COMPARATIVE LIMNOLOGY OF LAKES IN THE
SOUTHERN ROCKY MOUNTAIN TRENCH, BRITISH COLUMBIA

by

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ABSTRACT

Within a restricted geographical area of British Columbia, a detailed examination was conducted in 1960 and 1961 of 9 lakes having similar morphometric and climatic influences, but exhibiting a wide dissolved nutrient range (50 to 1460 ppm). Attempts were made to relate total dissolved solids as well as other chemical and physical indices, to biological factors indicating or influencing lake productivity.

Measurements were made of standing crops of plankton, bottom fauna and fish as well as hypolimnial oxygen deficits, sedimentation rates and gross primary productivity. Standing crops of plankton appeared related to oxygen deficits and perimeter to area ratios. Furthermore, total dissolved solid content correlated with gross primary productivity estimates based on Light and Dark Bottle techniques.

Total dissolved solid content of lakes was not correlated with standing crops of plankton, bottom fauna or fish. Ranking of selected physical or chemical indices of productivity failed to agree with ranking based on standing crops or other biological measurements of productivity. A number of possible factors which interact to modify the expression of primary correlates of productivity are discussed.

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INTRODUCTION

Northcote and Larkin (1956) found total dissolved solids (T.D.S.) the best single indicator of standing crops of plankton, bottom fauna and fish, in 100 lakes exhibiting a wide range of T.D.S. throughout British Columbia. However, for 33 lakes within the Southern Interior Plateau region of the province, total dissolved solids (ranging between 85 and 558 ppm) showed no significant relationship with standing crops of organisms (Larkin and Northcote, 1958). Thus, although total dissolved solid content of lake waters apparently was related to standing crop level observations over the whole province, no such relationship was apparent when lakes exhibiting a fairly broad range in T.D.S., but within a restricted geographic area, were investigated.

The purpose of this study was to ~~examine~~ examine in detail nine lakes all located within the Southern Rocky Mountain Trench having a wide dissolved nutrient range (50 to 1460 ppm) and to evaluate the importance of T.D.S. in determining standing crop levels in lakes where variation in climatic and morphometric factors modifying these levels was minimal.

HISTORICAL RESUME OF PRODUCTIVITY MEASUREMENT

Many studies of lake productivity have examined the possibility of using a single variable as an index of productivity in comparisons of lakes. Various degrees of success have been achieved, but no single index has been particularly satisfactory, especially in comparisons of lakes from a variety of regions.

Thienemann (1927) was the first to suggest the use of lake morphometry, and in particular mean depth, as an indicator of productivity. Rawson (1930, 1952 and 1953) also stressed the importance of mean depth on the production of plankton, bottom fauna and fish, as it applied primarily to deep lakes.

Strøm (1931) and Hutchinson (1938) emphasized the measurement of hypolimnetic oxygen deficit as providing a means of classifying lakes. Oligotrophic lakes having small oxygen deficits and eutrophic lakes having complete oxygen depletion in the hypolimnion, were exceptions to this classification.

Naumann (1932), Öhle (1934), Deevey (1940) and Moyle (1946), all considered the geology of the drainage area or some portion of the nutrient cycle, as being of primary importance to the measurement of productivity among lakes.

Other workers have used plant abundance and distribution as a useful index of production in lakes. More recently, emphasis has centered around the use of C^{14} or oxygen measurement by Light (LB) and Dark Bottles (DB), as a measure of photosynthetic activity or net and gross primary productivity.

MATERIALS AND METHODS

Hand line soundings were used to plot contour maps of Hiawatha, Kiakho, Horseshoe and Bednorski lakes. A Kelvin-Hughes echo sounder provided information for the construction of contour maps of the others. Soundings were plotted on lake outlines, enlarged from British Columbia Department of Lands and Forests interim maps compiled from aerial photographs.

The volume between 2 depth contours was estimated by using the formula $V = \frac{h}{2} (A_1 + A_2)$ where h is the distance between the 2 strata, and A_1 and A_2 represent the areas of the respective upper and lower contours. The volume of the lowermost portion of the lake was estimated using the area of the lower contour multiplied by the estimated mean depth within the area. Other parameters of lake morphometry and morphology, with the exception of the perimeter to area ratio, were calculated as suggested by Welch (1948).

The transparency of the lake water, measured with a Secchi disk 20 cm in diameter, was stated as the mean of the depth of disappearance and reappearance of the disk. All Secchi disk readings were taken on the shaded side of the boat. Notes on cloud cover and condition of water surface were recorded.

Water samples for analysis of dissolved oxygen were obtained using a 1200 cc Kemmerer water bottle. The sampler had been in use for several years but had not been coated to prevent contact of water with the metal. Dissolved oxygen was determined using the unmodified Winkler technique. Corrections for altitude and temperature were according to Truesdale,

Downing and Lowden as tabled in Hutchinson (1957). No adjustment was made in the titration values to account for the volume of reagents added except for those used in gross primary productivity calculation. All oxygen titrations up to 27 June 1961 were made using 100 cc aliquots and titrated with 0.025N sodium thiosulphate; thereafter 50 cc aliquots and 0.01N sodium thiosulphate were used.

Analytical chemists of the Consolidated Mining and Smelting Company of Canada, Kimberley, B.C., analyzed water samples for dissolved nutrients utilizing methods outlined in Standard Methods (1960).

A Yellow-Springs thermistor-thermometer, model 43TB, was used to record air and water temperatures. This instrument had been standardized with a long stem mercury thermometer calibrated to 0.1°C. Temperatures were estimated to the nearest 0.1 of a Centigrade degree.

Until March 1961, a "Wisconsin" plankton net with a diameter of 11.2 cm was adopted for taking total vertical plankton hauls. Thereafter, a 25 cm diameter net of the Wisconsin type was used. Both nets were fitted with new No. 10 silk having 109 meshes per linear inch. Each time a lake was sampled, 3 total vertical plankton hauls were taken at the deep water station. A total of 18 samples was obtained from each lake and each was preserved in a 5 percent formalin solution.

Ward (1957) found that rapid random changes in net efficiency did not obscure differences in crustacean availability between stations on Shuswap Lake. Ward also found that Wisconsin type nets were not subject to gradual changes in efficiency during the period of use, nor were catches significantly different over

a range of hauling rates.

Net plankton volumes were determined using a 24 hour settling period in 15.0 cc centrifuge tubes calibrated to 0.1 cc. Because the formalin contained a flocculent precipitate, all samples taken prior to March 1961, were mixed with dilute oxalic acid and filtered, before volume determination. Two plankton samples from triplicate vertical hauls, were dried in an oven at 60C for 48 hours or until a constant weight was obtained. Samples were first washed with distilled water. Weights were determined using a Mettler model K7 analytical balance, sensitive to 0.03 grams.

Bottom fauna samples were taken at 5 different periods of the year although none were taken during ice cover of the lake. Samples were discarded where the dredge failed to close completely. Although molluscs were found to be a minor part of the bottom fauna in most lakes, shells were removed prior to weighing. The total number of dredgings in each lake varied from 22 to 42, with duplicate samples being taken at each depth sampled.

Bottom fauna dredging consisted of sampling with a 6 inch Ekman dredge at approximately the same position in each depth zone, each time a lake was examined. The depth zone was chosen for ease of sampling, on initiation of the study. Samples were washed using a 30 mesh per lineal inch screen and sorted on a white enamel tray while the organisms were alive. A five percent formalin solution preserved the bottom fauna for later identification.

Only the common higher aquatic plants were noted as evident in bottom dredgings and by examination of lake shoal areas.

The fish fauna was sampled with standard sets of braided nylon experimental gill nets having stretched mesh sizes of 1 to $3\frac{1}{2}$ inches at $\frac{1}{2}$ inch intervals. Gill nets were set at selected shoal areas for a 12 hour period during the night. All fish taken from the net were weighed with a spring balance and measured to the nearest 0.1 cm by using a measuring board. A 10 percent solution of formalin was used as a fish preservative.

A sediment trap, following the design of Patalas (personal communication), consisted of a 24 ounce ice box jar suspended at the lower limit of the thermocline for a 10 day period. The lid was designed to close when the trap was brought to the surface. Formalin was placed in the bottom of the jar prior to the suspension of the sediment sampler in the lake.

Gross primary productivity was estimated using the "Light and Dark Bottle" method of oxygen evolution. Light and Dark Bottles consisted of 300 cc BOD (biochemical oxygen demand) bottles with the "dark" bottles having been made light tight by covering with black "Scotch Tape" as well as having several coats of black "Glyptol" paint. Paired Light and Dark Bottles were suspended at depths of 1, 3, 5 and 7 feet from metal hinges fastened to a weighted wire line. The line was in turn suspended from a 1 square foot styrofoam buoy. Water samples were taken with a Kemmerer bottle from which 3 BOD bottles could be filled. One bottle, termed a "blank," was used to determine the dissolved

oxygen at the start of the experiment. Bottles were shielded from sunlight until they could be suspended at their appropriate depth. Gross primary productivity was measured in the 9 study lakes during the period of June 27th to July 8th, 1961.

