 —	18.0	17.6	trace	6.85
	7	5.55 —	18.2	19.0	1.8	7.10
	8	6.04 —	18.4	18.5	14.15	8.00
	9	6.15 —	17.9	18.4	19.40	8.35

(Table 8 continued)

Oct. 27	1	9.30 a.m.	9.0	10.3	33.73	8.2
	2	10.20 —	9.6	10.5	32.47	8.2
	3	10.27 —	9.3	10.5	32.15	8.1
	4	10.33 —	9.4	10.8	29.90	8.1
Fig. 10	5	10.42 —	9.4	8.8	7.80	7.7
	6	10.47 —	9.5	8.5	7.50	7.4
	7	10.50 —	9.5	7.5	1.00	7.2
	8	11.00 —	9.0	7.0	trace	6.9
	9	10.10 —	8.5	6.8	—	6.9
	10	11.20 —	8.5	7.4	—	6.8
	11	11.35 —	8.5	7.0	—	6.8
	12	12.40 p.m.	8.3	6.0	—	6.7

From the end of May to the early part of June the water temperature of the small river is lower than that of the air but a little higher than that of the sea water which measures 14°C. However the temperature of the larger rivers, the Oborogawa and Bekanbeushigawa is still lower than that of the sea water. Towards the end of summer the temperature of the river water as well as the lake water is raised up gradually and on August 28 it becomes everywhere more than 16°C. Even 20°C was read at station 1 (Fig. 9), on the upper part of the Bekanbeushigawa. But sometimes in the lower section of the river the temperature was a little lower than that of the lake.

Towards the end of October the river become much colder. The temperature of the sea water showed 13°C while it became colder the further one went in interior of the lake and in the upper reaches of the river. The difference of the temperatures at stations 1 and 12 (Fig. 10) is more than 4°C. From the above, we see that in summer the sea water is responsible for the rather cold temperature of the lake water, whereas in winter the river discharge is the chief cause for lowering it.

The salinity and pH of the lake water

As we have confinded ourselves till now chiefly to the question of the water temperature of the lake, now we return to the problem of the influence of the sea water and the river discharge on the salinity and pH of the lake water. Naturally the salinity is highest in the neighbourhood of the channel and becomes gradually lower as we approach the discharging point of the river and the interior of the lake (Fig. 12–13).

First, the salinity of the water both on the surface and at the bottom was measured at different times, and it was found that the difference between the two levels is less than 1‰ all over the lake, except at the time of the changing tide. Though the momentary difference of the salinity according to the depth of the water appears markedly where the lake is connected to the bay and also at the discharging point of the river, the strong and swift current in the lake caused by the sea tide very soon mixes up water of different degrees of salinity and temperature. The approximate measurements of temperature, pH and specific gravity in relation to the salinity on the surface and also at the bottom from the time of low water to the flood tide, were taken at a point near Kakijima between the channel and the mouth of the river at a depth of 1.5 metre. Figure 11 shows the result of observation diagrammatically.

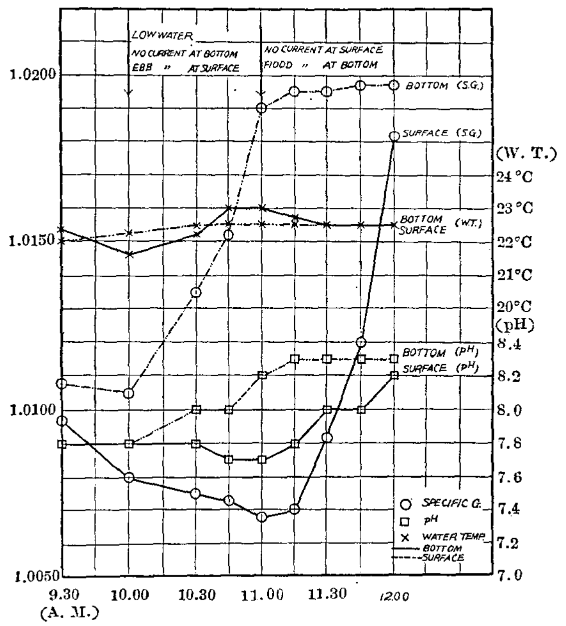

Fig. 11.

