Hydrographical Observations and Plankton Studies of Some Brackish Water Lakes on the Okhotsk Sea Coast of Hokkaido in Winter

By

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With 11 text-figures

Introduction

There is a series of brackish water lakes lying on the Okhotsk Sea Coast of Kitami Province, Hokkaido. Among them the seven following lakes, Komuke, Sibunotunai, Saroma, Notoro, Abasiri, Mokoto and Tohutu, were studied by the writer in March, 1938 with monetary aid from the HATTORI Hokokai. Here, the writer's best thanks are tendered to the foundation and also to Mr. E. ASAHINA who helped him in field work.

Among these lakes, Lake Sibunotunai has never been surveyed. Limnological researches of some of these lakes have been published by members of the Hokkaido Fisheries Experimental Station as follows; Lake Komuke by TAKAYASU, IGARASI & SAWA in 1930 and by TAKAYASU in 1937; Lake Saroma by TAKAYASU, IGARASI & KONDO in 1934 and by KINOSITA & NAKASIMA in 1936 and 1938; Lake Notoro by TAKAYASU & KONDO in 1934; Lake Abasiri by TAKAYASU & TOBISIMA in 1930; Lake Tohutu by TAKAYASU, IGARASI & SAWA in 1030. YOSIMURA (1938) reported the hydrographical observations of Lakes Notoro and Abasiri while OKADA & KOBA (1936) and UÉNO (1937, 1938) reported their biological studies of Lake Abasiri. Lake Mokoto has been investigated several times; the chemical stratification has been recorded by YOSIMURA (1938), the plankton by UÉNO (1937, 1938) and the writer (1939), and the bottom fauna by UÉNO (1937, 1938) and KINOSITA & SIBUYA (1939).

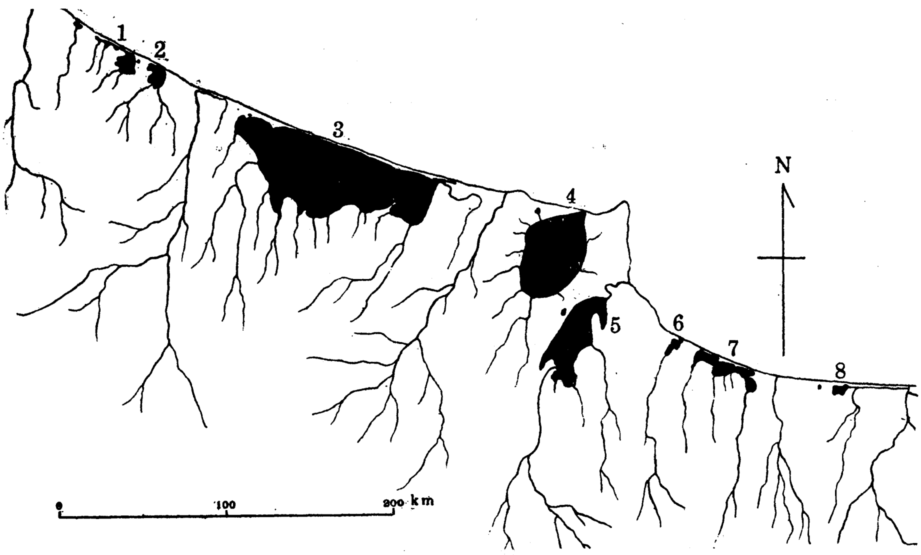


Fig. 1. Map of the Okhotsk Sea Coast of Kitmi Province where the following lakes are distributed:
1. Komuke; 2. Sibunotunai; 3. Saroma; 4. Notoro; 5. Abasiri; 6. Mokoto; 7. Tohutu; 8. Toturu.

General features of the lakes

1. Lake Komuke

The northernmost brackish water lake among those here considered, consists of a squarish main basin and an elongated branch part extending to the northwest along the sand bar. The area of the former is 4.2 km^2 and its greatest depth is 2.5 m. The latter part which has two dilated regions is 1.45 km long and 7 m deep at the deepest point. The deposits of the main basin are generally

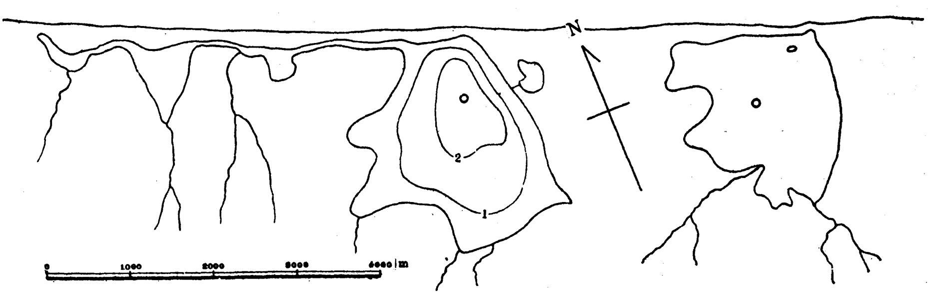


Fig. 2. Map of Lake Komuke and Sibunotunai.
(Depth in meter; point showing the position of the observation station.)

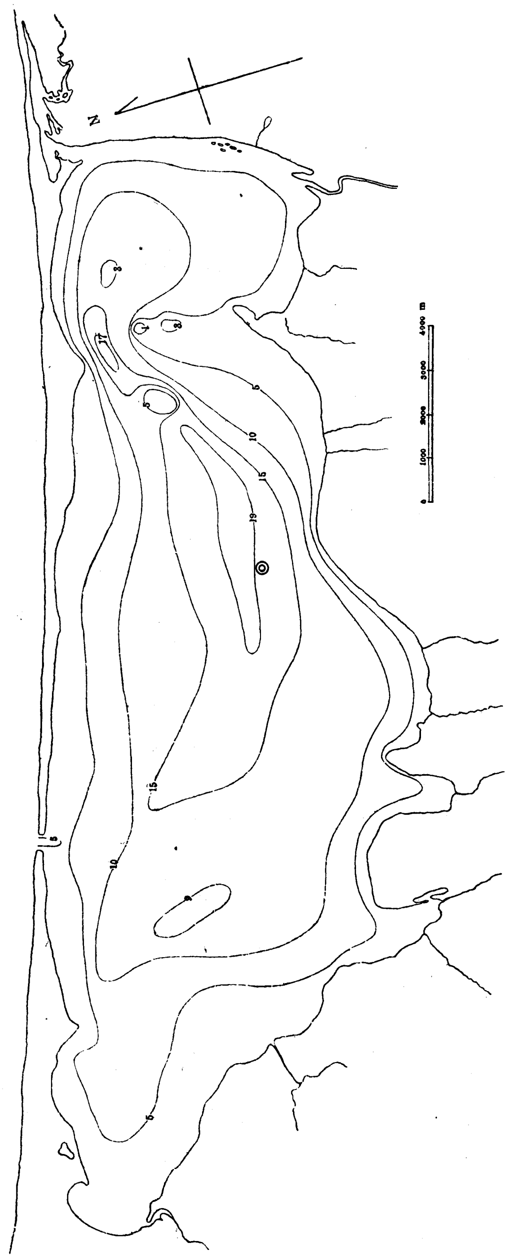


Fig. 3. Map of Lake Saroma.

composed of sand and mud. The lake has no mraked influent river. The connection with the sea is usually closed during the winter and opens in spring at the north-eastern corner of the main basin.

2. Lake Sibunotunai

This lake dammed by a sand bank is a small triangular body of water occupying an area of 3 km^2. The maximum depth has not been recorded. This is sometimes connected with the Okhotsk Sea at the eastern corner where a small sandy islet stands.

3. Lake Saroma

Lake Saroma covering an area of 151.2 km^2 with a long axis of 25.2 km and a short one of 9.1 km, is the largest lake in Hokkaido, and is separated from the sea by a marked long bar. This lagoon had been regularly connected with the sea at the eastern corner untill an artificial passage was made in 1929 in the middle portion of the bar in order to discharge the lake water and to make an entrance for fishing boats. Since then, the new passage has been widened and deepened by tidal currents, and finally the old channel has been closed. The bottom deposits are muddy in the central deep region of the maximum depth of 19.5 m, but in the shallow area they are composed of sand or muddy sand containing shells of the oyster, *Ostrea gigas*, which form shell-reefs near the old channel as in Lake Akkesi (INUKAI & NISIO, 1937). The Saromabetu is the longest river among those emptying into this lagoon.

