# LIMNOLOGICAL STUDIES OF KARLUK LAKE, ALASKA, 1926–1930[1]

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## Part I. GENERAL LIMNOLOGY

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### INTRODUCTION

The following report deals with the limnological data that were collected on Karluk Lake, Alaska, during the summers of 1926 to 1930, inclusive. In 1926 and 1927 considerable time was spent in making observations on this lake, but from 1928 to 1930 the studies were limited to brief visits in early July each year and again in late August or early September.

These lake studies were made in connection with the general salmon investigations that have been carried on in Alaska for a number of years. These investigations have included a detailed study of the red salmon (*Oncorhynchus nerka*) of Karluk River with the particular object of determining the factors affecting the fluctuations in the size of the runs from year to year. One of the most important of these factors is the size of the breeding populations, as is clearly indicated by the definite periodicity in the size of the runs (Gilbert and Rich, 1927). Beginning in 1921 a weir has been maintained each year in the Karluk River through which the escapement of spawning fish is annually enumerated. These data, together with those of the commercial catch of salmon in the Karluk district, will make possible,

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in time, a fairly reliable determination of the correlation existing between the size of the escapement—that is, breeding population—and the number of the resulting progeny. On *a priori* grounds, however, it could be anticipated that this correlation would not be perfect, since there are various environmental factors which doubtless affect the rate of mortality throughout the life of the salmon from the time the eggs are laid until sexual maturity is reached and the fish return from the sea to spawn. A few clear cut cases are known in which enviromental conditions have destroyed the effect of large spawning escapements. Of the various factors which may affect survival in the ocean we know, at present, very little, but it seems rather probable that conditions in the sea are much more constant than in fresh water. Certainly such factors as the water conditions at the time of spawning and during the incubation period, the abundance of enemies and competitors, and the abundance of natural food organisms in the lakes bear directly upon the ultimate success of breeding.

The Karluk watershed, which is situated in the western part of Kodiak Island, is occupied by the Karluk River, Karluk Lake, Thumb Lake, O'Malley Lake, and a considerable number of tributary streams of various sizes and which together constitute very important breeding grounds for the red salmon. The spawning escapements since 1921 have varied from about four hundred thousand to approximately two and a half millions. Gilbert and Rich (1927) estimated that well over 1,000 million red salmon eggs were deposited in the lakes and streams of this watershed during the spawning season of 1926.

The young red salmon derived from the eggs deposited in this watershed spend some time in Karluk Lake, where they are almost exclusively plankton feeders; they migrate to the sea in the spring of their second to fourth year. The great majority of them leave the lake in the spring of their third year. By far the larger number of them mature in their fifth year and return to spawn at that time, so they spend approximately half of their lives in the lake and half in the sea. The lake, therefore, plays a very important rôle as a nursery for the young red salmon, and this fact has led to a general assessment of its physical, chemical, and biological status. The Karluk system is of special interest in this connection since it is generally recognized that, for its size and the area of its suitable spawning grounds, it is unusually productive. It has maintained a large run over a long period of intense exploitation—a run that is still considered one of the best of the whole of Alaska outside of Bristol Bay where there are numerous streams and lakes all of which are much larger than those of the Karluk system. Those engaged in the salmon investigations at Karluk have spent some time each year on the spawning grounds making such studies of the conditions as were possible in such an isolated locality and with the limited time available. Particular attention has been paid to conditions on the spawning beds, but the obvious importance of a knowledge of conditions in the lakes led to the collection of the data which form the basis of this report.

## PHYSICAL AND CHEMICAL DATA

### LOCATION AND PHYSICAL FEATURES OF LAKE

Karluk Lake lies in latitude 57° 24′ N. and longitude 154° 5′ W. The lake is long, narrow, and straight sided, with a prominent bay, the Thumb, situated about the middle of the east side. (See fig. 1.) Three small islands help to separate the Thumb from the main part of the lake. The main axis of the lake lies in a general north and south direction and its maximum length is 19.6 kilometers (12.2 miles);

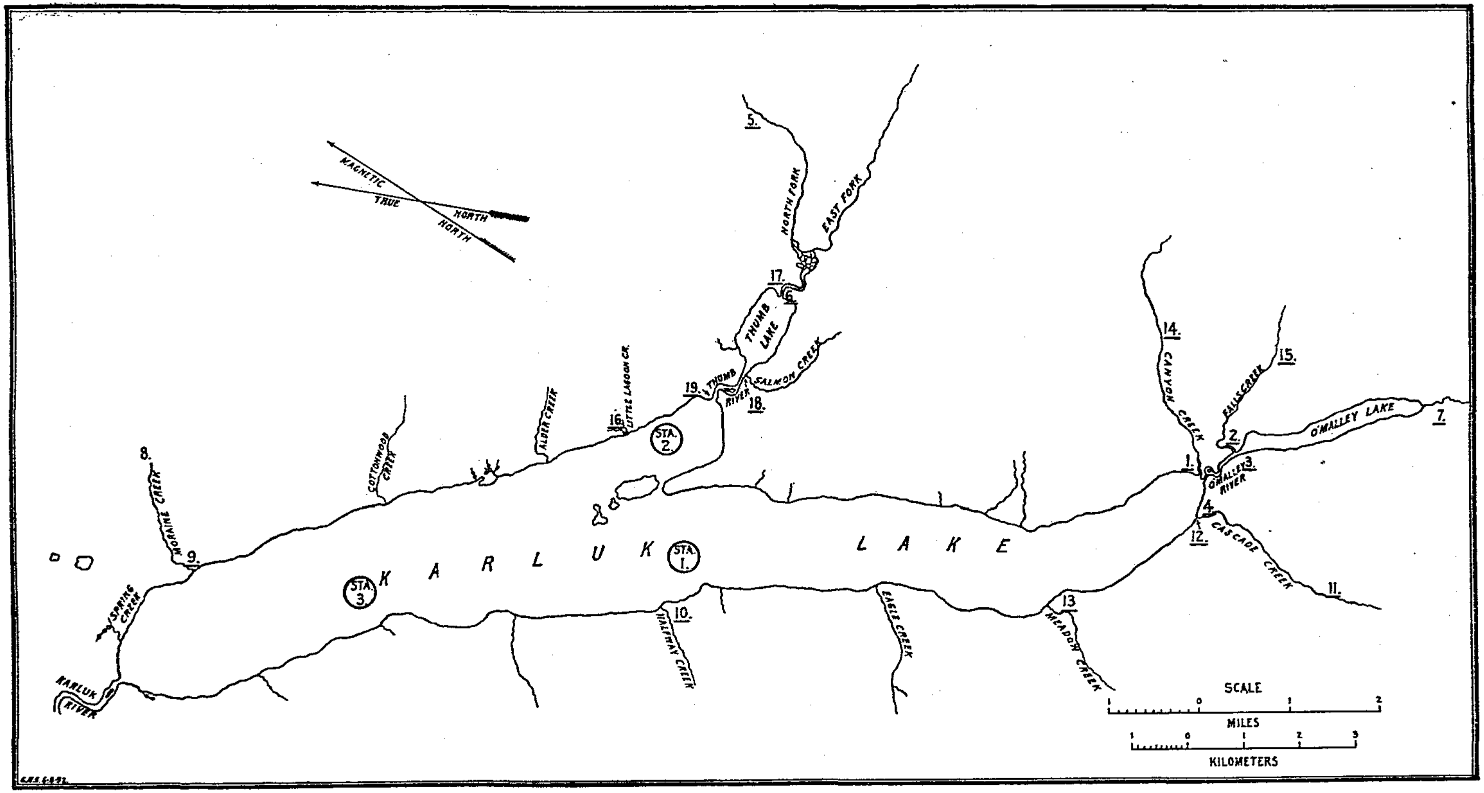


FIGURE 1.—Map of Karluk Lake region, Kodiak Island, Alaska

the greatest width is 3.1 kilometers (2 miles). The area is 39.5 square kilometers (15.2 square miles) and the maximum depth is 126 meters (413 feet). The mean depth is 48.6 meters (159 feet). The surface of the lake is about 106 meters (350 feet) above sea level, so that the deepest part of the basin is about 20 meters (65 feet) below sea level.

The lake is surrounded by mountains which rise to a height of 760 meters (2,500 feet) and the immediate shores consist of shale with an occasional small ledge or vein of quartz. The lake basin appears to be of recent glacial origin and the water is impounded by a large terminal moraine at the north end. In general, the beaches are composed of gravel and bowlders of various sizes. The shores are still in a youthful stage and the subaqueous terrace is poorly developed; as a result the bottom slopes away abruptly from the shores. The outlet, the Karluk River, flows out of the north end of the lake; it is a stream of considerable size and it is about 48 kilometers (30 miles) long (Gilbert and Rich, 1927). A rough estimate of the quantity of water discharged into Karluk Lake by the more important tributary streams was placed at 7 cubic meters per second in late August 1928.

The narrow subaqueous terrace and the steep slope of the bottom make conditions unfavorable for the growth of the large aquatic plants along most of the shore; such growths are found in only three favorable localities. Filamentous algæ are found in considerable abundance on submerged rocks and bowlders along the margin of the lake. The shores are well covered with groves of cottonwoods, alders, birches, willows, and shrubs.

Thumb Lake is situated about the middle of the east side of Karluk Lake (fig. 1); it is about 1 kilometer (¾ mile) long and half a kilometer (⅜ mile) wide. Its maximum depth is 10 meters (33 feet). A short stream known as the Thumb River connects Thumb Lake with Karluk Lake.

O'Malley Lake is situated at the south end of Karluk Lake; it is about 3 kilometers (2 miles) long and ⅓ of a kilometer (⅕ mile) wide. It has a maximum depth of 12 meters (40 feet); and its outlet, the O'Malley River, flows into the south end of Karluk Lake.

Gilbert and Rich (1927) published a hydrographic map of Karluk Lake which was based on surveys and soundings made in the summer of 1926. The data concerning the area and the volume of the lake, which are given in Table 1, are based upon measurements of the original map prepared by these authors.

TABLE 1.—*Area and volume of Karluk Lake*

| Depth in meters | Areas | | Per cent of total area | Stratum | Volume | | Per cent of total volume |
|---|---|---|---|---|---|---|---|
| | Square kilometers | Square miles | | | Million cubic meters | Million cubic yards | |
| 0 | 39.5 | 15.2 | 100.0 | 0-10 | 374.3 | 489.6 | 19.50 |
| 10 | 35.4 | 13.7 | 89.6 | 10-20 | 334.7 | 437.8 | 17.44 |
| 20 | 31.6 | 12.2 | 80.0 | 20-30 | 288.9 | 377.9 | 15.06 |
| 30 | 26.3 | 10.1 | 66.6 | 30-40 | 230.9 | 302.0 | 12.02 |
| 40 | 20.2 | 7.8 | 51.1 | 40-50 | 173.2 | 226.5 | 9.02 |
| 50 | 15.4 | 5.9 | 39.0 | 50-60 | 121.2 | 158.5 | 6.31 |
| 60 | 11.0 | 4.2 | 27.8 | 60-70 | 102.4 | 133.9 | 5.33 |
| 70 | 9.5 | 3.7 | 24.0 | 70-80 | 86.9 | 113.7 | 4.52 |
| 80 | 7.9 | 3.0 | 20.0 | 80-90 | 70.8 | 92.6 | 3.69 |
| 90 | 6.3 | 2.4 | 16.0 | 90-100 | 55.3 | 72.3 | 2.88 |
| 100 | 4.8 | 1.8 | 12.1 | 100-110 | 42.9 | 56.1 | 2.23 |
| 110 | 3.8 | 1.5 | 9.6 | 110-120 | 32.9 | 43.0 | 1.71 |
| 120 | 2.8 | 1.1 | 7.1 | 120-126 | 5.6 | 7.3 | 0.29 |
| | | | | | 1,920.0 | 2,511.2 | 100.00 |

## TRANSPARENCY OF WATER

The transparency of the water was measured by means of the Secchi disk. The results of the readings in the three lakes are given in Table 2. In general, the water of Karluk Lake was more transparent than that of Thumb and O'Malley Lakes. Thumb Lake was the least transparent of the three. Karluk Lake was more transparent in 1928 than in either of the other years represented in the table.

TABLE 2.—*Transparency of the water in Karluk, Thumb, and O'Malley Lakes*

[The readings of the Secchi disk are indicated in meters and they show the depth at which the disk disappeared from view]

| Karluk Lake | | Thumb Lake | | O'Malley Lake | |
|---|---|---|---|---|---|
| Date | Depth | Date | Depth | Date | Depth |
| July 10, 1928 | 8.6 | July 9, 1928 | 2.5 | July 10, 1929 | 5.5 |
| Sept. 3, 1928 | 8.0 | Sept. 3, 1928 | 3.0 | Sept. 12, 1929 | 3.8 |
| July 9, 1929 | 5.5 | July 11, 1929 | 2.8 | July 15, 1930 | 4.0 |
| Sept. 7, 1929 | 4.5 | Sept. 7, 1929 | 2.5 | Sept. 5, 1930 | 4.0 |
| July 12, 1930 | 7.5 | July 13, 1930 | 2.6 | | |
| Sept. 9, 1930 | 7.8 | Sept. 6, 1930 | 2.0 | | |

## TEMPERATURES

The climate of Kodiak Island, on which Karluk Lake is situated, is temperate. The lake lies in the Pacific coast climatic zone of Alaska, and this region possesses a marine climate, with a large amount of cloudy weather. There is no permanent settlement in the vicinity of Karluk Lake, and the nearest weather-observing station is located at the village of Kodiak on the eastern end of Kodiak Island, about 160 kilometers (100 miles) from the lake. Table 3 shows the range of variation of atmospheric temperatures at Kodiak from 1926 to 1930, inclusive, as well as the mean temperature for these years. The United States Weather Bureau reports that temperatures were above normal throughout the year in 1926 at nearly all Alaskan stations, considerably exceeding all previous records. The mean annual temperature was about normal in 1927 and 1930 and just a little above normal in 1928 and 1929.