As is at once seen from the figure the salinity at 9.30 a.m. at the end of the ebb tide in this part is the same at the surface and the 1.5 metre deep bottom. At the beginning of the high water the saline water appears first at the bottom while the water at the surface is still running downstream. At the time of the slack on the surface there is still a flood current from the sea at the bottom. Therefore it comes out

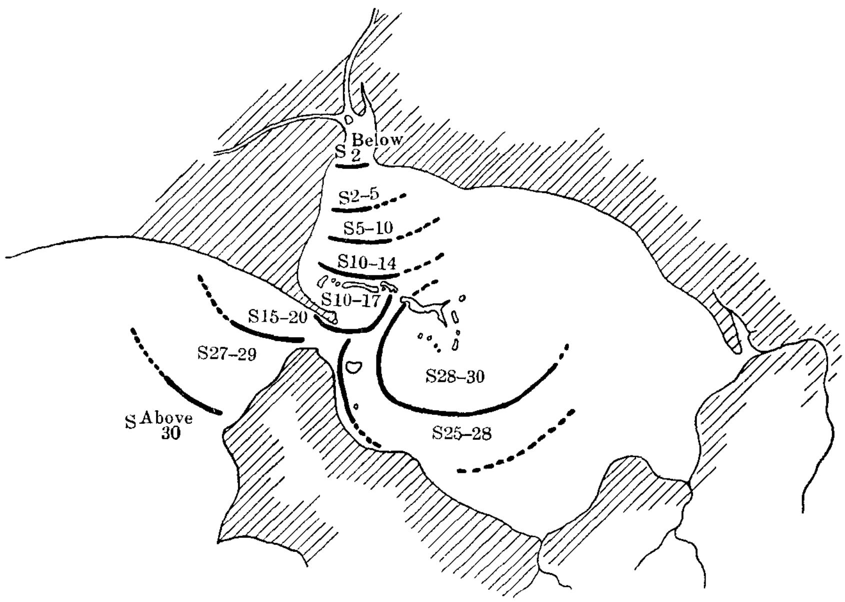

Fig. 12. Horizontal distribution of salinity at low water.

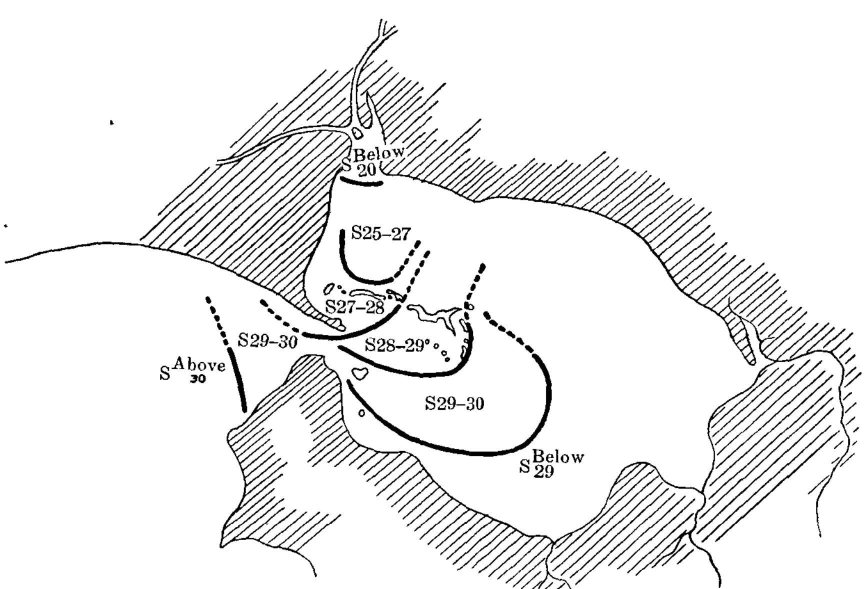

Fig. 13. Horizontal distribution of salinity at high water.

that the salinity is higher at the bottom than at the surface. Though the specific gravity of the water at the surface in the flooding tide is much lower than that of the water at the bottom, at the height of the flood tide it approaches the mean value and quickly becomes uniform. The pH value and the water temperature do not differ much according to the depth of the water even when the tide is changing. It is interesting to observe the distribution of salinity on the surface both in flood and ebb tide. Fig. 12 and 13 show the results of observations carried out on July 20, 1933.

Before examining the salinity and pH value of the lake water, for the sake of convenience an experiment was carried out in which the river water was mixed with the sea water in various ratios, and the salinity and pH value were determined. Figure 14 shows the result.

Then by determining the salinity and pH value of the water sample taken from the lake, we can estimate an approximate volume of the sea water or river water in the mixture. Comparing the results shown in figures 12 and 13 with the above we get a crude amount of river water mixed with sea water at different points. At high water in the central part of the lake the ratio of sea water to river water is less than 5 : 1 and near Kakijima it is almost 5 : 1.

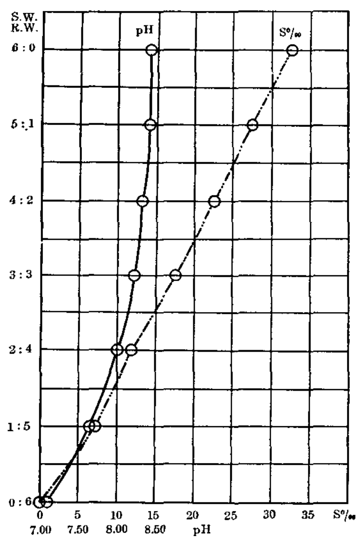

Fig. 14.
S.W. means sea water; R.W. means river water.

