FURTHER LIMNOLOGICAL OBSERVATIONS ON THE FINGER LAKES OF NEW YORK

By Edward A. Birge and Chancey Juday

Wisconsin Geological and Natural History Survey, Madison, Wis.

CONTENTS.

FURTHER LIMNOLOGICAL OBSERVATIONS ON THE FINGER LAKES OF NEW YORK.

By EDWARD A. BIRGE and CHANCEY JUDAY,
Wisconsin Geological and Natural History Survey, Madison, Wis.

INTRODUCTION.

In 1910 and 1911 the U. S. Bureau of Fisheries enabled the authors of the present paper to spend some weeks in the study of the Finger Lakes of New York. The results of this work were published in the Bulletin of this Bureau for 1912 (Birge and Juday, 1914). In this expedition there were applied to the study of the New York lakes methods that had already been tried on the lakes of Wisconsin, which are much smaller and shallower than those of New York. The resulting report dealt with the hydrography of the lakes, their temperatures and heat budgets, their content of dissolved gases, and their net plankton. Since that study was made, the Wisconsin survey has increased the scope of its observations on lakes. In particular there has been devised and used extensively a new instrument, the pyrlimnometer, designed for measuring the transmission of the sun's radiation through the water of a lake; numerous determinations of the weight of the individual members of the net plankton have been made; an elaborate study of the nannoplankton, both numerical and quantitative, has been completed; and it is now possible to make a rough correlation between count and weight of both net plankton and nannoplankton.

The Bureau of Fisheries authorized a second expedition to the New York lakes in July and August of 1918, in order to apply these newer methods to them. The following paper reports the results of the observations.

The authors are indebted to Hobart College, Geneva, for the free use of its laboratories during their stay on the lakes, and to Prof. E. H. Eaton, of the same college, for unwearied assistance in their work. Much of the success which was reached was due to this aid. All recorded series of temperatures between 1911 and 1918 were taken by Prof. Eaton, as also were those taken after August 1, 1918.

This report comes from both of its authors, as was the case with their former paper on the same subject. Mr. Juday, however, has prepared the part which deals with the plankton and Mr. Birge that which relates to temperatures and transmission of radiation.

TEMPERATURES AND HEAT BUDGETS.

The temperatures of the Finger Lakes were discussed in our former paper (Birge and Juday, 1914, pp. 546–575), and it is unnecessary to repeat what was said there. Additional observations have been made and the discussion can be enlarged, therefore, at certain points.

Table 1 shows the dates at which series of temperatures have been taken for use in computing the summer heat income. A five-year mean of August temperatures may be obtained for Canandaigua and Cayuga Lakes and a four-year mean for Seneca Lake. Additional observations are not likely to make essential changes in the results thus obtained.

SURFACE AND BOTTOM TEMPERATURES.

Observations of the surface in August and early September show in Canandaigua Lake a mean of 21.4° C., ranging from 20.7 to 21.7°; in Cayuga Lake the mean is 21.1°, ranging from 19.8 to 22.6°; in Seneca Lake, 20.4°, ranging from 20.0 to 21.1°. These must not be taken as the maximum surface temperatures, which undoubtedly are likely to come earlier in the season. Seneca Lake was visited on July 24, 1918, in the afternoon of a clear, hot day and at the close of a hot and windless period. The surface temperature in water 40 m. deep was 25.0° C. A heavy shower with violent squalls occurred later in the afternoon. The surface temperature on July 25 was 20.8° and there was a marked rise of temperature above that of the 24th at all depths between 5 and 30 m.

TABLE 1.—DATES OF TEMPERATURE SERIES: SURFACE, BOTTOM, AND MEAN TEMPERATURES.

Lake and date.	Surface.	Bottom.	Mean.
CANANDAIGUA LAKE.	°C.	°C.	°C.
Aug. 20, 1910	21.7	5.4	11.05
Sept. 4, 1911	20.7	4.3	10.02
Aug. 27, 1914	21.6	4.5	10.11
Aug. 31, 1916	21.6	5.0	11.57
July 27, 1918	23.1	5.1	11.91
Sept. 1, 1918	21.5	5.0	11.42
Mean	21.4	4.8	10.95
CAYUGA LAKE.			
Aug. 11, 1910	19.8	4.3	9.24
Sept. 2, 1911	20.0	4.1	8.93
Sept. 4, 1914	21.4	4.1	9.65
CAYUGA LAKE—continued.	°C.	°C.	°C.
Aug. 16, 1917	22.6	4.3	9.44
Aug. 30, 1918	22.0	4.2	9.66
Mean	21.1	4.2	9.43
SENECA LAKE.			
Aug. 3, 1910	20.2	4.2	7.71
Sept. 1, 1911	20.0	4.0	7.34
Sept. 5, 1914	21.1	4.0	8.27
Aug. 29, 1918	20.8	4.0	8.07
Mean	20.4	4.05	7.84

Bottom temperatures average 4.8° C. in Canandaigua Lake (84 m. deep), ranging from 4.3 to 5.4°; in Cayuga Lake (133 m.) they average 4.2° with a range from 4.1 to 4.3°; in Seneca Lake (188 m.) the mean is 4.05° and the range from 4.0 to 4.2°. The reading was 4.0° in three of the four series.

In most of these cases the observations were made with a Negretti and Zambra deep-sea thermometer divided to 0.5°. Such an instrument gives approximate but not very exact results. In 1918 the attempt was made to ascertain whether the water of Seneca Lake might not be below 4.0° C. at the bottom. The temperature of maximum density is lowered by pressure, as pointed out by Hamberg (1911, pp. 306–312). Since the depth of Seneca Lake is 188 m. the pressure at the bottom is about 19 atmospheres, and maximum density would be reached between 3.3 and 3.4°.

A special thermometer was used, ranging from −2.0 to +14.0° and divided to 0.1°. This instrument read exactly 4.1° when at the temperature of the surface water, 19.3°. Correction for the expansion of the mercury shows that the true temperature at the bottom was 3.88° and, therefore, below 4.0°, though decidedly above the temperature of maximum density for the depth. Hamberg (loc. cit.) quotes examples of similar temperatures from Lakes Ladoga and Mjösen. It is worth noting that the temperature in both these lakes at the depth of 190 m. was between 3.8 and 3.9°. The observations of Huitfeld-Kaas (1905, p. 4) in Mjösen give temperatures at 200 m. which rise as high as 4.1° in November and as low as 3.65 or 3.75° in April and May. At the bottom, 400 m. or more, 3.60 and 3.75° were found. At this depth the temperature of maximum density is slightly above 3.3°.

It is very probable that the temperature of Seneca Lake, recorded in 1910 as 4.2°, was really close to 4.0°, and that all readings of 4.0° at the bottom indicate temperatures as low as 3.8 or 3.9°. It is not worth while, however, to apply an estimated correction to these readings. There is no reason to believe that the bottom temperature of Cayuga Lake is below 4.0° in late summer.

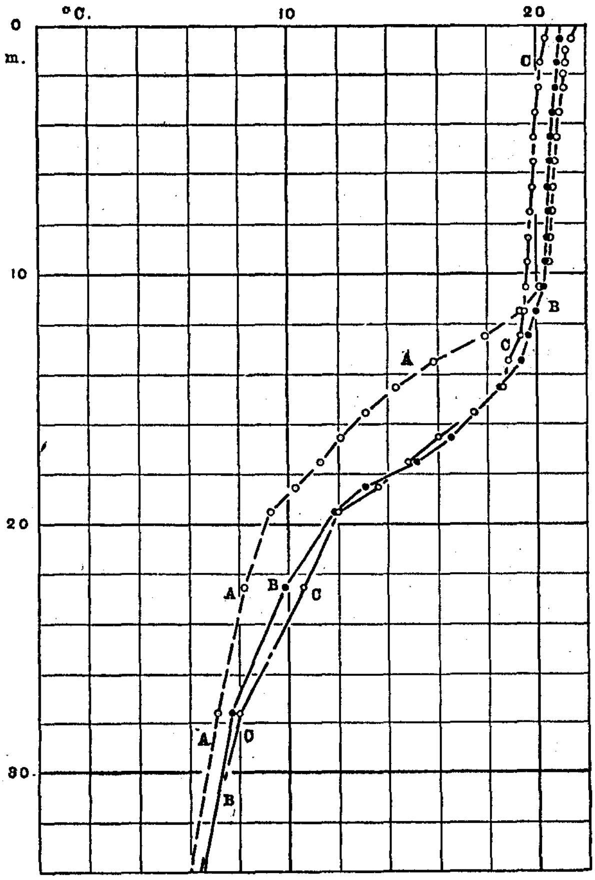

FIG. 1.—Curves of mean temperature to 34 m. depth. *A*, Canandaigua Lake; *B*, Cayuga Lake; *C*, Seneca Lake. (See Table 1, p. 212.)

THERMAL REGIONS.

Table 2 shows the thermal regions of the several lakes. The epilimnion of Canandaigua Lake was 11 or 12 m. thick; the thermocline was 4 to 8 m. thick, averaging 6 m. In Cayuga Lake the epilimnion was 13 to 15 m. thick and the thermocline 4 to 5 m. thick.

There was more variation in Seneca Lake. The epilimnion was 15 to 19 m. thick and the thermocline 4 to 6 m. On August 1, 1918, the epilimnion at Hector Point was only 10 m. thick; on August 29, at Kashong, it was determined at 20 m. But since Kashong is near the north end of the lake and the readings were taken on the day following a hard south wind, the epilimnion was no doubt thicker there than observations at the center of the lake would have shown. In computing gains of heat, therefore, the thickness of the epilimnion for 1918 was taken as 15 m.

On July 24, 1918, at the north end of the lake in 40 m. of water the epilimnion was only 7 m. thick. This was at the end of nine days of hot and calm weather and is an exceptional condition. The thickness of the epilimnion rapidly increased to 14 or 15 m. in the course of the following week and was subject to considerable fluctuations.

TABLE 2.—DISTRIBUTION OF SUMMER HEAT INCOME TO THERMAL REGIONS OF LAKES.

[NOTE.—Mean is derived from mean temperatures. Extent=vertical thickness of region in meters; R. T.=reduced thickness of region, i. e., the thickness in meters of the region when reduced to the area of the surface of the lake. It is computed by dividing the volume of the stratum expressed in meters by the area of the surface of the lake expressed in square meters; T=gain of heat above 4.0°, i. e., the summer heat income expressed in degrees centigrade; Cal.=gram calories per square centimeter of lake surface; P. ct.=per cent.]

CANANDAIGUA LAKE.

Thermal region.	1910					1911				
	Extent.	R. T.	T.	Cal.	P. ct.	Extent.	R. T.	T.	Cal.	P. ct.
Epilimnion	0–12	10.0	16.8	16,800	61.8	0–12	10.0	15.5	15,500	66.4
Thermocline	12–20	5.6	9.3	5,200	19.1	12–20	5.6	9.2	5,200	22.0
Hypolimnion	20–84	23.1	2.73	5,200	19.1	20–84	23.1	1.04	2,400	11.6
Mean or total	....	38.7	7.07	27,200	....	....	38.7	5.99	23,200	....

Thermal region.	1914					1916				
	Extent.	R. T.	T.	Cal.	P. ct.	Extent.	R. T.	T.	Cal.	P. ct.
Epilimnion	0–11	9.34	21.0	15,830	58.6	0–12	10.8	21.2	17,420	59.3
Thermocline	11–18	5.01	14.0	5,010	18.6	12–20	5.64	13.3	5,270	17.9
Hypolimnion	18–84	24.45	6.5	6,160	22.8	20–84	23.08	6.9	6,680	22.7
Mean or total	....	38.8	10.96	27,000	....	....	39.52	11.57	29,370	....

Thermal region.	1918					Mean.				
	Extent.	R. T.	T.	Cal.	P. ct.	Extent.	R. T.	T.	Cal.	P. ct.
Epilimnion	0–11	9.34	20.7	15,610	54.3	0–11	9.34	20.8	15,660	58.0
Thermocline	11–15	2.91	16.2	3,560	12.4	11–17	7.18	15.9	4,970	18.4
Hypolimnion	15–84	26.25	7.7	9,600	33.3	17–84	25.82	16.5	6,350	23.6
Mean or total	....	38.5	11.42	28,770	....	....	42.34	10.95	26,980	....

CAYUGA LAKE.

Thermal region.	1910					1911				
	Extent.	R. T.	T.	Cal.	P. ct.	Extent.	R. T.	T.	Cal.	P. ct.
Epilimnion	0–15	11.8	15.5	18,300	64.2	0–16	12.5	15.2	19,000	71.1
Thermocline	15–22	4.62	10.3	4,800	16.9	16–21	3.3	9.2	3,300	12.4
Hypolimnion	22–133	38.3	1.41	5,400	18.9	21–133	38.7	1.14	4,400	16.5
Mean or total	....	54.72	5.26	28,500	....	....	54.5	4.94	26,700	....

Thermal region.	1914					1917				
	Extent.	R. T.	T.	Cal.	P. ct.	Extent.	R. T.	T.	Cal.	P. ct.
Epilimnion	0–15	11.97	21.2	20,624	66.8	0–13	10.56	21.0	17,977	60.5
Thermocline	15–20	3.35	16.7	4,266	13.8	13–17	2.76	15.6	3,201	10.8
Hypolimnion	20–133	39.27	5.5	5,980	19.4	17–133	14.29	6.1	8,542	28.8
Mean or total	....	54.59	9.65	30,870	....	....	27.61	9.44	29,720	....

Thermal region.	1918					Mean.				
	Extent.	R. T.	T.	Cal.	P. ct	Extent.	R. T.	T.	Cal.	P. ct.
Epilimnion	0–15	11.97	20.4	19,734	63.9	0–15	11.97	20.3	19,538	66.2
Thermocline	15–19	2.70	14.0	2,716	8.8	15–20	3.35	14.9	3,643	12.4
Hypolimnion	19–133	39.94	6.1	8,460	27.3	20–133	39.27	5.6	6,309	21.4
Mean or total	....	54.61	9.66	30,910	....	....	54.59	9.40	29,480	....

TABLE 2.—DISTRIBUTION OF SUMMER HEAT INCOME TO THERMAL REGIONS OF LAKES—Continued.

SENECA LAKE.

Thermal region.	1910					1911				
	Extent.	R. T.	T.	Cal.	P. ct.	Extent.	R. T.	T.	Cal.	P. ct.
Epilimnion	0–12	11.5	15.4	17,700	53.8	0–15	13.8	15.4	21,200	71.5
Thermocline	12–20	6.2	10.2	6,400	19.5	15–22	6.0	8.6	5,200	17.5
Hypolimnion	20–188	70.9	1.21	8,800	21.7	22–188	68.8	0.47	3,300	11.0
Mean or total	....	88.6	3.71	32,900	....	....	88.6	3.35	29,700	....

Thermal region.	1914					1918				
	Extent.	R. T.	T.	Cal.	P. ct.	Extent.	R. T.	T.	Cal.	P. ct.
Epilimnion	0–19	16.92	20.0	27,000	71.2	0–15	13.60	20.0	22,420	62.2
Thermocline	19–25	4.83	13.9	4,780	12.6	15–19	3.32	14.6	3,510	9.8
Hypolimnion	25–188	66.85	4.9	6,090	16.2	19–188	71.68	5.4	10,030	27.9
Mean or total	....	88.6	8.27	37,870	....	....	88.6	8.07	36,060	....

Thermal region.	Mean.				
	Extent.	R. T.	T.	Cal.	P. ct.
Epilimnion	0–15	13.60	19.8	21,410	63.0
Thermocline	15–20	4.13	14.8	4,450	13.1
Hypolimnion	20–188	70.87	5.2	8,160	24.0
Mean or total	....	88.6	7.84	34,020	....

SUMMER HEAT INCOME.

The summer heat income represents the gains in heat of the water of the lake above the temperature of 4°. This notion was put forward in our paper on the New York Lakes (Birge and Juday, 1914, p. 562) under the name of "wind-distributed heat." In the following year (1915, p. 167) I proposed the name "summer heat income" for the same gains of heat, preferring a term which does not imply any theory as to the method of distributing such heat. For reasons discussed in the same paper (1915, p. 186) the summer heat income of lakes can be used as an index of their heat exchanges in much the same way as the annual heat budget. The heat income, like the heat budget, is stated in gram calories per square centimeter of lake surface. For the sake of brevity it is ordinarily stated as so many calories without adding in every case the qualifying terms. The whole question of heat budgets and the methods of computing them is discussed in the paper already referred to (Birge, 1915).

Table 2 shows the summer heat income of the three lakes concerned. Canandaigua Lake shows a mean income of nearly 27,000 cal./cm.^{2}, ranging from 23,000 to more than 29,000 cal. Cayuga Lake has an income of about 29,500 cal., ranging from less than 27,000 to nearly 31,000 cal. The income of Seneca Lake is about 34,000 cal., ranging from less than 30,000 to nearly 38,000 cal. The smaller income of Canandaigua Lake is mainly due to the thinner epilimnion, which, in turn, is due to the smaller size of the lake and to the protection from wind afforded by its high shores. So far as area goes, Cayuga Lake is as well off as Seneca and its depth is ample to secure as large an income. But while the epilimnion in both lakes is 15 m. thick, its reduced thickness is nearly 12 per cent less in Cayuga Lake than in Seneca. This fact is due to the large extent of shallow water at the north end of the lake, which causes a corresponding reduction in the amount of heat as stated in terms of units of surface area. The upper 20 m. of these lakes contains 75 to 80 per cent of the total quantity of heat, and the reduced thickness of this stratum in Cayuga Lake is nearly 14 per cent less than in Seneca Lake. (See Table 3.) The slightly higher temperature of the stratum in Cayuga Lake is not great enough to compensate for this difference in thickness (cf. Birge and Juday, 1914, p. 574).