4. Lake Notoro

Lake Notoro surrounded by terraces, is also a large oblong lagoon having a simple shore line of 31 km. Its long and short axes are 11.3 km and 7.1 km respectively, and its area is 59.3 km^2. In this basin a deep ditch with a maximum depth of 21.2 m extends along the eastern shore, while the central part is elevated (8 m in depth). The bottom is generally covered with sand and mud. This lake shows no marked inflow of fresh water, and the connection with the sea is usually blocked by a sand bank during the winter.

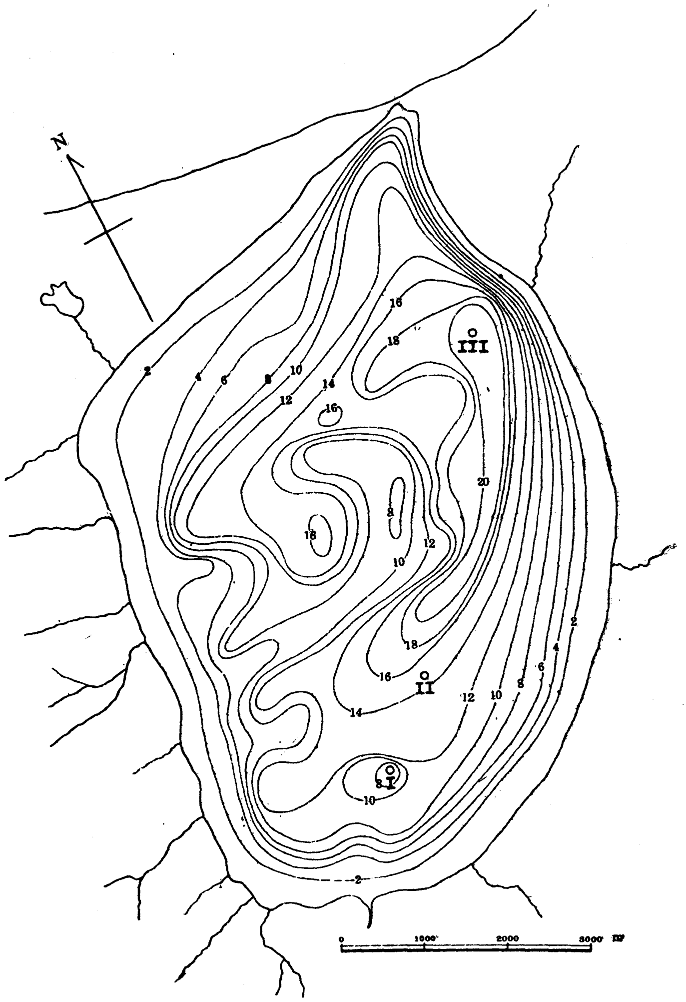


Fig. 4. Map. of Lake Notoro.

5. Lake Abasiri

Lake Abasiri covering an area of 34 km², is regarded as a large inflated part of the River Abasiri, of which a influent flows into the lake through a delta developed in the southern region of the lake, and a draining channel, 7.5 km long, connects the north-eastern end of the lake with Abasiri Harbour. The surface of the lake is 0.6 m higher than that of the sea. Having a large headland of Nakanosima besides the delta, the lake is more or less irregular in form. The maximum depth is 17.6 m near the center. The bottom of the shallow area is covered with sand and mud, but the central deep region with black mud.

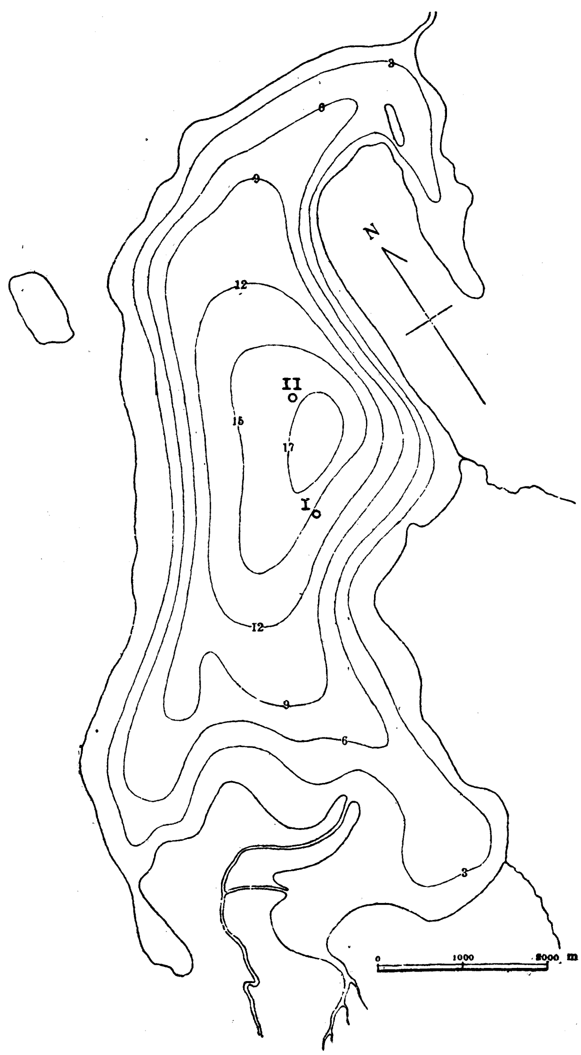


Fig. 5. Map of Abasiri.

6. Lake Mokoto

This is the smallest lake described in the present paper, being 2.3 km in length and 1.3 km^2 in area. This basin is probably formed by damming the esturarine depression of the River Mokoto with a sand bank. The maximum depth is 5.8 m. Bottom deposits deeper than 2 m are composed of black mud.

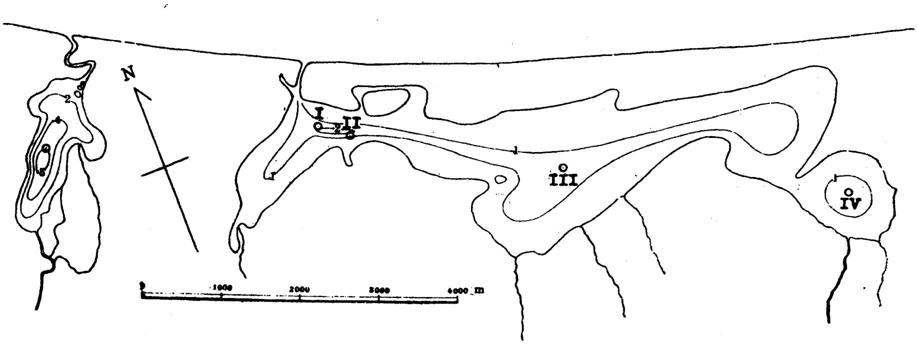


Fig. 6. Map of Lakes Mokoto and Tohutu.

7. Lake Tohutu

Lake Tohutu separated from the Okhotsk Sea by a long bar, is an elongate shallow lake an auxiliary fresh water basin. Its length is 7.7 km and the greatest width about 2 km. This lake occupies an area of 9.5 km^2. The maximum depth is 3 m. The bottom of the brackish water basin is generally covered with sand or muddy sand, while that of the fresh water basin is entirely mud. The outlet of this lake is temporarily closed with sand.

Hydrographical observation in winter

1. Lake Komuke

The observation of Lake Komuke was made at a single station of a depth of 2.5 m in the main basin on March 2, 1939. At that time the air temperature was $-3.2°C$. Collection of water samples and plankton materials was carried out through a hole made in the ice-cover, which was 58 cm in thickness. The colour of the water was No. 14 in Forel's scale as in summer (TAKAYASU, IGARASI & SAWA, 1930). Water temperature was $-1°C$ on the surface and $-9.3°C$ in the bottom layer of a depth of 2 m. Salinity, not

Table 1

Hydrographical observation of Lake Komuke (2/III, 1938)

Depth m	Water Temp. °C	pH	O_2 cc/l	O_2 %	Cl ‰	Salinity ‰
0	−1.0	7.3	3.43	38	12.43	22.47
1	−0.8	7.3	3.00	33	12.83	23.19
2	−0.3	7.3	3.23	36	13.08	23.64

greatly variable at all depths, was fairly lower than that of sea water. pH-values[1] were 7.3, and dissolved oxygen decreased to ¼–⅓ of the normal condition in all the layers.

