Gould

To Bill
– Best Regards
Ken Cummins

Comparative Limnology of Lakes on the Beartooth Plateau, south-central Montana

By

C. Michael Falter

B. S. Kansas State University 1964

Submitted to the Graduate Faculty in the Division of the Natural Sciences in partial fulfillment of the requirements for the degree of

Master of Science

University of Pittsburgh

1966

TABLE OF CONTENTS

Page

FOREWORD iv

I. INTRODUCTION 1

II. DESCRIPTION OF STUDY AREA 4

A. Location of Lakes 4

B. Geology of Study Area 7

C. Climate of Study Area 9

D. Ecology of Study Area 11

III. HYDROGRAPHY AND MORPHOMETRY 13

A. Methods 13

B. Results 14

IV. METHODS 23

A. Sampling Schedule 23

B. Physical and Chemical Methods 24

C. Primary Productivity 25

D. Biota Treatment 26

1. Plankton 26

2. Benthos 28

V. RESULTS 29

A. Physical Data 29

1. Temperatures 29

2. Light Penetration 35

B. Chemical Data 35

1. Oxygen 35

2. Alkalinities and pH 40

3. Chemical characteristics of the water and sediments . 42

TABLE OF CONTENTS (cont.)

Page

C. Primary Production 45

D. Phytoplankton 50

E. Zooplankton. 56

F. Benthos 60

VI. DISCUSSION 67

VII. SUMMARY 90

APPENDIX A 92

BIBLIOGRAPHY 100

FOREWORD

I wish to express my sincere appreciation to my academic advisor, Dr. Kenneth W. Cummins, for his guidance, support, and criticism throughout the course of this study and preparation of the final manuscript. Dr. C. A. Tryon, Jr. and Dr. R. T. Hartman, as members of my committee, also offered advice and criticism during planning and final reporting. Particular credit is due Dr. Cummins and Dr. Hartman for permission to include data which they had gathered in previous summers from these lakes. Dr. Cummins worked on Round, Star, and Goose Lakes in 1963 and 1964 while Dr. Hartman is responsible for the data from Beartooth Lake in 1960 and Long Lake in 1962, 1963, and 1964.

Thanks are gratefully extended to Mr. William P. Coffman and his wife Paulette for their invaluable assistance in the field work. Dr. D. J. Hall, Cornell University, provided zooplankton identifications; Dr. R. O. Brinkhurst, University of Toronto, identified the Oligochaetes; Mr. Peter A. Roff, University of Pittsburgh, identified the diatoms; and William Coffman verified midge identifications. The U. S. Geological Survey, Sacramento, California, conducted the spectrographic trace metal analyses. Credit for final preparation of the manuscript is given to Andrea Gavula and Wilma Yeschke.

Finally, my wife Karla, deserves praise for her work on the figures and her continual encouragement throughout this study.

I. INTRODUCTION

Alpine lakes have been defined as those above general treeline (Thomassen, 1956; Vinyard, 1951) since this definition serves as a good index of the intermixed environmental factors. Subalpine lakes are thus considered to be those at and immediately below treeline until montane or mesophytic transition forest is reached. Strøm (1938) gives a similar but less distinct definition based upon thermal qualities. He considered an alpine lake as ". . . a lake which is thus considerably elevated above the sea-level that its net heat income is materially less than that of the lowland lakes within the same geographical region." By this latter criterion, definitive lines are hard to draw, but nontheless, alpine lakes markedly differ from lakes of lower elevation in physical, chemical, and biological characteristics.

It was the intent of this study to comparatively examine the limnology of three alpine and subalpine lakes in the Beartooth Mountains of southwestern Montana. Initial productivity studies were conducted in late summer of 1963 and 1964, with the main field work being conducted in August, 1965. It is regrettable that this study was limited to the late summer season, but the great distance from the study area and general inaccessibility at other times prohibited sampling for seasonal variation.

The present condition of a lake is to a large part directed by the climate of the region. This control becomes even more important in alpine environments because of the great variability of environmental conditions. Generally, with altitude solar insolation increases, soil temperature ranges increase, winds and wind velocity increase, and total precipitation, evaporation, cloud cover, and snow percentages increase. Air pressure, absolute humidity, and air temperatures decrease with increased altitude.

Arctic and alpine lakes are often compared on the basis of similar climates. Mean temperatures of alpine regions may approximate those of arctic regions, but the former have much wider diurnal and seasonal temperature ranges. In addition, alpine situations receive more intense solar insolation due to a thinner and more pure atmosphere at high elevations. Reduced air pressure at high latitudes has a unique effect (Mean atmospheric pressure at 2911 miles (9550 feet) the average altitude of the study area, is 20.85 inches of mercury as opposed to 30 inches at sea level.) With lowered atmospheric pressure, partial pressures of oxygen drop considerably, thus abetting the inherent nature of soils to develop low oxygen concentrations. Ionizing fractions of solar insolation increase considerably with altitude since there remains less of the energy-absorbing blanket of carbon dioxide, water vapor, and dust above these high areas.

Foundation work in alpine limnology can be credited,to a large extent, to Pesta (1929), Steinböck (1934 and 1938), and Strøm (1938), in Europe and Hutchinson (1937) and Pennak (1945, 1955, 1958) in the United States. High altitude lake investigations in the Western United States have been due primarily to fisheries interests. At least up to the time of Pennak's 1941 published bibliography of alpine studies in this country, these works were primarily applied to fisheries use. In a sense, this is regrettable since preconceived goals often limit the scope and eventual conclusions of new research. Recently, however, has come the needed recognition of these pure waters as excellent places to study workings of simple uncluttered aquatic systems on their own merits. Goldman's work in the Sierra high lakes (1960, 1961, 1963, 1964, 1965) demonstrates the picture-window view of lentic metabolism offered by these extreme oligotrophic lakes.

A lake's present condition is a direct result of its basin geology. Therefore, in this study I have attempted to correlate water quality and productivity with present geology of the watersheds. Pennak (1945) emphasizes the importance of this approach as have Deevey (1940) and the works of Birge and Juday (1927, 1934, 1938) in northeastern Wisconsin. It is hoped that this present study, through the presentation of a somewhat instantaneous picture, will serve as the first step towards a more intensive study of these three lakes in the future.

II. DESCRIPTION OF STUDY AREA

A. Location of Lakes

The lakes studied lie on the Beartooth Plateau of southcentral Montana at altitudes of 2831 meters (9340 feet) to 2998 meters (9830 feet), in the Gallatin National Forest. As shown in Figure 1, the lakes lie on the southwestward-facing slope of the Beartooth fault block. The U. S. Geological Survey topographic map (1956) places them at 45°06' N. latitude; 109°55' W. longitude, or about 9 miles N. E. of the northeast corner of Yellowstone National Park near the Montana-Wyoming border (Figure 2). U. S. Highway 212 traverses the area, crossing Beartooth Pass out of Red Lodge, Montana. Round Lake, the lowest lake studied, lies north of Highway 212 and is accessible by a two-hour jeep trail. Star Lake is an additional 1. 5 miles; and Goose Lake yet another mile, all three being on the same trail (Figure 2). July through September the trail is regularly traveled by fishing and touring parties out of Cooke City, Montana, to the south on Highway 212. One camping cabin is on the shore of Round Lake with regular but light fishing pressure on the lake. Star Lake's shore is free from any improvements save an occasional campsite. The shores of Goose Lake are presently uninhabited, but for several years prior to 1925 the Copper King Mining Company of Cooke City worked diggings around the lake, concentrating on a 60 foot shaft adjacent to the main north inlet (Lovering, 1929).

Round and Star Lakes drain southward into the Clarks Fork of the Yellowstone River which flows east off the Plateau, then turns north to join the Yellowstone River. Goose Lake is drained by

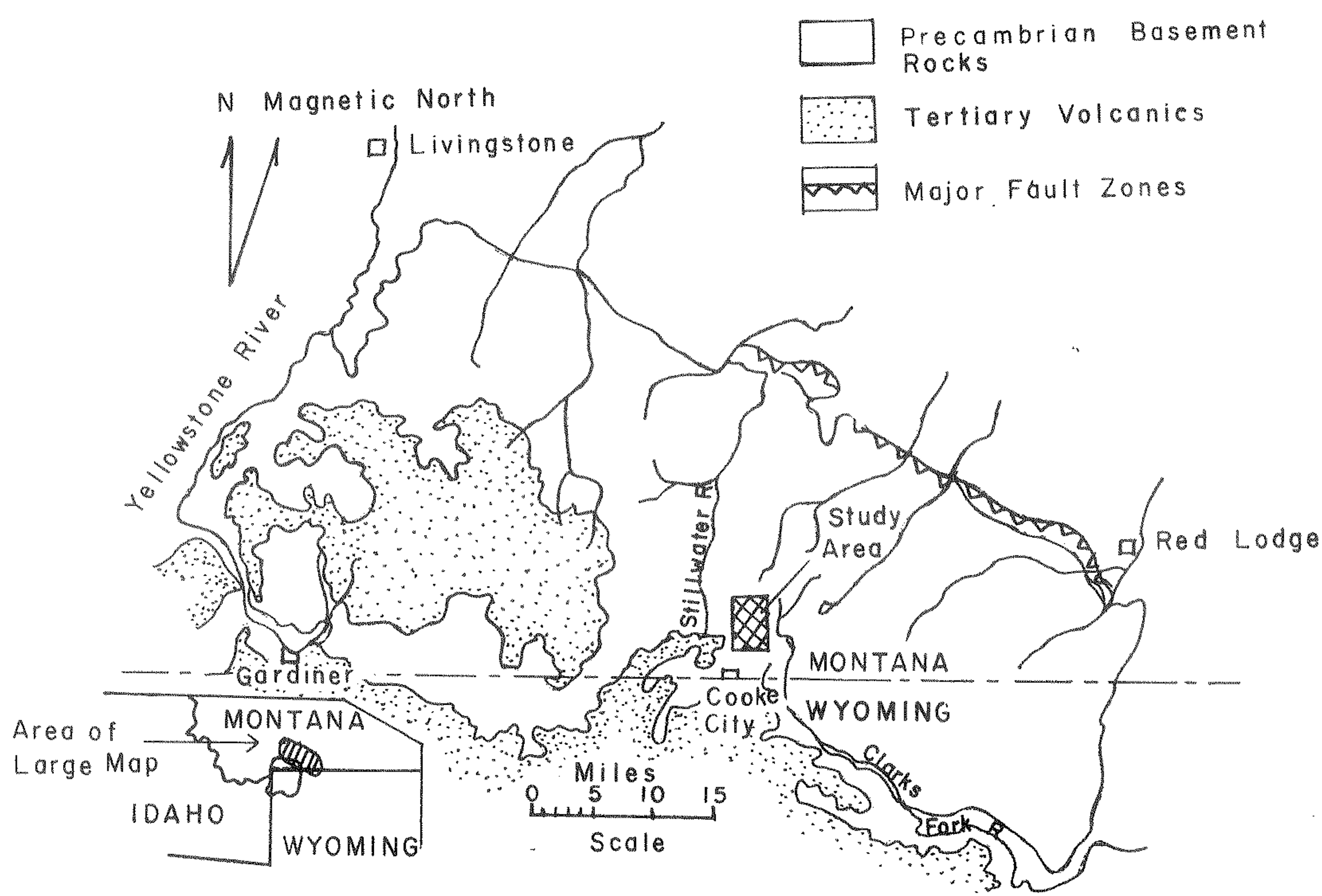

Figure 1. Geographical location and major geological structures of the Beartooth Plateau.