A longer series of years would undoubtedly change the figures stated above. But it is not probable that such a series would greatly alter them or that it would change the general relations of the heat income of the several lakes to each other. The smaller lake has the smaller income, largely because of its thinner epilimnion. Cayuga Lake has less heat than Seneca, largely because of the smaller ratio between maximum and mean depth. The differences are not so great but that the series of budgets overlap, the largest heat income of Canandaigua being larger than the smallest of Cayuga, and Cayuga's series overlapping in a similar way that of Seneca. The largest heat income in the series is that of Seneca in 1914, nearly 38,000 cal.

Table 2 also shows the distribution of heat to the three thermal regions of the lakes. The epilimnion contains about 60 per cent of the summer heat income, ranging from 53 to more than 70 per cent. This stratum, together with its thermal dependency, the thermocline, contains from 70 to nearly 90 per cent of the heat. Thus in Seneca Lake, which may be nearly 200 m. deep, a surface stratum occupying little more than the upper one-tenth of the depth contains from three-fourths to nine-tenths of the heat accumulated from the sun during the season.

Table 3 shows the distribution of the summer heat income by 10 m. intervals. It shows the same facts as Table 2 but in another form. It makes especially clear the small amount of heat which can be carried to considerable depths. In Canandaigua Lake, for example, the total quantity of heat transmitted below 50 m. during the season does not exceed the quantity delivered to the surface in one summer day; and even in the much larger and deeper Seneca Lake it does not exceed two days' supply.

TABLE 3.—DISTRIBUTION OF TEMPERATURES AND OF CALORIES OF SUMMER HEAT INCOME.

[NOTE.—R. T.=reduced thickness of stratum in meters; T.= temperature in degrees centigrade; Cal. =calories of summer heat income, i. e., gain of heat above 4°; P. ct.=per cent of heat income in stratum.]

CANANDAIGUA LAKE.

Depth in meters.	R. T.	1910			1911			1914		
		T.	Cal.	P. ct.	T.	Cal.	P. ct.	T.	Cal.	P. ct.
0-10	8.56	21.2	14,720	53.3	19.9	13,610	58.2	21.1	14,640	56.3
10-20	7.16	14.3	7,370	27.0	14.2	7,300	31.5	13.6	6,870	26.4
20-30	6.43	7.4	2,190	8.0	6.1	1,350	5.6	7.4	2,190	8.4
30-40	5.71	6.2	1,260	4.7	4.9	510	2.4	6.3	1,310	5.0
40-50	4.88	5.8	880	3.3	4.6	290	1.2	5.4	680	2.6
50-60	3.65	5.6	580	2.3	4.5	180	.8	4.8	290	1.1
60-70	1.90	5.5	280	1.1	4.35	70	.3	4.6	110	.4
70-84	.53	5.4	70	.3	4.3	20	....	4.5	20	.1
	....	11.05	27,350	100.0	10.02	23,330	100.0	10.71	26,110	100.3

Depth in meters.	R. T.	1916			1918			Mean.		
		T.	Cal.	P. ct.	T.	Cal.	P. ct.	T.	Cal.	P. ct.
0-10	8.56	21.4	14,890	50.7	20.8	14,380	50.0	20.9	14,450	53.5
10-20	7.16	14.9	7,800	26.6	14.9	7,800	27.1	14.4	7,430	27.5
20-30	6.43	8.6	3,420	11.6	8.9	3,150	11.0	7.8	2,460	9.1
30-40	5.71	6.6	1,480	5.0	6.8	1,600	5.6	6.1	1,230	4.6
40-50	4.88	5.9	930	3.2	5.9	930	3.2	5.5	740	2.7
50-60	3.65	5.5	550	1.9	5.6	570	2.0	5.2	430	1.6
60-70	1.90	5.3	250	.8	5.4	270	1.0	5.1	200	.7
70-84	.53	5.0	50	.2	5.3	70	.2	4.8	40	.2
	....	11.57	29,370	100.0	11.42	28,770	100.1	10.95	26,980	99.9

TABLE 3.—DISTRIBUTION OF TEMPERATURES AND OF CALORIES OF SUMMER HEAT INCOME—Con.

CAYUGA LAKE.

Depth in meters.	R. T.	1910			1911			1914		
		T.	Cal.	P. ct.	T.	Cal.	P. ct.	T.	Cal.	P. ct.
0–10	8.42	19.2	12,800	44.8	19.9	13,400	40.8	21.3	14,600	47.3
10–20	6.88	17.7	9,400	32.9	17.1	9,000	33.5	18.8	10,200	33.0
20–30	6.27	8.8	3,000	10.5	8.2	2,600	9.7	9.6	3,500	11.3
30–40	5.79	6.4	1,400	4.9	5.6	900	3.4	6.2	1,300	4.2
40–50	5.12	5.4	700	2.4	4.7	350	1.3	5.2	600	1.9
50–60	4.52	4.9	400	1.4	4.4	180	.7	4.6	290	.9
60–70	4.03	4.6	250	.9	4.4	140	.5	4.4	160	.5
70–80	3.60	4.5	190	.6	4.3	130	.5	4.3	90	.3
80–100	5.89	4.5	290	1.0	4.2	120	.4	4.1	90	.3
100–133	4.09	4.4	170	.6	4.2	80	.3	4.1	40	.1
	54.61	9.24	28,600	....	8.93	26,900	....	9.65	30,870	....

Depth in meters.	R. T.	1917			1918			Mean.		
		T.	Cal.	P. ct.	T.	Cal.	P. ct.	T.	Cal.	P. ct.
0–10	8.42	21.3	14,600	49.2	21.1	14,400	46.6	20.6	14,000	47.5
10–20	6.88	16.1	8,300	28.0	16.4	8,500	27.5	17.3	9,100	31.0
20–30	6.27	8.8	3,000	10.1	9.1	3,200	10.4	9.0	3,100	10.5
30–40	5.79	6.9	1,700	5.7	7.1	1,800	5.8	6.4	1,400	4.8
40–50	5.12	5.7	880	3.0	6.3	1,200	3.9	5.5	770	2.6
50–60	4.52	4.9	410	1.4	5.7	750	2.4	4.9	410	1.4
60–70	4.03	4.8	320	1.1	5.1	440	1.4	4.6	260	.9
70–80	3.60	4.5	180	.6	4.7	250	.8	4.5	160	.5
80–100	5.89	4.4	210	.7	4.5	290	.9	4.3	190	.7
100–133	4.09	4.3	120	.4	4.2	80	.3	4.2	90	.3
	54.61	9.44	29,720	....	9.66	30,910	....	9.40	29,480	....

SENECA LAKE.

Depth in meters.	R. T.	1910			1911			1914		
		T.	Cal.	P. ct.	T.	Cal.	P. ct.	T.	Cal.	P. ct.
0–10	9.35	19.6	14,600	44.4	19.6	14,600	49.5	20.3	15,200	40.1
10–20	8.40	15.7	9,600	29.2	16.2	10,200	34.5	19.2	12,800	33.8
20–30	7.86	8.7	3,700	11.2	7.3	2,600	8.8	11.4	5,800	15.3
30–40	7.41	6.4	1,800	5.5	5.8	800	2.7	7.1	2,300	6.1
40–50	6.92	5.5	1,000	3.0	4.6	400	1.3	5.4	970	2.6
50–60	6.49	4.9	600	1.8	4.4	280	1.0	4.7	450	1.2
60–70	5.89	4.8	450	1.4	4.3	160	.6	4.4	240	.6
70–80	5.52	4.6	320	1.0	4.3	160	.6	4.2	110	[illegible]
80–100	9.82	4.5	460	1.4	4.2	200	....	4.0	....	....
100–130	12.14	4.2	200	....	4.1	100	....	4.0	....	....
130–150	5.76	4.2	100	....	4.0	80	....	4.0	....	....
150–188	3.22	4.2	70	....	4.0	....	....	4.0	....	....
	....	7.71	32,900	....	7.34	29,600	....	8.27	37,870	....

Depth in meters.	R. T.	1918			Mean.		
		T.	Cal.	P. ct.	T.	Cal.	P. ct.
0–10	9.35	20.5	15,400	42.7	19.9	14,900	43.8
10–20	8.40	17.2	11,100	30.8	17.1	10,960	32.4
20–30	7.86	9.9	4,600	12.7	9.3	4,200	12.4
30–40	7.41	6.8	2,100	5.8	6.3	1,700	5.0
40–50	6.92	6.0	1,400	3.9	5.4	940	2.8
50–60	6.49	5.2	760	2.1	4.6	420	1.2
60–70	5.89	4.4	230	.6	4.5	270	.8
70–80	5.52	4.3	160	.4	4.3	180	.5
80–100	9.82	4.2	190	.8	4.2	260	.8
100–130	12.14	4.1	120	.3	4.1	130	.4
130–150	5.76	4.0	....	....	4.0	40	.1
150–188	3.22	4.0	....	....	4.0	20	....
	....	8.07	36,060	....	7.84	34,020	....

DISTRIBUTION OF HEAT.

The radiation from the sun which enters a lake is rapidly absorbed by the strata of water near the surface. Even in very clear lakes only 20 per cent of the total radiation passes the 1-meter level, and only about 10 per cent passes the 3-meter level. (See p. 228.) All of the warming of the deeper water and most of the warming of that which lies below the surface meter is due not to insolation but to mixture of warmer water carried down from near the surface. This mixture of warm surface water with the cooler water below is effected by the wind for all temperatures above 4°. It involves work against gravity, since the warmer water is lighter than the cooler. This work may be measured and may be conveniently stated in gram-centimeters per square centimeter of lake area. These facts were stated in our paper on the New York Lakes (Birge and Juday, 1914, p. 562). The principles underlying these ideas were later published as a special paper (Birge, 1916, pp. 341–391) and were applied to Lake Mendota. It was there shown that about 1,210 gram-centimeters of work per square centimeter of area are needed to distribute 18,400 gram-calories of heat per square centimeter of area through the waters of a lake 24 meters in maximum depth and 12.1 meters in mean depth. It is understood that in this statement the term "work" is not used in an exact sense; since in it are included both the action of the wind in distributing heat, which is properly work; and also the direct effect of insolation, which does not involve work. (See Birge and Juday, 1914, p. 574; Birge, 1916, p. 360.) This division of the distribution of heat between sun and wind is discussed later in the paper. For the present, however, the matter is discussed as though the entire distribution of heat were due to wind.

TABLE 4.—TEMPERATURE (T) IN DEGREES CENTIGRADE AND GRAM CENTIMETERS (G. CM.) OF WORK NECESSARY TO DISTRIBUTE THE SUMMER HEAT INCOME.

[NOTE.—This table shows the "direct curve of work," i. e., the work necessary to carry the warmed water from the surface to the stratum in question. It is stated in gram centimeters per square centimeter of surface of the lake.]

CANANDAIGUA LAKE.

Depth in meters.	1910		1911		1914		1916		1918		Mean.	
	T.	G. cm.	T.	G. cm.	T.	G. cm.	T.	G. cm.	T.	G. cm.	T.	G. cm.
0–5	21.6	236.2	20.0	224.0	21.5	240.8	21.5	240.8	21.1	224.0	21.1	224.0
5–10	21.0	582.0	19.6	505.3	20.7	574.1	21.3	613.0	20.6	568.1	20.6	568.1
10–15	18.0	630.7	17.5	589.5	16.9	539.3	17.8	612.4	17.0	548.4	17.5	589.5
15–20	10.6	199.1	10.6	199.1	10.2	176.6	12.0	288.3	12.5	309.6	11.2	235.5
20–25	8.2	100.4	6.2	25.8	7.4	62.7	9.2	149.8	9.8	191.9	8.2	100.4
25–30	7.0	60.8	5.4	13.7	6.9	56.5	8.0	106.1	8.0	106.1	7.1	64.2
30–40	6.2	75.2	4.9	13.9	6.3	83.2	6.6	104.9	6.8	122.8	6.1	69.3
40–50	5.8	57.2	4.6	6.6	5.4	35.2	5.9	63.8	5.9	63.8	5.5	39.6
50–60	5.6	42.0	4.5	4.0	4.8	10.0	5.5	36.0	5.6	42.0	5.2	24.0
60–70	5.5	22.3	4.4	1.2	4.6	3.7	5.3	17.4	5.4	19.8	5.1	12.4
70–84	5.4	6.7	4.5	.4	4.5	.8	5.0	3.3	5.3	5.8	4.9	2.9
	....	2,022.6	....	1,583.5	....	1,782.9	....	2,235.8	....	2,202.3	....	1,929.9

TABLE 4.—TEMPERATURE (T) IN DEGREES CENTIGRADE AND GRAM CENTIMETERS (G. CM.) OF WORK NECESSARY TO DISTRIBUTE THE SUMMER HEAT INCOME—Continued.

CAYUGA LAKE.

Depth in meters.	1910		1911		1914		1917		1918		Mean.	
	T.	G. cm.	T.	G. cm.	T.	G. cm.	T.	G. cm.	T.	G. cm.	T.	G. cm.
0–5	19.6	187.6	20.0	195.4	21.4	229.8	21.8	239.8	21.4	237.5	20.8	215.3
5–10	19.6	488.4	19.9	497.1	21.4	598.2	20.7	554.9	20.8	560.7	20.5	540.4
10–15	19.4	727.6	19.6	745.3	20.9	864.4	18.8	674.7	19.3	718.8	19.6	745.3
15–20	16.0	603.6	14.9	503.4	16.7	673.9	13.2	363.9	13.4	379.1	14.8	494.6
20–25	9.9	189.6	9.0	137.9	11.0	264.2	9.8	183.8	10.0	196.1	9.9	89.6
25–30	7.8	95.0	6.9	56.0	8.0	105.2	7.7	90.7	8.2	115.3	7.7	90.7
30–40	6.4	94.9	5.6	30.3	6.2	70.7	6.9	133.3	7.1	147.5	6.4	92.9
40–50	5.4	41.6	4.7	5.8	5.2	20.8	5.9	53.1	6.3	97.0	5.5	41.6
50–60	4.9	17.4	4.4	5.0	4.6	6.2	4.9	17.4	5.7	54.8	4.9	17.4
60–70	4.6	9.2	4.4	2.6	4.4	2.6	4.8	13.1	5.1	26.2	4.6	9.2
70–80	4.5	5.4	4.3	2.7	4.3	2.7	4.5	5.4	4.7	12.1	4.5	4.0
80–100	4.5	10.6	4.2	....	4.1	....	4.4	5.3	4.5	10.6	4.3	5.3
100–134	4.4	7.2	4.2	....	4.1	....	4.3	4.8	4.2	....	4.2	....
	....	2,478.1	....	2,181.5	....	2,838.7	....	2,340.2	....	2,555.7	....	2,446.3

SENECA LAKE.

Depth in meters.	1910		1911		1914		1918		Mean.	
	T.	G. cm.	T.	G. cm.	T.	G. cm.	T	G. cm.	T.	G. cm.
0–5	19.8	205.9	19.7	203.5	20.4	220.2	20.6	226.1	20.1	213.0
5–10	19.4	552.8	19.2	539.4	20.2	603.0	20.5	626.4	19.8	579.6
10–15	17.8	718.2	17.8	718.2	20.1	959.4	20.2	975.5	19.2	863.0
15–20	13.3	457.8	14.0	526.3	18.0	996.4	14.0	526.3	14.8	609.4
20–25	9.3	194.6	8.0	112.2	13.4	585.5	11.5	380.1	10.6	296.8
25–30	7.9	126.3	6.3	44.9	9.4	237.5	8.2	145.5	8.0	132.7
30–40	6.4	119.6	5.8	67.6	7.1	195.0	6.8	161.2	6.3	109.2
40–50	5.5	56.0	4.6	9.3	5.4	49.8	6.0	99.5	5.4	49.8
50–60	4.9	24.6	4.4	3.5	4.7	14.0	5.2	42.1	4.6	10.5
60–70	4.8	19.0	4.3	3.8	4.4	3.8	4.4	3.8	4.5	7.6
70–80	4.6	22.0	4.3	5.5	4.2	....	4.3	5.5	4.3	4.5
80–100	4.5	19.6	4.2	....	4.0	....	4.2	....	4.2	....
100–130	4.2	....	4.1	....	4.0	....	4.1	....	4.1	....
130–150	4.2	....	4.0	....	4.0	....	4.0	....	4.0	....
150–188	4.2	....	4.0	....	4.0	....	4.0	....	4.0	....
	....	2,516.4	....	2,234.2	....	3,864.6	....	3,192.0	....	2,876.1

DIRECT WORK.

Table 4 shows the distribution of heat for the lakes under consideration. The results of the computation only are given; the details of the method being quite similar to those illustrated in the paper before referred to (Birge, 1916) and also in Table 5, page 220, of this paper. Taking the means only it appears that in Canandaigua Lake about 1,930 g. cm. of work per square centimeter of the area of the lake are needed to distribute about 27,000 cal. of heat through the water, the depth of which is 84 m. In Cayuga Lake about 2,450 g. cm. of work distribute 29,500 cal. in water, the maximum depth of which is 133 m.; in Seneca Lake 2,880 g. cm. distribute 34,000 cal. in water the maximum depth of which is 188 m.

