region seem surprisingly small for so great a lapse of time. Apparently molluscs have the slowest rate of change and insects the most rapid; the mammals perhaps being modified almost equally rapidly.

While no older Pleistocene deposits are known from Ontario there is reason to believe that the Aftonian beds of Iowa are more ancient, since they occur between the Nebraskan and Kansan boulder clays and occupy the first of four interglacial intervals recognized in that state. If the Toronto formation comes about half way down in the Pleistocene, as seems probable, the Aftonian must be some hundreds of thousands of years older and its flora and fauna should be correspondingly more ancient in character. Among plants, pine, tamarack, oak, elm, ash, walnut, hickory, and sumac are reported, but unfortunately the species seem undetermined, so that one cannot be sure as to whether they are of still living forms or not. It may be observed that all of the genera except the walnut and the sumac are represented in the Toronto formation.

Among animals only mammals have been found, and these have been determined mostly from isolated bones, jaws, and tusks; though the remains are more complete than those found at Toronto. Calvin describes and figures remains of two or three species of horses, a camel, two ground sloths, cervalces, two mammoths, and one mastodon.[1] All the mammals are extinct and have left no North American descendants, unless cervalces is an ancestor of the moose.

It will be recalled that cervalces and either mammoth or mastodon occur in the Toronto formation, but that the other mammals may be of still living species. The number of extinct species of mammals is greatly increased in the older interglacial formation.

[1]Aftonian Mammalian Fauna, Bull. Geol. Soc. Am., Vol. 20, pp. 341-356.

UNIVERSITY OF TORONTO STUDIES

PUBLICATIONS OF THE
ONTARIO FISHERIES RESEARCH LABORATORY
No. 11

THE LIMNOLOGY OF LAKE NIPIGON

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1923

THE LIMNOLOGY OF LAKE NIPIGON

During the months of June, July and August, 1921, an intensive limnobiological investigation of Lake Nipigon was commenced by a field party from the Ontario Fisheries Research Laboratory, of the Department of Biology, University of Toronto, under the direction of the writer. The purpose of the investigation was to carry out a thorough study of the biological and environmental factors, with special reference to the fish fauna and its economic and conservational aspects. Lake Nipigon was selected for investigation because of its isolation for a long period of time from the Great Lakes and, as far as known, from any other drainage system. As a result, natural conditions have been undisturbed either in the drainage basin or in the lake itself, except by reason of the opening of the lake to restricted commercial fishing in recent years. In 1916, the Department of Game and Fisheries of the Province of Ontario opened the lake under supervision to commercial fishing for the purpose of augmenting the food supply during the war, and have continued the policy with some modifications to the present time. Statistics are available for only four years, 1916-1919, but during that time the following amounts of fish were removed: whitefish 2,511,614 lbs., lake trout 1,059,632 lbs., pike perch 51,431 lbs., sturgeon 21,810 lbs., other species, chiefly pike, ciscoes and northern suckers, 57,694 lbs. In 1920, the following plants were made: whitefish 8,943,000 fry, lake trout 734,000 fry, and 240 parent black bass. It seemed desirable therefore to determine the conditions existing in a lake before the effects of such disturbances of natural conditions had become pronounced. An opportunity was thus afforded of studying the effects of commercial fishing in a circumscribed body of water and of developing working plans for the best utilization of the productive possibilities of such a body.

In view of the above considerations, the investigation during the first season followed three main lines:—

(1) the identification of the species of fish, their distribution, relative abundance, natural history, food and rates of growth;

(2) qualitative and quantitative studies of the food organisms, confined largely to the plankton and the bottom fauna;

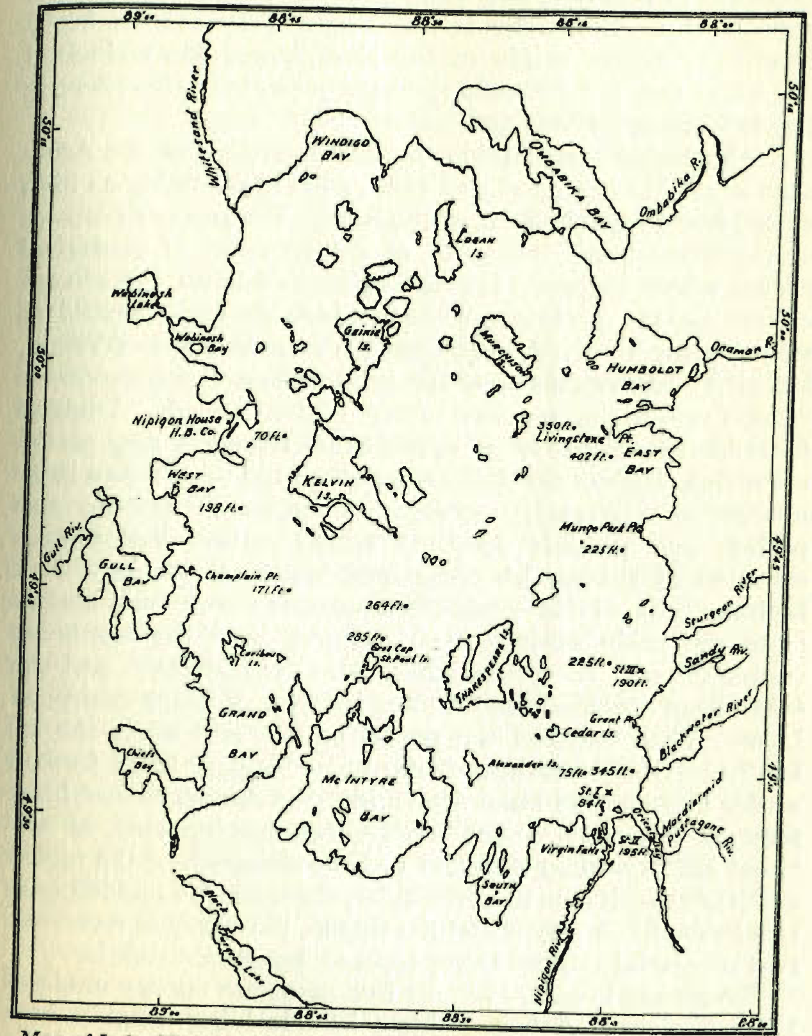
(3) a study of the physical features, particularly temperatures, dissolved oxygen and carbon dioxide, colour and transparency, and the significance of these factors in respect of the biology of the lake.

