THE BIOLOGICAL BOARD OF CANADA
UNDER THE CONTROL OF
THE HON. THE MINISTER OF FISHERIES

BULLETIN No. XLII

PRODUCTIVITY STUDIES IN LAKES OF THE KAMLOOPS REGION, BRITISH COLUMBIA

BY
DONALD S. RAWSON
University of Saskatchewan

OTTAWA
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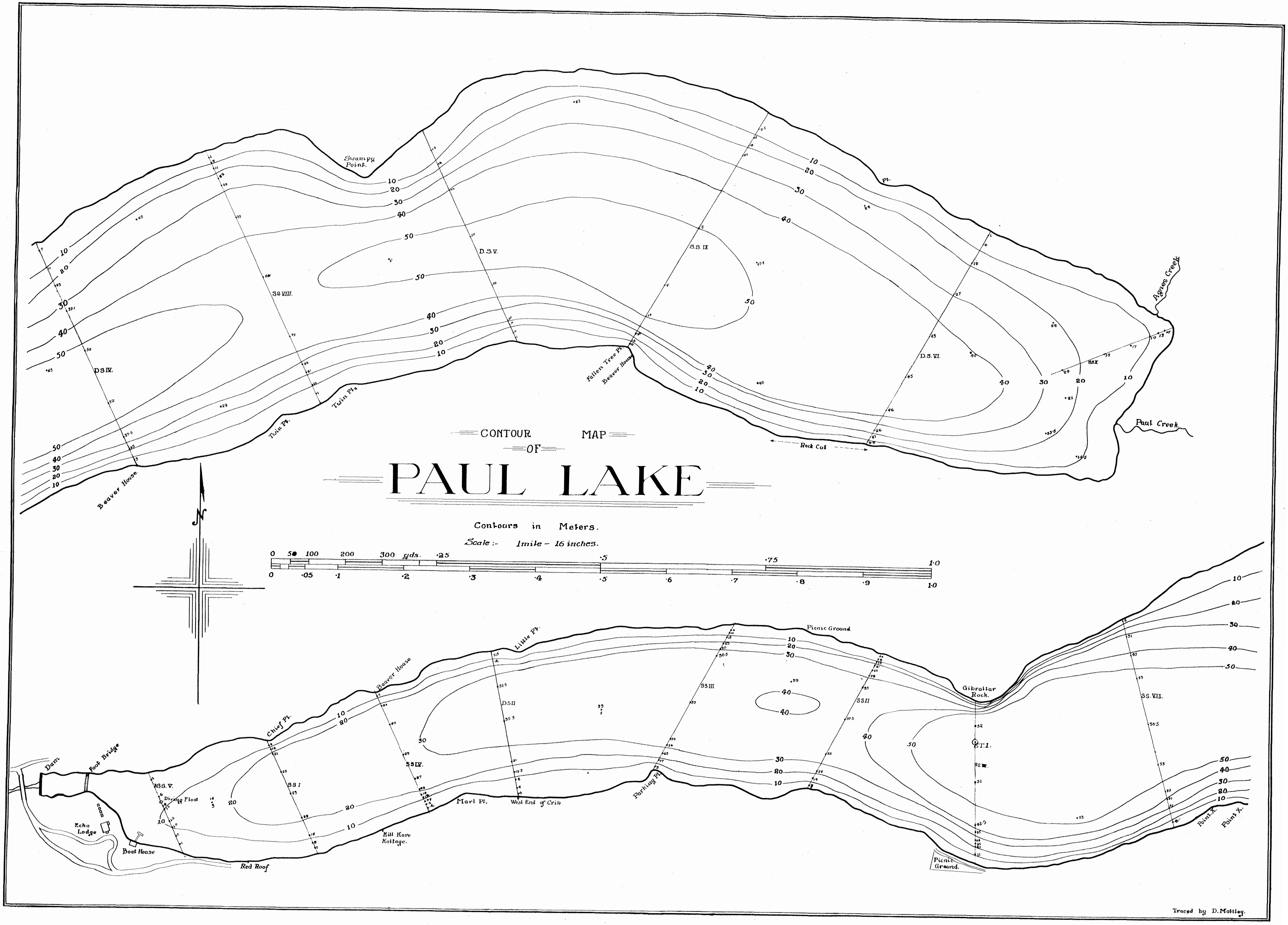

CONTOUR MAP OF
PAUL LAKE
Contours in Meters.
Scale :- 1mile - 16 inches.
N
Swampy Point.
Pt.
Agnes Creek
Paul Creek
Rock Cut
Fallen Tree Pt.
Beaver House
Twin Pts.
Twin Pt.
Beaver House
D.S.IV.
SS.VIII.
D.S.V.
S.S.IX
D.S.VI.
Picnic Ground
Little Pt.
Beaver House
Chief Pt.
Foot Bridge
Dam
Diving Float
Echo Lodge
Boat House
Red Roof
Kill Kare Kottage.
Marl Pt.
West End of Crib
Parking Pt.
Gibraltar Rock.
Picnic Ground.
Point X.
S.S. V.
SS I
SS IV.
DS II
SS III
SS II
S.T.I.
S.S. VII.
Traced by D. Motley.

INTRODUCTION

This study of productivity was undertaken in 1931 as a part of a general investigation of the Kamloops trout, *Salmo gairdneri kamloops*. Its purpose was to furnish data necessary in studies of life history, populations and culture which were already begun by Mr. Chas. McC. Mottley. It was proposed also to work out a plan of investigation suitable for further studies of productivity in British Columbia lakes.

Since Paul lake had been chosen as headquarters for the investigation the study of its limnology and ecology was made as thorough as possible. Four other lakes, Pinantan, Penask, Fish and Nicola were chosen as representing a variety of conditions to be compared with those in Paul lake and irregular visits were made to these lakes during the summer (see figure 1).

The present report is based upon work done in one summer and is therefore of a preliminary nature. The information presented concerns chiefly the ecological conditions and the amount of fauna in the lakes. While such data are clearly fundamental in the problem of trout production it is recognized that such a study is but a small step in estimating the actual "productivity" of the lakes.

The author desires to express to the Biological Board of Canada, his appreciaciation of the opportunity of carrying out the investigation and to Dr. W. A. Clemens and Mr. C. McC. Mottley for many courtesies.

PAUL LAKE

PHYSIOGRAPHY

Location, Size and Drainage

Paul lake lies between the North and South Thompson rivers about 19.2 km. (12 mi.) from their junction at Kamloops. It has an area of 388 ha. (1.5 sq. mi.) and is situated in a narrow rocky valley at an altitude of 777 m. (2542 ft.) some 387 m. (1400 ft.) above Kamloops where its outlet, Paul creek, empties into the North Thompson. The lake is fed by two small streams, one of which comes from Pinantan lake. Since the lake surface has remained about five feet below its former level, there has been practically no flow in the outlet in recent years.

The accompanying map was drawn from a rough survey made by the writer during the summer of 1931. Using as a baseline the only surveyed part, from Echo Lodge to the parking ground, the positions of some 25 points around the lake were located by means of a prismatic compass. Distances were checked in the same way and by timing a small outboard motor which was found to run at exactly 9.6 km. (6 mi.) per hour. The same boat was used throughout and the rate checked frequently over a known course. Two hundred and fifty determinations of depth were obtained from eleven series of soundings as well as from determinations made when dredging and during a survey of the *Chara* zone. Depth contours have been inserted on the map at 10 metre intervals.

DEPTH

An analysis of the depth determinations is given in table I which indicates the actual and relative areas of the six depth zones. It will be seen that of the