TABLE 3.—*Range of air temperatures at Kodiak on Kodiak Island, Alaska, during the years 1926–1930, inclusive, and the mean annual temperature for these five years*

| Year | Maximum | | Minimum | | Mean annual | |
|---|---|---|---|---|---|---|
| | °C. | °F. | °C. | °F. | °C. | °F. |
| 1926 | 25.5 | 78 | −12.2 | 10 | 7.3 | 45.1 |
| 1927 | 20.0 | 68 | −13.3 | 8 | 4.6 | 40.3 |
| 1928 | 22.2 | 72 | −15.6 | 4 | 5.2 | 41.4 |
| 1929 | 27.8 | 82 | −11.6 | 11 | 6.2 | 43.2 |
| 1930 | 27.2 | 81 | −16.7 | 2 | 4.7 | 40.5 |

The mean monthly temperature was lowest in February, 1926, being 0.5° C. or 33° F., but December was almost as low, namely, 0.7° C. or 33.2° F. The mean monthly temperature was lowest in March from 1927 to 1929; it was −1.8° C. (28.7° F.) in 1927, −1.3° C. (29.7° F.) in 1928, and −0.3° C. (31.4° F.) in 1929. February had the lowest mean in 1930, namely, −5.3° C. (22.5° F.). The monthly mean was highest in August in 1926 to 1928, inclusive; it was 13.7° C. (56.6° F.) in 1926, 11.7° C. (53° F.) in 1927, and 12° C. (53.4° F.) in 1928. In 1929 the monthly means were the same for July and August, namely, 13.2° C. (55.8° F.). It was highest in August, 1930, namely, 13.5° C. (56.3° F.).

The total precipitation at the Kodiak weather station was 195.8 centimeters (77.08 inches) in 1926; 151 centimeters (59.47 inches) in 1927; 167.1 centimeters (65.79 inches) in 1928; 135.7 centimeters (53.42 inches) in 1929; and 119.3 centimeters (46.99 inches) in 1930.

Karluk Lake is usually covered with ice in winter; it freezes over during the latter part of December and opens again some time in April. In 1931 the lake became free of ice on April 20. In very mild winters, such as that of 1925–26, the lake does not freeze, but this is reported to happen only once in about 20 to 25 years.

Table 4 shows the results of the temperature readings obtained at station 1, which is situated in the deepest part of Karluk Lake. The surface temperature ranged from

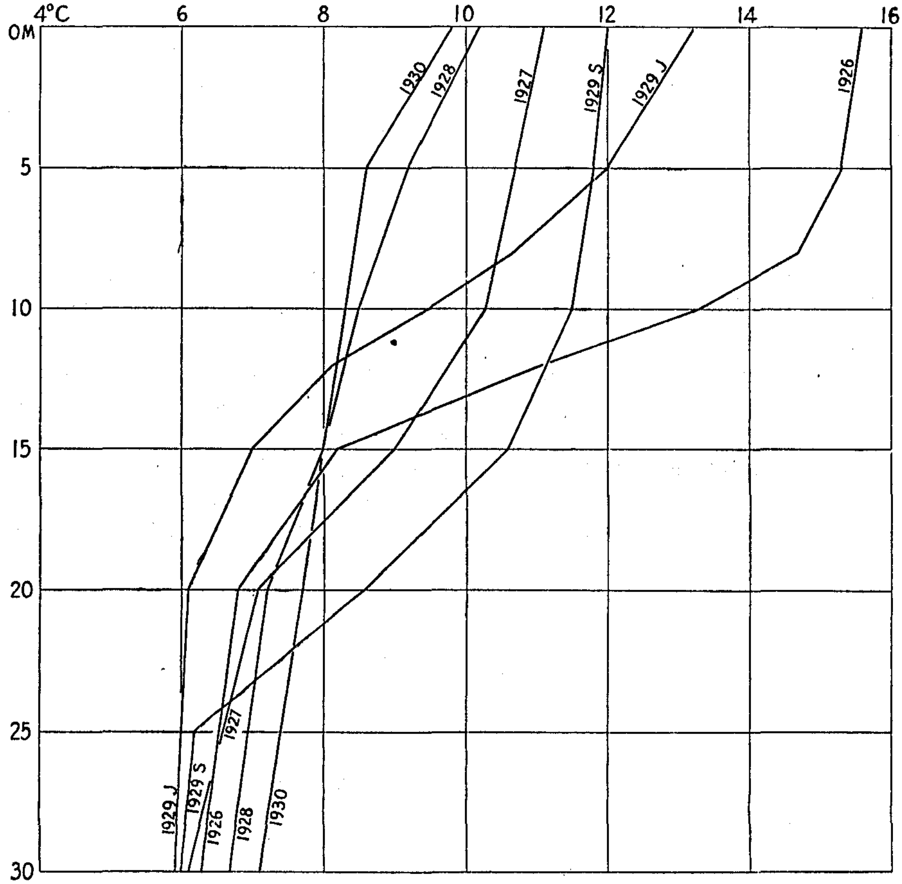


FIGURE 2.—Summer temperatures of the upper 30 meters of Karluk Lake, 1926 to 1930, inclusive. The series shown in the diagram were taken as follows: August 15, 1926; August 13, 1927; July 10, 1928; July 9, 1929 (*J*); September 8, 1929 (*S*); July 12, 1930. The temperatures are indicated in degrees centigrade. Note the definite stratification in 1926

about 10° C. (50° F.) in early July to a maximum of 15.6° C. (56° F.) about the middle of August; the highest temperatures were found during the warm summer of 1926. In this year the three thermal strata of the lake were well marked. The epilimnion extended from the surface to a depth of about 8 meters on August 15, 1926; the thermocline extended from 8 to 15 meters and the hypolimnion from the latter depth to the bottom. The epilimnion and thermocline were not so definitely outlined in the other years.

Six sets of the temperature readings for the upper 30 meters are shown in Figure 2. The readings taken on July 12, 1930, show the lowest surface temperature and those of August 15, 1926, the highest. The curve for 1926 shows that the epilimnion and the thermocline were more sharply defined in that year than in the other years. At a depth of 30 meters the highest temperature (7.1° C.) was noted on July 12, 1930, and the lowest (5.9° C.) on July 9, 1929. The two curves for 1929 show the temperature changes which took place in the upper 30 meters of water between July 9 and September 8 of that year. Between these two dates there was a decrease in the temperature of the upper 5 meters; but there was a marked rise in temperature between 5 and 25 meters, with a slight increase between the latter depth and 30 meters. The bottom temperatures in the deepest water of Karluk Lake ranged from a minimum of 4.1° C. (39.4° F.) to a maximum of 4.9° C. (40.8° F.). (Table 4.)

TABLE 4.—*Summer temperatures of Karluk Lake at station 1*

[The readings are indicated in degrees centigrade at the different depths]

| Depth in meters | Aug. 15, 1926 | July 19, 1927 | Aug. 13, 1927 | July 10, 1928 | Sept. 3, 1928 | July 9, 1929 | Sept. 8, 1929 | July 12, 1930 |
|---|---|---|---|---|---|---|---|---|
| 0 | 15.6 | 11.3 | 11.1 | 10.2 | 9.7 | 13.2 | 12.0 | 9.8 |
| 5 | 15.3 | 11.0 | ---- | 9.2 | 9.7 | 12.0 | 11.8 | 8.6 |
| 8 | 14.7 | 9.7 | ---- | ---- | ---- | 10.7 | ---- | ---- |
| 10 | 13.5 | 9.7 | 10.3 | 8.5 | 9.7 | 9.5 | 11.5 | 8.3 |
| 12 | 11.1 | 8.4 | ---- | ---- | ---- | 8.1 | ---- | ---- |
| 15 | 8.2 | 7.2 | 9.0 | 8.0 | 9.7 | 7.0 | 10.6 | 8.0 |
| 20 | 6.8 | 6.2 | 7.1 | 7.2 | 8.6 | 6.1 | 8.6 | ---- |
| 25 | ---- | ---- | ---- | 6.6 | 8.3 | ---- | 6.2 | ---- |
| 30 | 6.3 | ---- | 6.1 | ---- | ---- | ---- | ---- | 7.1 |
| 50 | 6.0 | ---- | ---- | 5.6 | 6.9 | ---- | ---- | 5.6 |
| 126 | 4.9 | 4.2 | 4.4 | 4.4 | 4.9 | 4.1 | 4.8 | 4.2 |

No winter temperatures have been taken in Karluk Lake, so that the winter minimum is not known definitely. Some observations made in the spring of 1931, however, serve as a basis for estimating the minimum. The covering of ice disappeared from Karluk Lake on April 20, 1931, while the ice disappeared from the lakes of northeastern Wisconsin on April 13 to 15, 1931, or only about a week earlier than on Karluk. On May 2, 1931, the temperature of the surface water of Karluk Lake was 2.4° C. (36.3° F.) and that at 126 meters was 2.6° C. These results are similar to those obtained on Wisconsin lakes soon after the disappearance of the ice, and it seems probable that the temperature cycle in Karluk Lake is substantially the same in winter as that of the Wisconsin lakes where the mean temperature at the time of freezing is about 1° C. Thus a minimum temperature of 1° C. may be used for the computation of the heat budget of Karluk Lake. The summer heat income represents the gain above a temperature of 4° C.

Table 5 shows the annual heat budget, the summer heat income, and the gain in heat which took place between the two sets of summer temperature readings in three of the years in which observations were made. The heat budgets represented in the table ranged from 28,200 gram-calories per square centimeter of surface on July 19, 1927, to 35,800 gram-calories on August 15, 1926. At the time of the July observations in 1927 to 1929, inclusive, the heat budgets amounted to 28,000 to 29,000 gram-calories per square centimeter and a further gain of 2,400 to 5,800 calories was made between the July readings and those of August or September. The heat budgets indicated for September 3, 1928, and September 8, 1929, probably represent the maximum budgets for those years as it does not seem probable that the water gained any heat after these dates. The budgets for August 15, 1926, and August 13, 1927, may not represent the maximum for those years, but the gain in heat after the middle of August is probably small in that latitude, except perhaps in years when it is unusually warm in the latter half of August and in early September.

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The summer heat income ranged from 16,000 calories on August 13, 1927, to 21,200 calories on August 15, 1926. The mean summer heat income for the four August and September observations is 18,900 calories.

The gain of 5,800 gram-calories between July 10 and September 3, 1928, represented an average daily gain of a little more than 105 gram-calories for this period of 55 days. The gain between July 19 and August 13, 1927, was about 96 calories per day, while that between July 9 and September 8, 1929, was only 68 calories per day.

TABLE 5.—*The mean temperature, heat budget, summer heat income, and gain in heat between the two dates on which summer temperature observations were made on Karluk Lake*

[The results for heat are indicated in gram-calories per square centimeter of surface]

| Date | Mean temperature, °C. | Heat budget | Summer heat income | Gain in heat | |
|---|---|---|---|---|---|
| | | | | Total | Average per day |
| Aug. 15, 1926 | 8.37 | 35,800 | 21,200 | | |
| July 19, 1927 | 6.80 | 28,200 | 13,600 | | |
| Aug. 13, 1927 | 7.30 | 30,600 | 16,000 | 2,400 | 96 |
| July 10, 1928 | 6.84 | 28,400 | 13,800 | | |
| Sept. 3, 1928 | 8.03 | 34,200 | 19,600 | 5,800 | 105 |
| July 9, 1929 | 7.02 | 29,200 | 14,600 | | |
| Sept. 8, 1929 | 7.87 | 33,400 | 18,800 | 4,200 | 68 |
| July 12, 1930 | 7.00 | 29,100 | 14,500 | | |

The mean of the August and September heat budgets of Karluk Lake in 1926 to 1929, inclusive, is 33,500 gram-calories. This budget is comparable in size to those of a number of lakes situated in much lower latitudes, such as Green Lake, Wis., and some of the Finger Lakes of New York, as well as some of the European lakes. The heat budgets of several American and European lakes are given in Table 6.

These data show that the average heat budget of Karluk Lake is exceeded somewhat by those of some of the larger lakes represented in the table, such as Seneca, Cayuga, and Owasco of New York, Geneva of Switzerland, and Loch Ness of Scotland, but the 1926 budget of Karluk almost or quite reaches that of some of the members of this group. The averages for Karluk and Green Lake are substantially the same, as well as that of Traun See of Austria. Four of the lakes included in the table have smaller heat budgets than Karluk Lake. While the temperature of the upper water of Karluk Lake is not as high as that of Green Lake, Wis., and of the Finger Lakes of New York, yet its area and depth are such that it absorbs a similar amount of heat per unit of area during the warming period each year, as indicated in the table.

TABLE 6.—*Heat budgets of some American and European lakes*

| Lake | Location | Heat budget, gram-calories | Lake | Location | Heat budget, gram-calories |
|---|---|---|---|---|---|
| Karluk | Alaska | 33,500 | Zürich | Switzerland | 21,800 |
| Green | Wisconsin | 34,000 | Würm | Germany | 26,000 |
| Seneca | New York | 36,700 | Traun | Austria | 33,400 |
| Cayuga | do | 37,400 | Vettern | Sweden | 32,000 |
| Owasco | do | 35,600 | Ness | Scotland | 37,200 |
| Geneva | Switzerland | 36,600 | Lochy | do | 31,500 |

Table 7 shows the results of the temperature readings on Thumb and O'Malley Lakes. The surface temperatures of these two lakes did not differ greatly from those of Karluk Lake on corresponding dates; the maximum difference was noted in 1929 when the surface water of O'Malley Lake had a temperature of 16° C. (60.8° F.) on July 10 and that of Karluk Lake was 13.2° C. (55.8° F.) on July 9. The maximum difference between surface and bottom temperatures in Thumb Lake was 4.2° C. on July 11, 1929, and a difference of 4° C. was noted in O'Malley Lake on July 10, 1929.