Some of the results obtained are presented in more or less preliminary form in this and the following five papers.

Lake Nipigon, the largest of the many inland bodies of water in Ontario, is situated in the northwestern portion of the province about 50 miles north of Lake Superior. It lies approximately between 87°35′ and 89°10′ west longitude and between 49°5′ and 50°30′ north latitude. The area as given by Wilson (1910) is 1769 square miles, of which about 1530 square miles is water surface, leaving an island area of about 239 square miles. The lake is roughly quadrangular in form, about 50 miles long and 30 miles wide, but very irregular in outline with numerous bays of various sizes and contours. The shore line is characterized by rocky projections and headlands alternating with indentations. The latter, when open and exposed, are rocky or sandy, but where extended and protected, tend to become muddy with an approach to marshy conditions. The length of the coast line exclusive of smaller bays and coves is over 580 miles (Bell, 1870). The islands are numerous, particularly in the northwestern portion, and range in size from small rocky projections to large wooded areas. The elevation of the water surface is 852 feet above sea level (White, 1915).

The drainage basin comprising about 6,000 sq. mi. is fairly well covered with tree growth consisting chiefly of balsam, spruce, poplar and birch, with a scattering of red pine, jack-

pine, tamarack, cedar and alder, and the major portion is included in the Nipigon Forest Reserve. Numerous catchment basins, ranging in size from small ponds to large lakes, are scattered throughout the basin and drain into Lake



Map of Lake Nipigon showing depths and the location of the three stations for the taking of plankton, temperatures and water samples.

Nipigon by a large number of streams. There is, on the other hand, but one outlet, the Nipigon River, by which the drainage is carried southward into Lake Superior, through a descent of 250 feet, over a series of rapids and falls. The uppermost of the latter is the Virgin Falls (35 ft. high) practically at the origin of the river, where the estimated low water flow is 5.500 cubic feet per second (Hydro Electric Power Comm. Report, 1907).

The region surrounding the lake is typical of the Archaean area. It is rugged and hilly, with bluffs rising as high as 600 feet above the level of the lake. The present features of the district are the result of a long series of geological events whose sequence appears to be as follows. A trough existed on the Archaean surface which during a period of submergence received large deposits of sediments. (Wilson, loc. cit.) Elevation above sea level followed with extensive erosion uncovering portions of the original trough. Diabase flows later invaded the area, but in a succeeding long period of erosion much of the diabase was removed as well as a large amount of the early sedimentary deposits. During this period, and possibly to some extent earlier, disturbances occurred in the earth's crust resulting in elevations, block faulting, etc. It is probable that there were two outlets from the basin during this time, one from the southeast corner through the Pijitawabic canon (Orient Bay) and the other from the southwest corner by way of Black Sturgeon Lake. Then followed the glacial period, and when the ice finally retreated northward, the Lake Nipigon basin formed a very large bay of Lake Algonquin, the predecessor of Lake Superior (Coleman, 1922). With the development of the Great Lakes drainage system and the elevation of the region north of what is now Lake Superior, the modern Lake Nipigon was formed. A new outlet developed, the Nipigon river, the two preglacial outlets being blocked by glacial debris.

There has been as yet no hydrographic survey made of Lake Nipigon. A line of large islands lying roughly in a north to south direction divides the lake more or less into east and west portions. The eastern portion contains the deeper water which lies well over towards the eastern shore. Soundings taken in the course of dredging and limnological operations gave the following depths:—

195 feet Pijitawabic Bay, opposite Macdiarmid village.
345 feet off mouth Blackwater river.
225 feet off mouth Sandy river.
225 feet off Mungo Park Point.
402 feet was recorded by McInnes (1894) two and a half miles south of Livingstone Point. This is probably the greatest depth in the lake.

In the western portion the following records were obtained:—

198 feet west of Kelvin island.
171 feet east of Champlain Point.
264 feet northeast of Grand Cape.
285 feet was recorded by McInnes just north of St. Paul island.

It is thus evident that there is a very large body of deep water in Lake Nipigon and that the amount of shallow water is limited. The open shores are rocky or sandy and because of the size of the lake, subject to strong wave action. It is only in the deep, protected bays and shallow areas among the islands where conditions are such as to permit the growth of the larger aquatic vegetation with the accompanying abundance of animal life.

Because of the great extent of Lake Nipigon, the first season's investigations were confined largely to the southeastern portion. Three stations were established for the taking of temperature records, water samples and plankton. Station 1 was located in comparatively shallow water (depth of 28 yards) off the mouth of the Nipigon river; station 2 in the deepest water (depth of 63 yards) of Pijitawabik bay (Orient Bay) directly opposite the village of Macdiarmid; station 3 in the open water off Sandy river (depth of 63 yards). One series was obtained on August 29 off the mouth of the Blackwater river (depth of 100 yards).

The temperature records were obtained with a standardized Negretti-Zambra deep-sea reversing thermometer. Water samples were taken immediately after the temperature records with a modified Kemmerer water bottle (Birge, 1922). The water samples were put in 250cc. glass-stoppered bottles, packed in broken ice and taken to the laboratory where the analyses were carried out. The oxygen content was determined by a modification of Miller's method (Provincial Board of Health of Ontario, 1920). For the carbon dioxide determinations N/22 sodium carbonate with phenolphthalein as indicator was used (Prov. Board of Health, loc. cit.).* The temperature records and the results of the analyses are given in Tables 1, 2 and 3, and from this data Figs. 1 to 6 have been constructed.

Since no record of the temperature of the deepest water was obtained in this season it has been assumed, on the basis of the results obtained at the three stations, that the temperature was 4.0°C. Fig. 3 may be taken as a fairly accurate record of events. From June 17 to July 9 the surface waters were gradually acquiring heat and the thermocline was slowly increasing in thickness (Table 4). No record for late July was obtained for Station 3, but judging from the record for Station 2 on July 26, by the end of July the epilimnion had doubled in thickness and the thermocline therefore had shifted downward.

During the morning of July 30 a wind of considerable violence came up accompanied by some rainfall. The wind blew first from the southwest and gradually shifted to northwest reaching its maximum velocity about 2 p.m. No meteorological records are available for the Nipigon region, but judging from records obtained at various stations in Northern Ontario, it is probable that the wind attained a velocity at times of about 35 miles an hour. Captains on the fishing tugs stated that this was the worst mid-summer storm they had experienced on this lake. The temperature records on August 2 show the effects of the storm. The thermocline in the open part of the lake was obliterated. Apparently the three strata were set in motion and some of

*All the solutions were prepared by Mr. George W. Lucas of the Department of Chemistry, University of Toronto, and the Provincial Board of Health.