When the observation was made, the connection with the sea was closed. During the period in which the lake is connected with sea, the lake water is nearly equal to sea water in salinity and pH-value[2], and is rich in oxygen in every layer (TAKAYASU, 1937).

2. Lake Sibunotunai

The observation of the Lake Sibunotunai was made in an air temperature of −4.8°C on the evening of the same day as that of Lake Komuke. The station at which the observation was made, was near the center of the lake, and only 1.6 m in depth. The thickness of the ice-cover was 48 cm there. Although the lake is very shallow, marked stratification was shown by the investigation. Water temperature considerably varied between the surface and bottom, being −0.4°C on the surface and 2.6°C at the bottom. Salinity was

Table 2

Hydrographical observation of Lake Sibunotunai (2/III, 1938)

Depth m	Water Temp. °C	pH	O_2 cc/l	O_2 %	Cl ‰	Salinity ‰
0.0	−0.4	6.9	5.96	60	3.89	7.05
1.0	1.3	7.3	0.11	1	11.00	19.89
1.4	2.6	7.3	0.00	0	11.27	20.37

1). Salt errors are not corrected.

2). pH above 8.2.

rather low, and abruptly increased to a depth of 1 m, but from this layer was not so changeable to the bottom. Deviation of pH was more or less small, while oxygen contents varied exceedingly: oxygen dissolved as much as 5.96 cc/l in surface water, was completely reduced to make an anaerobic layer on the bottom.

3. Lake Saroma

The winter observations of the lake were made by the Hokkaido Fisheries Experimental Station at six points in February, 1632 and at a station 6.5 m deep once every day from 1935 to 1937.

Table 3

Hydrographical observation of Lake Saroma (1/III, 1938)

Depth m	Water Temp. °C	pH	O_2 cc/l	O_2 %	Cl ‰	Salinity ‰
0.0	−1.5	8.25	8.42	98	17.92	32.38
1.0	−1.5	8.25	8.06	94	17.81	32.18
3.0	−1.5	8.25	8.08	95	17.84	32.23
5.0	−1.4	8.10	8.42	98	17.86	32.27
7.5	−1.4	8.10	7.86	92	17.86	32.27
10.0	−1.4	8.10	8.26	96	17.90	32.34
12.5	−0.9	8.10	7.70	92	18.00	32.52
15.0	−0.8	8.10	7.65	91	18.00	32.52

The writer's investigation was performed at a station of a depth of 17 m near the deepest region on March 1, 1938. During the observation the air temperature was −2.3°C. The ice-cover measured as thick as 47 cm at the station. The colour of the water corresponded to No. 5 of the Forel's scale, and the transparency[1] observed through a hole in ice, was 6.5 m. Water temperatures below 0°C throughout the whole depth, were slightly higher in deeper strata than in upper layers. Salinity was somewhat higher in surface water cemented by ice, and lowest at a depth of 1 m, and then gradually increased to the bottom. pH-values were not generally as great as those of the other records[2] given by investigators of the above mentioned station. Oxygen was quite saturated in every layer.

1). Transparency indicating the visible depth of a Secchi's white disc.
2). pH, 8.35–8.50.

4. Lake Notoro

The writer visited Lake Notoro on March 7, 1838, and made observations at the three stations shown in fig. 4 in air temperatures of -1.3–$0.8°C$. Depths were 7.5 m, 14.5 m and 20.5 m respectively at Stats. I, II and III. Thickness of ice was more or less variable at each station, being 55 cm at Stat. I, 63 cm at Stat. II and 60 cm at Stat. III. The nearer the outlet a station was situated, the lower the water temperature of the surface fell, on the contrary the higher its salinity became. At Stat. III the surface temperature went down exactly

Table 4
Hydrographical observations of Lake Notoro (7/III, 1938)

Station	Depth m	Water Temp. °C	pH	O_2 cc/l	O_2 %	Cl ‰	Salinity ‰
I	0	−0.8	8.00	8.28	93	13.38	24.18
	7	−0.8	7.90	6.96	78	13.80	24.94
II	0	−0.9	8.30	8.30	123	13.77	24.88
	1	−0.9	8.10	—	—	—	—
	2	−0.9	8.10	7.83	88	13.80	24.94
	3	−0.9	8.10	—	—	13.82	24.98
	4	−0.9	8.10	8.50	69	13.87	25.07
	6	−0.9	8.10	—	—	—	—
	8	−0.9	8.10	—	—	13.87	25.07
	10	−0.9	81.0	8.15	89	13.87	25.07
	12	−0.8	8.00	—	—	—	—
	14	−0.5	7.80	1.51	63	13.87	25.07
III	0	−1.3	8.10	8.11	90	19.32	25.16
	2	−1.1	8.10	8.10	90	13.87	25.07
	5	−1.1	8.00	7.85	88	13.83	24.99
	10	−1.1	8.00	8.10	89	13.83	24.99
	15	−0.9	7.95	7.75	87	13.83	24.99
	20	−0.6	7.90	2.91	31	13.87	25.07

to the theoretical freezing point at its salinity. During the winter the lake has no direct connection with the sea, so the salinity is lower than that of the summer and autumn while a short channel is open. At Stat. III it was slightly higher in the surface layer than in deeper ones as seen in Lake Saroma. The change of pH was generally small, but the pH-value of surface water at Stat. II was especially great. This is due to the abundance of a minute Dinoflagellata.

In consequence, oxygen was rather rich there. In winter a fairly good aeration in bottom strata was observed, but dissolved oxygen is quite free in bottom water in autum according to TAKAYASU & KONDO (1934) and YOSIMURA (1938). The transparency was 3.1 m at Stat. II and 8.5 m at Stat. III. The difference between them is probably caused by the richness of the minute flagellate plankton at Stat. II.

5. Lake Abasiri

The writer's observations of Lake Abasiri were made on March 5, 1938 at the two stations of depths of 14.5 m and 16.3 m located in the central area. While the observations were made, air temperatures varied from 3.6°C to 4.5°C. The thickness of the ice was nearly equal (70 cm and 68 cm respectively at Stats. I and II), and the transparency was also quite the same (2.5 m) at both stations. Water temperature was very variable, being 0.5–4.3°C at Stat. I and

Table 5

Hydrographical observations of Lake Abasiri (5/III, 1938)

Station	Depth m	Water Temp. °C	pH	O_2 cc/l	O_2 %	Cl ‰	Salinity ‰
I	0	0.5	6.65	8.29	82	—	—
	1	0.8	6.65	—	—	—	—
	3	0.9	6.90	—	—	—	—
	5	1.1	6.90	—	—	—	—
	7	1.1	6.90	—	—	—	—
	10	1.2	6.90	8.62	86	—	—
	12	1.8	6.95	7.39	76	—	—
	13	2.9	7.15	4.50	48	—	—
	14	4.2	7.40	0.00	0	7.200	13.03
II	0	0.2	6.70	8.67	85	0.015	—
	1	0.4	6.70	8.60	85	0.020	—
	3	0.7	6.90	—	—	—	—
	5	1.1	6.90	9.16	92	0.300	—
	7	1.1	6.90	8.94	90	—	—
	10	1.2	6.90	8.67	87	0.580	—
	12	1.8	6.90	7.53	78	1.960	3.57
	13	2.8	7.15	4.26	47	5.290	9.58
	14	3.2	7.40	1.34	15	6.200	11.22
	15	5.0	7.50	0.00	0	8.030	14.52
	16	5.2	—	—	—	—	—

0.2–5.2°C at Stat. II, and a distinct thermocline was observed below a depth of 10 m at each station. Judging from the results obtained by YOSIMURA (1938) in summer and by the writer in winter, water temperature at the bottom of the central deep region seems to be fairly constant throughout the year as in Lake Harutori which is an oligohaline lake allied to this lake in chemical stratification (HADA, 1938). The content of salt in the surface water was as small as in fresh water, and gradually increased to the 10 m layer, then suddly downward from this layer to the bottom. This layer thus forms a stratum roughly dividing the upper fresh and the lower brackish water masses. This boundary layer probably exists at the same depth all the year round. As the body of brackish water is very stable, the circulation caused by thermal phenomena as found in fresh water lakes, occurs only in the upper fresh water stratum. Saline water containing such a large amount of salts as in this study, was not found even in deeper strata at the time of the investigation made by the Hokkaido Fisheries Experimental Station in June, 1927 (TAKAYASU & TOBISIMA, 1930). It is probable that sea water afterwards invaded the lake through the River Abasiri at times of heavy storms, and stagnated in deep strata. The lake water was generally weakly acidic in the upper fresh water layers, while faintly alkaline in the lower brackish water ones. It is, however, more alkaline[1] in summer or autumn due to abundance of algal plankton. Dissolved oxygen was entirely lacking below the metalimnion, and hydrogen sulphide appeared in place of the former (12.2 mg/l at a depth of 15 m).