The amount of work needed to carry the heat to the corresponding stratum of the several lakes varies with the loss of density of the water due to rise of temperature and with the quantity of water in the stratum. The latter factor is represented by the reduced thickness of the stratum. (See Table 3.) The first factor is the more variable in these lakes, and to it are due most of the striking differences in the work required to warm the deeper strata. In the 30 to 40 m. stratum of Canandaigua Lake, for instance, it required about 70 g. cm. to put 1,230 cal. into place. In the corresponding stratum of Cayuga Lake it required 93 g. cm. to place 1,400 cal. The difference in calories is about 14 per cent, in work over 30 per cent. This is mainly due to the difference in loss of density. At 6.1°, the temperature of Canandaigua Lake, this is 35 points,[1] and at 6.4°, the temperature of Cayuga Lake, it is 46 points, or over 30 per cent greater.

Table 4 shows that a great amount of work is necessary to produce by mixture the high temperature of the upper strata; it shows also that an almost incredibly small amount of work is needed to carry considerable heat to great depths if only it involves but little rise of temperature. Note, for example, Seneca Lake, where 42 cal./cm.[2] of surface are transported to a mean depth of 55 m. for an expenditure of about 1 g. cm. On the other hand, in the corresponding stratum of Canandaigua Lake, each gram centimeter of work transports only about 18 cal. The difference is due to the much greater rise of temperature in the smaller lake—reaching 5.2° instead of 4.5° in Seneca Lake.

TABLE 5.—DETAIL FOR SENECA LAKE OF THE FACTS OF DISTRIBUTION OF MEAN SUMMER HEAT INCOME.

[NOTE.—T.=temperature in degrees centigrade; 1-D=loss of density due to warming; RTXZ=factor, reduced thickness multiplied by depth. Direct=work done *in behalf of* stratum in question; Dist.=work done *in* stratum in question; Cal.=calories of summer heat income in stratum. All expressed in units per square centimeter of lake surface. See fig. 3, p. 229; also Birge, 1916, p. 349, 355.]

Depth in meters.	T.	1-D.	RTXZ.	Direct work.		Dist. work,		Cal.	Depth in meters.	G. cm.	Cal.
				G. cm.	G. cm.	G. cm.	G. cm.				
0–1	20.4	0.001853	49.5	9.2	....	284.6	....	1,624	0	2,874.4	34,020
1–2	20.2	1815	147	26.8	....	266.5	....	1,588	1	2,589.8	32,396
2–3	20.2	1815	240	43.7	....	248.8	....	1,555	2	2,323.3	30,808
3–4	20.1	1790	333	59.6	....	231.5	....	1,530	3	2,074.5	29,253
4–5	20.0	1770	423	74.9	214.2	213.6	1,245.0	1,504	4	1,843.0	27,723
5–6	20.0	1770	512	90.6	....	197.0	....	1,488	5	1,629.4	26,219
6–7	19.9	1749	592	103.6	....	180.8	....	1,447	6	1,432.4	24,731
7–8	19.8	1729	675	117.8	....	164.9	....	1,422	7	1,251.6	23,284
8–9	19.7	1708	748	127.9	....	149.6	....	1,382	8	1,086.7	21,862
9–10	19.7	1708	827	141.4	581.3	134.6	826.9	1,366	9	937.1	20,480
10–11	19.6	1688	914	154.5	....	119.8	....	1,357	10	802.5	19,114
11–12	19.5	1668	989	165.2	....	105.2	....	1,333	11	682.7	17,757
12–13	19.3	1628	1,076	176.0	....	90.9	....	1,316	12	577.5	16,424
13–14	18.8	1519	1,147	176.0	....	76.5	....	1,258	13	486.6	15,108
14–15	18.6	1491	1,232	183.3	855.0	65.6	457.0	1,241	14	410.1	13,850
15–16	17.4	1269	1,304	165.7	....	53.0	....	1,126	15	345.5	12,609
16–17	16.0	1030	1,370	141.1	....	43.3	....	996	16	292.5	11,483
17–18	14.8	0844	1,453	123.4	....	35.6	....	896	17	249.2	10,487
18–19	13.6	0674	1,517	102.4	....	29.3	....	787	18	213.6	9,591
19–20	12.0	0475	1,580	74.6	607.2	24.6	185.8	648	19	184.3	8,804
20–25	10.6	0328	9,050	....	296.8	....	80.8	2,653	20	159.7	8,156
25–30	8.0	0124	10,735	....	132.7	....	35.7	1,560	25	78.9	5,503
30–40	6.3	0042	26,040	....	109.2	....	29.5	1,714	30	43.2	3,943
40–50	5.4	0016	31,130	....	49.8	....	9.1	969	40	13.7	2,229
50–60	4.6	0003	35,120	....	10.5	....	2.9	485	50	4.6	1,260
60–70	4.5	0002	38,005	....	7.6	....	1.3	263	60	1.7	775
70–80	4.3	0001	45,280	....	4.5	....	.4	165	70	.4	512
Below 80	......	....	....	....	....	....	....	347	80	.0	347
Total	......	....	....	....	2,868.8	....	2,874.4	34,020	....	....	....

[1] By a "point" is meant a decrease in density of one part per million. The density of water at 6.1 as compared with that at 4.0° is 0.999965. The loss in density is, therefore, 0.000035 and this represents the loss in weight of the lighter surface water at 6.1°, and, therefore, is one factor in determining the work to be done in pushing it down into deeper and cooler strata. For convenience in computation this factor is taken as a positive quantity and a whole number is stated as 35 points. (See Birge, 1916, p. 391.)

DISTRIBUTED WORK.

Table 4 deals with the *direct curve of work.* It gives for each stratum the amount of work necessary to convey the warmer and lighter water from the surface to the depth in question, assuming that the lower water has a temperature of 4.0°. In warming all strata below that at the surface most of the work is performed in the strata above that for the benefit of which the work is done. If the work for each stratum is thus distributed to the several strata above it, we derive the *curve of distributed work.* (See Birge, 1916, p. 355). This is shown for the mean of each lake in Table 6 and for Seneca Lake in figure 3. The numbers for each stratum show how many gram centimeters are necessary to distribute through the stratum the heat retained in it and to convey through it the heat which goes on to lower strata. The table shows how shallow is the stratum which receives most of the work of the wind. More than 94 per cent of this work is expended in conveying the heat through the upper 20 m. of the lake. While the effect of the wind extends to the bottom, even in Seneca Lake, the work done in the deeper water is very small, as measured by the fall in density due to increased temperature. In the upper 5 m. are found from 43 to 50 per cent of the work and in this stratum the largest deductions from the apparent work are to be made for the influence of direct insolation.

TABLE 6.—DISTRIBUTED WORK, MEAN.

[NOTE.—This shows work done in each stratum in distributing the heat brought to it, and in carrying on to the next stratum the heat which passes through it. This is computed only for the means of the lakes.]

Depth in meters.	Canandaigua Lake.		Cayuga Lake.		Seneca Lake.	
	G. cm.	Per cent.	G. cm.	Per cent.	G. cm.	Per cent.
0–5	965.4	50.0	1,100.5	45.0	1,245.0	43.4
5–10	548.5	28.4	698.1	28.5	826.9	28.8
10–15	239.3	12.4	367.3	15.1	457.0	15.9
15–20	83.8	4.3	136.6	5.6	185.8	6.5
20–30	58.4	3.1	97.1	4.0	116.5	4.1
30–40	20.0	.9	28.3	1.2	29.5	1.0
40–50	9.1	.4	10.4	.4	9.1	.3
50–60	3.6	.2	4.2	.2	2.9	.1
60–70	1.0	.1	1.8	.1	1.3	....
70–80	.1	....	.9	....	.4	....
80–100	....	....	.3	....	....	....
	1,929.2	....	2,445.5	....	2,874.4	....

SUBTRACTION CURVES.

Table 7 shows the data for the mean subtraction curves of the three lakes. (See Birge, 1916, p. 384.) It shows the number of calories which pass through the several levels of the lakes and the amount of work needed to distribute them through the water below these levels. Comparison of the data at the surface shows that 12 to 14 cal. of heat are distributed through the subjacent water by 1 g. cm. of work. At lower levels the temperature declines and the decrease in density falls off even more rapidly with the result that an increasingly large number of calories is distributed by 1 g. cm. of work. At the depth of 10 m. the ratio is 25 to 30 cal. to 1 g. cm.; at 20 m. the ratio rises to 40:1 or 50:1; at 30 m. in Seneca Lake and at 40 m. in the others it has risen nearly or quite to 100:1. This relation explains how in lakes of great depth a large quantity of heat is carried in spring to the lower water. The great quantity of work needed for distribution in the upper water as the temperature rises equally makes clear the reason why the lower water soon ceases to gain heat as the season advances.

In Seneca Lake work amounting to only 0.4 g. cm. is needed to distribute 512 cal. to depths below 70 m., while no appreciable amount of work is needed to distribute 347 cal. through the water below 80 m. The last statement is obviously not strictly accurate, but it is not worth while to compute the work in those cases where the decrease in density due to increase of temperature is less than one part per million.

TABLE 7.—SUBTRACTION CURVE MEANS: AMOUNT AND PER CENT OF HEAT IN SUMMER HEAT INCOME AND OF WORK NECESSARY TO DISTRIBUTE THIS HEAT FOUND AT THE SURFACE AND AT DIFFERENT DEPTHS OF THE SEVERAL LAKES.

[NOTE.—Stated in units per square centimeter of the surface of the lakes.]

Depth in meters.	Canandaigua Lake.				Cayuga Lake.				Seneca Lake.			
	Cal.	P. ct.	G. cm.	P. ct.	Cal.	P. ct.	G. cm.	P. ct.	Cal.	P. ct.	G. cm.	P. ct.
0	26,980	100.0	1,929	100.0	29,480	100.0	2,446	100.0	34,020	100.0	2,874	100.0
5	19,140	70.9	964	50.0	21,860	74.1	1,345	55.0	26,220	77.2	1,629	56.8
10	12,460	46.2	415	21.6	15,480	52.5	647	26.5	19,120	56.3	802	28.0
15	1,500	27.8	176	9.2	9,980	33.8	280	11.4	12,610	37.1	345	12.0
20	4,980	18.4	92	4.9	6,380	21.6	143	5.8	8,160	24.0	159	5.6
30	2,640	9.8	34	1.8	3,280	11.1	46	1.8	3,960	11.7	43	1.5
40	1,410	5.2	14	.8	1,880	6.4	18	.6	2,260	6.7	13	.5
50	670	2.5	5	.2	1,110	3.8	8	.2	1,320	3.9	4	.2
60	280	.9	1	.1	700	2.4	4	.0	900	2.6	1	.0
70	40	.15	0	.0	440	1.5	2	...	630	1.8	...	...
80	0	...	...	...	280	1.0	0	...	450	1.3	...	...
100	...	...	...	...	90	.5	...	...	190	.6	...	...
130	...	...	...	...	0	...	...	...	60	.2	...	...
150	...	...	...	...	...	...	...	...	20	.0	...	...
188	...	...	...	...	...	...	...	...	0	...	...	...

HEAT AND WORK AS MEASURED AT DEPTH.

In Table 7 the data are given in terms of the surface of the lake—so many calories, or gram centimeters, per square centimeter of surface. If the datum plane is taken as the area of the lake at the depth in question, the number of calories and gram centimeters at each level will be increased proportionally to the decrease of area as compared with that of the surface; but the ratio between the amounts of work and of heat would remain unaltered. This relation is shown in Table 8. Perhaps the most interesting fact shown by it is the very close agreement between Cayuga and Seneca Lakes in both heat and work after the surface level is passed. Approximately equal quantities of heat pass through the 5 to 40 m. levels of both lakes. Cayuga Lake shows at the surface considerably less heat per unit of area than Seneca has, but this is largely due to the great area of shallow water at the north end of Cayuga Lake. No such area is found anywhere in Seneca Lake. The area of Cayuga Lake at 5 m. is about 79 per cent of the surface area, while that of Seneca Lake at the same depth is 87 per cent of the surface. The area of the 10 m. level in Cayuga is about 92 per cent of that at 5 m., and in Seneca about 93 per cent of the 5 m. level, a very close correspondence, which shows itself in the heat and work. The large area of shallow water in Cayuga Lake adds nothing to its effective area in absorbing heat, nor does it seem to diminish the efficiency of the lake. Canandaigua Lake, however, is plainly less efficient than either of the others. Its smaller area and higher banks cause this condition, since both factors lessen the efficiency of the wind. (See Birge and Juday, 1914, Pls. CXIII, CXIV, CXVI.)

TABLE 8.—AMOUNT OF HEAT IN SUMMER HEAT INCOME AND WORK NECESSARY TO DISTRIBUTE IT.

[NOTE.—Expressed in units per square centimeter of the depth in question; not (as in other tables) in units per square centimeter of the lake surface.]

Depth in meters.	Canandaigua Lake.		Cayuga Lake.		Seneca Lake.	
	Cal.	G. cm.	Cal.	G. cm.	Cal.	G. cm.
0	26,980	1,929	29,480	2,446	34,020	2,874
5	22,970	1,150	27,750	1,710	28,000	1,740
10	16,540	549	21,440	892	21,900	922
15	10,560	246	14,530	406	14,900	410
20	7,350	136	9,800	220	10,100	197
30	4,340	56	5,420	76	5,190	56
40	2,630	26	3,440	33	3,150	17
50	1,520	11	2,330	17	1,980	6
60	830	4	1,640	9	1,480	1.7
70	40		1,150	5	1,110	
80			820		840	
100			300		420	
130					170	
150					90	
188					0	

ABSORPTION OF SUN'S ENERGY.

Observations were made in 1918 on Seneca, Cayuga, and Canandaigua Lakes in order to ascertain the rate at which the energy of the sun's rays is absorbed by the water of the lakes. The instrument is described in another paper (Birge, 1921), and the description will not be repeated. It consists of a receiver containing 20 small thermal couples which can be lowered into the lake to any desired depth and alternately exposed to the sun and covered. The electrical effect of the sun's radiation on the thermal couples is proportional to the energy in its rays, and the resulting electrical currents are measured by the deflections caused in a d'Arsonval galvanometer. The galvanometer is kept on shore and is connected with the receiver by an insulated cable 100 m. long.

The observations on the three lakes afford excellent illustrations of the results obtainable by this instrument, and also of the difficulties which necessarily attend observations of the kind if made in the course of a short visit, when every opportunity must be fully used. The general results from each lake are clear and unmistakable, but in each case the details are affected by special conditions of sky or water.

A part of the observations on Seneca Lake is given in Table 9 in order to show the nature of the data.

TABLE 9.—TRANSMISSION OF SUN'S ENERGY BY THE WATER OF SENECA LAKE OFF HECTOR POINT, N. Y., AUG. 1, 1918.

[NOTE.—1.50 to 2.23 p. m., Government time=12.40 to 1.11 sun time. Transparency 6.8 m.]

Hour, p. m.	Depth in centimeters.	Zero.	Reading.	Deflection.
1.50	0	10.5 10.0	127.8 126.7	117.0
1.55	25	13.5 13.0	83.0 84.0	70.3
1.57	50	13.0 13.0	77.0 77.0	64.0
1.58	100	12.5 12.5	59.5 50.0	47.3
1.59	150	12.5 12.5	50.5 51.5	38.5
2.00	200	12.5 12.2	45.8 45.5	33.2
2.01	250	12.2 12.0	40.6 40.2	28.3
2.03	300	12.1 12.0	35.8 36.5	24.1
2.05	350	12.3 12.1	32.3 32.1	20.0
2.07	400	12.1 12.1	29.2 29.2	17.1
2.09	500	12.2 12.2	24.2 24.0	11.9
2.12	600	12.1 12.1	20.3 20.5	8.3
2.14	700	12.2 12.2	18.1 18.1	5.9
2.17	800	12.2 12.2	16.2 16.1	4.0
2.18	900	12.1 12.3 12.2	15.1 15.1 15.0	2.9
2.23	1,000	12.2 12.2 12.2 12.4 12.3	14.5 14.4 14.6 14.6	2.2

NOTES ON ABOVE TABLE.

1. Sky perfectly clear and sun's radiation steady; no clouds; practically no haze. Light south air, causing ripples on surface. Some swell from wind of yesterday and of early morning. The swell caused irregularities of reading in upper water, as it raised and lowered the boat. At 100 cm. the scale moved over 4 to 5 divisions, and reading had to be estimated under these conditions. This effect became less as depth increased. Ripples cause a quivering of the reading in the galvanometer but are too small to cause swings of the scale.

2. In reading the direct sun a shunt coil is included in the circuit in order to keep the reading within the limits of the scale. This coil is cut out by a switch when the receiver is used in water. The reading in air must be multiplied by 1.89 to reduce it to the same scale as those in the water. Its value, therefore, on this occasion is 221 divisions. One division equals 0.059 cal./cm.^{2}/min., so that the sun was delivering about 1.30 cal./cm.^{2}/min.

3. The observations not reported included a repetition of several of the readings, and a second reading in the air, which gave a value of 116.2 divisions, or substantially the same as the first reading.

4. The numbers in the columns headed *zero*, *reading*, *deflection*, indicate divisions of the scale of the galvanometer.

From these readings may be computed the value of the energy delivered by the sun at different depths of the lake, as is shown in the following table:

TABLE 10.—CALORIES PER SQUARE CENTIMETER PER MINUTE FOUND AT VARIOUS DEPTHS OF SENECA LAKE, AUG. 1, 1918.

Depth in centimeters.	Per cent.	Cal./cm.^{2}/min.
In air	100.0	1.30
25	31.8	.41
50	29.0	.38
100	21.4	.28
150	17.4	.23
200	15.0	.20
250	12.8	0.17
300	10.9	.14
350	9.0	.12
400	7.7	.10
500	5.4	.07
600	3.8	.05
700	2.7	0.035
800	1.8	.023
900	1.3	.017
1,000	1.0	.013

TABLE 11.—TRANSMISSION OF SUN'S ENERGY PER METER OF DEPTH.