TABLE 1

STATION 1

Depth in yards	June 13				July 23				August 18			
	Temp. C.	Ox.	% Sat.	CO_2	Temp. C.	Ox.	% Sat.	CO_2	Temp. C.	Ox.	% Sat.	CO_2
Surface	8.3	7.8	94		19.4	5.8	87	1.4	16.2	6.2	88	1.7
1	7.1			1.7	19.4							
2	6.8				19.2							
3	6.7											
5					19.2	5.8	87	0.6	16.0			
6	6.4	7.8	89	1.6								
9	5.8											
10					18.7	6.0	89	0.9	15.9			
11	5.8	8.0	90	1.1								
13	5.7				14.2							
15					11.5	7.4	95	1.0	15.8	6.4	90	1.1
16	5.6	7.8	88	1.1								
20					6.7	7.7	89	1.1	11.3	6.7	86	2.0
21	5.5	7.9	88									
25									7.0			
26	5.4	8.0	89	0.0								
28					4.8	7.7	85	1.4	6.5	7.1	82	2.2

TABLE 2

STATION 2

Depth in yards	June 14				June 28				July 8			
	Temp. C.	Ox.	% Sat.	CO_2	Temp. C.	Ox.	% Sat.	CO_2	Temp. C.	Ox.	% Sat.	CO_2
Surface	9.4.	7.7	95	none	17.4	6.2	90	1.1	20.2	6.55	100	0.9
1					15.5							
2					12.9							
3												
4					12.4							
5	8.2	8.0	96		12.4	6.9	91	0.6	11.4	7.00	90	0.9
8									9.3	7.65	94	1.1
10	7.1	7.9	92		10.4	6.9	87	0.6	7.2			
15	6.8				9.0	7.8	95	0.8	6.4	7.70	88	1.1
20	6.5	8.1	93		7.2	7.8	91	1.1	5.8			
25	5.4	8.3	93		6.4				5.4	7.85	88	1.1
30	5.1				5.6	7.7	87	1.1				
35									4.8			
40	4.9				5.1	7.8	87	1.1				
45	4.8								4.5			
50		8.0	88		4.6	7.9	87	1.1				
55									4.3			
60										7.80	85	1.1
63					4.0	8.0	86	0.8				
65									4.2			

TABLE 2 (*continued*)

STATION 2

Depth in yards	July 26				August 1				August 17			
	Temp. C.	Ox.	% Sat.	CO_2	Temp. C.	Ox.	% Sat.	CO_2	Temp. C.	Ox.	% Sat.	CO_2
Surface	20.1	5.80	89	1.4	17.7	5.90	86	0.9	17.2	6.00	87	1.4
1												
2												
3									16.1			
4												
5	19.9	5.75	87	0.9	17.7				15.7			
8	19.1	6.00	90	1.1								
10	12.9				17.6				15.4			
15	8.0	6.05	72	1.1	17.2	5.95	86	1.1	15.0	6.15	85	1.4
20	6.8				10.3	7.00	88	1.1	11.0	6.50	83	1.7
25	6.0				8.6	7.40	90	1.7	7.4	6.85	75	1.1
30	5.6	7.75	87	1.7	7.6				6.4			
35												
40	5.0				6.3	7.50	89	1.7	5.8			
45												
50	4.8				5.6				5.6			
55	4.6	7.85	86	1.9								
60									5.4	7.15	80	1.7
63					4.8	7.60	84	2.2				
65												

TABLE 3

STATION 3

Depth in yards	June 17	June 23				July 9				August 2			
	Temp. C.	Temp. C.	Ox.	% Sat.	CO_2	Temp.C.	Ox.	% Sat.	CO_2	Temp.C.	Ox.	% Sat.	CO_2
Surface	12.5	14.9	7.7	106	1.4	22.0	6.3	99	1.2	16.2	6.3	89	1.1
5	8.5	13.4	7.8	104	1.1	16.6	6.4	91	1.1	15.9			
8						11.3							
10	7.7	8.2	7.9	94	1.7	9.3	7.3	90	1.1	15.8	6.4	90	1.1
15	7.4	7.1				6.7				15.0			
18													
20	6.0	5.8	7.9	89	1.1	6.2	7.6	87	1.7	13.0	6.6	88	1.1
25	5.2	5.2								11.8	6.9	90	1.1
30	5.0		8.0	88	1.7	4.9	7.6	84	1.4	8.8	7.0	85	1.1
40	4.8		7.9	87	1.7	4.3				6.5			
45						4.2	7.7	84	1.4				
50										5.1			
53	4.0												
60													
63										4.6	7.65	84	2.2
80													
90													
100													

STATION 3 *(continued)*

Depth in yards	August 29†			
	Temp. C.	Ox.	% Sat.	CO_2
Surface	17.1	6.05	87	1.1
5	16.8			
8				
10	15.9			
15	15.2	7.00	97	1.1
18	9.0			
20	8.0	6.25	74	1.1
25	6.7			
30	6.3			
40	5.7			
45				
50				
53				
60	5.2			
63				
80	4.9			
90	4.5	6.40	70	1.6
100	4.2	5.70	62	2.2

†Off mouth Blackwater river.

TABLE 4

STATION 2

	July 8, 1921		July 26		August 1		August 17	
	Depth m.	Temp. C.	Depth m.	Temp. C.	Depth m.	Temp. C.	Depth m.	Temp. C.
Epilimnion	0.0- 1.0	20.2-19.9	0-5	20.5-19.5	0-11	17.7-17.1	0-12	17.2-14.0
Thermocline	1.0- 7.0	19.9- 7.2	5-10	19.5- 8.5	11-14	17.1-10.6	12-17	14.0- 8.2
Hypolimnion	7.0-60.0	7.2- 4.2	10-60	8.5- 4.4	14-60	10.6- 4.8	17-60	8.2- 5.3

STATION 3

	June 17		July 9		August 2		August 29	
	Depth m.	Temp. C.	Depth m.	Temp. C.			Depth m.	Temp. C.
Epilimnion	0-3	12.5-11.0	0-2	22-21			0-14	17.1-15.0
Thermocline	3-4	11.0- 9.0	2-8	21-10			14-16	15.0- 9.5
Hypolimnion	4-123.4	9.0- 4.0	8-123.4	10-4			16-123.4	9.5- 4.0

the warm surface waters were carried almost to the bottom of the lake. At Station 2 in the sheltered bay (Fig. 2) the thermocline was not obliterated but was decreased in thickness and pushed downward several metres. We have here a good example of the effect of the wind in distributing heat in a lake. Later on in August typical stratification was again established as shown by the record for August 29.