6. Lake Mokoto

Lake Mokoto is a brackish water lake similar to Lake Abasiri in chemical condition, but the fresh water layer is much thinner: the layer is only a few centimeters thick on account of the frequent invasion of sea water at times of high tides. The observation was made near the deepest portion in an air temperature of −4.3°C on March 8, 1938. Ice, 55 cm in thickness at the station, covered the whole surface excepting the small area of the outlet. The transparency was 2 m. The thermal stratification was allied to that of fresh water lakes in rather high temperature. A slight thermocline was found at depths between 1 m and 2 m, but the salt contents of the lake water changed exceedingly in the layer above a depth of 1 m: a thin water layer near the surface was quite fresh, but the salinity at a depth of 1 m was as high as 26.3 ‰. The lake water was almost neutral in the fresh water layer, while weakly alkaline in the deeper brackish water stratum. Dissolved oxygen so rapidly decreased

1). The greatest pH-value of the surface water is 7.88 in the record of TAKAYASU & TOBISIMA (1930).

Table 6

Hydrographical observation of Lake Mokoto (8/III, 1938)

Depth m	Water Temp. °C	pH	O_2 cc/l	O_2 %	Cl ‰	Salinity ‰
0	0.2	7.10	8.99	88	0.28	—
1	0.4	7.45	3.45	40	14.56	26.31
2	2.0	7.45	1.25	16	16.63	30.05
3	2.1	7.45	1.34	17	16.73	30.23
4	2.8	7.50	0.58	8	16.82	30.39
5	3.0	7.50	0.00	0	16.87	30.48

in the upper strata, that it was entirely absent in the bottom water, and was replaced by hydrogen sulphide. The anaerobic layer of this lake seems to be seasonally variable in thickness, being about 2 m in the summer of 1936 after YOSIMURA's investigation (1938), but 1 m more or less in the present winter observation.

7. Lake Tohutu

When the survey of the lake was carried out on March 6, 1938, the short channel connecting it with the sea was open. Air temperature varied between 3.1–4.1°C during the observation at the four stations shown in fig 6. The ice-cover, 34, 52, 55 and 60 cm in thickness respectively at Stats. I, II, III and IV, was broken off near the channel. Among these stations the last was located

Table 7

Hydrographical observations of Lake Tohutu (7/III, 1938)

Station	Depth m	Water Temp. °C	pH	O_2 cc/l	O_2 %	Cl ‰	Salinity ‰
I	0.0	0.1	6.50	1.39	20	2.010	3.66
	0.5	0.3	6.70	1.70	17	1.970	3.59
II	0.0	0.4	6.40	2.71	25	1.000	1.84
	0.6	0.8	6.50	0.85	9	1.020	1.87
III	0.0	0.8	6.65	5.34	54	1.070	1.96
	0.6	1.2	6.90	0.92	10	6.720	12.16
IV	0.0	0.2	6.50	8.87	87	0.027	—
	0.8	0.2	6.50	8.73	85	0.028	—

in the auxiliary fresh water basin forming a large closed bay of the lake. It is clear that sea water does not come into the auxiliary basin from the fact that the clorine contents of water at Stat. IV is as scarce as 27–28 mg/l. In the main basin water temperature on the syrface gradually rose towards the eastern end. Salinity generally indicated small degrees, but was comparatively high only in the bottom water at Stat. III. This is probably owing to stagnation of sea water there. The lake water was weakly acidic in the main basin as well as in the auxiliary. The amount of oxygen dissolved in surface water gradually decreased towards the channel, so that the lake water was apparently in process of being discharged into the Okhotsk Sea when the writer's observation was made. At Stats. II and III oxygen in the layer lying just above the bottom was fairly scant showing the existence of stagnant water.

Plankton of the lakes in winter

1. Lakes Komuke

The plankton of the lake is very poor also in winter as in other seasons (TAKAYASU, IGARASI & SAWA, 1930). As zooplankton, *Sinocalanus tenellus* and *Ceratium tripos* only were found: the copepod was more abundant in surface water, and the dinoflagellate was restricted to the bottom.

Table 8

Quantitative study of the plankton of Lake Komuke in winter (number per 10 liters of water)

Depth m	0	2
Sinocalanus tenellus (KIKUTI)	36	20
Nauplius	57	65
Ceratium tripos MÜLLER	0	5
Sum	93	90

2. Lake Sibunotunai

The zooplankton of this shallow lagood is remarkably rare in winter: a few individuals of Copepoda, *Sinocalanus tenellus* and *Pseudodiaptomus japonicus* were examined in the writer's collection. The Copepoda were mainly obtained at a depth of 1 m where dissolven oxygen was almost lacking, but they were fewer in the surface layer containing sufficient oxygen. *P. japonicus* has not yet been reported from Hokkaido.

Table 9

Quantitative study of the plankton of Lake Sibunotunai in winter

Depth m	0	1
Pseudodiaptomus japonicus KIKUTI	5	5
Sinocalanus tenellus (KIKUTI)	0	7
Sum	5	12

3. Lake Saroma

The winter zooplankton of the large lagoon consisted of two species of Copepoda, six forms of Tintinnoinea and one Dinoflagellata as follows; *Calanus finmarchius*, *Oithona similis*, *Tintinnopsis lohmanni*, *T. brevicollis*, *T. bütschlii*, *T. scyphiformis*, *T. kofoidi*, *Parafavella denticulata* and *Peridinium* sp. The Copepoda were the most predominant group being distributed in all the strata, but the Tintinnoinea except *T. brevicollis* and *P. denticulata*, were rarely found in bottom water. The Dinoflagellata were also scantily obtained in deep layers. They are all immigrants from the Okhotsk Sea. Phytoplankton in winter was markedly meagre as compared with that in summer (TAKAYASU, IGARASI & KONDO, 1934).

Table 10

Quantitative study of the plankton of Lake Saroma in winter

Depth m	0	5	10	15
Calanus fimarchius (GUNNER)	35	26	7	13
Oithona similis CLAUS	12	20	19	81
Nauplius of the Copepoda	29	38	25	144
Tintinnopsis lohmanni LAACKMANN	0	0	0	5
Tintinnopsis brevicollis HADA	27	19	18	86
Tintinnopsis büschlii DADAY	0	0	0	3
Tintinnopsis scyphiformis HADA	0	0	0	2
Tintinnopsis kofoidi HADA	0	0	0	6
Parafavella denticulata (EHRENBERG)	2	0	0	2
Peridinium sp.	0	10	9	2
Sum	105	113	78	344

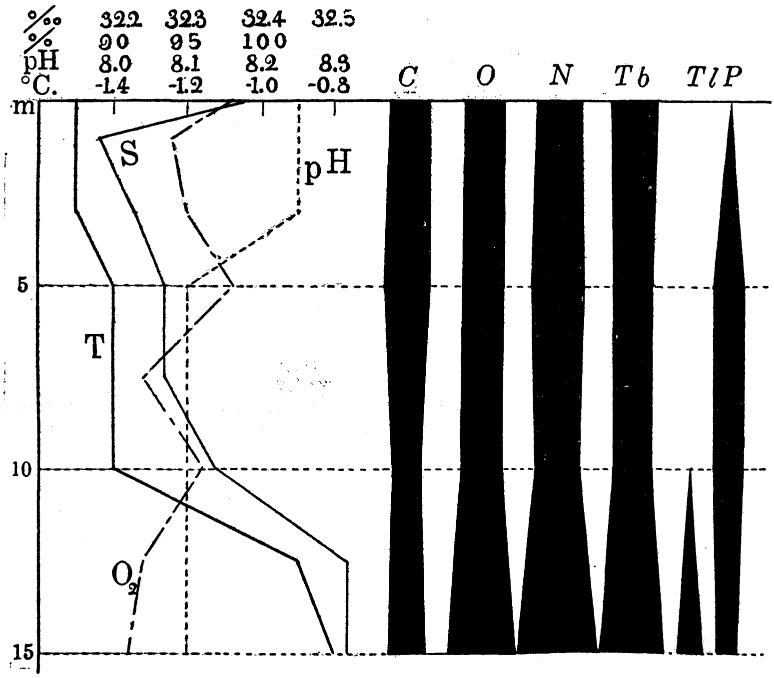


Fig. 7. Vertical distribution of the winter plankton of Lake Saroma.
C. *Calanus finmarchius*; *O.* *Oithona similis*;
N. nauplius of the Copepoda; *Tb.* *Tintinnopsis brevicollis*;
Tl. *Tintinnopsis lohmanni*; *P.* *Peridinium* sp.