The salinity does not change much with the tide in the greater interior half of the lake and at the place in the bay a little distant from the lake opening and just opposite the Bekanbeushigawa.

Generally in Akkeshi lake the water shows 8.2–8.4 in pH value, being alkaline under the influence of the sea water. Only at the moment of low water when the river water covers the surface does it show a lower value. Parts of the lake where the influence of the tidal current is small and the water almost stagnant for example, at the north-eastern part of Kakijima, the pH value attains a hight of nearly 9 in summer. This condition seems to be attributable to the influence of vegetable life,

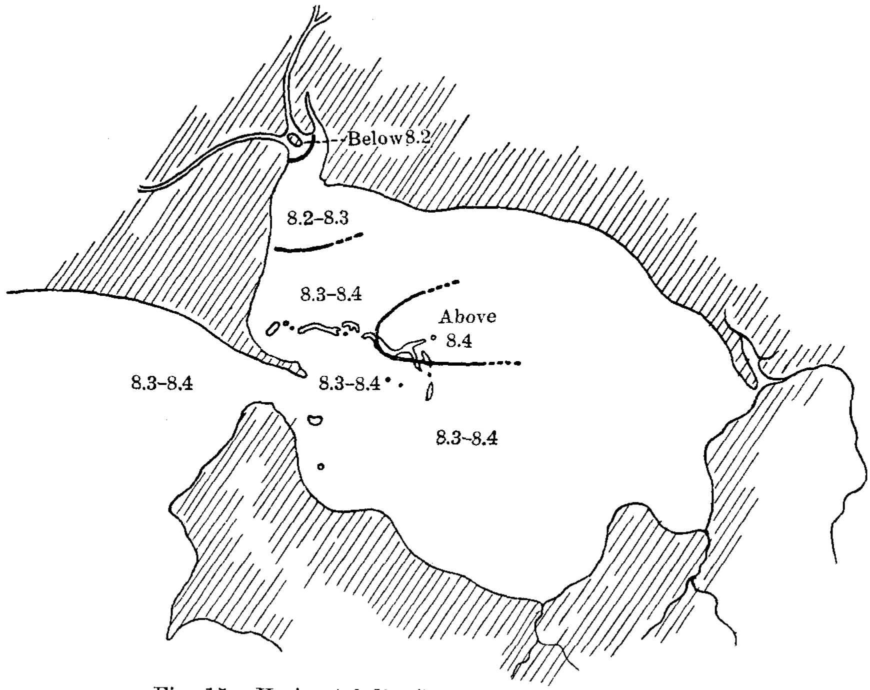

Fig. 15. Horizontal distribution of pH at high water.

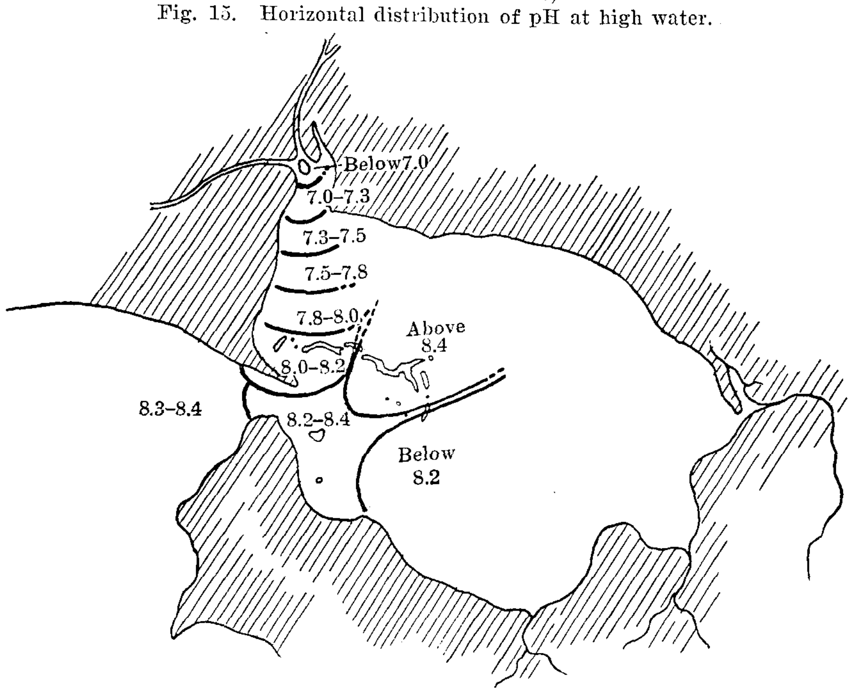

Fig. 16. Horizontal distribution of pH at low water.

such as the sea weeds which consume CO_2 by active photocynthesis. As the lake is very shallow and the water is always changing there is no marked difference in pH value at different depths. The horizontal distribution of hydrogen-ion concentration was measured in the middle of August, 1933. The result is given in figures 15 and 16.