The records in Figs. 1 and 2 coincide in general with that in Fig. 3 to depths of 30 and 60 metres respectively.

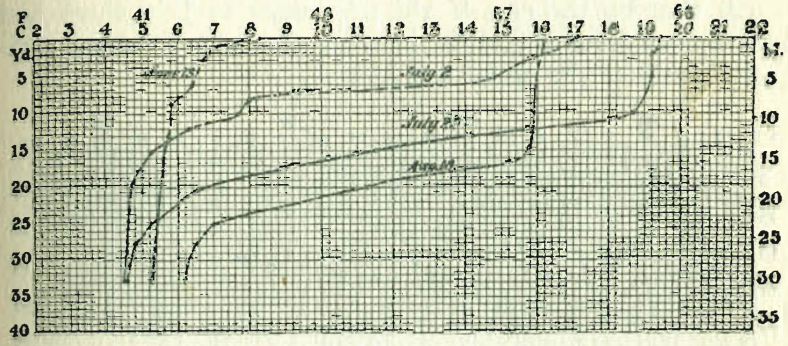


FIG. 1. Curves illustrating temperature records at Station 1, Lake Nipigon.

DISTRIBUTION OF HEAT.

In the absence of an hydrographic survey of Lake Nipigon, it is impossible at the present time to calculate the summer heat income and the work involved in the distribution of the heat on the basis of mean temperature and reduced thickness. Calculations have been made, however, for a column of water one square centimetre in area extending from surface to bottom. These figures are of some interest in indicating the distribution of heat and work for those particular points in the lake but do not furnish very accurate data which may be compared with that calculated for other lakes on the basis of mean temperature and reduced thickness (Birge, 1916).

In Tables 5, 6 and 7 are given, (1) the temperatures at five-metre intervals as taken from Figs. 1, 2 and 3, and (2) the mean temperature for each five-metre stratum. The latter

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June about a third of the ...eason had been gained and that the upper half of the lake, that ...;

of the first week in July there had ...ain in heat by the upper waters, con- ...upper five metres.

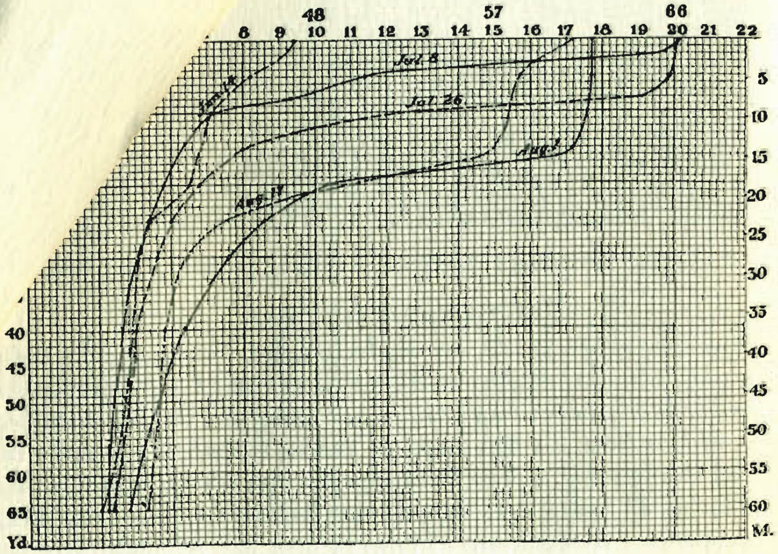

FIG. 2. Curves illustrating temperature records at Station 2, Lake Nipigon.

(3) that by the end of July there had been large gains in heat by the upper 20 metres. Unfortunately no temperature records were obtained in late July in the open waters, but it is doubtful if at the end of July any appreciable amount of heat had penetrated below 60 metres.

(4) that the effect of the storm on July 30 was to dis-

TABLE 5

TEMPERATURES—STATION 1

Depth m.	June 13 Temp. C.	June 13 Av. Temp. per 5-m. l.	July 2 Temp. C.	July 2 Av. Temp. per 5-m. l.	July 23 Temp. C.	July 23 Av. Temp. per 5-m. l.	August 18 Temp. C.	August 18 Av. Temp. per 5-m. l.
0	8.30	7.37	17.1	15.80	19.40	19.27	16.2	16.07
5	6.45	6.12	14.5	10.95	19.15	18.75	15.95	15.92
10	5.80	5.70	7.4	6.25	18.35	14.17	15.9	15.80
15	5.60	5.55	5.1	4.87	10.00	8.05	15.7	12.60
20	5.50	5.45	4.65	4.60	6.1	5.50	9.5	8.05
25	5.40	5.35	4.55	4.52	4.9	4.75	6.6	6.40
30	5.30		4.50		4.6		6.2	

figures have then been used for the calculation of the number of gram calories per square centimetre of surface received by each five-metre stratum above 4°C. using the formula (T−4)×500. These results are given in Tables 8, 9 and 10 and show:

(1) that by the middle of June about a third of the total amount of heat of the season had been gained and that this heat was contained in the upper half of the lake, that is, in the upper 60 metres;

(2) that by the end of the first week in July there had been a considerable gain in heat by the upper waters, confined largely to the upper five metres.

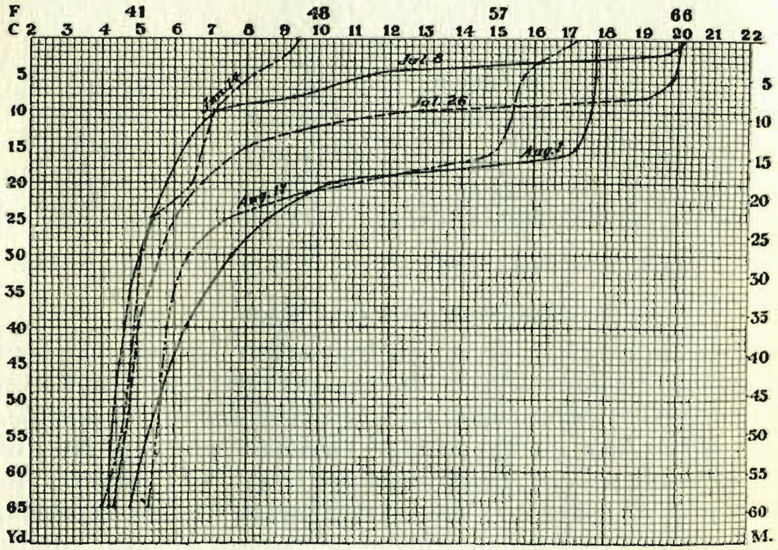

FIG. 2. Curves illustrating temperature records at Station 2, Lake Nipigon.

