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A BIOLOGICAL SURVEY OF OKANAGAN LAKE, BRITISH COLUMBIA

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INTRODUCTION

By W. A. Clemens

During July and August, 1935, a study of the physical, chemical and biological features of Okanagan lake, British Columbia, was carried out by the writer in association with Dr. D. S. Rawson of the University of Saskatchewan and Mr. J. L. McHugh of the University of British Columbia, assisted by Mr. A. Clemens and Mr. C. Child. The investigation centred about the Kamloops trout, *Salmo gairdneri kamloops*, which is at present the only important "sport" fish in the lake.

At the time white settlers entered the Okanagan valley, about 1860, and during the years immediately following, trout are said to have been very abundant. In recent years, however, anglers have maintained that the stock of trout has been seriously diminishing and have pressed for more extensive fish-cultural operations as a means of improving the fishing. The investigation had for its object, therefore, the determination of the conditions existing in the lake as a scientific basis for the possible development of a comprehensive fish-cultural program.

In view of the fact that the field work was confined to but two months in the summer, the survey cannot be said to be complete. A study of spring and autumn conditions is especially desirable, particularly in relation to the spawning and abundance of the trout and the kokanee, *Oncorhynchus nerka kennerlyi*. However, sufficient data have been obtained from the present investigation and from enquiry to permit of the presentation of certain facts, conclusions and recommendations.

Headquarters were established at Okanagan Mission on the east shore, and from there excursions were made to all parts of the lake. In addition, it was found desirable to examine three lakes in the immediate drainage basin, namely, Kalamalka, Woods and Duck lakes, as well as two small mountain lakes connected with the system, namely, Beaver and Chute lakes.

The investigation was carried out as part of the program of the Pacific Biological Station of the Fisheries Research Board of Canada. Some financial aid was given by the Fish Cultural Branch of the Department of Fisheries, Ottawa, for which grateful acknowledgment is made. Our sincere thanks are tendered to many residents of the region who gave assistance in many ways, in particular to various members of the local fish and game associations and to Mr. G. N. Gartrell, Fisheries Inspector, Summerland. We are also indebted to Major J. A. Motherwell for information concerning the stocking of the various lakes and the removal of carp.

The following reports are included:

PHYSICAL AND CHEMICAL STUDIES, PLANKTON AND BOTTOM FAUNA OF OKANAGAN LAKE, B.C., IN 1935 WITH APPENDED DATA FROM ADJACENT SMALLER LAKES

By D. S. Rawson

ACKNOWLEDGMENT

Grateful thanks are extended to the Dominion Water Power and Hydrometric Bureau which supplied useful hydrometric data, to Mr. C. C. Kelly of the Provincial Soil Survey Branch for data with respect to the geology of the Okanagan valley and to the following persons for identifications of organisms: Dr. E. G. Berry (Gastropoda), Dr. S. T. Brooks (Pelecypoda), Dr. G. C. Carl (Cladocera and Copepoda), Dr. W. J. Clench (Physa), Miss J. Fraser (Trichoptera), Dr. F. P. Ide (Ephemeroptera), Prof. C. W. Lowe (Algae), Dr. Ruth Marshall (Hydracarina), Dr. J. P. Moore (Hirudinea), Dr. F. J. Myers (Rotatoria), Prof. F. Neave (Plecoptera), Dr. J. G. Rempel (Chironomidae), Dr. E. M. Walker (Odonata).

PHYSIOGRAPHY AND HYDROGRAPHY

Location and Geology

Okanagan lake is one of four large lakes in the southern part of the interior plateau of British Columbia. From east to west they are Kootenay, Arrow and Okanagan with Shuswap lying just north of Okanagan. All are narrow and lie in deep valleys which extend generally in a north and south direction.

Since its formation in the middle of the Tertiary period the Okanagan valley has had a varied and interesting history, certain features of which are of importance in the present study. Glacial activity at one time blocked the valley so that the lake drained northward into the Thompson river system. Thus the lake was at one time connected with the present Shuswap basin. Since the recession of the last ice sheet, about 25,000 years ago, drainage to the south was re-established.

The valley is older and its adjacent mountains show more erosion than those of the Fraser valley to the north. The surroundings are still rugged with the lake lying in a deep narrow basin and mountains in the vicinity rising nearly 6,000 feet above its surface (figure 1). The upper parts of its tributary streams are rapid with frequent falls. Lower in the valley irrigation is carried on to such an extent that some streams fail to reach the lake.

Drainage

The question of drainage is of particular interest in this investigation since the chief fisheries problem in the region involves the Kamloops trout, a stream spawning species.

The watershed drains southward into the Columbia river and that part of it which empties into Okanagan lake measures 2,300 sq. mi. (*Surface water supply of Canada, Pacific Drainage for the climatic year 1929-30, Dept. of the Interior, 1935*). This drainage area is proportionately smaller than that of other large lakes, such as Shuswap and Kootenay. There is also a lower precipitation and lower run off in the Okanagan valley and consequently a greater tendency for the tributary streams to dry up. In the following comparison the outflows of Okanagan, Shuswap and Kootenay lakes are measured at Penticton, Chase and Nelson respectively. The run off is indicated both as discharge in cubic feet per square mile of drainage area and as the equivalent depth in inches over the drainage area.

Lake	Drainage area sq. mi. (approx.)	Mean monthly discharge (10 yr. av.) cu. ft./sec.	Run off cu. ft./sec. per sq. mi.	Run off depth, in. per sq. mi.
Okanagan..	2,340	433	0.17	2.3
Shuswap...	7,000	9,940	1.42	19.2
Kootenay..	17,700	25,400	1.35	19.5

The average monthly discharge from Okanagan lake at Penticton is indicated as 433 cu. ft. per sec., but in the past ten years it has varied from 59 to 1,100. This is in part the result of controlling the outflow at the dam and in part the effect of variation in the annual precipitation. A comparison of the influence of these factors is made in figure 2, where the mean monthly discharge is plotted along with annual precipitation for a period of 10 years. The figure used for precipitation is the average of five stations, Vernon, Okanagan centre, Kelowna, Peachland and Penticton. In some periods the correlation is evident, as in 1927 where exceptionally heavy precipitation is followed by increased discharge in 1928. At other times the effect of storage is evident, as in the period 1932-35 where discharge remained high while precipitation fluctuated considerably.

	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	Aver.
Inches of precipitation at Okanagan L., average 5 sta...	12.2	17.4	10.4	11.2	10.5	11.0	14.8	11.4	13.2	12.8	12.5
Mean monthly discharge at Penticton (cu. ft. per sec.)....	212	228	1,100	270	80	59	422	599	695	669	433

The control of the outflow of the lake is of moderate importance as compared with the control exercised over its tributary streams for irrigation purposes. Records of monthly discharge through the period April-September are available for about 15 streams tributary into Okanagan lake. An examination of these records gives little suggestion of the natural flow in the streams but much evidence of the extent to which they are utilized for irrigation. Long lake creek, the outlet from Kalamalka to Vernon creek, had an average flow near its source of 33 ft. per sec. and only 19 ft. per sec. at a station two miles below.