[NOTE.—Per cent of the energy found at the upper surface of each 1 m. stratum which is present at the lower surface of such stratum.]

Stratum in meters.	Transmission, per cent.	Stratum in meters.	Transmission, per cent.	Stratum in meters.	Transmission, per cent.
0–1	21.4	4–5	69.6	8–9	72.2
1–2	70.2	5–6	69.8	9–10	75.9
2–3	72.6	6–7	71.1		
3–4	71.0	7–8	67.8		

Table 11 is given as it stands in order to bring out the various small variations in percentage which are inherent in the observations. In all cases the fraction of a division of the galvanometer scale must be estimated and is, therefore, subject to error. The value taken as zero is not a fixed one and in any observation may be recorded slightly too low, or more probably a little too high. The motion of the boat, due to the swell, as stated above, might introduce some errors in this case, especially in the readings from the upper water. In figure 2 the results are plotted and a smooth curve *a–a* is drawn through them. All of the observations are very close to the curve. It is plain that there was transmitted through each 1 m. stratum of water below the surface meter about 71 per cent of the energy received at its upper surface. It is not probable that the higher transmission indicated in the 9 to 10 m. stratum has any significance. A reading of 2.1 divisions of the scale at 10 m. instead of 2.2 divisions would bring this interval into line with the others.

Lake water differs widely from pure water in the quantity of energy transmitted. If we assume a solar energy curve corresponding to a path of the rays in the air of 1.5 atmosphere, with about 0.5 cm. condensable water in the atmosphere, about 47 per cent of the solar energy will be left after passing through 1 m. of pure water. The water of Seneca Lake, therefore, cuts off about 25 per cent more than does pure water and adds one-half to the loss due to pure water. Pure water transmits through the 1 to 2 m. stratum nearly 80 per cent of the energy reaching its upper level and over 90 per cent passes through all deeper 1 m. strata, the loss per meter rapidly declining to a minimum of about 2 per cent of the energy incident on the upper surface of the stratum. At 5 m., therefore, there would remain about 29 per cent of the original energy of the sun and about 23.4 per cent at 10 m. instead of 5.4 per cent and 1 per cent found in Seneca Lake. This wide difference between pure water and the lake water is probably due chiefly to matter suspended in the water of Seneca Lake, since there is very little stain present in the water. The suspended matter is partly organic but chiefly fine silt derived from the soft shales that constitute much of the shores.

In pure water the transmission through the 1 to 2 m. stratum is much smaller than in those below. This is due to the rapid absorption of the rays of the red end of the spectrum as compared with the slow absorption of the shorter waves. No such effect seems to be present in the lake, nor is it ordinarily demonstrable in lakes. Sometimes, but not commonly, the deeper strata of a lake show a transmission 1 or 2 per cent higher than the 1 to 2 m. stratum, but in general the transmission in that stratum is nearly the same as in those immediately below. This means that the large nonselective absorption due to turbidity and the selective absorption due to stain obscure the selective absorption of the water, as water, after the first meter has been passed. In that meter of water is absorbed practically all of the energy contained in that part of the spectrum

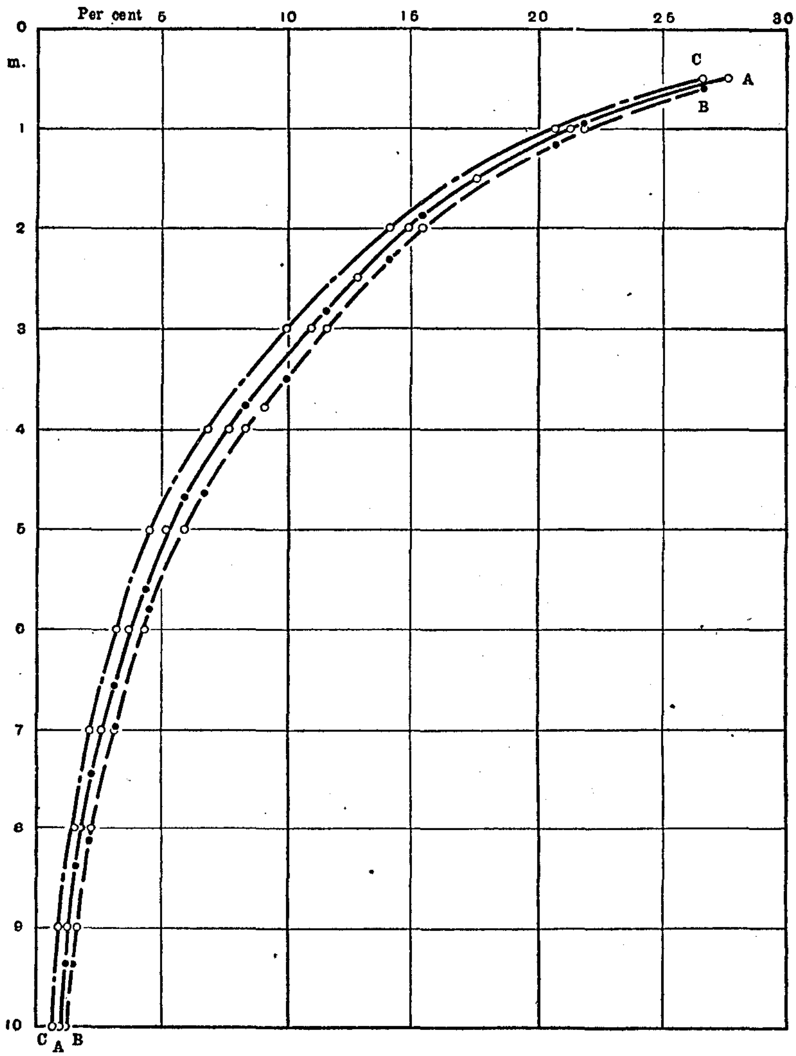

FIG. 2.—Curves of transmission of sun's radiation, Seneca Lake, Aug. 1, 1918. The vertical axis gives depth and the horizontal axis gives per cent of the total radiation of the sun. *A-A*, direct observations; *B-B*, vertical sun; *C-C*, mean sun. The sun's rays passed through a thickness of 100 cm. water of the lake at the depth of 94 cm. Dots are placed corresponding to this depth on the curve *A-A*, and from these is plotted the curve *B-B*, for the sun in the zenith when depth and stratum traversed by rays are equal. The rays pass through a mean distance of 115 cm. during the warming season in reaching a depth of 100 cm. These points are marked on the curve *B-B*, and from them is plotted the curve *C-C* or the curve of mean sun. (See Table 12, p. 228.)

lying below the *A* line which is commonly taken as the lower limit of the visible spectrum.

The general result of these observations is, therefore, plain. Under the conditions of the time and place 21 to 22 per cent of the sun's energy delivered to the surface was present at a depth of 1 m. In the deeper 1 m. strata there was a loss of 28 to 29 per cent of the energy present at the upper surface of the stratum. At 5 m. depth there remained about 5.4 per cent, and at 10 m. about 1 per cent of the energy delivered to the surface.

We may infer from such a set of observations the penetration of the sun's rays during the whole day or during a longer period, assuming that the turbidity and color of the water remain unchanged. In such a process it is not hard to secure results which are correct in general, but it is impossible to secure minute accuracy. Certain, though not all, of the facts which prevent minute accuracy will be mentioned.

1. Sunlight is a mixture of the direct rays of the sun and of rays reflected from the sky. The percentage of sky radiation is very variable, being sometimes as low as 8 per cent of the total radiation and rising nearly to 100 per cent when the sun barely shines through haze or cloud. The quantity of energy reflected from a unit area of sky is also variable and differs with the nature of the sky and the proximity of the area to the sun. The mean percentage of sky radiation reflected from the surface of the water differs from that of the direct rays, and the mean path in water of the rays from the sky differs from that of the direct rays. It is practically impossible, under the conditions of observations on lakes, to determine either the amount or the distribution of the sky radiation. It is, therefore, impossible to make full correction for the elements in the mixture of direct and diffuse rays at the time of observations.

2. It is also impossible to make such corrections for longer periods, since the average amount of sky radiation is still quite unknown for most places, and is not accurately known anywhere.

3. No correction has been made in the observations for radiation reflected from the surface of the water, but the readings at 1 m., etc., have been compared directly with the reading in air. The direct sun radiation, at the altitude of the sun when the observations were made, would lose about 2.1 per cent by reflection. The sky radiation would lose 17.3 per cent if equal quantities came from equal areas of sky. This loss at the surface, which can not be known accurately, has been balanced against the opposite effect of the hemispherical glass cover of the sunshine receiver. There would be about 4 per cent of the sun's radiation reflected from this in air and about 0.5 per cent in water.

In computing a standard curve of absorption for Seneca Lake, all radiation has been referred directly to the sun, and the path of the rays in the water has been computed on that basis, from the following elements:

Time of observations, August 1, 1918, 12.40 to 1.11 sun time.
Corresponding altitude of sun, August 1, 64.1 to 62.3°.
Depth at which sun's rays pass through 1 m. of water, at first observation, 94.5 cm; at last observation, 93.7 cm.; mean 94.1 cm.

On the *curve of direct observations* (*A–A*, fig. 2) are noted the readings at the distances corresponding to this path of the rays in water. These periods are plotted and connected by a new curve, *B–B*, the *curve for vertical sun*. In this curve, which assumes a sun in the zenith, the depth below the surface equals the length of path of the rays in reaching that depth. This constitutes a standard curve, from which may be derived the energy which remains at given depths below the surface at any time of the day or year, provided the altitude of the sun is known and the corresponding length of the path of its rays in water. It must be assumed also that all radiation comes directly from the sun, or at least that the value of the sky radiation is the same as at the time of observation.

The results are stated in Table 12, vertical sun.

The mean distribution of sunshine and cloud at Seneca Lake is not known, but at Madison, Wis., the mean daily supply from sun and sky during the five months April 1 to August 31 is 398 cal. The mean path of the rays during this period to reach a depth of 100 cm. below the surface is 115 cm. In this computation allowance is made for reflection from the surface in excess of 2.1 per cent; all radiation is supposed to come from the sun; and the form—though not the area—of the solar energy curve is supposed to be constant.

The points corresponding to this distance of 115 cm. per 100 cm. of depth are noted on the curve for vertical sun, carried up to their proper place, and a third curve, *C–C*, figure 2, is drawn, which is the curve for mean sun (Table 12).

TABLE 12.—TRANSMISSION OF SUN'S RAYS BY WATER OF SENECA LAKE, AUG. 1, 1918. (See fig. 2, p. 226.)

Depth in centimeters.	Per cent radiation remaining at depth indicated.			Depth in centimeters.	Per cent radiation remaining at depth indicated.		
	Observed per cent.	Computed per cent.			Observed per cent.	Computed per cent.	
		Vertical sun.	Mean sun.			Vertical sun.	Mean sun.
100	21.4	21.9	20.7	600	3.8	4.4	3.3
200	15.0	15.6	14.3	700	2.7	3.2	2.3
300	10.9	11.5	9.9	800	1.8	2.3	1.6
400	7.7	8.3	6.8	900	1.3	1.7	1.0
500	5.4	6.0	4.7	1,000	1.0	1.2	.7

This curve of mean sun and Table 12 show that in Seneca Lake at 1 m. depth there is found an average of about 20.7 per cent of the incident radiation and that each 1 m. stratum below transmits less than 70 per cent of the radiation received by its upper surface. The water has absorbed 99 per cent of the incident energy at about 9 m. as compared with about 10 m. for the observed curve and 11 m. or more for the curve of vertical sun.

The difference in the three curves are not striking in this case; but if the observations had been made at an hour farther from noon, or later in the season, the difference would have been correspondingly larger.

It must not be supposed that this mean sun curve represents exactly the mean conditions actually present during the period when the lake is warming. The transparency of the water is variable and the sun's penetration varies with it. No account is taken in this curve of the energy received during cloudy hours. Yet after all deductions are made it remains true that the curve gives a generally correct picture of the actual direct delivery of the sun's radiation to Seneca Lake so far as a single observation can give this. Hardly more than 20 per cent of the incident energy is delivered to water below the surface meter. Not over 5 per cent is delivered to a greater depth than 5 m. and not over 1 per cent below 10 m. Even a considerable increase in transparency would leave these figures, not unchanged, but of the same order of magnitude.

Observations such as these are ordinarily made at times when the sky radiation is relatively small—near noon of clear days. When, therefore, such an observation is used as the basis of larger conclusions and when in computing the results all radiation is assumed to be direct, the effect of the direct rays of the sun in warming the lake is placed at a maximum. In the preceding paragraph all radiation is supposed to come directly from the sun. In fact at Madison about 16 per cent of the total radiation

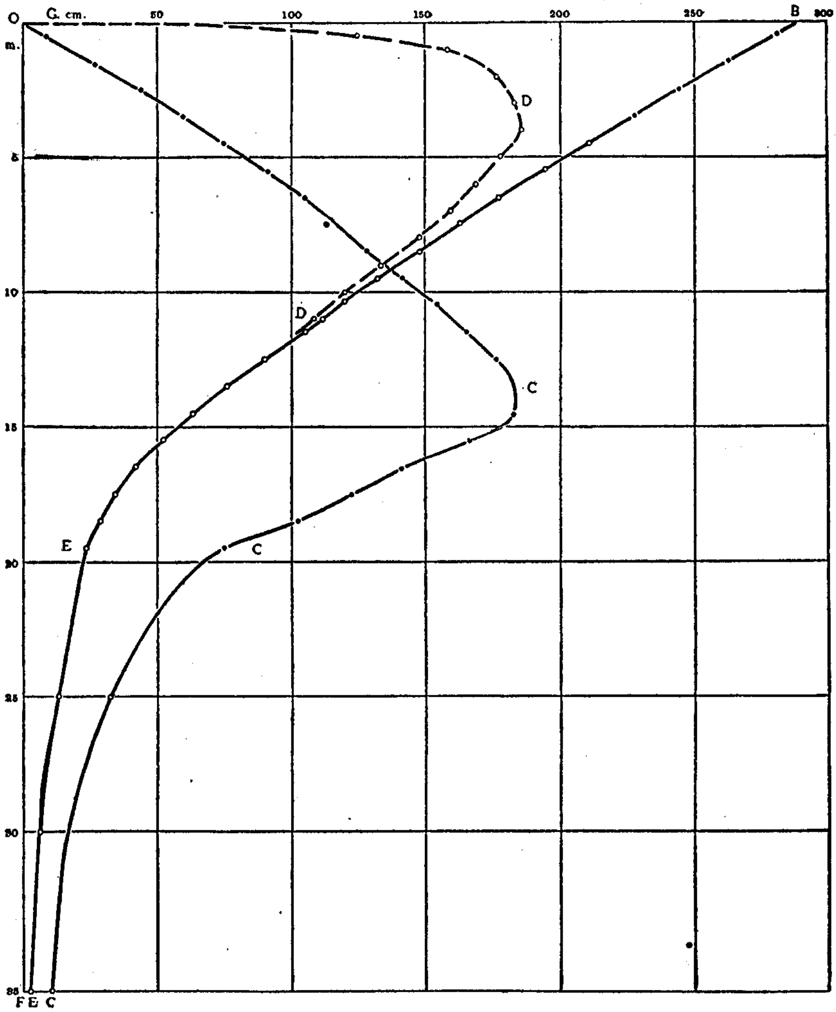

FIG. 3.—Work curves of Seneca Lake, mean temperature. The vertical axis shows depth; the horizontal axis shows gram centimeters of work per meter of depth and square centimeters of surface of lake. *OCC*, curve of direct work. About 145 g. cm. of work, for instance, are necessary to carry the heat of the 9 to 10 m. stratum from the surface and put it in place. *BDE*, curve of distributed work, derived from *OCC*, showing the amount of work done in each 1 m. stratum. The area *OBEFO* (distributed work) is equal to the area *OCCFO* (direct work). *ODD* shows the contribution of the sun in distributing the sun's energy. The area *ODDBO* gives the contribution of the sun, and that of the wind is represented by the area *ODEFO*. (See Table 16, p. 235.)

received April 1 to August 31 comes during cloudy hours, and about 16 per cent more comes from the sky during sunny hours. The direct sun, therefore, supplies only about two-thirds of the radiant energy received by the lake. It may be assumed that during cloudy hours equal areas of sky supply equal amounts of energy to a surface normal to the rays. On this basis, and allowing for reflection from water surface, the mean path of the diffuse radiation in reaching a depth of 100 cm. would be about 126 cm. as compared with 115 cm. for the direct rays. The mean path for sky radiation during sunny hours would be between the numbers given above, depending on the relative amount of the sky radiation coming from areas close to the sun and, therefore, having approximately the same length of path in the water as the sun's rays have.

In the absence of knowledge of the amount of sky radiation at Seneca Lake, either general or on the date of observation, no correction can be made for sky radiation. Such correction can be made where observations are so numerous that it may safely be assumed that sky radiation was the mean amount. This is the case with Lake Mendota, and the best computation that can be made shows that the mean path of all rays to reach a depth of 100 cm. in the period of April 15 to August 15 is about 118 cm. No essential difference, therefore, is made in the results if all radiation is attributed to the sun with a mean path of 115 cm., as has been done in the previous paragraphs.

The observations on Canandaigua and Cayuga Lakes may be treated much more briefly. They were taken at the same intervals as on Seneca Lake but to the depth of 5 m., which is ample for the determination of the rate of absorption. The results are shown in figures 4 and 5, and summarized in Tables 13 and 14.