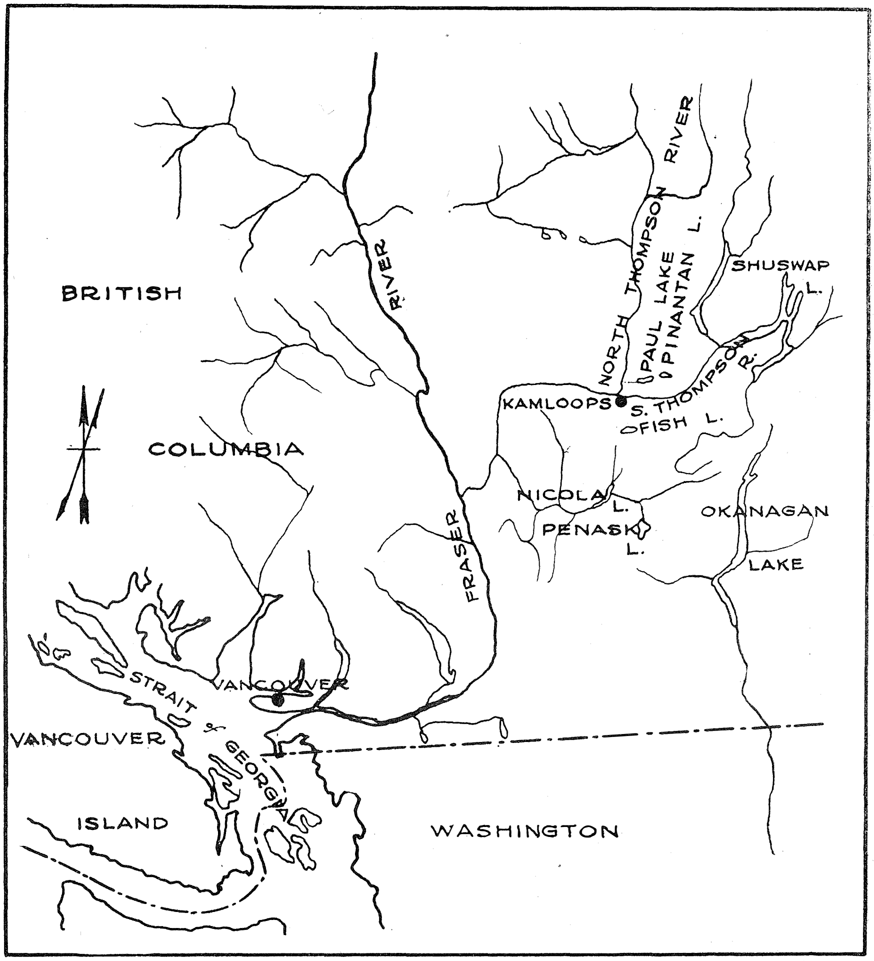

FIGURE 1. Portion of the province of British Columbia, showing the location of the five lakes of the Kamloops region referred to in the present report, namely, Paul, Pinantan, Fish, Nicola and Penask.

total area of 399 ha. (1.54 sq. mi.) 32.7 per cent. lies below the 50 metre contour. The maximum depth observed was 56 m., a short distance east of Gibraltar point. The mean depth (*i.e.* volume ÷ area) is 34.2 m., a considerable depth for a lake of this size.

At each end of the lake the contours indicate a gradual decline, the angle of surface with bottom being only 3° to 5°. The greater portion of the shore falls off with great rapidity, in most places the angle of decline being 20 to 25° with a maximum at Gibraltar rock of 61°.

TABLE I. Areas of depth zones in Paul Lake

Depth zone	Area (hectares)	% of total area
(m.)		
0–10	41.7	10.4
10–20	71.8	17.9
20–30	44.5	11.2
30–40	53.0	13.3
40–50	58.0	14.6
50–55	130.0	32.7
0–55	399	(1.54 sq mi.)

ECOLOGICAL ZONATION

The region from water level down to a depth of 0.75 m. is here called the shore zone. This zone was quite variable as to substrate and vegetation, five "types" of shore being recognized. From the lower limit of the shore zone down to 11 metres there is typically a dense growth of *Chara* with a rich and fairly distinctive fauna. Since this appears to be neither truly littoral nor sublittoral it is referred to simply as the "*Chara* zone". The region between 11 and 20 metres, characterized by steep inclines and no very distinctive fauna, is designated as the lower sublittoral. The profundal zone from 20 to 55 metres is extensive and clearly marked by uniform physical conditions and fauna. The relative areas of these ecological zones have been determined as follows:

Zone	Depth limits (m.)	Per cent. of total area
Shore zone	0-0.75	3.9
Chara zone	0.75-11.0	7.3
Lower sublittoral	11.0-20.0	16.7
Profundal	20.0-55.0	71.8

SHORELINE

The shoreline of the lake was fairly regular but long in proportion to the area. The shore development (relation of shore length to minimum circumference for the same area) is 5.55. This condition is of considerable significance since it brings much of the lake area into "near shore" conditions.

PHYSICAL AND CHEMICAL CONDITIONS IN THE WATER

WATER TEMPERATURES

Series of temperature determinations were made at station 1 (52 m.) off Gibraltar rock at intervals of approximately ten days throughout the period of investigation, June to September. The resulting temperature data are shown in table II.

The degree of thermal stratification and the course of seasonal change is indicated in figure 2 in which the three curves show thermal conditions on June 27, early summer; on August 22, midsummer; and on September 29, early autumn.

The June curve shows that from the uniform temperature of the spring turnover the warming process has brought the water above the 10-metre depth to about 14° C., warming from that depth to 15 m. being slight and below 15 m. negligible. The thermocline between 10 and 12.5 m. is not considered to have much ecological significance in view of the depth of the lake and the low temperature prevailing.

The August curve illustrates midsummer conditions which were reached as early as July 21 and which prevailed almost unchanged until September 1. During this period the surface temperature fluctuated more or less regularly over a range of 2° to 4° C. At 5 m. the temperature showed an irregular fluctua-

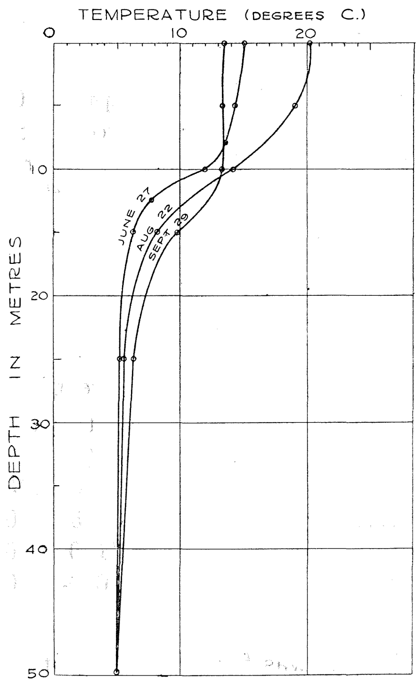

FIGURE 2. Temperature conditions in Paul lake, B.C., summer of 1931.

tion correlated with occasional winds and storms. At 10 m. fluctuations were almost absent, the temperature rising gradually to a maximum of 16° C. in early September.

The curve for September 29 indicates that the autumn period of cooling and mixing, which was found to begin about September 1, had made considerable progress. The water from surface to 10 m. has cooled to a uniform temperature of 13.4° C. while from 10 to 20 m. warming has continued as during the summer. A comparison of the areas between the August and September curves above and below the 10 m. line suggests that, of the heat lost by the upper 10 metres during

September, a large part went to warming the water between 10 and 30 metres, the remainder being lost by surface cooling.

During the period of observation (late June to late September) the upper 10 metres of water warmed up about 5° C. and returned to approximately the same temperature, while the water between 10 and 20 m. warmed on an average 3° C. and then cooled more slowly than the upper stratum. The regularity of

TABLE II. Limnology at Station 1, Paul lake, June to September, 1931

Temperature Series (Centigrade).									
Depth	June 27	July. 9	Jul. 21	Jul. 29	Aug. 10	Aug. 22	Sept. 1	Sept. 15	Sept. 29
Surf.	15.1	21.0	24.0	19.7	19.9	20.2	18.6	16.0	13.5
5 m.	14.4	16.7	18.6	19.2	15.9	19.1	18.4	15.9	13.4
7.5	13.6	14.7	16.9	16.9	---	---	---	---	---
10.0	12.0	12.8	12.4	13.4	14.9	14.3	15.7	15.9	13.4
12.5	7.7	9.2	---	9.7	---	---	---	---	---
15.0	6.3	7.1	7.4	7.8	10.1	8.2	9.6	9.4	9.8
25.0	5.2	5.2	5.8	5.5	5.3	5.3	5.2	5.4	6.3
50.0	4.7	4.7	4.9	4.7	4.7	4.8	4.8	4.8	4.7
Oxygen Determinations (p.p.m.)									
Surf.	6.0	15.0	11.2	15.5	7.5	6.3	5.7	11.8	11.5
15	6.0	6.3	6.2	6.4	7.5	6.3	6.9	8.6	8.8
50	4.9	4.9	4.7	4.4	4.5	4.4	4.3	---	6.5
"pH" Determinations									
Surf.	8.0	8.1	8.2	8.2	8.2	8.2	8.2	8.2	8.0
15 m.	7.9	7.9	7.9	7.9	7.9	7.9	8.0	7.9	7.9
50 m.	7.8	7.8	7.7	7.6	7.6	7.6	7.6	7.5	7.5

all three curves below 10 metres would indicate that there was little mixing in this region at any time in the summer, while there was considerable variation in the upper waters. Below the 25 m. level the temperature varied less than 1° C. during the summer. It is probable that changes in this region throughout the whole year are of small magnitude or consequence.

Dissolved Oxygen

The oxygen content of Paul lake water throughout the summer is indicated along with the temperatures and pH in table II. Determinations were made at the surface, at 15 m., which was just below the thermocline, and at the bottom, 52 m. The surface oxygen varied over a wide range, that at 15 m. much less with some increase towards the end of the summer. The bottom oxygen decreased slightly during mid-summer but recovered in September. The lowest bottom oxygen reached was 4.3 p.p.m. (50 m. September 1) which is still a relatively high value. Such a condition is typical of the oligotrophic lake type where the oxygen supply is always abundant and thus does not act as a limiting factor for the life in the deep water. The occurrence of *Gammarus limnaeus* at depths of more than 50 m. is striking evidence of the "freshness" of bottom conditions.