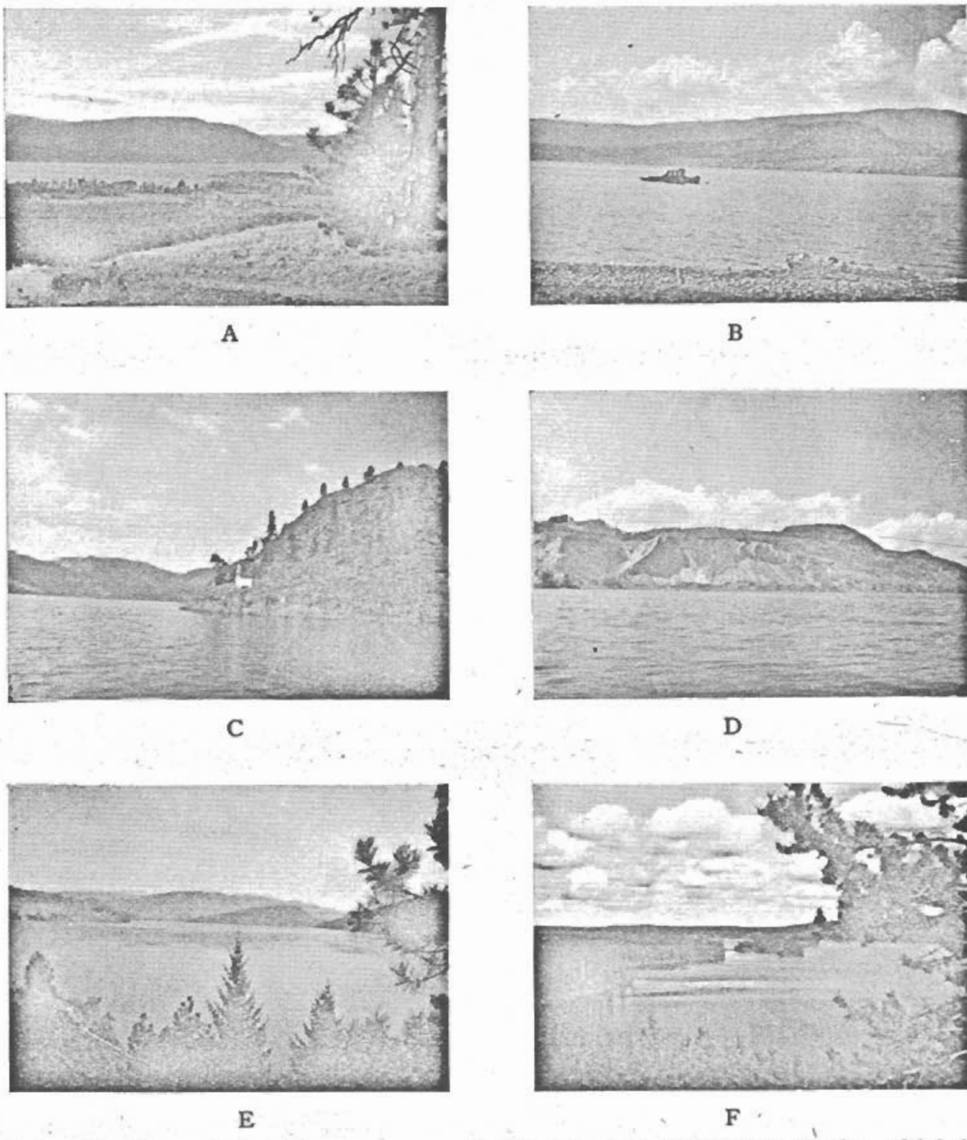

FIGURE 1. Views of lakes, Okanagan area. A. Okanagan lake at Okanagan Mission, with irrigated fruit lands below. B. Okanagan lake at Okanagan Mission. C. Okanagan lake at Squally point. D. Okanagan lake at Summerland. E. Kalamalka lake looking toward north end. F. Beaver lake located in dense forested area at 4,500 feet.

A further complicating factor is found in the irregularity of the natural run off during the season, causing severe flooding at times and shortage at others.

It is apparent that the combined effect of a meagre and variable precipitation, an irregular run off and a still more irregular utilization of the streams for irrigation, creates a situation in which the natural reproduction of stream spawning fish is very uncertain.

Size and Shoreline

The lake has an area of 143 sq. mi. The length is 67 mi. and the average width about 2 mi. Being so narrow it has a proportionately long shoreline, 165 mi., as measured from a map on the scale of 1 mile to the inch. The shore

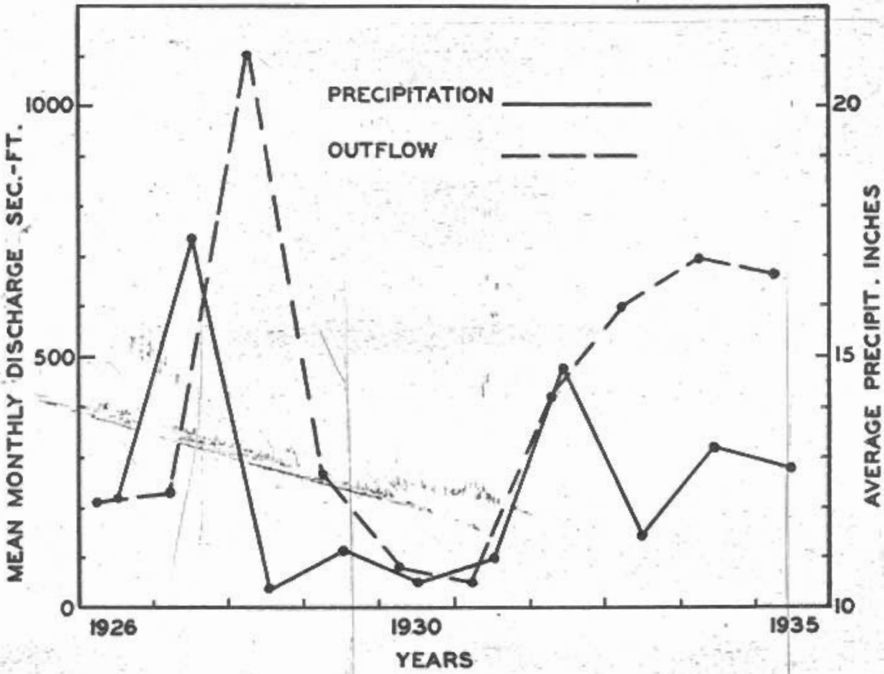

Figure 2. Precipitation and lake discharge, 1926-1935, Okanagan lake.

development (relation of shore length to minimum circumference for the same area) is therefore 3.9, but this figure is somewhat misleading since the shoreline is only moderately irregular and the "protected" type of shore is very scarce. Field notes indicate that of the total shore length about 9 per cent has a rooted aquatic vegetation. This is made up chiefly of bulrush (*Scirpus*) beds and is found in scattered localities mostly along the western shore and in the shallow bay at the north. Of the remaining shore line, 52 per cent is of bare rock or large stones, 26 per cent of fine gravel often with shrubbery and terrestrial plants growing close to the water's edge, and the remaining 13 per cent is of bare sand.

Depth

The lake is very deep with an observed maximum of 760 ft. (232 m.) between Carr's landing and Nahun. The mean depth has been determined as 228 ft. (69.5 m.). A total of 250 soundings was used to obtain depth contours, some of