The LB and DB were suspended for a 12 hour period, from 0815 or 0915 to 2015 or 2115, depending upon the time required to finish setting the bottles at the various depths. Titration followed methods given by Strickland (1960). All oxygen determinations were done on the same day as the "in situ" oxygen measurements. The photosynthetic quotient was assumed to be 1 for gross primary productivity calculations.

DESCRIPTION OF THE STUDY AREA

Geographic Location

All of the lakes in the study are located between longitude $115^{\circ} 30'$ and $116^{\circ} 30'$, and between 49 and 51 degrees of latitude. Figure 1 shows the location of the nine lakes in the Southern Rocky Mountain Trench, British Columbia.

Two main mountain ranges delimit the Southern Rocky Mountain Trench. The Rocky Mountains rise abruptly to the east of the valley floor and attain an average height of 6,000 to 8,000 feet. The Columbia Mountains, and in particular, the Purcell Range, border the west side of the trench but rise less abruptly as rolling hills. The Purcell Range has an average altitude of 6,000 feet. The floor of the Rocky Mountain Trench varies between 2,460 and 2,800 feet elevation in the study area.

The lakes studied range between 2,757 feet and 3,921 feet elevation (Table III). Figure 1 gives the location of the 9 lakes in the Southern Rocky Mountain Trench.

All lakes are accessible throughout the year except Kiakho and New lakes, which are usually inaccessible for winter sampling because of heavy snowfall.

Geology

Figure 2 gives the position of the 9 lakes in relation to the regional geology of the Southern Rocky Mountain Trench. Geological areas have been obtained from map 932A of the

Figure 1. Location of the 9 study lakes and weather stations within the Southern Rocky Mountain Trench of British Columbia

Figure 2. Location of the 9 study lakes in the Southern Rocky Mountain Trench with respect to regional geology

Department of Mines and Technical Surveys.

Schofield (1915) shows Hiawatha, Kiakho and Jim Smith lakes situated in the Aldridge formation (map 147A). The southern portion of Kiakho Lake lies within an area of granite and porphyritic granite. Schofield describes the Aldridge formation as consisting of argillaceous quartzites, purer quartzites and argillites. Interlocking grains of quartz have been thoroughly cemented together and a small amount of feldspar is present.

Rice (1937) in map 396A depicts Kiakho and New lakes within the Creston formation. Argillaceous quartzites and quartzites compose the Creston formation according to Rice. This formation has quartz as the most abundant mineral. Calcareous beds are not uncommon and carbonates occur in minor quantities.

Lazy Lake is located in an area of sedimentary sand and clay on map 932A. Horseshoe Lake and Enid Lake are located in areas of stream and glacial deposits (map 932A) where the bedrock remains concealed.

Schofield (1915) mentions a formation of siliceous limestone which surrounds Bednorski Lake (map 147A). Lillian Lake is likewise situated in an area of Limestone (map 2070). Walker (1926) describes the area as the Mt. Nelson formation, composed of magnesian limestone and slate.

Soils

Information is available on soil classification in areas surrounding some of the lakes. Kelley and Sprout (1956) state

that glacial till and its derivatives are the main soil-forming materials in the Southern Rocky Mountain Trench.

Enid and Lazy lakes and approximately one quarter of Lillian Lake lie within an area of the Wycliff Silt Loam soils (Kelley and Holland, 1961). The parent material of this soil is a loamy, strongly calcareous till containing gravel and stones. This soil type is noted for its high total calcium content and the accompanying low total phosphorus.

Bednorski Lake, the south end of Lazy Lake and a small portion of Lillian Lake are situated within the Wigwam Soil Complex. This group of soils have been developed on alluvial fans of limestone or non-calcareous sedimentary rocks (Kelley and Sprout, 1956).

Elko Silt Loam soils comprise approximately one half of the soils around Lillian Lake. The amount of phosphorus in this soil type is comparable with the Wycliff soils. The soil texture is a loam to silt loam and the amount of stones in the surface varies.

Around Horseshoe Lake the Elko Silt Loam is combined with the Saha Soils to form the Elko-Saha group. This soil type supports a mixture of grass and trees. The Saha soils are gravelly with highly porous subsoil.

Vegetation

The principal species of trees in the southern part of the trench are ponderosa pine (Pinus ponderosa), western larch (Larix occidentalis) and Douglas-fir (Pseudotsuga menziesii).

Hiawatha and New lakes have wooded shore lines consisting of western larch and lodgepole pine (Pinus contorta). The drainage areas of both lakes were logged more than ten years ago. Lillian Lake has a forested shoreline consisting of Douglas-fir and some deciduous trees such as trembling aspen (Populus tremuloides).

Kiakho and Jim Smith lakes have partially open shore lines with lodgepole pine and western larch as the dominant coniferous trees. The Jim Smith Lake drainage was logged over whereas the Kiakho Lake drainage has been the site of logging practices in the last 10 years. The eastern slope of the Kiakho drainage is partially open and composed of rock slides and semi-open grassland. The south and north ends of Jim Smith Lake are open to wind action and are composed of grassland or pasture.

The shoreline is free of trees around Enid, Horseshoe and Lazy lakes and partially treed around Bednorski Lake. Douglas-fir and ponderosa pine stands occur back from the shore of Lazy Lake. The drainage area was the site of logging about 10 to 15 years ago. Only limited logging took place around Horseshoe Lake where Douglas-fir, lodgepole pine and ponderosa pine are the major species. Bednorski Lake has Douglas-fir, western larch and lodgepole pine in the drainage area, which was logged about 10 years ago. Deciduous trees such as aspen and alder are the most prominent about the southwest portion of the lake. Most of the lake shore is open grassland and the north or west end of the lake is cultivated land. The shores of Enid Lake have some Douglas-fir and aspen but a large part of the shore is open grassland or sparsely treed.

Weather and Climate

In the British Columbia Atlas of Resources, the Southern Rocky Mountain Trench is classified as the Southeastern Interior subregion of the Interior climatic region. The trench assumes a north-south direction and for this reason air masses may assume a similar direction of movement. Cold air may move into the trench area from the north or the region may be subjected to masses of warm air from the south during the summer.

The local topography produces regional climatic differences throughout the trench, compared with the dominant, modified Polar Maritime air mass. Variations in temperature and precipitation occur with changes of altitude throughout the Rocky Mountain Trench.

Air Temperature

Temperature records are available from The Climate of British Columbia for 1960 and 1961 (B.C. Dept. of Agriculture), for 1 inactive and 4 active weather stations, close to the lakes studied (Fig. 1). The monthly and annual mean temperatures for 1960 and 1961 are given for the 4 active stations in Table I. Also shown are the averages for the periods on record.

The Cranbrook, Kimberley and Wilmer weather stations all have approximately the same altitude. The average temperatures are lower as one progresses north from Cranbrook to Wilmer. The greatest difference is observed during the winter period. The 1960 and 1961 temperatures for Cranbrook and Kimberley reflect the same pattern as the averages on record.

TABLE I

Monthly and annual mean temperatures for the years 1960 and 1961 and averages for the periods shown
(Degrees F.)

Station		<u>Jan.</u>	<u>Feb.</u>	<u>Mar.</u>	<u>Apr.</u>	<u>May</u>	<u>June</u>	<u>July</u>	<u>Aug.</u>	<u>Sept.</u>	<u>Oct.</u>	<u>Nov.</u>	<u>Dec.</u>	A ₁	Yr ₂
Cranbrook															
3013 ft	1960	12	23	31	M.	M.	M.	M.	M.	M.	M.	M.	M.	M.	
	1961	M.	M.	35	41	53	63	66	68	49	40	25	17	M.	
	Average	16	22	32	43	52	58	64	62	54	43	29	22	41	30
Aberfeldie															
2640 ft	1960	16	26	33	44	50	58	70	62	56	40	32	20	43	
	1961	25	35	38	42	53	63	67	68	50	42	27	21	44	
	Average	21	26	33	43	53	58	65	63	55	44	31	25	43	11
Radium															
Hot Springs	1960	9	21	28	41	46	54	66	59	51	42	25	15	38	
3570 ft	1961	18	27	32	39	50	61	62	63	45	37	19	15	39	
	Average	15	21	29	40	51	57	63	60	50	39	22	17	39	7
Kimberley															
Airport	1960	11	22	30	43	48	58	69	60	54	45	28	17	40	
3016 ft	1961	21	30	35	41	52	63	64	66	48	39	24	16	42	
	Average	15	22	29	42	52	58	64	62	54	42	28	20	41	18
Wilmer															
(Inactive)	Average	14	20	31	43	51	58	64	61	52	41	27	16	40	16
3100 ft															

M. Missing
1. Annual
2. Years

Cranbrook and Aberfeldie have about the same latitude (Fig. 1) but different elevations (Table I). The average temperatures are colder at Cranbrook which has the highest elevation.

