Papers

A LIMNOLOGICAL INVESTIGATION OF A LARGE ARCTIC LAKE, NETTILLING LAKE, BAFFIN ISLAND

D. R. Oliver*

Introduction

NETTILLING LAKE, the largest lake in the Canadian Arctic Archipelago, lies between 65°56'N. and 67°02'N. in south-central Baffin Island. The large size of this lake and its geographical position give it a place of special interest in limnology. Little is known of the physical and chemical conditions existing in arctic lakes (Rawson 1953a). Except for Lake Hazen, Ellesmere Island (Deane 1958, 1959, and McLaren 1959), limnological studies in the arctic region have been restricted to small, relatively shallow lakes, such as the investigations in northern Alaska by Comita and Edmondson (1953), Brewer (1958), Livingstone *et al.* (1958), and Hobbie (1961); in Southampton Island by Frey and Stahl (1958); and in Greenland by Johansen (1911), Trolle (1913), and Andersen (1946).

In 1956, J. A. Thomson and the author spent approximately 5 months at Nettilling Lake. A general limnological survey was made in conjunction with detailed studies of arctic char (by Thomson) and of chironomids (by the author). The physical and chemical data derived from our survey are presented here. However, these data give only a general impression of the conditions existing in Nettilling Lake and a detailed investigation is needed. Such a detailed study would contribute to some of the basic problems of limnology, especially lake classification.

Although incomplete, lists are given of the animals collected from Nettilling Lake. Some of these are northernmost records or new records for the Nearctic. Furthermore, they list animals that live in conditions near the thermal minimum under which freshwater organisms can be expected to survive. The productivity of the lake was not studied, but the physical and chemical data suggest that it is low.

Historical

Boas, during his stay in Baffin Island in 1883-1884, was probably the first non-Eskimo to see Nettilling Lake. In 1902 Noble travelled around the lake and established some idea of its shape and size (Millward, 1930). Hantzsch, during his ill-fated journey in 1911, travelled around the southern end of the lake (Anderson, 1930). On July 8 of that year, the lake was firmly frozen but the ice was clear of snow. Hantzsch did not record the

*Entomology Research Institute, Research Branch, Canada Department of Agriculture, Ottawa, Ont.

date when the ice left the lake, but it was ice-free by August 15 when he left his summer camp for the Koukdjuak River. Burwash briefly visited the west side in 1924 (Millward, 1930).

Soper (1928) spent considerable time in the vicinity of Nettilling Lake in 1925 and 1926. He gives a few observations on the ice conditions in 1925. The ice was safe for travel in early July, "though badly honey-combed". Decay was very rapid after the middle of July. The lake rose 2.5 feet from the middle of June "until far into July. In early August the main body of the lake was filled with ice as far as the eye could see". The eastern area of the lake became free of ice on the evening of August 9. No ice had formed on the lake by September 9, though large areas of thin ice formed along the edges of the Koukdjuak River on September 1.

Manning (1943) sledged across Nettilling Lake in 1940. He observed that the ice in Camsell Bay had dropped 3 feet in the spring, suggesting a drop in the water level by the same amount.

Geographical Situation

The north, east, and south shores of the lake are bordered by the low edge of the Precambrian region of the east coast of Baffin Island. Most of the hills in the vicinity of the lake in this area vary between 25 and 75 feet above the lake level, with ridges on the north shore attaining heights of 200 feet. The Great Plain of the Koukdjuak, consisting of Ordovician sedimentary rocks overlain with a thick cover of glacial drift, borders the west side of the lake. Along the shore the Great Plain does not rise more than 20 ft. above the lake level. For further details of the environs of the lake see Soper (1928).

The lake is drained by the Koukdjuak River, which leaves the west side of the lake and flows through the Great Plain of the Koukdjuak into Foxe Basin, dropping evenly about 100 ft. in 50 mi. It is about 2.5 mi. wide where the lake narrows to form the river, but the current is not always perceptible at this point. Elsewhere the current is rapid and the surface smooth (Soper 1928). Throughout the length of the river it is never narrower than 1 mi. Manning (1943) estimated the flow to be of the order of 140,000 $ft.^3$ per second.

The major inlet, the Amadjuak River, enters Burwash Bay at the southern tip of the lake. This river, described by Soper (1928) as very fast with numerous rapids, drains Amadjuak and Mingo lakes. There are several other large, unnamed rivers flowing into the lake. One, carrying water from the Penny Ice-Cap, empties silt-laden water into the north-eastern area. Two others enter east of Magnetic Point, draining the area between Nettilling and Amadjuak lakes.

Morphometry

Nettilling Lake, roughly triangular in shape, is approximately 75 mi. (111 km.) long by 60 mi. (97 km.) wide (Fig. 1). Its area is recorded as

2,200 mi.^{2} (5699 km.^{2}) (Rawson 1953a), which makes it the sixth largest lake in Canada. It can be subdivided into two morphological regions by a line from Caribou Point to Magnetic Point. The region west of this line has a deep regular basin, almost devoid of islands. The area east of this line, including Camsell Bay, has a very irregular basin with numerous islands.