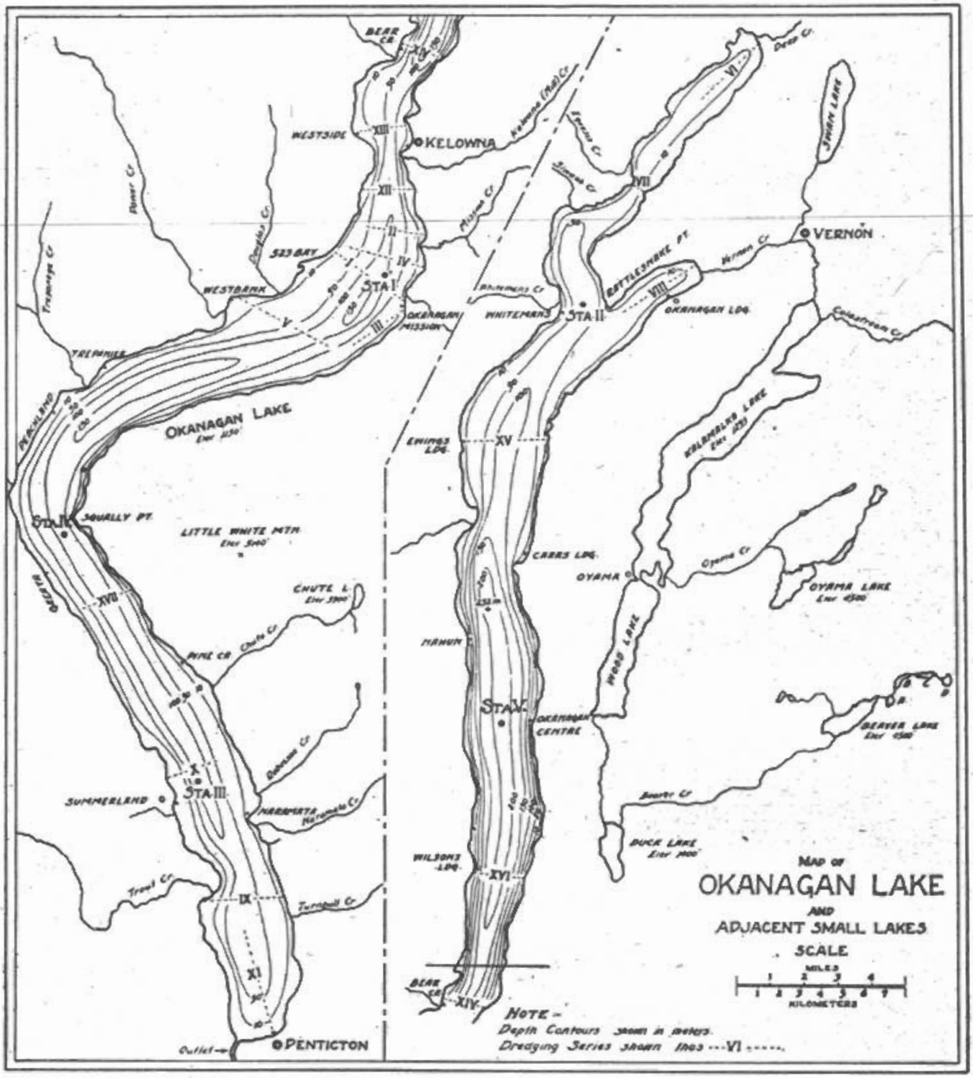

Figure 3. Map of Okanagan lake showing depth contours and location of observation stations.

which are seen on the accompanying map, figure 3. The greatest depths were found north from the centre of the lake where a 10-mile stretch is more than 655 ft. (200 m.) deep. A second deep region is found off Trepanier where a considerable area exceeds 500 ft. in depth. Both ends of the lake are relatively shallow. At the north end, a large bay about 6 miles long is mostly shallow and muddy with beds of bulrushes (*Scirpus*) and low shores quite unlike the remainder of the lake. Only 15 per cent of the lake area is less than 10 m. (33 ft.) deep and most of this shallow water is near the ends of the lake. In the central region of the lake the shores shelve rapidly into deep water.

The volumes of water in the different depth strata are of importance in dealing with the distribution of temperature, of oxygen, and in other connections. The relative volumes of the various strata have therefore been calculated and are shown in table I.

TABLE I. Analyses of depth data for Okanagan lake (1 m. = 3.28 ft.)

Depth zone or stratum	% of total area	% of total volume	Depth zone or stratum	% of total area	% of total volume
0– 10 m.	15.3	13.4	0– 25 m.	26.5	30.9
10– 20	9.4	11.6	25– 50	20.0	21.9
20– 30	7.6	10.2	50– 75	12.2	16.1
30– 40	8.1	9.1	75–100	10.8	12.1
40– 50	8.0	8.0	100–125	11.3	8.4
50– 75	12.2	16.3	125–150	6.8	5.3
75–100	10.7	12.2	150–175	4.6	3.4
100–125	11.3	8.5	175–200	2.5	1.3
125–150	6.8	5.3	200–225	2.0	0.7
150–200	7.1	4.7	225–250	1.5	....
200–250	3.4	0.7			

It will be seen that 70 per cent of the lake volume lies below the 20 m. (66 ft.) level and 50 per cent below the 50 m. (164 ft.) level. Less than 1 per cent of the total volume was found below the 200 m. (656 ft.) level.

In studying the morphometry of lake basins use is made of an index obtained by dividing the volume of the 0-10 m. (0-33 ft.) stratum into the remainder of the volume of the lake. For Okanagan lake this index is 6.7, and this, along with other morphometric data presented above, classifies Okanagan as a typical alpine lake. Seneca lake, New York, and Lake Constance, Switzerland, are well-known examples of this type.

PHYSICAL AND CHEMICAL CONDITIONS

TEMPERATURE

Five stations for the observation of temperature are indicated on the accompanying map. At station I temperature series were taken at approximately weekly intervals throughout July and August. At station II off Rattlesnake point near the north end and III off Summerland in the south, three series were taken; at stations IV and V off Squally point and Okanagan Centre respectively, a single series. Each series included from 10 to 15 temperatures at various depths from surface to bottom. These were taken with a deep sea reversing thermometer attached to apparatus which brought up from the same depth a sample of water for chemical analysis.

The temperature observations at station I are presented in figure 4, which indicates the variation in vertical distribution of temperature over this period. The surface temperature was 17.1°C. (63°F.) on July 4 and rose through the month to 20 or 21° (68 or 70°) about which level it fluctuated during August. The observed maximum surface temperature was 21.3° on August 13. At the bottom (100 m.) the temperature varied less than one-tenth of a degree, remaining between 4.5 and 4.6°C. (40.1 and 40.3°F.).

The vertical temperature change is more readily observed from figure 5. The upper 10 m. (33 ft.), known as the epilimnion, is comparatively warm; from 10-15 m. (33-49 ft.) is a stratum of rapid change in temperature, the thermocline; and below this a large body of relatively cold water, the hypolimnion. On July 4

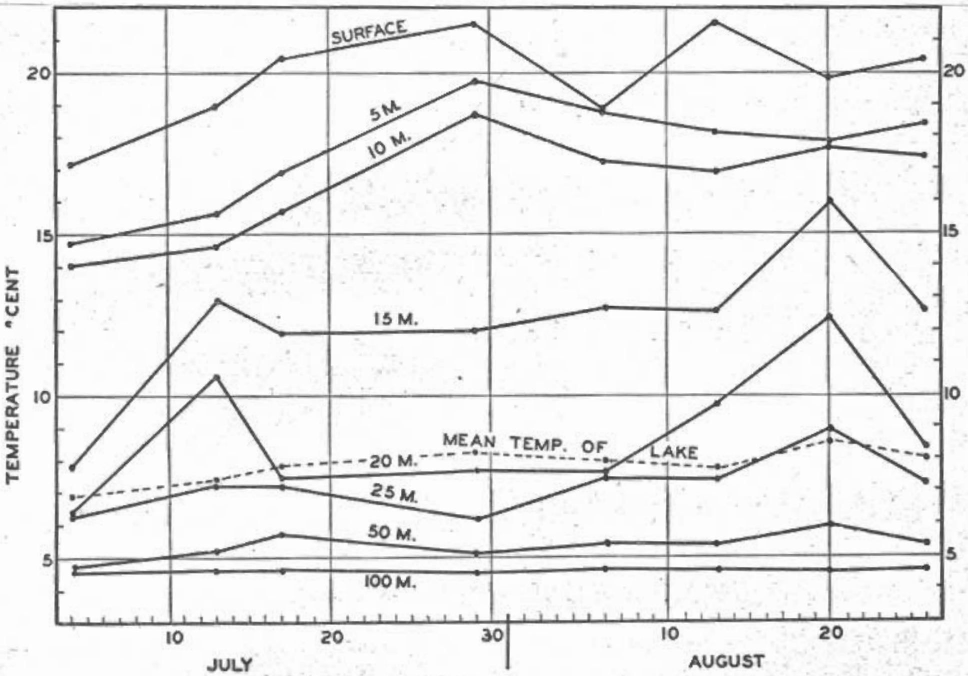

FIGURE 4. Temperature observations, July and August, station I, Okanagan lake.

the vertical distribution of temperatures was such that three regions may be distinguished, a condition described as thermal stratification. On July 13 stratification had been disturbed and a considerable amount of heat forced down to between 15 and 25 metres (49 and 82 ft.) depth. On July 17 stratification had been re-established with the thermocline at a lower level. Figure 5 serves to indicate both the nature of the stratification and the readiness with which it may be altered in Okanagan lake.