TABLE 7.—*Summer temperatures of Thumb and O'Malley Lakes*

[The readings are indicated in degrees centigrade]

| Thumb Lake | | | O'Malley Lake | | |
|---|---|---|---|---|---|
| Date | Depth in meters | Temperature | Date | Depth in meters | Temperature |
| July 21, 1927 | 0 | 11.8 | July 23, 1927 | 0 | 13.1 |
| Do | 10 | 10.0 | Do | 12 | 12.8 |
| Aug. 3, 1927 | 0 | 12.0 | Aug. 10, 1927 | 0 | 13.2 |
| Do | 10 | 10.4 | Do | 12 | 12.2 |
| July 9, 1928 | 0 | 10.7 | July 10, 1929 | 0 | 16.0 |
| Do | 10 | 8.1 | Do | 12 | 12.0 |
| Sept. 3, 1928 | 0 | 8.2 | Sept. 12, 1929 | 0 | 13.2 |
| Do | 10 | 7.4 | Do | 12 | 12.4 |
| July 11, 1929 | 0 | 10.3 | July 15, 1930 | 0 | 13.4 |
| Do | 10 | 6.1 | Do | 12 | 13.0 |
| Sept. 12, 1929 | 0 | 12.4 | Sept. 5, 1930 | 0 | 14.9 |
| Do | 10 | 10.2 | Do | 12 | 14.8 |
| July 13, 1930 | 0 | 10.4 | | | |
| Do | 10 | 8.3 | | | |
| Sept. 6, 1930 | 0 | 12.7 | | | |
| Do | 10 | 10.1 | | | |

## CHEMISTRY OF LAKES

Table 8 shows the results of the chemical analyses that were made on the waters of Karluk, Thumb, and O'Malley Lakes during July and August, 1927. In Karluk Lake the hydrogen-ion concentration ranged from pH 8.6 at the surface to pH 7.0 at a depth of 120 meters. In Thumb Lake the hydrogen-ion readings were somewhat lower, ranging from pH 8.2 at the surface to pH 6.8 at the bottom, while in O'Malley Lake the readings were still lower, being pH 8.0 at the surface and pH 6.6 at the bottom.

In Karluk Lake the free carbon dioxide amounted to 1 milligram per liter of water at the surface and to 3.5 to 4 milligrams at the bottom. In both Thumb and O'Malley Lakes the free carbon-dioxide content was somewhat larger in the bottom water than in the main basin of Karluk Lake, but the quantity found in the lower water of the Thumb Basin of Karluk Lake on August 2, 1927, was a little greater than that in the lower water of Thumb Lake. The fixed or bound carbon dioxide in Karluk Lake varied between 9 and 10 milligrams per liter of water and O'Malley Lake had the same amount; the quantity was a little larger in Thumb Lake, namely 11 to 12 milligrams per liter. This relatively small quantity of fixed carbon dioxide indicates that these waters contain correspondingly small amounts of carbonates in solution, and this comparatively small carbonate content is due to the fact that the country rock of this drainage basin consists chiefly of slate.

TABLE 8.—*Results of chemical analyses of the waters of Karluk, Thumb, and O'Malley Lakes in 1927*

[The results are stated in milligrams per liter of water; Tr.=trace]

| Date, 1927 | Depth in meters | Temperature, °C. | pH | Carbon dioxide | | Oxygen | Phosphorus | | | Silica | Nitrogen | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Free | Fixed | | Soluble | Organic | Total | | Ammonia | Nitrite | Nitrate |
| **KARLUK LAKE, STATION 1** | | | | | | | | | | | | | |
| July 19 | 0 | 11.3 | 8.4 | 1.0 | 9.5 | | 0.002 | 0.004 | 0.006 | 0.0 | 0.008 | | |
| Do | 120 | 4.2 | 7.0 | 4.0 | 9.0 | 11.3 | | | | .6 | .040 | Tr. | 0.030 |
| July 31 | 0 | 11.4 | 8.2 | 1.0 | 9.5 | | .002 | .003 | .005 | .5 | .000 | | .012 |
| Do | 13 | 8.9 | 8.0 | 1.0 | | | .002 | | | .5 | | | |
| Do | 122 | 4.3 | 7.6 | 2.0 | | | .010 | | | | | | |
| Do | 125 | 4.3 | 7.5 | 3.5 | 9.5 | 12.1 | .010 | | | .5 | .050 | .001 | .052 |
| Aug. 13 | 0 | 11.1 | 8.2 | 1.0 | 9.5 | | .002 | .028 | .030 | 0 | .004 | .000 | |
| Do | 125 | 4.4 | 7.5 | 3.5 | 9.5 | | .008 | .014 | .022 | .5 | .022 | .000 | |
| **KARLUK LAKE, STATION 2 (THE THUMB)** | | | | | | | | | | | | | |
| July 20 | 0 | 11.2 | 8.2 | 1.0 | 9.5 | | .002 | .003 | .005 | | | | |
| Do | 40 | 5.5 | 7.2 | 3.5 | 10.0 | 8.8 | .010 | | | | | | .020 |
| Aug. 2 | 0 | 11.2 | 8.2 | 1.0 | | | .002 | .018 | .020 | 0 | .000 | .000 | .035 |
| Do | 10 | 10.8 | 8.0 | 1.5 | | | .003 | .022 | .025 | 0 | .030 | .000 | .035 |
| Do | 41 | 5.5 | 7.4 | 3.5 | | | .006 | .014 | .020 | 0 | .060 | .000 | |
| Do | 42.5 | 5.5 | 7.2 | 8.5 | | 9.6 | .015 | | | .5 | .120 | .000 | .050 |
| Aug. 12 | 0 | 11.0 | 8.6 | 0 | 10.0 | | .002 | | | | Tr. | .000 | |
| Do | 40 | 5.6 | 7.6 | | | | .010 | | | | | | |
| Do | 41.5 | 5.6 | 7.2 | 2.5 | 10.0 | | .018 | .012 | .030 | | .080 | Tr. | |
| **THUMB LAKE** | | | | | | | | | | | | | |
| July 21 | 0 | 11.8 | 8.2 | 1.5 | 10.5 | | .004 | .006 | .010 | .5 | .040 | .002 | .012 |
| Do | 10 | 10.0 | 6.8 | 7.5 | 10.5 | 6.3 | .020 | .022 | .042 | 1.0 | .250 | .002 | .018 |
| Aug. 3 | 0 | 12.0 | 8.2 | 2.0 | 11.5 | | .004 | .016 | .020 | 0 | .064 | .000 | .050 |
| Do | 10 | 10.5 | 6.8 | 6.5 | 11.0 | | .020 | .020 | .040 | 1.0 | .400 | .005 | .060 |
| Aug. 12 | 0 | 11.1 | 8.0 | 2.0 | 11.5 | | .006 | .044 | .050 | .5 | .032 | .001 | |
| Do | 3 | | 7.8 | 1.5 | | | .004 | | | | | | |
| Do | 5 | | 7.6 | 2.5 | 11.5 | | .012 | .033 | .045 | .5 | .040 | .001 | |
| Do | 10 | 9.7 | 7.0 | 5.0 | 12.0 | | .070 | .022 | .092 | 2.0 | .400 | .001 | |
| **O'MALLEY LAKE** | | | | | | | | | | | | | |
| July 23 | 0 | 13.1 | 7.2 | 1.5 | 10.0 | | .003 | .044 | .047 | 0 | .008 | .000 | .056 |
| Do | 12 | 12.8 | 6.6 | 3.0 | 10.0 | 6.3 | .007 | .041 | .048 | .5 | .084 | .000 | .052 |
| Aug. 10 | 0 | 13.2 | 8.0 | 1.5 | 9.0 | | .003 | .032 | .035 | 1.0 | Tr. | | |
| Do | 11 | 12.2 | 7.4 | 2.8 | 9.5 | 10.5 | .005 | .035 | .040 | 1.5 | .020 | | |
| **BOG POND** | | | | | | | | | | | | | |
| July 30 | 0 | 17.0 | 7.8 | 2.5 | 11.0 | | .000 | | | 1.5 | .000 | | |

No complete series of dissolved oxygen determinations was made, but samples were obtained from the bottom water of each of the three lakes. At station 1 in the deepest water of Karluk Lake the lower water was well supplied with dissolved oxygen; the quantity ranged from 85 to 92 per cent of the amount required for saturation. A smaller amount was found in the lower water of The Thumb Basin of Karluk Lake; here the amount reached only 69 to 72 per cent of saturation. A still smaller amount was found in the bottom waters of Thumb and O'Malley Lakes where the quantity reached only 55 and 58 per cent of saturation, respectively. In spite of the lower percentages in the latter lakes, the lower water of all three lakes was well supplied with dissolved oxygen, so that all three of them belong to the oligotrophic type.

The quantity of soluble phosphorus in the surface water of Karluk Lake was 0.002 milligram per liter. In Thumb Lake it varied from 0.004 to 0.006 milligram per liter and in O'Malley Lake it was 0.003 milligram per liter. The amount of soluble phosphorus was larger in the lower water than in the surface water in all cases. This is due to the decomposition of organic matter in the lower stratum. The plankton and other organic material which settles into the lower water and decomposes there contains organic phosphorus which is changed to the soluble form during the decomposition process. As a result of this change the soluble phosphorus shows a more or less marked increase in quantity in the lower water during the summer; the extent of this increase is dependent upon the amount of organic matter which decomposes in this stratum.

The organic phosphorus consists of that part of this element which is combined with the organic matter that is present in the water in the form of living organisms, or in organic material derived from such organisms. The quantity of organic phosphorus is dependent upon the amount of organic matter, but the former is not directly proportional to the latter. The various organic compounds possess different percentages of phosphorus, so that there is no direct quantitative relation between the two. The quantity of organic phosphorus is usually larger than that of the soluble phosphorus; frequently the former is several times as large as the latter, as shown in the surface water of Karluk Lake on August 13, 1927. In the bottom water, however, the quantity of soluble phosphorus may be several times as large as that of the organic phosphorus; the 10-meter sample of Thumb Lake on August 12, 1927, contained more than three times as much soluble as organic phosphorus. In Karluk Lake there was only half as much organic phosphorus in the 125-meter sample as in the surface sample on August 13, 1927. A similar result was obtained in Thumb Lake on August 12, 1927; on July 21, however, there was a larger amount of organic phosphorus in the lower than in the upper water of this lake.

The quantity of titratable silica in the waters of the three lakes varied from none to 2 milligrams per liter. This substance is used by the diatoms in making their siliceous shells, so that the quantity of silica in the water is correlated more or less closely with the growth of these organisms. A large crop of diatoms may completely exhaust the supply of available silica as shown in some of the surface samples of these three lakes. The largest amounts of silica were found in the lower water where light conditions were unfavorable for the growth of diatoms. The plankton contained a rather large number of diatoms, so there was an active demand for silica in the upper water.

Only small amounts of ammonia nitrogen were found in the upper waters of the three lakes, but larger amounts were obtained from bottom samples. The activities of the phytoplankton in the upper strata create a demand for nitrogen, and free ammonia can be used by these organisms as well as nitrite and nitrate nitrogen. This accounts for the small amount of ammonia nitrogen in the upper water. The free ammonia of the lower water is derived from the organic matter which decomposes in that region; since light conditions are unfavorable for photosynthesis there is no demand for the ammonia nitrogen in the lower strata.

Only a very small amount of nitrite nitrogen was found at any depth. In Karluk Lake the nitrate nitrogen varied from 0.02 to 0.052 milligram per liter, the largest amount being found in the bottom water. The waters of Thumb and O'Malley Lakes yielded from 0.012 to 0.06 milligram of nitrate nitrogen per liter.

Two liter samples of surface and bottom water from Karluk Lake were evaporated in July and September, 1930, and the residues obtained from them were analyzed for various constituents. Residues were obtained from surface samples of Thumb and O'Malley Lakes also. The results of these analyses are given in Table 9.

The residues obtained from the Karluk samples of water ranged from a little more than 30 to 34 milligrams per liter. The surface and bottom samples yielded nearly the same amounts of residue in the four sets taken in 1930. The residues from O'Malley Lake were somewhat smaller than those from Karluk Lake. While the July sample from Thumb Lake was about the same as those from Karluk Lake, the September sample from the former was distinctly larger than those of the latter.

The quantity of silica was substantially the same in Karluk and Thumb Lakes, but a somewhat larger amount was found in the O'Malley samples. The amount of calcium was approximately the same in the three lakes. but the September sample from Thumb Lake yielded a somewhat larger quantity than any of the others. The quantity of magnesium also was not very different in the various samples; in general the amount of magnesium was somewhat smaller than that of calcium. The quantity of phosphorus was about the same in Karluk and O'Malley Lakes, but about twice as much was found in the Thumb Lake samples as in those from the other two lakes. This extra quantity of phosphorus in Thumb Lake was undoubtedly derived from the decomposing carcasses of the red salmon.

TABLE 9.—*Chemical analyses of residues from Karluk, Thumb, and O'Malley Lakes*

[The results are indicated in milligrams per liter of water]

| Lake | Date, 1930 | Depth in meters | Residue | $SiO_2$ | Ca | Mg | Total P |
|---|---|---|---|---|---|---|---|
| Karluk Lake, station 1 (upper basin) | July 12 | 0 | 31.5 | 1.7 | 5.62 | 4.42 | 0.016 |
| | do | 125 | 33.4 | 1.9 | 5.48 | 5.91 | .016 |
| | Sept. 2 | .0 | 30.5 | 1.5 | 5.58 | 5.36 | .019 |
| | do | 125 | 30.3 | 1.6 | 4.80 | 5.34 | .015 |
| Karluk Lake, station 2 (the Thumb) | July 12 | 0 | 34.0 | 2.0 | 5.82 | 3.46 | .018 |
| | July 13 | 43 | 32.0 | 1.8 | 6.21 | 4.35 | .018 |
| | Sept. 3 | 0 | 32.1 | 1.7 | 5.76 | 5.44 | .014 |
| | Sept. 2 | 43 | 30.9 | 1.6 | 5.11 | 5.00 | .016 |
| Thumb Lake | July 13 | 0 | 31.4 | 1.8 | 5.90 | 5.62 | .028 |
| | Sept. 6 | 0 | 38.3 | 1.9 | 7.16 | 6.53 | .039 |
| O'Malley Lake | July 15 | 0 | 28.5 | 2.7 | 5.92 | 4.86 | .015 |
| | Sept. 5 | 0 | 29.8 | 2.9 | 6.15 | 4.55 | .014 |

## CHEMISTRY OF STREAMS

The results of the temperature and chemical observations that were made on 10 affluents of Karluk Lake during the summer of 1927 are shown in Table 10. The temperature of the water in these streams was lower than that of the surface water of Karluk Lake during that season. In the various streams the temperature ranged from a minimum of 4.2° C. (39.5° F.) in Little Lagoon Creek on July 29, 1927, to a maximum of 13° C. (55.4° F.) in O'Malley River on July 17, 1927. The surface temperature of Karluk Lake in 1927 varied from 11° C. (51.8° F.) to 11.4° C. (52.5° F.). All of the streams are relatively short and have rapid currents, so that the water is not warmed very much on its way to the lake. (See fig. 1.)