(3) that by the end of July there had been large gains in heat by the upper 20 metres. Unfortunately no temperature records were obtained in late July in the open waters, but it is doubtful if at the end of July any appreciable amount of heat had penetrated below 60 metres.

(4) that the effect of the storm on July 30 was to dis-

TABLE 5

TEMPERATURES—STATION 1

Depth m.	June 13		July 2		July 23		August 18	
	Temp. C.	Av. Temp. per 5-m. l.	Temp. C.	Av. Temp. per 5-m. l.	Temp. C.	Av. Temp. per 5-m. l.	Temp. C.	Av. Temp. per 5-m. l.
0	8.30		17.1		19.40		16.2	
5	6.45	7.37	14.5	15.80	19.15	19.27	15.95	16.07
10	5.80	6.12	7.4	10.95	18.35	18.75	15.9	15.92
15	5.60	5.70	5.1	6.25	10.00	14.17	15.7	15.80
20	5.50	5.55	4.65	4.87	6.1	8.05	9.5	12.60
25	5.40	5.45	4.55	4.60	4.9	5.50	6.6	8.05
30	5.30	5.35	4.50	4.52	4.6	4.75	6.2	6.40

TABLE 6

TEMPERATURES—STATION 2

	June 14		July 8		July 26		August 1		August 17	
Depth m.	Temp. C.	Av. Temp. per 5-m. l.	Temp. C.	Av. Temp. per 5-m. l.	Temp. C.	Av. Temp. per 5-m. l.	Temp. C.	Av. Temp. per 5-m. l.	Temp. C.	Av. Temp. per 5-m. l.
0	9.4		20.2		20.1		17.7		17.2	
5	8.0	8.70	11.0	15.6	19.9	20.00	17.7	17.70	15.65	16.42
10	7.05	7.52	7.0	9.0	11.4	15.65	17.55	17.62	15.35	15.50
15	6.7	6.87	6.1	6.55	7.6	9.50	16.40	16.97	14.40	14.87
20	6.15	6.42	5.6	5.85	6.45	7.02	9.55	12.97	9.2	11.80
25	5.2	5.67	5.2	5.4	5.80	6.12	8.1	8.82	6.9	8.05
30	5.05	5.12	4.9	5.05	5.40	5.60	7.2	7.6	6.15	6.52
35	4.95	5.00	4.7	4.8	5.15	5.27	6.6	6.9	5.9	6.02
40	4.85	4.90	4.5	4.6	4.95	5.05	6.0	6.3	5.7	5.80
45	4.7	4.77	4.4	4.45	4.80	4.87	5.6	5.8	5.6	5.65
50	4.55	4.62	4.3	4.35	4.65	4.72	5.3	5.45	5.5	5.55
55	4.30	4.42	4.2	4.25	4.50	4.57	5.0	5.15	5.4	5.45
60	4.0	4.15	4.2	4.20	4.30	4.40	4.75	4.87	5.3	5.35

TABLE 7

TEMPERATURES—STATION 3

	June 17		July 9		August 2		August 29	
Depth m.	Temp. C.	Av. Temp. per 5-m. l.	Temp. C.	Av. Temp. per 5-m. l.	Temp. C.	Av. Temp. per 5-m. l.	Temp. C.	Av. Temp. per 5-m. l.
0	12.5		22.0		16.2		17.1	
5	8.4	10.45	15.8	18.9	15.8	16.02	16.75	16.92
10	7.7	8.05	8.7	12.2	15.7	15.77	15.8	16.27
15	7.1	7.4	6.5	7.6	14.4	15.05	12.8	14.30
20	5.6	6.35	6.05	6.27	12.6	13.5	7.4	10.10
25	5.1	5.35	5.3	5.67	10.4	11.5	6.5	6.95
30	4.95	5.02	4.6	4.95	8.15	9.27	6.15	6.32
35	4.8	4.87	4.35	4.47	6.9	7.52	5.8	5.97
40	4.7	4.75	4.2	4.27	5.95	6.42	5.6	5.70
45	4.3	4.5	4.15	4.17	5.2	5.57	5.45	5.52
50	4.0	4.15	4.0	4.07	4.85	5.02	5.35	5.40
55	4.0	4.0	4.0	4.0	4.65	4.75	5.2	5.27
60	4.0	4.0	4.0	4.0	4.6	4.62	5.1	5.15
65	4.0	4.0	4.0	4.0	4.55	4.57	5.0	5.05
70	4.0	4.0	4.0	4.0	4.5	4.52	4.95	4.97
75	4.0	4.0	4.0	4.0	4.45	4.47	4.85	4.90
80	4.0	4.0	4.0	4.0	4.4	4.42	4.75	4.80
85	4.0	4.0	4.0	4.0	4.35	4.37	4.65	4.70
90	4.0	4.0	4.0	4.0	4.3	4.32	4.60	4.62
95	4.0	4.0	4.0	4.0	4.25	4.27	4.55	4.57
100	4.0	4.0	4.0	4.0	4.2	4.22	4.45	4.50
105	4.0	4.0	4.0	4.0	4.2	4.20	4.35	4.40
110	4.0	4.0	4.0	4.0	4.15	4.17	4.25	4.30
115	4.0	4.0	4.0	4.0	4.1	4.12	4.15	4.20
120	4.0	4.0	4.0	4.0	4.05	4.07	4.05	4.10
123.4	4.0	4.0	4.0	4.0	4.0	4.00	4.00	4.00

TABLE 8

CALORIES ABOVE 4° C.—STATION 1

Depth m.	June 13		July 2		July 23		August 18	
0-5	1685		5900		7635		6035	
5-10	1060		3475		7375		5960	
10-15	850		1125		5085		5900	
15-20	775		435		2025		4300	
20-25	725	5095	300	11235	750	22870	2025	24220
25-30	675	675	260	260	375	375	1200	1200
		5770		11495		23245		25420