Temperature series were taken at stations I to V to test the reliability of observations at station I as applied to the lake as a whole. Because of the diffi-

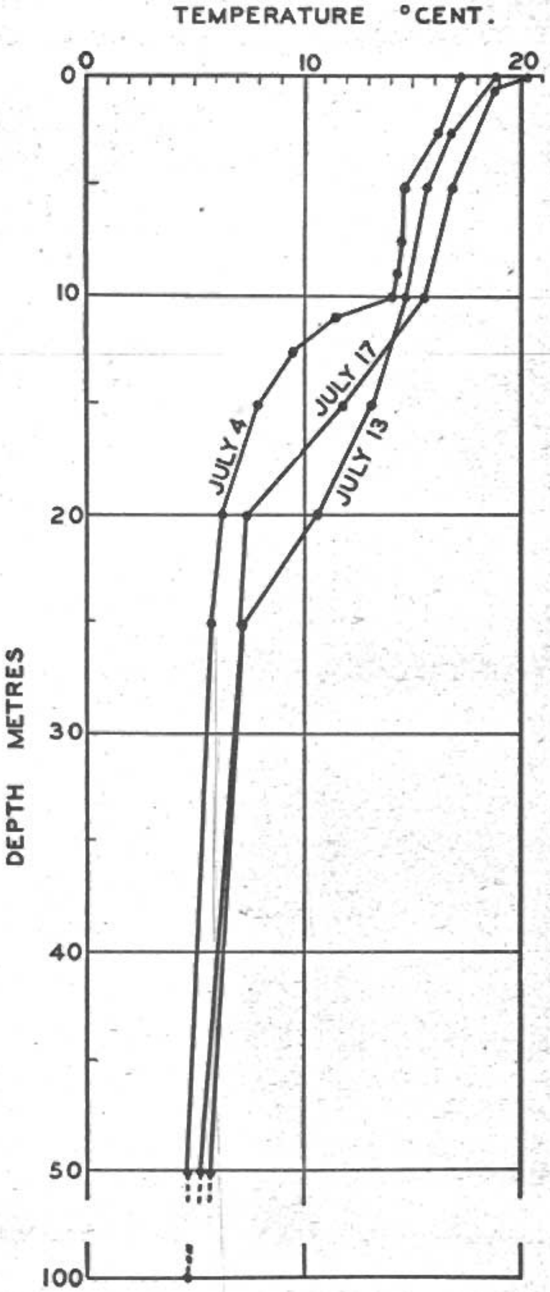

FIGURE 5. Vertical distribution of temperatures, July, station I, Okanagan lake.

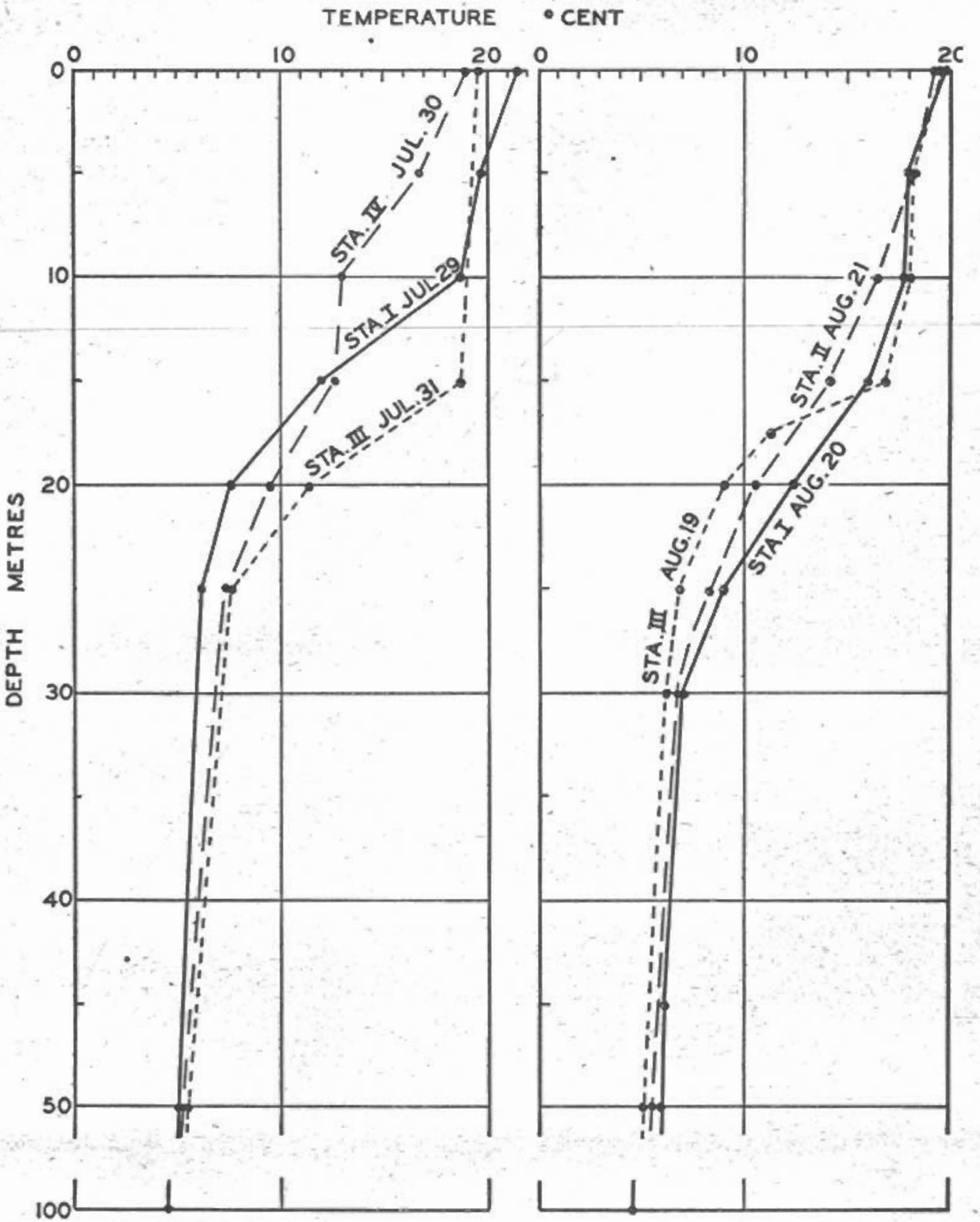

FIGURE 6. Temperature records on successive days at various stations, July and August, Okanagan lake.

culty of the distances separating these stations it was impossible to take simultaneous readings, and the best alternative was to take readings on successive days. Figure 6 shows the results of such series, the former indicating extreme variation on successive days between stations I, II and IV, and the latter less extensive differences between stations I, II and III. The evidence tends to show that these fluctuations are a result of movements in the lake water and not of variations in the temperature of the lake as a whole. For this reason records from station I were used to calculate the mean temperature of the lake inserted in figure 4.

The mean temperature of the lake varied between 7.0°C. (44.6°F.) on July 4 and 8.7° (47.5°) on August 20. Thus the lake water as a whole remains exceedingly cold throughout the summer. The total annual range of mean lake temperture would be less than 5°C. (9°F.). Such a condition might be expected in a lake where 70 per cent of the volume lies below the 25 metre (82 ft.) level, where as figure 4 shows, the temperature changes very little.

The temperature records indicate frequent and complex movements of the water in the upper 25 metres (82 ft.), the description of which would require a much more thorough study than was possible in 1935. The question is of special interest since periodic temperature fluctuations or seiches have been demonstrated in lakes of this morphological type.

Transparency

The lake water is very clear as was indicated by the high visibility in the near shore area and by the use of Secchi's disc. This is a white disc 20 cm. (8 inches) in diameter. The depth to which it remains visible provides a measure of the transparency of the water. Readings at station I in Okanagan lake varied from 8 to 10 m. (26 to 33 ft.).

Dissolved Oxygen

The amount of dissolved oxygen was determined on samples taken along with the temperature series, and a summary of these observations appears in table II. The high oxygen content of the hypolimnion is at once evident, and even at the bottom (100 m. or 328 ft.) the lowest dissolved oxygen was 6.8. cc. per litre. In a single determination with a sample from 175 m. (574 ft.) at station

Table II. The vertical distribution of oxygen at station I, Okanagan lake, in July and August, 1935

	Oxygen in cc. per litre						
Depth (m.)	July 4	July 13	July 17	July 29	Aug. 6	Aug. 13	Aug. 20
Surface	6.0	5.0	5.2	5.2	5.5	5.3	5.4
15	6.5	5.8	5.9	6.4	6.3	6.2	6.1
25	6.4	6.2	6.7	6.9	6.9	6.8	6.6
50	6.6	6.9	6.8	6.9	...	...	...
100	6.8	6.8	...	6.9	7.3	7.3	7.2

IV on July 17 the dissolved oxygen was 6.3 cc. per litre. Saturation values corrected for altitude ranged between 72 and 92 per cent, which is a further expression of the abundance of dissolved oxygen.