Goose Creek flowing westward to serve as a main feeder stream of the Stillwater River. The latter also eventually empties into the Yellowstone River to the north.

B. Geology of Study Area

In Montana as well as Colorado and Wyoming, the cores of the mountain ranges are formed by a highly metamorphosed and folded group of Precambrian rocks. An overlying sedimentary group, Precambrian also, but less metamorphosed, is often stripped away to expose the basement group of schists, gneisses, and granites (Clark and Stearn, 1965). The Beartooth Mountains form an archlike uplift with a northwest-southeast axis and bounded on the northeast face by the Beartooth fault (Figure 1).

Eckelmann and Poldervaart (1957), using potassium-argon methods, estimated that these granitization processes occurred 2.7 ± 0.1 billion years ago. Depression of a geosyncline to the west then caused the blocklike uplift of the Beartooth region as well as the Big Horn, Teton, Gros Ventre, and Wind River Ranges. Characteristic of these mountains are their associated basins whose thicker sediment accumulations prevented a corresponding uplift. Then late Pre-Cambrian peneplanation of this uplift left an exposed core for Paleo- and Mesozoic sedimentation to cap over during a drawn-out epeirogenic subsidence. Renewed uplift of the Beartooth Block during the Laramide orogeny combined with differential thrusting resulting in the present assymetrical southwest-sloping anticlinal fold (Harris, 1959; Spencer, 1959). Nowhere on the uplift are there any remaining Mesozoic sediments. Glaciation has effectively scoured the Archean core of later deposits resulting in a deeply dissected spectacular relief of greater than 7,000 feet on the northeast side and 2,000 feet on the gradually sloping southwest flank. There has been no extrusive igneous activity in the evolution of the Beartooth Block. Spencer (1959) and Prinz (1964), however, report that the folded granitic gneisses throughout the core are complexly fractured and intruded with dikes. With the exception of an outcropping of the sedimentary Gros Ventre formation in the Round Lake drainage, these dikes are the only source of mineral variation in the predominating Goose Creek granite bedrock formation (Lovering, 1929). Tertiary times saw the covering of the Block's southwest flank by volcanic flows of the Yellowstone and Absaroka formations (Harris, 1959). The Clark's Fork River canyon flowing eastward marks the fartherest point of lava flowage onto the downward-tilting crystalline rocks.

As evidenced by the knob and kettle topography, the entire region was once submerged by ice. Large valley glaciers were numerous a comparatively short time ago since glaciers may still be found in the area (notably Grasshopper Glacier just northeast of Goose Lake but not draining into it). Lovering (1929) contends that the retreating glaciers probably left most of the deeper unconsolidated materials in the valleys, but nearly all presently exposed mantle rock can be attributed to landslides. The three lakes studied, as all lakes on the Plateau, are of glacial origin. Round and Star are shallow basins apparently plucked out by moving ice. Goose Lake, however, is the floor of a wide, U-shaped hanging valley surrounded by high peaks on three sides. The lake appears to have been formed by subsequent morainal damming of the valley.

More specific details of rock types of the individual watersheds will be discussed later in relation to limnological details of the lakes.

Soils in the area studied are predominately podzols of a sandy loam texture. Cox (1957) describes them as having ". . . humus high in organic acids, an eluvial siliceous platy gray A_2, and an illuviated yellowish-brown B_2 which has been colored by iron oxides and organic matter." Montane and subalpine soils have developed on surprisingly deeply weathered granitic rocks, but the surface and substratum are freely interspersed with boulders and cobbles. Leiberg (1904) reports them as being generally poor in nutrient quality. Exchangeable hydrogen is high with low base content. With increased altitude and the accompanying decreased soil maturity due to cryopedogenic processes, the B horizon diminishes. Most alpine soils of the Plateau have only A and C profiles with surface organic matter accumulation as the most conspicuous vertical variation (Johnson and Billings, 1962). Leaching is not an important factor in profile development as attested to by low clay content, medium pH values, and prominance of lithosols. These high plateau soils have a texture of a gravelly, sandy loam, low in clays and organic matter.

C. Climate of Study Area

Because of the high altitude of this region, its climate is much different from that of Red Lodge, Montana, 60 miles to the east and 4,000 feet lower in elevation. The table below illustrates the differences between the study area and the Red Lodge station. The 4,000 foot increase in elevation of the study area accounts for the 55 per cent increase in annual precipitation from 47 cm. (18.4 in.) at Red Lodge to 69-70 cm (27-30 in.) annually on the Plateau.

Table 1. Climatological data for the Beartooth study area and Red Lodge, Montana *.

	Red Lodge	Beartooth Area
Altitude	1692 m (5550 ft.)	2911 m (9550 ft.)
Growing Season**	140 days	48 days
Precipitation	46.7 cm (18.4 in.)	69-77 cm (27-30 in.)
Mean Annual Air Temperature	4.4° C. (39.9° F.)	-7.8° C. (18° F.)
Average Maximum Temperature, July	24.1° C. (75.4° F.)	18.3° C. (65° F.)
Average Minimum Temperature, January	3.9° C. (9.1° F.)	-20.0° C. (-7° F.)
Snowfall	269 cm (106 in.)	432 cm (170 in.)
Precipitation in June, July, and August	12.7 cm (5.0 in.)	15.0 cm (5.9 in.)

* The data for the study area were compiled from Larsen (1930), Baker (1944), and Johnson and Billings (1962) since climatological stations even at moderate altitudes in the Beartooth area are rare. There appear to be none above 1980 m (6,500 ft.) on the Plateau itself, but a few are operating in or near Yellowstone National Park. Red Lodge data are taken from Larsen (loc. cit.), and U.S.D.A. 1941 Yearbook of Agriculture, Climate and Man.

**Growing Season=number of days when mean temperature is greater than 5.6° C. (42° F.).

A synthesis of reports from several authors shows that a true subalpine precipitation peak is present in this area; thus, Round Lake is shown to have a 15 per cent higher rainfall than Goose Lake above treeline (Larsen, 1930; Oosting, 1956; and Johnson and Billings, 1962). Likewise, when going up to 2911 m (9550 ft.) mean annual air temperature drops from 4.4° C. to -7.8° C (39.9° F. to 18° F.) and length of the growing season drops from 140 days to 48 days. Total precipitation for the summer months is approximately equal at both locations meaning that the elevational total precipitation increase is manifested as increased snow cover during winter months. As in most mountainous areas of the central Rockies, the yearly pattern of precipitation is one with a February-April peak and a late summer (July-August) low (Lull and Ellison, 1950). Annual cloud cover averages 55 per cent annually with 40 per cent cloud cover in August. Wind velocities range from a mean of 27 kilometers per hour (17 miles per hour) in January to 14 kilometers per hour (9 miles per hour) in August (Johnson and Billings, Ibid).

D. Ecology of Study Area

Ecologically speaking, the three lakes studied fall into two zones, the mesophytic subalpine forest and the central Rockies alpine zone of alpine forest merging into true tundra.

Round Lake lies in subalpine forest, which, in this region extends from tree line down approximately 460 m (1,500 ft.) to where it merges into a transition forest of Douglas fir (*Pseudotsuga menziesii*, Englemann spruce (*Picea engelmanii*), and is dominated by lodgepole pine (*Pinus contorta* var. *murrayana*). The subalpine zone itself consists of Englemann spruce and alpine fir (*Abies lasiocarpa*) with smaller amounts of whitebark pine (*Pinus albicaulis*) (Oosting, 1956). Bryophytes and herbaceous plants predominate as ground cover on the moist slopes with *Vaccinium* spp. common on drier sites. In this region timberline is found at approximately 2990 m (9800 ft.) although on the Eastern part of the plateau, it occurs at 3050 m -3350 m (10,000 - 11,000 ft) (Larsen, 1930; Griggs, 1938). Treeline lies above or below 2990 m (9800 ft.) depending upon local terrain, soil condition, and exposure. Star Lake at 2968 m (9730 ft) is in the transition zone while Goose Lake is higher at 2998 m (9830 ft) but isolated, stunted pines are still to be found 15 m (50 ft.) above the lake. This transition zone is marked by limber pine (Pinus flexilis) in addition to Englemann spruce and alpine fir. Sedges and grasses predominate in the true alpine zone above treeline. I have considered Goose Lake to be within this zone. Johnson and Billings (1962) report that true tundra on the Plateau is characterized by: Avens (Geum rossii), sedges (Carex drummondiana and C. scopulorum), deschampsia (Deschampsia caespitosa), sage (Artemesia scopulorum), and cotton grass (Eriophorum callitrix).

III. HYDROGRAPHY AND MORPHOMETRY

A. Methods

Shore outlines of the lakes were determined by the plane table and alidade method as described by Welch (1948). Stations around the lakes were sighted on through a non-telescopic alidade from either end of a baseline of known length. Constant voice contact was maintained by 2-mile range walkie-talkies between map and stakemen to avoid confusions in station numbering and to permit rapid description of shoreline irregularities to a recorder at the plane table. Shoreline maps were then constructed to scale in Pittsburgh. Comparison with aerial photographs at a scale of 1:12,400 showed high accuracy of ratios. A Heathkit battery-operated sonic depth sounder was employed to sound the lakes. Simultaneously with each sounding, the boat's location was fixed by sextant readings of two adjacent shore angles upon three of several signals located during the shoreline mapping. A three-armed protractor (B. K. Elliot, Co., Pittsburgh) was used to plot each sounding on the shoreline maps after which depth contours were drawn. Areas within depth contours were measured by planimetry. These values were then used to calculate individual strata and total lake volumes using the volume formula of Welch (1948). Shoreline length was measured by a linear distance map measurer. Mean depth is represented as the volume of a lake divided by its surface area. Lake drainage areas were calculated by planimetry of stereo relief aerial photographs.