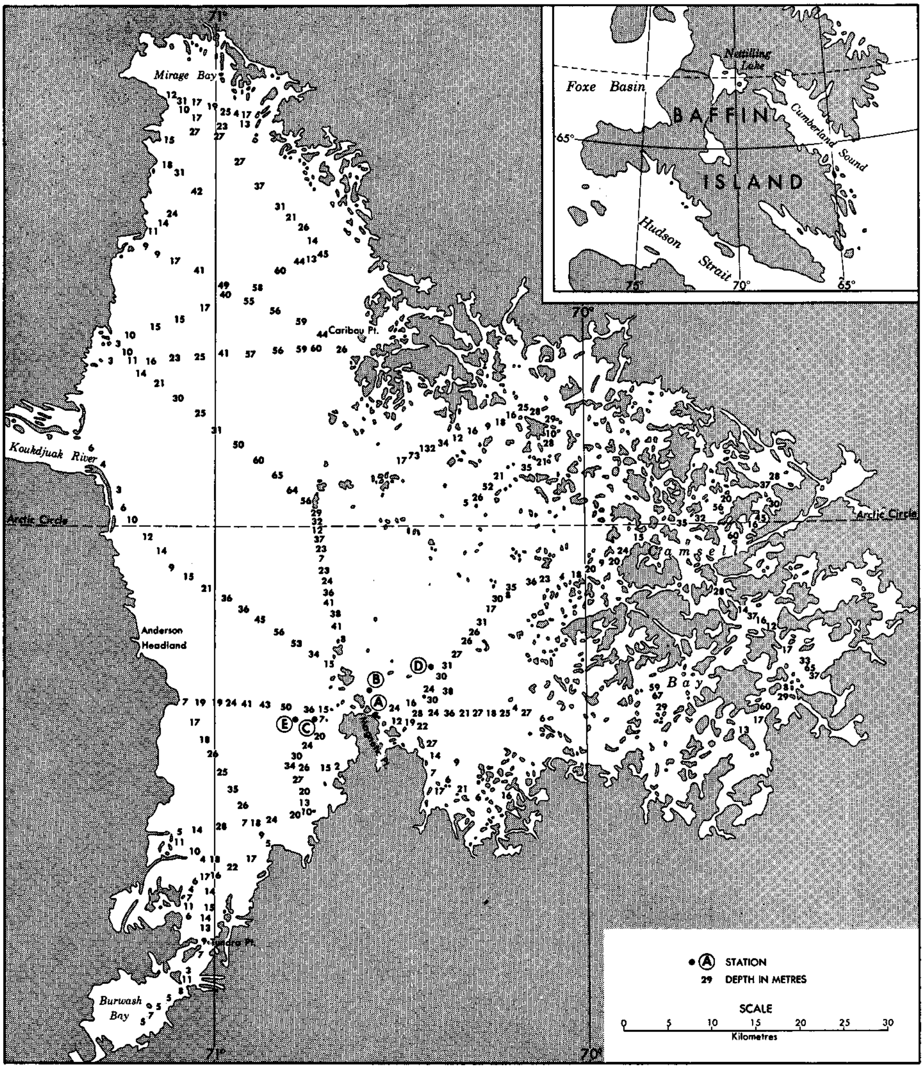

Fig. 1. Map of Nettilling Lake showing spot soundings and stations.

The shore line of the western region is relatively regular, with most of the irregularity due to long gravel ridges. These gravel ridges, formed by ice-push, lie along the low western shore of the lake and may extend 0.25 mi. out into the lake from the actual shore. They sometimes cut off lagoon-like areas from the lake. The shore line is progressively more irregular towards Magnetic and Caribou Points, with an increasing number of near-shore islands. In the eastern region the shore line is exceedingly irregular. The division between irregular and regular shore lines roughly coincides with the junction of the Ordovician and Precambrian formations.

The depth of the lake was measured by 573 soundings. A pre-stretched, tarred cotton metre-line with an attached weight was used to obtain these soundings of which approximately one-half are shown in Fig. 1. The bottom slopes evenly away from the shore on the west side of the lake. The bottom in the rest of the lake slopes steeply and irregularly away from the shore, often reaching depths of 20 m. or more a few metres from shore. Most of the lake is less than 60 m. deep. The maximum observed depth was 132 m., south-southeast of Caribou Point.

In a lake as large and complex as Nettilling Lake 573 soundings are not sufficient to allow accurate placing of depth contours at the usual 5-m. intervals. As the bottom of the western region is regular, it was felt that 10-m. contour lines could be estimated with relative accuracy. The areas between successive contours were determined. The resulting calculations of relative areas of the depth zones and volumes of the depth strata are presented in Table 1. Nearly one half (46.3 per cent) of the western region is less than 20 m. and only 6.7 per cent is deeper than 60 m. Approximately one half (53.4 per cent) of the lake volume lies above 20 m. and 5.7 per cent below 50 m.

The surface of Nettilling Lake is 100 ft. above sea-level. The level of the lake began to rise during the first week in June 1956 and continued to rise until the end of June. No accurate measurements were made, but the increase was estimated to be about 1 m. From the end of June until July 4, the level of the lake fell about 5 cm. A water-level marker was placed in the lake on July 4. From this date until September 11 (last date recorded) the lake level fell 60.9 cm. at a uniform rate. The level of the lake probably continues to decrease throughout the winter as is suggested by Manning's (1943) observation of the drop in ice-level.