The effects of altitude and latitude on air temperatures is also reflected in the growing season of lakes. Figure 5 shows that ice had not yet begun to form by November 6 on Lazy Lake or November 7 on Bednorski Lake, but Enid and Lillian lakes were half frozen by November 15. A more striking pattern is given for the date of ice cover removal. Bednorski, Horseshoe and Lazy lakes are lower in altitude than Jim Smith, Kiakho or New lakes. Ice formed earlier and remained longer on lakes of higher elevation (Fig. 5).

Precipitation

Total annual precipitation records in the study area vary from 12 to 23 inches between stations. Precipitation in the form of snow accounts for 35 to 85 inches per annum between regions. Approximately 30 percent of the precipitation is in the form of snow (Table II). The month of June is on the average the wettest month at all five recording stations. March and April are the months usually having the lowest precipitation.

Table II shows there is approximately the same annual precipitation at Cranbrook and Kimberley airports. A decrease in precipitation at Wilmer is evident when compared to the Cranbrook and Kimberley averages. An increase in precipitation is reflected by changes of altitude between Wilmer and Radium

Hotsprings. The higher precipitation at Aberfeldie when compared to Cranbrook, could be due to Aberfeldie being located near a route taken by thunderstorms (Kelley and Sprout, 1956).

Enid and Lillian lakes, in proximity to Wilmer, would be expected to have lower precipitation than other lakes studied. Likewise, Bednorski, Horseshoe, Hiawatha and Lazy lakes, because of their elevation being lower than New, Kiakho and Jim Smith lakes, would have lower precipitation

Wind

Wind records are available for the years 1938 to 1945 from the Cranbrook airport weather station. Kelley and Sprout (1956) give the average wind speed of 7.1 mph for south winds in the trench region and 4.5 mph for the north winds. Chapman (1952) states that northwest and southeast winds are dominant at Windermere in January and July, but south and southwest winds are dominant at Cranbrook in both seasons. This is shown by records where 63 percent of the winds at Cranbrook are from the south, southeast and southwest. North, northeast and northwest winds account for 29 percent of the total winds at Cranbrook.

New, Lazy and Kiakho lakes, which have their maximum length as the north-south axis, and Jim Smith Lake which has a southwest - northeast axis, would be expected to have the greatest effect from dominant winds at Cranbrook. Hiawatha and Kiakho lakes are protected from excessive wind action as a result of hills situated around the lakes. Horseshoe Lake with its open shoreline, is susceptible to wind from any direction.

TABLE II

Monthly and annual total precipitation for the year 1960 and 1961 and averages for periods₁ shown (Total precipitation is the sum of the rainfall plus the water equivalent of the snowfall, which is snowfall divided by 10)
(Inches)

Station		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	A ₂
Aberfeldie	1960	1.81	2.00	1.41	0.78	2.39	1.61	0.44	1.64	1.03	1.90	4.54	0.96	20.51
2640 ft	1961	2.01	2.06	1.54	1.46	2.57	1.64	1.82	1.47	4.28	1.73	1.53	2.34	24.49
(58.8) ₃	Average	3.30	1.84	1.04	1.02	1.80	2.73	1.03	1.66	1.50	1.86	2.13	2.32	22.23
Cranbrook	1960	0.76	0.74	1.35	M.	M.	M.	M.	M.	M.	M.	M.	M.	M.
3013 ft	1961	M.	M.	1.20	1.16	1.40	1.00	1.41	0.79	3.11	0.89	1.34	3.45	M.
(64.2)	Average	1.58	1.41	0.81	0.79	1.21	1.95	0.83	1.07	0.95	1.24	1.34	1.99	15.17
Kimberley	1960	0.88	0.86	0.82	0.44	1.11	0.58	0.34	2.21	0.55	0.51	2.72	0.80	11.81
Airport	1961	0.84	2.01	0.94	0.62	1.96	1.16	2.08	1.54	1.98	1.21	0.83	1.81	16.98
3016 ft	Average	1.77	1.22	0.94	0.75	1.27	1.96	0.74	1.36	0.90	1.21	1.36	1.64	15.12
(60.3)														
Radium	1960	0.97	1.25	1.30	0.58	2.43	1.42	0.53	0.81	1.15	2.36	M.	1.58	M.
Hot Springs	1961	2.38	1.80	0.35	2.00	2.38	1.70	2.48	1.49	2.64	1.06	0.95	1.25	20.48
3570 ft	Average	1.59	1.36	0.90	1.85	1.92	3.00	2.34	1.75	2.30	1.94	1.56	2.08	22.59
(83.4)														
Wilmer														
(Inactive)	Average	1.23	0.61	0.52	0.63	1.20	1.64	1.29	1.53	1.10	0.78	0.88	1.15	12.56
3100 ft														
(35.5)														

M. - Missing

1. - Periods of record are same as in Table I

2. - Annual

3. - Average snowfall in inches

PHYSICAL CHARACTERISTICS OF THE LAKES

Topography of the Drainage Area

Table III lists the drainage areas and water level fluctuation of the lakes examined. Hand line soundings from a limnological station were used to record the water level fluctuation, except in Horseshoe and Lazy lakes, where fluctuations were measured between high and low water marks on the shore.

Enid and Horseshoe lakes have no surface inlets or outlets. The lake level of Horseshoe begins to rise during the early summer and falls once again in late summer. This lake has unusually large water level fluctuations since a difference of 21 feet was measured between low water of May 2, 1962 and the visible high water mark.

Hiawatha, Lillian, Jim Smith and New lakes have seasonal inlets or outlets or both, which are normally dry by late summer. Most of the creeks have volumes less than $0.5 \text{ ft}^3/\text{sec}$ but the inlet flow of Lillian Lake is between 1 and $2 \text{ ft}^3/\text{sec}$.

Kiskho Lake, described by Stenton (1960), has a drainage area of approximately 3 square miles. Two inlet creeks enter Kiakho Lake and in 1958 Stenton found the flow of each inlet to be $0.5 \text{ ft}^3/\text{sec}$. The outlet in the spring has a flow of 3 to $4 \text{ ft}^3/\text{sec}$ but in summer is considerably less. The permanent inlet of Lazy Lake has a volume of about $0.25 \text{ ft}^3/\text{sec}$ throughout the year and the stream falls sharply from the mountains on the east side. Between September 1960 and March 1961, a 4 foot fluctuation was recorded in the lake level. However,

TABLE III

Morphometric data for lakes in the Southern Rocky Mountain Trench

		<u>Horseshoe</u>		<u>Bednorski</u>	<u>Hiawatha</u>	<u>Kiakho</u>	<u>Lillian</u>	<u>Ehid</u>	<u>Jim Smith</u>	<u>Lazy</u>	<u>New</u>
Elevation	m (ft)	853 2799		853 2757	957 3200	1097 3600	942 3091	963 3160	1058 3470	905 2970	1195 3921
Surface Area	Hectare Acre	10.7* 26.4	31.5 77.8	9.6 23.8	4.1 10.1	12.1 29.9	26.6 65.8	22.3 55.0	21.2 52.5	31.4 77.6	27.6 68.3
Maximum Depth	m (ft)	6.1* 20	11.6 38	13.1 43	5.2 17	9.8 32	11.6 38	8.2 27	7.3 24	10.7 35	10.4 34
Mean Depth	m (ft)	2.7* 8.8		8.5 27.9	2.6 8.7	4.7 15.3	5.1 16.7	4.1 13.5	4.9 16.2	5.2 17.2	3.4 11.1
Volume	m ³ X m ⁵ (Acre ft)	2.87* 233		8.19 644	1.08 88	5.65 458	13.57 1100	9.18 744	10.53 854	16.51 1338	9.31 755
Maximum Length	m (ft)	600* 1969	1152 3780	503 1650	344 1128	1006 3300	777 2550	701 2300	846 2775	1372 4500	1052 3450
Maximum Width	m (ft)	277* 909	503 1650	226 742	168 552	117 385	777 2550	594 1950	320 1050	297 975	372 1220
Shore Development		1.20* 1.63		1.21 1.17		2.34 1.76	1.76 1.44	1.44 1.43	1.43 1.95	1.95 0.95	1.33
Volume Development		1.32* 1.95		1.95 1.53		1.44 1.31	1.31 1.50	1.50 2.04	2.04 1.50	1.50 0.98	0.98
Perimeter	m (ft)	1400* 4594	3246 10650	1333 4372	845 2773	288 9460	3228 10590	2414 7920	2359 7740	3886 12750	2487 8160
<u>Perimeter</u> <u>Area</u> X 10 ³		3.99* 3.14		4.22 6.28		7.28 3.70	3.70 3.31	3.31 3.38	3.38 3.77	3.77 2.74	2.74
Drainage Area	Hectare (mile ²)	2020 7.80		4105 15.85	124 0.48	777 3.00	461 1.78	132 0.51	1243 4.80	1362 5.26	202 0.78
Water Level Fluctuation	(ft)	21.0		1.0	1.5	1.5	1.5	2.0	2.0	6.0	2.0

* - Low water data

Figure 3: Bathymetric maps of the nine study lakes with limnological stations as indicated (S). All lakes have the same compass orientation and scale of measurement.

the difference between the low water level and the visible high water mark has been measured at 6 feet. Bednorski Lake has permanent inlet and outlet streams estimated at $1 \text{ ft}^3/\text{sec}$ in June 1960. The volume ($0.25 \text{ ft}^3/\text{sec}$) during the late summer to spring period is reduced considerably.