Hydrogen Ion Concentration

The hydrogen ion concentration of the surface water varied from 8.0 to 8.2. This degree of alkalinity is undoubtedly associated with the extent of marl beds around the shoreline and the dense growth of lime encrusted *Chara*. The decrease in pH from 7.8 to 7.5 in deep water is no doubt due to the decomposition of organic materials and the increase in carbon dioxide. It is probably not great enough to have any significant effect on the bottom fauna.

Comparison with Other Lakes

The characteristics of Paul lake at once suggest a resemblance to the Finger lakes of New York investigated by E. O. Birge and C. Juday (*A limnological study of the Finger lakes of New York, Bull. U.S. Bur. Fish., vol. 32, 1914.*). Of these, Keuka lake appears most like Paul and the data for the two lakes are tabulated as follows:

	Paul lake	Keuka lake
Area sq. km. (sq. mi.)	3.9 (1.5)	46.6 (18.0)
Length km. (mi.)	6.1 (3.8)	30.6 (19.0)
Width km. (mi.)	0.48 (0.3)	3.2 (2.0)
Shore development	5.6	4.58
Maximum depth m.	56.0	55.8
Mean depth m.	34.2	30.5
Surface temperature °C. at midsummer	20.0	21.0
Bottom temperature °C. at midsummer	4.8	4.8
Depth at thermocline m. at midsummer	10-15	10-16
Dissolved oxygen at bottom midsummer	4.6	5.57
Mean annual temperature of region °C. (°F.)	8.3 (47.0)	8.5 (47.3)

Keuka lake, although of greater area, resembles Paul lake in the relation of width to length. It is remarkably similar with respect to shore development, depth, temperature, and oxygen conditions. The mean annual temperatures listed represent five-year averages of mean annual temperatures recorded by the meteorological stations at Kamloops, British Columbia, and Ithaca, New York. They indicate that although Paul lake is 590 m. (1800 ft.) higher and about

1124 km. (700 mi.) farther north the two lakes are subject to similar thermal conditions.

Paul lake may be said to belong to a type which includes some of the Finger lakes of New York. V. Brehm (*Einführung in die Limnologie, Berlin, 1930*) cites the Finger lakes as illustrating his "subalpine" type. While such lakes are not all subalpine in distribution they do appear to have in common certain distinctive features, notably the possession of an extensive hypolimnion.

FAUNA

The bottom fauna, plankton and fish were studied with a view to working out their ecological interrelations in the lake. The bottom fauna was stressed because the Kamloops trout, the focus of the whole investigation, was found to derive most of its food from that source. For the same reason the studies were chiefly of a quantitative nature in order that an estimate might be made on the amount of food present in the lake, and that a record might be kept of any variations during the subsequent years of investigation. Specific identifications of the organisms are still incomplete in many cases.

Identity of Bottom Fauna

The collections of bottom fauna include 67 quantitative samples from all parts of the lake and a number of quantitative collections chiefly from the shallow water. The following lists include the names of the organisms as far as they have been identified.

PORIFERA

Spongilla sp. Common in shallow water.

TURBELLARIA

Planaria sp. Large planarians apparently all of one species were common at all depths.

NEMATODA

A small number of free living species were obtained but have not been identified.

CHAETOPODA

OLIGOCHAETA. The Tubificidae were scarce and of small size.

HIRUDINEA

The following species have been reported by Miss Ruby Bere.

RHYNCHOBDELLIDA. Glossiphonidae. *Helobdella stagnalis* (Linn.). A small leech taken in shallow water on a few occasions.

Glossiphonia complanata (Linn.). This species marked dorsally by two dark lines was the most abundant of the smaller forms.

Theromyzon occidentalis (Verrill). This large leech, green with orange spots, was found in moderate numbers.

ARHYNCHOBDELLIDA. Erpobdellidae. *Erpobdella punctata* (Leidy). This leech is marked by four dark dorsal bands. It was abundant but less so than the following species.

Nephelopsis obscura Verrill. This was the most abundant of the larger leeches. It varied in coloration from a light grey to a dark green with grey spots.

CRUSTACEA

CLADOCERA. *Daphnia pulex* (De Geer). Common at all depths.

Eurycercus lamellatus (Muller). Although they were not considered as bottom organisms, *Eurycercus* and *Daphnia* were frequently taken in dredgings.

AMPHIPODA. *Gammarus limnaeus* Smith. Large individuals of this species were abundant even at the unusual depth of 50 metres.

Hyalella knickerbockeri (Bate). Found in its usual habitat, *i.e.* near shore and particularly abundant in the *Chara* beds. Scattered individuals were found from 10 to 20 metres but none at greater depths.

INSECTA

EPHEMEROPTERA. *Caenis*. Nymphs common, chiefly near shore.

Callibaetis spp. Nymphs more widely distributed than those of *Caenis* though rarely found deeper than 5 metres. Adults of at least two species, one of which was swarming on July 11, were collected.

Centroptilum. Nymphs and adults have been collected in small numbers.

ODONATA. The Odonata material has been identified by Dr. E. M. Walker, University of Toronto.

Enallagma cyathigerum Charpentier. Nymphs and adults were very abundant. Several newly emerged specimens were taken on June 13. Nymphs were found in trout stomachs on many occasions.

Ischura sp. Nymphs of this form were identified as of the species *cervula* or *perparva*. They were found at a depth of 5 metres.

Aeschna eremita Scudder. Adults and many nymphs collected in August.

Aeschna palmata Hagen. Adults and nymphs taken in August.

Aeschna umbrosa Walker. One adult and several nymphs taken.

Cordulia shurtleffi Scudder. Many nymphs were taken throughout the summer.

Sympetrum costiferum Hagen. Common in July and August, some emerging on August 8.

Sympetrum danae Sulzer. Abundant in August. No nymphs were taken in the dredge.

PLECOPTERA. *Perla* sp. (Near *P. nona* Needham and Classen.) Several adults were collected at the surface of the water.

NEUROPTERA. *Sialis* sp. Larvae common near shore.

TRICHOPTERA. A small collection of trichopterous larvae and adults has been identified by Prof. C. Betten, Cornell University.

Phryganea cinerea Walker. This large dark coloured species is one of the most abundant in the lake. Trout stomachs were frequently gorged with pupae during the latter part of June. The larvae were common in dredgings.

Phryganea spp. Larvae of at least two species were not capable of identification.

Glyphopsyche bella Banks. Adults collected in early June by W. Nation.

Limnephilus oslari Banks. This and the preceding species are both light brown forms known to the anglers as June "Cinnamon Sedges".

An adult of the form known as the "September Cinnamon" was examined by Professor Betten who describes it as representing a new genus of the Limnephilidae.

(Various Limnephilid larvae have not been identified.)

Leptocerus aspinosus Betten. Large numbers of pupae were found in stomachs of trout late in June.

Leptocerus sp. Unidentified larvae.

Leptocella sp. (probably *L. exquisita*). Adults emerging on July 8.

Molanna sp. Larvae common in shallow water.

HEMIPTERA. Many corixids were found near shore.

Lethocerus sp. In the shallow water near the outlet of the lake.

Notonecta spp. Notonectids were common and frequently found in the stomachs of trout.

The water striders present were not identified.

DIPTERA. *Corethra* sp. A single adult *Corethra* was seen at the upper end of Paul lake although no larvae were found in the plankton samples or dredgings. It is possible that the specimen came from Pinantan lake where *Corethra* is very numerous.

Chironomus sp. (one of the *hyperboreus* group and probably a new species). The large larvae of this species were characteristic of all dredgings in the deep water, extending from 15 to 55 metres. The morphological characters of the larvae are those of species living in the deep water of oligotrophic lakes.

Chironomus sp. (near *flavus*). A small form, the larvae of which were abundant in the shallow water.

Chironomus spp. Larvae of several other species of the genus were collected.

Tanytarsus agrayloides Kieffer. Larva common in deep water. It is one of the "lauterborn" group characteristic of oligotrophic lakes.

Tanypinae. A few tanypine larvae were found mostly in shallow water.

COLEOPTERA. The aquatic beetles were not taken in sufficient numbers to warrant special identification.

ARACHNIDA

HYDRACARINA. Not abundant and not yet identified.

MOLLUSCA

GASTROPODA. The following species were identified by Professor F. C. Baker, University of Illinois.

Lymnaea stagnalis wasatchensis Hemp. The largest and one of the most numerous of the gastropoda.

Stagnicola vahlii elongata (Moller). Few living specimens but many shells were found.

Helisoma (*Planorbis*) *hornii* (Tryon). Abundant in the shallow water.

Memetus (*Planorbis*) *exacuus* Say. Common over a considerable depth range.

Gyraulus (*Planorbis*) *arctisus* ("Beck" Moller). A minute form, common.

Physa politissima Tryon. Very abundant in the upper 10 metres.

Valvata lewisi Currier. Common at moderate depths.

PELECYPODA. Large numbers of Sphaerium and Pisidium were present. The species have not been identified.