The hydrogen-ion concentration of the stream waters varied from pH 6.8 to pH 8.0, while that of the surface water of Karluk Lake was more alkaline, ranging from pH 8.2 to pH 8.6.

The free carbon dioxide of the stream waters varied from a minimum of 1 milligram to a maximum of 6.5 milligrams per liter, while the average amount in the surface water of Karluk Lake was 1 milligram per liter. In general the stream waters yielded a somewhat larger amount of fixed or bound carbon dioxide than the surface water of Karluk Lake. They contained from 10.5 to 12 milligrams per liter, with a maximum of 22 milligrams in one stream; the surface water of the lake yielded from 9.5 to 10 milligrams of fixed carbon dioxide per liter. The 22 milligrams per liter found in Little Lagoon Creek was about twice the amount present in the other streams. This indicates that there is a much larger quantity of calcareous material in the drainage basin of this stream than in those of the other streams.

TABLE 10.—*Results of the chemical analyses of the stream waters*

[Results are stated in milligrams per liter of water. Tr. means trace. The station numbers are indicated on the map, fig. 1]

| No. | Stream | Locality | Date, 1927 | Temperature °C. | pH | Carbon dioxide | | Phosphorus | | | Silica | Nitrogen | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Free | Fixed | Soluble | Organic | Total | | Ammonia | Nitrite | Nitrate |
| 1 | Canyon Creek | At lake | July 17 | 7.5 | 7.7 | 1.2 | 11.7 | 0.008 | 0.032 | 0.040 | 3.0 | 0.084 | ------ | 0.015 |
| 2 | Falls Creek | At mouth | do | 8.0 | 7.6 | 1.2 | 11.5 | .005 | .003 | .008 | 3.0 | .056 | ------ | .015 |
| 3 | O'Malley River | Above Falls Creek | do | 13.0 | 8.0 | 1.0 | 12.0 | .004 | .020 | .024 | 1.0 | .021 | ------ | .008 |
| 4 | Cascade Creek | At lake | do | 7.5 | 8.0 | 1.2 | 12.0 | .005 | .011 | .016 | 3.5 | .052 | ------ | .010 |
| 5 | Upper Thumb River | North fork above falls. | July 21 | 8.9 | 7.6 | 2.2 | 10.0 | .004 | .006 | .010 | 2.2 | Tr. | 0.000 | .005 |
| 6 | do | At Thumb Lake | do | ------ | 7.2 | 6.5 | 10.5 | .025 | .015 | .040 | 2.0 | .328 | .018 | .060 |
| 7 | Upper O'Malley River. | ------ | July 23 | ------ | 7.4 | 2.5 | 10.5 | .002 | .030 | .032 | 2.0 | .020 | .000 | .072 |
| 8 | Moraine Creek | Upper end | July 25 | ------ | 7.4 | 2.0 | 11.0 | .004 | .018 | .022 | 2.0 | .000 | .000 | .040 |
| 9 | do | At lake | do | 7.5 | 7.0 | 5.0 | 11.0 | .060 | .130 | .190 | 2.0 | .400 | .009 | .085 |
| 10 | Halfway Creek | do | do | 7.9 | 6.9 | 3.5 | 10.0 | .023 | .032 | .055 | 2.0 | .160 | .005 | .042 |
| 11 | Cascade Creek | At falls | July 27 | 8.3 | 8.0 | 2.0 | 11.5 | Tr. | .003 | .003 | 3.0 | Tr. | ------ | .040 |
| 12 | do | At lake | do | 8.3 | 7.8 | 3.5 | 12.0 | .016 | ------ | ------ | 2.0 | .080 | .004 | .030 |
| 13 | Meadow Creek | do | do | 9.5 | 7.6 | 4.0 | 10.5 | .030 | .005 | .035 | 3.0 | .220 | .008 | .050 |
| 14 | Canyon Creek | Above falls | July 29 | 8.0 | 7.6 | 2.5 | 12.0 | .002 | .016 | .018 | 1.5 | Tr. | ------ | .020 |
| 15 | Falls Creek | do | do | 9.2 | 7.8 | 2.5 | 11.5 | .003 | .019 | .022 | 1.5 | Tr. | ------ | .020 |
| 16 | Little Lagoon Creek | Above Salmon | do | 4.2 | 7.8 | 2.5 | 22.0 | .005 | .025 | .030 | 2.0 | Tr. | ------ | .040 |
| 17 | Upper Thumb River | At lake | Aug. 3 | 8.3 | 6.8 | 4.5 | 11.0 | .019 | ------ | ------ | 2.0 | .280 | .010 | .060 |
| 18 | Salmon Creek | At Thumb River | do | 7.2 | 7.2 | 4.5 | 11.5 | .005 | .010 | .015 | 1.5 | ------ | .005 | ------ |
| 19 | Thumb River | At Karluk Lake | Aug. 13 | 10.0 | 7.8 | 3.0 | 11.0 | .015 | .020 | .035 | 1.5 | .080 | .001 | ------ |

Most of the streams carried a larger quantity of phosphorus, both soluble and organic, than the surface water of Karluk Lake. There was also a marked difference in the amount of phosphorus found in the different streams. The soluble phosphorus varied from only a trace in Cascade Creek at the falls to a maximum of 0.06 milligram per liter in Moraine Creek at the lake. The organic phosphorus ranged from a minimum of 0.003 milligram in Falls and Cascade Creeks to a maximum of 0.13 milligram per liter in Moraine Creek at the lake.

There was also a marked difference in the quantity of both soluble and organic phosphorus in the upper courses and in the lower courses of several streams. Such differences are shown in Table 10 for Canyon Creek, Cascade Creek, Moraine Creek, and the Upper Thumb River. The stations at which the various samples were taken are indicated on Figure 1. The water at the mouth of Moraine Creek yielded 15 times as much soluble phosphorus as that at the upper end of this stream and 7 times as much organic phosphorus. The quantity of soluble phosphorus was more than six times as large at the mouth of the Upper Thumb River as it was above the falls in the north fork of this stream. The differences in Canyon and Cascade Creeks were not as marked as those in the other two streams indicated above, while a smaller quantity of phosphorus was found at the mouth of Falls Creek than at the station above the falls in that stream.

The titratable silica in the various streams ranged from 1 to 3.5 milligrams per liter of water. This quantity was larger than that in the upper water of Karluk Lake.

In general, much larger amounts of ammonia, nitrite, and nitrate nitrogen were found in the stream waters than in the surface water of Karluk Lake; also considerable differences were noted in the different streams, as well as between the upper and lower courses of the individual streams. The maximum quantity of ammonia nitrogen was found in the sample obtained at the mouth of Moraine Creek on July 25, 1927, namely 0.4 milligram per liter of water; the next in rank was a sample from the mouth of Upper Thumb River which contained 0.328 milligram of ammonia nitrogen per liter. The smallest amounts of free ammonia were found in the upper courses of some of the streams, such as none in the upper part of Moraine Creek and only traces in the upper parts of Canyon, Falls, and Little Lagoon Creeks, and the north fork of Upper Thumb River.

The maximum quantity of nitrite nitrogen was found at the mouth of Upper Thumb River, namely 0.018 milligram per liter, while none was found in the samples taken in the upper courses of three streams. The other samples on which determinations were made yielded from 0.001 to 0.01 milligram of nitrite nitrogen per liter.

The largest amount of nitrate nitrogen found in the stream waters was obtained at the mouth of Moraine Creek, namely 0.085 milligram per liter. In the other stream samples the quantity of nitrate nitrogen ranged from 0.005 milligram in the north fork of the Upper Thumb River to 0.072 milligram per liter in Upper O'Malley River. In Canyon, Cascade, and Falls Creeks there was a somewhat larger amount of nitrate nitrogen in the samples from the upper courses than in those from the mouths of these streams. In Moraine Creek, on the other hand, there was a little more than twice as much nitrate nitrogen in the sample obtained from the mouth as in that from the upper course of this stream. In the Upper Thumb River there were 12 times as much in the sample taken at the mouth as in that taken in the north fork of this stream above the falls.

The red salmon which come into these lakes and streams to spawn have a very important effect upon the chemical status of their waters. After spawning these salmon die and the carcasses decompose either in the water or along the shores of the lakes and streams. The greater part of this decomposition takes place in the streams. In an average year more than a million red salmon, each weighing from 2 to 3 kilograms or more, migrate into these waters for the purpose of spawning, and their subsequent death adds probably in excess of 2,000,000 kilograms of decomposable organic matter to the waters of the Karluk drainage system. The decomposition of this material makes a very important contribution to the quantity of both organic and inorganic substances that are held in solution by these waters.

Some observations made during the summer of 1927 serve to give an idea of the abundance of dead salmon in some of the streams. On July 17, Canyon Creek was listed as having comparatively few dead salmon; on July 21 it was estimated that there were 50,000 to 60,000 dead salmon in the two forks of Upper Thumb River. On July 25 Moraine Creek was listed as having about 10,000 dead fish.

Shostrom, Clough, and Clark (1924) give the following results for chemical analyses of bone-free samples of the red salmon of Karluk River: Moisture, 69.5 per cent; fat, 5.6 per cent; protein, 21.6 per cent; and ash, 1.3 per cent. They state that bone constitutes 2.2 per cent of the total weight of the fish. On this basis more than 400,000 kilograms of the total estimated decomposable matter contributed by the dead salmon would consist of protein material, and the decomposition of this protein furnishes a supply of nitrogen compounds to these stream and lake waters. In their final stages of decomposition these compounds yield ammonia, nitrites and nitrates which, in turn, serve as a source of nitrogen for the various plant forms that populate these lakes and streams; they are of special importance to the organisms that constitute the phytoplankton.

No data are available for the phosphorus content of the red salmon, but Atwater (1892) states that $P_2O_5$ constitutes 0.69 per cent of the flesh of the California salmon and Taylor (1926) gives 0.57 per cent for the edible portion of the chinook salmon. From these results the $P_2O_5$ content of the red salmon may be estimated as about 0.6 per cent, which is equivalent to 0.26 per cent when expressed in terms of the element phosphorus. This percentage represents about 5,000 kilograms of phosphorus in the estimated 2,000,000 kilograms of organic matter in the red salmon which migrate into these waters to spawn in an average year. In the process of decomposition this phosphorus is liberated and becomes available for the plants which thrive in these waters.

Some of the salmon carcasses decompose in very shallow water or are washed up on the shores of the lakes and streams above the water line; in such cases a large part or all of the ammonia nitrogen is lost to the water, but the nitrates and phosphates of those decomposing on shore are washed back into the water by rain or melting snow and thus become available for the aquatic plants. The nitrates and phosphates derived from the decaying salmon are excellent fertilizers and serve to stimulate the growth of phytoplankton organisms. This is shown by the fact that enormous growths of certain algæ are correlated with an abundance of decomposing salmon carcasses in Thumb Lake, and also by the fact that Karluk Lake supports a larger crop of phytoplankton than several lakes belonging to the same class; the latter problem is discussed further in the section dealing with the plankton of Karluk Lake.

The decomposition of the salmon carcasses in the lower courses of the streams accounts for the differences in the quantity of nitrogen and phosphorus found in the upper and lower courses of some of the streams. The samples taken at the upper stations were obtained from portions of the streams that were not occupied by the salmon, consequently the water in these localities contained only the nitrogen and phosphorus compounds leached from the earth through which the water had passed; in the lower courses of the streams, on the other hand, these amounts were augmented by those derived from the decomposing salmon. Some of the streams were not as densely populated by the salmon as others, and this accounts for the differences noted between the different streams.

## CHEMISTRY OF BOTTOM DEPOSITS

Five samples of bottom material were collected in Karluk Lake and one each from Thumb and O'Malley Lakes during July and August, 1927, for the purpose of making chemical analyses of them. One of the samples was taken in the deepest part of Karluk Lake, indicated as station 1 on the map, Figure 1. One was taken in the deeper part of The Thumb (station 2 on the map), and two others were secured in this basin of Karluk Lake. One sample was also obtained in the third or lower basin of Karluk Lake which is indicated as station 3 on the map. One sample was taken in the deepest part of Thumb Lake and another from that of O'Malley Lake.

The samples were spread out and air dried as promptly as possible after they were secured. When dry they were placed in glass containers and kept until the analyses were made in the autumn of 1927. The air-dried samples were ground in a disk mill; the material was then spread out on watch glasses and dried in a vacuum desiccator for 10 days at a temperature of 70° C. The drying was carried out at 70° rather than at 100° or higher in order to avoid the possible loss of carbonaceous material, especially of any volatile oils that might be present. The moisture content ranged from 1.43 to 5.19 per cent of the weight of the undried material in the various samples.

The character of the water in these three lakes is indicated in the analyses given in Tables 8 and 9. There is a comparatively small amount of fixed or bound carbon dioxide present and relatively small amounts of calcium, magnesium, and silica. The water, therefore, may be regarded as having a medium hardness. It might be better, in fact, to class them as soft-water lakes. They are certainly at the lower limit of the class with medium hardness.