Morphometry

Morphometric parameters are listed for the lakes in Table III and bathymetric maps are given in Figure 3.

The areas of the lakes range from 10.1 acres (Hiawatha) to 77.8 acres (Horseshoe). The lakes could be grouped into two sizes; Hiawatha, Bednorski, Kiakho and Horseshoe at low water, as the smaller lakes, and the remainder as the larger size group. The 4 smaller lakes range from 10.1 to 29.9 acres and 5 large lakes have a range of 52.5 to 77.6 acres.

The shoreline development of Hiawatha Lake most closely approximates that of unity. Kiakho Lake, on the other hand, shows the greatest departure (2.34) from a circular form. The perimeter to area ratio is probably a better criterion than shore line development when comparing lakes of different areas (Rawson, 1960). With the exception of Hiawatha and Kiakho lakes, all other lakes have similar ratios.

The hypsographic curves (Fig. 4) show the features of shape and area of the lakes at various depths. Bednorski and Jim Smith lakes have 68 and 73 percent of their surface areas represented at one half of their maximum depths. New Lake has 24 percent of its surface area at 50 percent of maximum depth. The remaining 6 lakes are similar in having 38 to 53 percent of

their area at one half the maximum depth.

Horseshoe Lake at low water level and Hiawatha Lake have mean depths which are about one half of the magnitude of other lakes. However, Table III shows a similarity of mean depth with a range of 8.7 to 27.9 (Bednorski Lake) for the 9 lakes studied.

The 9 lakes have similar maximum lengths ranging from 1,128 feet for Hiawatha to 4,500 feet for Lazy Lake. This distance is the effective length of the lake over which the wind may act.

The 9 lakes chosen for examination are similar in many of their morphometric features including maximum depth, mean depth, volume development and maximum length. This is especially true when considering the great differences to be found among lakes in B.C. or even within the Rocky Mountain Trench.

Temperature

Figure 5 illustrates the temperature at various depths of all lakes during the period of examination in 1960 and 1961. Except for Hiawatha Lake, all lakes have similar surface and bottom temperatures and all exhibit thermocline formation.

Table IV shows that mean summer epilimnion temperatures for July 20 to August 5, 1960 and August 30 to September 1 of 1961. Computation was according to the formula in Welch (1948). Except for Hiawatha Lake, all lakes had similar epilimnion temperatures. Epilimnion temperatures showed a greater variation in 1961 compared to 1960. Lazy Lake had a thermocline located at approximately 25 feet, whereas other lakes except Hiawatha, had thermoclines at 10 to 15 feet (Fig. 5).

Figure 4. Hypsographic curves of the 9 study lakes

Figure 5. Seasonal temperature ($^{\circ}\text{C}$) distribution with depth (ft) from one limnology station in each of the 9 lakes in 1960 and 1961. Approximate period of ice cover is indicated

TABLE IV

Mean epilimnion temperatures (°C) of the 9 lakes
for 1960 and 1961

<u>Lake</u>	<u>Mean Epilimnion Temperature (°C)</u>	
	<u>20 July - 5 August, 1960</u>	<u>30 August - 1 September, 1961</u>
Kiakho	21.2	17.6
Lillian	20.6	18.9
Enid	21.4	18.3
Newell	21.5	19.4
Hiawatha	23.8	20.0
Jim Smith	21.4	19.9
Horseshoe	21.3	20.0
Bednorski	20.2	19.3
Lazy	21.5	21.3

By mid-September of 1960, the surface and epilimnion temperatures of all lakes decreased considerably. However, Bednorski, Lillian and Enid lakes still exhibited a thermocline, but at a lower depth than during July and August.

Temperatures in November were higher in Lazy Lake than other lakes. A near homothermous condition existed in all lakes (Fig. 5) during November, when temperatures ranged between 1.5 and 6.3 C. Figure 5 shows the approximate time of ice formation in November.

As Kiakho Lake was inaccessible during March, no temperatures were recorded. New and Jim Smith lakes, being at the highest elevation, had ice sheets 21 to 23 inches in thickness. Hiawatha had 18 inches of ice while the remaining lakes had 8 to 14 inches of ice. Horseshoe and Lazy lakes were the warmest during the period of winter stagnation. Most lakes show a slight increase in temperature near the bottom. The approximate time of ice removal is indicated for all lakes in Figure 5.

Temperatures taken during the summer of 1961 can be compared with those of 1960 (Figure 5). All lakes were well stratified in the summer of 1961. New Lake was much warmer in 1961 than 1960. Likewise, Hiawatha, Jim Smith, Lillian and Enid lakes were also warmer in 1961. Lazy lake had temperatures in 1961 that were similar to those of 1960, whereas, Bednorski and Kiakho lakes had temperatures that were colder in 1961.

Transparency

The greatest transparency was observed in Lillian, New,

Figure 6. Secchi disk transparency in relation to maximum depth (ft) of the 9 lakes during 1960 and 1961

Lazy and Jim Smith lakes (Fig. 6). Intermediate in transparency were Hiawatha, Kiakho, Horseshoe and Bednorski lakes. Enid lake was outstanding by having the lowest visibility of the nine lakes. Enid, Hiawatha, Jim Smith and Bednorski lakes exhibited little variation in transparency measurement during the year.

Ranking of the Lakes by Physical Factors

Ranking of the lakes is based on a scale of 0-9 with the lake having the highest value being given 9 and the lake with the lowest value given 0 (Reimers, Maciolek and Pister, 1955). Lakes with intermediate values between highest and lowest are ranked between 0 and 9 in proportion to their absolute values. The following formula is used for factors directly related to productivity.

$$\text{Rank } X = \frac{(9) \text{ Value for lake} - \text{minimum value for all lakes}}{\text{Range of values for all lakes.}}$$

For a factor inversely related to productivity the formula is:

$$\text{Rank } X = \frac{(9) \text{ Maximum value for all lakes} - \text{value for lake}}{\text{Range of values for all lakes.}}$$

Table V lists some physical factors which have been reported in the literature as influences or indicators of productivity. With the exception of transparency, all are

TABLE V

Ranking of the 9 lakes by physical factors.

Lake	Mean Depth	<u>Perimeter</u> Area	Mean Transparency	Mean Epilimnion Temperature	Drainage Area	Mean Rank
Hiawatha	9.0	7.0	5.8	9.0	0	6.2
Kiakho	5.9	9.0	4.8	0	1.5	4.2
Horseshoe	8.9	2.5	5.1	4.3	4.3	5.0
New	7.9	0	0	3.6	0.1	2.3
Jim Smith	5.5	1.3	3.0	4.3	2.5	3.3
Bednorski	0	3.0	5.8	1.1	9.0	3.8
Lazy	5.0	2.0	1.6	7.2	2.9	3.7
Lillian	5.3	1.9	1.3	1.1	0.8	2.1
Enid	6.7	1.1	9.0	1.4	0	3.6

directly related to productivity. The mean rank is not meant to imply that all physical factors influence productivity equally, but in the absence of knowledge concerning their individual influences, equal weight must be given to each factor. The mean ranks exhibit a narrow range of values with the possible exception of Hiawatha Lake (Table V). Mean depths are similar except for Bednorski Lake which has the highest mean depth and therefore the lowest rank. Kiakho and Hiawatha have perimeter to area ratios much higher than other lakes. Likewise, New and Enid lakes are outstanding by having the highest and lowest transparency. A likeness exists among mean epilimnion temperatures except for the high temperatures of Hiawatha and Lazy lakes. Horseshoe Lake, and Bednorski Lake in particular, received a high rank for the size of drainage area.

CHEMICAL CHARACTERISTICS OF THE LAKES

Total Dissolved Solids and Alkalinity

The lakes studied varied from 50 (Hiawatha) to 1463 (Enid) parts per million in total dissolved solids (Table VI). The lakes were chosen purposely to include a wide range of T.D.S. The dissolved solid content showed seasonal and annual variation, however values listed in Table VI are averages for the summer and autumn of 1960 only. Bednorski Lake was the only lake with T.D.S. higher in summer than autumn. All lakes had summer total dissolved solids higher in 1961 than 1960. Seasonal variations were greatest in lakes of high total dissolved content.

Alkalinity increased with increases in total dissolved solids. Lazy lake was the only lake which showed a departure from the trend of increasing alkalinity with increasing T.D.S.

Hydrogen Ion Concentration

All the lakes studied were alkaline with only Hiawatha Lake ever having a pH in the range of 7 to 8. Most lakes ranged from 8 to 9 and Enid Lake had pH values sometimes in excess of 9. The pH was higher in summer than autumn, or opposite to the T.D.S. relationship.