Quantity of Bottom Fauna

NUMERICAL ANALYSIS OF DREDGING DATA

The abundance of distribution of the bottom organisms has been worked out from the 67 dredgings mentioned above. Table III is arranged to show this distribution and in it the various groups appear roughly in order of their abundance. It is readily seen that the Chironomidae, Amphipoda and Sphaeriidae make up ninety-four per cent. of the total fauna. It is also clear that certain organisms are confined to the upper twenty metres while others are well represented even in the deepest water. Among the former are the amphipod *Hyalella*, the gastropods *Physa*, *Lymnaea* and *Planorbis* sens. lat., the Trichoptera, Ephemeroptera and Hirudinea. The widely distributed forms include the Chironomidae, *Gammarus*, the Sphaeriidae, *Planaria* and the Oligochaeta. It is of interest in this connection that shallow water groups include a great variety of species while the deep water groups were represented by relatively few species. The decrease in the total number of organisms per square metre from shallow water to deep water is apparent from the lower line of the table for "all organisms".

As may be seen, the maximum population is to be found in the upper five metres. This is probably due to the abundant "*Chara* population". Between five and ten metres there is a considerable decrease in numbers which might be mistaken for the sublittoral minimum often found in the distribution of bottom

TABLE III. Numerical analysis of Paul lake dredging data

Organism	Av. No. per sq. m. in depth zones							# 0-20 metres		# Whole Lake	
	0-5	5-10	10-20	20-30	30-40	40-50	50-55	no. per sq. m.	% of total	no. per sq. m.	% of total
Chironomidae	100	69	945	360	940	560	410	679	28.5	672	49.5
Amphipoda Hyalella	2149	834	40	+	-	-	-	752	31.7	198	14.6
Gammarus	66	51	510	39	-	40	58	372	15.6	166	12.2
Mollusca Physa	32	180	2	-	-	-	-	28	1.2	7	.5
Lymnaea	7	42	13	-	-	-	-	15	.6	4	.3
Planorbis	5	-	-	-	-	-	-	1	.0	-	-
Sphaeriidae	40	4	482	990	195	105	17	340	14.7	247	18.1
Odonata Zygoptera	19	67	-	-	-	-	-	12	.5	3	.2
Anisoptera	19	-	-	-	-	-	-	6	.2	2	.1
Trichoptera	20	44	2	-	-	-	-	12	.5	3	.2
Ephemeroptera	4	-	-	-	-	-	-	1	.0	-	-
Hirudinea	54	49	80	-	-	-	-	75	3.2	19	1.4
Planaria	19	59	45	3	108	10	10	42	1.8	30	2.2
Oligochaeta	29	-	7	5	-	24	10	13	.5	10	.7
Miscellaneous	28	+	+	-	-			8	.3	2	.1
All Organisms	2591	1399	2126	1397	1243	739	505	2356	100	1363	100

Averages in these columns have been weighted to correct for differences in area of the various depth zones.

fauna in eutrophic lakes. (*D. S. Rawson,—The bottom fauna of lake Simcoe and its role in the ecology of the lake. Univ. Tor. Stud. Biol. 34. Pub. Ont. Fish. Res. Lab. 40, 1930*). This is apparently not the case since as we have indicated above there is no observable sublittoral region in Paul lake.

The comparative numbers of organisms above and below the 20-metre level are of interest because the profundal zone, 20 to 55 m., is quite distinct, and also because the results of gill net settings in Paul lake indicate that the trout feed chiefly above 20 metres. In the columns of table III which indicate the relative numbers of organisms above 20 metres, *Hyalella*, Chironomidae, *Gammarus*, Sphaeriidae and Hirudinea predominate in the order named and the total fauna averages 2,356 individuals per sq. m. Considering the whole lake, the order of abundance changes somewhat, *i.e.*, Chironomidae, Sphaeriidae, *Hyalella*, *Gammarus* and *Planaria*. The fauna of the deep water, 20-55 m., averages only 701 per sq. m., bringing the combined average over all depths to 1,363 per sq. m. In comparison with other lakes this (1,363 per sq. m.) represents a moderate fauna.

The numerical analysis is incomplete since it gives no consideration to the relative sizes of the organisms. Since the weights of different species vary widely, the need for a gravimetric analysis is apparent.

GRAVIMETRIC ANALYSIS

In making these determinations the preserved organisms were weighed with no excess moisture but before shrinkage had begun. This "wet" weight has been shown to be practically equivalent to live weight and it has been transformed to a dry weight basis using a ratio 5 : 1 determination by drying experiments. At the same time the weight of mollusc shell has been deducted, the shell of *Physa* representing 20% of the total wet weight, other mollusc shells 32%.

The gravimetric data appear in table IV. Here are shown the average wet and dry weight per dredging in the various depth zones and the equivalent in kilograms per hectare and pounds per acre. The average amount of bottom fauna at all depths was found to be 36.4 kgm. per ha. (32.5 lb. per acre).

TABLE IV. Gravimetric analyses of bottom fauna, Paul lakes

Depth zone	Number of dredgings	Ave. live (wet) wt. per dredging gms.	Equivalent dry weight gms.	Kgms. dry wt. per hectare	Lbs. dry wt. per acre
0-10 m.	21	2.390	.478	89.3	79.7
10-20	9	1.710	.342	63.9	57.0
20-30	6	.931	.186	34.7	31.0
30-40	4	.911	.182	34.0	30.3
40-50	4	.219	.044	8.2	7.3
50-55	7	.469	.100	18.8	16.7
All depths	51	1.108	.222	*41.5	*37.0

True average corrected for variation in area of depth zones is 36.4 kgms. per hectare or 32.5 lbs. per acre.

Considering the four ecological zones rather than the arbitrary depth zones the values are somewhat different. A survey of the shore zone (0. to 0.75 m.) was made in order to complete the data for this comparison. It was found that the shore could be classified into five main types. The extent of each type was determined and five quantitative samples of the bottom fauna collected from each. The results are summarized as follows:

Shore type	Per cent. of total shore area	Av. dry wt. fauna in grams per sq. m.
Marl with low moss or *Chara*	35	8.88
Bare marl or marly clay	24	3.44
Rock or gravel	20	15.1
Rich vegetation	13	40.8
Scirpus beds	8	7.92

The average amount of shore fauna calculated from the above and weighted according to the extent of each type is 10.48 gm. per sq. m. or 98.0 kgm. per hectare.

Combining these data with those from the remaining ecological zones the following amounts are noted:

Shore zone 0. to 0.75 m.	98.0 Kg/ha., or	87.3 lb. per ac.
Chara zone 0.75 to 11.0 m.	117.7 Kg/ha., or	105.0 lb. per ac.
Lower sublittoral 11.0 to 20.0 m.	40.7 Kg/ha., or	36.3 lb. per ac.
Profundal 20.0 to 55.0 m.	21.8 Kg/ha., or	19.5 lb. per ac.

From these figures it may be seen that the *Chara* zone shelters a very large population. The profundal fauna is comparatively lean and since it includes 75 per cent. of the total area of the lake, the average amount of fauna is lowered accordingly.

In order that the composition of the bottom fauna might be considered by weight as well as numerically, rough determinations of the dry weights of individual organisms were made as follows: Average dry weight of chironomid larvae 2.5 mgm., *Hyalella* 0.6 mgm., *Gammarus* 7.0 mgm., *Physa* (shell deducted) 20.0 mgm., Sphaeriidae (shell deducted) 0.3 mgm., Trichoptera and Odonata nymphs 8.0 mgm., Hirudinea 20. mgm. and *Planaria* 10. mgm. Using these values and the numerical data from table III, the percentage composition by weight has been calculated and appears in table V, showing the composition of the bottom fauna of the whole lake and of that in the upper 20 metres.

DISCUSSION

From an examination of the available data on the amount of bottom fauna in small lakes, it is apparent that Paul lake is of average richness in this respect. The average amount of fauna in 57 lakes studied by J. Lundbeck (*Die bodentierwelt Norddeutschen Seen. Arch. Hydrobiol. Supp. Bd. 7, 1926*) in northern Germany was 56 kgm. dry weight per hectare—mollusc shell deducted. Turkey lake in

Indiana, 11.6 sq. km. in area and 21 m. deep had about 74 kgm. per hectare (*W. Scott et al, Quantitative studies of the bottom fauna of lake Wawasee (Turkey lake) Dep. Cons. Indiana Div. Fish Game, 1928*) and Third Sister lake Michigan, 3.85 ha. in area and 18 m. deep had less than 112 kgm. per hectare in depths of 3 to 18 m. (*F. E. Eggleton, A limnological study of the profundal bottom fauna of certain fresh water lakes, Ecol. Monog., vol. 1, no. 3, 1931*). Since Paul lake is two to three times as deep as any of these lakes we should not compare their fauna with its average fauna over all depths (36.4 kg/ha) but rather with the amount of fauna in the upper 20 metres, 59.4 kg/ha, or the still larger amount, 112 kg/ha, in the upper 10 metres. On such a basis we see that Paul lake supports a bottom fauna of the same order of magnitude as that which has been found in other small lakes.