B. Results

The lake maps are shown in Figures 3, 4, and 5. Accompanying morphometric details are shown in Table 2. The data are expressed as both metric values and their english equivalents. The ratio of areas for Goose, Round, and Star Lakes is 14:4:1, total areas being 41. 18 Ha (101. 75 A), 12. 54 Ha (30. 98 A), and 3. 21 Ha (7. 94 A), respectively. The approximate ratio of volumes is 41:3:1 for Goose, Round, and Star Lakes. Goose is deepest with a maximum depth of 39. 6 M (130 ft.) and a mean depth of 14. 4 M (46. 4 ft.), while Round is shallowest at a mean depth of 3. 5 M (11. 1 ft.). Mean depth of Star Lake is 4. 5 M (14. 4 ft.). Shore development values (Ratio of a lake's shoreline to the circumference of a circle of the same area) for Goose, Round, and Star Lakes are 1. 54, 2. 27, and 2. 88. Water level fluctuations are negligible throughout the year. Shoreline examination showed them to be no greater than $\pm$ 0. 2 meter.

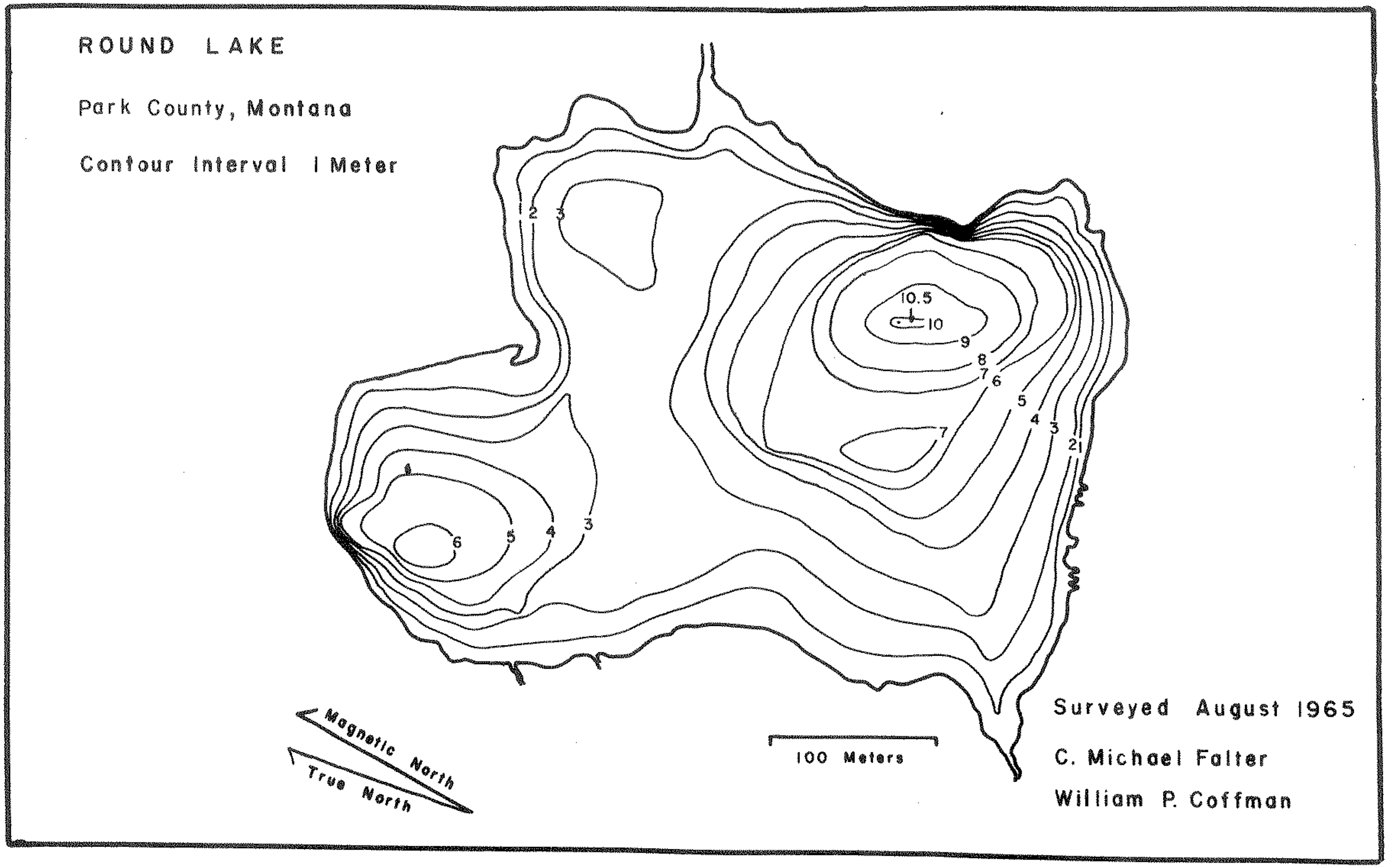

Figure 3. Hydrographic Map of Round Lake.

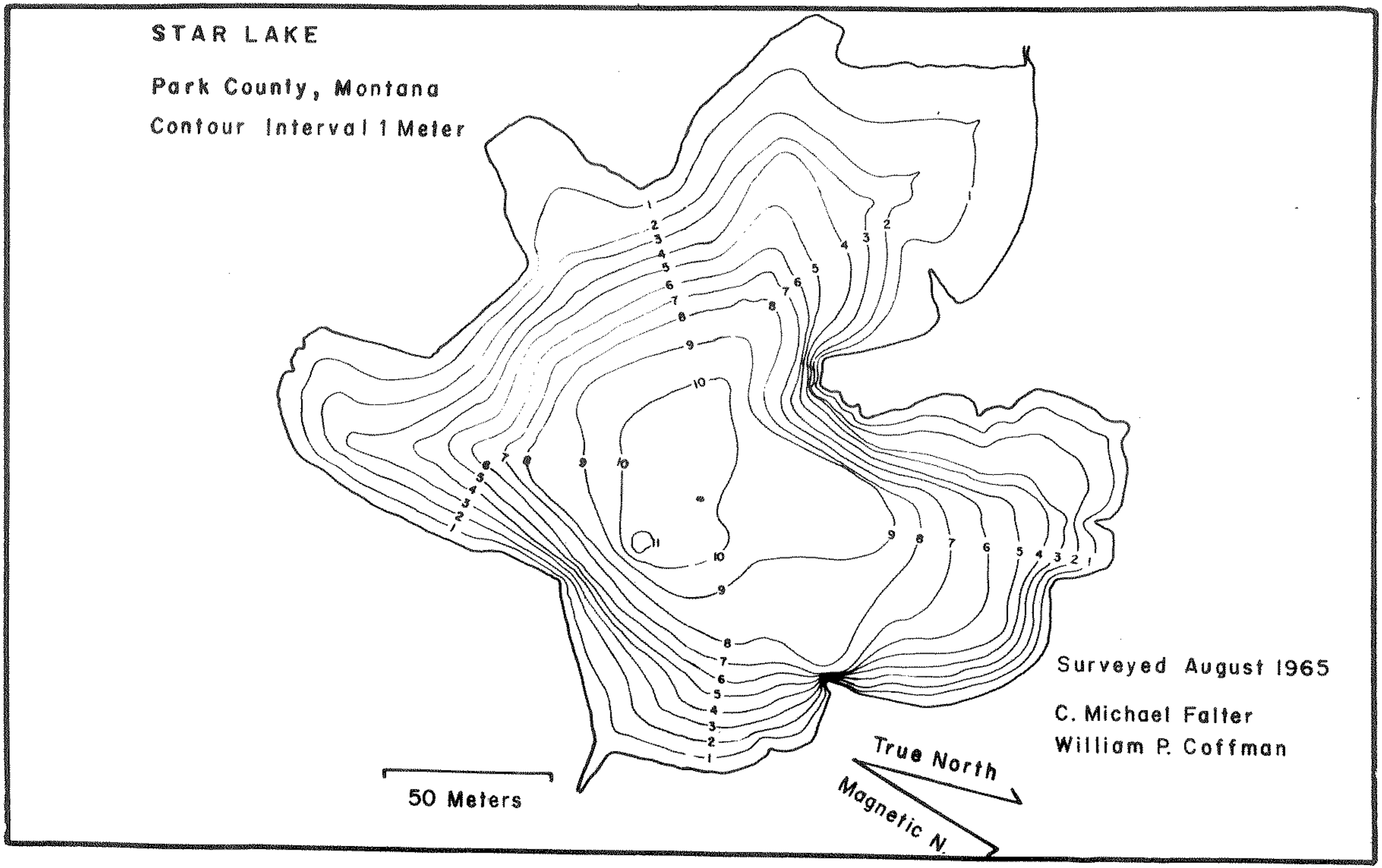

Figure 4. Hydrographic Map of Star Lake.