Ice

In May 1956 the thickness of the ice varied between 1.5 and 1.9 m. During the early part of June the ice began to thin and melt-water running off the adjacent land collected around the edge of the lake on the ice. By June 16, the surface of the ice was covered with about 10 cm. of water, lying either on bare ice or under snow. A week later the surface was clear of snow and water, except for occasional pools, and showing a beautiful pattern of ice crystals. A shore lead developed around the edge of the lake during the first week in July comprising an area 5 to 50 m. wide that was completely free of ice and the ice thickness on the main body of the lake varied between 1.0 and 1.3 m., with the top 0.25 m. composed of candled ice. By July 25, the average thickness of the ice was 0.75 m. It was candled throughout and no longer safe for travel.

Large areas of open water, often several miles across, formed at the mouths of rivers during the last week in July. On August 4, the western region was completely free of ice. A large ice-floe persisted northeast of Magnetic Point until the night of August 10, when strong winds completely cleared the lake of ice. Hantzsch (Anderson 1930) and Soper (1928) also observed that Nettilling Lake became free of ice during the first part of August.

Table 1. Percentages of area and volume of the 10-m. depth zones of the western region, Nettilling Lake.

	Percentage	
Depth units m.	*of lake area in depth zones*	*of lake volume in depth strata*
0 – 20	26.1	31.0
10 – 20	20.2	22.4
20 – 30	14.8	16.6
30 – 40	9.4	15.8
40 – 50	11.9	8.5
50 – 60	10.9	4.4
60 – 65	6.7	1.3

Wind, insolation and lead formation combine to destroy the ice on Nettilling Lake, but apparently wind is most effective. Insolation is primarily responsible for the weakening and thinning of the ice-sheet, until it is converted into loose masses of crystals held together by lateral support. Lead formation is caused by melting of the ice, rise of lake level and inflow of warmer water. Once the leads are wide enough to allow the wind to move the ice-sheet around, grinding against the shore and melting by wave action decreases the area of ice rapidly, especially when the ice-sheet consists of loose crystals. If strong winds persist the lake is finally cleared.

Temperature

Four stations (A, B, C, and D) were established through the ice in the vicinity of Magnetic Point in May and June, and following break-up, a fifth station, E, was added (see Fig. 1 for locations). The depths of the stations are: A, 11 m.; B, 16 m.; C, 24 m.; D, 39 m.; and E, 46 m. The temperature and other physical and chemical data taken every 10 to 14 days, are presented in Tables 2 to 5. Intermittent observations taken in other parts of the lake show that the temperature records at these stations reflect the general conditions of the lake. The temperatures were measured by a reversing thermometer accurate to 0.1° C. This reversing thermometer was calibrated at regular intervals against a standard thermometer.

In May and early June the water under the ice showed a temperature inversion. The first observations in May showed the bottom temperature of the water to be 1.0° C. or less. As these temperatures were recorded before spring warming set in, they probably reflect the thermal conditions of the lake at the time of ice formation the previous year.

Table 2. Physical and chemical observations at Station A, Nettilling Lake, 1956.

	May	*June*			*July*			*Aug.*		*Sep.*
	30	*18*	*28*	*7*	*17*	*24*	*3*	*12*	*29*	*8*
Temperature °C.										
Air	0.2	1.2	9.6	7.8	—	8.0	9.5	9.0	8.4	3.3
Surface	—	—	—	—	—	4.2	5.2	7.0	7.8	5.5
5m.	0.2	0.7	1.7	2.5	3.9	3.9	4.9	6.7	7.3	5.1
Bottom (11 m.)	1.0	3.0	4.0	4.0	4.3	3.9	4.9	6.7	6.8	5.1
Oxygen (cm.³/l.)										
Surface	—	—	—	—	—	9.3	9.0	8.6	10.4	9.9
5 m.	10.6	11.8	11.7	11.0	11.1	9.4	9.3	8.7	10.4	10.0
Bottom	8.7	11.6	12.8	11.7	11.3	9.4	9.3	8.7	10.4	10.0
Secchi disc (m.)	—	—	—	—	—	11.0	11.0	11.0	11.0	11.0

Table 3. Physical and chemical observations at Station B, Nettilling Lake, 1956.

	May		*June*		*July*			*Aug.*		*Sep.*
	22	*6*	*18*	*28*	*7*	*17*	*4*	*13*	*28*	*7*
Temperature °C.										
Air	5.0	—	1.3	9.6	12.1	9.8	9.8	8.5	7.6	3.8
Surface	—	—	—	—	—	—	4.7	5.5	6.0	5.8
5 m.	0.3	0.1	0.4	0.8	1.6	2.4	4.1	4.7	5.7	—
10 m.	0.5	0.3	0.4	0.9	1.6	2.5	3.9	4.4	5.7	5.3
Bottom (16 m.)	0.6	0.6	0.7	1.1	1.7	2.7	3.9	4.4	5.7	5.2
Oxygen (cm.³/l.)										
Surface	—	—	—	—	—	—	8.7	—	10.6	9.6
10 m.	—	—	—	—	—	10.0	9.2	11.3	10.6	9.7
Bottom	8.2	—	—	—	—	10.0	9.2	10.5	10.6	9.8
Secchi disc (m.)	—	—	—	—	—	—	14.7	—	14.7	—