4. Lake Notoro

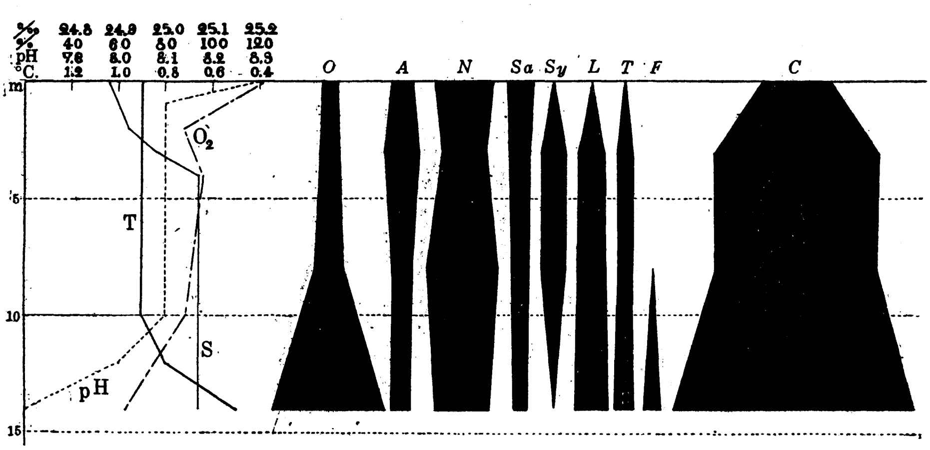
Plankton collection in the lake was made at Stats. II and III. The winter plankton of the lake was richer than that of Lake Saroma. It is probably due to the fact that the lake has no connection with the sea during the winter. The Copepoda, *Oithona similis*, was rather abundant in the bottom layer at both stations, especially at Stat. II, but *Acartia clausi* showed a constant vertical distribution, and their nauplius larvae were very numerous every layer throughout. *Sagitta tumida* was sometimes found from upper strata, and Actinotrocha larvae which are common in summer plankton of the sea, were rarely detected from the layer of a depth of 8 m at Stat. II. It is interesting that these animals occurred in the closed brackish water basin in winter. From median strata of Stat. II was taken a marine Rotatoria belonging to the genus *Synchaeta*. Seven species of Tintinnoinea, *Leprotintinnus pellucidus*, *Tintinnopsis karajacensis* var. *tenuis*, *T. lohmanni*, *T. büschlii*, *T. kofoidi*, *Favella taraikaensis* and *Para-*

Table 11

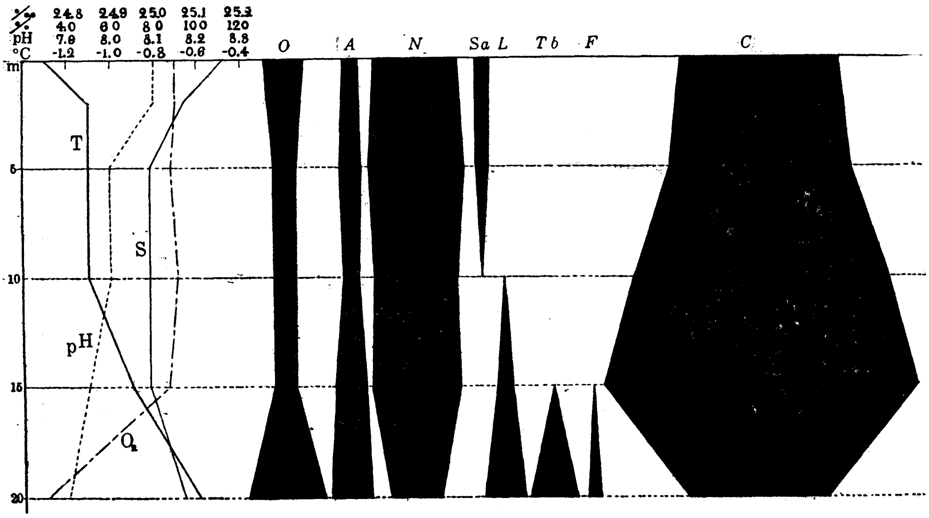
Quantitative studies of the plankton of Lake Notord in winter

Station	II				III				
Depth m	0	3	8	14	0	5	10	15	30
Oithona similis CLAUS	6	7	28	1672	85	20	26	13	704
Acartia clausi GESCHUCT	11	48	9	7	7	19	7	46	97
Nauplius of the Copepoda	228	88	844	192	835	1305	921	988	326
Sagitta tumida TOKIOKA	20	9	7	2	5	3	0	0	0
Actinotrocha larva	0	0	2	0	0	0	0	0	0
Synchaeta sp.	0	18	19	0	0	0	0	0	0
Leprotintinnus pellucidus (CLEVE)	0	19	29	38	0	0	0	5	98
Tintinnopsis karajacensis var. *tenuis* HADA	0	0	0	0	0	0	0	0	3
Tintinnopsis lohmanni LAACKMANN	0	0	0	0	3	0	0	0	5
Tintinnopsis büschlii CADAY	0	0	0	0	2	0	0	0	0
Tintinnopsis kofoidi HADA	0	5	3	10	0	0	0	0	134
Favella taraikaensis HADA	0	0	0	5	0	0	0	0	2
Parafavella denticulata (EHRENBERG)	0	0	0	0	0	0	0	0	2
Ceratium fusus (EHRENBERG)	345	5298	8774	15456	5876	9024	24500	45504	3609
Sum	610	5492	9715	17382	6813	10371	25444	46557	4980

favella denticulata, were examined. Most of then were frequently in deeper parts than near the surface.



(Fig. 8*a*. At Stat. II)



(Fig. 8 *b*. At Stat. III)

Fig. 8. Vertical distribution of the winter plankton of Lake Notoro.

O. *Oithona similis*; *A*. *Acartia clausi*;
N. nauplius of the Copepoda; *Sa*. *Sagitta similis*;
Sn. *Synchaeta* sp.; *L*. *Leprotintinnus pellucidus*;
T. *Tintinnopsis kofoidi*; *F*. *Favella taraikaensis*;
C. *Ceratium fusus*.

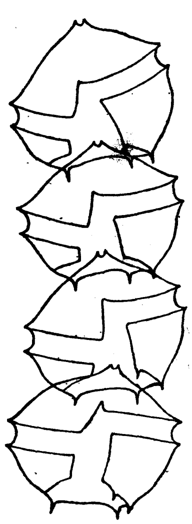


Fig. 9.
Goniaulax catenata
(LEVANDER) ×750

The Dinoflagellata were the most characteristic group in the winter plankton of the lake: two forms have been studied from the present material. At Stat. II *Goniaulax catenata*, 28–29 μ wide and 25–26 μ high, forming chains was exceedingly abundant in the upper layer and gave brown colour there, but gradually decreased towards the bottom. The species was very rare in plankton from surface water of Stat. III, and such coloured water as Stat. II was not found at Stat. I. It seems that in winter this minute organism is only prolific under the ice-cover in a limited area of the lake. The other flagellate, *Ceratium fusus*, common in brackish water was also very rich at Stats. II and III. At Stat. II it increased from the surface to the bottom contrary to the former, but at Stat. III it was most numerous in 15 m layer, and then abruptly decreased to the bottom. Hence, these dinoflagellates obviously show irregularity of the horizontal distribution. In this lake diatoms were rather frequently found in comparison with the other lakes reported in this paper.

5. Lake Abasiri

The body of water of the lake is divided by a metalimnion into a upper fresh water layer and a lower brackish water one. Therefore, the plankton consists of fresh and brackish water elements. In the writer's investigation plankton organisms were taken only from the fresh water layer, while no animal could be collected from the anaerobic stratum containing hydrogen sulphide, although zooplankton composed principally of Ciliata is usually secured from such anaerobic water as in the next lake, Mokoto and in Lake Harutori (HADA, 1938).