Dissolved oxygen is a useful index to the nutritive condition of a lake and the large quantities mentioned above would indicate a high degree of oligotrophy in Okanagan lake. Oligotrophy, as contrasted with eutrophy, denotes a condition marked by relatively small quantities of plankton, much oxygen and relatively low productive capacity. A useful measure is found in Thienemann's (*Der Sauerstoff im eutrophen und oligotrophen See. Die Binnengewässer, Band IV, Stuttgart, 1928*) relation $\frac{O_2H}{O_2E}$, that is, the ratio of the total oxygen of the hypolimnion to that of the epilimnion, the 10-metre (33 ft.) level being considered as the division between these regions. With this index any value greater than one indicates oligotrophy and only in deep alpine lakes are values of 5 to 10 found. This value for Okanagan lake is 6.4.

Hydrogen Ion Concentration

The alkalinity was measured by hydrogen ion (pH) determinations made colorimetrically with La Motte standards. At the surface the pH values were from 8.0 to 8.2, at 15 metres (49 ft.) usually 7.9 or 8.0 and at the bottom (100 m.) 7.8. In the deepest water examined (175 m.) the value was 7.6.

Mineral and Organic Analyses

A sample of the surface water collected on April 28, 1936, has been analysed for mineral and organic constituents (table III). The total solid content was 145 mg. per litre, which is near the average for lakes of this type. The water is of moderate hardness and contains considerable amounts of sulphate and calcium. The very small amounts of nitrogen compounds add to the evidence of extreme oligotrophy.

Table III. Analyses of sample surface water, Okanagan lake, collected April 28, 1936, one mile off Okanagan Mission and some distance south of Station I. Analyses by Mr. J. P. Tully, Pacific Biological Station, Nanaimo.

Residue on evaporation	145.0	Aluminum (Al)	12.9
Organic residue	41.1	Calcium (Ca)	28.7
Free ammonia	0.0023	Magnesium (Mg)	0.0
Albuminoid ammonia	0.00051	Carbonate (CO_3)	16.9
Nitrate (NO_3)	0.00	Bicarbonate (HCO_3)	131.0
Nitrite (NO_2)	0.00	Sulphate (SO_4)	48.0
Silica	3.9	Chlorine (Cl)	0.0
Iron (Fe)	0.00		

In its physical and chemical features Okanagan is a typical large alpine lake comparable to Seneca, of the Finger lakes, New York, or to lake Constance in Switzerland. Like them it has a long deep basin, cold water, and exhibits an extreme oligotrophy in its oxygen relations (table IV).

TABLE IV. Comparative data for Okanagan and other large Alpine lakes.

	Okanagan L., B.C., Canada	L. Constance, Switzerland	Seneca L., New York, U.S.A.
Altitude m.	345.	395.	135.
Latitude	50°00′	47°38′	42°30′
Area sq. km.	370.	475.	175.
Length and width km	117x3.2	67x13	57x3.1
Mean depth m	69.5	100.	88.6
Max. depth m.	232.	252.	188.
Volume cu. m. x 10^6	25,700.	46,700.	15,540.
Vol. E* as % of total	13.4	10.1	10.6
Mean temp. °C., midsummer	8.6	6.5	7.5
Wind distrib. heat gr. cal/cm^2	32,700.	22,400.	31,500.
Ann. heat budgets gr. cal/cm^2	34,000.	23,200.	36,500.
Oxygen of epilimnion cc/l.	5.8	7.0	7.0
Oxygen of hypolimnion cc/l.	6.6	7.4	8.6
$\frac{O_2H}{O_2E}$	6.4	10.4	10.4
O_2 in greatest depth cc/l.	6.3	7.6	8.4
O_2 in greatest depth % sat.	71.	90.	92.

*E is the "hydrographic epilimnion" of Thienemann (1928), i.e. the 0-10 stratum.

PLANKTON

The plankton, which includes the microscopic plants and animals throughout the water of the lake, is a basic source of food for larger animals. In a survey of this kind it is of interest to know both the kinds of organisms and the quantities in which they occur.

The sampling was done by means of silk nets, a method subject to considerable error but the only one practicable in this case. Two nets of number 20 silk bolting cloth were used, a small one with an aperture of about 5 inches and a larger one with a mouth 10 inches wide. They were of the "Wisconsin" type and could be closed at any level, thus making it possible to take a series of hauls to demonstrate vertical distribution of organisms. The larger net was used to obtain samples large enough for the determination of total organic nitrogen.

The composition of the hauls has been studied by a number of specialists interested in the different groups. In the present account only the more abundant and characteristic organisms are mentioned. A full list will be found in table XVII of the appendix.

The phytoplankton or plant members of the plankton include three groups of algae, blue green, green and diatoms. The blue green algae, Myxophyceae, were represented by eight species of which *Anabaena flos-aquae* and *Aphanizo-*

menon dispersus were the most characteristic. The green algae (Chlorophyceae), of which twenty species were identified, were most commonly represented by such forms as *Dictyosphaerium pulchellum*, *Oocystis parva*, *Staurastrum gracile* and *Botryococcus Braunii.*

Of 34 species of diatoms (Bacillarieae) six were most abundant: *Asterionella formosa*, *Cyclotella compta*, *Fragilaria crotonensis*, *Melosira granulata*, *Stephanodiscus niagarae* and *Tabellaria fenestrata.*

The zooplankton or animal forms may be considered in four groups, Protozoa, rotifers, waterfleas and copepods. The Protozoa, unicellular forms, were made up chiefly of *Ceratium hirundinella* and two species of *Dinobryon.*

Seven species of rotifers (Rotatoria) included *Notholca longispina*, very widespread, *Conochilus unicornis* and *Ploesoma truncatum*, common in surface tows, *Collotheca mutabilis* and *Synchaeta sp.* common in deep water.

The water fleas (Cladocera) were represented by eleven species of which two, *Daphnia longispina* and *Bosmina longispina*, were most widespread. Other species were found to be common in certain localities.

Only three species of copepods (Copepoda) were identified but they formed a large fraction of the total plankton. They were *Diaptomus ashlandi*, *Cyclops biscuspidatus* and *Epischura nevadensis*, the first two being abundant throughout the season and at all depths.

Variations in the composition of the plankton during the two-month period were comparatively slight and consisted chiefly of the appearance and disappearance of a few species. The most stable group included *Diaptomus*, *Cyclops*, *Ceratium* and *Tabellaria*. Certain other forms were steadily present but never in large numbers, while a third group, notably *Epischura*, *Scapholeberis*, *Diaphanosoma*, *Anabaena* and *Botryococcus* occurred irregularly and in more variable numbers. This condition of general constancy in the plankton population is in marked contrast to the violent "pulses" common in the smaller lakes of the region.

Examination of the vertical series indicated that on a few occasions there was a concentration of the blue green alga *Anabaena* on the surface constituting a slight water bloom. Certain rotifers mentioned above were more abundant in the deeper water (150 to 300 ft.). The nauplii or larvae of copepods also tended to be more numerous in the deeper water. With these exceptions the vertical distribution consisted in a gradual reduction with depth of the many forms found at the surface.

On two occasions hauls were taken on successive days at stations I, II and III. Comparison of these showed that the species mentioned above as "stable" throughout the season were also uniformly present in widely separated parts of the lake. Differences in the catch at the three stations involved certain less abundant species which had been found variable at a single station. It was also noteworthy that the total quantity of plankton taken at each of the three stations on successive days was practically uniform.

Quantitative analyses have been made of total vertical hauls with the large net taken at approximately weekly intervals at station I and less frequently at stations II and III. As suggested above, the plankton net is not completely satisfactory for sampling because it is difficult to determine the exact volume of water which it strains. Further sampling errors may result from irregularity in the distribution of the plankton organisms. From the available data and from the results of other investigators, we have no reason to suspect that there is any great irregularity in the distribution of organisms in the open water region of Okanagan lake. Undoubtedly some irregularity of distribution does occur in the shallow near shore area. In further justification of the method, it should be noted that the equipment and methods of sampling were similar to those used in other British Columbia lakes with which comparisons are made.

The average volume of eleven total vertical hauls between July 4 and August 26 was 1.40 cc. The dry weight was 28.4 mg. and the total organic nitrogen 1.86 mg. (table V). Of this amount, about 57 per cent was from the upper 10 m., 24 per cent from 10-20 m., 10 per cent from 20-50 m., and 9 per cent from 50-100 m. The deeper water was therefore extremely unproductive with respect to plankton.