The last temperature records through the ice before it became unsafe for travel in late July, showed that the water had warmed up several degrees. The bottom waters at Station A reached 4.0°C. and 3.8°C. at Station B, in the shallow inshore regions of the lake. In the deeper regions, Station C warmed up to 2.6°C. and Station D to 1.9°C. The water in the deeper regions probably rose to higher temperatures before break-up than is indicated in the last temperature records through the ice, as there were about 3 weeks without records between these two dates. For example, on August 13, two days after Station D became free of ice, the bottom water temperature was 2.9°C., one degree higher than the last record before break-up. During a period beginning about June 20, until the time of ice disappearance, the bottom water warmed up 1.5 to 3.0 degrees.

During June numerous small temporary streams drained the melt water from the surrounding land. The water in these streams was generally warmer than that in the lake. The inflow of this warmer water combined with the inflow of the permanent rivers contributed to the warming of the lake water under the ice. Rawson (1950) showed that the heating influence of the inflow of the Slave River into Great Slave Lake is pronounced to 12 mi. from the inlet and just detectable at 20 mi. This, combined with heating by insolation, both direct and reflected from shallow bottoms and the shore, accounts for the greater increase in water temperature around the edge of the lake.

In the main body of large lakes such as Nettilling Lake the effect of incoming water is expected to be slight and insolation is probably the main warming agent. This is supported by the fact that the onset of the increase in water temperature roughly coincided with snow crystalization and the disappearance of snow from the ice surface, which would allow an increase in the amount of insolation reaching the water below the ice. The instability created by the warmed water under the ice insured the transport of heat into the depths. The whole body of water would gradually increase in temperature. It is not known how large the increase is in insolation passing through the ice once the surface is free of snow but the following figures from Porter (1943) illustrate how effectively snow blocks the passage of visible light.

Depth of snow (inches)	Foot-candles	Light transmission (per cent)
0	247	100
3¼	2	0.8
1¼	5½	2.4
⅝	15½	6.3

Apparently anomalous temperature readings were recorded on July 24 at Station A. and on August 4 at Station B. (Tables 2 and 3). Water at or near the temperature of maximum density was found between 0 and 5 metres at A and between 5 and 10 metres at B above water of a lower density. These stations became free of ice in the 24 hour period prior to the recording of the temperatures. The observed anomalies may have been caused by rapid warming of the surface water after the disappearance of the ice, which would have passed through the temperature of maximum density. This would have caused the sinking of some of the surface water. As the density differences between the various layers of water were small, the rate of settling would have been slow and perhaps not enough time had elapsed for stability to be reached when the temperature readings were taken.

The surface water at Station A, in a region protected from all but strong wind action, rose to 7.8°C. by the end of August. In small restricted bays, surface temperatures were recorded up to 8.8°C. The surface temperature at stations C and D rose above 4°C. Temperature series scattered throughout the eastern region established that surface temperatures rose above 4°C. in all this region. At Station E the maximum surface temperature recorded was 3.7°C. Records from this Station and temperature series in other parts of the western region showed that the central mass of the water did not rise above 4.0°C., whereas the water around the periphery rose to almost 5.0°C. No significant cooling had taken place by September 7, the last date of temperature observations.

No thermocline formation was observed in Nettilling Lake, and a homothermic condition prevailed generally.

Dissolved oxygen

The organisms in the large volume of cool, deep water of Nettilling Lake do not use up oxygen rapidly, and there was no significant shortage at any time or place. Miller's method was used to determine the oxygen concentration. The oxygen content in the surface water, varying with the temperature (Tables 2 to 5) ranged from 8.0 cm.^{3}/l. to 11.8 cm.^{3}/l., that is from 80 per cent saturation to supersaturation. The oxygen content at the bottom was nearly the same as at the surface and frequently higher.

Hydrogen-ion concentration

The pH never exceeded the range 6.8 to 7.0 and there was no apparent relation to depth or other conditions.

Transparency

The depth of light penetration into the water was measured by the standard Secchi disc technique. The diameter of the Secchi disc was 9 inches. Transparency varied from 1.1 to 21.3 m. (some of the readings are presented in Tables 2 to 5).

Table 4. Physical and chemical observations at Station C, Nettilling Lake, 1956.

	May 22	*June* 16	*June* 26	*July* 6	*July* 18	*Aug.* 6	*Aug.* 13	*Aug.* 28	*Sep.* 7
Temperature °C.									
Air	8.0	3.0	10.2	10.5	8.3	7.8	8.5	7.2	3.0
Surface	—	—	—	—	—	2.2	3.0	5.0	5.1
5 m.	—	—	0.8	1.1	1.4	1.8	2.6	—	—
10 m.	—	0.2	0.8	1.1	1.4	1.8	2.9	4.7	4.4
15 m.	0.5	—	0.8	1.0	1.9	1.8	3.1	4.6	4.2
20 m.	—	0.5	0.8	1.0	2.2	2.3	—	4.3	—
Bottom (24 m.)	0.6	0.6	0.9	1.1	2.6	2.5	3.4	4.3	4.2
Oxygen (cm.^{3}/l.)									
Surface	—	—	—	—	10.0	8.4	10.3	10.6	—
15 m.	9.8	—	8.7	—	10.0	9.4	10.3	10.7	10.8
Bottom	9.8	—	9.2	—	10.4	9.4	10.4	10.9	10.9
Secchi disc (m.)	—	—	—	—	—	19.0	20.3	16.7	18.0

An unnamed river, carrying melt-water from the Penny Ice-Cap, pours a large amount of silt into the northeastern corner of the lake. The following Secchi disc readings, taken in a 2 week period in August, show the extent of the silt in the lake.