TABLE 9

CALORIES ABOVE 4° C.—STATION 2

Depth m.	June 14		July 8		July 26		August 1		August 17	
0-5	2350		5800		8000		6850		6210	
5-10	1760		2500		5825		6810		5750	
10-15	1435		1275		2750		6485		5435	
15-20	1210		925		1510		4485		3900	
20-25	835	7590	700	11200	1069	19145	2410	27040	2025	23320
25-30	560		525		800		1800		1260	
30-35	500		400		635		1450		1010	
35-40	450		300		525		1150		900	
40-45	385		225		435		900		825	
45-50	310	2205	175	1625	360	2755	725	6025	775	4770
50-55	210		125		285		575		725	
55-60	75	285	100	225	200	485	435	1010	675	1400
		10080		13050		22385		34075		29490

TABLE 10

CALORIES ABOVE 4° C.—STATION 3

Depth m.	June 17		July 9		August 2		August 29	
0-5	3225		7450		6010		6460	
5-10	2025		4100		5885		6135	
10-15	1700		1800		5525		5150	
15-20	1175		1135		4750		3050	
20-25	675	8800	835	15320	3750	25920	1475	22270
25-30	510		475		2635		1160	
30-35	435		235		1760		985	
35-40	375		135		1210		850	
40-45	250		85		785		760	
45-50	75	1645	35	965	510	6900	700	4455
50-55					375		635	
55-60					310		575	
60-65					285		525	
65-70					260		485	
70-75					235	1465	450	2670
75-80					210		400	
80-85					185		350	
85-90					160		310	
90-95					135		285	
95-100					110	800	250	1595
100-105					100		200	
105-110					85		150	
110-115					60		100	
115-120					35		50	
120-123.4					0	280	0	500
		10445		16285		35365		31490

tribute heat practically to the bottom of the lake. The amount distributed to the deep water is relatively small, however, the great bulk being retained in the upper five metres.

(5) that by the middle of August the lake had begun to

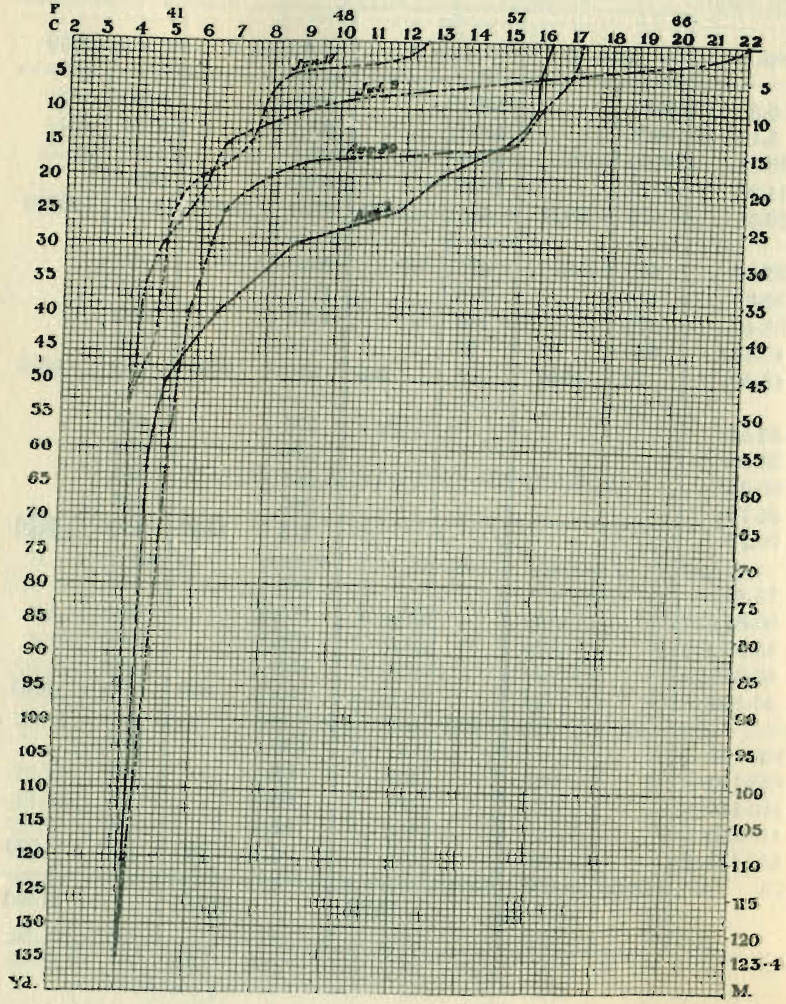

FIG. 3. Curves illustrating temperature records at Station 3, Lake Nipigon.

give up some of its heat. The loss in the upper 25 metres has probably been into the air, while the 25-50 metre area may have contributed of its heat to the underlying waters which apparently continued to gain heat for some days following the storm.

It is probable that the summer heat income for Lake Nipigon in 1921 was in the neighbourhood of 30,000 gram calories per sq. cm. of surface. The mean summer heat income for Cayuga Lake, N.Y., over a period of five years was 29,480 calories (Birge and Juday, 1921), with the maximum in one year of 30,910 calories. The two lakes have approximately the same maximum depth, Cayuga 133 metres, Nipigon 123.4 metres.

Distribution of Heat

The amount of work in gram-centimetres involved in the distribution of the heat contained in a column of water one square centimetre in area has been calculated for each metre stratum using the formula $(I-D) \times CG$, where $(I-D)$ is the loss of density due to warming, C, the depth in centimetres and G, the weight in grams. This is based on the principle stated by Birge (1916), that for the most part, the warming of the water in a lake is done by the transference of warm lighter water from the surface downward through water at its maximum density, by the agency of the wind. This involves an expenditure of work which can be calculated.

The results here given are for each five-metre stratum and the temperatures used in the calculations are the means of the five-metre strata as given in Tables 5, 6 and 7. Further accuracy in this instance did not seem warranted. The results are shown in Tables 11, 12 and 13. The significant points are:—

(1) that from the middle of June to the end of the first week in July practically all of the work was expended in the upper 10 metres and particularly in the upper five metres.

(2) that during July, the work was expended to a greater depth but especially in the 5-10 metre stratum.