The results of the analyses of the bottom deposits are given in Table 11. One of the striking features of these bottom deposits is the large percentage of silica found in them; this substance comprises from 60 per cent to a little more than 73 per cent of the dry material. Such high percentages of silica raised a question regarding its source and portions of the various samples were submitted to Dr. Albert Mann who examined them for diatom remains. He found the shells of 67 different species of diatoms in these bottom deposits. His estimates of the percentages of diatoms in the various samples from Karluk Lake, based upon his microscopical examination, show a rather striking similarity to the results obtained in the chemical analyses. His statement regarding the sample from station 3 of Karluk Lake is "nearly pure diatoms, 80 to 90 per cent of the mass." The 40-meter sample from The Thumb is estimated as 60 per cent or more diatoms, and the 125-meter sample from station 1 of Karluk Lake as 75 to 80 per cent. He states that diatoms are not so abundant in the samples from Thumb and O'Malley Lakes (20 to 30 per cent), but the percentage of silica is the same in them as in those from Karluk Lake. No explanation of this difference is evident from the data in hand. (See Doctor Mann's report on p. 434.)

There is almost a twofold difference in the percentage of iron in the various samples and likewise almost a fourfold difference in the percentage of alumina. The calcium and magnesium content of these bottom deposits is small and the same is true of the phosphorus, sulphate, and carbon dioxide. The percentage of organic carbon shows a little more than a fourfold difference. The largest percentage was found in the sample from O'Malley Lake. Large aquatic plants grow much more abundantly in this lake than in the other two, and it seems probable that they make an important contribution to the bottom deposits here and thus increase the amount of organic carbon therein.

In comparison with the results obtained on other lakes, the high percentage of silica is the outstanding characteristic of the bottom deposits of these three Alaskan lakes. Bottom material from two of the lakes of northeastern Wisconsin yielded a little more than 42 per cent of silica and this is the largest percentage that has been found in any of the Wisconsin lakes up to the present time. A maximum of 54 per cent was found in one sample from Lake Balaton, Hungary (Emszt 1911), and a little over 36 per cent was the largest amount found in the bottom deposits of the lakes at Lunz, Austria (Mulley, 1914). Halbfass (1923) reports a maximum of 78 per cent of silica in Lake Girotte and 74 per cent in Lac Pavin.

The small percentage of calcium is also an important characteristic of the deposits of these Alaskan lakes. Smaller percentages have been obtained only in the very soft water lakes of northeastern Wisconsin. Less than 1 per cent of calcium has been found in 4 of these soft-water lakes, and from 1 to almost 2 per cent in 8 others. In the hard-water lakes of southeastern Wisconsin, the percentage of calcium shows a maximum of a little more than 17 per cent, while a bottom sample from one of the lakes at Lunz, Austria, yielded a little more than 38 per cent of calcium and one from Lake Balaton, Hungary, a little more than 37 per cent.

The percentage of organic carbon is distinctly smaller in the bottom samples from the Alaskan lakes than in those obtained from the lakes of northeastern Wisconsin; in the latter samples the percentage of organic carbon varied from somewhat more than 10 to almost 39 per cent of the dry weight of the deposits.

TABLE 11.—*Chemical analyses of bottom deposits of Alaskan lakes*

[The samples were taken in 1927 with a small Ekman dredge, so that they represent only the upper 15 cm. of the deposits. The results of the analyses are given in percentages of the dry weight of the samples. Upon drying the various samples lost from 1.43 to 5.19 per cent of moisture]

| Lake | Date | Depth | $SiO_2$ | $Fe_2O_3$ | $Al_2O_3$ | Ca | Mg | $P_2O_5$ | $SO_4$ | $CO_2$ | Org. C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Meters* | | | | | | | | | |
| Karluk, station 1 | Aug. 13 | 125 | 60.50 | 4.93 | 6.88 | 1.62 | 0.44 | 0.92 | 1.06 | 0.69 | 4.58 |
| Karluk, The Thumb | Aug. 8 | 17 | 73.07 | 3.36 | 5.65 | 1.86 | .54 | 1.37 | 1.85 | .70 | 5.34 |
| Do | do | 38 | 63.91 | 5.45 | 11.76 | 2.60 | 1.50 | .65 | .44 | .52 | 1.95 |
| Do | do | 40 | 66.10 | 7.00 | 12.22 | 2.05 | 1.30 | .82 | .51 | .20 | 4.22 |
| Karluk, station 3 | July 19 | 50 | 69.81 | 6.05 | 5.42 | 2.96 | .90 | .92 | 1.37 | .67 | 5.05 |
| Thumb Lake | July 21 | 10 | 60.00 | 6.42 | 9.65 | 1.89 | 1.07 | 1.02 | 1.78 | .20 | 6.56 |
| O'Malley Lake | July 23 | 12 | 71.76 | 4.32 | 3.75 | 2.71 | .93 | 1.35 | 1.12 | .80 | 8.50 |

## PLANKTON DATA

### NET PLANKTON

Catches of net plankton were obtained from Karluk, Thumb, and O'Malley Lakes at the same time that samples were taken for the chemical analyses, and at other times also. This plankton material was secured by means of the regular type of closing net that has been used in making catches on the Finger Lakes of New York, on a number of lakes in northwestern United States, and on various lakes in Wisconsin. This type of closing net has been fully described by Juday (1916) so that no further description is necessary at this time. The net has a relatively large straining surface of bolting cloth in proportion to its opening and numerous tests have shown that its coefficient lies between 1.8 and 2; that is, it strains approximately half of the water in the column through which it is hauled.

The plankton material obtained in these catches was enumerated by the usual method and the numbers found in each catch were multiplied by 2 in order to indicate the total number of organisms in the column through which the net passed.

The results of these quantitative studies are given in Table 12 in which the average numbers of organisms per liter of water are indicated for the different series. No attempt was made to count the different species separately; the different forms were enumerated by genera, and the various genera were then combined into groups as shown in the table.

The great variety of organisms found in the catches is shown by the following list of genera which are represented in the material.

Cladocera:
- Alona.
- Bosmina.
- Chydorus.
- Daphnia.
- Holopedium.

Copepoda:
- Cyclops.
- Diaptomus.
- Epischura.

Rotifera:
- Anuraea.

Rotifera—Continued.
- Asplanchna.
- Asplanchnopus.
- Brachionus.
- Conochilus.
- Conochiloides.

Rotifera—Continued.
- Diplois.
- Diurella.
- Floscularia.
- Gastropus.
- Monostyla.

Rotifera—Continued,
- Notholca.
- Ploesoma.
- Polyarthra.
- Rattulus.
- Synchaeta.
- Triarthra.

Protozoa:
- Actinosphaerium.
- Ceratium.
- Dinobryon.
- Epistylis.
- Glenodinium.
- Mallomonas.
- Peridinium.
- Stentor.
- Uroglena.
- Vorticella.

Blue-green algæ:
- Anabaena.
- Aphanocapsa.
- Chroococcus.
- Coelosphaerium.
- Gloeocapsa.
- Leptobasis.
- Lyngbya.
- Microcystis.
- Oscillatoria.
- Spirulina.

Green algæ:
- Ankistrodesmus.
- Actinastrum.
- Botryococcus.
- Coelastrum.
- Chlamydomonas.
- Chlorangium.

Green algæ—Continued.
- Cosmarium.
- Crucigenia.
- Mougeotia.
- Pediastrum.
- Pandorina.
- Staurastrum.
- Scenedesmus.
- Sphaerocystis.
- Spondylosium.
- Tetraspora.
- Ulothrix.

Diatoms:
- Asterionella.
- Amphora.
- Ceratoneis.
- Cocconeis.
- Cyclotella.

Diatoms—Continued.
- Cymbella.
- Epithemia.
- Fragilaria.
- Gomphonema.
- Melosira.
- Navicula.
- Nitzschia.
- Stephanodiscus,
- Synedra.
- Tabellaria.

TABLE 12.—*Numerical analysis of the net plankton catches of Karluk, Thumb, and O'Malley Lakes*

[The average number of organisms per liter of water from surface to bottom is indicated for the different series]

| Date | Depth | Cladocera | Copepoda | Nauplii | Rotifera | Protozoa | Blue-green algæ | Green algæ | Diatoms |
|---|---|---|---|---|---|---|---|---|---|
| **KARLUK STATION 1** | | | | | | | | | |
| | *Meters* | | | | | | | | |
| July 19, 1927 | 0–125 | 1.0 | 8.7 | 30.5 | 244.0 | 11 | 273 | 2,928 | 4,457 |
| July 31, 1927 | 0–125 | 1.3 | 1.9 | 32.3 | 257.0 | 1,279 | 445 | 28,561 | 4,802 |
| Aug. 13, 1927 | 0–125 | .7 | 4.0 | 47.0 | 214.0 | 543 | 241 | 1,547 | 553 |
| Aug. 24, 1927 | 0–125 | 2.5 | 12.6 | 53.4 | 106.0 | 729 | 65 | 3,679 | 542 |
| Sept. 13, 1927 | 0–125 | 2.1 | 15.3 | 37.7 | 29.3 | 43 | 9 | 3,681 | 226 |
| July 10, 1928 | 0–125 | .8 | 5.0 | 32.4 | 107.0 | 42 | 61 | 2,378 | 752 |
| Sept. 3, 1928 | 0–125 | 8.1 | 24.5 | 100.0 | 54.5 | 133 | 18 | 4,121 | 417 |
| July 9, 1929 | 0–125 | 1.2 | 8.9 | 57.5 | 164.0 | 204 | 13 | 2,645 | 3,591 |
| Sept. 8, 1929 | 0–125 | 6.7 | 35.5 | 82.0 | 70.0 | 274 | 191 | 1,482 | 1,624 |
| July 12, 1930 | 0–125 | .4 | 14.7 | 3.3 | 159.0 | 309 | 868 | 2,164 | 7,025 |
| Sept. 9, 1930 | 0–125 | 1.5 | 7.3 | 26.0 | 60.7 | 177 | 548 | 634 | 605 |
| **KARLUK STATION 2** | | | | | | | | | |
| July 21, 1927 | 0–45 | 1.8 | 8.5 | 9.8 | 367.0 | 14 | 1,058 | 23,452 | 67,424 |
| Aug. 2. 1927 | 0–45 | 4.0 | 7.0 | 52.7 | 316.0 | 1,990 | 200 | 16,721 | 10,285 |
| Aug. 12, 1927 | 0–45 | 6.2 | 5.1 | 28.1 | 322.0 | 663 | 414 | 2,544 | 3,596 |
| Aug. 26, 1927 | 0–45 | 7.0 | 17.0 | 51.0 | 172.0 | 629 | 233 | 8,309 | 23,997 |
| Sept. 15, 1927 | 0–45 | .6 | 6.5 | 12.5 | 17.2 | 43 | 6 | 1,298 | 4,114 |
| July 11, 1928 | 0–45 | .2 | 2.7 | 8.9 | 143.0 | 154 | 6 | 2,853 | 5,582 |
| Sept. 2, 1928 | 0–45 | 13.4 | 33.0 | 120.0 | 90.0 | 207 | 59 | 2,555 | 1,270 |
| July 13, 1929 | 0–45 | .9 | 7.0 | 21.8 | 148.0 | 242 | 78 | 1,105 | 3,896 |
| Sept. 7, 1929 | 0–45 | 5.8 | 37.6 | 106.0 | 92.0 | 65 | 1,473 | 1,009 | 8,449 |
| July 13, 1930 | 0–45 | .5 | 5.2 | 2.9 | 204.0 | 430 | 40 | 2,283 | 50,268 |
| Sept. 2, 1930 | 0–45 | 4.4 | 19.9 | 181.0 | 240.0 | 24 | 484 | 2,338 | 748 |
| **KARLUK STATION 3** | | | | | | | | | |
| July 19, 1927 | 0-50 | 0.9 | 5.5 | 15.3 | 361.0 | 21 | 760 | 19,910 | 28,485 |
| July 9, 1929 | 0-50 | 1.0 | 10.0 | 20.6 | 188.0 | 281 | 149 | 1,622 | 948 |
| Sept. 11, 1929 | 0-50 | 7.1 | 46.9 | 122.0 | 130.0 | 221 | 352 | 1,081 | 1,911 |
| **THUMB LAKE** | | | | | | | | | |
| July 21, 1927 | 0–10 | 29.5 | 29.1 | 24.1 | 370.0 | ---------- | ---------- | 3,896 | 1,375,370 |
| Aug. 3, 1927 | 0–10 | 160.0 | 33.8 | 4.6 | 405.0 | ---------- | 31,172 | ---------- | 985,825 |
| Aug. 12, 1927 | 0–10 | 4.2 | 13.4 | .9 | 58.2 | 355 | ---------- | ---------- | 889,000 |
| Aug. 26, 1927 | 0–10 | 17.8 | 5.0 | .9 | 133.0 | 195 | ---------- | ---------- | 55,134 |
| Sept. 16, 1927 | 0–10 | 5.0 | .9 | 1.4 | 456.0 | 178 | ---------- | 355 | 309,906 |
| July 9, 1928 | 0–10 | 2.5 | .9 | 69.0 | 87.0 | 433 | ---------- | 660 | 146,286 |
| Sept. 3, 1928 | 0–10 | 10.5 | 5.8 | 2.2 | 78.4 | 949 | ---------- | 11,979 | 104,628 |
| July 11, 1929 | 0–10 | .5 | .2 | 6.0 | 177.0 | 6,647 | ---------- | 130 | 322,010 |
| Sept. 7, 1929 | 0–10 | 103.0 | 8.3 | 6.0 | 1,433.0 | 174 | 71,948 | 17,302 | 793,320 |
| July 13, 1930 | 0–10 | 31.0 | 46.2 | 489.0 | 1,120.0 | 157,400 | ---------- | 94,724 | 7,386,500 |
| Sept. 6, 1930 | 0–10 | 99.5 | 12.8 | 1.6 | 2,679.0 | 852 | 118 | 5,828 | 1,752 |

TABLE 12.—*Numerical analysis of the net plankton catches of Karluk, Thumb, and O'Malley Lakes*—Continued

[The average number of organisms per liter of water from surface to bottom is indicated for the different series]

O'MALLEY LAKE

| Date | Depth | Cladocera | Copepoda | Nauplii | Rotifera | Protozoa | Blue-green algæ | Green algæ | Diatoms |
|---|---|---|---|---|---|---|---|---|---|
| | *Meters* | | | | | | | | |
| July 23, 1927 | 0–10 | 1.2 | 11.8 | 6.9 | 386.0 | | 129 | | 36,040 |
| Aug. 10, 1927 | 0–10 | 5.0 | 12.9 | 5.5 | 167.0 | | | 3,896 | 502,650 |
| Aug. 24, 1927 | 0–10 | 2.7 | 1.8 | 8.3 | 147.0 | 782 | 7,820 | 1,564 | 133,466 |
| Sept. 14, 1927 | 0–10 | 6.0 | 1.8 | 1.0 | 180.0 | | 1,760 | 782 | 145,445 |
| July 10, 1929 | 0–10 | 11.0 | 1.8 | 9.7 | 364.0 | 40 | | 1,447 | 12,104 |
| Sept. 12, 1929 | 0–10 | 1.2 | 2.8 | 4.6 | 175.0 | 241 | 1,564 | 404 | 6,737 |
| July 15, 1930 | 0–10 | 11.6 | 6.7 | 9.7 | 205.0 | 227 | 1,173 | 1,315 | 12,789 |
| Sept. 5, 1930 | 0–10 | 3.7 | 3.0 | 2.8 | 246.0 | 178 | 568 | 2,523 | 21,495 |

KARLUK LAKE

Five series of catches were taken in the deepest part of Karluk Lake (station 1) in 1927 and two series in each of the other years, 1928 to 1930, respectively. Twelve series of catches were also taken at station 2 in the Thumb during this same period of time and two at station 3 in the Lower Basin. (See map, fig. 1.)