Such Rotatoria as *Keratella cochlearis*, *Kellicotia longispina*, *Synchaeta pectinata*, *S. oblonga* and *Polyarthra trigla*, from the most predominant group in the winter plankton of the lake. Among these species the first two were rarely found in the material taken from the 10 m layer, but the others frequently

Table 12

Quantitative study of the plankton of Lake Abasiri in winter (number per 10 liters of water at Stat. II)

Depth m	9	5	10	15
Sinocalannus tenellus (KIKUTI)	0	5	11	0
Limnocaea genuis KOKUBO	0	0	2	0
Keratella cochlearis (GOSSE)	0	0	9	0
Kellicotia longispina (KELLICOT)	0	0	3	0
Synchaeta spp.	632	170	264	0
Polyarthra trigla (EHRENBERG)	392	48	96	0
Tintinnopsis cratera (LEIDY)	5	17	5	0
Sum	1029	240	390	0

occurred in all strata above that. The two forms of Copepoda, *Sinocalanus tenellus* and *Limnocaea genuis*, were sometimes found in more or less deep strata. A sinple fresh water tintinnoid, *Tintinnopsis cratera*, was distributed scarcely in all the fresh water layer. As summer or autumnal plankton, several other forms were reported from the lake as follows; *Eudiaptomus pachypoditus* (KIKUTI, 1936), *Diaphanosoma brachyurum*, *Ceriodaphnia pulchella* and *Bosmina longirostoris* (UÉNO, 1933).

The phytoplankton in winter was very poor: only one diatom and a bluegreen alga were secured, but in other seasons the phytoplankton is very abundant, and "water-bloom" was formed by *Aphanizomenon flos-aquae* (TAKAYASU & TOBISIMA, 1930).

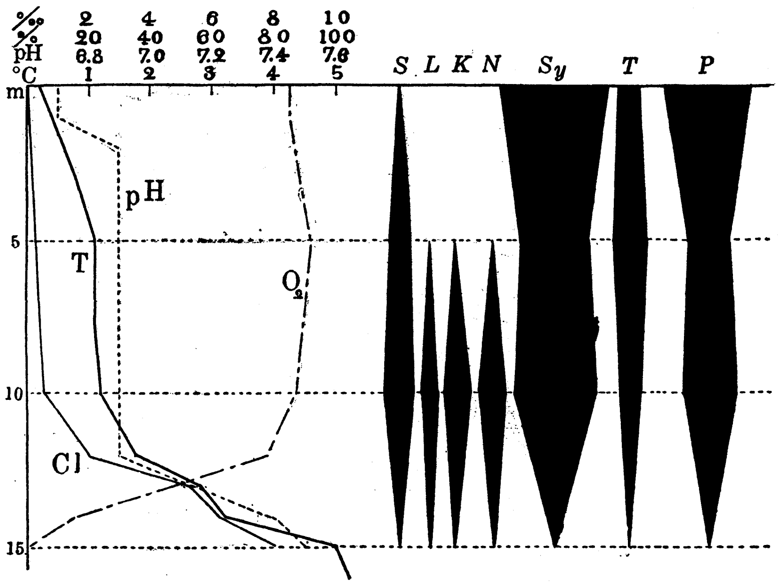


Fig. 10. Vertical distribution of the winter plankton of Lake Abasiri.
S. *Sinocalanus tenellus*; *L.* *Limnocaea genuis*;
K. *Keratella cochlearis*; *N.* *Notholca longispina*;
Sy. *Synchaeta* spp.; *P.* *Polyarthra trigla*;
T. *Tintinnopsis cratera*.

6. Lake Mokoto

The plankton of Lake Mokoto has been characteristic because of violent multiplication of greenish *Noctiluca* as numerous as 450,000 per 10 liters of lake water in median strata in summer (UÉNO, 1937, 1938). According to the writer's winter collection, *Noctiluca* could be barely found in fresh water on the surface, but it abruptly increased at a depth of 1 m and was most abundant at a depth of 3 m, then it again gradually decreased to the bottom. The vertical distribution of *Noctiluca scintillans* exactly agrees with the chemical stratification of this lake: only a small number of *Noctiluca* were secured from the quite fresh surface water, and the protozoon gradually decreased towards the bottom water containing hydrogen sulphide from the 3 m layer where it was most abundant. The green coloration of *Noctiluca* is due to the occurrence of many

Table 13

Quantitative study of the plankton of Lake Mokoto in winter
(number per 10 liters of water)

Depth m	0	1	2	3	4	5
Oithona similis CLAUS	0	107	1952	1328	1152	202
Sinocalanus tenellus (KIKUTI)	0	0	1	1	6	0
Naulius of the Copepoda	0	11	12	9	4	0
Polychaeta larva	0	10	44	15	21	0
Synchaeta vorax ROUSSELET	0	61	28	0	0	0
Noctiluca scintillans (MAÇARTNEY)	2	1072	796	18400	5088	1938
Ceratium fusus (EHRENBERG)	536	64	24	0	0	0
Sum	538	1325	2857	19753	6271	2140

minute green flagellates belonging to *Chlamydomonas* in this body fluid. The green algae swim actively and multiply there, and sometimes escape from the *Noctiluca* body through an oral part into open water. *Noctiluca* can easily catch and digest them with its plasma. In this lake, therefore, *Noctiluca* very actively reproduces on account of such a rich food supply in addition to the favorable enviromental condition.

In the winter plankton of this lake were found the following zooplankters; *Sinocalanus tenellus*, *Oithona similis*, *Polychaeta* larvae, *Brachionus angularis*, *Synchaeta vorax*, *Prorodon teres*, *Tintinnopsis undella*, *T. kofoidi*, *Helicostomella fusiformis*, *Favella taraikaensis*, *Euplotes elegans*, *Ceratium fusus*, *Peridinium* sp. and *Dinophysis* sp. In the summer plankton *Keratella cruciformis* var. *eichwaldi* and *T. kofoidi* var. *limnetica* have been also detected. In the winter plankton the Copepoda, Polychaeta larvae and the Tintinnoinea were maximum in number at a depth of 2 m, the Rotatoria at a depth of 1 m and the Ciliata exclusive of the Tintinnoinea in anaerobic water. The richness of *C. fusus* in the surface layer is probably to the fact that this dinoflagellate aggregates below an ice-cover as *Goniaulax catenata* in Lake Notoro. Diatoms were also more or less rich in the winter plankton of the lake.

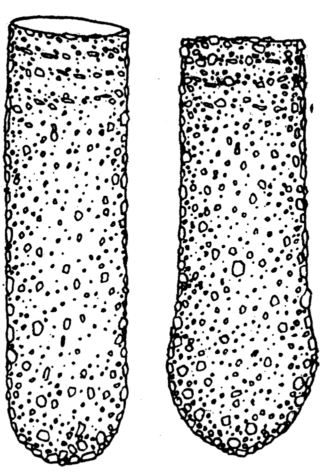


Fig. 11.
Tintinnopsis undella MEUNIER
×700

As the fresh water layer was wholly occupied by ice, no number of fresh water plankton was found from Lake Mokoto. From deep water containing hydrogen sulphide were taken a copepod, *O. similis*, and four Ciliata, *P. teres*, *T. kofoidi*, *H. fusiformis* and *E. elegans*. Therefore, this anaerobic layer seems to have no marked influence upon some plankters, being not at all thick, and containing a small amount of hydrogen sulphlde.

7. Lake Tohutu

The winter plankton of the lake is the most meagre among the brackish water lakes reported in the present paper. As zooplankton from the main brackish water basin were found only two specimens of Ostracoda in 10 liters of water taken from the bottom of Stat. II and seven individuals of Rotatoria in the same amount of surface water at Stat. III. From Stat. IV in the auxiliary fresh water basin 24 specimens of *Synchaeta* and 16 individuals of *Rotaria* were obtained from each 10 liters of surface and bottom water respectively. It is obvious that organisms of this basin mainly consist of fresh water elements: some Testacea and Heliozoa wer collected from the bottom besides the fresh water plankton.

The poorness of plankton in the lake is chiefly owing to its shallowness and the marked variation of chemical condition according to times and places.