TABLE 13.—TRANSMISSION OF RADIATION BY WATER OF CAYUGA LAKE, SHELDRAKE POINT, JULY 29, 1918, 1.45 TO 2.45 P. M., GOVERNMENT TIME. (See fig. 4.)

[NOTE.—Sky with cumulus clouds drifting across; clear between clouds. Transparency of water 6.2 m. Transmission per meter about 66 per cent.]

Depth in centimeters.	Per cent radiation remaining at depth indicated.				Depth in centimeters.	Per cent radiation remaining at depth indicated.			
	Observed per cent.	Mean observed per cent.	Computed per cent.			Observed per cent.	Mean observed per cent.	Computed per cent.	
			Vertical sun.	Mean sun.				Vertical sun.	Mean sun.
100	19.2 19.6	19.4	19.9	17.9	400	5.6 5.4	5.5	6.1	4.9
200	13.4 11.3 11.4	12.8	13.3	11.9	500	3.6 3.4 3.6 3.5 3.7	3.6	4.1	3.1
300	8.1 8.6	8.4	9.1	7.6					

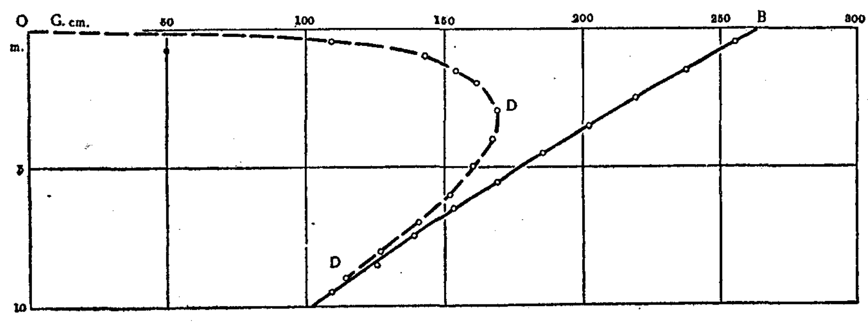

FIG. 4.—Work curves for Cayuga Lake. (See explanation, fig. 3.)

The observations on Cayuga Lake are rendered somewhat irregular by the fact that numerous white cumulus clouds were passing over the sky and work had to be done when the sun was in the spaces between the clouds. Under these conditions the radiation from the sun is sure to be variable; the approach to the sun of a white cloud momentarily raises the radiation and unnoticed wisps of cloud may reduce it. In the series it is clear that the mean of the readings at 200 cm. is too low as compared with all of the others, since the transmission in the 1 to 2 m. stratum should be about the same as below. The value of 12.8 per cent has been assumed, therefore, for the 200 cm. level and a mean transmission of about 66 per cent per meter. Under these conditions about 99 per cent of the sun's energy would be delivered to the upper 8 m. of water, somewhat more than 80 per cent going to the first meter, or with mean sun about 82 per cent.

It will be noted that corresponding with the smaller transparency of the water, as compared with Seneca Lake, the transmission of radiation is decidedly lower.

TABLE 14.—TRANSMISSION OF SUN'S ENERGY BY WATER OF CANANDAIGUA LAKE, JULY 27, 1918, 11.37 A. M. TO 12.03 P. M., GOVERNMENT TIME. (See fig. 5.)

[NOTE.—Sky hazy. Transparency of water 4.4 m. Transmission per meter about 60 per cent.]

Depth in centimeters.	Per cent radiation remaining at depth indicated.			Depth in centimeters.	Per cent radiation remaining at depth indicated.		
	Observed per cent.	Computed per cent.			Observed per cent.	Computed per cent.	
		Vertical sun.	Mean sun.			Vertical sun.	Mean sun.
100	18.7	19.4	18.0	400	4.2	4.8	3.7
200	11.3	12.2	10.7	500	3.1	3.1	2.2
300	6.9	7.8	6.3				

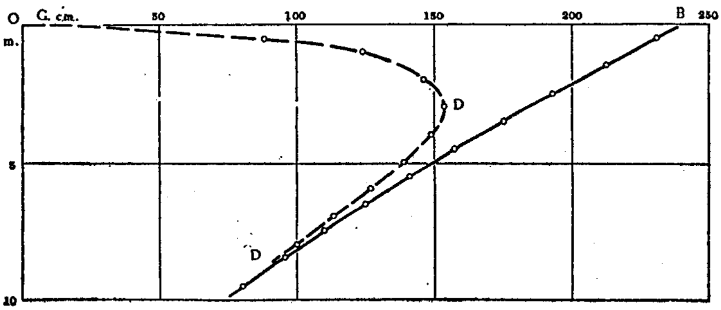

FIG. 5.—Work curves for Canandaigua Lake. (See explanation, fig. 3.)

The observations on Canandaigua Lake were also somewhat irregular, not on account of clouds, but haze. The sky was cloudless, but the hills a few miles up the lake were nearly invisible in the haze which filled the valley. Under such conditions the value of the sun's radiation is much reduced, and it was found to be about 0.95 cal./cm.^{2}/min. as compared with 1.30 cal. in the case of the two other lakes. The readings of the sun at the beginning and end of the observations in the lake were in close agreement. The readings of the first series taken in the water—those taken while the receiver was going down—were also in close agreement and indicate that 18 to 19 per cent of the radiation in air was present at 100 cm. depth and that each meter below that depth transmitted about 60 per cent of the radiation received by its upper surface. At 500 cm., however, the reading rose so that the transmission seemed to rise to about 74 per cent. The second set of readings—those taken while the receiver was being raised—again indicated about 60 per cent transmission but showed at all depths a higher percentage of the radiation at the surface, amounting at 100 cm. to 21 per cent. Comparison with the other lakes shows that the lower value at 100 cm. is to be chosen, as the transparency of the water is decidedly less than in either Cayuga or Seneca Lakes. The haze must have become slightly thinner during the later readings in the water but thickened again before the second reading in the air. The accuracy of the value at 100 cm. must remain somewhat uncertain under the conditions of sky then prevailing. Since the value of the radiation may alter during haze almost from minute to minute with no visible indication of change, such as cloud offers, it would need a very large number of readings to show whether 18 to 19 per cent or a slightly lower figure should be taken as the value for mean sun at 100 cm. The error is not likely to exceed 1 per cent in any case, nor is it large enough to affect general relations of sun to the distribution of heat.

Under these conditions 99 per cent of the sun's energy would be delivered to the upper 6.5 m. of water.

We may now put together the general results from the three lakes in which observations were made.

TABLE 15.—TRANSPARENCY AND TRANSMISSION OF RADIATION—VERTICAL SUN.

	Transparency in meters.	Per cent at 100 centimeters.	Per cent transmission per meter.
Seneca Lake	6.8	21.9	72
Cayuga Lake	6.2	19.9	66
Canandaigua Lake	4.4	19.4	60

In these cases there is some parallelism between the percentage of transmission and the transparency of the lake. This is due to the fact that all these lakes have water which is only slightly stained and which does not differ greatly in color. In general there may be little correlation between transparency and rate of transmission.

WORK OF THE SUN IN DISTRIBUTING HEAT.

From the data at hand it is possible to make a general estimate of the part which the sun plays in distributing the heat gained by Seneca Lake as its summer heat income. We have as data (*a*) the amount of heat so gained as the mean of four seasons; (*b*) the amount and the distribution of the work necessary to carry this heat through the lake, assuming that all work is done by the wind; (*c*) the actual amount of heat delivered into the water of the lake directly by the sun on one date, and the conclusions drawn from these observations in the preceding paragraphs. We lack as data (*a*) the total amount of heat delivered to the lake during the period when the summer heat income is gained; (*b*) the losses of heat during this period from different strata near the surface.

The absence of the data specified and others as well make it impossible to state the rôle of the sun with any approach to exactness. But it is possible to make estimates which will show the general situation and in our almost complete ignorance of the subject, such statements are not without value.

We take, therefore, as the summer heat income of Seneca Lake 34,000 cal./cm.^{2} of surface. Of this sum, 32,400 cal. are found below 1 m.; 28,000 cal. below 5 m.; and 21,900 cal. below 10 m. These figures are based on the calories found per square centimeter of the depth in question, and not those per square centimeter of the surface. In computing the relative work of sun and wind these figures must be used, since the sun's radiation which passes through the shallow water is absorbed by the bottom of the lake.

The distribution of this heat, attributing all work to the wind, requires about 2,874 g. cm. of work per square centimeter of the lake's surface. This work is distributed (fig. 3) at the rate of about 290 g. cm./cm.^{2} of the surface at the surface; 270 g. cm./cm.^{2} at 1 m. depth; 202 g. cm./cm.^{2} at 5 m.; and 125 g. cm./cm.^{2} at 10 m. In the upper 5 m. there is done about 45 per cent of the total work; about 33 per cent in the 5 to 10 m. stratum, both of which are within reach of the direct influence of the sun; about 20 per cent more of the work comes in the 10 to 15 m. stratum.

Applying the experience gained from observations on Lake Mendota, it may fairly be assumed that Seneca Lake receives about 65,000 cal./cm.^{2} of surface during the period of the summer heat income. The lake loses, therefore, about one-half of the incident heat.

If we apply the mean sun data of Table 12 to this gross income, the sun delivers during this period about 13,400 cal. to the depth of 1 m.; 3,000 to 5 m.; and 450 to 10 m. These numbers are, respectively, 41 per cent, 11 per cent, and 1.9 per cent of the quantity of heat which passes through these levels. (See Table 7 for quantity of heat.)

The work attributed to the wind at these depths would be diminished by the aid of the sun in the same ratio that the heat delivered by the sun bears to the total amount of heat passing through those levels. Computed on this basis, the sun does all of the work of distributing heat at the surface, 41 per cent at 1 m. depth, 11 per cent at 5 m., etc. These quantities may be plotted as on figure 3 (p. 229) and the points connected by a curve. Then the area *ODBO* is proportional to the total work done by the sun under the conditions assumed. This area may be measured with a planimeter. It is equal to about 16 per cent of the area representing the total work. The part of it below 1 m. is about 10.9 per cent of the work done below 1 m. of depth.

This represents the maximum possible aid which, under the conditions assumed, the sun can give in the distribution of heat, for it assumes that the entire loss of incident radiation by the lake, amounting to one-half of that received, falls on the wind-placed heat and that no loss falls on the sun-placed heat. This assumption is evidently not correct. If, instead, we assume that the sun-placed heat suffers equal losses with that distributed by the wind, the aid of the sun will be reduced to about 8 per cent of the total work done and to about 5.5 per cent of the work done below 1 m.

Probably the assumption of equal losses is unfair to the sun. A great part of the lost heat is in that which is absorbed by the thin stratum at the surface and is used in evaporation, lost to the air at once or during the following night, etc. Almost all of the heat in the longer waves of the spectrum is absorbed by a much thinner layer of water than 1 m. Schmidt (1908, p. 240) computes that about 27 per cent of the solar energy is absorbed by 1 cm. of pure water and about 45 per cent by 1 dm. He uses Langley's energy curve for the solar spectrum, which makes his figures somewhat larger than would be the case in a curve for moderately high sun. In the curve which we have used as standard (path of rays equals 1.5 atmospheres) about 43 per cent of the energy would be absorbed by 25 cm. of pure water and 49 per cent by 50 cm. While no great accuracy can be claimed for the figures shown by Seneca Lake of about 67 per cent absorption for 25 cm. and 72 per cent for 50 cm., they are probably not greatly in error. The differences between them and the data for pure water are much the same as for greater depths. Thus more than one-half of the sun's energy is delivered to the upper centimeters of water from which loss to the air is easy. But much of the heat so delivered is distributed by the wind from the surface strata to deeper water, especially in the early part of the warming season when the lake is gaining heat rapidly. From this source comes the greater part of the heat which the lake gains below 1 m. in excess of that delivered by the sun. This heat amounts to 19,000 cal./cm.^{2} and much of it must come from the 40,000 cal./cm.^{2}, or more, absorbed by the upper 25 cm. of the lake. During bright and windy days there must be thus moved down into the lake by the wind much heat which is lost during cool periods when the whole upper water of the lake cools down.

It is true that on the whole the heat delivered by the sun to strata below the surface is more likely to be retained, as the water above a stratum must be cooled to a lower temperature than the deeper water before any heat can be lost by the latter. But several times each season there is a general cooling of the upper water, when much heat is lost, that placed by the sun as well as that placed by wind.

At present, therefore, no accurate estimate can be made of the loss of sun-placed heat at various depths. The subject must be left here with the general statement that between 84 and 92 per cent of the work done in distributing heat through the water of Seneca Lake is performed by the wind, on the assumption that conditions of transparency, etc., on August 1 were average ones. The amount really attributable to the sun is probably as much as 10 to 12 per cent. More than this can not be said, both in view of considerations presented above, and also in view of one other consideration which the study of Lake Mendota has shown. In the early part of the warming period, when gains of heat are rapid and when the deeper water is securing most of its heat, the sun plays a small part in distributing the heat. Later in the summer the sun has a much larger share of the work, when the epilimnion is forming, when gains of heat are small (perhaps only 5 to 10 per cent of the incident radiation), and when these gains are confined to the surface strata.

The foregoing paragraphs have dealt with Seneca Lake alone. The same methods may be applied to the other lakes with similar results. It is unnecessary to give the details of the computations; the results are shown in Table 16 (p. 235) and figures 4 and 5 (pp. 230, 231).

TABLE 16.—DIVISION OF DISTRIBUTION OF SUMMER HEAT INCOME BETWEEN SUN AND WIND IN THE LAKES AS A WHOLE AND IN THEIR SEVERAL STRATA. (See figs. 3, 4, 5, and text.)

[NOTE.—In this table, as elsewhere in this paper, "work" means the total work which would be needed to distribute the heat from the surface of the lake through the adjacent water, computed on the assumption that all heat is put into place by the wind mixing the warmer surface water with the cooler water below. In the division of the task of distributing heat between sun and wind it is also assumed that all losses of heat fall on wind-placed heat. This evidently attributes too large a share to the sun. Probably a fair estimate would be to allow to the sun all that it does below 1 m., i. e., about 10 to 11 per cent of the total.]

	Canandaigua Lake.		Cayuga Lake.		Seneca Lake.	
	Sun.	Wind.	Sun.	Wind.	Sun.	Wind.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Total work	16.9	83.1	15.0	85.0	15.8	84.2
Work, 0 to 5 m.	31.6	68.4	33.1	66.9	32.0	68.0
Work, 5 to 10 m.	2.9	97.1	4.6	95.4	6.6	93.4
Work, 0 to 1 m.	62.3	37.7	60.8	39.2	58.3	51.7
Work, below 1 m.	10.5	89.5	10.0	90.0	11.1	88.9
Work, below 5 m.	1.7	98.3	2.4	97.6	3.3	96.7
Total work of sun and wind	1,929 g. cm.		2,446 g. cm.		2,874 g. cm.	

PLANKTON.

The fresh-water organisms which constitute what is known as the plankton may be separated into two groups, namely, (*a*) those forms which are large enough to be captured readily with a regular plankton net whose straining surface is made of bolting cloth, size No. 20 (new No. 25) and (*b*) those forms which are so small that they readily pass through the meshes of this bolting cloth. The former constitutes the net plankton and the latter may be called the nannoplankton. The latter term has been applied specifically to those organisms whose maximum diameter does not exceed 25 μ; but it is proposed to extend the meaning of this term to include all of the material that passes through the meshes of the net. The terms "macroplankton" and "microplankton" have been used to designate these two groups.

METHODS.

The net plankton was obtained by means of a closing net which has been fully described in a previous paper so that it is not necessary to consider it further here (Juday, 1916). The coefficient of this net is 1.2; that is, about 80 per cent of the column of water through which it is drawn is strained. The catches from the different strata were concentrated in the plankton bucket; the material was then transferred to 8-dram vials and preserved in alcohol. In the enumeration the volume of the catch was reduced to 10 cm.^{3}; after shaking thoroughly 2 cm.^{3} were removed with a piston pipette and the crustacea and rotifers contained therein were counted with a binocular microscope. The number thus obtained multiplied by the factor five represents the total of such organisms in the catch. When only a few of the larger crustacea were present, the total number was ascertained by direct count. The smaller organisms, such as the Protozoa and algæ, were enumerated by placing 1 cm.^{3} of the material in a Sedgwick-Rafter cell and ascertaining the number of the various forms in the usual manner by means of a compound microscope.

Samples of water for a study of the nannoplankton were obtained by means of a water bottle. The minute organisms were secured from these samples by means of an electric centrifuge having a speed of 3,600 revolutions per minute when carrying two

15 $cm.^3$ tubes of water. The sedimentation was usually completed in about six minutes. The material was then transferred to a counting cell with a long pipette and the organisms were enumerated with a compound microscope having a 16 mm. objective and a No. 8 ocular. Many of these organisms, more especially the minute flagellates, are destroyed by the various preserving agents, so that it is necessary to have the living material for these enumerations; such counts must be made, therefore, as soon as possible after the samples of water are obtained.

The results obtained in the various enumerations are shown in Tables 17, 18, and 21. The figures indicate the number of individuals per cubic meter of water at the different depths. For purposes of comparison the results obtained for net plankton on Canandaigua, Cayuga, and Seneca Lakes in 1910 are shown in Table 18. Observations were made on the net plankton and nannoplankton of Green Lake, Wis., in 1918, soon after these were made on the Finger Lakes, and these have been included in Tables 17 and 21 for comparative purposes also.

NET PLANKTON.