Only a little difference of pH is seen at low water (Fig. 16). It was proved by occasional observation that the pH value varies seasonally from 0.2 to 0.4 at the same station in the similar condition of the tide. In summer generally it is a little higher than in winter.

Dissolved oxygen

The oxygen content of the lake water was measured periodically. The tables (Tables 9 and 10) show the results of measurements made on May 27 and June 29, 1933, at 17 different points at low tide (Fig. 17). All the figures given in the table are corrected under the normal atmospheric pressure (760 mm Hg).

Fig. 17.

TABLE 9.

Oxygen content of the lake water

Station		1	2	3	4	5	6	7	8	9
Time of observ.										
May 27 at 11 a.m.	Oxygen	—	5.30	—	—	6.68	6.69	—	6.00	—
	Temp.		14.5			15.8	14.8		14.5	
June 29 at 0.30 p.m.	Oxygen	6.21	6.69	6.91	6.42					
	Temp.	15.8	17.0	17.5	17.3					

The dissolved oxygen of the river water was also measured for comparison on May 31 and June 6 at 8 different points (Fig. 17). The results are as follows:

TABLE 10.

Oxygen content of the river water

Station		10	11	12	13	14	15	16	17
Time of observ.									
May 31 at 1.0 p.m.	Oxygen	6.82	6.82	5.41	6.41				
	Temp.	15.5	15.0	13.5	15.7				
June 6 at 8.30 a.m.	Oxygen					6.42	6.70	6.56	6.70
	Temp.					14.8	12.7	12.5	14.8

In order to see the range of oxygen content of the lake water during 24 hours, measurements were made in October, 1936, at 2 different stations both on the surface and in the water at some depth (Station 7 and 9 in Fig. 17). The table in the following page gives the results.

For convenience of comparison the solubility of oxygen in fresh water at different temperatures when exposed to the air free from CO_2 and NH_3 under the normal pressure is given below.

TABLE 13.

From KOPPEL's Chemiker-Kalender (1937)

Temp. 0°C	0_2 cm³ per liter
0	10.19
10	7.69
15	7.04
18	6.61
20	6.36
25	8.78

As the water in the lake is always stirring under the influence of the tide and the river discharge, it is aerated. As is seen in the above table there is no noticeable difference in oxygen content at any point or at any depth of water. The water is in nearly saturated condition with oxygen.

Velocity of the tidal current in the lake

At the entrance of the River Bekanbeushi the ebb current ac-

TABLE 11.

Temperature and oxygen content of the lake water at Station 7 measured on Oct. 11–12 under a pressure of 760 mm., S. means surface and the figure below it shows the depth of water in metres

Time of observ.	depth	water temp. °C	O_2 c.c./l.
p.m. 1.30	s 2	15.1 14.7	6.52 6.48
„ 3	s 2	15.2 15.0	6.82 6.71
„ 4.30	s 2	15.0 15.4	7.29 7.53
„ 6	s 1.5	15.0 15.2	7.29 7.52
„ 7.30	s 1.5	14.1 14.7	7.48 7.05
„ 9	s 1.5	14.1 14.5	6.11 6.78
„ 10.30	s 1.5	14.5 14.6	6.47 6.35
a.m. 12.30	s 2	11.2 —	6.68 6.58
„ 1.30	s 2	13.9 13.9	6.42 6.47
„ 3	s 1.5	13.5 13.7	6.18 6.25
„ 4.30	s 1.5	13.0 13.0	5.66 5.50
„ 6	s 1.5	13.2 13.1	5.67 5.40
„ 7.30	s 1.5	13.4 13.4	5.60 5.60
„ 9	s 1.5	14.1 13.9	5.89 5.65
„ 10.30	s 2	14.2 14.0	5.91 5.80
„ 12	s 2	14.3 14.3	6.61 6.01
p.m. 1	s 2	14.4 14.4	6.68 6.68

TABLE 12.