GENERAL REMARKS

1. Observation

Invasion of sea water in winter: Among the seven lakes here reported, Lakes Abasiri and Mokoto are connected with the sea by rivers and Lake Saroma by an artificial passage. These lakes usually discharge lake water into the Okhotsk Sea even in winter, but the other lakes have no connection with the sea, being interrupted by sand drifts which close their outlets during the winter. Among the lakes having connection with the sea in winter, Lake Saroma is always invaded by a great amount of sea water, but Lakes Abasiri and Mokoto very rarely only at heavy storms and sometimes at high tides respectively. When the writer's study was made, Lake Tohutu had an outlet. The lake seems to be usually invaded by a small amount of sea water.

Surface water temperature: Surface water temperatures of brackish waters usually register lower than 0°C, but never go down below the freezing points at each salinity as shown in table 14. It is possible, therefore, roughly to guess the salinity from the surface temperature in winter.

Table 14

Surface water temperature in brackish water lakes in winter

Lake	Saroma	Notoro			Komuke	Sibuno-tunai	Tohutu		
Station		III	II	I			I	II	III
Salinity of surface water ‰	32.38	25.16	24.88	24.18	22.47	7.05	3.66	1.84	1.96
Surface water temperature °C	−1.50	−1.30	−0.90	−0.80	−1.00	−0.40	0.10	0.40	0.80
Freezing point of surface water °C	−1.76	−1.34	−1.30	−1.21	−1.21	−0.38	−0.20	−0.10	−0.11

Stratification: In brackish water lakes thermal phenomena so strongly depend upon chemical conditions, especially mainly upon salinity of the sea water stagnated in lakes, that the circulation caused by water temperature is scarcely observable. The chemical stratification is changed by invasion of sea water. In Lake Saroma which always exchanges lake and sea water, therefore, no marked stagnation occurs throughout the year in spit of its great depth, but in Lake Notoro which is also deep the stagnation appears to be due to the slight invasion of sea water. In cases where small amounts of sea water flow into lakes, the deep brackish water lakes as Abasiri and Mokoto exhibit a stable stagnation all the year round, and oxygen in the bottom strata is completely removed to form a body of anaerobic water where hydrogen sulphide is produced by the action of sulphur bacteria. In shallow lakes an obvious stratification is also formed under ice as observed in Lake Sibunotunai, if sea water does not enter into the lakes during the winter. When the ice-cover disappears, this stratification will be destroyed even by a breath of wind.

Applying to these brackish water lakes the classification of fresh water lakes based upon thermal conditions as YOSIMURA (1938) attempted, Lake Abasiri and Mokoto are included in the first order of temperature Lakes Saroma and Notoro in the second, and Lakes Komuke, Sibunotunai and Tohutu in the third.

Salinity: According to the classification of brackish waters regarding salinity, Lakes Saroma, Notoro and Komuke belonging to the polyhaline type of salinities over 19 ‰, and Lake Mokoto to the moderate type of this group. Lake Tohutu is of the mesohaline lakes ranging from 2 ‰ to 20 ‰ in salinity, and Lake Abasiri generally exhibits the character of the oligohaline lakes having low salinities of 1–2 ‰. Lake Sibunotunai should probably be comprised in the polyhaline type in consequence of the high salinity while it is connected with the sea.

In the writer's observation of Lake Saroma and Notoro, the salinities of surface water were more or less higher than those of the layer just below the ice-cover. The fact seems to be due to the increse of salt contents in the surface water from the formation of an ice-cover.

2. Plankton

Sea and brackish water plankton was collected from these lakes except Lake Abasiri. Winter plankton of large polyhaline lake is wholly composed of marine inhabitants, but some brackish water elements are added to those in small lakes of the same type. The winter plankton of these deep lakes principally consists of three groups of zooplankton: Copepoda, Tintinnoinea and Dinoflagellata, excepting Lake Abasiri in which the Rotatoria is predominant. Being composed of a single group of the Copepoda, plankton of shallow lakes in winter is usually simple and poor as in Lakes Komuke and Sibunotunai.

It is clear that winter plankton of brackish waters is qualitatively and quantitatively interior to that of the summer. In Lake Mokoto the difference between them is very considerable; for example, *Oithona similis* and its larvae were counted by UÉNO (1938) as many as 14,200 per 10 liters of water and *Noctiluca scintillans* 449,400 in the summer plankton of 1936, but in the writer's collection in the winter of 1938 the number of the former per 10 liters of water is 1,964 and that of the latter 18,490.

Influence of chemical conditions upon plankton: In winter, plankton is more or less rich in brackish water having such a body of stagnant water as Lakes Notoro and Mokoto have. The fact is probably due to the accumulation of nutriments in lake water. In brackish waters salinity has the most remarkable effect upon plankton, and then oxygen and hydrogen sulphide are effective. As hydrogen sulphide always exists in a deep anaerobic layer, lack of oxygen is usually concomitant with production of hydrogen sulphide which adversely affects plankton: the evident example was shown in the vertical distribution of the plankton of Lake Abasiri. When the amount of hydrogen sulphide in anaerobic water is small or the layer containing it is thin, some organisms live there without any injury as well as in aerobic water, for example, in Lake Mokoto. In brackish waters some Ciliata are adapted to an anaerobic life by means of synbiosis with thiobacteria (KAHL, 1927; LIEBMANN, 1938). Such Ciltata can reproduce also in water containing a large amount of hydrogen sulphide as found in Lake Harutori (HADA, 1938).

Copepoda: The Copepoda are usually commonest in the winter plankton of the brackish water lakes in Kitami Province, being found in each lake surveyed by the writer except Lake Tohutu. Six species in all have been examined. Of them three are marine forms, two brackish inhabitants and one a fresh water dweller. The brackish water form, *Sinocalanus tenellus*, frequently occurred in brackish water ranging from 0.5 ‰ to 30.4 ‰ in salinity, and the marine species, *Oithona similis*, in saline water between slinities of 24.9-32.5 ‰. In winter plankton of brackish waters nauplii of the Copepoda were generally more numerous than their adults as in Lakes Saroma, Notoro and Sibunotunai, but very rare in Lake Mokoto, and were not secured in Lakes Komuke and and Abasiri. They seem to be more effected than their adults by the presence of hydrogen sulphide. It is also known from the present study that the Copepoda are usually abundunt in deep strata during winter in large and deep lakes, such as Saroma and Notoro.

Rotatoria: The Rotatoria are not generally important constituents in winter plankton of brackish waters. Five fresh and a single brackish water species have been secured in this study. Brackish water forms belonging to *Synchaeta* were usually found from the median strata of the polyhaline lakes as Lakes Notoro and Mokoto.

Ciliata: The Ciliata found in this collection mainly belong to the Tintinnoinea excepting *Prorodon teres* and *Euplotes elegans* from Lake Mokoto. Among eleven forms of Tintinnoinea, *Tintinnopsis cratera* is a fresh water dweller and *T. kofoidi* var. *limnetica* a blackish water inhabitant. These were not found from any shallow lake and more frequently occurred in the bottom strata than in the upper layers of the large and deep lakes of Saroma and Notoro.

From the anaerobic layer of Lake Mokoto containing hydrogen sulphide, the following four species of Ciliata were detected; *P. teres*, *T. kofoidi*, *Helicostomella fusiformis* and *E. elegans*. However, they are by no means true anaerobic organisms.

Flagellata: Six species of Dinoflagellata have been studies in brackish waters. All of them are common in sea waters. It is noteworthy that some marine dinoflagellates as *Goniaulax catenata* in Lake Notoro and *Ceratium fusus* in Lake Mokoto, vigorously multiply under the ice-cover. For these flagellates low temperature and weak penetration of light seem to be very favorable. It is interesting that special propagation and coloration of *Noctiluca* in Lake Mokoto are due to the presence of a commensal, *Chlamydomonas*, in its body fluid.

Production of winter plankton: The production of winter plankton is the most excellent in Lake Notoro, next in Lake Mokoto, then in Lakes Abasiri, Saroma, Komuke and Sibunotunai. Lake Tohutu shows the most inferior among them. Judging from the plankton productivity, Lakes Notoro, Abasiri and Mokoto having all stable chemical stratification throughout the year, distinctly belong to the eutrophic type of brackish waters, but Lake Saroma exhibiting no obvious stratification in winter, is of mesotrophic type. In shallow lakes seasonal variation in plankton productivity is usually so marked, that it is difflcnlt to determine the type of brackish waters only from studies of winter plankton.