TABLE V. Quantity of plankton in total vertical hauls in Okanagan lake.

Station	Date	Volume cc.	Dry weight mg.	Total organic N_2 mg.
Station I	July 4	1.05	17.7	1.4
" "	July 13	1.85	25.0	1.9
" "	July 19	2.35	48.0	3.6
" "	July 29	1.15	21.2	1.5
" "	Aug. 6	1.00	17.4	1.4
" "	Aug. 12	1.35	39.2	2.2
" "	Aug. 20	1.55	37.8	2.1
" "	Aug. 26	0.60	16.6	0.8
Station II	Aug. 21	1.20	23.8	1.4
Station III	July 31	2.05	33.9	1.7
" "	Aug. 19	1.30	32.3	2.4
Average		1.40	28.4	1.86

The average of eight hauls taken in Paul lake near Kamloops, B.C., in July and August, 1934, may be compared with the average hauls in Okanagan lake as follows:

	Volume cc.	Dry wt. mg.	Total org. N_2 mg.
Okanagan lake, 11 hauls, July-Aug. 1935..........	1.4	28.4	1.86
Paul lake, 8 " " " 1931..........	4.4	36.2	2.61

The amounts of nitrogenous material in the total vertical hauls from Paul lake is about one and one-half times as great as that from Okanagan although the latter is a much deeper lake. Paul is a small and highly productive lake (cf. table VII). Shuswap lake, lying north of Okanagan in the Thompson drainage, has a more comparable area and depth. In Shuswap lake total vertical hauls gave, on July 17, 1931, a total volume of 2.55 cc. and on September 5, 1.95, an average of 2.25 cc. It is thus seen that plankton collections from Okanagan lake are very much less than those of small lakes in the region but not much smaller than those from Shuswap which is another deep alpine lake.

BOTTOM FAUNA

The organisms on the lake bottom were investigated by the use of an Ekman dredge which took a sample of 500 sq. cm. (77 sq. inches) in area. The quantitative samples included 115 dredge hauls and 20 collections in the near shore region. These were supplemented by qualitative collections from about 25 locations. All quantitative samples were washed through fine meshed screens from which the macroscopic organisms were recovered.

Composition

As with the plankton, the bottom organisms have been examined and measured. In most cases they have been identified by specialists in the various groups. In the following description only the more significant species are mentioned. A complete list is given in table XVIII of the appendix. The major groups represented were the leeches, crustaceans, insects, water-mites and molluscs.

The leeches (Hirudinea) collected were of four species with *Helobdella stagnalis* and *Placobdella montifera* common near the shore. *Piscicola punctata* was found attached to squawfish and other minnows.

The crustaceans were represented by two fresh water shrimps (Amphipoda), *Gammarus limnaeus* present in small numbers near the shore, and *Hyalella azteca* common down to a depth of 10 m. (33 ft.). A crayfish, *Potamobius klamathensis*, was taken in small numbers.

The insects included a number of orders, four of which will be considered here. The mayflies (Ephemeroptera) included more than twelve species. The larger forms, *Hexagenia limbata* and *Ephemera simulans*, were widely distributed in the upper 25 m. (82 ft.). Small species of *Caenis* were also found at these depths, but the remainder of the group were chiefly near shore. The dragonflies (Odonata) were of three species of which the damselfly, *Enallagma cyathigerum*, was the most abundant. The caddis flies (Trichoptera) included fifteen species, the larvae of which were mostly in depths of less than 10 m. (33 ft.). The genera *Hydroptila*, *Polycentropus* and *Limnephilus* were common. The true flies (Diptera) were represented chiefly by the midges (Chironomidae) of which more than twenty-five species were collected. Midge larvae were the most abundant and widespread of all bottom organisms. Large larvae of the genus *Chironomus* and smaller forms belonging to the genera *Cryptochironomus*, *Polypedilum*, *Orthocladius* and *Tanytarsus* were prominent.

Water-mites (Hydracarina) of two species, *Piona rotunda* and *Hygrobates longipalpis*, were collected.

The molluscs were scarce except in a very limited near shore region. Of the snails (Gastropoda) six species were identified. *Lymnaea caperata*, *Gyraulus parvus* and a new species of *Physa* were the most common. The mussels or "clams" (Pelecypoda) included two large species of the genus *Anodonta*, namely, (*oregonensis* and *beringiana*), neither of which were numerous, and many minute forms sometimes known as white clams (Sphaeriidae) of a single species, *Pisidium compressum*, which ranged in depths from approximately 8 to 250 feet.

Other groups not mentioned above but of moderate importance were the aquatic bugs (Hemiptera), beetles (Coleoptera) and the aquatic earthworms (Oligochaeta).

Distribution

The availability of the bottom organisms as food for fish is affected both by their distribution and abundance. In table VI the distribution of organisms with respect to depth is readily seen. The midge larvae are most numerous and they are fairly uniform in their distribution down to a depth of 75 m. (246 ft.). White clams and oligochaete worms were the only other forms found in the deepest water, the latter group being numerous even at depths of 400 ft.

Table VI. The average numbers of bottom organisms per square metre at various depths in Okanagan lake

Depth (metres)	0–1	1–5	5–10	10–20	20–30	30–50	50–75	75–125	All depths
No. of samples	20	29	22	18	12	14	15	4	135
Midge larvae	113	260	405	356	206	313	300	188	268
Oligochaete worms	20	26	36	40	23	110	68	102	53
Mayfly nymphs	67	8	23	17	5	..	..	..	15
Fresh-water shrimps	32	11	35	21	..	..	..	..	12
Caddis larvae	24	9	7	8	..	..	..	..	6
White clams	0	3	..	1	..	6	5	..	2
Snails	9	1	4	..	..	..	..	..	2
Miscellaneous	22	3	3	13	2	..	3	..	6
All organisms	287	321	513	456	236	429	376	290	364

In the shallower water greater irregularity of distribution was found. Mayfly nymphs were practically confined to the upper 25 m. (82 ft.), and the remaining groups to the upper 20 m. (66 ft.). Since this represents only one-quarter of the lake area, it is evident that most of the lake bottom is populated only by chironomids, oligochaetes and white clams, and these in comparatively small numbers.

An unusual feature of the fauna is the scarcity of molluscs. In the shore area *Physa* and a few planorbids are found. These with the scattered Sphaeriidae comprise almost the whole molluscan fauna of the lake.

Certain organisms showed special distribution with respect to bottom types. In the deeper water, the bottom was frequently light in colour with little organic content and varied from soft ooze to stiff clay. This supported smaller numbers of oligochaetes and midge larvae than the darker muds of shallower portions of the bottom. Such regions were found at depths of 5-20 m. (16-66 ft.) and contained more organic matter. Sand was the usual bottom type from shore to 10 m. (33 ft.), but in a few places rooted vegetation occurred and in these the fresh water shrimp (*Hyalella*) was abundant. Mayfly nymphs of the genus *Hexagenia* were most commonly found in soft clay ooze. Some of the midge larvae appeared to prefer certain types of bottom material, a striking example being that of *Limnochironomus*, which was found only on bare stone or rock bottom near the shore.

Quantity

The number of bottom organisms has been indicated in table VII where it is seen that the average for the whole lake is 364 per square metre (305 per square yard). Of this number the midge larvae make up 74 per cent, oligochaetes 15, mayfly nymphs 4, fresh-water shrimps 3, and all other organisms 4 per cent.

Table VII. The amount of bottom organisms in various lakes.

Lake	Area		Mean depth		Av. number organisms	Dry weight organisms
	sq. km.	(sq. mi.)	m.	(ft.)	per sq. m.	kg./ha.
Okanagan	143	(370)	69	(226)	364	2.0
Nipigon	1,760	(4,550)	55	(180)	1,056	5.9
Ontario	7,050	(18,200)	91	(299)	.....	4.3
Simcoe	280	(720)	15	(49)	820	11.0
Waskesiu	27	(70)	11	(36)	6,554	13.7
Paul	1.5	(4)	34	(112)	1,363	41.5
Mendota	15	(39)	13	(43)	.....	45.1

In some respects the weight of organisms is more useful as a measure of the amount of fauna than their numbers. The net weight of the organisms from each dredging was determined, using a delicate torsion balance. The deduction for the shell weight of the molluscs was made after determining the average proportion of shell to body weight in different species. The average weight of organisms per dredging was 0.049 grams (0.75 gr.), equivalent to 0.982 grams per square metre. Since the dry weight of these organisms is approximately 20 per cent of the net weight, the average dry weight of bottom organisms in Okanagan lake is 0.196 grams per square metre, mollusc shell deducted. For comparative purposes this may be called 2.0 kg. per hectare, as given in table VII, or 1.8 lb. per acre.