Temperature and oxygen content of the lake water at Station 9 measured on Oct. 16–17, 1936, under a pressure of 760 mm. S. means surface and the figure below it shows the depth of water in metres

Time of observ.	depth	water temp. °C	0_2 c.c./l.
p.m. 12.40	s	13.7	7.18
	1	13.7	7.13
„ 2	s	13.8	6.49
	1	13.8	6.65
„ 3.30	s	13.65	6.12
	1.5	13.6	6.08
„ 5	s	13.45	6.18
	1.5	13.5	6.12
„ 6	s	13.5	6.66
	1	13.4	6.61
„ 8	s	13.5	6.85
	1	13.5	6.77
„ 9.30	s	13.3	6.85
	0.9	13.4	6.84
„ 11	s	13.2	6.72
	—	—	—
a.m. 12.30	s	12.9	6.75
	—	—	—
„ 2	s	12.8	5.77
	—	—	—
„ 3.30	s	12.6	5.6
	1	12.8	6.61
„ 5	s	12.5	6.10
	1	12.6	6.10
„ 6.30	s	12.5	6.13
	1	12.6	6.07
„ 8	s	12.4	6.13
	1	12.5	6.12
„ 9.30	s	12.7	6.61
	1	12.6	6.83
„ 11	s	12.9	6.67
	1	12.8	6.64

celerated by the rich river discharge, obtains the greatest velocity. The following table (Table 14) and the figure (Fig. 18) show the velocity of the tidal current in a tidal cycle measured at the station near Kakijima where the current is the next strongest.

The maximum velocity measured at the station is 70 cm per minute. Naturally the velocity of the current even at the change of tide diminishes gradually towards the opposite side of the Bekanbeushigawa in the lake until it becomes zero.

TABLE 14.

Velocity of the tidal current at the surface measured on Aug. 21, 1933 near Kakijima between the lake opening and the entrance of the Bekanbeushigawa

Time	Velocity cm per min.	Time	Velocity cm per min.
a.m. 7.30	20	p.m. 1.30	66
„ 8	18	„ 2	71
„ 8.30	17	„ 2.30	71
„ 9	15	„ 3	71
„ 9.30	12	„ 3.30	64
„ 10	8	„ 4	57
„ 10.30	5	„ 4.30	41
„ 11*	0	„ 5	24
„ 11.30	22	„ 5.30**	0
„ 12	40	„ 6	15
p.m. 0.30	50	„ 6.30	20
„ 1	60		

* low water slack ** high water slack

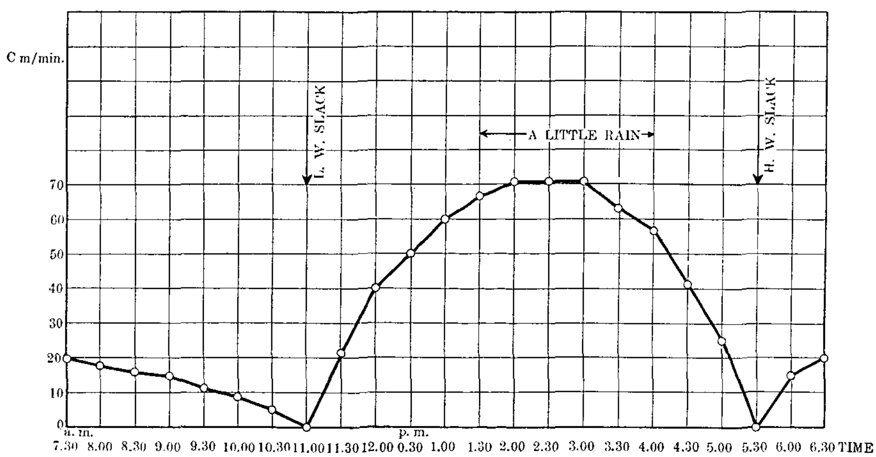

Fig. 18. Velocity of tidal current in a tidal cycle (surface velocity)

The condition of the lake in winter

The staffs of the Marine Biological Station are carrying on the study of the limnological condition of the lake in winter and we expect a precise report very soon. So far as the present study is concerned we have noticed no particular state of water which influences the oyster in winter. The lake is covered by ice sometimes 1 metre thick from the middle of January to the middle of March. The water temperature in the middle of January under the ice was -1.3–-1.5(°C) in 1936.

However, in colder winters when the ice attains a thickness of more than one metre in some places, there is an unfortunate consequence for the oyster as well as for the vegetable life in the lake. At that time the melting ice floats up with the bottom substances of the lake attaching to its under surface, and flows away into the bay, breaking up into pieces of varying size. This results sometimes in the complete cleaning up of the oyster beds.

General considerations of oyster culture in the lake

The limnological features of the lake in connection with oyster life have been investigated in the foregoing chapter and in the following we turn our attention to the direct relation of each factor upon oyster culture in the lake.