TABLE 11

DIRECT WORK—STATION 1

Depth m.	June 13	July 2	July 23	August 18
0-5	13.50	150.00	243.75	156.75
5-10	14.00	144.00	608.00	406.00
10-15	14.95	26.00	490.75	650.00
15-20	18.00	5.40	112.50	490.50
20-25	19.55	3.45	20.70	143.75
25-30	21.00	2.80	7.00	63.00
	101.00 g. cm.	331.65 g. cm.	1482.70 g. cm.	1910.00 g. cm.

TABLE 12

DIRECT WORK—STATION 2

Depth m.	June 14	July 8	July 26	August 1	August 17
0-5	25.50	144.75	265.50	198.75	165.00
5-10	38.80	76.00	390.00	524.00	380.00
10-15	42.25	32.50	149.50	773.50	555.75
15-20	42.30	25.20	63.90	531.00	409.50
20-25	25.30	18.40	40.25	207.00	143.75
25-30	14.00	12.60	29.40	140.00	70.00
30-35	13.20	8.25	23.10	107.25	54.45
35-40	13.30	5.70	17.10	79.80	49.40
40-45	10.75	2.15	12.90	55.90	47.30
45-50	7.20	2.40	9.60	40.80	48.00
50-55	2.65	2.65	7.95	29.15	45.05
55-60	0	0	2.90	17.40	43.50
	235.25 g. cm.	330.60 g. cm.	1012.10 g. cm.	2704.55 g. cm.	2011.70 g. cm.

TABLE 13

DIRECT WORK—STATION 3

Depth. m.	June 17	July 9	August 2	August 29
0-5	47.25	232.50	154.50	177.75
5-10	50.00	200.00	396.00	428.00
10-15	58.50	65.00	571.00	500.50
15-20	40.50	36.00	594.00	252.00
20-25	17.25	25.30	483.00	80.20
25-30	11.20	9.80	294.00	60.20
30-35	9.95	3.30	161.70	49.50
35-40	7.60	1.90	89.30	43.70
40-45	4.30	0	43.00	38.70
45-50	0	0	19.20	38.40
50-55			10.60	34.45
55-60			8.70	31.90
60-65			9.45	28.35
65-70			6.80	27.20
70-75			7.30	25.55
75-80			3.90	19.50
80-85			4.15	16.60
85-90			4.40	13.20
90-95			4.65	13.95
95-100			0	9.80
100-105				5.15
105-110				5.40
110-115				0
115-120				0
120-123.4				0
	246.55 g. cm.	573.80 g. cm.	2865.65 g. cm.	1900.00 g. cm.

(3) that during the storm of July 30, the expenditure took place chiefly in the 10-20 metre area of the open portion of the lake, but in the 10-15 metre area of the more or less sheltered bay. In both cases considerable work was involved in distributing heat in the hypolimnion. It would appear that during the storm probably about 10,000 calories per sq. cm. of surface were distributed in the open waters of the lake requiring about 1500 g. cm. of work.

(4) that a considerable amount of work was expended in the deeper waters of the hypolimnion during August, since these waters continued to gain heat for some time following the storm.

In approximate terms then it may be said that in 1921, 2500 gram-centimetres of work per square centimetre of area were needed to distribute 30,000 gram-calories of heat per square centimetre of area in the waters of Lake Nipigon. This means, then, that our northern waters are essentially similar to those of more southerly distribution in the matter of summer heat income and its distribution. Where they differ, is in the length of the period from the time when the temperature begins to rise above 4°C. until a uniform temperature of 4°C. is again reached in the autumn. This summer period is of short duration. For example, ice may appear in Lake Nipigon in November and the lake be entirely frozen over by the end of December. The lake may not be free of ice again until the middle of May and occasionally not until early in June. In contrast to this, Cayuga Lake rarely freezes over and when it does so, the period lasts but little over a month (Birge and Juday, 1914). Strong summer winds would therefore appear to be of special importance in the northern regions. It is probable that in a season of little wind the summer heat income for Lake Nipigon would be very small. It is evident that the summer or growing period for the organisms in Lake Nipigon is comparatively short and it is hoped that data in regard to the effect of this condition in causing a slow rate of growth for fish may be presented later. However, it does not appear that the productiveness of such a lake in respect of those fish which can tolerate a short summer period, such as the common white-fish, will be any less than that of a lake with a longer summer period, if other factors such as those of food, oxygen supply, spawning conditions, etc., are equal. That the short summer period is one of the factors contributing to the absence of certain species of fish from our northern waters is probable, in that doubtless some species are unable, in the short time available, to accumulate sufficient reserve material to carry them through the long winter period and allow them to spawn successfully in the spring.

Colour and Transparency

A white wooden disk 20 cm. in diameter was used in the determination of the transparency and a U.S. Geological Survey standard colorimeter for the colour. The following records were obtained by Mr. George Geiger:

No.	Date	Time	Location	Trans-parency feet	Colour
1	Sept. 11	10 a.m.	off Cedar Island		7
2	" 11	10 a.m.	east of Shakespeare Island	11.7	10
3	" 13	3.30 p.m.	2 mi. south of Echo Rock		7
4	" 16	2 p.m.	Sturgeon river	12.6	37
5	" 17	11 a.m.	Gull river		61
6	" 17	12 noon	Gull Bay		31
7	" 17	12.30 p.m.	Gull Bay		31
8	" 23	11.45 a.m.	Open waters south of Cedar Is.	17.0	7

In No. 2, the water seemed to be slightly turbid with clay. In determining the colours the standard tube was used empty since no distilled water was available. Many other tests in the open parts of the lake gave colour values of about 7.

The transparency of the open waters is thus high, comparing closely with those of Cayuga Lake (Birge and Juday, loc. cit.). The colour is slight in the open waters but is very dark brown in all of the streams tested and observed and persists to some extent in the shore waters of the lake, particularly around the mouths of the streams. This dark brown colour, no doubt, has some relation to the dark colouration of many shore-water fish such as the pike perch, lake trout and some of the whitefish.