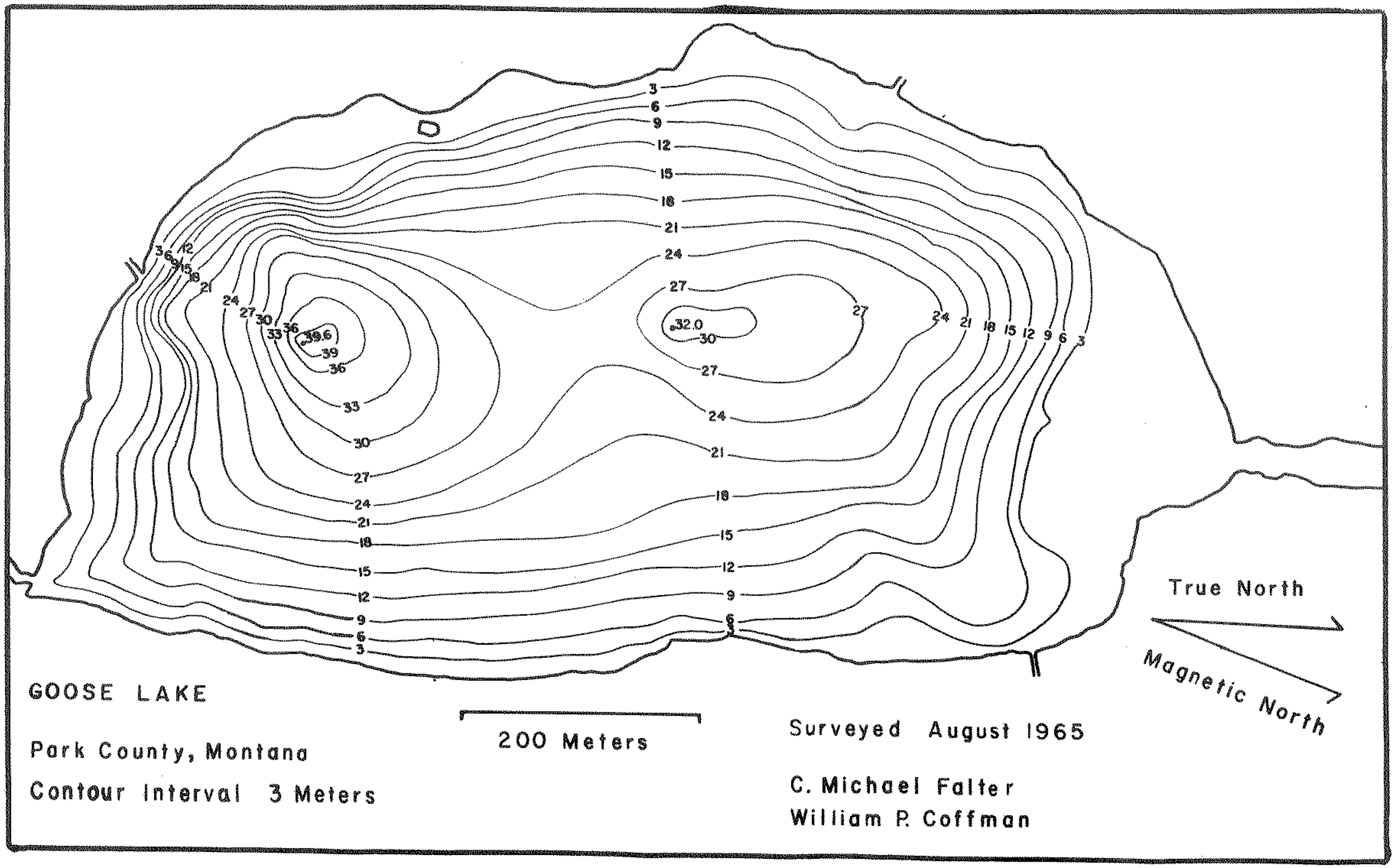

Figure 5. Hydrographic Map of Goose Lake.

Table 2. Round, Star, and Goose Lakes. Morphometric features.

		Round L.	Star L.	Goose L.
Altitude				
	Meters	2831	2968	2998
	Feet	9340	9730	9830
Area				
	Hectares	12. 54	3. 21	41. 18
	Acres	30. 98	7. 94	101. 75
Volume				
	Cubic Meters	433, 460	143, 750	5, 943, 650
	Gallons	114, 498, 400	37, 971, 100	1, 570, 015, 900
Maximum Depth				
	Meters	10. 5	11. 0	39. 6
	Feet	34. 5	36. 1	130. 0
Mean Depth				
	Meters	3. 5	4. 5	14. 4
	Feet	11. 5	14. 4	46. 4
Shoreline Length				
	Meters	1890	1085	2820
	Feet	6082	3492	9252
Shore Development				
		2. 27	2. 88	1. 54
Maximum Length				
	Meters	488	257	990
	Feet	1601	827	3185
Maximum Width				
	Meters	378	224	513
	Feet	1220	721	1650

Table 3. Round and Star Lakes. Areas within each Depth Contour.

Depth	Round L.	Star L.
Shoreline	12.54 Hectares 30.98 Acrea	3.21 Hectares 7.94 Acres
1 Meter	10.84 Ha 26.78 A	2.56 Ha 6.33 A
2 M	9.38 Ha 23.18 A	2.14 Ha 5.28 A
3M	6.11 Ha 15.10 A	1.81 Ha 4.47 A
4M	4.09 Ha 10.10 A	1.57 Ha 3.89 A
5M	2.98 Ha 7.36 A	1.34 Ha 3.31 A
6M	1.93 Ha 4.77 A	1.13 Ha 2.80 A
7M	1.10 Ha 2.70 A	0.93 Ha 2.30 A
8M	0.62 Ha 1.54 A	0.75 Ha 1.85 A
9M	0.21 Ha 0.53 A	0.67 Ha 1.64 A
10M	0.04 Ha 0.09 A	0.16 Ha 0.40 A
11M	———	0.03 Ha 0.08 A

Table 4. Goose Lake. Areas within each depth contour.

Depth	Area
Shoreline	41.18 Hectares 101.75 Acres
3 Meters	33.51 Ha 82.81 A
6 M	29.82 Ha 73.69 A
9 M	26.31 Ha 65.01 A
12 M	22.90 Ha 56.58 A
15 M	19.79 Ha 48.91 A
18 M	16.67 Ha 41.18 A
21 M	12.79 Ha 31.62 A
24 M	8.46 Ha 20.91 A
27 M	4.46 Ha 11.02 A
30 M	2.08 Ha 5.13 A
33 M	0.97 Ha 2.41 A
36 M	0.33 Ha 0.82 A
39 M	0.10 Ha 0.25 A

Table 5. Round and Star Lakes. Individual strata and total lake volumes. Values in cubic meters and gallons.

Strata	Round L. Vol. of Strata	Round L. % of Total	Star L. Vol. of Strata	Star L. % of Total
0-1 Meter	116,776 m^3 30,846,200 gal	26.94%	28,815 m^3 7,611,400 gal	19.78%
1-2 M	101,004 m^3 26,680,100 gal	23.30%	23,447 m^3 6,193,500 gal	15.98%
2-3 M	76,881 m^3 20,308,000 gal	17.74%	19,698 m^3 5,203,200 gal	13.50%
3-4 M	50,651 m^3 13,379,400 gal	11.69%	16,903 m^3 4,464,900 gal	11.55%
4-5 M	35,185 m^3 9,294,100 gal	8.12%	14,544 m^3 3,841,800 gal	9.90%
5-6 M	24,353 m^3 6,432,800 gal	5.62%	12,287 m^3 3,245,600 gal	8.35%
6-7 M	14,932 m^3 3,944,300 gal	3.44%	10,303 m^3 2,721,500 gal	7.14%
7-8 M	8,494 m^3 2,243,700 gal	1.96%	8,395 m^3 2,217,500 gal	5.64%
8-9 M	4,008 m^3 1,058,700 gal	0.92%	7,071 m^3 1,867,800 gal	4.71%
9-10 M	1,119 m^3 295,600 gal	0.26%	3,852 m^3 1,017,500 gal	2.47%
10-11 M	59 m^3 15,600 gal	0.01%	1,434 m^3 378,800 gal	0.98%
Total Lake Volume	433,462 m^3 114,498,400 gal	100.00%	143,749 m^3 37,971,100 gal	100.00%

Table 6. Goose Lake. Individual strata and total lake volumes. Values in cubic meters and gallons.

Strata	Volume of Strata	% of Total
0-3 Meters	1,114,673 m^3 294,439,800 gal	18.76%
3-6 M	948,723 m^3 250,604,200 gal	15.96%
6-9 M	841,382 m^3 222,250,200 gal	14.16%
9-12 M	737,521 m^3 194,815,400 gal	12.41%
12-15 M	639,823 m^3 169,008,600 gal	10.76%
15-18 M	546,251 m^3 144,291,700 gal	9.19%
18-21 M	440,646 m^3 116,396,200 gal	7.14%
21-24 M	316,734 m^3 83,665,000 gal	5.33%
24-27 M	190,672 m^3 50,365,800 gal	3.21%
27-30 M	95,827 m^3 25,312,600 gal	1.61%
30-33 M	46,277 m^3 12,224,000 gal	0.79%
33-36 M	18,711 m^3 4,942,500 gal	0.31%
36-39 M	6,208 m^3 1,639,800 gal	0.10%
39-39.6 M	205 m^3 54,200 gal	———
Total Lake Volume	5,943,653 m^3 1,570,015,900 gal	100.00%

IV. METHODS

A. Sampling Schedule

Work done in late summer of 1960, 1962, 1963, and 1964 on these and other lakes of the Plateau consisted of irregularly spaced carbon-14 productivity and standard chemical determinations. This work carried out by Dr. Cummins and Hartman of the University of Pittsburgh, has been used to supplement my own study.

Throughout August, 1965, five sampling trips were made to Round, Star, and Goose Lakes from a base camp at Cooke Pass on Highway 212. It was impossible to transport enough supplies and sampling equipment to carry out all measurements on every trip so sampling runs were divided accordingly.

On August 6, an exploratory trip was made to each lake. Goose Lake was briefly sounded and a temperature profile was taken. On August 10-11, Round Lake was mapped and sounded; a jeep breakdown prevented further work. From August 15 through August 18, Goose and Star Lakes were mapped and sounded. Standard physical and chemical measurements were taken, in addition to benthic samples and water for organic matter and chemical analyses on all three lakes. A trip to Star Lake occupied August 21-22 as a carbon-14 productivity run was made. Plankton sampling was done at this time. These same operations for Goose and Round Lakes were carried out on the final trip of August 23-24. Standard physical and chemical measurements were also carried out during these final two trips.