1. Temperature

Of course the temperature of the surrounding medium is of primary importance, first for the general metabolism and, then, for the reproductive activity of the oyster. The activity and the nutrition of the oyster are controlled by the activity of the gill, the movement of which induces the water current containing the necessary oxygen and at the same time the food substances available for the animal. A number of experiments on the influence of the temperature upon the gill activity in relation to respiration and feeding of the animal have been made by many investigators, such as Galstoff (1929), Hopkins (1933) etc. There are naturally some differences of reaction to temperature according to the species of the oyster. Galstoff ascertained in *O. virginica* that the ciliary movement of the gill of the animal indicating the activity of the gill becomes most intense at a temperature of 25°–30°C. According to him the lower limit of the temperature for the gill activity is 5°C, at which the ciliary movement becomes irregular and abnormal. It has been shown by him that in the majority of oysters the water begins to flow through the gill actively at first when the temperature is raised to 8°C from the lower. HOPKINS (1933) measured the activity in *O. gigas* by means of the width of the opening of the shell and observed that it was widest at a temperature of 20°C. On the other hand he showed also that the optimum temperature for the activity of the cilia of the gill is above 25°C in *O. gigas* while it is 25°–30°C in *O. virginica.*

With the oyster, *O. gigas,* obtained in the lake, the activity of the ciliary movement was observed in September, 1936, by means of NOMURA's method (NOMURA and TOMITA 1933). By raising the temperature of the medium from 12°C the movement gradually increases until it reaches a maximum at 28°–29°C after 2 hours. A sudden decrease in movement occurs after 29° and becomes worse after 35°. Above 37°C there occurs an irregular acceleration of the movement. In the experiment of lowering the temperature from 12°C we see a gradual decrease of movement until it ceases at 0.3°C after 3 hours.

From the above observations of other authors and also from our own investigations it has become clear that the range of temperature for the active life of *O. gigas* extends from 0.3° to 29°C. In Akkeshi lake the water temperature is always above 8°C from the beginning of May to the end of November in ordinary years. Therefore the oyster in the lake leads an active life for these 7 months at least. This is by no means short compared with the other oyster producing localities. In the depth of winter, in January and February when the surface of the lake is perfectly covered with ice, the water temperature becomes −1.3°–−1.5°C, and the oyster seems to hibernate with an extremely decreased movement of branchial cilia and reduced feeding action.

Let us discuss the condition of the reproduction of the oyster in this lake. The oyster in Akkeshi lake is found to grow ripe in ordinary years from the middle of July and the spawning takes place from the beginning of August to the beginning of September. NELSON (1928) and PRYTHARCH (1928) observed that the oyster does not spawn at definite times, but depends only upon the water temperature. According to AMEMIYA (1928) and GALSTOFF (1929) *O. gigas* spawns when the water temperature is above 25°C. The above author succeeded in inducing the spawning of a ripe oyster artificially within half an hour by increasing the temperature of the surrounding medium to 25°–30°C. However, when the temperature does not rise to this degree the spawning will not occur, although the gonad of the oyster is in full maturity.

Unfortunately in Akkeshi lake the water rarely has a temperature higher than 25°C. Even if it becomes warmer than 25°C for a short time just at low water, the flood tide which follows soon afterward lowers the temperature with its cold saline water from the open sea. Thus it often happens that there are few and sometimes no seed oysters at all in this lake for several years. In addition to the above the settling of the young oyster is also affected by the water temperature. NELSON (1928) ascertained that the free-swimming larvae are very sensitive to changes of temperature. A sudden fall in the water temperature may cause the death of the larvae or otherwise completely prevent their settling. However the range of the water temperature in the lake does not exceed 5°C in 24 hours in summer. This is by no means unfavorable for the settling of the larvae. In short, insofar as the water temperature is concerned Akkeshi lake is considered unsuitable for oyster culture chiefly because of the low temperature affects the reproduction of the animal during summer.

Next comes into consideration the salinity of the lake water. AMEMIYA (1931) has shown in his brilliant work that the saline content of water suitable for the life of *O. gigas* ranges from 11–32‰, the optimum degree of salinity for the development of the oyster being 17–26‰. A still wider range has been also proved to exist. It has been shown that the salinity of the water near Kakijima varies from 10–30‰ and therefore in this respect the lake is suitable for oyster life.

Besides the above factors which may affect oyster culture in Akkeshi lake, the sediment of the lake must be taken into account. As already mentioned the transparency of the lake water is always less than 2 metres on account of the river discharge containing much organic sediment and of the muddy bottom of the lake which is constantly stirred up by the tidal current. Supposing that the oyster spawns normally and the larva begin to develop, the dense sediment may affect the later life of the animal not a little. The sediments are particularly thick after heavy rain. The sediments keep the larva from its necessary setting on some solid substances.

KOKUBO (1929) proved with his extensive experiments on *O. circumpicta* that the oyster can live when the pH value of its blood becomes as low as 5.00 and as high as 12.00. In his case the pH value of the sea water of the general habitat of the oyster is 8.00–8.20. There is no noticeable defect for the oyster in Akkeshi lake in pH value.

Nothing is of particular objection to the lake as regards oyster life insofar as the oxygen content and the velocity of the current are concerned.