TABLE VI

Chemical analysis of water samples for the 9 lakes in the Southern Rocky Mountain Trench expressed as a mean and range for 1960 and 1961

	T.D.S. (1)	pH (1)	Total Alk (3)	Phen Alk (4)	S as SO ₄	MgO	CaO	SiO ₂	Al ₂ O ₃ + Fe ₂ O ₃
Hiawatha									
Summer	53	8.2	47	1.0	0.8	5.2	16.3	6.2	2.1
Autumn	58	8.1	(28-60)	(0-2)	(0-3)	(4-6)	(11-24)	(2-12)	(0-3)
Kiakho									
Summer	94	8.8	73	4.5	1.0	12.1	32.5	14.4	2.7
Autumn	116	8.2	(50-87)	(3-6)	(0-2)	(10-15)	(28-38)	(2-27)	(0-3)
Horseshoe									
Summer	111	8.4	87	5.5	1.0	18.5	46.3	9.6	2.6
Autumn	115	8.4	(70-124)	(5-6)	(0-2)	(13-36)	(33-86)	(8-12)	(2-4)
New									
Summer	144	8.7	123	6.0	0.5	25.9	44.6	14.4	2.1
Autumn	149	8.5	(86-162)	(5-7)	(0-1)	(19-46)	(34-64)	(2-20)	(1-3)
Jim Smith									
Summer	168	8.5	145	9.0	1.1	35.7	49.7	15.9	2.6
Autumn	193	8.5	(104-187)	(8-10)	(0-3)	(29-50)	(33-55)	(12-18)	(1-4)
Bednorski									
Summer	268	8.5	189	13.0	12.8	41.3	64.7	11.8	3.1
Autumn	259	8.6	(135-241)	(12-14)	(0-48)	(10-50)	(24-80)	(10-16)	(1-5)
Lazy									
Summer	300	8.9	132	11.0	35	73.9	41.3	9.7	2.7
Autumn	326	8.6	(98-164)	(10-12)	(20-37)	(60-79)	(34-66)	(6-11)	(1.4)
Lillian									
Summer	462	8.8	249	11.5	36	94.0	58.5	10.1	2.9
Autumn	478	8.7	(147-406)	(9-14)	(22-80)	(65-105)	(39-75)	(9-11)	(2-4)
Enid									
Summer	1183	9.2	356	37	132	271.7	84.4	8.6	4.1
Autumn	1371	8.9	(280-560)	(34-40)	(79-195)	(153-357)	(16-236)	(6-11)	(2-7)

(1) T.D.S. and pH are summer and autumn averages for 1960 only

(2) numbers in parenthesis represent range of samples taken in 1960 and 1961

(3) Alkalinity

(4) Phenolphthalein

Ion Composition

Calcium and Magnesium

The calcium concentration was high in all lakes except Hiawatha (Table VI); Öhle (1934) considered calcium as being high when in excess of 25 mg/liter. Bednorski, Lillian and Enid lakes were the richest in calcium concentration. These lakes were also the lakes having marl formations on the lake bottom.

The magnesium concentration was less than the calcium concentration in the lakes of lowest T.D.S. In lakes of high T.D.S., the quantity of magnesium was greater than the quantity of calcium. Large seasonal fluctuations in magnesium concentration were apparent in lakes of high T.D.S. Enid and Lillian had magnesium quantities in excess of 50 ppm while the remaining lakes had from 3 to 50 ppm.

Sulphate

Enid Lake had a sulphate concentration varying from 79 to 195 ppm. The odor of H_2S from lake bottom samples was very prevalent. The 5 lakes of lowest T.D.S. also showed the lowest concentrations of sulphate, with little subsequent annual variation. Lakes of high T.D.S. had high sulphate concentration with large annual fluctuations.

Dissolved Oxygen

Figure 7 illustrates the oxygen characteristics of the lakes during the summer and autumn of 1960, and the spring and

summer of 1961.

Hiawatha, Bednorski and Enid lakes illustrate examples of a clinograde oxygen curve. Summer oxygen values in 1961 confirm results obtained in 1960.

Kiakho Lake is illustrated in Figure 7 as having a positive heterograde oxygen curve during July and August of 1960. However, in September of 1960 and July of 1961, Kiakho Lake had a more typical clinograde oxygen distribution.

Examples of orthograde oxygen distribution are Horseshoe, New, Jim Smith, Lazy and Lillian lakes. New Lake in June 1961 and Lazy Lake in August of 1960 show a tendency toward clinograde oxygen distributions.

Oxygen concentrations in all lakes in November of 1960 are similar with more or less equal amounts of oxygen at all depths. However, between lakes striking differences in oxygen curves are observed during March of 1961 (Fig. 7). Clinograde oxygen distributions are evident in Hiawatha, New, Jim Smith, Lazy and Enid lakes in March 1961, while orthograde curves are found in Horseshoe and Lillian lakes. Bednorski Lake shows an indication of a positive heterograde oxygen distribution.

Between November of 1960 and March of 1961 (Fig. 7) all lakes except Horseshoe Lake, exhibit marked oxygen decrease. This is particularly evident in Enid and New lakes where a partial winter kill of fish has been observed by the writer. Bednorski, Lazy and Jim Smith lakes have a marked oxygen decrease below 15 feet between November and March.

Figure 7. Variation of dissolved Oxygen (mg/liter) with depth (ft) in the 9 lakes during 1960 and 1961

Ranking of the Lakes by Chemical Factors

Chemical factors were ranked by the same method as physical factors. Low oxygen concentrations in the hypolimnion have been used as an indicator of high productivity in the epilimnion. Magnesium and calcium have significance in plant and animal ecology. High silica concentrations were assumed to indicate a potential for productivity, however low concentrations could indicate high utilization.

Table VII gives the ranking for the 9 lakes, based on chemical factors. The mean rank of lakes other than Enid, lie within a somewhat narrow range (1.6 - 4.1). Enid Lake has a mean rank nearly twice the value of the next highest lake.

TABLE VII

Ranking of the 9 lakes by chemical factors.

Lake	Mean T.D.S.	Mean MgO	Mean CaO	Mean S ₂ O ₂	Mean Bottom Oxygen (Summer)	Mean Rank
Hiawatha	0	0	0	0	8.0	1.6
Kiakho	0.4	0.2	2.1	7.6	8.5	3.8
Horseshoe	0.4	0.4	4.0	3.2	5.5	2.7
New	0.7	0.7	3.8	7.6	3.6	3.3
Jim Smith	1.0	1.0	4.4	9.0	1.6	3.4
Bednorski	1.5	1.2	6.4	5.2	6.0	4.1
Lazy	2.0	2.3	3.3	3.3	0.3	2.2
Lillian	2.9	3.0	5.6	3.6	0	3.0
Enid	9.0	9.0	9.0	2.2	9.0	7.6

BIOLOGICAL CHARACTERISTICS OF THE LAKES

Primary Productivity

Most duplicate titrations for gross primary productivity estimates agreed with the $\pm \frac{0.08}{N_2}$ mg O₂/liter limits set by Strickland (1960). Greatest disagreement in oxygen titration values occurred in New, Lazy and Lillian lakes (Table VIII).

At certain depths the Dark Bottle oxygen concentration exceeded that of the Light Bottle. This was evident in Lazy and Enid lakes (Table VIII). Also, oxygen concentrations were higher in the Blank than in the Light Bottle in some lakes. Where DB values exceeded LB values, they were not used for estimates of gross primary productivity.

Average gross primary productivity estimates for the 9 lakes may be grouped into lakes of low, moderate and high productivity. Hiawatha, Horseshoe and Bednorski lakes have low primary productivity (113-119 mg C/m³/day), whereas Kiakho, Jim Smith, New and Lazy have moderate productivity (286-395 mg C/m³/day). High gross primary productivity was observed in Enid and Lillian lakes (1040-1157 mg C/m³/day).

The minimum mean gross primary productivity was observed in Hiawatha Lake and the maximum in Lillian Lake (Table VIII); these values are in the range reported in the literature. Eberley (1959) gave a mean production rate in Myers Lake of 754 μ g O₂/liter (282 mg C/m³) with daily gross primary production rates as high as 1377 μ g O₂/liter in the metalimnion. Weber (1958) has given rates of 910 mg C/m³/day for West Okoboji Lake in Iowa.