*Zooplankton.*—The Cladocera were represented in Karluk Lake by specimens of Bosmina and Daphnia. Numerically these two forms were about equally abundant in the various catches. Both forms were most abundant in the upper 50 meters; in some series, in fact, they were not found in the catches taken below this depth. The smallest number of Cladocera was noted in the series of catches taken on July 12, 1930. The maximum number of Daphnia was obtained in the 5–10-meter stratum at station 1 on September 8, 1929, namely, nine individuals per liter of water. The largest catch of Bosmina (13 per liter) was found in the 30–50-meter stratum on September 3, 1928. (See Table 12.)

The Copepoda were represented in the catches by species of Diaptomus and Cyclops; individuals belonging to the latter genus were more abundant than those belonging to the former. Both forms were more abundant between the surface and 70 meters than they were below the latter depth. The maximum number of Diaptomus was found in the 0–5-meter catch taken at station 1 on September 8, 1929, namely, 22 individuals per liter of water. In the same catch Cyclops reached the maximum number of 145 per liter. The average number of Copepoda from surface to bottom in the catches taken on September 8, 1929, was 35 per liter. This was the highest average obtained in any of the series at station 1. The copepod nauplii were more numerous than the adults; they were more abundant in the upper 10 to 20 meters than at greater depths. In 1927 the largest average number of nauplii for the entire depth of the lake was found on August 13 when 47 individuals per liter were found. A maximum average of 100 per liter was noted on September 3, 1928. The smallest average number was found on July 12, 1930, namely, 3.3 per liter.

Numerically the Rotifera constituted the major part of the zooplankton in Karluk Lake. Asplanchna, Anuraea, and Polyarthra were the most abundant forms in this group and they were most numerous in the upper 10 meters. Notholca was obtained in considerable numbers below a depth of 15 meters in some of the series. In all of the series the rotifers were much more abundant in July than in September. The decrease in the number of rotifers during the summer is well illustrated in the five series of catches which were taken at station 1 in 1927. The average number from surface to bottom in the series of catches taken on July 19 was 244 per liter; it was 257 on July 31, then declined to 213 on August 13, fell to 106 on August 24, and reached a minimum of only 30 per liter on September 13. In 1928 the average was 107 per liter on July 10 and 55 on September 3, and similar decreases were noted in the September series taken in 1929 and in 1930.

The protozoan population of Karluk Lake consisted principally of Epistylis and Vorticella. These organisms were attached to the Copepoda; they were found in considerable numbers on both Cyclops and Diaptomus, but they were not present on the Cladocera. A third protozoan, namely, Peridinium, was found in some of the catches taken at station 1. The largest number of protozoa noted at station 1 was obtained in the series taken on July 31, 1927, namely, an average of 1,279 per liter from surface to bottom; at station 2 the largest average number was 1,990 per liter down to a depth of 45 meters, the maximum depth at the station, on August 2, 1927. In the other catches taken at the three stations in Karluk Lake, the average number of protozoa varied from 11 to 729 per liter.

*Phytoplankton.*—The results obtained in the enumeration of the phytoplankton forms of the net plankton are given in Table 12. This table shows that the blue-green algæ played only a minor rôle in the catches secured between 1927 and 1930, leaving the green algæ and the diatoms as the dominant elements of this group of organisms. As might be expected these forms were most abundant in the upper 20 meters where light conditions were favorable for their photosynthetic activities. The phytoplankton material obtained in the lower strata represented senile or dead individuals that were settling to the bottom, or else organisms that were living saprophytically in this region. A maximum of 102,000 green algæ per liter was found in the 0–10-meter stratum of station 1 on July 31, 1927, and the next largest number was noted in the 15–20 meter catch of this same series. The largest average number of green algæ from surface to bottom was obtained in this series also, namely 28,500 per liter. The diatom maximum at station 1 yielded 25,700 cells and colonies per liter in the 10–15 meter stratum on July 31, 1927; the average number of diatoms from surface to bottom on this date was 4,800 per liter. An average of 7,000 was obtained on July 12, 1930.

The September catches in general showed a smaller number of green algæ and of diatoms than the July catches. The average number of green algæ declined from 28,500 per liter on July 31 to 3,680 on September 13, 1927. Decreases were noted also in 1929 and 1930, but in 1928 the September average was larger than that obtained in July. The diatoms, on the other hand, showed a smaller average number in September than in July from 1927 to 1930, inclusive.

The vertical distribution of various net plankton organisms at station 1 is shown graphically in Figures 3 to 6. The number of individuals belonging to the different forms varies so widely that it is necessary to use the spherical type of curve in order to get all of the groups on the same diagram. The construction of this type of curve has been discussed by Birge and Juday (1922), so that it need not be repeated here. For the purpose of bringing out more clearly the vertical distribution of the Cladocera and Copepoda, the diagrams have been platted on the basis of the number of organisms per cubic meter of water instead of on the liter basis as given in the tables. The blue-green algæ were omitted in some of the diagrams because they were present in such small numbers; for the same reason the Cladocera were omitted in Figure 5.

These diagrams show that Diaptomus, nauplii and Cladocera were most abundant in the upper 40 to 50 meters of water; Cyclops was more uniformly distributed from surface to bottom, but Figure 6 shows a more marked difference between the upper and lower strata than the other three figures. A relatively small number of nauplii are shown in Figure 5 and they are rather evenly distributed from surface to bottom; larger numbers are represented in Figures 3, 4, and 6, and they are more abundant in the upper strata in these cases. The Rotifera have been omitted from Figure 4 and they are represented only by a comparatively small number in Figure 3; they are present in considerable numbers in Figures 5 and 6, the largest numbers being found in the upper strata.

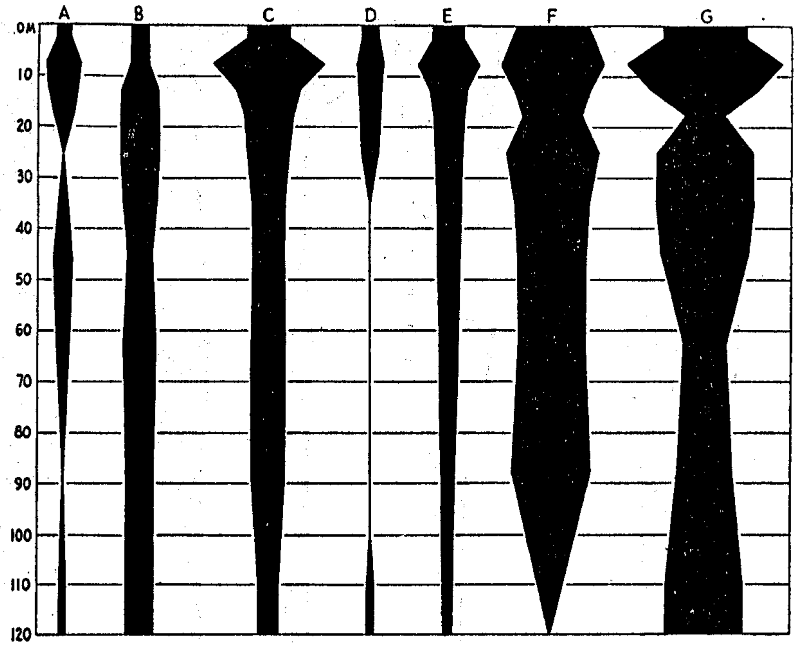


FIGURE 3.—Vertical distribution of net plankton in Karluk Lake, station 1, July 9, 1929. *A*, Diaptomus; *B*, Cyclops; *C*, nauplii; *D*, Cladocera; *E*, Rotifera; *F*, green algæ; *G*, diatoms

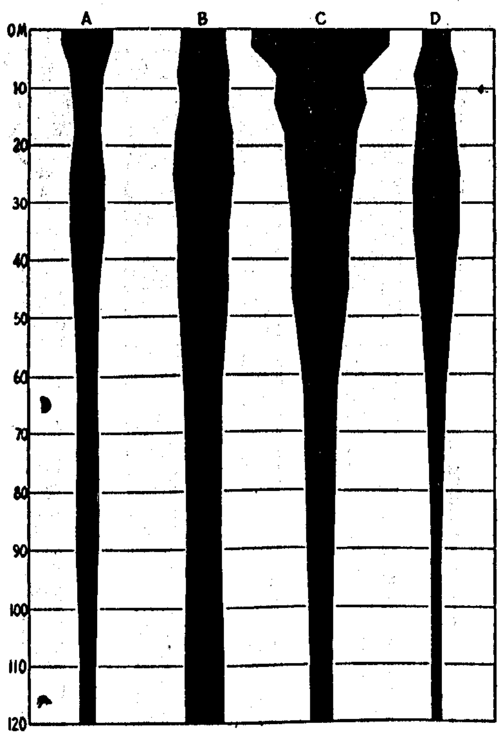


FIGURE 4.—Vertical distribution of zooplankton in Karluk Lake, station 1, September 8, 1929. *A*, Diaptomus; *B*, Cyclops; *C*, nauplii; *D*, Cladocera. Note the large number of nauplii in the upper stratum

Figures 3, 5, and 6 bring out clearly the fact that the algæ were most abundant in the upper 20 meters, but there were large numbers of green algæ and diatoms below this depth as shown in Figures 3 and 5. Attention may be called to the maximum of blue-green algæ in the 10–20-meter stratum in Figure 5 and to the marked decline in the number of green algæ in the 5–10-meter stratum in Figure 5; similar decreases are shown for the diatoms in the 15–20-meter stratum of Figure 3 and in the 10–15-meter stratum of Figure 5.

For purposes of comparison with the results obtained at station 1 several vertical series of catches were taken at station 2 located in The Thumb Basin which has a maximum depth of 46 meters; the series

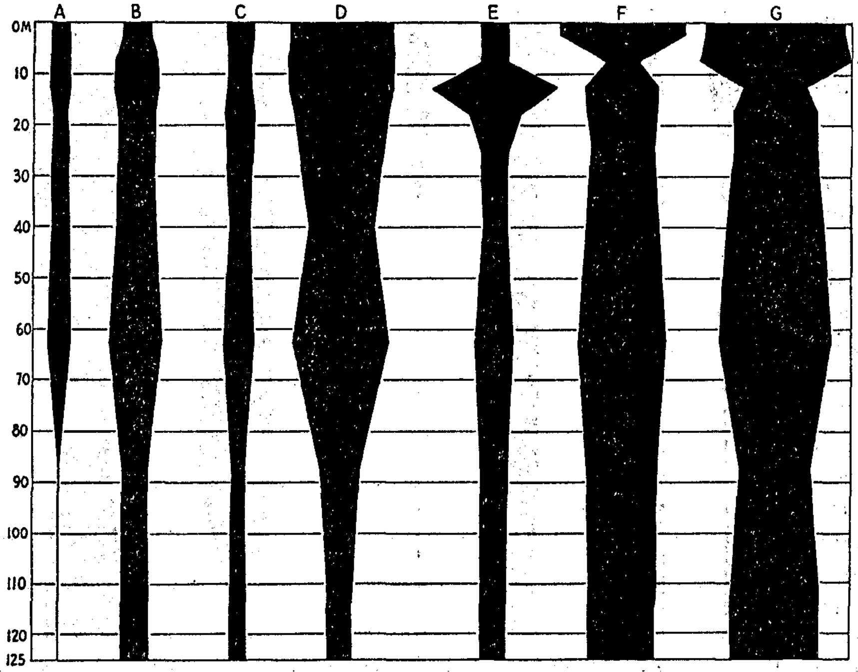


FIGURE 5.—Vertical distribution of the net plankton in Karluk Lake, station 1, July 12, 1930. *A*, Diaptomus; *B*, Cyclops; *C*, nauplii; *D*, Rotifera; *E*, blue-green algæ; *F*, green algæ; *G*, diatoms. The number of Cladocera was too small to be indicated in the diagram

taken at this station extended to a depth of 45 meters. (See fig. 1.) In general, the average number of organisms obtained at these two stations was within the range of variation of duplicate samples taken at a single station. A twofold or threefold variation in number may be expected in certain forms in duplicate catches, and most of the forms in the various series taken at these two stations fall within this range.