It is interesting here to compare the limnological condition of Akkeshi lake with that of Saroma lake on the Okhotsk coast of Kitami which has productive natural oyster beds and from where the oyster seeds were once transplanted in Akkeshi lake with success. The investigations were made during the season from August 28 to September 1, 1936, by the kind assistance of Messrs. SATO and KANAZAWA of our Institute. The figure (Fig. 19) and the table (Table 15) given below show the results.

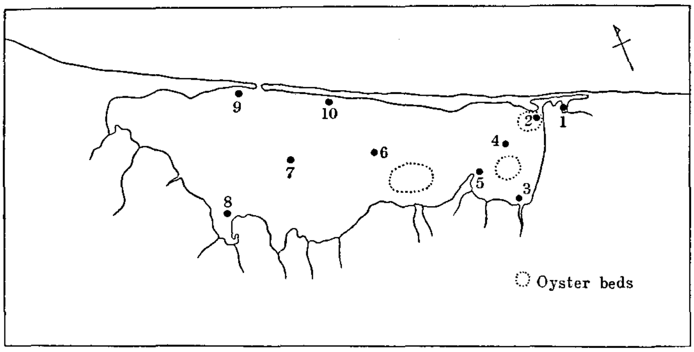

Fig. 19. Sketch map of Saroma lake showing the stations of observations. Oysters are found all over in the lake.

TABLE 15.

Results of observation in Saroma lake

Station	Time of observ.	Depth in metres	Temp. °C (surface)	pH (surface)	Salinity (surface)	Trans-parency	Condition of bottom
	(Aug. 28)					(metres)	
1	p.m. 1.5	0.3	28	7.6	1.3	—	—
2	„ 3	3	25	8.5	19.42	—	—
3	a.m. 10.5	0.5	23	8.4	25.06	—	—
4	„ 11.5	9	22	8.4	32.03	5	—
5	p.m. 12.5	6	22.2	8.3	32.03	—	oyster with mud
6	p.m. 2	9	22.7	8.4	31.75	9	—
	(Aug. 29)						
7	„ 3	12	22.5	8.4	32.02	9	mud
8	a.m. 9	5	21.8	8.4	32.03	—	sand
	(Aug. 30)						
9	„ 11	5	21.5	8.4	32.67	5	sand
10	„ 12	5.5	—	8.4	32.67	4	mud and sand

The lake water was examined not only at the surface as shown in the above table but also at some depth. However so far as the temperature, pH value and salinity are concerned there is not so much difference between the surface and the lower part of the water. For example the greatest difference in temperature was obtained at the station 2 in which the water of the bottom was 2°C lower than that of the surface. No greater difference was seen in the other stations. The difference in pH value according to the depth of the water did not exceed 0.1 at any station. Only at the discharging point of the river the difference of the salinity with the depth of the water appeared markedly (at the stations 2, 3 and 4) but in the interior of the lake there existed almost no difference.

Now we compare the result of the observations of Saroma lake with those made in Akkeshi lake around the same season (on September 1, 1936) near Kakijima (Table 16).

TABLE 16.

Results of observation made in Akkeshi lake. Temperature, pH and salinity were measured on surface

Station	Time of observ.	Depth in metres	Temp. °C	pH	Salinity	Transparency	Condition of bottom	Tide
1	a.m. 10.5	3	21	8.3	25.06	1.5 m.	mud	low. w.
2	„ 12	4	20	8.4	25.06	1.5 m.	mud	high w.
3	p.m. 12.5	7	20.1	7.6	7.07 bottom 31.11	1.2 m.	mud	„
4	„ 1.5	5	21.7	8.2	4.15 bottom 23.71	—	mud	h.w. slack

We see that the water temperature of Akkeshi lake did not rise much above 21°C whereas the warmer water was easily obtainable in Saroma lake at any station. In addition to this we can find a great difference in transparency of water between the two lakes. In short the results of the above examination affirm again what we have repeatedly explained in the foregoing chapter, proving the disadvantage of Akkeshi lake for oyster culture on account of the excessively low temperature of the water and the presence of so much sediment.

Practical considerations on oyster culture in the lake

Here the question naturally arises as to the origin of the prosperous state of oyster production in the lake in ancient days. As long as the catching of the oyster in Akkeshi lake was limited, its reduction did not appear remarkably although the productivity was not great. However recently the limnological conditions of the lake have experienced some undesirable changes caused chiefly by the river discharge, by the changed natural condition of the vast upstream region of the greater river, the Bekanbeushigawa, which has been turned to agricultural use, and moreover by the wasting of the greater part of the upper regions as a result of mountain fires. The direct influence of the precipitation which occurs frequently in summer upon the lake water is by no means favourable for the oyster.