TABLE VIII

Gross primary productivity estimates for Light and Dark Bottle experiments in the 9 lakes during June 27 - July 8, 1961

Lake	Depth (ft)	Blank	Light	Dark	Gross Primary Productivity	
		O ₂ _{l.}	O ₂ _{l.}	O ₂ _{l.}	(mgC/m ³ /day)	Mean
Hiawatha	1	8.59	8.62	7.84**	292	113
	3	8.42*	8.73	8.44	109	
	5	6.75*	8.61	8.48	49	
	7	8.74	8.54	8.53	4	
Kiakho	1	8.41	8.43	8.34	34	286
	3	7.87	7.88	7.89*	-	
	5	7.88	7.88	5.83	769	
	7	8.27	8.29	8.14	56	
Horseshoe	1	10.06	10.07	9.70	139	116
	3	10.06	10.04	9.63	154	
	5	10.03	10.11	9.96	56	
	7	10.40	10.40	Spoiled	-	
New	1	7.95	7.93	7.58	131	329
	3	7.91	7.82	6.39**	536	
	5	7.87	7.93	7.76	64	
	7	7.98	7.83	6.29**	577	
Jim Smith	1	7.76	7.86	6.21	608	306
	3	7.72	7.94	7.81	48	
	5	7.65	8.01	7.31	262	
Bednorski	1	7.75	8.16	7.75	154	119
	3	8.01	8.17	7.99	67	
	5	7.73	8.19	7.74	169	
	7	7.94	8.17	7.94	86	
Lazy	1	9.89	9.84	10.20**	-	395
	3	9.30**	9.45	9.80**	-	
	5	10.28	9.37	7.68	634	
	7	9.08	9.73	9.31*	157	
Lillian	1	7.46	8.22	4.49**	1399	1157
	3	6.62**	8.72**	6.91	679	
	5	7.57**	8.49**	8.17	120	
	7	6.77	8.59	2.11	2430	
Enid	1	9.79	9.95	9.76	71	1040
	3	9.69	10.00	2.20*	2925	
	5	9.69	8.66	9.47	-	
	7	9.70	9.80*	9.47	124	

- * - Duplicate titrations agree within 0.06 and 0.10 mg O₂/liter
 ** - Duplicate titrations with difference greater than 0.10 mg O₂/liter
 l. - O₂ mg/liter

Flora

Enid, Lillian, Lazy and Bednorski lakes had the highest T.D.S. of the lakes examined as well as marl substrates with Chara as the major aquatic plant (Table IX). Enid Lake had a sparse representation of Chara with meagre areas of associated marl substrate. Bednorski, and in particular Lazy Lake, had Chara well represented as the dominant plant.

Hiawatha, New and Jim Smith lakes had the greatest abundance of macrophytes, with Potamogeton, Nuphar and Chara as the major genera. These lakes had low mean depths and during the summer Hiawatha and New lakes had approximately one-half of their surface areas covered by emergent aquatic plants.

Potamogeton was evident in the north and south ends of Kiakho Lake and then only sparsely distributed.

Horseshoe Lake had a large part of its substrate composed of gravel. Substrate composition coupled with major water level fluctuation is the probable reason for no major aquatic plant distribution in Horseshoe Lake. Terrestrial grasses formed part of the aquatic plant association at high water in Horseshoe Lake.

Net Plankton

Plankton samples obtained from total vertical plankton hauls (#10 net) in 1960 and 1961, had the greatest volume during the summer months (Table X). An analysis of variance of plankton volumes showed significant differences between lakes ($p < 0.01$) and between periods of sampling ($p < 0.01$). Using Duncan's

TABLE IX

The dominant forms of aquatic plants found in the 9 lakes
of the Southern Rocky Mountain Trench

Dominant Forms of Aquatic Plants

Lake	<u>Chara</u>	<u>Nuphar</u>	<u>Potamogeton</u>	<u>Myriophyllum</u>	<u>Valisneria</u>	<u>Nitella</u>	<u>Riccia</u>	<u>Typha</u>
Hiawatha		+++	++			+		+
Kiakho			+				+	
Horseshoe								
New	++	+++	+++	++	+			+
Jim Smith	++	+	++					+
Bednorski	+++							+
Lazy	+++							
Lillian	++							+
Enid	+							

+++ - Abundant

++ - Moderate

+ - Sparse

multiple range test (Duncan, 1955), Horseshoe, Bednorski, Hiawatha and Kiakho lakes had significantly the greatest standing crops of plankton. Of the 5 remaining lakes, Enid, Jim Smith and Lazy had significantly greater plankton volumes than New or Lillian lakes.

Average dry weight of plankton from each lake gave a quantitative rank similar to the rank based on plankton volume (Table XI). The major difference involved the order of Enid and Bednorski lakes in the range of values. Enid Lake had the greatest weight of plankton but had the sixth highest plankton volume. But Bednorski Lake ranked fifth by plankton weight and second by plankton volume. The other 7 lakes had approximately the same relative rank by plankton volume or weight.

Gammarus lacustris although often taken in plankton samples in Enid Lake, was omitted prior to recording plankton volumes and weight.

Daphnia sp. was represented in plankton samples from all lakes and Diaptomus sp. from all but Lazy Lake (Table XII). Ceriodaphnia sp. and Cyclops sp. were other forms of zooplankton commonly observed.

Phytoplanktonic forms were identified to genus although most phytoplankton would be expected to pass through the number 10 net. Two flagellates, Volvox sp and Ceratium sp. were the most common phytoplankters. Volvox sp. was moderately abundant in samples from Hiawatha Lake.

TABLE X

Mean plankton volumes (cc/m³) for the 9 lakes examined in 1960 and 1961
(Numbers in parenthesis refer to the range of triplicate total vertical hauls)

Lake	June-July 22 20 1960	July-Aug. 25 11 1960	Sept.-Sept. 12 22 1960	Nov.-Nov. 5 15 1960	March-March 14 28 1961	June-July 27 8 1961	Mean Total Volume (cc/m ³)
Hiawatha	18.2 (16.7-21.4)	51.1 (41.0-59.0)	9.4 (7.7-10.3)	10.3 (10.3)	1.8 (1.3- 2.0)	13.6 (13.4-13.9)	17.6
Kiakho	16.5 (11.5-19.5)	10.0 (6.9-11.5)	17.6 (17.2-18.4)	5.9 (5.9)	- - -	12.3 (10.6-15.3)	12.4
Horseshoe	28.5 (25.3-33.3)	8.9 (4.8-12.4)	11.9 (8.3-15.5)	10.6 (7.2-13.0)	6.7 (3.8- 8.5)	7.4 (5.5-10.4)	12.3
New	11.4 (8.6-13.3)	4.3 (4.0- 5.0)	2.9 (2.9)	5.6 (3.7- 7.4)	1.4 (0.6- 2.8)	3.4 (3.1- 3.5)	4.9
Jim Smith	10.2 (6.9-16.7)	16.2 (15.1-16.7)	10.1 (7.2-15.9)	4.0 (3.0- 6.1)	0.8 (0.6- 0.9)	10.1 (4.9-13.4)	8.6
Bednorski	49.4 (43.9-52.6)	18.3 (16.2-19.8)	13.7 (12.3-14.9)	7.8 (6.3- 9.9)	2.8 (2.5- 2.9)	4.9 (4.6- 5.2)	16.8
Lazy	26.7 (24.8-30.5)	16.1 (13.0-18.5)	13.9 (13.0-14.8)	5.1 (4.8- 5.7)	0.2 (0.2)	7.2 (7.1- 7.3)	11.5
Lillian	5.1 (4.3- 6.0)	8.9 (6.0-10.3)	5.0 (4.4- 5.3)	4.4 (3.5- 5.3)	0.9 (0.8- 1.0)	3.8 (3.6- 4.0)	4.7
Enid	4.1 (3.3- 4.4)	9.6 (8.0-11.5)	9.2 (8.0-10.3)	2.9 (1.1- 5.4)	4.1 (3.9- 4.4)	5.9 (5.3- 6.4)	6.0

1
4
4
1

TABLE XI

Mean dry weight of plankton samples obtained during 1960 and 1961.

Dry weight of Plankton	<u>Lakes</u>								
	Hiawatha	Kiakho	Horseshoe	New	Jim Smith	Bednorski	Lazy	Lillian	Enid
mg/m ³	131.	99.1	100.4	22.9	41.3	75.7	68.3	33.3	158.1
kg/hectare	16.9	18.6	27.1	7.9	8.5	28.5	25.5	11.3	47.9

TABLE XII

Relative abundance of the dominant plankton genera in the 9 lakes during 1960 and 1961.

Lake	Plankter												
	<u>Daphnia</u>	<u>Ceriodaphnia</u>	<u>Bosmina</u>	<u>Diaptomus</u>	<u>Cyclops</u>	<u>Chaoborus</u>	<u>Notholca</u>	<u>Anabaena</u>	<u>Oscillatoria</u>	<u>Zygnema</u>	<u>Fragillaria</u>	<u>Ceratium</u>	<u>Volvox</u>
Hiawatha	+++	++	+	++		+				+		+	++
Kiakho	+++	++		+++		+							+
Horseshoe	+++	+++	+	++	+	+						+	
New	+++			+++	++	+	+		+			+	+
Jim Smith	++			+++	+	+		+				+	
Bednorski	++	++		+++	+++	+					+		
Lazy	+	+++			+								
Lillian	+++			++	+								
Enid	+			+++									

+++ - Abundant

++ - Moderate

+ - Sparse

Bottom Fauna

Qualitative Composition

Figure 8 gives the qualitative composition of bottom fauna in the 9 lakes. Many of the same taxonomic groups of organisms were represented in all lakes. Notable exceptions were the absence of amphipods from Hiawatha Lake and the presence of only chironomids and amphipods in Enid Lake. Hyalella azteca has been observed in Hiawatha Lake but was not present in bottom fauna samples.

Chironomids were present in all lakes and culicids (Chaoborus sp.) were found in all but Lazy and Enid lakes.

Kiakho, Jim Smith, Bednorski and Lillian lakes had Hyalella azteca and Gammarus lacustris represented in samples, whereas Horseshoe, New Lazy and Enid lakes had one or the other of the amphipods, but not both.