As a basis for evaluating the above data, information as to the amount of bottom fauna found in lakes of various sizes is included in table VII. In Okanagan lake the number of organisms is small and the organisms themselves of small size so that the amount of fauna by weight is exceedingly low. The extent of this paucity is more evident when we note that even very large lakes like Nipigon and Ontario have twice or three times the amount of bottom organisms to be found in Okanagan. It should be recorded that the results from a small number of dredgings taken in Shuswap, another lake of this general type, in July, 1931, suggest a similar paucity of bottom organisms.

PRODUCTIVITY

The quantities of plankton and bottom organisms have been determined to give some suggestion of the productive capacity of the lake with respect to fish.

It should be remembered that we are measuring the "standing crop" of organisms which does not indicate the "annual harvest" or the rate of production. Also the degree of accuracy with which these organisms can be measured, or the efficiency of their utilization estimated, is not high. Nevertheless it seems reasonable that since these organisms are the ultimate source of all fish food, their amounts should indicate in a rough way the possible fish production. With a plankton which may be described as moderate to poor and a very poor bottom fauna, the basic productivity of Okanagan lake must be comparatively low. It is thus not surprising that although the eastern whitefish, *Coregonus clupeaformis*, was introduced into the lake and is now widely distributed, it failed to reach either numbers or size which would provide a profitable fishery.

While food organisms occur in oligotrophic lakes in relatively small quantities, it has been suggested by some authors that in them there is a more efficient utilization than in eutrophic lakes where nutritive materials are abundant. While we have no means of verifying this in Okanagan lake, it should be noted that in spite of the small amounts of plankton taken in the net samples, many of the fish stomachs contained plankton. In fact ten of the fourteen species of fish in the lake had eaten important quantities of plankton.

It has been stated that Okanagan lake is an extreme oligotrophic type and that lakes of this group are marked by a comparative scarcity of organisms. The extreme depth and low temperature are undoubtedly factors in this low productivity but probably not the complete explanation. Further investigation of the amount of organic and inorganic materials both in the water and in the bottom deposits would be of use in an understanding of this problem.

SUMMARY

Okanagan lake is a large and deep alpine lake in the southern portion of the central plateau of British Columbia. Its area is 370 sq. km. (143 sq. mi.), its maximum depth 232 m. (760 ft.) and its mean depth 69.5 m. (228 ft.). The lake basin is long and narrow with a shoreline predominately rocky or stony.

The surface temperature of the lake rose to about 20°C. (68°F.) at midsummer and thermal stratification was usually present with a variable thermocline between 10 and 20 metres (33-65 ft.). The hypolimnion was always cold and so extensive that the mean temperature of the lake did not exceed 8.7°C. (47.5°F.). The dissolved oxygen was plentiful from surface to bottom with never less than 70 per cent saturation.

Morphometry, temperature, oxygen and nitrogen analyses indicate Okanagan lake as an extremely oligotrophic type. In its richness in calcium it resembles the deep oligotrophic lakes of the Alps rather than those of Norway.

The net plankton of the open water was compared with similar samples from other lakes and found to be comparatively poor. The macroscopic bottom organisms were very scanty averaging 364 per square metre and 2.0 kg. dry weight per hectare (304 per sq. yard and 1.8 lb. per acre).

The paucity of minute organisms in the lake suggests that it is capable of a relatively limited fish production.

OTHER LAKES OF THE OKANAGAN VALLEY

In the course of the survey it was found advisable to visit several smaller lakes which were involved in the Kamloops trout problem. Of the five lakes visited two, Beaver and Chute, were at high altitudes and the remaining three, Duck, Woods and Kalamalka, form a chain which drains into Okanagan lake through Vernon creek. The location of these lakes is shown on the accompanying map.

BEAVER LAKE

Beaver, also known as Swalwell, lake is located about 15 miles north-west of Kelowna, at an altitude of 4,500 ft., in a densely wooded area. It is slightly more than one square mile in area and has a maximum depth of about 24 metres. A chain of smaller lakes known as A, B, C and D drain into its upper (eastern) end. A second stream, Echo (Buckhorn) creek, empties into the lake on the north shore opposite the outlet. This is a cold spring creek and on it is located a rearing station for trout.

WATER CONDITIONS

Temperature series taken on July 11 and August 25 show in both cases comparatively cold water and marked thermal stratification. The temperatures were as follows:

Depth (m.)	July 11 (°C.)	Aug. 25 (°C.)
Surface	13.4	15.6
5.0	12.4	14.3
7.5	9.3	7.8
10.0	7.3	7.6
15.0	6.2	6.7
Bottom, 22.0	5.2	6.1

The thermocline, between 5 and 7.5 metres, shows on July 11 a total temperature drop of 3.1 and on August 25, 6.5°C. This increase in the extent of thermal stratification was accompanied by a corresponding decrease in the dissolved oxygen of the hypolimnion.

Depth	Dissolved oxygen July 11		August 25	
(m.)	(cc./1.)	(% sat.)	(cc./1.)	(% sat.)
Surface	5.4	87	4.9	83
5.0	5.4	86	5.0	81
7.5	...	..	3.1	44
10.0	5.2	74	0.6	8
15.0	4.5	62	0.5	7
22.0	1.8	24	0.4	5

The water was somewhat acid in reaction, on July 11 a pH of 6.9 at surface and 6.7 at bottom. On August 25 it was 7.3 at surface and less than 6.5 at the bottom. A strong odour of hydrogen sulphide was observed from the bottom water on the latter date.

These data indicate the degree of thermal stratification and of stagnation in the hypolimnion. On August 25 there was only an insignificant amount of oxygen beneath the thermocline.

PLANKTON

Plankton samples were taken on July 11 and on August 25 and at both times the copepods *Diaptomus ashlandi* and *D. arcticus* were predominant. These forms with the rotifer *Conochilus unicornis* made up the bulk of the plankton. (A list of the organisms collected in Beaver, Chute, Kalamalka, Woods and Duck lakes is given in table XX of the appendix.)

The plankton from the total vertical hauls with the large net was measured volumetrically and the amount of organic nitrogen determined.

July 11	Total vertical haul Vol. 1.15 cc.	Total org. N_2 2.1 mg.
August 25	" " " " 1.85 cc.	" " " 2.7 mg.

The amount of plankton is seen to be larger than that collected in Okanagan lake where the hauls were made in a depth five times as great. This amount is somewhat smaller than that observed in small lakes of the Kamloops region, 1931, but the samples are too few to support final conclusions. Collections from Penask lake, at similar altitude, had approximately twice as much nitrogenous material as those from Beaver lake.

BOTTOM FAUNA

The bottom fauna was sampled with 12 dredgings on July 11. These were taken in two series, one in the long axis of the lake and the other at right angles to the first and crossing the deepest water. Additional collections were made along the shore, at the outlet and in the upper lakes.

Midge larvae were the most numerous organisms occurring in eleven of the twelve dredgings and in average numbers equal to 234 per square metre. White clams, oligochaete worms and caddis larvae were fairly numerous and other organisms rare.

The average net weight of organisms in these dredgings with mollusc shell deducted was 2.06 gm., which is equal to about 8 kilograms dry weight per hectare. In view of the small number of samples no great reliance can be placed on this figure.

THE UPPER LAKES

Observations on A, B, C and D lakes were made on July 12. The maximum observed depths were 17, 18, 14 and 11 metres respectively. Each lake showed marked thermal stratification with the thermocline nearer the surface than in

Beaver lake. The dissolved oxygen of the bottom water was 0.9, 0.3, 1.2 and 0.5 cc. per litre respectively. This indicates a stagnation more severe than that in Beaver lake at the same time.