Phytoplankton.—Table 17 shows that the green and blue-green algæ were scarce in the three Finger Lakes at the time of the observations in 1918. Only three forms were present, namely, Anabaena, Microcystis, and Staurastrum. In Canandaigua Lake a relatively small number of colonies of Microcystis was found in the upper 10 m. and Staurastrum was noted in the 10 to 40 m. stratum. In Cayuga Lake Anabaena was obtained in the upper 5 m. and Microcystis in the upper 10 m. In Seneca Lake this group was represented only by a few colonies of Microcystis in the 10 to 15 m. stratum. A comparison with Table 18 shows that fewer forms were present in 1918 than in 1910 and also that the number of individuals was much smaller in the former year. The two sets of catches on Canandaigua Lake present the most marked difference in this respect.

The net catches from Green Lake, Wis., contained a much larger algal population than the Finger Lakes, owing to the presence of a large number of filaments of Oscillatoria. This form was unusually well represented in the upper 15 m., a maximum of nearly two million filaments per cubic meter of water being found in the 0 to 5 m. stratum.

In the Finger Lakes the most abundant diatom, both in 1910 and 1918, was Asterionella, while Fragilaria was second in importance both years. In Canandaigua Lake the diatom population was substantially the same in these two years, while in Cayuga Lake the number was much larger in the former year. In Seneca Lake, on the other hand, the number was larger in 1918 than in 1910.

In Green Lake Asterionella was the only diatom noted, a few individuals of this form being present in two catches.

Zooplankton.—Uroglena was fairly abundant in the upper 30 m. of Canandaigua Lake and a few colonies of Epistylis were noted in the 5 to 10 m. stratum. In 1910 Ceratium was the most abundant protozoan in this lake; but it was not found in 1918.

In Cayuga Lake Actinosphaerium and Ceratium were about equally numerous in 1918, both being most abundant in the upper 15 m. The former was not found in 1910. and the latter was much more abundant in this year than in 1918, the number reaching more than a million and a half per cubic meter in the 0 to 5 m. stratum. Dinobryon was not as abundant in 1918 as in 1910 and Mallomonas was not noted in the former year.

In Seneca Lake Ceratium and Dinobryon constituted the protozoan population. A relatively small number of the latter was noted in the 5 to 10 m. stratum. Ceratium was distributed through the upper 20 m. but was most abundant in the upper 5 m.

The rotifer population was largest in Cayuga Lake and smallest in Canandaigua Lake in 1918. In the latter lake rotifers were most numerous in the upper 10 m. while in Cayuga and Seneca Lakes the largest number was found in the upper 15 m.

The maximum number of individuals in the rotifer group was noted for Synchaeta in Cayuga Lake, where it reached 44,700 per cubic meter of water in the 10 to 15 m. stratum; the average number in the upper 15 m. was 35,950 individuals. This form was not found in the other two lakes.

Polyarthra was noted in the catches from each of the three lakes in 1918, but it was most numerous in Cayuga Lake, reaching a maximum of 21,000 individuals per cubic meter in the 5 to 10 m. stratum. The maximum number in this lake in 1910 was a little more than ten times as large as this.

Conochilus was also found in the catches from each of the three lakes, but it, too, was most abundant in Cayuga Lake, reaching a maximum of 33,750 per cubic meter in the 0 to 5 m. stratum.

A few individuals of *Anuraea cochlearis* were found in the upper water of Canandaigua and Seneca Lakes, but this form also was distinctly more numerous in Cayuga Lake. The catches from Canandaigua Lake contained a few specimens of *Notholca longispina*, and the material from Cayuga Lake showed the presence of a few individuals of Asplanchna and Ploesoma in the upper water.

The rotifer population of Canandaigua Lake was substantially the same in 1918 as in 1910. (See Tables 17 and 18.) In Cayuga Lake Polyarthra was not nearly as abundant in 1918 as in 1910, but the other forms were more numerous, in general, in the former year. In Seneca Lake not so many forms were represented in 1918 as in 1910, but those that were present were more numerous, so that the total rotifer population was somewhat greater in the former year.

In Green Lake the rotifers were more abundant than in Canandaigua Lake, but they were not as numerous as in Cayuga Lake; the number in the upper 20 m. was substantially the same as that of this stratum in Seneca Lake.

Copepod nauplii were most abundant in the upper 20 m. or 30 m. of each lake, but they were present in the lower strata also. A larger number was found in Seneca Lake than in the other two lakes and the number in Seneca Lake was larger in 1918 than in 1910. In the other two lakes they were more numerous in the latter than in the former year. They were more abundant in Green Lake than in any of the Finger Lakes.

Three genera of copepods were represented in the net catches from each of the three Finger Lakes, namely, Cyclops, Diaptomus, and Limnocalanus; while a fourth, Epischura, appeared in the 5 to 10 m. stratum of Canandaigua Lake. By far the greater portion of the copepod population consisted of Cyclops and Diaptomus, the former being numerically greater than the latter in each of the lakes. Both of these forms were more abundant in Seneca Lake than in either of the other Finger Lakes. In the former the maximum number of Cyclops was 25,100 per cubic meter in the 0 to 5 m. stratum, with an average number of 21,460 in the upper 15 m. The maximum number of Diaptomus was 9,810 per cubic meter in the 15 to 20 m. stratum of Seneca Lake. Limnocalanus was present in the catches from each of the three Finger Lakes, but was confined to the deeper water.

75412°—22——16

In Canandaigua Lake the Copepoda were more numerous in 1910 than in 1918, but the reverse was true of the other two lakes.

The number of Diaptomus was larger in the upper strata of Green Lake than in any of the Finger Lakes, but Cyclops reached a larger number than in Seneca Lake only in the 0 to 5 m. stratum.

The Cladocera consisted of representatives of Sida, Diaphanosoma, Daphnia, Ceriodaphnia, and Bosmina. Bosmina was the most abundant form, and it was present in the water of Cayuga and Seneca Lakes in much larger numbers than in Canandaigua Lake. The maximum number obtained was 19,100 per cubic meter of water in the 10 to 15 m. stratum of Seneca Lake. The average number in the upper 15 m. of Cayuga and Seneca Lakes was 12,770 and 11,200 individuals per cubic meter, respectively.

Ceriodaphnia was found only in the 5 to 10 m. stratum of Cayuga Lake and Sida only in the 0 to 5 m. stratum of this lake. Diaphanosoma was noted only in the 0 to 5 m. stratum of Canandaigua Lake.

Daphnia retrocurva was obtained from the upper 30 m. of Canandaigua Lake, and a few young of this species were present in the 5 to 15 m. stratum of Cayuga Lake and in the 10 to 15 m. stratum of Seneca Lake.

In Canandaigua and Cayuga Lakes Cladocera were more abundant in 1910 than in 1918, while the reverse was true of Seneca Lake.

The Cladocera were more numerous in Green Lake than in Canandaigua Lake, but they did not reach as large a number as in Cayuga and Seneca Lakes.

The numerical data serve to give a reasonably accurate notion of the plankton population of these lakes, but such data alone do not give an adequate idea of the relative value of the various forms as a source of food for other organisms. When they are combined with data relating to the weights of the different organisms their value is very greatly enhanced. By means of small platinum crucibles and a sensitive assayer's balance the weights of the more important crustacean constituents of the plankton were obtained and the results of such determinations are shown in Table 19. Such data have also been secured for various constituents of the plankton of Wisconsin lakes and where such results were not obtained for some of the forms from the Finger Lakes, those from the former lakes have been used in computing the data shown in Table 20. The dry weight was obtained for all of the material and the wet weight as well for a few of the forms; after taking the dry weight the material was ignited in an electric furnace for the purpose of ascertaining the percentages of organic and inorganic matter.

In computing the data for crustacea in Table 20 the number of crustacea per cubic meter of water in a stratum was multiplied by the volume of that stratum and the total for the lake was ascertained by adding the numbers in the various strata. This total multiplied by the weight of the particular organism under consideration gave the amount of such material in the entire lake; this quantity divided by the surface area of the lake gave the weight per unit area, which is expressed in the table in kilograms and pounds per square kilometer and acre, respectively.

The amount of material per unit of surface is larger in the deep water than in the shallow water, but the sides of these lakes have such steep slopes that the results would not be altered very materially by taking this fact into consideration. Also it must be borne in mind that these figures are based upon a single set of catches in each lake and that a more extended series of observations might have yielded somewhat different results. The data in hand, however, are sufficient for a fairly good estimate. No organisms were weighed in 1910, but for purposes of comparison the data obtained in 1918 have been applied to the numerical results of the former year.

In 1910 Canandaigua Lake possessed the largest amount of crustacean material, having about 2,579 kg./km.^{2} of surface, while Seneca Lake was second with slightly more than three-quarters of this amount. Cayuga Lake, however, was less than 10 per cent below Seneca Lake. The greater portion of the material consisted of copepods in Canandaigua and Seneca Lakes; in the former they comprised about 67 per cent of the total amount of crustacean material and in the latter about 79 per cent.

In Cayuga Lake, however, about 72 per cent of the material consisted of the cladoceran Bosmina. Of the cladoceran material in Canandaigua Lake in 1910, *Daphnia retrocurva* furnished about 30 times as much as Bosmina and about 4 times as much as Diaphanosoma. Bosmina was the only representative of this group that was obtained from the other two Finger Lakes in 1910. Among the copepods Diaptomus was the most important form in this year and Cyclops ranked second.

In 1918 Canandaigua Lake possessed only about a third as much crustacean material as in 1910 and Cayuga Lake only about four-fifths as much. Seneca Lake, on the other hand, showed a much larger amount in the former year, the amount exceeding that of the latter year by about 62 per cent. Thus Seneca Lake in 1918 had almost four times as much crustacean material as Canandaigua Lake and more than twice as much as Cayuga Lake. *Daphnia retrocurva* was again the chief cladoceran element in Canandaigua Lake, but it was greatly exceeded by Bosmina in the other two lakes. Diaptomus furnished the largest amount of crustacean material in Canandaigua and Cayuga Lakes, but Cyclops was the chief constituent in Seneca Lake.

Green Lake, Wis., possessed a larger amount of crustacean material in 1918 than was found in the three Finger Lakes either in 1918 or in 1910. It was almost 10 per cent greater than that of Seneca Lake in 1918, which was the maximum for the three Finger Lakes. The copepods formed a much larger proportion of the material in Green Lake than in the Finger Lakes, because the Cladocera constituted a little less than 3 per cent of the total in this lake. Nearly two-thirds of the entire amount of crustacean material in Green Lake was furnished by Diaptomus.

Table 19 shows that the ash constitutes from 13 to 19 per cent of the dry weight of the crustacea of the Finger Lakes. In addition, also, it has been found that plankton crustacea contain from 4 to 9 per cent of chitin, which has no food value. In round numbers, then, it may be said that about 20 per cent of the dry weight of the plankton crustacea from the Finger Lakes consists of ash and chitin, while about 80 per cent may be regarded as actual food material. In the living state from 85 to 90 per cent of the mass of these organisms consists of water, so that the live weight would be approximately 10 times as large as the figures given in the dry weight column of Table 20, page 248.

In the crustacea from Green Lake the ash was much smaller, averaging somewhat less than 6 per cent; adding to this about 6 per cent for chitin leaves about 88 per cent of food material. The latter figure is higher than that for the Finger Lakes, which is due to the higher percentage of ash in the material from these lakes.

No determinations of the weight of the rotifers were made for the Finger Lakes, but such results have been obtained for three species from Wisconsin lakes, namely, *Asplanchna brightwellii*, *Brachionus pala*, and *Conochilus volvox*. The weight of these forms has been used as a basis for estimating the weight of the various rotifers in the plankton catches from the three Finger Lakes, N. Y., and from Green Lake, Wis. The computations are based on the relative volumes of the different forms, so that they are to be regarded as estimates and not the results of actual weighings. These estimates are shown in Table 20.

Cayuga Lake had the largest amount of rotifer material both in 1910 and in 1918, with 111 kg./km.^{2} (1 pound per acre) in the former year and 145 kg. (1.3 pounds) in the latter year. It had 4½ times as much as Seneca Lake in 1910 and about 3½ times as much in 1918; it had 12 times as much as Canandaigua Lake in 1910 and about 52 times as much in 1918. Green Lake had just half as much rotifer material as Cayuga Lake in 1918.

In the rotifers that have been weighed the ash averaged about 7.4 per cent of the dry weight, ranging from a minimum of a little less than 6 per cent to a maximum of a little more than 9 per cent. Thus between 90 and 95 per cent of the dry weight of these rotifers may be regarded as organic matter, but what proportion of this is indigestible has not been determined. Also it has been found that from 90 to 94 per cent of the living rotifer consists of water, so that the weight of the live organisms would be somewhat more than 10 times as large as the figures given in the table.

The relative importance of the crustacea and the rotifers as sources of organic matter which will serve as food for other organisms is shown in Table 20. In Canandaigua Lake, which had a very small rotifer population, the ratio of the organic matter in the rotifers to that in the crustacea was 1:256 in 1910 and 1:292 in 1918. Owing to the very much larger rotifer population in Cayuga Lake the ratio there was 1:13 in 1910 and about 1:9 in 1918. In Seneca Lake these ratios were about 1:70 each year. In Green Lake the crustacea contributed about 49 times as much dry organic matter as the rotifers in 1918.

The dry weight of the crustacea and rotifers combined amounted to 2,588 kg./km.^{2} (23 pounds per acre) in Canandaigua Lake in 1910; this was the maximum quantity found in the three Finger Lakes in that year. The minimum amount was noted for Cayuga Lake, namely, 1,945 kg. (17.3 pounds). (See Table 20, p. 248.)

In 1918 the maximum for these two groups of organisms was found in Seneca Lake and it amounted to 3,267 kg. of dry matter per square kilometer (29.1 pounds per acre). Canandaigua Lake possessed the minimum amount for this year, namely, about 852 kg. (7.6 pounds). This was only about one-third as much as this lake yielded in 1910.

In Green Lake these two groups of plankton animals yielded about 3,458 kg. of dry matter per square kilometer of surface (31.6 pounds per acre) which was about 10 per cent larger than the amount in Seneca Lake in 1918.

No attempt was made to determine the weight of the algæ in the net plankton, but as the catches appeared under the microscope by far the greater portion of the material consisted of rotifers and crustacea, probably three-quarters of it or more. Adding 25 or even 50 per cent to the above figures would still leave a relatively small amount of material per unit of surface. In general, these lakes may be regarded as poor in net plankton, the usual characteristic of lakes as large and as deep as these.

The figures given in the various tables represent the amount of material that is present on a particular date—that is, the standing crop at that time—but they do not indicate the quantity of such material that is produced annually. Production and destruction are processes which continue throughout the year, so that it is a very difficult problem to ascertain just how much net plankton is produced annually by a lake.

NANNOPLANKTON.

The nannoplankton includes the various forms of plants and animals which are so small that they readily pass through the meshes of the bolting-cloth strainer in the plankton net and are lost. These small organisms are easily obtained with a centrifuge. The results obtained in these enumerations on the three Finger Lakes of New York and on Green Lake, Wis., are shown in Table 21.

The Protozoa were represented by rhizopods, flagellates, and ciliates. The rhizopods consisted of Amoeba and some other forms which were not definitely identified. A minute Monas-like form was the most numerous flagellate found, while Cryptomonas was present in considerable numbers in Canandaigua and Seneca Lakes. A disk-shaped flagellate was noted in the upper strata of Cayuga and Green Lakes. Synura was also present in the surface stratum of Canandaigua Lake.

The only representative of the ciliates was Halteria. It appeared in the upper strata of Canandaigua and Cayuga Lakes.

The green and blue-green algæ consisted of Scenedesmus, Oocystis, and Aphanocapsa. A colonial form composed of very minute cells, 25 to 100 or more, embedded in a gelatinous matrix, has been referred to the genus Aphanocapsa. It appears to be widely distributed, geographically, since it has been found in all of the Wisconsin lakes from which nannoplankton has been obtained, and also in the three Finger Lakes. This alga has usually been fairly evenly distributed throughout the entire depth of the various lakes. This phytoplankton and the monads constitute the most common elements, numerically, of the nannoplankton.

The water bacteria belong to this group of plankton organisms, but they were not taken into consideration in these investigations.

No attempt was made to determine the amount of nannoplankton by weight, but some results that have been obtained on Lake Mendota, Wis., will serve as a basis for making a rough estimate for the Finger Lakes. The studies on Lake Mendota covered a period of more than two years and they consisted of both gravimetric and numerical determinations. The dry organic matter of the nannoplankton varied from a minimum of approximately 0.8 gr. to a maximum of 3.1 gr. per cubic meter of water. The numerical determinations which correspond most closely to those of the Finger Lakes average about 1.0 gr. of dry organic matter per cubic meter of water, so that this figure may be taken as a basis for estimating the amount of nannoplankton material in the latter. The results of this estimation are shown in Table 22, and also the results for total plankton. In the latter it has been assumed that the crustacea and rotifers furnished 75 per cent of the organic matter of the net plankton. Green Lake has not been included in this table because its net plankton contained a larger percentage of vegetable material.

These computations seem to indicate that the nannoplankton of Seneca Lake contained somewhat more than 2½ times as much dry organic matter as the net plankton, while in Canandaigua Lake the former was more than 4 times as great as the latter. These differences are of the same magnitude as those that have been obtained on Lake Mendota in midsummer. On an average, also, it may be considered that this material weighs at least 10 times as much in the living state, since most of these organisms, when alive, are made up of 90 per cent or more of water.