Ephemeropterans were found in all lakes and molluscs in all but Horseshoe Lake. Hiawatha Lake was the only lake without representation of Hydracarina sp. Trichoptera, Coleoptera and Nematoda were additional groups classified as "others" in Figure 8. Hemiptera were not represented and this is no doubt due to the limited types of sampling.

Quantitative Composition

The relative abundance of each major insect group, classified on a numerical basis, is given in Figure 8 for bottom fauna samples examined from the 9 lakes.

Figure 8: Relative abundance of benthos in bottom samples taken from the 9 study lakes. Figure indicates an average of all bottom organisms taken from dredge samples on 6 sample dates in 1960 and 1961

Dipterans, represented by chironomids and culicids, were the most abundant bottom organism in all lakes except Bednorski and Enid, where amphipods were most numerous. Dipterans accounted for 93 percent of the total bottom fauna in Horseshoe Lake and 30 percent in Bednorski Lake. The remaining lakes had values between those of Horseshoe and Bednorski.

Oligochaetes formed 22 percent of the bottom fauna numbers in Hiawatha Lake. In Jim Smith and Hiawatha lakes, the only other numerically important bottom fauna components were Anisoptera and Zygoptera.

Diptera and amphipoda accounted for more than 78 percent of the benthic fauna numbers in all lakes except Hiawatha, which had 59 percent.

In Figure 9 the number of organisms are shown for each 10 foot stratum of the 9 lakes. The standing crops of bottom fauna by weight and number, showed a similar trend. The dissimilarity was most evident in Hiawatha, Lazy, New and Jim Smith lakes, which had moderate numbers of damselflies and dragonflies represented.

Comparisons of the number of bottom organisms per dredging in the 0 - 20 foot region, with the number in the region over 20 feet, gave a significant "t" value ($p < 0.05$) in Jim Smith, Bednorski and Lazy lakes. No significant difference between depth zones was indicated in other lakes.

Figure 9. Average number of all bottom organisms taken per square meter from bottom dredge samples. Numbers along the ordinate represent the maximum depth of each 10 foot stratum sampled.

Fish

Rainbow trout (Salmo gairdneri), Eastern Brook trout (Salvelinus fontinalis), and Cutthroat trout (Salmo clarki lewisi) were the major species taken in gill nets from the 9 lakes. Northern squawfish (Ptychocheilus oregonense) were present in Bednorski Lake and longnose suckers (Catostomus catostomus) in Hiawatha Lake. Largescale suckers (Catostomus macrocheilus) have also been observed in Hiawatha Lake. Bednorski and Lazy lakes also had reidside shiners (Richardsonius balteatus) represented in gill net samples. Shapley (personal communication) stated that suckers had gained entry to Kiakho Lake but none were taken in gill nets during this study.

Table XIII gives the number and weight of the various species taken in an overnight gill net set. No weights are given for the small number of reidside shiners captured.

Natural reproduction of trout occurs in Bednorski, Lillian and Kiakho lakes. With the exception of Bednorski and Kiakho, all the lakes are stocked by the Fish and Game Branch of the Department of Recreation and Conservation. Enid and New lakes are known to have part of their fish populations "winter killed" and such a phenomena was observed during the spring of 1961.

Bednorski Lake had the greatest fish biomass (Table XIII). If the lakes were ranked on the catch of trout alone, Bednorski would place sixth out of nine. All the remaining lakes would maintain the same position in the rank order regardless of species separation.

TABLE XIII

Number and weight of fish taken in a gill net set in each lake during June
and July of 1961

Lake	Species	Number of Fish	Weight (kg)	Total Weight (kg)
Bednorski	Rainbow trout	4	2.84	
	Northern Squawfish	58	11.79	14.63
	Redside Shiner	3	-	
Horseshoe	Rainbow trout	19	11.20	
	Eastern Brook trout	1	1.03	12.23
Kiakho	Cutthroat trout	33	7.84	7.84
Lillian	Rainbow trout	6	0.60	
	Eastern Brook trout	28	4.70	5.30
Jim Smith	Rainbow trout	6	4.50	4.50
Hiawatha	Rainbow trout	7	3.17	
	Longnose Suckers	3	-	3.17
New	Rainbow trout	8	1.93	1.93
Enid	Eastern Brook trout	2	0.84	0.84
Lazy	Rainbow trout	3	0.68	
	Redside Shiners	3	-	0.68

Hypolimnion Oxygen Deficit

In this investigation, the hypolimnetic oxygen deficit was calculated for all lakes except Horseshoe. Horseshoe Lake was omitted because of its extensive water level fluctuation at the time of summer temperature stratification. Summer stagnation was taken as July 25 to August 11 of 1960. The period of stagnation was estimated on the basis of the time of ice cover removal in 1961.

Oxygen concentrations were not always taken at the point of thermocline formation. Therefore, the oxygen concentration just above the thermocline was used in the calculation of deficits. Calculation of the oxygen deficit was based on the use of the hypolimnion layer, in which the thermocline was included. The upper plane of the thermocline, at the time of summer stagnation, was 15 feet in most lakes.

The areal absolute hypolimnetic oxygen deficits (Table XIV) related to the lake surface, show some variation among lakes (0.0013 to 0.0270 cc/cm²/day). The areal deficits related to the hypolimnion surface exhibit a larger range (0.0054 to 0.0346 cc/cm²/day). Mean hypolimnial oxygen deficits (Table XIV) ranged from 0.022 to 0.049 cc/liter/day. The lakes with the highest mean deficits also had the smallest volumes.

Only Bednorski Lake would be classified as eutrophic, according to the limit set by Hutchinson (1957) of 0.033 mg/cm²/day. The reason for the low values of oxygen deficit was probably due to the depths of the lakes under consideration, as well as the fact that photosynthesis probably takes place in the hypolimnion. Deevey (1940) gave similar low values for Oxygen deficits in shallow lakes in Connecticut.

TABLE XIV

Absolute areal and mean hypolimnetic oxygen deficits

Lake	Deficit to Hypolimnion surface cc/cm ² /day	Deficit to Epilimnion surface cc/cm ² /day	Mean Deficit cc/liter/day
Hiawatha	0.0054	0.0024	0.049
Kiakho	0.0188	0.0084	0.040
New	0.0102	0.0026	0.029
Jim Smith	0.0057	0.0037	0.033
Bednorski	0.0346	0.0270	0.047
Lazy	0.0061	0.0013	0.039
Lillian	0.0055	0.0023	0.022
Enid	0.0054	0.0019	0.031

Sedimentation Rates

Between August 30 and September 1 of 1961, sedimentation collectors (Patalas, personal communication) were suspended in each lake for a 10 day period. Where possible, the depth of suspension coincided with the lower limit of the thermocline.

Since none of the lakes examined contained large amounts of inorganic matter in suspension, the collectors should trap organic detritus passing through the epilimnion. No allowance can be made for material which is oxidized within the epilimnion. The so called "plankton rain" would be collected in the sediment collector in proportion to the amount to be deposited on the lake bottom. Table XV gives the sediment volumes obtained from a 10 day suspension of the collector in each lake.

Lazy, Bednorski and Kiakho lakes are outstanding as having the greatest sedimentation rates. The remaining lakes have similar quantities of sediment.

Ranking of the Lakes by Biological and Other Factors Indicating Productivity.

The method of ranking biological and other factors indicating productivity was the same as used for physical and chemical factors.

Ranking of the 9 lakes by biological factors or standing crops of plankton, bottom fauna and fish is given as Table XVI. Bednorski Lake was assigned a high rank for plankton, bottom fauna and fish whereas New and Enid lakes ranked low for the same standing crop estimates. Lakes other than those already mentioned did not show consistency in rank for all 3 factors.

Table XVII lists the individual and mean rank for other factors indicating productivity. No general relationship appears evident except perhaps that Hiawatha Lake was somewhat consistant in having a low rank by all 3 productivity measurements.

TABLE XV

Sediment volumes as measured from sediment collectors suspended
at a specified depth in each lake for a 10 day period
in September, 1961

Lake	Sediment Volume (cc)	Depth of Suspension (ft)
New	0.3	33
Enid	0.2	18
Lillian	0.3	32
Jim Smith	0.3	23
Hiawatha	0.4	14
Kiakho	1.2	23
Bednorski	1.9	30
Horseshoe	0.5	22
Lazy	3.3	35

TABLE XVI

Ranking of the 9 lakes by biological factors

Lake	Quantity of Plankton	Quantity of Bottom Fauna	Quantity of Fish	Mean Rank
Hiawatha	9.0	0.0	1.6	3.5
Kiakho	5.3	9.0	4.6	6.3
Horseshoe	5.3	4.8	7.4	5.8
New	0.1	4.2	0.8	1.7
Jim Smith	2.7	3.2	2.4	2.8
Bednorski	8.4	6.3	9.0	7.9
Lazy	4.8	2.5	0.0	2.4
Lillian	0.0	5.3	2.9	2.7
Enid	0.9	3.8	0.1	1.6

TABLE XVII

Ranking of the 9 lakes by other factors indicating productivity

Lake	Mean Hypolimnion Deficit	Gross Primary Productivity	Sedimentation Rates	Mean Rank
Hiawatha	0.0	0.0	0.6	0.2
Kiakho	4.1	1.5	2.9	2.8
Horseshoe		0.0	0.9	0.4
New	1.5	1.9	0.0	1.1
Jim Smith	0.1	1.6	0.3	0.7
Bednorski	9.0	0.0	5.0	4.7
Lazy	0.2	2.4	9.0	3.9
Lillian	0.0	9.0	0.3	3.1
Enid	0.0	8.0	0.0	2.7

DISCUSSION

While it may be true that mean depth, climate or some edaphic factor is singly most important in influencing productivity in a broad geographic area (Rawson (1955) and Northcote and Larkin, 1956), a multitude of factors by their interaction modify the primary correlates of productivity when lakes within a restricted geographic region are examined.