Three miles south of the river from the ice-cap .... 1.1 m.
Ten miles southwest of the above river .... 5.0 m.
Station D .... 19.0 m.
Station E .... 19.7 m.
Mirage Bay .... 17.0 m.

Most of the silt settled out within 15 to 20 mi. of the river mouth. In the rest of the lake, which has the greater proportion of the water volume, the Secchi disc readings are 13 m. or more, often 20 m. Such clear water and deep light penetration is characteristic of large oligotrophic lakes.

Mineral analyses

The analyses of 7 samples of surface water, taken at various parts of the lake between August 21 and September 7, showed that Nettilling Lake has a low mineral content. The samples were analyzed 2 to 3 months after collection by the chemistry department, University of Saskatchewan. The mineral content of the samples ranged from 28 p.p.m. to 42 p.p.m. total solids, except for one sample (11 p.p.m.) taken 10 mi. southwest of the inlet of the river from the Penny Ice-Cap. The western region has a greater amount of

Table 5. Physical and chemical observations at stations D and E, Nettilling Lake, 1956.

	Station D					*Station E*		
	June 22	*July 20*	*Aug. 13*	*Aug. 28*	*Sep. 7*	*Aug. 13*	*Aug. 28*	*Sep. 7*
Temperature °C.								
Air	—	9.1	6.7	7.0	3.5	7.5	6.5	3.8
Surface	—	—	3.1	4.6	4.8	2.4	3.4	3.7
10 m.	0.4	1.7	2.9	4.4	4.7	2.2	3.3	3.4
20 m.	0.4	1.6	2.8	4.3	4.6	2.2	3.3	3.4
30 m.	0.8	1.7	2.8	4.3	4.2	2.2	3.3	3.4
39 m.	1.0	1.9	2.9	4.3	4.2	—	—	—
40 m.	—	—	—	—	—	—	3.2	3.4
46 m.	—	—	—	—	—	2.2	3.2	3.4
Oxygen ($cm.^3/l.$)								
Surface	—	8.9	11.0	10.7	10.3	—	—	9.9
20 m.	10.8	9.8	10.8	11.0	10.5	10.4	11.4	10.6
Bottom	7.8	10.1	10.9	11.9	10.5	10.4	11.4	10.6
Secchi disc (m.)	—	—	20.5	19.0	13.0	21.3	19.7	19.5

total solids (31 to 42 p.p.m.) than the eastern region (11 to 41 p.p.m.). The difference between the amount of minerals in the western and eastern region is attributed to the inflow of the Amadjuak River into the western region. This river drains Ordovician areas, whereas the rivers entering the eastern region drain Precambrian areas. A similar variation between west and east regions correlated with geology is exhibited in Great Slave Lake (Rawson 1950).

The detailed analyses of 3 samples taken in the western region near Magnetic and Caribou Points, is as follows. The figures represent mean values of the 3 samples.

	p.p.m.		*p.p.m.*
Total solids (105°)	37	Silica (SiO_2)	4.2
Total solids (180°)	34	Iron (Fe)	nil
Carbonates (CO_3)	nil	Manganese (Mn)	nil
Bicarbonates (HCO_3)	40.2	Calcium (Ca)	1.6
Chlorides (Cl)	1.4	Magnesium (Mg)	1.4
Sulphates (SO_4)	4.4	Sodium (Na)	16.7 (by diff.)
Nitrates (NO_3)	0.13		

The small amount of minerals present in the water is thus composed mainly of sodium and bicarbonates. This scarcity of minerals is considered as an indication of low productive capacity. Northcote and Larkin (1956) found there was a better correlation of productivity with total solids than with any other single factor. Rawson (1958) also emphasizes this correlation.

Fish

Three species of fish occur in Nettilling Lake: arctic char, *Salvelinus alpinus* Linn.; threespine stickleback, *Gasterosteus aculeatus* Linn.; and ninespine stickleback, *Pungitius pungitius* Linn. The arctic char and the ninespine stickleback are found throughout the lake. Ninespine sticklebacks are also common in small ponds around the edge of Nettilling Lake. The threespine stickleback appears to have a restricted distribution, and it was collected only from the southeast region of the lake near Tundra Point. This is the northernmost record for this species in eastern Canada.

Thomson (1957) considered the Nettilling Lake char to be a mixed population of anadromous and landlocked fish. Considered as a single population, Thomson found the char to have a lower growth rate and to spawn at an earlier age than other populations of arctic char previously studied. Ninety-six per cent of the food of the char was insect material and most of this was chironomid pupae.