3. Fishery in winter

Among the seven lakes recorded in the present paper, fishing in winter is carried out in the following three lakes; from Lake Notoro flatfishes are taken during the winter with a net fixed on the bottom, in Lake Abasiri *Hypomesus olidus* is collected by means of a drag-net under ice, and from Lake Mokoto *Corbicula sadoensis* is obtained with a sieve at the small ice-free area near the outlet.

It is an important and interesting fact that these lakes are all eutrophic in type of brackish waters as just above mentioned.

SUMMARY

1. Hydrographical observations and plankton collections were made at the beginning of March, 1938 in the seven brackish water lakes on the coast of the Okhotsk Sea in Kitami Province, Hokkaido.

2. There is no direst connection with the sea in Lake Notoro, Komuke and Sibunotunai during the winter. At present, Lake Saroma is usually invaded by sea water, Lake Mokoto occasionally at high tides and Lake Abasiri seldom at times of heavy storms.

3. The surface of these lake was entirely covered with a thick ice-cover, when observations were made. The temperatures of surface water generally approached the freezing points at each salinity.

4. Lakes Saroma, Notoro, Komuke and Mokoto are of the polyhaline type of brackish water lakes, Lake Tohutu is mesohaline and Lake Abasiri oligohaline.

5. In winter marked stratification is observed in the deep lakes excepting Lake Saroma. Among the shallow lakes it is also present under the ice-cover in Lake Sibunotunai.

6. Lakes Abasiri and Mokoto exhibit permanent stagnation in the deep layer where dissolved oxygen disappeares and hydrogen sulphide occurs. The position of the metalimnion of these lakes is almost unchangeable throughout the year, and the seasonal variation of bottom temperature is very small.

7. Members of plankton of the polyhaline lakes are wholly marine dwellers, but in oligohaline waters fresh water organisms are as superior as brackish water inhabitants in the mesohaline lakes.

8. The winter plankton of these lakes mainly consists of the three groups: Copepoda, Tintinnoinea and Dinoflagellata.

9. The marked influence of chemical conditions upon the vertical distribution of plankton was observed in the plankton of Lake Abasiri: not any zooplankton was secured from the anaerobic layer below the metalimnion, but in Lake Mokoto several forms of zooplankton were collected from such oxygen-lacking water containing hydrogen sulphide.

10. Six species of Copepoda have been examined in this study. Among them *Pseudodiaptomus japonicus* is reported from Hokkaido for the first time. It is also known that *Sinocalanus tenellus* occurs in brackish water of wide range of salinity (0–30.3 ‰), and in winter *Oithona similis* tends to increase in number towards the bottom in the deep polyhaline lakes.

11. Eleven forms of Tintinnoinea have been found in collections of winter plankton taken from the deep lakes. Most of them were usually obtained from deeper strata.

12. Six marine species of Dinoflagellata have been detected in this investigation. *Goniaulax catenata* forming chains was exceedingly rich in the surface layer of Lake Notoro just below the ice-cover. *Noctiluca scintillans*, very abundant in Lake Mokoto is greenish due to a minute flagellate commensal, *Chlamydomonas*, swimming in the body fluid of *Noctiluca*.

13. According to winter plankton productivity, these brackish water lakes can be ordered as follows; Notoro>Mokoto>Abasiri>Saroma>Komuke>Sibunotunai>Tohutu.

14. Fishing in winter is carried on only in the three eutrophic brackish water lakes.

LITERATURE

HADA, Y. 1937. The Fauna of Akkeshi Bay. IV. The pelagic Ciliata.—Journ. Fac. Sci., Hokkaido Imp. Univ., Ser. VI, Zool., Vol. 5.

——— 1938. Characteristics of Lake Harutori. Living organisms of Lake Harutori (in Japanese). —Kagaku, Vol. 8.

——— 1939a. On the Plankton of Lake Mokoto, especially on *Noctiluca* (in Japanese).—Shokubutu oyobi Dobutu, Vol. 7.

——— 1939b. Fresh Water Tintinnoinea in Japan.—Trans. Sapporo Nat. Hist. Soc., Vol. 16.

——— 1939c. Some Rotatoria from Sea and Brackish Water (in Japanese with English résumé). —Zool. Mag., Vol. 51.

HORASAWA, I. 1934. Notes on *Diaptomus Okadai* sp. nov.—Annot. Zool. Jap., Vol. 14.

INUKAI, T. & S. NISHIO, 1937. A Limnological Study of Akkeshi Lake with Special Reference to the Propagation of the Oyster.—Journ. Fac. Agric., Hokkaido Imp. Univ., Vol. 40.

KAHL, A. 1928. Die Infusorien (Ciliata) der Oldesloer Salzwasserstellen.—Arch. Hydrob., Bd. 19.

——— 1933. Ciliata libera et ectocommensalia.—Tierw. Nord- n. Osts., Lief. 23, T. II.

KIKUCHI, K. 1923. Freshwater Calanoida of Middle and Southwestern Japan.—Mem. Coll. Sci., Kyoto Imp. Univ., Ser. B, Vol. 4.

——— 1936. Fresh-water and Brackish-water Calanoid Copepods of Japan with Notes on their Geographical Distribution.—Bull. Biogeog. Soc. Japan, Vol. 6, No. 29.

KINOSITA, T. & Y. NAKASIMA, 1936. On the Relation of the Occurrence of *Noctiluca* and Water Temperature and Specific Gravity in Lake Saroma, Hokkaido (in Japanese).—Yoshokukaisi, Vol. 6.

——— 1938. Hydrographic Studies on Saroma-Lake, Hokkaido (in Japanese with English résumé). —Jap. Journ. Limn., Vol. 8.

KINOSITA, T. & S. SIBUYA, 1939. Breeding Season of *Corbicula* in Lake Mokoto (in Japanese).—Hokkaido Suisan Sikenzyo Zigyo Zyunpo, No. 417.

LEBOUR, M. V. 1925. The Dinoflagellates of Northern Seas.—Mar. Biol. Ass. Unit. King.

LIEBMANN, H. 1938. Biologie und Chemismus der Bleilochsperre.—Arch. Hydrob., Bd. 33.

MORI, T. 1937. The Pelagic Copepoda from the Neighbouring Waters of Japan.

OKADA, Y. & K. KOBA, 1936. Limnological Observations in Hokkaido (in Japanese).—Shokubutu oyobi Dobutu, Vol. 4.

TAKAYASU, T. 1937. On the Lakes of Hokkaido (in Japanese).—Hokkaido Kagaku Kyokai, Vol. 12.

TAKAYASU, S., H. IGARASI & K. SAWA, 1930a. Survey of Lake Tohutu (in Japanese).—Suisan Chosa Hokoku, Hokkaido Fish. Exp. Stat., Vol. 21.

——— 1930b. Survey of Lake Komuke (in Japanese).—ditto Vol. 22.

TAKAYASU, S., H. IGARASI & K. KONDO, 1934. Survey of Lake Saroma (in Japanese).—ditto Vol. 34.

TAKAYASU, S. & K. KONDO, 1934. Limnological Researches. III. Lake Notoro (in Japanese).—ditto Vol. 36.

TAKAYASU, S. & K. TOBISIMA, 1930. Survey of Lake Abasiri (in Japanese).—ditto Vol. 22.

TOKIOKA, T. 1939. A New Brackish-water Chatognath—Annot. Zool. Japan., Vol. 18.

UÉNO, M. 1933. The Freshwater Brachiopoda of Japan. II. Cladocera of Hokkaido.—Mem. Boll. Sci. Kyoto Imp. Univ., Ser. B, Vol. 8.

——— 1937a. Limnological Reconnaissance of Mokoto-numa, Hokkaido (in Japanese).—Shokubutu oyobi Dobutu, Vol. 5.

——— 1937b. Bottom Fauna of Lake Abasiri, Hokkaido (in Japanese).—ditto.

——— 1938a. Bottom Fauna of Lake Abasiri and the Neighbouring Waters in Hokkaido.—Trans. Sapporo Nat. Hist. Soc., Vol. 15.

——— 1938b. Stratification of Noctiluca in a Brackish Water Lake of Hokkaido, Japan.—Proc. Imp. Acad. Tokyo, Vol. 14.

YOSHIMURA, S. 1938. Dissolved Oxygen of the Lake Waters of Japan.—Sci. Reps. Tokyo Bunrika Daigaku, Ser. C, No. 8.

(KIKUCHI = KIKUTI and YOSHIMURA = YOSIMURA; SAWA renamed as KONDO.)