B. Physical and Chemical Methods

Temperature measurements were taken with a Model Ft-2 Electrical Resistance Thermometer (Allied Research Associates, Austin, Texas). Underwater light readings were taken in the middle of each carbon-14 run with a Marine Submarine Photometer (G. M. Mfg. Co., New York). The deck cell readings were later calibrated to Langleys(cal. per cm^2) with a Belfort Pyrheliograph. A portable Oxygen Cell Analyser (Precision Scientific Co., Chicago) was used to determine oxygen content. These readings were taken in the boat, as soon as the 250 ml. B. O. D. bottles were filled, with the aid of a battery-operated magnetic stirrer. The Oxygen Cell Analyser was calibrated at the beginning and end of August using the unmodified Winkler analysis since nitrite was assumed to be negligible (Hutchinson, 1957; A. P. H. A., 1960). Free CO_2 and alkalinities were determined by titration with 0.02 N Sulfuric acid and Sodium hydroxide, using phenolphthalein and methyl orange as indicators. Hydrogen ion concentrations were determined colorimetrically with bromthymol blue and phenol red, using standard Hellige disc comparators (Hellige Corp., Garden City, New York).

Water samples for nutrient, organic matter, total dissolved solids, and conductivity analyses were collected from a depth of 3 meters over each lake's deep point. These water samples, as well as water samples taken for all other purposes, were collected in a 2 liter brass Kemmerer Water Bottle. Each sample was placed in a 4 liter polyethylene bottle, immediately packed in snow, then taken back to camp where the samples were divided into 250 ml portions in sterile Twirl-Pak bags and frozen until analysis. Two exceptions to this procedure were the preparation of samples for nitrate and trace metal analysis. Nitrate samples were collected as separate 300 ml Twirl-Pak samples to which 3-4 drops of 5 per cent chloroform were added to retard bacterial action until freezing. For trace metal analyses, 2 liters of water were concentrated to 35 ml by slow boiling in Pyrex flasks. These concentrates were frozen and shipped to the U. S. Geological Survey, Sacramento, California, for emission spectrographic analysis of 17 trace metals. Silica, nitrogen, and phosphorous were measured colorimetrically with the Hellige Aqua Tester. Total residue, ash, and non-volatile organic matter content were obtained by drying replicated 125 ml samples at 100° C. To determine particulate residue of water, replicates were filtered through tared 0. 45 micron Millipore filters (Millipore Filter Corp, Bedford, Mass.) then dessicator-dried. Conductivity of the water converted to ppm total dissolved solids was read from a Myron Dissolved Solids Meter (Precision Scientific Co. , Chicago).

C. Primary Productivity

Primary productivity may be measured in several ways, the two most reliable being direct measurements of carbon uptake and oxygen evolution. Various aspects of these and other methods are reviewed by Ryther (1956). In the present study, the method of carbon-14 uptake measurement initiated by Steemann-Nielsen (1951) and improved upon by Goldman (1960 and 1963) was used. The basic method involves the resuspension of a water sample at its original depth in a clear 250 ml B. O. D. bottle after innoculation with 5 microcurie ampoules of $NaHC^{14}O_3$ in aqueous solution (New England Nuclear

Table 20. Diatom occurrence list. Round, Star, and Goose Lakes, August, 1965.

SPECIES	Round			Star			Goose		
	1M	4M	6M	Surf.	3M	5M	5M	10M	20M
Relative ranking system: r= rare p= present c= common									
CHRYSOPHYTA (Bacillariophyceae)									
Achnanthes clevei Grynow						r	r		
A. lanceodata var. rostrata Hust					r		r		
A. linearis W. Smith	p	p	p		p				
A. minutissima Kütz	p						r		
A. oestrupii Hust			r						
A. peragallii Brun et Heriband		r							
A. sp.			r						
Amphora perpusilla Grun		r	r		r				
A. sp.					r	r			
Anomoeoneis exilis (Kütz) Cleve						r			
Asterionella formosa Hass	p	p	p				r		
Caloneis latiuscula (Kütz) Cleve							r		
C. sp.						r			
Ceratoneis (Kütz)						r		r	p
C. sp.							r		
Coconeis themensis Mayer		r							
C. sp.	r								
Cyclotella bodanica Eylenst					r				
C. steligera Cl. Grun	p	r	r		p		c	c	c
C. spp.		r	p						
Cymbella affinis Kütz	r	r							
C. cistula (Hemprich) Grun		r							
C. herbridica (Gregory) Grun			r	r	p	p			p
C. microcephela Grun	p	p	p		p				
C. naviculiformis Auerswald			p		p	p	p		
C. turgidula Grun	r								
C. ventricosa Kütz	c	c	c	r	p	p	p	p	r
C. sp.		r			r				
Diatoma anceps (Ehr.) Grun		p			p	p	p	p	c
Diploneis ovalis (Hilse) Cleve			r						
D. sp.		r							
Epithema sorex Kutz	c	p	r				r		
Eunotia areus Ehr						r	r		r
E. bidentula W. Smith			r						

Table 20 (Continued). Diatom occurrence list. Round, Star, and Goose Lakes, August, 1965.

SPECIES	Round			Star			Goose		
	1M	4M	6M	Surf.	3M	5M	5M	10M	20M
E. pectinalis var. minor (Kutz) Rab								r	
E. praerupta Ehr	r	p			r	r			
E. serra var. diadema (Ehr.) Patr.					r				
E. incisa (Kütz) Rabh					r				
Fragilaria capuncina Desmazieres		r		p					
F. constuens (Ehr) Grun	p	c	c			p	p		
F. crotonensis Kitton	p								
F. pinnata Ehr	c	c	c		p	p	c	p	c
F. virescens Falfs		p	p			p	p		
F. spp.			p					r	
Frustulia rhomboides (Ehr) Detoni					r			r	
var sanonica					p		r		
F. vulgaris Thwaites				r					
Gomphonema angustatum (Kütz) Rabh			r						
var producta Grun					r				
G. constrictum Ehr	p	p	r				r		
var capiata (Ehr) Cleve				r		r			
G. gracile Ehr	r		r		r				
G. longiceps var. subclavata Grun					r				
G. olivaceum Lyng			r						
G. parvulum Kütz					r	r	r	c	
Gyrosigma attenatum (Kütz) Rabh		r	r						
Hantzschia amphioxys (Ehr) Grun					r				
Melosira distans (Ehr) Kütz	p	r			c				
var. lirata (Ehr) Bethge					c	c			
M. italica (Ehr) Kütz				p	c	p	p	c	p
Meridion circulare Agardh		r	r				r		
Navicula anglica Ralfs			r						
N. bacilliformis Grun		p			r	r	c		
N. bacillum Ehr		p	r						
N. cincta var Haufleri Grun			r						
N. cryptocephala Kütz	p	p	p	p	r		r		p
var. intermedia Grun			p						
N. var. veneta (Kütz) Grun			r						
N. cuspidata Kütz		r							
N. exigua-like (Greg) O. Muller			r						
N. minima-like Grun			p				r		
N. new species			r				r		
N. pupula Kütz			p	p	p			r	p
var. rectangularis (Greg) Grun	p	p				p			

Table 20 (Continued). Diatom occurrence list. Round, Star, and Goose Lakes, August, 1965.

SPECIES	Round			Star			Goose		
	1M	4M	6M	Surf.	3M	5M	5M	10M	20M
N. pesudosaitiformis Hust		p		r	p	r	r		p
N. sp.	r	r	r	r	r	r	r	r	r
N. ventralis Krasske				r	c	r			
N. verecunda Hust		r							
Neidium affine (Ehr) Cleve			r						
var. longiceps (Greg) Cleve					r				
N. dubium (Ehr) Cleve						r			
N. iridis (Ehr) Cleve									r
var. amphigomphus (Ehr) V. Heuvck	r	r	r		r				
var. ampliata (Ehr)								r	
fo. vernalis Reickelt					r		r		
N. new species						r			
Nitzschia amphibia Grun		p	r		r				
N. dissipata (Kütz) Grun		r			p	r	r		
N. epiphytica O. Müll	p	r	r				r		
N. fonticula Grun	r	r	r	r		r	r		p
N. sp.		r		r	r			r	
Pinnularia borealis Ehr					p		p	r	e
P. Brevidostata Cleve						r			
P. fasciata Lagerstedt	r		r		r	r	r		
P. gibba Ehr.		p	p	r		p			
var. mesogongyla (Ehr) Hust			r						
P. interupta W. Smith	p	r		p	c	p	p	p	p
P. Karelica Cleve					r				
P. mesolepta (Ehr) W. Smith						p			
fo. angusta Cleve								r	
P. microstauron (Ehr) Cleve					p	p		p	p
var. brebissonii (Kütz)				p					
P. new species		r							
P. spp.		r			r			r	
Rhopalodia	r			r					
R. gibba (Ehr) O. Mull		p							r
Stauroneis anceps Ehr				p	p	r	p		
var. gracilis (Ehr) Cleve				p					
fo. linearis(Ehr) Cleve		r							
S. new species					r	r			
S. parvula var. prominula Grun					r				
S. phoenocentron Ehr			p	p		r		r	
S. pygmaea Krieger					r				

Table 20 (Continued). Diatom occurrence list. Round, Star, and Goose Lakes, August, 1965.

SPECIES	Round			Star			Goose		
	1M	4M	6M	Surf.	3M	5M	5M	10M	20M
Suriella biseriata Brebisson		r							
S. gracilis (W. Smith) Grun		r							
S. linearis W. Smith				r					
var. *helvetica* (Brun) Meister					r				
S. ovata Kütz								r	
S. robusta	r								
S. sp.					r				
Synedra affinis Kütz			p						
S. parasitica W. Smith		p	p	r	p			p	r
S. rumpens Kütz							r		

Table 21. Complete species occurrence list of Round, Star, and Goose Lakes, August, 1965.

	Round L.	Star L.	Goose L.
CHLOROPHYTA			
Acanthosphaera zachariasi Lemm.	X	X	
Chlamydomonas sp.	X		
Chlorella vulgaris Beijerinck	X		
Closteridium sp.	X		
Closteriopsis sp.	X		X
Coelastrum microporum Nag	X		
Cylindrocapsa conferta W. West	X		
Dictosphaerium pulchellum Wood	X	X	X
Elakotothrix gelatinosa Wille		X	
Gloeocystis ampla Kuetz	X	X	
G. gigas (Kuetz) Lag.	X	X	
Kirchueriella sp.		X	
Mougetia sp.	X	X	
Scenedemus bijuga (Turp.) Lag	X		
Scenedesmus spp.	X	X	
Sphaerocystis schroeteri Chodat.	X		
Sphaeroplea annulina (Roth.) Agardh			X
Spirogyra sp.	X		
Ulothrix zonata (Weber and Mohr) Kuetz.		X	
Vancheria sp.	X		
Unknown Green	X	X	X
CHLOROPHYTA (Desmidiaceae)			
Closterium setaceum Ehr.	X		
Desmidium sp.	X	X	
Hyalotheca mucosa (Dillw.) Ehr	X		
Staurastrum gemelliparum Nordst.		X	
Staurastrum spp.	X	X	X
Unknown Desmids	X		
CYANOPHYTA			
Anabaena sp.	X	X	X
Aphanocapsa delicatissima West and West		X	
Chroocuccus pallidus Naeg.	X		
Coelosphaerium sp.		X	
Lyngbya sp.	X	X	
Merismopedia glauca (Ehr.) Naeg	X	X	
Microcystis aeruginosa Kuetz	X	X	X
Oscillatoria sp.	X		
Unknown Bluegreens		X	

Table 21 (Continued). Complete species occurrence list of Round, Star, and Goose Lakes, August, 1965.