At station 1 on July 19, 1927, the average number of Copepoda in the upper 50 meters was 13 per liter and 5.5 per liter down to 45 meters at station 2; for the same strata the nauplii averaged 19 per liter at station 1 and 15 per liter at station 2, while the Rotifera averaged 350 at station 1 and 360 at station 2. There was an eightfold difference in favor of station 2 in the green algæ and a fivefold dif-

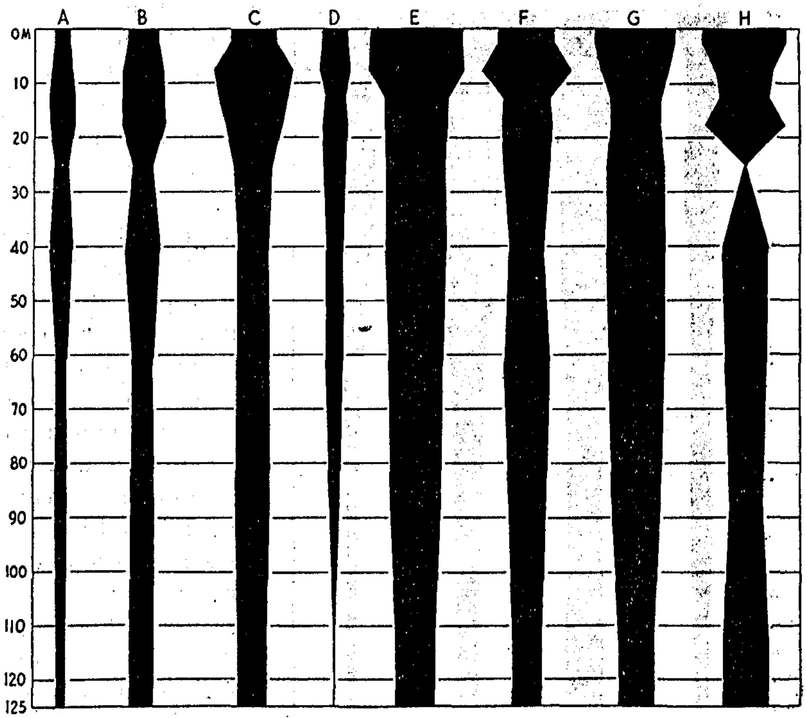


FIGURE 6.—Vertical distribution of the net plankton in Karluk Lake, station 1, September 9, 1930. *A*, Diaptomus; *B*, Cyclops; *C*, nauplii; *D*, Cladocera; *E*, Rotifera; *F*, blue-green algæ; *G*, green algæ; *H*, diatoms

ference in the diatoms. On July 12 and 13, 1928, the average numbers down to 50 and 45 meters, respectively, were substantially the same at station 1 and at station 2 for the green algæ and the rotifers, but the diatoms were about five times as abundant at the latter as at the former station. The nauplii were a little more than five times as abundant at station 1 as at station 2. On July 12 and 13, 1930, there was substantially the same average number of rotifers, nauplii, green algæ and diatoms in the upper 50 meters at station 1 as in the 45-meter series at station 2.

Similar variations in numbers were noted between the catches taken at station 1 and those at station 3. On July 19, 1927, the average number of nauplii down to 50 meters at station 1 was 44 per liter and 19 per liter at station 3; the rotifers numbered 350 per liter at station 1 and 360 at station 3. The green algæ were five times and the diatoms four times as numerous at station 3 as at station 1. On July 9, 1929, the catches in the upper 50 meters at station 1 yielded a larger number of net plankton organisms than those at station 3; the difference was less than twofold in the rotifers and the green algæ, but it was fourfold in the nauplii and fivefold in the diatoms. In the series taken at station 1 on September 9, 1929, and that at station 3 on September 11, 1929, the average number of nauplii, rotifers, and diatoms was somewhat smaller down to a depth of 50 meters in the former than in the latter series, but the reverse was true of the green algæ. A comparison of the average numbers in the series taken at station 2 on July 21, 1927, and on July 13 and September 7, 1929, with those from station 3 on July 19, 1927, and on July 9 and September 11, 1929, shows that the most marked differences are represented in the diatoms; even the maximum difference in this group is only a fourfold one.

## THUMB LAKE

Five sets of net catches were secured from Thumb Lake in 1927 and two in each of the other three years, making a total of 11 series. (See Table 12.) The Cladocera were more abundant in Thumb Lake than in the upper 10 meters of Karluk Lake. A maximum of 263 Bosmina per liter was noted in the upper 5 meters of Thumb Lake on August 12, 1927; this form seems to have been concentrated in the upper stratum at this time, since the 5–10-meter stratum showed only 6.5 individuals per liter. On the other hand, a larger number was found in the 5–10-meter stratum (121 individuals per liter) than in the upper 5 meters (82 per liter) on September 7, 1929. Again on September 6, 1930, a larger number of Bosmina was found in the upper 5 meters than in the 5–10-meter stratum. The maximum number of Daphnia (10 per liter) was obtained in the upper 5 meters on August 26, 1927.

A maximum of 92 Cyclops per liter was noted in the 5–8-meter stratum on July 13, 1930. Relatively small numbers of Diaptomus were obtained in Thumb Lake; the maximum was 3 per liter in the upper 3 meters on September 3, 1928. An unusually large number of nauplii was noted in the 5–8 meter stratum on July 13, 1930, namely 968 per liter; the next highest was 202 per liter on July 9, 1928.

The zooplankton of Thumb Lake was characterized by the large number of rotifers. The maximum was found on September 6, 1930, when the average from surface to 8 meters was more than 3,600 per liter. The smallest number of rotifers was obtained in the catches of 1928; on July 9 the average number was 87 per liter and on September 3 it was 78.

Protozoa were most abundant in Thumb Lake on July 13, 1930, when the average number was 157,400 per liter of water.

The phytoplankton consisted chiefly of diatoms; an average of 7,386,000 diatoms per liter was obtained in the net catch taken on July 13, 1930. A maximum average of 94,700 green algæ per liter of water was noted on the same date. The largest number of blue-green algæ was found on September 7, 1929, namely, an average of 71,900 per liter.

## O'MALLEY LAKE

Eight series of net catches were taken on O'Malley Lake, four in 1927, and two each in 1929 and 1930. (See Table 12.) In general, the crustacea were not as abundant as in the Thumb Lake catches. The Cladocera were represented by a few Chydorus in one catch and by varying numbers of Bosmina in all of the catches. A maximum of 17 Bosmina per liter was taken in the 5–10 meter catch on July 10, 1929. The Copepoda were represented by a maximum of 8 Diaptomus per liter in one catch and a maximum of 4 Cyclops per liter in another. Epischura appeared in three catches, with a maximum of 5 per liter in one.

As in Karluk and Thumb Lakes, the Rotifera were the dominant group numerically in the zooplankton of O'Malley Lake. The catch taken on July 23, 1927, yielded the largest average number of rotifers, namely, 386 per liter.

Protozoa and blue-green algæ were found in relatively small numbers. The green algæ reached a maximum average of almost 3,900 per liter on August 10, 1927. As in Thumb Lake, the phytoplankton of O'Malley Lake was dominated by the diatoms, but they were not as abundant in the latter as in the former lake; a maximum of 562,600 diatoms per liter was obtained on August 10, 1927.

TABLE 13.—*Average number of net plankton organisms per liter of water in seven American lakes*

| Lake | Date | Depth | Cladocera | Copepoda | Nauplii | Rotifera | Protozoa | Blue-green algæ | Green algæ | Diatoms |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *Meters* | | | | | | | | |
| Canandaigua, N. Y. | Aug. 20, 1910 | 0–80 | 1.9 | 5.4 | 3.0 | 0.7 | 12 | 30 | 1 | 15 |
| Do | July 27, 1918 | 0–72 | .5 | 1.8 | 2.4 | .7 | 10 | 5 | 2 | 17 |
| Cayuga, N. Y. | Aug. 12, 1910 | 0–120 | 19.2 | 2.8 | 10.6 | 59.0 | 851 | 22 | ---------- | 3,068 |
| Do | July 30, 1918 | 0–100 | 5.0 | 3.1 | 2.2 | 30.0 | 83 | 3 | ---------- | 19 |
| Seneca, N. Y. | Aug. 4, 1910 | 0–165 | 6.3 | 9.8 | 16.2 | 13.2 | 23 | 9 | ---------- | 230 |
| Do | Aug. 1, 1918 | 0–170 | 4.1 | 9.2 | 8.7 | 3.4 | 19 | 1 | ---------- | 113 |
| Skaneateles, N. Y. | Aug. 15, 1910 | 0–80 | .3 | .4 | 2.5 | 1.3 | 92 | 31 | ---------- | 1,384 |
| Crescent, Wash. | Aug. 17, 1913 | 0–160 | .01 | .8 | .2 | 2.8 | 2 | 3 | 110 | ---------- |
| Fallen Leaf, Calif. | July 25, 1913 | 0–110 | .5 | 2.1 | 1.0 | 4.8 | 18 | ---------- | ---------- | 282 |
| Karluk | July 9, 1929 | 0–125 | 1.2 | 8.9 | 57.5 | 173.8 | 125 | 13 | 2,111 | 3,592 |
| Do | July 12, 1930 | 0–125 | .4 | 14.7 | 3.3 | 160.0 | 307 | 886 | 2,164 | 4,638 |
| Do | Sept. 9, 1930 | 0–125 | 1.5 | 8.1 | 26.0 | 61.0 | 18 | 537 | 636 | 605 |

## COMPARISON OF KARLUK WITH OTHER LAKES

Table 13 shows the average number of net plankton organisms per liter of water from surface to bottom in some lakes that are similar to Karluk Lake in depth and character. Four of the Finger Lakes of New York and one each from the States of California and Washington are included in this table. The series of catches represented in these averages were taken with the same type and with the same size of plankton net, so that the general results obtained in the various lakes are comparable.

The average number of Cladocera was larger in Cayuga and Seneca Lakes than in Karluk; they were about the same in Canandaigua and Karluk Lakes, but a smaller average was found in the other three lakes shown in the table. The average number of Copepoda and nauplii was larger in Karluk than in the other six lakes and the same was true of the Rotifera. The average number of protozoa in Cayuga Lake exceeded that of Karluk Lake, but the average number of the other five lakes was smaller than that of Karluk.

The blue-green and the green algæ were more abundant in Karluk Lake than in the other six lakes. With the exception of the series of net catches taken on Cayuga Lake on August 12, 1910, the average number of diatoms was considerably larger in Karluk Lake than in the other six lakes included in the table. The general results given in this table indicate that the net plankton is more abundant in Karluk than in the other lakes; the most striking difference is the great abundance of green algæ in the former as compared with that group of phytoplankton organisms in the latter.

This greater production of plankton in Karluk Lake is due, in part at least, to the nitrogen and phosphorus compounds that are contributed to the water of this lake and to that of the streams flowing into it by the decomposing carcasses of the red salmon which spawn in its watershed. Both of these substances are essential food materials for the phytoplankton and they serve the function of fertilizers; thus the addition of these compounds derived from the dead salmon to those already present in the water makes it possible for the lake to support a larger crop of phytoplankton. A more abundant crop of phytoplankton will, in turn, support a larger crop of zooplankton forms which depend upon the algæ for food; as a result this abundant supply of phytoplankton and zooplankton provides a good supply of food for the young red salmon, since they feed almost exclusively on plankton material while they inhabit the lake. Thus the fertilizers derived from the adult salmon are very important factors in producing an abundant food supply for the young red salmon. Gilbert and Rich (1927) state that the Karluk fingerling red salmon are unusually large and form a sturdy stock; these authors attribute the large size to the very favorable conditions for growth which they find in this watershed. It seems probable from the results obtained in the present investigation that the chief factor in these favorable growth conditions is the abundant crop of plankton which is available for them in Karluk Lake.

## CENTRIFUGE PLANKTON

A series of centrifuge catches was taken at station 2 in Karluk Lake on August 8, 1927, and two sets of these samples were obtained from Thumb Lake, one on August 3 and another on August 12, 1927. These centrifuge catches were taken for the purpose of comparing the number organisms obtained by this method with that obtained with the net; many plankton organisms are so small that they readily pass through the meshes of the net and are thus lost in such a catch. A hand centrifuge operated at a speed of about 1,200 revolutions per minute was used for the centrifuge catches; from 100 cubic centimeters to 120 cubic centimeters of water were used for each catch. Numerical results for the various catches are given in Table 14. The protozoa and blue-green algæ have been omitted from the table because they were found in only 2 of the 11 catches.

The six centrifuge samples taken at station 2 in Karluk Lake on August 8, 1927, yielded an average of 65,600 green algæ and 88,200 diatoms per liter of water. No net catches were taken at station 2 on this date, but a series obtained there on August 12 gave an average of 2,500 green algæ and 3,600 diatoms per liter. The centrifuge material yielded a little more than 25 times as many green algæ and almost 25 times as many diatoms as the net samples obtained on the latter date. The series of net catches taken at station 2 on August 2, 1927, yielded an average of 16,700 green algæ and 10,300 diatoms per liter, so that the centrifuge catches contained only about four times as many green algæ as these net catches and only a little more than eight times as many diatoms.