The results shown in this table represent only a single phase of the annual cycle, and hence they do not give any indication of the yearly production of such material. This latter question involves the actual turnover in stock each year and includes the various relations of the organisms to each other and to their environment; the chief phases of this question are the rate of reproduction of the various forms at different seasons of the year, and the relations of the consumers and their foods. The whole problem is very complex and would require an extended investigation for an adequate solution.

These quantities of dry organic matter in the total plankton of the Finger Lakes are very much smaller than those that have been obtained for Lake Mendota, Wis., in midsummer. In this latter lake the average amount for the month of July in 1915 and in 1916 was 40,630 kg./km.^{2} of surface (362.4 pounds per acre) in that portion of the lake having a depth of 20 m. or more; the average for August of these same years was 31,560 kg. (281.5 pounds). The average for Lake Mendota in July is more than three times the amount shown in this table for Seneca Lake and more than eight times that for Canandaigua Lake.

Comparisons have been made between the productivity of the land and of the water, but such comparisons have been based upon the production of beef on the one hand and of fish, or oysters, or other edible aquatic forms on the other hand. These materials are what may be termed the "finished products," and statistics relating to them give no idea of the relative amounts of food required or available for their production. This is accounted for by the fact that data concerning the quantity of food available, either directly or indirectly, for aquatic organisms have been for the most part wholly lacking and at best only fragmentary in character.

The quantitative results given above for the plankton, however, enable one to make direct comparisons with the land on material which is not an end product. The grass produced by a pasture is probably the best land crop for such a comparison, because it is less subject to artificial conditions resulting from cultivation than the grain crops. Henry (1898, p. 180) cites an experiment in which a pasture consisting of blue grass and white clover yielded 165,827 kg. of dry organic matter per square kilometer (1,477 pounds per acre) between May 1 and October 15. This quantity is just a little more than four times the average amount of organic matter maintained by the deeper water of Lake Mendota in July. In other words, a fourfold turnover in the stock of plankton maintained by Lake Mendota during this month would have yielded as much organic material annually as the pasture in the above experiment. During the vernal and autumnal maxima of the plankton the difference is distinctly less than fourfold. The roots were not included in this yield of grass and, taking them into consideration, we may say that the average difference for the year would be substantially fourfold. The differences are much greater in the Finger Lakes, ranging from about fourteenfold in Seneca Lake to almost thirty-fivefold in Canandaigua lake. (See Table 22, p. 250.)

The dry organic matter of the grass was made up of about 25.4 per cent crude protein, 4.7 per cent ether extract, while the remainder consisted of carbohydrates. The plankton of Lake Mendota, however, was distinctly richer in nitrogenous material and in fats; the average for the crude protein was 45.1 per cent of the dry organic matter and for the ether extract 8 per cent.

Attention should also be called to the fact that the plankton does not represent all of the food material that is produced by a lake; the bottom fauna and the large aquatic plants growing in the shallower water make notable contributions to this material. The quantity of plankton is not as large per unit of surface in the shallower water as it is in the deeper water, but the larger bottom population in the former region tends to counterbalance this deficiency when the question of the total production is considered.

PLANKTON TABLES.

Tables 17 and 18 show the vertical distribution of the various organisms constituting the net plankton, giving the number of individuals per cubic meter of water in the different strata. The members grouped in the different columns are indicated as follows:

CLADOCERA.—B=Bosmina, C=Ceriodaphnia, D=Daphnia, Di=Diaphanosoma, L=Leptodora, P=Polyphemus.

COPEPODA.—C=Cyclops, D=Diaptomus, E=Epischura, L=Limnocalanus.

NAUPLII.

ROTIFERA.—A=Asplanchna, A.a.=*Anuraea aculeata*, A.c.=*Anuraea cochlearis*, C=Conochilus, N=Notholca, P=Polyarthra, Pl=Ploesoma, R=Rattulus, S=Synchaeta, T=Triarthra.

PROTOZOA.—A=Actinosphaerium, C=Ceratium, D=Dinobryon, E=Epistylis, M=Mallomonas, U=Uroglena, V=Vorticella.

GREEN AND BLUE-GREEN ALGÆ.—An=Anabaena, Ap=Aphanocapsa, Coe=Coelosphaerium, G=Gloeocapsa, L=Lyngbya, M=Microcystis, O=Oscillatoria, S=Staurastrum.

DIATOMS.—A=Asterionella, F=Fragilaria, M=Melosira, S=Synedra, T=Tabellaria.

TABLE 17.—ANALYSIS OF NET PLANKTON, 1918.

CANANDAIGUA LAKE, JULY 27, 1918.

Depth in meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Green and blue-green algæ.	Diatoms.
0–5	B 785 D 655 Di 785	C 1,310 D 1,830	13,470	A. c. 130 C 785 P 525	U 13,600	M 13,600	F 6,800
5–10	B 390 D 130	C 525 D 2,880 E 130	2,485	C 2,485 N 260	E 130 U 13,600	M 20,400	A 6,800
10–20	B 200 D 130	D 2,100 L 195	330	N 390	U 17,000	S 10,200	A 54,400 F 3,400
20–30	B 260 D 65	D 530 L 325	65	N 325 P 65	U 20,400	S 3,400	A 27,200
30–40	B 195	D 260 L 525	65	N 65	U 3,400	S 3,400	A 10,200
40–60	....	D 625 L 130	100	....	U 1,700	....	A 5,100
60–72	....	C 55 D 1,350 L 165	55	....	....	....	A 2,800

TABLE 17.—ANALYSIS OF NET PLANKTON, 1918—Continued.

CAYUGA LAKE, JULY 30, 1918.

Depth in meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Green and blue-green algæ.	Diatoms.
0–5	B 10,200 S 130	C 7,200 D 260	2,485	A 915 A. c. 2,880 C 33,750 P 17,400 Pl. 150 S 25,770	A 108,800 C 129,200	An 13,600 M 6,800	A 13,600 F 20,400
5–10	B 14,250 C 130 D 130	C 915 D 1,700	2,880	A 1,180 A. c. 4,580 C 17,265 P 21,000 Pl. 300 S 37,400	A 34,000 C 102,000 D 6,800	M 6,800	A 27,200 F 27,200
10–15	B 13,865 D 130	C 650 D 4,580	3,800	A. c. 3,530 C 5,500 P 10,850 S 44,700	A 204,000 C 40,800 D 13,600		A 40,800 F 6,800
15–20	B 1,050	C 390 D 130	3,140	A. c. 390 C 260 P 1,960 S 2,350	A 13,600		A 6,800
20–30	B 130	C 1,635 D 1,960	3,990	A. c. 65 C 130 P 2,420 S 520			
30–50	B 65	C 2,500 D 1,520	790	A. c. 165 C 230 P 1,250 S 790	A 3,400 C 5,100		A 1,700 T 1,700
50–75	B 25	C 240 D 820 L 32	500	A. c. 50 C 50 P 340 S 105			A 1,360
75–100	B 25	C 50 D 160 L 32	80	A. c. 25 C 25 P 290 S 50	C 1,360		F 1,360

SENECA LAKE, AUG. 1, 1918.

Depth in meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Green and blue-green algæ.	Diatoms.
0–5	B 6,500	C 25,100 D 3,800	12,700	A. c. 900 C 4,300 P 11,800	C 129,200		A 353,600 T 13,600
5–10	B 8,000	C 21,100 D 4,700	22,000	A. c. 400 C 400 P 6,700	C 47,600 D 6,800		A 272,000 T 6,800
10–15	B 19,100 D 260	C 18,180 D 6,800	19,100	A. c. 130 C 260 P 9,550	C 13,600	M 6,800	A 272,000 T 6,800
15–20	B 11,500	C 8,370 D 9,810	23,940	P 7,720	C 6,800		A 306,000
20–30	B 260	C 1,045 D 6,345 L 40	4,970	P 390			A 10,200
30–50	B 33	C 66 D 1,180 L 46	10,200	P 230			A 1,700
50–75		D 160 L 16	2,560	P 210			
75–100		D 26 L 5	55	P 55			A 1,300
100–125		C 26 D 26 L 5	53				
125–150		C 26 D 26 L 10	26	P 53			
150–170		C 132 D 33 L 13	230	P 66			A 800

TABLE 17.—ANALYSIS OF NET PLANKTON, 1918—Continued.

GREEN LAKE, WIS., AUG. 20, 1918.

Depth in meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Green and blue-green algæ.	Diatoms.
	B 1,570	C 26,550		C 5,100	C 20,400	An 27,200	
0–5	D 392	D 33,225	87,900	N 3,140	D 6,800	O 1,822,400	
	Di 915			P 5,495			
	B 260	C 8,765		C 4,970		An 13,600	
5–10	D 525	D 21,715	36,360	N 1,310	C 13,600	O 510,000	
	Di 130			P 7,325			
				A. c. 260		An 6,800	
10–15	B 130	C 6,280	3,530	C 2,095	C 6,800	O 387,600	
	D 1,440	D 4,055		N 1,310			
				P 2,485			
				A. c. 10,725			
		C 785		C 915			
15–20	D 655	D 1,180	14,260	N 525		O 136,000	A 6,800
				P 130			
				T 260			
				A. c. 4,250			
		C 195		C 130			
20–30	D 65	D 2,160	3,660	N 65	D 3,400	O 142,800	
				P 130			
				T 520			
		D 1,245		A. c. 110		An 6,800	
30–40	D 65	L 118	195	N 65		O 173,400	
				T 460			
		D 1,440		A. c. 720		An 3,400	
40–50	D 65	L 365	195	C 130		O 85,000	
				T 260			
				A. a. 45			
		C 90		A. c. 615			
50–65	B 45	D 1,270	45	C 45		O 68,800	
		L 175		N 90			
				P 45			
				T 220			

TABLE 18.—ANALYSIS OF NET PLANKTON, 1910.

CANANDAIGUA LAKE, AUG. 20, 1910.

Depth in meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Green and blue-green algæ.	Diatoms.
	B 260	C 4,500	18,500	C 130	C 23,200	Ap 11,600	A 34,800
0–5	D 920	D 14,200		P 1,300		M 61,900	F 3,800
	Di 3,270					S 3,800	
	B 260	C 3,700		C 130		Ap 11,600	A 34,800
5–10	D 1,600	D 7,200	5,900	P 2,100	C 92,900	Coe 3,800	
	Di 2,500					M 58,000	F 200
	B 260	C 2,400		C 520	C 50,300	Ap 3,800	A 50,300
10–15	D 1,300	D 7,600	2,150	N 130	D 7,700	Coe 23,600	T 3,800
	Di 2,750			P 650		M 54,200	
	B 130			C 520		An 7,700	A 2,100
	D 130	D 4,190	390	P 200	C 3,800	Ap 7,700	T 1,200
15–20	Di 260					Coe 42,600	
						M 15,500	
	B 100	D 1,640				An 1,900	
	D 2,230	L 460		N 130	C 3,800	Ap 7,700	
20–30	L 30					Coe 7,700	
						M 7,700	
				C 65		Ap 1,900	
30–40	B 200	D 400	65	N 130	C 1,900	Coe 3,800	F 1,900
	D 590	L 130				M 1,900	
	B 230	D 360				Ap 2,900	A 960
40–60	D 25	L 100	25	C 130		Coe 1,900	F 960
						M 2,900	T 960
60–70	B 130	D 400		C 65	C 1,900	Coe 3,800	
		L 130		P 30		M 1,900	
	B 200	D 850					
70–80		L 200			C 1,900	Ap 1,900	
						Coe 3,800	

TABLE 18.—ANALYSIS OF NET PLANKTON, 1910—Continued.

CAYUGA LAKE, AUG. 12, 1910.

Depth in meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Green and blue-green algæ.	Diatoms.
0–5	B 21,500 C 260 P 130	C 1,200	400	A 200 A. c. 520 P 239,900 S 1,000	C 1,648,600 D 15,500 V 8,800	A 9,000 M 1,000	A 2,105,300 F 812,700 T 54,200
5–10	B 32,700 C 390	C 260 D 130	650	A 300 A. c. 650 P 38,500 Pl 130 S 750	C 960,000 D 15,500 V 650	A 8,000 M 7,700	A 3,204,000 F 928,800 T 108,300
10–15	B 30,500	C 520 D 1,600	2,500	A 170 A. c. 130 P 12,600 Pl 1,600 S 350	C 665,600 D 15,500 V 260	A 7,700 M 31,000	A 2,182,700 F 944,300 T 123,800
15–20	B 28,000	C 260 D 2,200	19,200	A 140 A. a. 130 A. c. 3,700 N 130 P 6,000 Pl 910 S 250	C 270,900 D 4,000 M 116,100	M 7,700	A 1,509,000 F 611,400 T 201,000
20–30	B 2,300	C 1,400 D 790	4,300	A 100 A. a. 130 A. c. 1,580 N 80 P 60 Pl 60 S 200 T 460	C 73,500 D 3,900 M 31,000	M 3,900	A 569,000 F 301,800 T 104,500
30–50	B 360	C 720 D 790	1,200	A. a. 60 A. c. 130 N 150 P 2,100 Pl 50 S 250 T 100	C 7,600 M 1,900	M 3,500	A 67,500 F 23,100 M 3,800 T 27,000
50–75	B 80	C 640 D 340	1,000	A. a. 25 A. c. 25 N 50 P 630 Pl 50 S 150 T 30	C 10,800	M 1,500	A 41,800 F 7,700 T 7,700
75–100	B 670	C 80 D 20	60	A. c. 30 N 30 P 630 Pl 50 S 200 T 30	C 26,300	M 1,500	A 35,600 F 20,000 T 7,700
100–120	B 60	C 50 D 100	160	A. c. 90 N 30 P 180 S 90 T 90	C 15,000 M 1,900	M 1,500	A 30,900 F 9,600 T 15,200

SENECA LAKE, AUG. 2, 1910.

Depth in meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Green and blue-green algæ.	Diatoms.
0–10	B 6,750 C 60	C 920 D 260	4,060	A 2,060 A. c. 2,100 N 60 P 2,300 Pl 1,450 R 50 S 2,000	C 32,800 D 1,900 V 60	An 1,900 M 7,700	A 135,000 F 17,300 M 1,900 T 7,700
10–20	B 8,060	C 4,200 D 1,300	9,500	A 50 A. c. 4,300 C 250 N 130 P 2,300 Pl 200 R 100 S 200	C 73,300 V 920	M 17,400	A 310,700 F 5,800 S 1,900 T 9,600

TABLE 18.—ANALYSIS OF NET PLANKTON, 1910—Continued.

SENECA LAKE, AUG. 2, 1910—Continued.

Depth in meters.	Cladocera.	Copepoda.	Nauplii.	Rotifera.	Protozoa.	Green and blue-green algæ.	Diatoms.
20–30	B 1,050	C 8,400 D 3,800	19,100	A 220 A. a. 220 A. c. 1,120 C 450 N 220 P 2,100 Pl 100 R 110	C 9,600 M 9,600	M 5,800	A 169,800 F 9,600 T 3,800
30–50	B 140	C 2,200 D 3,400	1,900	A. c. 200 P 280 S 30	C 500	M 1,000	A 3,400 F 1,000 T 500
50–75	B 25	C 50 D 820	2,000	A. c. 70 P 70	C 500	M 500	A 1,000 F 250 T 250
75–100	....	C 50 D 250 L 30	750	A. c. 30 P 130	C 250	M 700	A 250
100–130	....	C 40 D 100 L 20	280	A. c. 20 P 40	C 600	M 400	A 200
130–165	....	C 20 D 150 L 10	400	A. c. 20 P 40	C 170	M 850	A 100 F 500

TABLE 19.—WEIGHTS OF DIFFERENT FORMS OF CRUSTACEA FROM THREE FINGER LAKES, N. Y., AND FROM GREEN LAKE, WIS.

CANANDAIGUA LAKE.

Organism.		Wet weight in milligrams.		Dry weight in milligrams.		Per cent. of water.	Per cent. of ash.	Remarks.
Name.	No.	Total.	Each.	Total.	Each.			
Daphnia	54	....	....	1.25	0.0230	....	22.40	Adults.
Diaptomus	200	....	....	1.64	.0082	....	13.41	
Limnocalanus	150	....	....	5.14	.0343	....	5.45	Mixed sizes.
Mysis	20	....	....	22.20	1.1100	....	12.02	Do.
Bosmina	304	....	....	.90	.00296	....	31.11	Chiefly adults.
Polyphemus	77	....	....	.78	.0101	....	21.80	Mixed sizes.

CAYUGA LAKE.

Cyclops	404	....	....	1.89	0.0047	....	12.70	Chiefly adults.
Limnocalanus	250	....	....	12.75	.0510	....	3.78	Large.
Cyclops	532	23.46	0.0441	2.34	.0044	90.00	15.38	Chiefly adults.

SENECA LAKE.

Diaptomus	200	12.16	0.0608	1.26	0.0063	89.64	15.08	
Limnocalanus	108	37.77	.3497	5.14	.0476	86.40	6.61	
Daphnia	500	....	....	2.56	.0051	....	15.62	Mixed sizes.

GREEN LAKE.

Diaptomus	500	....	....	3.69	0.0074	....	5.15	Chiefly adults.
Limnocalanus	550	....	....	17.88	.0325	....	3.75	

TABLE 20.—DRY WEIGHT AND ORGANIC MATTER OF PLANKTON CRUSTACEA AND ROTIFERS IN THREE FINGER LAKES, N. Y., AND IN GREEN LAKE, WIS.

CANANDAIGUA LAKE.