TABLE V. Composition of the bottom fauna numerically and by weight

	% of fauna in whole lake		% of fauna in upper 20 metres	
	numerically	by weight	numerically	by weight
Chironomidae	49.5	42.5	28.5	22.0
Hyalella	14.6	2.9	31.7	5.9
Gammarus	12.2	28.8	15.6	31.0
Physa	.5	3.4	1.2	7.5
Sphaeriidae	18.1	1.8	14.7	1.3
Insecta (ex. Chironomidae)	.5	1.4	1.2	3.0
Hirudinea	1.4	9.5	3.2	20.0
Planaria	2.2	7.4	1.8	5.6
Miscellaneous	.9	2.6	1.5	3.9

The production of bottom fauna in lakes of various depths and areas was compared by the writer (*Rawson 1930, loc. cit.*) to establish a depth and area relation which indicates within limits the amount of fauna to be expected in a given lake. While the relation is not expected to hold for very small lakes where so many additional factors have become active, it is nevertheless possible to say that the bottom fauna of Paul lake is less than the expected fauna by about fifty per cent. This condition is attributed in part to the extreme depth of Paul lake and the declivity of its shores as compared with the usual lake of such small area.

Plankton

Plankton samples were taken at ten-day intervals coincident with the temperature readings and chemical analyses. At each sampling a closing net of the Wisconsin pattern (*C. Juday,—Limnological apparatus, Trans. Wis. Acad. Sci., vol. 18, 1916*) was used to take a total vertical haul and a series to determine vertical distribution. A net of similar shape but larger was used to take total vertical hauls which could be analysed chemically. The large net was also used to take surface tows.

A qualitative microscopic examination has been made of the vertical series and surface tows. In recording the plankton forms, long lists and repetition have been avoided by the construction of table VI which indicates the relative abundance of plankton organisms in the samples from various lakes of the region. Forms of which only one or two specimens have been found have not been included in the table.

The plankton varied greatly both in amount and composition during the three months of observation. The major features of this variation are indicated in the following notes which should be used in conjunction with table VI.

July 2. Haul large in quantity, *Diaptomus* predominant, *Daphnia* and *Ceratium* common. *Conochilus* common in deeper water.

July 9. Largest haul of the season. *Diaptomus* of large size and abundant. *Daphnia* also abundant—a "pulse" of Entomostraca. Algae very scarce.

July 21. Similar in quality but less in amount than on July 9.

July 29. Moderate quantity. *Diaptomus*, *Daphnia* and *Ceratium*. Algae slightly increased.

August 10. Less than on July 29. *Diaptomus* and *Daphnia* abundant. *Scapholeberis* appearing in great numbers at the surface.

August 22. Smallest haul of the season. Fragments of Entomostraca were very common suggesting a sudden mortality of planktonts.

TABLE VI. Plankton organisms collected in Kamloops lakes

Lakes	Myxophyceae								Chlorophyceae							
	Anabaena	Nostoc	Microcystis aeruginosa	Microcystis	Aphanizomenon	Trichodesmium	Coelosphaerium	Rivularia	Dictyosphaerium	Sphaerocystis	Pediastrum	Crucigenia	Volvox	Zygnaema	Spirogyra	Staurastrum
Paul	C	O	C	C					C	O	O	O		O	O	O
Pinantan	O			O					O	O			A		O	
Penask	O		O	O	A	O	C	O	O		O				O	O
Fish	C			C	O			C								
Nicola	A		C	C	A				C							C

Lakes	Baccilariaceae								Protozoa		
	Asterionella formosa	Stephanodiscus	Fragillaria	Melosira	Synedra	Tabellaria	Nitzschia	Amphora	Ceratium hirundinella	Vorticella sp.	Dinobyron sp.
Paul	C	O		O	O	O	O	O	A	C	
Pinantan	O				O				A	O	
Penask	A	C	C	A		C			O		
Fish	O		O	O					A		
Nicola		C	O	O					C		

Lakes	Rotifera							
	Conochilus sp.	Notholca longispina	Anuraea cochlearis	Anuraea aculeata	Asplanchna priodonta	Polyarthra platyptera	Triarthra longiseta	Brachionus sp.
Paul	A	O	O					
Pinantan	C		O	O	A	C		
Penask		O		O		O		
Fish		O		O	O	O	O	
Nicola		O	C				O	O

Lakes	Copepoda & Cladocera									
	Diaptomus spp.	Cyclops sp.	Daphnia pulex	Daphnia longispina	Scapholeberis mucronata	Eurycercus lamellatus	Ceriodaphnia reticulata	Bosmina longirostris	Chydorus sp.	Leptodora kindtii
Paul	A		A		C	O				
Pinantan	C		C				C		O	
Penask	C	O	O	C						
Fish	A	C	A	O						
Nicola	C	C		C				O		O

Note: A - abundant, C = Common, O = Occasional.

September 1. Algae recovering, many *Diaptomus*, *Daphnia* and *Scapholeberis*—the latter confined to surface waters as before.

September 15. Marked "pulse" of algae, mostly the diatom *Asterionella* with *Dictyosphaerium* and *Microocystis* common. *Diaptomus* and *Daphnia* abundant.

September 29. Entomostraca much increased apparently as a result of the recent increase in phytoplankton. The algae still present in large numbers though less numerous than on the 15th.

Considering the whole summer it might be said that the bulk of the open water plankton of Paul lake was made up of a few genera namely, two entomostracans, *Diaptomus* and *Daphnia*, one rotifer, *Conochilus*, one protozoan, *Ceratium*, one diatom, *Asterionella*, and one blue-green alga, *Anabaena*.

QUANTITY OF PLANKTON

Total vertical hauls were taken on nine occasions during the period of three months with each of the two nets described above. The total vertical haul was regarded as the most effective way of taking a representative sample of the lake plankton. This opinion was based on the assumption that the horizontal distribution of the plankton was fairly uniform. Recent investigation by Ricker (unpublished) at Cultus lake, British Columbia, indicates that in some cases at least this assumption is not justified.

The first analysis of the total vertical hauls was volumetric, each haul being allowed to settle for twenty-four hours in a measuring cylinder of 1 cm. diameter. The purpose of this measurement was to relate the amount caught by the large net to that caught by the standard Wisconsin net. Comparing the average catch of the two nets calculated from values in table VII, columns 1 and 2, it was found that the large net (L) collected 3.6 times as much as the Wisconsin net (W).

The dry weight and total organic nitrogen determinations in columns 3 and 4 of table VII are regarded as more satisfactory indicators of the actual amount of plankton present at the various dates. It is seen that the amount of plankton present during July and the first half of August is more than twice as great as that of late August and September. No explanation is advanced for this sudden decrease in the amount of plankton in the middle of August.

The average amount of plankton taken with the large net throughout the season can be expressed as 2.34 cc., 19.9 mgm. dry weight or 1.6 mgm. organic nitrogen. Using the factor of 3.6 determined above, the average catch of the Wisconsin net may be calculated as 0.65 cc., 5.5 mgm. dry wt. or 0.44 mgm. organic nitrogen. While the limitations of the sampling technique make it impossible to compare in detail these results with those of other workers it can be said with certainty that this is not a rich plankton but neither is it decidedly poor.

This result is in keeping with other observations which indicated that Paul lake was oligotrophic in type since oligotrophic lakes always have poor or moderate amounts of plankton. It should be noted that some investigators regard this low or moderate plankton as indicating an efficiency of utilization in the rapid "turn over" and non-accumulation of nutrient materials.

TABLE VII. Quantitative analyses of Paul lake plankton hauls

Date	1. *Volume T.V.L. c.c.	2. **Volume T.V.W. c.c.	3. Dry Wt. T.V.L. mgm.	4. Tot. Org. N_2 T.V.L. mgm.
July 2	3.25	1.20	23.5	2.25
July 9	4.50	.70	27.7	1.81
July 21	2.85	.70	20.7	1.59
July 29	2.30	.60	25.7	2.16
Aug. 10	3.00	.80	22.5	1.32
Aug. 22	1.00	.35	9.1	.89
Sept. 1	1.85	.55	17.9	1.66
Sept.15	1.20	.55	11.8	1.02
Sept.29	1.10	.35	-	-

* T.V.L. = total vertical haul with large net
** T.V.W. = total vertical haul with Wisconsin net

ECOLOGICAL RELATIONS

The capacity for trout production is especially involved with what might be called the whole nutritive capacity of the lake. Little is known as yet of the rate at which food organisms are produced or of the amount of food needed by fish. We can however, by examining the food taken by trout obtain some help in estimating the value of plankton and bottom organisms in trout production. The problem in Paul lake is simplified by the absence of other species of fish.

FOOD OF TROUT

The stomach contents of 161 trout from Paul lake have been examined by the writer. These specimens were of various sizes and collected at different times throughout the summer. They were taken by fly fishing, trolling, gill netting and seining. The various organisms found in each stomach were recorded as percentages of the total volume. Table VIII is arranged to show the variation in food taken during the four months and the average composition of food for the summer.