Dissolved Gases

The results of the oxygen determinations (Tables 1, 2 and 3, and Figs. 4 and 5), for this season show:

(1) that from the middle of June to the middle of August

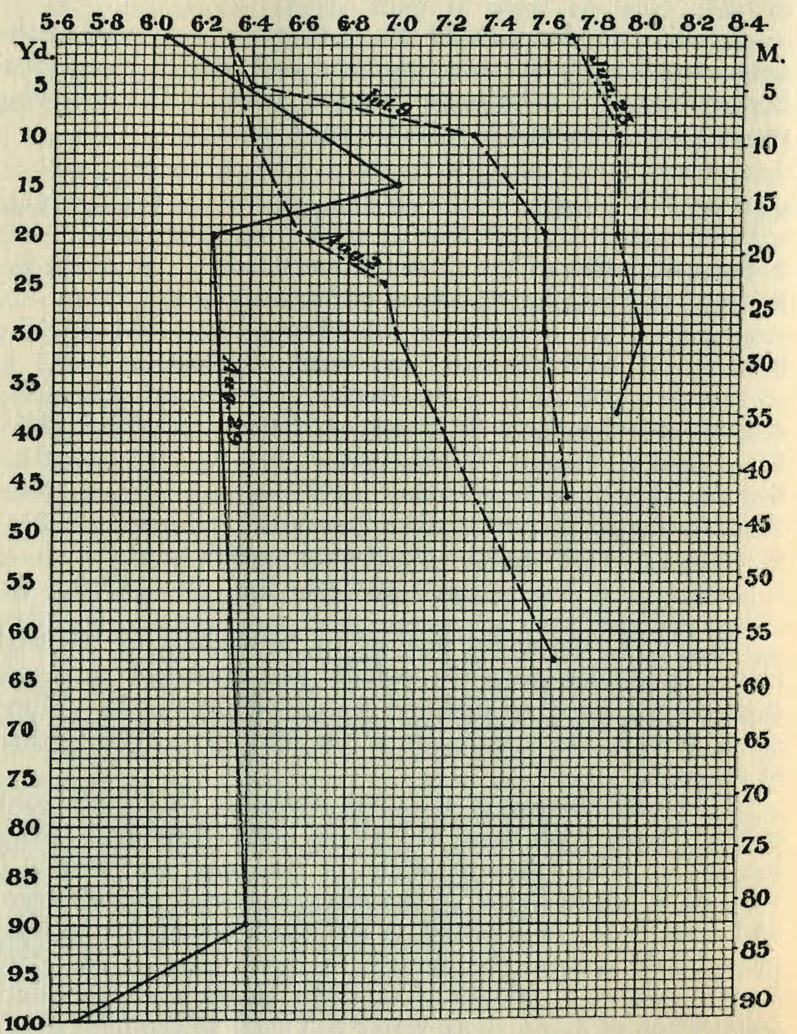

FIG. 4. Curves illustrating amounts of dissolved oxygen in cc. per litre, Station 3, Lake Nipigon.

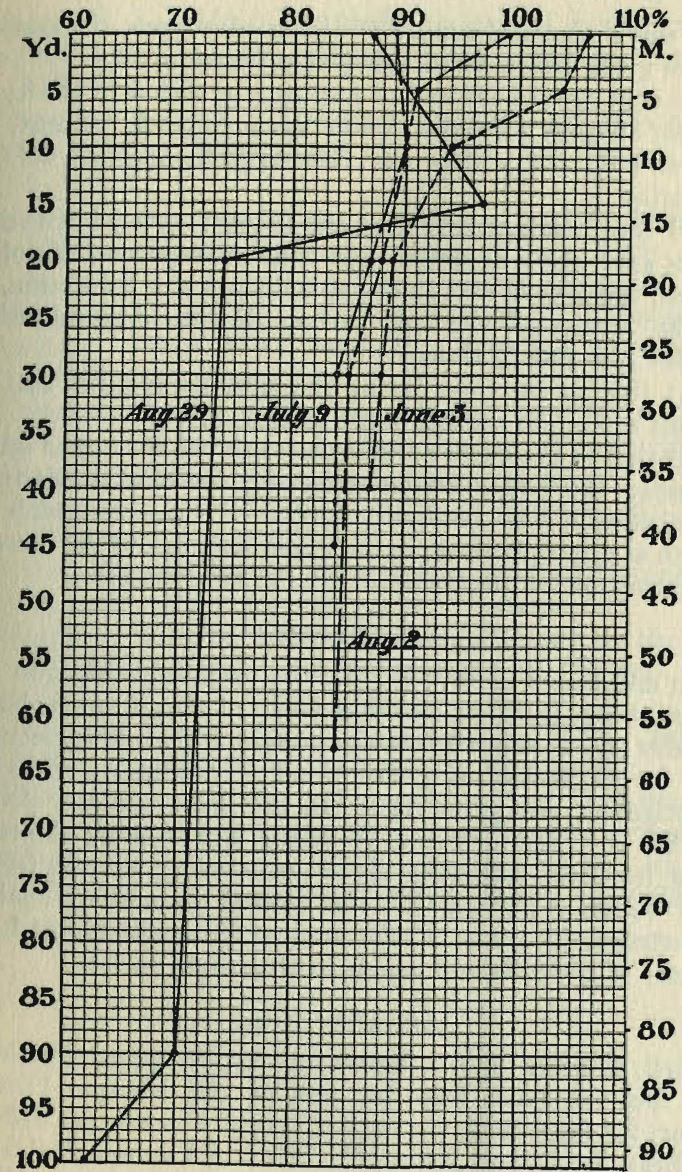

FIG. 5. Curves illustrating percentages of saturation of dissolved oxygen, Station 3, Lake Nipigon.

there was a plentiful supply of dissolved oxygen, the content seldom going below about 85% of saturation.

(2) that toward the end of August, the waters of the hypolimnion showed a marked reduction in oxygen content, the bottom waters at a depth of 100 yards having but 62% of saturation.

(3) that it is unlikely that the oxygen supply in the deep waters ever nears depletion and that in respect of dissolved oxygen, the lake is well suited to a deep-water fish fauna.

The results of the free carbon dioxide determinations (Tables 1, 2 and 3) show:—

(1) that at no time during the summer months was the amount of carbon dioxide large at any depth.

(2) that in the early part of the summer the upper waters contained the larger amounts but as the season advanced this condition was reversed, doubtless correlated with the growth of phytoplankton in the upper waters and the increase in decomposition processes in the bottom waters.

Conclusion

In conclusion it may be said (1) that Lake Nipigon possesses those features characteristic of large open bodies of water and does not appear to present any striking peculiarities in respect of physico-chemical conditions thus far investigated, except in regard to the short summer period; (2) that the peculiarities of its fauna and flora are the result of, at least the following three outstanding factors, (a) the short summer period, (b) the limited amount of shallow, protected water areas, (c) the isolation from the Great Lakes because of the falls and rapids in the single outlet.

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