Few studies have been undertaken using lakes which were morphometrically similar and which were situated within a restricted geographical area. Reimers et al. (1955) examined 10 lakes within a restricted region and found almost complete disagreement of physical and chemical factors with standing crops of invertebrates. Trout growth was related to quantities of dissolved nutrients in the study by Reimers et al. (1955). On the other hand, Rawson (1960) obtained good agreement of five physical factors (T.D.S. included) with the "score" of three biological factors. The lakes examined by Rawson (1960) were widely scattered throughout a large area of Saskatchewan and exhibited greater morphometric differences than lakes in this study.

Ranking of the study lakes by physical, chemical and biological conditions, as well as other factors indicating productivity, is given in Table XVIII. Complete agreement of physical or chemical ranking with biological ranking was not evident. There was also disagreement between combined physical and chemical ranks with either biological factors or other factors indicating productivity. Mean summer plankton volumes were related to mean hypolimnial oxygen deficits as evident from Figure 10.

Standing crops of plankton, bottom fauna and fish in 9 lakes within the Southern Rocky Mountain Trench failed to correlate with a wide range of T.D.S. Also, mean depth and epilimnion temperatures were not correlated with standing crops of organisms. However, a plot of perimeter to area ratios versus mean plankton volumes (Fig. 11) resulted in a regression of 0.636 (p 0.05-0.10).

Lazy and in particular Horseshoe Lake, have major seasonal water level fluctuations which contributed to the respective low to moderate standing crops of bottom organisms. Gammarids were not represented in bottom dredge samples in either lake. Larkin and Northcote (1958) mention the possible effect on littoral bottom organisms resulting from appreciable water level fluctuation. Grimås (1961) stated that Gammarus sp. were heavily reduced with water level fluctuation in Lake Blåsjön, Sweden. Rooted macrophytes would likewise be influenced by water fluctuations which may have accounted for their absence from Horseshoe and Lazy lakes.

U-shaped lake basins with narrow littoral zones were characteristic of Jim Smith, Bednorski and Lazy lakes (Fig. 4). These were the only lakes where significant differences were observed between the average number of bottom organisms per dredging, above and below 20 feet in depth.

New and Hiawatha lakes, with large areas less than 20 feet in depth, had abundant aquatic plants. The importance of macrophytes to the production of bottom fauna has been stressed by Rawson (1930), Ball (1948) and more recently Wohlschlag (1950). It was true that lakes with numerous aquatic plants had a greater

TABLE XVIII

Ranking of the lakes by physical, chemical and biological characteristics as well as other factors indicating productivity

Physical		Chemical		Physical and Chemical		Biological		Other Factors Indicating Productivity	
Hiawatha	6.2	Enid	7.6	Enid	5.6	Bednorski	7.9	Bednorski	4.7
Horseshoe	5.0	Bednorski	4.1	Kiakho	4.0	Kiakho	6.3	Lazy	3.9
Kiakho	4.2	Kiakho	3.8	Hiawatha	3.9	Horseshoe	5.8	Lillian	3.1
Bednorski	3.8	Jim Smith	3.4	Bednorski	3.9	Hiawatha	3.5	Kiakho	2.8
Lazy	3.7	New	3.3	Horseshoe	3.8	Jim Smith	2.8	Enid	2.7
Enid	3.6	Lillian	3.0	Jim Smith	3.3	Lillian	2.7	New	1.1
Jim Smith	3.3	Horseshoe	2.7	Lazy	2.9	Lazy	2.4	Jim Smith	0.7
New	2.3	Lazy	2.2	New	2.8	New	1.7	Horseshoe	0.4
Lillian	2.1	Hiawatha	1.6	Lillian	2.5	Enid	1.6	Hiawatha	0.2

Figure 10. Relationship of average summer (June-August, 1960) plankton volumes (cc/m³) to mean hypolimnial oxygen deficits (cc/liter/day) for 9 study lakes in 1960 and 1961

variety of bottom fauna (Fig. 8) than did lakes with sparse aquatic flora. Lakes with abundant macrophytes did not have large standing crops of bottom fauna.

The lush aquatic vegetation of New and Hiawatha lakes was responsible for oxygen loss during winter stagnation (Fig. 7). Patalas (1960) mentioned lack of oxygen as a factor limiting available areas for bottom fauna. Hiawatha Lake had a low standing crop of bottom fauna while New Lake was moderate for bottom fauna but had winter fish mortality resulting from low oxygen concentrations. Although few aquatic plants were present in Enid Lake, a low standing crop of fish reflected the results of winter-kill. The limited qualitative bottom fauna of Enid Lake (Fig. 8) was due to oxygen stagnation.

Larkin (in press) stated that a small surface to volume ratio may mean less heat per unit of volume from circulation. This could have been the main reason for low epilimnion temperatures in Bednorski and Lillian lakes and high temperatures in Hiawatha Lake. Rawson (1942), and Northcote and Larkin (1956) have shown a significant relationship between summer epilimnion temperatures and standing crops of plankton. The highest mean epilimnion temperature was associated with plankton abundance in Hiawatha Lake and the lowest temperature with meagre plankton in Lillian Lake.

Perimeter to area ratios appeared related to mean summer plankton volumes (Fig. 10). Length of growing season or the large volume per unit area may mask the effects of "littoral development" on standing crops of organisms. The littoral zone should exhibit the greatest productivity because of the

Figure 11. Relationship of the ratio of perimeter to area to average plankton volumes (cc/m³) for the 9 study lakes in 1960 and 1961

overlap of the productive upper and lower surfaces at this point.

Ball and Hayne (1952) recorded significant changes in bottom fauna with removal of the fish population. Significantly lower numbers of bottom organisms per dredging were present in the littoral zone of Bednorski and Lazy lakes. Since both lakes contain redbreasted shiners which frequent the littoral zone, the faunal reduction may have resulted from grazing by fish. The limited measurement of fish biomass in this study is somewhat influenced by the species complex within lakes (Table XIII) and the occurrence of natural reproduction in some lakes and not others. The 3 lakes having natural reproduction of fish, namely Bednorski, Kiakho and Lillian, ranked as 3 out of the 4 highest by fish biomass in an overnight gill net set.

The size and nature of the drainage area (Table III) was important to the productivity of Bednorski, Lillian and Enid lakes. The large drainage area of Bednorski was composed of calcareous sedimentary deposits (Fig. 2) which undoubtedly supplied the lake with water rich in nutrients. Soils surrounding Enid and Lillian lakes were low in phosphates and this could have contributed to low to moderate plankton crops.

Without more extensive sampling it is difficult to say whether faunal deficiencies exist within the lakes studied. The absence of Gammarus sp. from some lakes has already been mentioned. Major groups such as the Hemiptera were not taken in dredge samples. Furthermore, the presence of more than 1 fish species would account for differences in fish biomass.

Gross primary productivity (Light and Dark Bottle) estimates appeared correlated with total dissolved solids (Fig. 12)

Figure 12. Relationship of total dissolved content (ppm) to gross primary productivity (mgC/m³/day) as measured by Light and Dark Bottle techniques during the period of 27 June - 8 July, 1961

but not with standing crops of plankton, bottom fauna or fish. The absence of lakes from the mid-range of T.D.S. leaves some doubt about this correlation.

Thus, although total dissolved solids may be correlated with productivity throughout British Columbia, within the limited geographic region of the Southern Rocky Mountain Trench, a number of factors interact to modify primary influences of productivity in a most complex manner.

SUMMARY

1. Standing crops of plankton, bottom fauna or fish were not correlated with a wide range (50 to 1460 ppm) of total dissolved solids in 9 lakes within a restricted geographical region of British Columbia.
2. Average summer plankton volumes appeared to be related to mean hypolimnial oxygen deficits.
3. The ratio of perimeter to area of lakes showed a relationship to average plankton volumes.
4. Total dissolved solid content was correlated with gross primary productivity estimates as measured by Light and Dark Bottle techniques.
5. Ranking of lakes by physical and chemical indices of productivity did not agree with ranking by biological or other factors indicating productivity.
6. A number of factors by their interaction were found to modify the expression of primary correlates of productivity within a restricted geographic region of British Columbia.

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