Bottom fauna

Dredgings were taken with small Ekman and Petersen dredges. The samples were not quantitative. Much of the bottom of Nettilling Lake is hard or has a large amount of broken rock and as a result the dredges were often held open. Even when the dredges closed a considerable amount of sediment was lost by leakage.

The total number of dredgings taken was 259. These were distributed throughout the lake. Although not quantitative the samples give some idea of the composition of the macrobenthos. Chironomid larvae made up over 95 per cent of the total macrobenthos. Of the remaining the most important groups were oligochaetes and nematodes. The following were occasionally taken in the samples: lamellibranchs (*Pisidium lilljeborge* Clessin, and *P. casertanum* (Poli) (Herrington 1961); ostracods; caddisfly larvae; amphipods (*Gammarus lacustris* Sars); and water mites (*Acalptonotus violaceus* Walter, *Lebertia* sp., *Neobrachypoda ekmani* (Walter), and *Hygrobates foreli* (Lebert)). Amphipods and lamellibranchs were taken in only two areas of the lake; in Burwash Bay and in the area immediately east of Magnetic Point.

A significant feature of the composition of the bottom fauna of Nettilling Lake is the predominance of chironomid larvae and the paucity of other groups such as amphipods and mollusks. In large oligotrophic lakes on the mainland (Great Slave Lake, Lake Athabaska, Reindeer Lake and Hunter Bay, the oligotrophic part of Lac La Ronge), amphipods occur in much larger numbers and often outnumber the chironomid larvae (Rawson 1953b, 1960; Oliver 1960). *Pontoporeia affinis,* the commonest amphipod in the deeper zones of these lakes, is absent from Nettilling Lake.

The determination of the chironomid larvae to species is not complete but a few general observations can be made. Orthocladiinae predominated, with smaller numbers of Tanypodinae and Chironominae. The proportion of Chironominae increased in the northeast region of the lake where the silt content of the water was the highest. The following species were reared; *Pseudodiamesa arctica* (Mall.), *Heterotrissocladius subpilosus* Kieff. and *Cricotopus alpicola* (Zett.). *H. subpilosus* was one of the commonest larvae found in the dredgings.

In early August immense swarms of chironomids were observed on Tundra Point. This point is less than 100 yards wide, extending a quarter of a mile or more out into the lake and has no water on it. It is probable that most of the chironomids found swarming over the point congregated there after emerging from the lake. The following is a list of the species found in the swarms.

Protanypus? caudatus Edw.
Cricotopus alpicola (Zett.)
Orthocladius consobrinus (Holmgr.)
Psectrocladius calcaratus Edw.
Parakiefferiella nigra Brund.
Trissocladius sp.
Chironomus (s.s.) sp.
Stictochironomus rosenscholdi (Zett.)
Micropsectra natvigi Goetgh.
Sergentia coracina Kieff.
Lauterbornia coracina Kieff.
Oeklandia borealis Kieff.
Procladius sp.

By the time Nettilling Lake is completely free of ice, the warmest part of the summer is over and the chironomids emerging often meet with unfavourable climatic conditions. The length of time for mating and egg-laying is very short. It appears that a number of species, especially the predominant species (*Heterotrissocladius subpilosus, Cricotopus alpicola* and *Pseudodiamesa arctica)* compensate for this short time of aerial activity by being prepared to emerge soon after the ice above them disappears. The outstanding example of this was the emergence of a female of *Pseudodiamesa arctica* on May 29, from a hole made in the ice in an area which did not become free of ice until several months later (Oliver 1959). Soon after lead formation began in July, chironomids emerged in large numbers from the narrow strip of open water around the periphery of the lake. Chironomid larvae in the prepupal stage, and pupae, were taken in dredgings through the ice. Evidence is insufficient but the development of the prepupal and pupal stages appears to be correlated with the warming of the water under the ice. A few larvae in the prepupal stage were taken in the earliest dredgings, suggesting that they may have overwintered as prepupal larvae. However, the number of prepupal larvae increased in July when the temperature of the water increased. Mature pupae of *H. subpilosus, C. alpicola,* and *P. arctica* were taken in the dredgings in the last half of July. The pupae of *P. arctica* and *H. subpilosus* were able to make their way upward through small cracks in the ice to the surface (Oliver 1959). Although many pupae do not reach the surface, this adaptation insures in years when the ice cover persists longer than normal that at least a few imagos are able to emerge.

The nature of the mechanisms that trigger the emergence once the ice clears away has not been investigated, but light and increase in water temperature must be involved. In the shallower regions of the lake light may be more important than water temperature, and the reverse is probably true in the deeper regions where light does not reach the bottom. It would be interesting to find out if the emergence from shallower regions, where the effect of light increase is immediate, begins sooner after the ice disappears than in the deeper regions. Rise in water temperature will be also quicker in the shallow regions. In the deeper regions the increase in water temperature will not be immediate.

Plankton

The plankton samples have been deposited at the Department of Biology, University of Saskatchewan. The following is a list of the plankton Crustacea of Nettilling Lake (E. R. Reed, personal communication).