The season variation in the food taken may be more clearly shown by combining *Gammarus* with *Daphnia* as Crustacea, Zygoptera with Anisoptera as Odonata and *Physa* with *Lymnaea* as Gastropoda, restating the results as follows:

Month — Percentage composition of food

- May—Crustacea 41, Chironomidae 19, Odonata 14, misc. Insecta 25.
- June—Trichoptera 43, Odonata 27, Crustacea 18.
- July—Crustacea 77, Gastropoda 14, Hirudinea 7.
- August—Crustacea 85, Insecta 11, Gastropoda 3.
- May to August—Crustacea 55, Insecta 39, Gastropoda 4, Hirudinea 2.

TABLE VIII. Percentage volume of food organisms in the stomachs of Paul lake trout in the summer months

Date of Collection	No. of fish	Length of fish mm.	Crustacea		Insecta				Gastropoda		Miscellaneous.
			Gammarus	Daphnia	Trichoptera	Zygoptera	Anisoptera	Chironomidae	Physae	Lymnaea	
May 11-17	5	370-460	41.0				14.0	19.0			Hymenoptera 23 Misc. 0.3
June 5 - 30	20	200-450	7.7	10.8	42.8	14.2	12.8	5.0			Leeches etc. 6.2
July 21-30	38	135-568	50.7	25.5	2.2	0.3			2.5	11.9	Leeches 6.7 Misc. 1.2
Aug. 5-31	98	159-622	59.7	25.6	0.2	1.2	1.1	3.2	2.9	.3	Boatman 3.0 Misc. 2.7
May-Aug. (whole summer)	161	135-622	39.8	15.5	11.3	3.9	6.9	6.8	1.4	3.0	Leeches & Misc. 11.7

It appears that the trout ate large quantities of insects in May and June during the early summer emergence and while the water was sufficiently cool to allow feeding at or near the surface. In July and August with the warming of the upper water the fish fed at greater depths, taking increasing amounts of crustacean food. Mr. Wm. Nation, who has observed fishing in Paul lake for a number of years, states that fly fishing declines when the water becomes warm enough for bathing.

A further analysis of the data was made to show the variation in food taken by trout of different ages. A preliminary paper on the food of Kamloops trout has been recently published by C. McC. and J. C. Mottley (*The food of the Kamloops trout, Biol. Bd. Can. Prog. Rep. Pac. 13, 1932*) and with the authors' approval certain data from their paper have been included in table IX.

The aquatic Insecta are an important item in the food of trout of all ages in Paul lake. In addition, the fry take quantities of Cladocera and terrestrial Insecta. The adult fish feed heavily on the Amphipoda. As might be expected, the yearling (1 to 2 yr.) fish form an intermediate group taking moderate quantities of all four of the foods listed.

Utilization of Bottom Fauna as Trout Food

Examination of stomach contents indicated that with the exception of *Daphnia*, the Paul lake trout feed almost entirely on bottom organisms. Table VIII shows that practically all kinds of bottom organisms were taken as food. To determine how much of the bottom fauna was really available for trout, an attempt was made to find the limits of their feeding range.

In early summer and again in the autumn the trout in Paul lake feed near the surface and fly fishing is effective. In July and August the fish are taken by trolling in the deep water. In the latter period gill net settings were made on six occasions in depths varying from 5 to 40 metres. Of 66 fish taken in these settings none were found deeper than 20 metres, few between 15 and 20 and many between 10 and 15 metres. The feeding range is thus indicated to cover roughly the upper 20 metres in the period from May to September inclusive.

To compare the average composition of the bottom fauna in the upper 20 metres with the average composition of trout food throughout the season, data from tables V and VII may be arranged as follows, the figures indicating percentages:

	Amphipoda	Insecta	Mollusca	Hirudinea	Misc.	Daphnia
Bottom fauna, 0-20 m.........	36.9	25.0	8.8	20.0	9.5	....
Food of trout, May-August...	39.8	28.9	4.4	7.0	4.5	15.5

A rough correspondence between the available organisms and the food taken exists in each case except for the Hirudinea in which the supply appears to exceed the demand. Whether the trout prefer other organisms or are less able to

Table IX. Percentage composition of food taken by fry, yearling and adult trout in Paul lake

	No. of Fish	Aquatic Insecta	Terrest. Insecta	Amphipoda	Cladocera	Miscellaneous
Fry from lake August 2-28	9	60	10	-	30	-
# Fry from lake Sept. 15	18	5	27	-	58	Copepoda 10
# Fry from stream	11	100	-	-	-	-
Yearling	80	25	11	39	25	
# Adults	241	32	5	59	2	Hirudinea 1 Gastropoda 1
Adults	81	35	3	41	7	Hirudinea 7 Gastropoda 8

Data from Mottley and Mottley (1932)

catch the leeches is not known. In view of the observed correlation between trout food and bottom organisms, and knowing that the Kamloops trout often feeds on fish if available, it might be concluded that they adapt themselves to the food supply, availability being the chief factor. It is at least clear that the food supply is well utilized.

Although the food of the trout corresponds more closely with the fauna of the upper twenty metres than with the fauna as a whole this does not necessarily indicate that the fauna below the twenty-metre level is of no value in fish production. The most important single food organism, *Gammarus*, is abundant in the deep water. It would seem probable that as the *Gammarus* of the upper water were reduced by feeding they would be replenished from this source. As a further illustration, chironomid larvae, which are the most abundant of the bottom organisms of deep water, pupate at the end of their larval period and rise to the surface to emerge. At this time they contribute greatly to the food of the trout.

Oligotrophic Condition

A classification of lakes based on their fundamental ecological features was worked out by a number of European workers and is clearly presented by E. Naumann(*Limnologische Terminologie, Berlin, 1931*). According to this classification Paul lake is clearly oligotrophic. Lakes of this type are deep with a plentiful supply of oxygen and a low temperature in the deep water. The plankton is relatively small in quantity and seldom forms a water bloom. The bottom organisms extend in large numbers into the deeper parts of the lake.

A. Thienemann (*Biologische Seetypen. Arch. Hydrobiol., 1921*, and *Die Binnengewässer Mitteleuropas-Die Binnengewässer 1, 1925*) regards the dominant forms of the profundal bottom fauna as excellent indicators of the trophic condition of a lake. In this respect the chironomid larvae of the deep water in Paul lake include two species known to be characteristic of oligotrophic lakes. They are *Tanytarsus agrayloides* of the lauterbornia group and a species of *Chironomus* not yet named but identical in form with larvae from highly oligotrophic lakes of northern Saskatchewan.

Lundbeck (1926, *loc. cit.*) concluded that in deep oligotrophic lakes production goes on more efficiently than in any other type. The above mentioned extent of utilization of bottom fauna as trout food in Paul lake would support this thesis. In the plankton of Paul lake the animal forms were relatively abundant. One zooplanktont *Daphnia* formed a considerable portion of the food of trout, thus contributing directly to fish production. In the oligotrophic scheme, the moderate quantity of plankton and the absence of "water bloom" in Paul lake would be taken as evidence of efficient utilization with no overproduction. In contrast, many lakes of the region are subject to great pulses of blue-green Algae which pile up on shore and disintegrate, an instance of overproduction or, to use Lundbeck's term, "disharmony of production".

This evidence as to the conditions for efficient trout production in Paul lake should be considered in the question of the advisability of introducing an intermediate food fish. There is little reason to suppose that introduction of either kokanees, *Oncorhynchus nerka kennerlyi*, or minnows would improve the production of trout in Paul lake. As the anglers point out, it might harm the fly fishing by supplanting insect materials in the trout diet.

In conclusion it might be said that, with bottom fauna and plankton as abundant as they could be expected in a lake of this type and with an efficient utilization of this food supply, Paul lake appears to be capable of supporting a relatively large population of Kamloops trout.

OTHER LAKES

The four lakes chosen for comparison with Paul lake may be considered in three groups. The first, Pinantan, is a shallow lake in the Paul lake drainage area. Penask and Fish lakes are of intermediate depth found at the high altitudes of 4,500 and 4,100 feet. Nicola is a large and deep body of water in a lower valley. The location of these lakes is indicated on the map (figure 1).

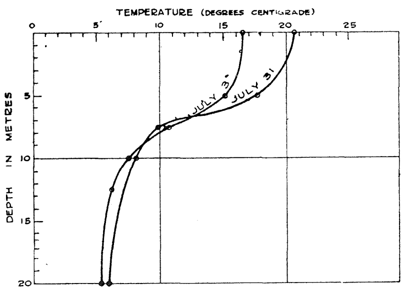

FIGURE 3. Temperature conditions in Pinantan lake, B.C., July, 1931.

PINANTAN LAKE

Pinantan lake lies about two miles above Paul in the same valley and drains into the latter by a small rapid stream. The lake is in marked contrast to Paul in many respects. The maximum depth is about 21 m. and its mean depth approximately 12 m. The area has been measured as 154 ha. (380 acres), not including upper Pinantan, which has an area of about 30 ha. The shores are mostly weedy and the bottom of oozy mud in contrast to Paul lake with its precipitous shores with marl or stone along the waterline. *Chara* is abundant in certain regions but not to an extent comparable with the definite *Chara* zone of Paul.