On the other hand, it has become quite clear that the chief reason for the scarcity of oysters in the lake is accounted for as a consequence of the lack of seed oysters. Practically the collection of seed oysters was repeatedly tried in 1933; every existing type of spat-collector, which is in common use in other oyster yards in Japan, was supplied, such as bushes, bamboos, stones, shells of oysters and scallops, but only a few seed oysters were found attaching to them. According to Mr. HATTORI who has engaged in oyster culture in the lake the collection of the oyster spats is successful when he supplies the culch of scallop shells as collectors in August in year when the degree of precipitation is low and the water temperature is comparatively high. It is to be noted that the growth of the developing oyster is not noticeably bad as compared with other localities. A large-scale public work to change the hydrographical condition of the lake so as to avoid the direct influence of the cold flood tide and to keep the rich sediment out of the oyster beds is to be desired. However the enterprise requires at present an extraordinary expenditure which will not be compensated in return.

The only economical method of cultivating the oyster in the lake is secured by transplanting the oyster seed from other districts. Mr. TANAKA a governmental expert in Nishibetsu Hatchery, tried in 1927 to transport seed oysters attached to scallop shells from Saroma lake in Kitami and raised them in Akkeshi lake with success. The junior author also had the opportunity of investigating Saroma lake and found it suitable for getting seed oysters without difficulty.

From the economical point of view, considering the expense of transportation, the time required etc., the transplantation method from Saroma lake or other localities near by is to be most recommended for the utilization of Akkeshi lake as an oyster bed.

On the Pacific coast of the State of Washington in America the

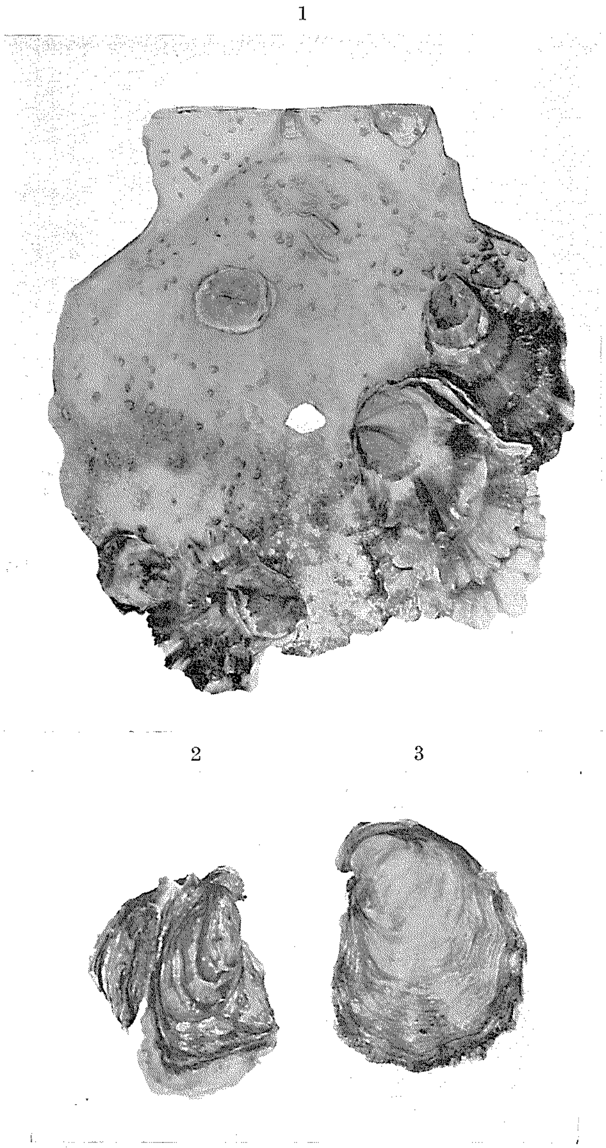

Fig. 20.

Young oysters raised in Akkeshi lake. $\times \frac{1}{2}$.

1. 2 years old oyster transplanted from Saroma lake attaching on the scallop shell.
2. 2 years old oyster of Miyagi strain.
3. 3 years old oyster native to Akkeshi lake.

transplanted seeds of the Japanese oyster, *O. gigas,* grow rapidly and about 1928 and 1929 there began tremendous elaboration in the new Japanese oyster industry (BRENNAN, 1936). Thus the method of seed planting in Akkeshi lake promises to be highly successful. Oyster seeds caught on oyster or scallop shells are shipped from Japan to Washington waters each spring as the oyster has not yet begun to propagate actively abroad. However there more than 2,000,000 pounds are said to be shipped every year.

In the spring of 1936 the oystermen in Akkeshi tried to transplant oyster seeds from Miyagi prefecture, whence the seeds are exported to America, and could get them grow enormously (Fig. 20), proving that transplantation rather than care of the native oyster is the most important factor in the development of the oyster on commercial lines.

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