Diaptomus minutus Lilljeborg	*Daphnia rosea* (Sars)
Cyclops scutifer Sars	*Bosmina longirostris* (O. F. Muller)
Cyclops capillatus Sars	*Chydorus sphaericus* (O. F. Muller)
Cyclops languidoides Lilljeborg	*Helopedium gibberum* Zaddach
Daphnia longiremis (Sars)	*Alonella nana* (Baird)

The freshwater Crustacea of Nettilling Lake consist of common species with *Cyclops scutifer, Diaptomus minutus* and *Daphnia longiremus* predominant.

Discussion

Most of the lakes previously investigated in the arctic have been small and relatively shallow. Nevertheless, despite the morphological differences, they share certain physical and environmental characteristics with Nettilling Lake. Water temperatures are low, except in the extremely shallow lakes, and thermocline formation is rare. Located in the high latitudes, they are subject to severe seasonal variation in insolation. They receive only a small supply of heat and have a short vegetation period in comparison with lakes in lower latitudes. Often in the spring, when the insolation is highest, snow cover on the ice reduces the total light-income. The light-income reaches significant amounts only when the snow has crystalized or melted off the ice. The warming of open lakes is through a range in which the density change is slight, and only moderate winds are required to mix the warmed surface water into the depths. This transport is facilitated by the absence of a thermocline.

Winds play a large role in determining the thermal conditions in arctic lakes. The few published records (e.g. Comita and Edmondson 1953, Brewer 1958) of the temperature of water under ice in arctic lakes indicates that the bottom temperatures are often considerably below 4°C. The bottom temperatures of the water in Nettilling Lake under ice were also below 4°C. If Nettilling Lake froze undisturbed by wind, the bottom temperatures would be expected to be near or at 4°C. It is apparent that wind action delays the formation of an ice cover and at the same time mixes the colder surface water with the underlying warm water prior to freeze-up in arctic lakes. Wind is also responsible for the ultimate destruction of the ice cover after it has been weakened by melting. It is very unlikely that insolation alone is sufficient to remove the ice from large arctic lakes. There are a number of records in arctic literature of ice persisting on lakes throughout the summer, e.g., Lake Hazen (Deane, 1959) and Yathkyed Lake (Rasmussen 1927). Wind speeds are very low throughout the year at Lake Hazen (Jackson 1959), which is probably the reason why ice may persist in some summers. Nettilling Lake lies in a region where high wind speeds are common, and it probably becomes ice-free every year.

The division of Nettilling Lake into two morphological regions is a direct result of its position across the boundary of the Precambrian Shield. Lac la Ronge and Great Slave Lake also situated on this boundary, similarly have two regions (Rawson and Atton 1953, Rawson 1950). The two regions of Nettilling Lake, western and eastern, differ not only in configuration of the basin and in the number of islands, but in several other important ways. The eastern region is slightly warmer than the western. By the Hutchinson and Loffler (1956) system of thermal classification, these regions are subpolar dimictic and cold monomictic, respectively. Furthermore, the northeastern area of the lake, has much suspended material, often a characteristic of lakes adjacent to glaciers. The effect of the suspended material on the transparency of the water and on the bottom sediments is detectable throughout most of the eastern region, but not in the western region. Thus we have, within the confines of a single lake, the transition from a clear water, ultra-oligotrophic condition to water murky with suspended particles. We also have a transition from a body of water not rising above 4°C. to one that rises above 4°C.

The surface water temperature of the western region was only 0.3°C. below 4°C. and it is not inconceivable that the overall temperature of this region may rise above 4°C. Since the eastern region is broken up by islands and the water contains considerable quantities of suspended silt, which increases heat absorption, this region probably will be always the warmer. Therefore, if the temperature of the western region rose above 4°C. the lake as a whole would be classified as dimictic. Yearly variation about 4°C. has been observed in Lake Schrader in Alaska (Hobbie 1961). It was dimictic in 1958 and monomictic in 1959.

In cold homothermic lakes such as Nettilling Lake, the fact that the temperature of part of the lake is above the temperature of maximum density and part of it remains just below it is surely unimportant in relation to the amount of exchange between surface and bottom waters. During the open season the density gradient is so small that the mixing of water from top to bottom can be initiated by low wind speeds, and the mixing is probably continuous. Therefore the terms monomictic and dimictic, when applied to such conditions, are confusing. What is important is that thermocline formation does not take place, and mixing of the water is possible at all times.

The restricted limits of the threespine stickleback, the amphipod, and the lamellibranchs in the lake warrant further investigation. The present investigation was not sufficiently detailed to determine the probable physical and chemical factors that are responsible for these restricted distributions. The areas in which these groups occur are close to the mouths of rivers, which may have some influence, such as altering the chemical conditions. Early opening of these areas is caused by the rivers. This results in longer ice-free conditions, which may be particularly important for the invertebrates. But there are other areas in the lake adjacent to river mouths, which open just as early and from which these organisms are absent, so that longer ice-free periods cannot be the only factor.

Acknowledgements

Grateful acknowledgement is made to the Arctic Institute of North America for a Banting Fund Grant that made the field work possible. Financial assistance was also received from the National Research Council of Canada and McGill University. I thank Mr. J. A. C. Thomson for his companionship and assistance during the field work. Dr. E. B. Reed, Colorado State University, kindly identified the plankton crustacea, Dr. H. Habeeb, Grand Falls, N.B., the Hydracarina, and Dr. E. L. Bousefield, National Museum of Canada, the amphipod. Dr. J. R. Vockeroth and Mr. J. A. Downes have very kindly read and criticized the manuscript.