TABLE 14.—*Number of phytoplankton organisms per liter of water at various depths in hand centrifuge catches taken in Karluk Lake, station 2, and in Thumb Lake in 1927*

| Organisms | Karluk Lake, Aug. 8 | | | | | | Thumb Lake | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Aug. 3 | | Aug. 12 | | |
| | 0 | 5 | 10 | 15 | 25 | 40 | 0 | 10 | 0 | 5 | 10 |
| | *Meters* | *Meters* | *Meters* | *Meters* | *Meters* | *Meters* | *Meters* | *Meters* | *Meters* | *Meters* | *Meters* |
| Green algæ: | | | | | | | | | | | |
| Ankistrodesmus | | | | | | | | | | 70,560 | |
| Chlamydomonas | 70,560 | 211,685 | | 23,520 | 70,560 | | 70,560 | 70,560 | 211,685 | 105,843 | 70,560 |
| Staurastrum | | 17,640 | | | | | | | | | |
| Scenedesmus | | | | | | | | | 105,825 | | |
| Diatoms: | | | | | | | | | | | |
| Asterionella | | | | | | | | 141,123 | 23,520 | | 211,685 |
| Amphora | | | 17,640 | | | | | | | | 23,520 |
| Cyclotella | | | 23,520 | 70,560 | | 70,560 | | | | | |
| Fragilaria | | | 70,560 | | | | 141,123 | 141,123 | | | |
| Melosira | 70,560 | 23,520 | 23,520 | 35,280 | | | 776,178 | 987,863 | 917,300 | 917,300 | 70,560 |
| Navicula | | | | | | | | 35,280 | | | |
| Synedra | | 35,280 | 17,640 | | 70,560 | | 35,280 | 423,370 | 94,082 | 70,560 | 35,280 |
| Stephanodiscus | | | | 70,560 | | | | | | | |
| Tabellaria | | | | | | | | 70,560 | | | |

The net catches taken in Thumb Lake on August 3, 1927, contained no green algæ, but the diatoms numbered 985,000 per liter of water. The surface and bottom centrifuge catches taken on this date gave an average of 70,500 green algæ and 1,377,000 diatoms per liter; the diatoms, therefore, were less than twice as numerous in the centrifuge catches as in the net material. In the net and centrifuge catches taken in Thumb Lake on August 12, 1927, the average number of diatoms in the former was 889,000 per liter and in the latter 788,000 per liter; in this case the net catches yielded a larger number of diatoms than the centrifuge samples.

Net and centrifuge samples taken in Lake Mendota at Madison, Wis., over a period of two and a half years showed that the latter yielded on the average about five times as much dry organic matter as the former; at certain times the organic matter in the centrifuge plankton was about the same in quantity as that in the net plankton, but at other times it amounted to about twenty-five times as much as that in the net plankton.

## SUMMARY


1. The area, maximum and mean depth, volume, temperature, and heat budget of Karluk Lake are given.

2. The chemical results show that the surface water was alkaline (pH 8.6) and that at 125 meters was neutral (pH 7); the water contained an abundance of dissolved oxygen at all depths during the summer, hence it belongs to the oligotrophic type of lakes; the water contained only 9 to 10 milligrams of fixed or bound carbon dioxide per liter.

3. The soluble phosphorus in Karluk Lake varied from 0.002 milligram in the surface water to 0.018 milligram per liter in the lower water; the organic phosphorus ranged from 0.003 to 0.028 milligram per liter in the surface water and from 0.012 to 0.014 milligram per liter in the lower water.

4. The titratable silica ranged from 0 to 0.6 milligram per liter.

5. Very little ammonia nitrogen was found in the surface water of Karluk Lake, but 0.12 milligram per liter was present in the bottom sample from station 2. Practically no nitrite nitrogen was present. The nitrate nitrogen ranged from 0.012 milligram in the surface water to 0.052 milligram per liter in the bottom water.

6. The water yielded from 5 milligrams to a little more than 6 milligrams of calcium per liter and from a little more than 3 to almost 6 milligrams of magnesium per liter.

7. The bottom deposits contained from 60 to 73 per cent of silica with only small percentages of calcium and magnesium.

8. The quantity of phosphorus, silica, and nitrogen was somewhat larger in Thumb and O'Malley Lakes than in Karluk Lake.

9. Larger amounts of carbon dioxide, silica, ammonia, and nitrate nitrogen were found in some of the affluents than in the surface water of Karluk Lake.

10. The decomposition of the dead salmon affects the chemical status of the water in the three lakes and their affluents.

11. The net zooplankton of Karluk Lake was character zed by a large population of Rotifera.

12. The phytoplankton of this lake consisted chiefly of green algæ and diatoms. These two forms were more abundant in July than in September.

13. In general, the net plankton was more abundant in Karluk Lake than in four of the Finger Lakes of New York and in two of the western lakes.

14 The net zooplankton of Thumb Lake was more abundant than that of the upper 10 meters of Karluk Lake. The same was true of the phytoplankton.

15. In general, the net plankton was not as abundant in O'Malley Lake as in Thumb Lake.

16. The rich crop of plankton produced by these lakes is due, in part at least, to fertilizing substances contributed to their waters by the decomposing carcasses of the salmon.

17. The large crop of plankton furnishes an abundant supply of food for the young salmon and, as a result, the fingerling salmon of Karluk Lake are unusually large and sturdy.

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## Part II. DIATOMS OF THE BOTTOM DEPOSITS OF KARLUK LAKE

By ALBERT MANN

During the course of certain investigations relating to the red salmon of Karluk River, Kodiak Island, Alaska, the investigators of the United States Bureau of Fisheries have secured limnological data in Karluk Lake and the two smaller lakes, Thumb and O'Malley, which are tributary to the main lake. These lakes have been surveyed and described by Gilbert and Rich (1927). In 1927 samples of the bottom deposits were secured by means of an Ekman dredge. A chemical analysis showed an unusually high silicon content in the deposits of each of these lakes (Black, 1929). It seemed probable that this was due to an abundance of diatoms and eight samples were submitted to the writer for study. All are high in diatom content, some of them remarkably so, from 80 to 90 per cent, which accounts for the high silicon content. The great richness and nutritive value of this bottom material is worthy of note.

The data bearing on the samples and remarks on the general character of their composition are given below:

1. *Lower basin, Karluk Lake (station 3) 50 meters, July 19, 1927.*—Nearly pure diatoms, 80 to 90 per cent of the mass. Mostly two species, *Cyclotella Bodanica* and *Stephanodiscus Niagarae*, the former outnumbering the latter 3 to 1. Scanty representatives of *Cymbella Mexicana* var. *Kamtschatica*, *Gomphonema herculeanum*, *Epithemia Zebra*, *Navicula tenella*, *Melosira Italica*, *Amphora ovalis*, *Surirella robusta*, etc.

2. *Thumb Lake, 10 meters, July 21, 1927.*—80 to 90 per cent diatoms; as in the last, mostly *Cyclotella Bodanica* and *Stephanodiscus Niagarae* in ratio of 3 to 1. Also

*Cymbella Mexicana* var. *Kamtschatica*, *Cymbella ventricosa*, *Melosira crenulata*, *Navicula elliptica*, *Gomphonema subclavatum*, *Tabellaria flocculosa*, etc.

3. *O'Malley Lake, 12 meters, July 23, 1927.*—Diatoms fewer, 20 to 30 per cent of the mass. Much fine quartz sand and decayed plant tissue. Here *Cyclotella Bodanica* and *Stephanodiscus Niagarae*, although present, are few; *Surirella elegans* is frequent, but the bulk of the diatoms is made up of minute species—*Tabellaria flocculosa*, *Melosira crenulata* var. *tenuis*, *Fragilaria construens*, *Ceratoneis arcus*, *Cymbella cistula*, etc.

4. *O'Malley Lake, July 23, 1927.*—The exact locality where this sample was taken was not recorded, but it was in comparatively shallow water, not over 2 meters, and probably near the head of the lake where the bottom consists largely of rather fine dark sand. Over half the mass is decayed plant tissue, mixed with sand. *Cyclotella Bodanica*, generally prolific in the other samples, seems to be wanting here, and *Stephanodiscus Niagarae* is scanty. Among the relatively few diatoms the following were prominent: *Melosira crenulata* var. *tenuis*, *Navicula elliptica*, *Navicula viridis*, *Epithemia Zebra*, *Cymbella ventricosa*, *Fragilaria construens*, *Tabellaria flocculosa*, etc.

5. *The Thumb, Karluk Lake (station 2) 40 meters, August 8, 1927.*—Sixty per cent or more is diatoms, the rest decayed plant tissue and a mere trace of sand. *Cyclotella Bodanica* and *Stephanodiscus Niagarae* compose four-fifths of the diatom bulk. Also present were *Cymbella Ehrenbergii*, *Cymbella gastroides*, *Cymbella cistula*, *Cymbella Helvetica*, *Navicula lata*, *Navicula major*, *Navicula viridis*, etc.

6. *The Thumb, Karluk Lake, 38 meters, August 8, 1927.*—Diatoms 30 to 40 per cent of the mass. Much sand and coarse plant tissue, moss and wood fiber. *Cyclotella Bodanica* and *Stephanodiscus Niagarae* dominant, about 3 to 1. Also *Cymbella Mexicana* var. *Kamtschatica*, *Epithemia turgida*, *Surirella biseriata*, *Surirella elegans*, *Melosira arenaria*, *Melosira Italica*, *Fragilaria construens* and desmids (Micrasterias).

7. *The Thumb, Karluk Lake, 17 meters, August 8, 1927.*—Not over 20 per cent diatoms, mostly decayed plant tissue and a little sand. *Cyclotella Bodanica* and *Stephanodiscus Niagarae* are here in abeyance; large chains of *Melosira arenaria* are frequent, also *Amphora Lybica*, *Amphora ovalis*, *Navicula elliptica*, *Gomphonema geminatum*, *Cymbella Helvetica*, *Pleurosigma acuminatum*. Some desmids (*Staurastrum gracile*) and some pin-head sponge spicules.

8. *Karluk Lake, upper basin (station 1) 125 meters, August 13, 1927.*—Seventy-five to eighty per cent of the mass is diatoms and of these four-fifths are *Cyclotella Bodanica* and *Stephanodiscus Niagarae* in their usual ratio of 3 to 1. The remainder is decayed plant tissue with practically no sand or spicules. Other diatoms are *Cymbella gastroides*, *Cymbella cistula*, *Rhoicosphenia curvata*, etc.

It is noticeable that the greatest abundance of diatoms in the deposits is found in the main basins of Karluk Lake and in Thumb Lake. The bottom of O'Malley Lake, even in the center of its basin (sample 3) is much less rich than are the samples from the other two lakes. The three samples from The Thumb are interesting in that they show a distinct negative correlation between the proportion of diatoms in the deposits and the depth from which they came. The Thumb is really a large, well-marked bay containing one of the main basins of Karluk Lake. The largest stream tributary to Karluk Lake, Thumb River, enters at the head of The Thumb and during and subsequent to the spawning season carries into the lake large quantities of organic matter derived from the decaying bodies of the spawned out salmon. In making the collections of bottom samples an attempt was made to get a series from about the center of the basin up toward the mouth of Thumb River. The first sample of this series was taken in about 40 meters, near the center of the basin and approximately one-half mile from the mouth of the river. The second sample was taken about one-fourth mile from the mouth of the river in 38 meters, and an attempt was then made to get a sample from a point approximately 100 yards from the mouth of the river in about 20 meters. This last was not successful, however, on account of twigs and other débris which prevented the dredge from closing. After several trials the attempt was abandoned and a sample taken in 17 meters near what is known as Island Point on the western side of Thumb Bay and about three-fourths mile from the mouth of the river.

Following is a list of the species of diatoms found in the collections as a whole:

*Amphipleura pellucida* K.
*Amphora Lybica* E.
*Amphora ovalis* K.
*Ceratoneis arcus* K.
*Cocconeis Placentula* E.
*Cyclotella Bodanica* Eul.
*Cyclotella antiqua* W. S.
*Cymatopleura Solea* (Breb.) W. S.
*Cymbella cæspitosa* (K.) Cl.
*Cymbella cistula* (Hemp.) Kirch.
*Cymbella cuspidata* K.
*Cymbella Ehrenbergii* K.
*Cymbella gastroides* K.
*Cymbella Helvetica* K. (not W. S.)
*Cymbella Mexicana* var. *Kamtschatica* Grun.
*Cymbella ventricosa* K. (not Ag.)
*Denticula tenuis* K., var.
*Diatoma anceps* (E.) Grun.
*Epithemia turgida* (E.) K.
*Epithemia Zebra* (E.) K.
*Eunotia bidens* (E.) W. S.
*Eunotia lunaris* (E.) Grun.
*Eunotia prærupta* E.
*Fragilaria construens* (E.) Grun.
*Fragilaria Harrisonii* (W. S.) Grun.
*Frustulia rhomboides* (E.) De T.
*Gomphonema constrictum* E. and varieties.
*Gomphonema geminatum* (Lyng.) Ag.
*Gomphonema herculeanum* E.
*Gomphonema subclavatum* Grun.
*Hantzschia amphioxys* (E.) Grun.
*Melosira arenaria* Moore.
*Melosira crenulata* var. *tenuis* (K.) Grun.
*Melosira Italica* (E). K.
*Melosira Rœsæna* Rab.
*Melosira varians* Ag.
*Meridion circu'are* Ag.
*Navicula amphirhynchus* E.
*Navicula borealis* (E.) K.
*Navicula commutata* Grun.
*Navicula elliptica* K.
*Navicula Gastrum* (E.) Donk.
*Navicula Iridis* var. *dilatata* (E.)
*Navicula lata* W. S.
*Navicula limosa* K.
*Navicula major* (K.) Grun., char. emend.
*Navicula mesolepta* E.
*Navicula Placentula* (E.) K.
*Navicula rupestris* (Hantz.) A. S.
*Navicula tenella* Breb.
*Navicula transversa* A. S.
*Navicula viridis* (W. S.) A. S., char. amend.
*Nitzschia Brebissonii* W. S.
*Nitzschia palea* (K.) W. S.
*Pleurosigma acuminatum* (K.) Grun.
*Rhoicosphenia curvata* Grun.
*Rhopalodia gibba* (E.) Muell.
*Stauroneis Phoenicenteron* E., and varieties.
*Stephanodiscus Niagaræ* E.
*Surirella amphioxys* W. S.
*Surirella bifrons* E.
*Surirella biseriata* (E.) Breb.
*Surirella elegans* E.
*Surirella robusta* E.
*Synedra delicatissima* W. S.
*Synedra subæqualis* Grun.
*Tabellaria flocculosa* (Roth) K.

The scarcity of members of the genus Pleurosigma in all the samples is noteworthy; for it is a semisaprophytic genus and the unusually high percentage of decaying organic matter in all of the gatherings would presuppose an abundance of Pleurosigma. A possible explanation of this scantiness is that the genus as a whole thrives best in temperate and subtropical waters.

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