	Round L	Star L.	Goose L.
EUGLENOPHYTA			
Euglena sp.	X		
CHRYSLOPHTA (Chrysophyceae)			
Dinobryon sertularia	X		
CRUSTACEA			
Cladocera			
Daphnia rosea		X	
D. pulex DeGeer	X		
Holopedium gibberum Zaddach		X	
Polyphemus pediculus Linne	X		X
Copepoda			
Cyclops sp.		X	
Diaptomus shoshoni Forbes			X
D. spp.	X	X	
Rotatoria			
Brachionus calyciflorus Pallus	X		
Conochiloides sp.			X
Conchilus unicornus	X	X	X
Filinia opoliensis Zacharias	X	X	
Gastropis stylifer		X	
Kellicottia longispinus Kellicott		X	X
Keratella cochlearis Gosse	X	X	X
K. quadrata Muller	X	X	X
Polyarthra vulgaris Carlin	X		
Unknown Rotifers	X	X	
MOLLUSKA			
Pisidium spp.	X	X	X
ANNELIDA			
Oligochaeta			
Eiseniella tetraedra	X		
Rhyacodrilus montana Brinkh.	X	X	X
Unknown Lumbridulidae	X	X	X
Unknown Oligochaetes	X	X	X
Hellobdella stagnalis L.	X	X	X

Table 21 (Continued). Complete species occurrence list of Round, Star, and Goose Lakes, August, 1965.

	Round L.	Star L.	Goose L.
INSECTA			
Diptera			
Chironomidae (Tendipedidae)			
Chironominae (Tendipedinac)			
Chironomus (Tendipes) riparius Meig.	X		
Cryptochironomus (Chironomus) sp.			X
Endochironomus (Chironomus) nigricans Joh			X
Harnishia (Harnischia) amachaerus Townes	X		
Limnochironomus (Chironomus) tenuicaudatus Mall	X	X	
Stictochironomus (Tanytarsus) sp. 1 Roback		X	X
Tanytarsus atridorsum Joh			X
T. (Calopsectra) confusa Mall	X		
T. dissimilis Joh		X	
T. (Calopsectra) guerla Joh	X	X	X
T. (Micropsectra) logani Joh			X
T. (Calopsectra) mancus Walk	X		
T. (Calopsectra) Sp. A Joh		X	
T. (Stempellina) sp. A Joh		X	
T. (Calopsectra) sp. 6 Roback			X
T. (Calopsectra) sp.			X
Orthocladiinae (Hydrobaerinae)			
Corynoneura scutellata Winn			X
Metriocnemus lundbecki Joh	X		
Psectrocladius (Spaniotoma) simulans Group P psilopterus Joh	X		
Tanypodinae (Pelopiinae)			
Procladius (Psilotanypus) adumbratus Joh	X	X	
P. (P) culiciformis Linn.		X	
Pentaneura monilus Joh	X		
Ceratopogonidae (Heleidae)			
Alluaudomyia splendida Winn	X		

BIBLIOGRAPHY

(Those entries preceeded by an asterisk have not been cited in the present work, but have been included so that this bibliography might serve as a better guide to the worldwide alpine literature.)

American Public Health Association, American Water Works Association and Water Pollution Control Federation. 1960. Standard methods for the examination of water and wastewater including bottom sediments and sludges. 11th ed. Amer. Public Health Assn. N. Y., 626 pp.

Bachmann, R. W. 1961. The Calculation of available carbon. Mimeo. Report, Dept. of Zoology, University of Michigan.

Bachmann, R. W., G. W. Saunders, and F. B. Trama. 1961. Investigations in lake metabolism-photosynthesis: a modified C 14 technique for estimates of photosynthesis in large lakes. (Abstract) Proc. 4th Couf. Great Lakes Res., Great Lakes Res., Div., Univ. of Michigan, Publ. No. 7: 1-63.

Baker, F. S. 1944. Mountain climates of the western United States. Ecol. Monogr. 14: 224-254.

*Beck., L. 1945. Hydrobiologische Studien an einem Alpiner Trumpel. Diss. Zoolog. Inst. Innsbruck.

Benson, N. G. 1961. Limnology of Yellowstone Lake in relation to cutthroat trout. U. S. Fish and Wildlife, Service Research Report 56, 33 pp.

Birge, E. A. and C. Juday. 1927. The organic content of the water of small lakes. Proc. Amer. Phil. Soc. 66: 357-372.

Birge, E. A. and C. Juday. 1934. Particulate and dissolved organic matter in inland lakes. Ecol. Monogr. 4:440-474.

*Bourcart, F. E. 1906. Les Lacs Alpins Suisses, etude chemique et physique. Geneve, Georgr. et Cie. 130 pp.

*Bourgin, A. 1945. Lacs d'altitude des alpes Francaises. Int. Rev. Geogr. Alp. 35: 739-745.

Brinkhurst, R. O. 1965. Studies on the North American aquatic Oligochaeta. II. Tubificidae. Proc. Nat. Acad. Sci. 117: 117-172.

Buscemi, P. 1961. Ecology of the bottom fauna of Parvin Lake, Colorado. Trans. Am. Micros. Soc. 80: 266-307.

*Calhoun, A. J. 1942. The biology of the black-spotted trout (Salmo clarkii henshawi Gill and Jordon) in two Sierra lakes. Dissertation Abstracts, Stanford University 18: 10-12.

Calhoun, A. J. 1944. The bottom fauna of Blue Lake, California. California Fish & Game 30: 86-94.

*Carl, G. C. 1940. The distribution of some Cladocera and free living Copepoda in British Columiba. Ecol. Monogr. 10:55-110.

*Christensen, E. M. 1956. Bibliography of Utah aquatic biology. Proc. Utah Acad. Sci. Arts Lett. 33: 91-100.

Clark, T. H., and C. W. Stearn. 1965. The geological evolution of North America. Ronald Press, New York. 434 pp.

Clarke, F. W. 1924. The data of geochemistry. Bull U.S. Geol. Survey 770: 1-841.

*Comita, G. W., and W. T. Edmondson. 1953. Some aspects of the limnology of an arctic lake. Stanford Univ., Publ. Biol. Sci. 11: 7-13.

*Cope, Oliver B. 1964. Revised bibliography on the cutthroat trout. U. S. Fish and Wildlife Service, Research Report 65. 43 pp.

Cox, G. S. 1957. The altitudinal distribution of soils in western Montana. Proc. Mont. Acad. Sci. 17: 7-15.

*Cushing, S. M. 1951. The vertical migration of planktonic crustacea. Biol. Rev. Cambridge Phil. Soc. 26: 158-192.

*Das, S. M. 1960. High altitude fisheries with special reference to Kashmir. Current Sci. 26: 220

Deevey, Jr., E. S. 1940. Limnological studies in Connecticut. V. A contribution to regional limnology. Amer. Jour. Sci. 238: 717-741.

*de Saussure, H. B. 1779-1796. Voyages dans les alpes.

*de Terra, H. and G. E. Hutchinson. 1934. Evidence of recent climatic change shown by Tibetan highland lakes. Geogr. F. 84: 311-320

Dodds, G. S. 1917. Altitudinal distribution of Entomostroca in Colorado. Proc. U. S. Nat. Mus. 54: 59-87.

Dodds, G. S. 1920. Entomostroca life zones. Biol. Bull 39: 89-107.

*Dodds, G. S., and F. L. Hisaw. 1925. Ecological studies on aquatic insects. IV. Altitudinal range and zonation of mayflies stoneflies, and caddisflies in the Colorado Rockies. Ecology 6: 380-390.

Domrose, R. J. 1960. Age and growth of brooktrout, Salvelinus Fontinalis, in Montana. M. S. Thesis. Montana State Col.

Eckleman, F. D., and A. Poldervaart. 1957. Geologic evolution of the Beartooth Mountains, Montana and Wyoming. Part I. Archean history of the Quad Creek Area. Geol Soc. Am. Bull. 68: 1225-1262.

*Edmonsdon, C. H. 1912. Protozoa of high mountain lakes in Colorado. University of Colorado, Stud. 9: 65-74.

Edmondson, W. T. 1956. The relation of photosynthesis by phytoplankton to light in lakes. Ecology 37: 161-174.

*Findenegg, I. 1933. Alpen Seen ohne Vollzirkulation. Int. Rev. Hydrobiol. 28: 295-311.

Findenegg, I. 1962. Types of planktonic primary production in the lakes of the eastern alps as found by the radioactive carbon method. 15th Int. Cong. Limnol. Madison (Abstract)

Fritz, S., and T. H. MacDonald. 1949. Average solar radiation in the United States. Heating and Ventilating 46(7): 61-64

*Gams, H. 1923. Einige Gewassertypen des Alpengebei es. Verh. Internat. Verein. Limnol.

Gerloff, G. C., and Folke Skoog. 1957. Nitrogen as a limiting factor for the growth of Microcystis aeruginosa in southern Wisconsin lakes. Ecology 38: 556-561.

Goldman, C. R. 1960a. Molybdenum as a factor limiting primary productivity in Castle Lake, California. Science 132:1016-1017.

Goldman, C. R. 1960b. Primary productivity and limiting factors in three large lakes of the Alaska Penninsula. Ecol. Monogr. 30: 207-230.

Goldman, C. R. 1961a. Primary productivity in cirque lakes of the Kalmath Mountains (Abstract). Bull Ecol. Soc. Amer. 42: 141.

*Goldman, C. R. 1961b. The contribution of alder trees. (Alnus tenuifolia) to the primary productivity of Castle Lake, California. Ecology 42: 282-288.