References

Andersen, F. S. 1946. East Greenland lakes as habitats for chironomid larvae. Studies on the systematics and biology of Chironomidae. II. Medd. om Grønl. 100:1-65.

Anderson, M. B. A. 1930. Hantzsch's crossing of Baffin Island. (Trans. from article by M. Rosenmüller in Mitt. Ver. Erdk. Dresden, 2:676-716, 1913). Dept. Interior, N. W. T. and Yukon Br.

Brewer, M. 1958. The thermal regime of an arctic lake. Trans. Am. Geophys. Union 39:278-84.

Comita, G. W. and W. T. Edmondson. 1953. Some aspects of the limnology of an arctic lake. Stanford Univ. Publ., Univ. Ser. Biol. Sci. 11:7-13.

Deane, R. E. 1958. Pleistocene geology and limnology. (*In* Operation Hazen, Narrative and Preliminary Reports for the 1957 Season, Preliminary Scientific Reports, Geology). Defence Research Board, Ottawa; Rept. D. Phys. R. (G) Hazen 2:19-23.

——————1959. Pleistocene geology and limnology (*In* Operation Hazen, Narrative and Preliminary Reports 1957-58, Geology and Geomorphology). Defence Research Board, Ottawa; Report D. Phys. R. (G) Hazen 4:61-3.

Frey, D. G. and J. B. Stahl. 1958. Measurements of primary production on Southampton Island in the Canadian arctic. Limnol. Oceanogr. 3:215-21.

Herrington, H. B. 1961. Mollusks of Astray Lake, Labrador, and Lac Aigneau, Ungava. Ann. Rept. Am. Malacolog. Union, pp. 9-10.

Hobbie, J. E. 1961. Summer temperatures in Lake Schrader, Alaska. Limnol. Oceanogr. 6.326-9.

Hutchinson, G. E. and H. Löffler. 1956. The thermal classification of lakes. Proc. Nat. Acad. Sci. 42:84-6.

Jackson, C. I. 1959. The meteorology of Lake Hazen, N.W.T., I. Analysis of the observations. Defence Research Board, Ottawa; Rept. D. Phys. R. (G) Hazen 8:1-194.

Johansen, F. 1911. Freshwater life in northeast Greenland. Medd. om. Grønl. 45:321-37.

Livingstone, D. A., K. Byran and R. G. Leahy. 1958. Effects of an arctic environment on the origin and development of freshwater lakes. Limnol. Oceanogr. 3:192-214.

Manning, T. H. 1943. The Foxe Basin Coasts of Baffin Island. Geogr. J. 101:225-51.

McLaren, I. A. 1959. Aquatic biology. (*In* Operation Hazen, Narrative and Preliminary Reports 1957-58, Biology and Archaeology). Defence Research Board, Ottawa; Report D. Phys. R. (G) Hazen 4:70-3.

Millward, A. R. 1930. Southern Baffin Island. An Account of exploration, investigation and settlement during the past fifty years. Dept. Interior, N.W.T. and Yukon Br., pp. 1-130.

Northcote, T. G. and P. A. Larkin. 1956. Indices of productivity in British Columbia Lakes. J. Fish. Res. Bd. Can. 13:515-40.

Porter, L. C. 1943. Light transmission through snow. Polar Record 4:81.

Oliver, D. R. 1959. Some Diamesini (Chironomidae) from the Nearctic and Palearctic. Ent. Tidskr. 80:48-64.

——————1960. The macroscopic bottom fauna of Lac La Ronge, Saskatchewan. J. Fish. Res. Bd. Can. 17:607-24.

Rasmussen, K. 1927. Across Arctic America. New York: Putnam's Sons, pp. 1-388.

Rawson, D. S. 1950. The physical limnology of Great Slave Lake. J. Fish. Res. Bd. Can. 8:1-66.

——————1953a. Limnology in the North American arctic and subarctic. Arctic 6:206-14.

——————1953b. The bottom fauna of Great Slave Lake. J. Fish. Res. Bd. Can. 10:486-520.

——————1958. Indices to lake productivity and their significance in predicting conditions in reservoirs and lakes with disturbed water levels. (*In* H. R. MacMillan Lectures in Fisheries, ed. P. A. Larkin). Univ. B. C., pp. 27-42.

——————1960. A limnological comparison of twelve large lakes in Northern Saskatchewan. Limnol. Oceanogr. 5:195-211.

Rawson, D. S. and F. M. Atton. 1953. Biological investigation and fisheries management at Lac La Ronge. Sask. Dept. Nat. Res. (Fish. Br.), pp. 1-39.

Soper, J. D. 1928. A faunal investigation of Southern Baffin Island. Bull. Natl. Mus. Can. 53:1-143.

Thomson, J. A. C. 1957. On the biology of the arctic char, *Salvelinus alpinus* (L.) of Nettilling Lake, Baffin Island, N.W.T. Unpub. M.Sc. Thesis, McGill Univ., pp. 1-95.

Trolle, A. 1913. Hydrographical observations from the Denmark expedition. Medd. om Grønl. 41:271-426.