Plankton samples indicated general similarity to that of Beaver lake, but the water flea *Daphnia pulex* was much more abundant and the blue green alga *Aphanizomenon* was present as a surface bloom, especially in lakes C and D.

The "drowned" shoreline resulting from artificial raising of the water level is obvious in these lakes but the shore fauna appeared to be quite rich. Caddis larvae, dragonfly and mayfly nymphs, leeches and water mites were all observed in considerable numbers on the shores of D lake.

From the brief examination of Beaver and its tributary lakes a few factors would appear to have special significance with reference to the trout problem. The high altitude and resulting low surface temperatures allow the trout to feed at or near the surface and thus provide fly fishing even at midsummer. It is probable also that the lowered oxygen supply of the hypolimnion forces the fish to stay in the upper stratum. The abundance of the large copepods and cladocera in the plankton suggests an ample food supply for the younger fish. Important food organisms of the adult fish such as caddis flies, mayflies and freshwater shrimps are present in the shallow water regions. Several anglers have reported a noticeable decline in the numbers of shrimps (*Gammarus*) and caddis in recent years. The quantity of organisms in this variable shallow water region could not be determined in the brief examination but they were certainly present in considerable variety.

Chute Lake

Chute lake, also known as Lequime, is a small lake of about one-sixth of a square mile in area and situated about eight miles south of Okanagan Mission. It is at the high altitude of 3,900 ft. and its surroundings resemble those of Beaver lake. The maximum depth observed was 14 metres.

Examined on August 26 the temperature and oxygen distribution were as follows:

Depth (m.)	Temperature (°C.)	Oxygen (cc./1.)
Surface	15.7	5.2
4.0	14.3	3.9
5.0	11.5	2.2
5.5	9.4	....
6.0	8.3	1.4
7.5	8.1	0.05
10.0	7.4	0.0
Bottom, 14.0	7.2	0.0

The water was thermally stratified and the oxygen of the deep water depleted to an even greater extent than in Beaver lake on the previous day. The smaller area of Chute lake would lessen the mixing effect of winds and thus favour the progress of stagnation. The deep layer of black organic ooze on the bottom would utilize much oxygen and also contribute to the stagnation. The lake water had a distinct yellowish colour and was somewhat acid in reaction. Secchi's disc was visible only to the depth of 1.0 metre.

The plankton appeared to be fairly rich and was dominated by the copepod *Diaptomus* and the rotifer *Keratella*. The amount in a total vertical haul was 0.95 cc. and 1.0 mg. total nitrogen. This is quite large considering that the haul was in a depth of only 14 metres. The bottom fauna was not sampled by dredging but a small quantity of bottom material was brought up for examination. This proved to be a very black organic ooze and contained a few minute midge larvae.

In a general way Chute lake resembles Beaver but it is smaller and suffers from a more severe summer stagnation.

Kalamalka Lake

Kalamalka is the largest of three lakes lying in a valley parallel to Okanagan lake and draining into it through Vernon creek (figure 1). Woods lake drains into Kalamalka by a short canal and the two are sometimes referred to as Long lake. The elevation of these lakes is about 1,300 feet. Kalamalka is about 10 miles long, one mile in width and has an area of 12 square miles. Its shape resembles that of Okanagan lake even to the forking of the northern end. The maximum depth observed was 130 metres. The deepest part was approximately central but the depth exceeds 50 metres for most of its length.

A temperature series was taken on August 14, two miles from the south end, in a depth of 56 metres.

Depth (m.)	Temp. (°C.)	O_2 (cc./1)	pH
Surface	17.5	5.6	8.2
5	17.2		
10	16.7		
15	15.3	6.9	8.2
20	12.2		
25	11.4	6.9	8.2
30	10.0		
35	9.0		
40	5.6	7.4	8.1
Bottom, 55	4.5	7.2	8.0

There was no thermocline present at this time but a drop of 3°C. between 15 and 20 metres. It will be noted that the temperatures, oxygen distribution and pH are decidedly like those in Okanagan lake on August 13. The transparency is high, Secchi's disc being visible at 6 to 7 metres, again like Okanagan.

Plankton samples from the deeper water include large numbers of the copepods *Diaptomus* and *Cyclops* and a few water fleas. At the surface *Dinobryon* and *Ceratium* were abundant and *Notholca* and *Aphanizomenon* common. The amount of plankton in the total vertical haul was 1.55 cc. and 2.0 mg. nitrogen, much the same as that from station I, Okanagan lake, at this time.

Six dredgings were taken at depths of 1 to 56 metres. The bottom material was mostly of grey ooze or clay. Midge larvae were present in all dredgings and made up 95 per cent of the total organisms. At depths down to 30 metres these were abundant, averaging more than 1,000 per square metre. In deeper water they were much less numerous. The average weight of organisms in the six dredgings was 0.16 grams wet weight, the equivalent of about 6.5 kilograms dry weight per hectare. This average is undoubtedly too high to represent the whole lake since only two of the dredgings were taken in the extensive and semi-barren deep water region.

With respect to physical conditions, plankton and bottom fauna, Kalamalka lake is much like Okanagan with its deep cold water, plentiful supply of oxygen and scanty fauna. As might be expected, in the smaller lake the scarcity of organisms is less extreme.

Woods Lake

Woods lake is about 4 square miles in area and closely connected to Kalamalka by the above mentioned canal. The depth is almost uniform over a large part of its area, variation being limited to the range of 25 to 32 metres except in the region near shore.

A series of temperatures and oxygen determinations was made on August 13.

Depth (m.)	Temp. (°C.)	O_2 (cc./1)	pH
Surface	18.5	5.7	8.4
5.0	18.7		
10.0	15.0	4.5	8.0
12.5	10.4		
15.0	8.5	4.5	7.8
20.0	6.8		
Bottom, 30.0	5.8	1.7	7.2

The thermocline, located between 10 and 15 metres, was sharply defined and the dissolved oxygen much reduced in the deeper water. Low transparency of the water was indicated by Secchi's disc readings of 2 to 2.5 metres, this being in part the result of an algal bloom.

The plankton samples contained a tremendous quantity of *Aphanizomenon* which was present as a heavy bloom at this time. The other organisms, chiefly the copepod *Diaptomus* and a few rotifers, were obscured by the algae. The quantity of plankton in the vertical haul was 7.0 cc. and the total nitrogen 223 mg. This is the result of a pulse rather than the normal plankton. A similar pulse of *Aphanizomenon* existed in Duck lake at the same time.

Eight dredgings in Woods lake brought up a very black organic ooze from depths of 15 to 30 metres and in it a very dense fauna of oligochaete worms and midge larvae. In most places the oligochaetes numbered more than 1,000 per square metre and in one sample at a depth of 21 metres 23,000 per square metre. Such numbers of oligochaetes are found only in stagnant and richly organic bottom deposits. The average wet weight per dredging was 2.17 grams, equivalent to 87 kilograms dry weight per hectare. This figure is probably too high to represent the lake as a whole and in any case the stagnant bottom condition would largely prevent the utilization of this fauna by fish.

Duck Lake

Duck, or Ellison, lake is the third and smallest in the chain and has an area of about 2 square miles. Its maximum depth is only 5 metres. On August 24 surface and bottom water samples were examined.

	Temp. (°C.)	O_2 (cc./1)	pH
Surface	18.9	5.3	8.8
Bottom, 5 m.	17.8	3.2	7.8

The surface sample was distinctly yellow, possibly from the presence of *Ceratium* in large numbers. The reason for the high alkalinity of the surface water is not known.

Plankton samples revealed a great pulse of *Ceratium* which had apparently followed the decomposition of the *Aphanizomenon* a week earlier. Diatoms and a few rotifers were common in the vertical haul. The total nitrogen from a vertical haul was 14.2 mg.

Two dredgings brought up a soft clay deposit with moderate numbers of midge larvae, oligochaete worms and a few *Corethra* larvae.

These three lakes, one draining into the other, are very different among themselves and very different also from Beaver lake. The latter would also drain into Duck lake, but, as has been indicated above, much of its flow is diverted elsewhere for irrigation purposes. The series of lakes varies from extreme eutrophy to extreme oligotrophy and yet is closely connected and with the same water supply. They offer most interesting possibilities for further investigation, both from the purely scientific point of view and to provide fundamental data of use in the Kamloops trout problem in these and in Okanagan lake.