Goldman, C. R. 1963. The measurementof primary productivity and limiting factors in freshwater with Carbon-14. In: Proc. Conf. of Prim. Productivity Measurement (1961). U. S. AEC Rep. TID07633. pp. 103-113, Wash. 25 D. S. 237 pp.

Goldman, C. R. 1964. Primary productivity and micro-nutrient limiting factors in some North American and New Zealand lakes. Verh. Internat. Verein. Limnol. 15: 365-374.

Goldman, C. R., and R. C. Carter. 1965. An investigation by rapid carbon-14 bioassy of factors affecting the cultural eutrophication of Lake Tahoe, California-Nevada. Jour. Water Pollution Control Fed., July, 1965. pp 1045-1059.

Goldman, C. R., and R. G. Wetzel. 1963. A study of the primary productivity of Clear Lake. Ecology 44: 283-293.

Goldman, C. R., D. T. Mason, and B. J. B. Wood. 1963. Light injury and inhibition in antarctic freshwater phytoplankton. Limnol. and Oceanog. 8: 313-322.

Goldschmidt, V. M. 1958. Geochemistry, Clarendon Press, Oxford. 730 pp.

Griggs, R. F. 1938. Timberlines in the northern Rocky Mountains. Ecology 19: 548-564.

*Haeker, W. 1933. Sichtiefe, Warmegang und Durchluftung in Hochgebirgseen. Geogr. Jahresbericht aus Osterreich 16: 88.

*Haempl, O. 1923. Zur Kenntnis einiger Alpenseen. III. Der Millstattersee. Arch. Hydrobiol. 14: 346-400.

*Haempel, O. 1926 Zur Kenntnis einiger Alpenseen. IV. Der Attersee. Int. Rev. Hydrobiol. 15: 273-322.

*Haempel, O. 1932. Zur Kenntnis einiger Alpenseen. V. Der Irrsee. Int. Rev. Hydrobiol. 26: 337-387.

Hanzel, D. A. 1960. The distribution of the cutthroat trout (Salmo clarki) in Montana. Proc. Montana Acad. Sci. 19: 32-71.

Harris, R. L. 1959. Geologic evolution of the Beartooth Mountains, Montana and Wyoming. Part 3. Gardner Lake, Area Wyoming. Geol. Soc. Amer. Bull. 70: 1185-1216.

Hayne, D. W., and R. C. Ball. 1965. Benthic productivity as influenced by fish predation. Limnol. and Oceanogr. 1:162-175.

*Henderson, J. 1936. Mollusca of Colorado, Utah, Montana, Idaho, and Wyoming. Univ. of Colo. Studies 23: 81-145.

Hustedt, F. 1943. Die Diatomenflora einiger Hochgebirgseen der Landschaft Davos in den Schweizer Alpen. Int. Rev. Hydrobiol. 43: 124-197, 225-280.

*Hutchinson, G. E. 1933. Limnological studies at high altitudes in Lodak. Nature 132: 136.

Hutchinson, G. E. 1937. Limnological studies in Indian Tibet. Int. Rev. Hydrobiol. 35: 134-177.

Hutchinson, G. E. 1938. On the relationship between the oxygen deficit and the productivity and typology of lakes. Int. Rev. der gesamten Hydrobiol. 36: 336-355.

Hutchinson, G. E. 1957. A treatise on limnology. Vol. 1. Geography, physics, and chemistry. John Wiley and Sons, Inc. New York. 1015 pp.

Ichimura, S. 1961. On the spatial difference of the primary production in the lake and its relation to environmental factors. The Bot. Mag. 74: 871.

Johannsen, O. A. 1937. Aquatic Diptera. Part 3. Chironomidae: Subfamilies Tanypodinae, Diamesinae, and Orthocladiinae. Cornell Univ. Agr. Exp. Station Memoir 205. 18 plates. 84 pp.

Johannsen, O. A., and L. C. Thomsen. 1937. Aquatic Diptera. Part 4. Chironomidae: Subfamily Chironominae. Part 5. Ceratopogoonidae. 18 plates, 80 pp.

*Johnson, K. R. 1941. Vegetation of some mountain lakes and shores in northwestern Colorado. Ecology 22: 306-316.

Johnson, P. L., and W. D. Billings. 1962. The alpine vegetation of the Beartooth Plateau in relation to cryopedogenic processes and patterns. Ecol. Monogr. 32: 105-135.

*Jordon, D. S. 1889. A reconnaissance of the streams and lakes of the Yellowstone National Park, Wyoming, in the interest of the United States Fish Commission. Bull. U. S. Fish Comm. 9: 41-63

Juday, E., E. A. Birge, and V. W. Meloche. 1938. Mineral content of the lake waters of the northeastern Wisconsin. Trans. Wis. Acad. Sci. Arts. and Lett. 31: 223-276.

Kuznetsov, S. J. 1958. A study of the size of bacterial populations and of organic matter formation due to photo- and chemosynthesis in water bodies of different types. Verh. Int. Verein. Limnol. 13: 156-169.

Larsen, J. A. 1930. Forest types of the northern Rocky Mountain region and their climatic controls. Ecology 11: 631-672.

Leiberg, J. B. 1904. Forest conditions in the Absaroka Division of the Yellowstone Forest Reserve, Montana. U. S. Geol. Surv. Prof. Pap. 29: 1-148.

*Leutelt-Kipke, S. 1934. Ein Beitrag zur Kenntnis der hydrographischen und hydrochemischen Verhaltnisse einiger trioler Hoch- und Mittelgebirgseen. Arch. Hydrobiol. 27: 286-352.

*Leutelt-Kipke, S. 1935. Hydrographische und hydrochemische Untersuchungen an Hochgebirgseen des Bulgarischen Rilo Da. Arch. Hydrobiol. 28: 415-436.

*Leutelt-Kipke, S. 1936. Hydrographische und hydrochemische Beobachtungen an Sudtiroler Hochgebirgseen. Arch Hydrobiol.

Lovering, T. S. 1929. The New World or Cook City mining district. U. S. Geol. Survey Bull. 811-A: 1-87.

Lull, H. W., and L. Ellison. 1950. Precipitation in relation to altitude in central Utah. Ecology 31: 479-484.

*Lugeon, M., and E. Jeremine. 1911. Les bassins fermes des Alpes Suisses. Bull. Soc. vand. Sci. Nat. 47: 461-650.

Lund, J. G. W. 1961. The periodicity of u-algae in three English lakes. Verh. Int. Verein Limnol. 14: 147-154.

*Lundbeck, J. 1936. Untersuchungen uber die Bodenoeseidlung der Alpenrandseen. Arch. Hydrobiol. 10: 208-357.

*Lundbeck, J. 1934. Über den primär oligotrophen Seetypus und den Wollingster See als dessen mitteleuropaischen Vertreter. Arch. Hydrobiol. 27: 221-250.

*Lyons, J. B., and R. E. Stoiber. 1959. The absoprtivity of ice: a critical review. Air Force Cambridge Res. Center Sci. Rept. No. 3, 13 pp.

*Maciolek, J. A., and H. D. Kennedy. 1964. Spacial variation in periphyton production in a mountain lake at fall overturn. Verh. Int. Verein. Limnol 15: 386-393.

*Matheson, D. H. 1951. Inorganic nitrogen in precipitation and atmospheric sediments. Can. Jour. Tech. 29: 406-412.

*Miller, L. R. 1936. Desmids of the Medicine Bow Forest of Wyoming. Univ. of Wyoming Publ. 2: 67-120.

Miyadi, D. 1931. Studies on the bottom fauna of Japanese lakes. II. Mountain lakes of the tributaries of the River Tone, with special reference to the azoic zone. Jap. Jour. Zool. 3: 259-298.

Moore, J. R. 1965. Productivity and standing crop of vascular hydrophytes. PhD Thesis. University of Pittsburgh.

Needham, P. R., and F. K. Sumner. 1941. Fish management problems of high western lakes with returns from marked trout planted in Upper Angora Lake, California. Trans. Am. Fish Soc. 71: 249-269.

Neldner, K. H., and R. W. Pennak. 1955. Seasonal faunal variations in a Colorado alpine pond. Am. Midld. Nat. 53: 419-430.

*Nursall, J. R. 1952. The early development of a bottom fauna in a new power reservior in the Rocky Mountains of Alberta. Can. Jour. Zool. 30: 387-409.

Ohle, Waldemar. 1956. Bioactivity, production, and energy utilization of lakes. Limnol. & Oceanogr. 1: 139-149.

*Olive, J. R. 1953. A bibliography of the limnology and fishery biology of Colorado, 34 pp. (Mimeo.).

Olive, J. R. 1953. A comparative limnological study to two northern Colorado montane lakes. Ohio Jour. Sci. 53: 59-67.

*Olstad, O. 1930. Observations on temperature and ice conditions in mountain lakes in Norway. Myt. Mag. Naturvidensk 68: 245-264.

Oosting, H. J. 1956. The study of plant communities. W. H. Freeman Co., San Francisco. 440 pp.

Pearsall, W. H. 1932. Phytoplankton in the English Lakes. The composition of the phytoplankton in relation to dissolved substances. Jour. Ecol. 20: 241-262.

*Pechlaner, R. R. 1964. Plankton production in natural lakes and hydroelectric water basins in the apline region of the Austrian Alps. Verh. Int. Verein. Limnol. 15: 375-383.

Pennak, R. W. 1941a. A bibliography of high altitude limnological investigations in the western United States. Univ. of Colo. Stud. Ser. D, 1L225-229.

Pennak, R. W. 1941b. An introduction to the limnology of northern Colorado. Univ. Colo. Stud. Ser. D, 1: 203-220.

Pennak, R. W. 1944. Diurnal movements of zooplankton in some Colorado mountain lakes. Ecology 25: 387-403.

Pennak, R. W. 1945. Hydrography and morphometry of some northern Colo. lakes. Univ. Colo. Stud. Ser. D, 2: 245-262.

Pennak, R. W. 1945. Some aspects of the regional limnology of northern Colorado. Univ. Colo. Stud. Ser. D, 2: 263-293.

Pennak, R. W. 1949a. Annual limnological cycles in some Colorado reservior lakes. Ecol. Monogr. 19: 233-267.

Pennak, R. W. 1949b. Species composition of limnetic zooplankton populations in some Colorado lakes. (Abstract). Bull. Ecol. Soc. Amer. 30: 61-62.