WATER CONDITIONS

Temperature observations and chemical analyses of the water, made on July 3 and July 31, revealed stratification and summer stagnation conditions of great interest. Data from these analyses appear in table X along with limnological observations from the three remaining lakes. The temperature curves in figure 3 indicate the degree of stratification and the position of the thermocline. As early as July 3 the stagnant condition of the bottom had set in as shown by

TABLE X. Limnology for four lakes of the Kamloops region

	Pinantan L.		Penask L.		Fish L.	Nicola L.	
	Jul. 3	Jul. 31	Jun. 6	Sept. 2	Aug. 7	Jul. 8	Aug. 20
Temperature °Centigrade							
Surf.	16.5	20.8	13.3	15.8	17.9	17.7	18.5
5 m.	15.2	17.9	12.8	-	16.9	15.6	17.9
7.5	10.7	9.9	-	-	-	-	-
10.	7.6	8.1	12.4	15.5	10.8	13.9	16.8
12.5	6.2	-	-	-	-	-	-
15.0		-	12.4	-	8.5		-
20.0	5.5	6.0	10.8	12.3	-	10.9	13.0
25.0					6.5	-	-
45.0						7.9	8.7
Oxygen Determinations p.p.m.							
Surf.	5.6	5.5	7.0	6.9	6.5	4.2	5.8
Bottom	0.6	0.1	5.8	0.1	0.3	2.9	0.4
"pH" Determinations							
Surf.	8.0	8.1	7.2	8.0	8.3	8.1	8.4
Bottom	7.2	6.8	7.2	6.4	7.1	7.5	7.2

the dissolved oxygen determination of 0.6 p.p.m. At the end of July the stagnation was even more severe, dissolved oxygen being practically absent at the bottom and only 0.45 p.p.m. at 10 metres which is just beneath the thermocline. The bottom water had a pH of 6.8 and at this time the mud gave off a strong odour of hydrogen sulphide.

Bottom Fauna

The bottom organisms were examined in two series of dredgings, fourteen in all, chosen to represent various types of shore and bottom and to indicate the vertical distribution of organisms with particular reference to the thermocline. An analysis of these dredgings is shown in table XI.

Table XI. Numerical and gravimetric analyses of bottom fauna from the Pinantan lake

	Dredging number	Depth m.	Number of organisms							Wet weight less shell mgms.
			Chironomidae	Oligochaeta	Amphipoda	Corethra	Gastropoda	Planaria	Miscellaneous	
Series I July 3.	1.	1.	41	-	18.	-	6.	9.	10	3,776
	2	7	77	-	162	-	5	-	-	972
	3	16	1	-	-	-	-	-	-	-
	4	20	1	-	-	-	-	-	-	-
	5	14	-	-	-	-	-	-	-	-
	6	10	42	75	-	3	-	-	-	1,485
	7	7	7	-	-	-	1	-	1	348
Series II July 31	1	4	2	-	17	-	9	7	6	2,546
	2	10	121	100	-	300	-	-	-	3,501
	3	12.5	-	-	-	-	-	-	-	-
	4	15	-	-	-	-	-	-	-	-
	5	20	-	-	-	-	-	-	-	-
	6	12.5	2[illegible]	108	-	1	-	-	-	1,460
	7	3	2	-	17	-	9	7	6	2,564
Totals			314	283	214	304	30	23	23	16,670
Average			22	20	15	22	2.1	1.6	1.6	1,191

The composition of the bottom fauna is quite different from that in Paul lake with respect to the scarcity of Amphipoda, and the abundance of Oligochaeta and *Corethra*. The small number of Amphipoda is probably correlated with the absence of any extensive *Chara* zone. The abundance of Oligochaeta and *Corethra* are quite typical of the muddy bottom of shallow eutrophic lakes.

The effects of the aforementioned stagnation below the thermocline can be seen from an examination of table XI. On July 3 three dredgings below the thermocline (10 m.) collected only two organisms. On July 23 no organisms were found below 12.5 m. At the 10 m. level in a single dredging, 520 individuals equivalent to 10,400 per sq. metre were taken, while three metres below none were found. The stagnation may destroy some of the bottom organisms and cause others to migrate up to the region of the thermocline. Even *Corethra*, one of the most resistant of bottom organisms, was not found in the deeper water.

An estimate of the average amount of bottom fauna based on the above 14 dredgings is approximately 45 kgm. per ha. (40 lb. per acre) dry weight, mollusc shell deducted. This figure is probably too low since it represents the fauna at the height of summer stagnation.

Plankton

The chief forms found in the plankton of Pinantan lake have been listed in table VI. The plankton differed from that of Paul lake in several ways. The Algae had few diatoms but included many green algae, *Volvox* being particularly numerous. Rotifera, especially *Asplanchna priodonta*, were plentiful and a cladoceran, *Ceriodaphnia reticulata*, not found in Paul lake, was common.

The quantity of plankton in collections from Pinantan lake was not as great as that from Paul at the same time.

Ecological Conditions

The extent of thermal stratification and the related depletion of oxygen below the thermocline indicates that Pinantan lake is highly eutrophic. Bottom stagnation at mid-summer is so severe that bottom organisms are practically absent beneath the thermocline. The area of productive lake bottom is in this way reduced by approximately one-half in the latter part of the summer. With the dissolved oxygen at 10 m. as low as 1.7 p.p.m. on July 3, it is probable that the actual feeding range of the trout is still further reduced since few lake fish thrive in water with less than 3 or 4 p.p.m. of oxygen. All these factors would lead to the conclusion that Pinantan lake may be rich in potential nutriment but relatively inefficient in production.

PENASK LAKE

Penask lake is located about 129 km. (80 mi.) southwest of Kamloops on a wooded plateau of 1,373 m. (4,500 ft.) elevation. Its area is about 7.8 sq. km. (3 sq. mi.) and the shoreline is most irregular with deep bays and islands. The maximum depth observed is 22 m., the mean being about 11 m. The bottom material is of sand, rock or mud down to 5 or 6 metres while in the deeper water there is usually a soft oozy mud rich in organic material.

Water Conditions

Water temperatures at the periods of examination, July 6 and September 2, are recorded in table X and plotted in figure 4. Thermal stratification was not present at either period. At both times of examination the difference in temperature between surface and bottom water was approximately three degrees with the surface temperatures relatively low and the bottom temperatures relatively high. Pinantan lake of similar depth showed on July 3 a difference of more than 10 degrees. The greater exposure to winds at Penask lake is certainly a factor in maintaining the relatively uniform temperature distribution throughout the summer.

The dissolved oxygen on July 6 was 6.0 p.p.m. at the surface and 5.8 p.p.m. at the bottom, but on September 2 the bottom oxygen had dropped to 0.1 p.p.m. This would suggest a somewhat unusual deficiency of oxygen without thermal stratification. The bottom stagnation was not necessarily general since the sample was taken at 21 m. in one of the deepest areas of the lake. Eggleton (1931, *loc. cit.*) has demonstrated stagnation occurring locally in depressions of a lake bottom.

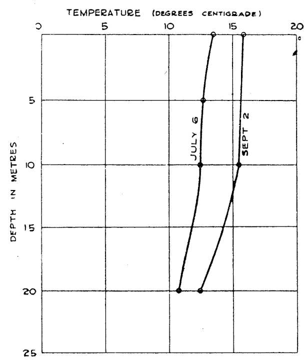

FIGURE 4. Temperature conditions in Penask lake, B.C., summer of 1931.

BOTTOM FAUNA

Two series of dredgings, fourteen in all, were taken on July 7 and September 3. Among the bottom organisms the larvae of *Chironomus plumosus* were of particular interest since this species was not found in any of the other lakes. The following list shows the chief groups of organisms and their average numbers per sq. m. over the whole lake.

Amphipoda, *Hyalella* and few *Gammarus*	1127 per sq. m.
Sphaeriidae, *Pisidium idahoense* and others	450 per sq. m.
Chironomidae, *Chironomus plumosus* and others	230 per sq. m.
Oligochaeta	89 per sq. m.
Hirudinea	23 per sq. m.
Miscellaneous Insecta and Hydracarina	43 per sq. m.
Total	1962 per sq. m.

The total population of 1,962 per sq. m. is somewhat greater than the average number of organisms in Paul lake but less than the average number in the region of equivalent depth. Gravimetric determinations show the average dry weight of fauna in Penask to be approximately 56 kgm. per ha. (50 lb. per acre). This is less than 73 kgm. per ha. in equivalent depths of Paul lake but greater than 45 kgm. per ha. in Pinantan.

Plankton

The chief organisms of the plankton have been listed in table VI. The Algae were numerous both on July 6 when the diatoms predominated and on September 3 when a heavy bloom of *Aphanizomenon* was present. Entomostraca were rather scarce and Rotifera rare. *Daphnia longispina* and *D. pulex* were both present. The distribution of these species in the lakes studied is of interest. Thus in Fish lake, the other high plateau lake, both species were present. In Paul and Pinantan lakes *Daphnia pulex* only was found. In Nicola *Daphnia longispina* was the only species taken.

The quantity of plankton was large on both occasions but no great significance should be attached to two collections because of the possibility of algal pulses.