Organism.	1910				1918			
	Dry weight.		Organic matter.		Dry weight.		Organic matter.	
	Kilograms per square kilometer of surface.	Pounds per acre.	Kilograms per square kilometer of surface.	Pounds per acre.	Kilograms per square kilometer of surface.	Pounds per acre.	Kilograms per square kilometer of surface.	Pounds per acre.
Plankton crustacea:								
Bosmina	22.95	0.20	15.80	0.14	27.70	0.25	19.10	0.17
Daphnia	667.10	5.94	517.70	4.61	94.70	.84	73.50	.65
Diaphanosoma	165.00	1.47	154.70	1.38	16.30	.14	15.30	.13
Cyclops	209.22	1.86	182.60	1.62	38.50	.34	33.60	.30
Diaptomus	1,263.60	11.25	1,094.15	9.74	385.10	3.43	333.50	3.00
Limnocalanus	168.00	1.50	158.80	1.42	271.20	2.41	256.40	2.28
Epischura					10.10	.09	9.50	.08
Nauplii	83.00	.74	72.21	.64	5.30	.05	4.60	.04
Total	2,578.87	22.96	2,195.96	19.55	848.90	7.55	745.50	6.65
Rotifers	9.25	.08	8.56	.074	2.76	.024	2.55	.022

CAYUGA LAKE.

Organism.	1910 Dry weight, kg per sq. km	1910 Dry weight, lb per acre	1910 Organic matter, kg per sq. km	1910 Organic matter, lb per acre	1918 Dry weight, kg per sq. km	1918 Dry weight, lb per acre	1918 Organic matter, kg per sq. km	1918 Organic matter, lb per acre
Plankton crustacea:								
Bosmina	1,320.25	11.75	909.52	8.10	459.43	4.09	316.57	2.82
Daphnia					14.38	.13	11.20	.10
Cyclops	155.41	1.38	135.67	1.20	374.61	3.33	327.00	2.90
Diaptomus	255.42	2.27	221.16	1.97	519.00	4.60	449.40	4.00
Limnocalanus					36.13	.32	34.70	.28
Nauplii	103.06	.92	89.66	.80	68.00	.60	59.20	.52
Total	1,834.14	16.32	1,356.01	12.07	1,471.55	13.07	1,198.07	10.62
Rotifers	110.91	1.00	102.78	.92	145.24	1.30	134.50	1.20

SENECA LAKE.

Organism.	1910 Dry weight, kg per sq. km	1910 Dry weight, lb per acre	1910 Organic matter, kg per sq. km	1910 Organic matter, lb per acre	1918 Dry weight, kg per sq. km	1918 Dry weight, lb per acre	1918 Organic matter, kg per sq. km	1918 Organic matter, lb per acre
Plankton crustacea:								
Bosmina	418.57	3.72	288.40	2.56	421.00	3.75	290.00	2.60
Daphnia					16.70	.14	13.00	.10
Cyclops	631.28	5.62	534.19	4.75	1,491.60	13.30	1,262.00	11.30
Diaptomus	693.22	6.17	589.24	5.24	1,192.00	10.60	1,013.20	9.00
Limnocalanus	33.72	.30	31.50	.28	69.00	.61	64.40	.57
Nauplii	215.25	1.91	182.47	1.62	35.70	.32	30.30	.27
Total	1,992.04	17.72	1,625.80	14.45	3,226.00	28.72	2,672.90	23.84
Rotifers	24.58	.22	22.78	.20	41.28	.37	38.22	.34

GREEN LAKE.

Organism.	1910 Dry weight, kg per sq. km	1910 Dry weight, lb per acre	1910 Organic matter, kg per sq. km	1910 Organic matter, lb per acre	1918 Dry weight, kg per sq. km	1918 Dry weight, lb per acre	1918 Organic matter, kg per sq. km	1918 Organic matter, lb per acre
Plankton crustacea:								
Bosmina					24.00	0.21	22.44	0.20
Daphnia					59.35	.53	50.00	.44
Diaphanosoma					20.60	.18	19.30	.17
Cyclops					809.00	7.20	760.50	6.80
Diaptomus					2,034.31	18.10	1,929.54	17.16
Limnocalanus					104.20	.92	100.30	.88
Nauplii					424.00	3.77	400.68	3.55
Total					3,475.46	30.91	3,282.76	29.20
Rotifers					72.70	.65	67.32	.60

Table 21 shows the vertical distribution of the organisms in the nannoplankton, indicating the number of individuals per cubic meter of water at the different depths. The forms are as follows:

PROTOZOA—A=Amoeba, C=Cryptomonas, F=unidentified asymmetrical flagellate, H=Halteria, M=monads, R=unidentified rhizopods, S=Synura,

GREEN AND BLUE-GREEN ALGÆ—Ap=Aphanocapsa, Oo=Oocystis, Sc=Scenedesmus

DIATOMS—N=Navicula, S=Stephanodiscus, Sy=Synedra.

TABLE 21.—ANALYSIS OF NANNOPLANKTON.

CANANDAIGUA LAKE, JULY 28, 1918.

Depth in meters.	Protozoa.	Green and blue-green algæ.	Diatoms.	Depth in meters.	Protozoa.	Green and blue-green algæ.	Diatoms.
	C 31,242,000	Ap 135,382,000	S 15,621,000	20	C 5,207,000	AP 98,933,000	N 10,414,000
0	M 52,000,000				M 10,414,000		S 83,300,000
	S 5,200,000			30	M 31,242,000	Ap 130,175,000	N 10,414,000
	C 10,414,000	Ap 182,245,000	S 36,449,000				S 88,520,000
5	H 5,200,000		Sy 10,414,000	45	C 15,621,000	Ap 135,382,000	N 5,207,000
	M 15,621,000				M 15,621,000		S 10,414,000
	C 5,207,000	Ap 187,452,000	S 31,242,000	60	C 5,207,000	Ap 130,175,000	S 26,035,000
10	H 5,200,000		Sy 5,207,000		M 10,414,000		
	M 20,828,000			65		Ap 229,108,000	S 10,414,000
	C 20,828,000	Ap 156,210,000	N 10,414,000				
15	H 5,200,000	Sc 20,828,000	S 57,277,000				
	M 10,414,000						

CAYUGA LAKE, JULY 30, 1918.

Depth in meters.	Protozoa.	Green and blue-green algæ.	Diatoms.	Depth in meters.	Protozoa.	Green and blue-green algæ.	Diatoms.
	F 31,242,000			20	M 20,828,000	Ap 62,484,000	S 5,207,000
	H 5,207,000	Ap 93,726,000	N 5,207,000	30	M 26,035,000	Ap 67,691,000	S 5,207,000
0	M 26,035,000	Sc 20,828,000	S 5,207,000	50	M 26,035,000	Ap 52,070,000	S 5,207,000
	R 20,828,000			75	M 15,621,000	Ap 62,484,000	
	F 26,035,000	Ap 62,484,000		100	M 10,414,000	Ap 67,691,000	S 5,207,000
5	M 20,828,000	Sc 20,828,000	S 5,207,000		R 5,207,000		
	R 52,070,000						
	C 5,207,000	Ap 78,105,000					
10	M 36,449,000	Sc 10,414,000	S 5,207,000				
	R 20,828,000						

SENECA LAKE, AUG. 1, 1918.

Depth in meters.	Protozoa.	Green and blue-green algæ.	Diatoms.	Depth in meters.	Protozoa.	Green and blue-green algæ.	Diatoms.
0	C 41,656,000	Ap 72,898,000	S 15,621,000		C 5,207,000	Ap 36,449,000	
	M 145,800,000	Oo 5,207,000	Sy 5,207,000	30	M 36,449,000	Oo 10,414,000	S 10,414,000
5	C 15,621,000	Ap 161,417,000	S 15,621,000		R 5,207,000		
	M 119,761,000	Oo 10,414,000		50	M 20,828,000	Ap 62,484,000	S 5,207,000
10	C 5,207,000	Ap 62,484,000	S 15,621,000	75	M 5,207,000	Ap 72,898,000	S 10,414,000
	M 20,828,000	Oo 15,621,000		100	M 15,621,000	Ap 67,691,000	S 10,414,000
15	C 5,207,000	Ap 67,691,000	S 15,621,000	135	M 10,414,000	Ap 46,863,000	S 5,207,000
	M 10,414,000	Oo 26,035,000		170	M 5,207,000	Ap 67,691,000	S 5,207,000
20	C 5,207,000	Ap 36,449,000	S 10,414,000				
	M 10,414,000	Oo 10,414,000					

GREEN LAKE, WIS., AUG. 20, 1918.

Depth in meters.	Protozoa.	Green and blue-green algæ.	Diatoms.	Depth in meters.	Protozoa.	Green and blue-green algæ.	Diatoms.
	F 5,207,000		S 5,207,000	20	M 20,828,000	Ap 72,900,000	S 5,207,000
0	M 10,414,000	Ap 145,800,000	Sy 20,828,000		R 5,207,000		
	R 5,207,000			30	M 5,207,000	Ap 46,800,000	S 5,207,000
	F 10,414,000	Ap 145,800,000	S 5,207,000	40	A 5,207,000	Ap 57,200,000	S 5,207,000
5	M 10,414,000		Sy 15,621,000		R 5,207,000		Sy 5,207,000
	F 15,621,000	Ap 130,200,000	S 5,207,000	50	M 5,207,000	Ap 67,700,000	S 10,414,000
10	M 26,035,000		Sy 15,621,000	65	M 5,207,000	Ap 62,500,000	S 5,207,000
15	M 10,414,000	Ap 52,070,000	S 5,207,000				Sy 5,207,000

TABLE 22.—ESTIMATES FOR QUANTITY OF NANNOPLANKTON AND TOTAL PLANKTON IN THREE FINGER LAKES IN 1918.

[NOTE.—Total plankton equals net plankton plus nannoplankton. Quantities are shown in kilograms of dry organic material per square kilometer of surface and pounds per acre. Living material would weigh about 10 times as much as is indicated in the table.]

Lake.	Nannoplankton.		Total plankton.	
	Kilograms per square kilometer.	Pounds per acre.	Kilograms per square kilometer.	Pounds per acre.
Canandaigua	3,877.3	34.5	4,809.2	42.8
Cayuga	5,450.0	48.5	6,947.5	61.6
Seneca	8,859.4	78.8	12,200.5	108.6

BOTTOM FAUNA.

Samples of the bottom at different depths were obtained in the three Finger Lakes and also in Green Lake by means of an Ekman dredge. This mud was sifted through a fine meshed net and the organisms found therein were enumerated. The dry weight and the ash of four of these bottom forms were ascertained. The results of these dredge hauls are shown in Table 23. The observations were far too few in number to give anything more than a fragmentary idea of the density of the bottom fauna, since only two hauls each were made in Canandaigua and Cayuga Lakes and but four in Seneca Lake; in addition to this they were taken only in the deeper water. Hundreds, or better still, thousands of observations, covering the bottom of each lake in various places from the shore line to the greatest depths and extending through the different seasons of the year, would be necessary to give an adequate idea of the character and abundance of their bottom fauna.

Only four forms have been included in the table because they constituted by far the greater portion of the material obtained. A few nematodes and an occasional ostracod and bivalve mollusk were noted in the shallower depths, but they were not present in sufficient numbers to obtain their weights.

A few larvæ of Protenthes were obtained in the 32 m. haul in Seneca Lake and in the 45 m. haul in Green Lake, but these were the only instances in which this larva was noted.

Chironomid larvæ were found in all of the hauls except the one made at 32 m. in Seneca Lake. They were most abundant in Cayuga Lake, where they constituted by far the most numerous form at a depth of 113 m. In the other three lakes, however, they formed only a minor element of the bottom population, both in numbers and in bulk. Earlier in the season they were probably more numerous, because many had undoubtedly transformed to the adult stage by the time these observations were made.

In Canandaigua and Seneca Lakes the relict amphipod Pontoporeia was second in importance, while it was third in Cayuga Lake and first in Green Lake. It was most abundant at a depth of 45 m. in Green Lake, where it furnished the largest amount of dry organic material that was found in any of the hauls, namely, about 8,214 kg./km.^{2}, or nearly 75 pounds per acre.

Oligochæta were found in all except one haul; that is, the one at 34 m. in Cayuga Lake. In half of the hauls they furnished the greater portion of the organic material.

The largest amount was obtained at 32 m. in Seneca Lake, where it reached 1,693 kg. of dry material per square kilometer, or a little more than 15 pounds per acre.

The deepest haul in Cayuga Lake yielded a larger amount of organic matter than the deepest haul in any of the other lakes, while the one at 34 m. was the poorest of all, due most probably to the fact that it was made on a very steep slope. Green Lake showed the second largest amount of material in its deepest water and Canandaigua Lake was third. In Seneca Lake the amount at 110 m. was only about three-quarters as great as at 172 m. In general, it appears that the bottom fauna in the deeper water of Green Lake yields a larger amount of dry organic matter per unit area than these three Finger Lakes.

TABLE 23.—NUMBER OF INDIVIDUALS AND WEIGHT OF BOTTOM FAUNA OBTAINED AT DIFFERENT DEPTHS IN THREE FINGER LAKES, N. Y., AND IN GREEN LAKE, WIS., IN 1918.

CANANDAIGUA LAKE, JULY 28, 1918.

Depth in meters	Organism.	Number per square meter of bottom.	Dry weight. Kilograms per square kilometer.	Dry weight. Pounds per acre.	Organic matter. Kilograms per square kilometer.	Organic matter. Pounds per acre.
20	Chironomus	800	219.2	1.95	155.0	1.38
	Pontoporeia	977	469.0	4.17	352.0	3.13
	Oligochaeta	1,420	522.9	4.65	459.1	4.08
74	Chironomus	45	12.0	.11	8.5	.07
	Pontoporeia	844	405.1	3.60	303.8	2.70
	Oligochaeta	890	326.8	2.91	286.9	2.55

CAYUGA LAKE, JULY 30, 1918.

Depth in meters	Organism.	Number per square meter of bottom.	Dry weight. Kilograms per square kilometer.	Dry weight. Pounds per acre.	Organic matter. Kilograms per square kilometer.	Organic matter. Pounds per acre.
34	Chironomus	133	36.4	.33	25.7	.23
	Pontoporeiia	178	85.4	.76	64.0	.57
113	Chironomus	3,863	1,058.5	9.42	784.4	6.66
	Pontoporeia	710	340.8	3.03	255.6	2.27
	Oligochaeta	1,288	474.0	4.22	416.2	3.70

SENECA LAKE, AUG. 1, 1918.

Depth in meters	Organism.	Number per square meter of bottom.	Dry weight. Kilograms per square kilometer.	Dry weight. Pounds per acre.	Organic matter. Kilograms per square kilometer.	Organic matter. Pounds per acre.
32	Protenthes	89	31.2	.28	28.8	.26
	Pontoporeia	1,110	532.8	4.74	399.6	3.55
47	Oligochaeta	5,240	1,928.0	17.16	1,692.8	15.07
	Chironomus	577	158.0	1.40	111.7	.99
	Pontoporeia	844	405.1	3.60	303.8	2.70
	Oligochaeta	1,330	489.4	4.35	429.7	3.82
110	Chironomus	444	120.6	1.07	85.3	.76
	Pontoporeia	355	170.4	1.52	127.8	1.14
	Oligochaeta	400	147.2	1.31	129.2	1.15
172	Chironomus	44	12.0	.11	8.5	.07
	Pontoporeia	133	63.8	.57	47.8	.43
	Oligochaeta	1,286	473.2	4.21	415.5	3.70

GREEN LAKE, AUG. 20, 1918.

Depth in meters	Organism.	Number per square meter of bottom.	Dry weight. Kilograms per square kilometer.	Dry weight. Pounds per acre.	Organic matter. Kilograms per square kilometer.	Organic matter. Pounds per acre.
45	Chironomus	59	27.7	.25	26.6	.24
	Protenthes	15	10.5	.09	9.7	.08
	Pontoporeia	6,882	9,910.0	88.26	8,213.6	74.93
	Oligochaeta	1,480	488.4	4.35	464.0	4.13
66	Chironomus	407	181.3	1.61	174.0	1.55
	Pontoporeia	459	661.0	5.90	561.2	5.00
	Oligochaeta	1,643	542.2	4.83	515.1	4.59

LITERATURE CITED.

BIRGE, EDWARD A.

1915. The heat budgets of American and European Lakes. Transactions, Wisconsin Academy of Sciences, Arts, and Letters, Vol. XVIII, pp. 1-47. Madison.

1916. The work of the wind in warming a lake. Ibid., pp. 341–391.

1921. Limnological apparatus. Ibid., Vol. XX (now in press).

BIRGE, EDWARD A., and CHANCEY JUDAY.

1914. A limnological study of the Finger Lakes of New York. Bulletin, U. S. Bureau of Fisheries, 1912, Vol. XXXII, pp. 525–609. Washington.

HAMBERG, AXEL.

1911. Dichteunterschiede und Temperaturverteilung hauptsächlich der Binnenseen. Petermanns geographische Mitteilungen, Bd. 57, pp. 306–312. Gotha.

HENRY, W. A.

1898. Feeds and feeding. 657 pp. Published by the author, Madison, Wis.

HUITFELD-KASS, H.

1905. Temperaturmessungen in dem See Mjösen und in drei anderen tiefen Norwegischen Seen. Archiv for Mathematik og Naturvidenskab, Bd. XXVII, No. 2, pp. 1–6. Kristiania.

JUDAY, CHANCEY.

1916. Limnological apparatus. Transactions, Wisconsin Academy of Sciences, Arts, and Letters, Vol. XVIII, p. 566–592. Madison.

SCHMIDT, WILH.

1908. Über die Absorption der Sonnenstrahlung im Wasser. Sitzungsberichte der kaiserlichen Akademie der Wissenschaften, Bd. CXVII, pp. 237–253. Wien.