*Pennak, R. W. 1950. A limnological reconnaissance of Grand Mesa, Colorado. Univ. Colo. Stud. Biol. Ser. 1: 15-23.

*Pennak, R. W. 1955a. Comparative limnology of eight Colorado mountain lakes. Univ. Colo. Stud. Biol. Ser. 1: 15-23.

Pennak, R. W. 1955b. Persistent changes in the dominant species composition of limnetic Entomostracan populations in a Colorado mountain lake. Trans. Am. Micros. Soc. 74: 116-118.

*Pennak, R. W. 1957. Species composition of limentic zooplankton communities. Limnol. & Cceangr. 2: 222-232.

Pennak, R. W. 1958a. Regional lake typology in northern Colorado, U. S. A. Verh. Int. Verein. Limnol. 13: 264-283.

Pennak, R. W. 1958b. Some problems of freshwater invertebrate distribution in the western states. Zoogeography. AAAS: 223-230.

Pennak, R. W. 1963. "Rocky Mountain States" in Limnology of North America, D. G. Frey, ed., Univ. of Wis. Press. Madison: 349-369.

Pesta, O. 1929. Der Hochgebirgseen der Alpen. Die Binnegewässer 8: 1-156.

Prescott, G. W. 1951. Algae of the western Great Lakes Area. Cranbrook Institute of Science, Bull. #30, 948 pp. 136 plates.

Prinz, M. 1964. Geologic evolution of the Beartooth Mountains, Montana, and Wyoming. Part 5. Mafic dike swarms of the southern Beartooth Mountains. Geol. Soc. Amer. Bull. 75: 1217-1248.

*Rawson, D. S. 1930. The bottom fauna of Lake Simcoe and its role in the ecology of the lake. Univ. Toronto Studies, Publ. Ont. Fish. Res. Lab. 40: 1-183.

*Rawson, D. S. 1936. Physical and chemical conditions in lakes of the Prince Albert Park, Saskatchewan. Jour. Biol. Bd. Can. 2: 227-284.

Rawson, D. S. 1942. A comparison of some large alpine lakes in western Canada. Ecology 23: 143-161.

Rawson, D. S. 1944. The calculation of oxygen saturation values and their correction for altitude. Spec. Publ. No. 15, Limn. Soc. Am. 15 pp.

*Rawson, D. S. 1947. Deterioration of recently established trout populations in lakes of the Canadian Rockies. Can. Fish. Culturist 2: 14-21.

Rawson, D. S. 1950. The physical limnology of Great Slave Lake. Jour. Fish. Res. Bd. Can. 8: 1-66.

Rawson, D. S. 1951. The total mineral content of lake waters. Ecology 32: 669-672.

Rawson, D. S. 1953. The limnology of Amethyst Lake, a high alpine type near Jasper, Alberta. Can. Jour. Zool. 31: 193-210.

Rawson, D. S. 1955. Morphometry as a dominant factor in the productivity of large lakes. Verh. Int. Verein. Limnol. 12: 174-175.

*Rawson, D. S. 1956. The net plankton of Great Slave Lake. Jour. Fish. Res. Bd. Can. 13: 53-127.

Rawson, D. S. 1960. A limnological comparison of twelve large lakes in northern Saskatchewan. Limnol. and Oceanogr. 5: 195-211.

Reed, E. B., and J. R. Olive. 1958 Altitudinal distribution of some Entomostraca in Colorado. Ecology 39: 66-74.

Reimers, N., J. A. Maciolek, and E. P. Pister. 1955. Limnological study of the lakes in Convict Creek Basin, Mono County, California. U. S. Fish. Bull. 103, 56: 437-503.

Ricker, W. S. 1937. Physical and chemical characteristics of Cultus Lake, B. C. Jour. Biol. Bd. Can. 3: 363-402.

Roback, S. S. 1957. The immature tendipedids of the Philadelphia area. Monographs of the Academy of Natl. Sciences of Philadelphia No. 9, 128 plates. 148 pp.

Robertson, O. H. 1947. An ecological study of two high mountain trout lakes in the Wind River Range, Wyoming. Ecology 28: 87-112.

Rodhe, W. 1949. The ionic composition of lake waters. Verh. Int. Verein Limnol. 10: 377-396.

*Rodhe, W. 1955. Can plankton production proceed during winter darkness in subarctic lakes? Verh. Int. Verein. Limno. 12: 117-122.

Rodhe, W., R. A. Vollenweider, and A. Nauwerk. 1958. The primary production and standing crop of phytoplankton. In: Perspectives in marine biology. A. A. Buzzati-Traverso, ed. Univ. Calif. Press. Berkeley and Los Angeles: 299-322.

*Rodina, A. G. 1963. The bacterial content of detritus from the lakes in the Ladoga area. Microbiology 32: 874-880.

Romanenko, V. I. 1965. A microbiological investigation of Lake Onega, Vygozero Reservior, and the lakes of the White Sea-Baltic Canal. Microbiology 34: 219-296.

*Ruttner, F. 1937. Limnologische Studien an einingen Seen der Ostalpen. Arch. Hydrobiol. 32: 167-319.

Ruttner, F. 1963. Rundamentals of limnology. D. G. Frey and F. E. J. Frey, transl. Univ. of Toronto Press, Toronto. 294 pp.

Ryther, J. H. 1956. The measurement of primary production. Limnol. & Oceangr. 1: 72-84.

*Sauberer, F. 1939. Beitrage zur Kenntnis des lichtlemas einiger Alpen-seen. Int. Rev. Hydrobiol. 39: 20-55.

Saunders, G. W. 1964. Studies of primary productivity in the Great Lakes. Great Lakes Research Division Publ. No. 11. Univ. of Mich. Ann Arbor. Mich.

Schindler, J. F. 1954. Taxonomy and ecology of algae in ponds and lakes of the Flathead Basin, Montana. M. S. Thesis. Michigan State College of Agriculture.

*Schmitz, E. H. 1959. Seasonal biotic events in two Colorado alpine tundra ponds. Am. Midl. Nat. 61: 424-446.

Sieminska, Jadwiga. 1965. Algae from Mission Wells Pond, Montana. Trans. Am. Micros. Soc. 84: 98-126

Silvey, W. D. 1961. Concentration method for the spectrochemical determination of minor elements in water. Geol. Surv. Water-Supply Paper 1540-B, 11-22.

*Simon, J. R. 1946. Wyoming fishes. Bull. Wyoming Game and Fish Dept. 4: 1-129.

Spencer, H. 1959. Geologic evolution of the Beartooth Mountains. Montana and Wyoming. Part 2. Fracture patterns. Geol. Soc. Am. Bull. 71: 467-508.

Steeman-Nielsen, E. 1951. Measurement of production of organic matter in the sea by means of carbon-14. Nature 167: 684-685.

*Steeman-Neilsen, E. 1959. Untersuchungen über Primarproducktion des Planktons in einigen Alpenseen Osterreichs. Oikos. 10: 24.

Steeman-Neilsen, E. 1965. On the terminology concerning production in aquatic ecology with a note about excess production. Arch. Hydrobiol. 61: 184-189.

Steinböck, O. 1934. Zur Frage der Sprungschicht in Hochgebirgsseen. Arch. Hydrobiol. 27: 397-415.

Steinböck, O. 1938. Arbeiten über die Limnologie der Hochbirgsgewässer. Int. Rev. Hydrobiol. & Hydrog. 37: 467-509.

*Steinböck, O. 1949. Der Schwarzsee ob Sölden in Ötztal. Veroffentl. des Museum Ferdinandeum (Innsbruck), 26/29: 117-146.

Strøm, K. M. 1931. Fefovatn. A Physiographic and biological study of a mountain lake. Arch. Hydrobiol 22: 491-536.

*Strøm, K. M. 1935. Bessvatn and other lakes of eastern Fotunheim. Skr. Vidensk. Acad. Oslo 1:4.

Strøm, K. M. 1938. Norwegian mountain lakes. Arch Hydrobiol 33: 82-92.

*Strøm, K. M. 1943. Analysis of a glacial lake sediment. Int. Rev. Hydrobiol. 43: 206-210.

*Strøm, K. M. 1944. High mountain limnology. Some observations on stagnant and running waters of the Rondane area. Auh. Morske Vidensk Acad. 8: 24 pp.

*Suchlandt, O. and W. Schmassmann. 1938. Limnologoschen Beobachtungen an acht Hochgebirgseen der Landschaft Davos. Zeitschr. Hydrol. 7: 1-201.

Tanner, V. M. 1931. A preliminary report on a biological survey of the Uintah Mountain Lakes. Proc. Utah Acad Sci., Arts, and Lett. 8: 155-158.

*Taylor, W. R. 1928. The alpine algal vegetation of the mountains of British Columbia. Proc. Acad. Nat. Sci. Philadelphia. 80:45-114.

*Thienemann, A. 1926. Holopedium gibberum in Holstein. Z. Morph. Ökol. Tiere 5: 755-776.

*Thomasson, K. 1952. Contributions to the knowledge of the plankton in Scandanavian mountain lakes. 3. Svensk. Bot. Tidskv. 46: 228-241.

Thomasson, K. 1956. Reflections on arctic and alpine lakes. Oikos. 7: 117-143.

United States Department of Agriculture. 1941. Climate and man. Yearbook of agriculture U. S. D. A. 1248 pp.

Vinyard, W. C. 1951. Distribution of alpine and subalpine algae in Western United States. M. S. Thesis. Michigan State College of Agriculture.

*Ward, H. B. 1904. A biological reconnaissance of the elevated lakes of the Sierras and the Rockies. Trans. Amer. Micros. Soc. 25: 127-154.

Ward, H. B. and G. C. Whipple. 1959. Fresh-water biology. 2nd edition. W. T. Edmonson, ed. John Wiley & Sons. New York, 1248pp.

Welch, P. S. 1948. Limnological methods. McGraw Hill. New York, 381 pp.

*Wolff, H. 1948. Hydrobiologische Untersuchungen an den hochalpen Seen des San Bernadina passes. Zeit Hydrologie. 10: 4.

*Yoshimura, S. 1932a. Calcium in solution in the lake waters of Japan. Jap. Jour. Geol. Geogr. 10: 33-60.

*Yoshimura, S. 1932b. Contributions to the knowledge of nitrogenous compounds and phosphate in the lake waters of Japan. Proc. Imp. Acad. 8: 94-97.