Ecological Conditions

Considering the features by which lakes are usually classified, Penask lake appears to be of an unusual type. The absence of stratification suggests oligotrophic conditions, but shallow lakes with *Chironomus plumosus* are usually eutrophic. On July 6, a bottom oxygen determination of 5.8 p.p.m. gave no indication of stagnation. On September 2, water from the deepest region (21 m.) was practically devoid of oxygen. Whatever may be the explanation of this deficiency there was no indication of its affecting the bottom population. The lake is oligotrophic in one respect at least, namely, the presence of large numbers of bottom organisms even in the deepest water.

The trout of Penask lake appear to be more abundant and of smaller average size than in any of the other lakes studied. From the angler's point of view, the success of fly fishing throughout the summer is just as important as the ease with which fish are caught. By comparison with conditions in Paul lake it would seem probable that the relatively low surface temperature of water in Penask allows the fish to feed near the surface even in the midsummer period.

FISH LAKE

Fish lake is 22 miles southeast of Kamloops at an elevation of 1,250 m. (4,100 ft.) and its surroundings much like those of Penask. It has an area of about 1.9 sq. km. (.75 sq. mi.) and a maximum observed depth of 27 m. The lake is elbow-shaped with a fairly regular shoreline and much shore vegetation. The bottom is mostly of rich organic ooze.

Water Conditions

Observations made on August 7 have been included in table X and the temperature curve plotted in figure 5. Thermal stratification was present at this time with the thermocline between 7 and 11 metres. Dissolved oxygen was almost absent in the deep water and as low as 3.5 p.p.m. at a point just below the thermocline. Additional evidence of stagnation was found in the strong odour of hydrogen sulphide in the bottom water and a pH. of 7.1 as compared with 8.3 at the surface.

Bottom Fauna

A single series of dredgings served to indicate that the bottom fauna included many Amphipoda and Chironomid larvae, also moderate numbers of Hirudinea, Oligochaeta and Sphaeriidae. Between 10 and 15 metres a few Oligochaeta and Chironomid larvae were collected while a dredging in the deepest water produced only one small Chironomid and one *Corethra* larva.

The total amount of fauna appears to be about equal to that of Pinantan lake and the lower waters almost equally barren during the period of summer stagnation.

Plankton

The surface plankton included a considerable bloom of blue-green Algae, chiefly *Anabaena* and *Rivularia*, as indicated in table VI. The total vertical hauls collected a moderate quantity of plankton including the two species of *Daphnia* already mentioned.

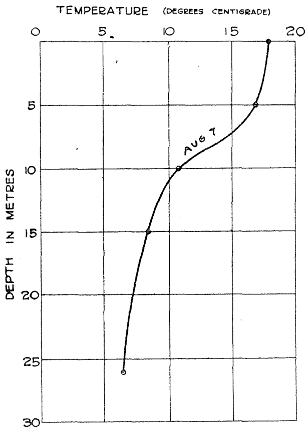

FIGURE 5. Temperature conditions in Fish lake, B.C., August, 1931.

Ecological Conditions

Bottom stagnation at the time of examination was pronounced and fishing was poor even with the baited troll. The warmth of the upper five metres would keep the trout from feeding in this region while the scarcity of oxygen would interfere with their feeding in the deeper water. The duration of this period of stagnation is not known but it is too severe to be a temporary condition.

NICOLA LAKE

Nicola lake is 64 m. (40 mi.) almost due south of Kamloops, lying in a low valley. Its altitude is recorded as 627 m. (2,056 ft.). It drains through the Thompson to the Fraser system. The lake is about 22.5 km. (14 mi.) long and in most places not more than 1.6 km. (1 mi.) in width. The shores are predominantly rocky though some weedy bays are to be found. Observations were made at a point about 9.5 km. (6 mi.) from the Nicola river outlet. At this point the shore drops off rapidly to reach a depth of 40 metres less than 100 metres from the shore. The maximum observed depth was 48 m.

WATER CONDITIONS

Observations made on July 8 and August 30 are recorded in table X and temperature curves in figure 6. The lake was unstratified but stagnant at the bottom particularly on August 20 when the bottom oxygen was 0.4 p.p.m. On this date the bottom water had a pH of 7.2, while the pH at the surface was 8.4.

BOTTOM FAUNA

The bottom fauna was sampled only in the deep water where a scanty population of Chironomid larvae, *Pisidium*, Oligochaeta and Nematoda was found.

PLANKTON

On July 8, the blue-green Algae, *Anabaena*, *Coelosphaerium* and *Aphanizomenon* were present as a dense bloom and extended down to a depth of two or three metres. On August 20 the blue-greens were again predominant and extended down to 10 metres. The plankton of the lower water included moderate numbers of Entomostraca as indicated in table VI.

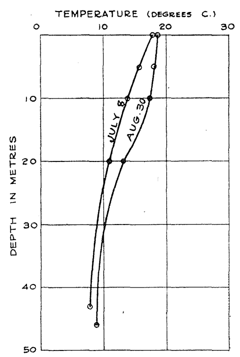

FIGURE 6. Temperature conditions in Nicola lake, B.C., summer of 1931.

ECOLOGICAL CONDITIONS

The samples taken in Nicola lake are representative only of the open-water conditions. In this region both plankton and bottom fauna were poor in quantity. The severe summer stagnation indicated by lowered oxygen and the appearance of water bloom is unfavourable for organic productivity. Since the lake contains a number of species of fish the problem of trout productivity is quite unlike that in those lakes already discussed.

SUMMARY AND CONCLUSIONS

1. Paul lake has an area of 388 ha. (1.54 sq. mi.) and is situated near Kamloops at an altitude of 777 m. (2,452 ft.). It is a long, narrow lake with a max-

imum depth of 56 m. and a mean depth of 32.7 m. The shore declines rapidly into deep water except at the ends of the lake.

2. A slight thermal stratification existed through most of the summer with the thermocline between 8 and 12 m. The stratification appeared to have little effect on the ecology of the deeper water since the dissolved oxygen of the bottom water was never less than 4.3 p.p.m.

TABLE XII. Summary of significant features in five lakes of the Kamloops region based on observations made from July to September, 1931

	Paul L.	Pinantan	Penask	Fish	Nicola
Area sq. km. (sq. mi.)	3.9 (1.5)	1.6 (0.6)	7.8 (3.0)	1.8 (0.7)	39 (15.)
Depth m. (max. obs'd)	56	21	22	27	46
Depth m. approx. mean	34	12	11	14	25
Bottom temp. max. obs. °C.	4.7	6.0	12.5	6.5	8.7
Bottom O_2 minim p.p.m.	4.3	0.1	0.1 only in Sept.	0.3	0.4
Stratific-ation	present	present	slight?	present	absent
Algal Water-bloom	none	none	slight	much	much
Bottom stagnation	none	great + H_2S	slight (Sept.) only	great + H_2S	much
Amount bot-tom fauna	1st (richest)	2nd	3rd	4th	6th (poorest)
Amount plank-ton (excl. w-bloom)	2nd good fair	3rd fair	1st good	5th fair	4th fair
Lake type	Oligot-rophic	Eutro-phic	?	Eutro-phic	?
Estimated efficiency of production	very great	fair	great	fair	poor

3. The bottom fauna was of average richness as compared with other small lakes. The average dry weight of fauna at all depths, mollusc shell deducted, was 36.4 kgm. per ha. (32.5 lb. per acre). The chief bottom organisms were Chironomid larvae and Amphipoda, with Mollusca, various Insecta, Hirudinea and *Planaria* forming the remainder. The bottom fauna decreased both in numbers and quantity from shore to deep water as shown in figure 3. Details of the composition, distribution and amount of bottom fauna are presented in tables III, IV, and V.

4. The plankton is of moderate quantity. The chief organisms were *Diaptomus*, *Daphnia*, *Conochilus*, *Ceratium*, *Asterionella* and *Anabaena*. The Entomostraca were clearly predominant and the Algae showed no tendency to form a water bloom.

5. The adult trout ate Crustacea (*Gammarus* and *Daphnia*) Insecta, Gastropoda and Hirudinea in this order of importance. In May and June insect food was taken in greater quantity while in July and August the Crustacea predominated.

6. The nutritive condition of the lake is distinctly oligotrophic. Evidence of the degree of utilization of bottom fauna by trout is in accord with the belief that oligotrophic lakes exhibit great efficiency of production. Paul lake appears to be capable of supporting a relatively large population of Kamloops trout.

7. Four lakes, Pinantan, Penask, Fish and Nicola have been studied briefly and compared with Paul lake. Without these comparisons certain conditions in Paul lake would not have been understood. By considering the five lakes together it has been possible to choose certain features which appear to indicate the essential nature of these lakes. Table XII brings together in a brief form these significant features.

8. From the present study it is clear that trout-producing lakes of the Kamloops region vary considerably. Paul and Penask are both considered "good" trout lakes but they are quite unlike in their physical and biological characters. Certain conditions have been indicated as favourable for the production of Kamloops trout but the actual productivity is to a large extent a special problem in each lake.