

THESIS

EFFECT OF REMOVAL OF THE FISH POPULATION ON THE INVERTEBRATE  
FAUNA AND PHYTOPLANKTON OF EMMALINE LAKE, COLORADO

Submitted by  
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In partial fulfillment of the requirements  
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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY William B. Wrenn ENTITLED EFFECT OF REMOVAL OF THE FISH POPULATION ON THE INVERTEBRATE FAUNA AND PHYTOPLANKTON OF EMMALINE LAKE, COLORADO BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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Permission to publish this report or any part of it must be obtained from the Dean of the Graduate School.

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## CHAPTER I

### INTRODUCTION

In a lake ecosystem, the trophic level of non-piscivorous fishes would be primarily a second level consumer of the invertebrates and a first level consumer of plants (Lindeman, 1942). A fluctuating equilibrium is assumed to exist between predator and prey. Relative population densities of the predator and of the prey may or may not be optimum.

The effect of fish predation upon prey organisms has been studied in a variety of lakes. Brook trout (Salvelinus fontinalis), introduced into Bunny Lake in eastern Sierra Nevada, reduced the bottom organisms to one-fourth the original number and volume within six years. Although not recorded quantitatively, it was noted that larger zooplankters (Daphnia and Diaptomus) became scarce after the introduction of fishes. A 10 per cent variation in the bottom fauna of a bass-bluegill lake was observed during three summers (Ball, 1948). In a controlled study, using one-acre ponds that contained bluegill (Lepomis macrochirus), redear sunfish (Lepomis microlophus), and pumpkinseed (Lepomis gibbosus); Hayne and Ball (1956) reported the bottom fauna production rate was 17 times the standing crop. In the absence of fishes, production rate apparently stopped at a higher standing crop. Eshenour (1953) reported that with bluegill and pumpkinseed present, the benthic population held constant. In the absence of fishes, there was a significant increase of bottom organisms. Hrbacek (1962) found the zooplankton standing crop (on a nitrogen basis) remained constant even with an increased fish stock. He did note a change in species composition.

This project was designed to study the invertebrate fauna and

phytoplankton of a small alpine lake, before and after removal of brook trout. An adjacent lake, of similar size but barren of fish, served as a control. Data on invertebrate fauna and phytoplankton from the lakes were compared relative to time of fish removal and to environmental conditions. Theoretically, a small alpine lake with a dense population of a single species of fish is a comparatively simple community in which to study the relationship of a fish predator upon food organisms.

The two study areas are Emmaline and Cirque lakes at the headwaters of the Little South Cache la Poudre River, Larimer County, Colorado. Emmaline Lake had a population of small brook trout. Cirque Lake is barren of fishes. The invertebrate and phytoplankton populations of the two lakes are similar. Both Emmaline and Cirque lakes were originally barren of fishes (Mrs. Koenig, personal communication). Residents of the area initially stocked cutthroat trout (Salmo clarki) in both lakes. Later brook trout were stocked in Emmaline Lake. There are no records of dates and numbers of fish stocked. Also it is not known when cutthroat trout were eliminated from either lake. However, Emmaline Lake has maintained a fish population for approximately 40 years. The study was initiated in conjunction with a proposal by the Colorado Department of Game, Fish and Parks to eradicate brook trout from Emmaline Lake.

This study determines the quantitative and qualitative composition of zooplankton, phytoplankton, and macroscopic bottom fauna of the two lakes before and after removal of brook trout from the experimental lake. Effect of rotenone on the invertebrate fauna after fish eradication was considered. Measurements were made of selected environmental factors that affect invertebrate and phytoplankton populations densities.

## CHAPTER II

### METHODS

Sampling was done during the ice-free periods of 1964 and 1965.

Nine samples of macroscopic bottom fauna, phytoplankton and zooplankton were collected from both lakes each year. An exception was the multi-plate samplers (Hester and Dendy, 1962) located in the gravel and boulder areas; these were removed at the end of eight weeks. Specimens were preserved in a solution of alcohol, formalin and glycerin.

Macroscopic bottom fauna were sampled with an Ekman dredge and multi-plate samplers. Dredge samples were taken where the bottom type was suitable. In Emmaline Lake, dredge samplers were made at approximate depths of 1, 2, 3, 5 and 6 meters; in Cirque Lake, at 1, 2, 3 and 5 meters. To collect a sufficiently large sample, two dredge hauls were considered one sample. The number of organisms in each sample was counted and separated by order or family when possible. A total wet weight (blot-dry) was recorded for each sample. All multi-plate samplers were removed at the same time, and the organisms counted and weighed in the same manner as the dredge samples. Counts and weights were expressed as total number or total weight per square meter.

Net plankton, of which only zooplankton were considered, were sampled by two vertical net hauls at the maximum depth in each lake. A No. 20 plankton net 1 m in depth and 38 cm in diameter was used. Each vertical haul was concentrated to 110 ml. Zooplankton were counted according to order. From the first haul three Sedgwick-Rafter cells were counted and the mean calculated. A smaller portion of the cell can be counted and still maintain accuracy (Kutkukn, 1958). The second net

haul was centrifuged in a Foerst continuous-flow centrifuge, then dried at 60 C for 12 hours before weighing. Numbers and weights were expressed per cubic meter. A total dry weight was recorded for each sampling date; counts were made for selected dates during the sampling period.

Phytoplankton were sampled with a 1 liter Kemmerer water bottle. In Emmaline Lake a 1 liter sample was taken at 1 m, 4 m, and 6 m. Samples were taken from 1 m and 4 m in Cirque Lake. A Palmer chamber was used for counting the number of cells after the sample had been concentrated by centrifuging. Five microscope fields (430 X) from each of three chamber preparations were counted. Mean number per microscope field was calculated and projected to the area of the chamber, which is equivalent to 0.1 ml. Counts were recorded as the number of cells per liter.

Each bottom fauna, phytoplankton and zooplankton sample was analyzed to determine the qualitative composition of organisms in each lake. Random horizontal plankton tows were also made and analyzed. Bottom organisms and zooplankton were classified to species when possible. However, no attempt was made to classify the Oligochaeta beyond order. Phytoplankton were classified to genus.

Brook trout were captured for stomach samples from Emmaline Lake by angling on eight sampling dates. Stomach contents were classified as plant, animal or detritus. Animal component was separated to aquatic, terrestrial, or aerial. Aquatic organisms were classified to order or family when possible. Total dry weight of each stomach sample was recorded. A two-way analysis of variance (IBM 1401 computer) was used to

determine significance at the 5 per cent level of significance for bottom fauna of the two lakes by years, before and after fish removal. A t-test at the 5 per cent level of significance was used to compare the phytoplankton and zooplankton by years (Steel and Torrie, 1960).

Temperatures were recorded by an electrical thermistor. A Hach oxygen kit was used to determine oxygen to the nearest ppm. A Beckman N2 pH meter was used in determining pH. Total dissolved solids were measured by conductance. Total alkalinity was determined by standard hydrogen chloride titration.

Emmaline Lake was treated with 1 ppm powdered Pro-Noxfish on September 15, 1964. As many fish as possible were removed from the lake during and after treatment.

## CHAPTER III

### STUDY AREA

The study area is located at the head of Fall Creek in the Little South Cache la Poudre drainage. Emmaline and Cirque lakes are adjacent and approximately  $\frac{1}{4}$  miles from the northern boundary of Rocky Mountain National Park on the eastern slope of the Rocky Mountains (Fig. 1).

#### LAKE CHARACTERISTICS

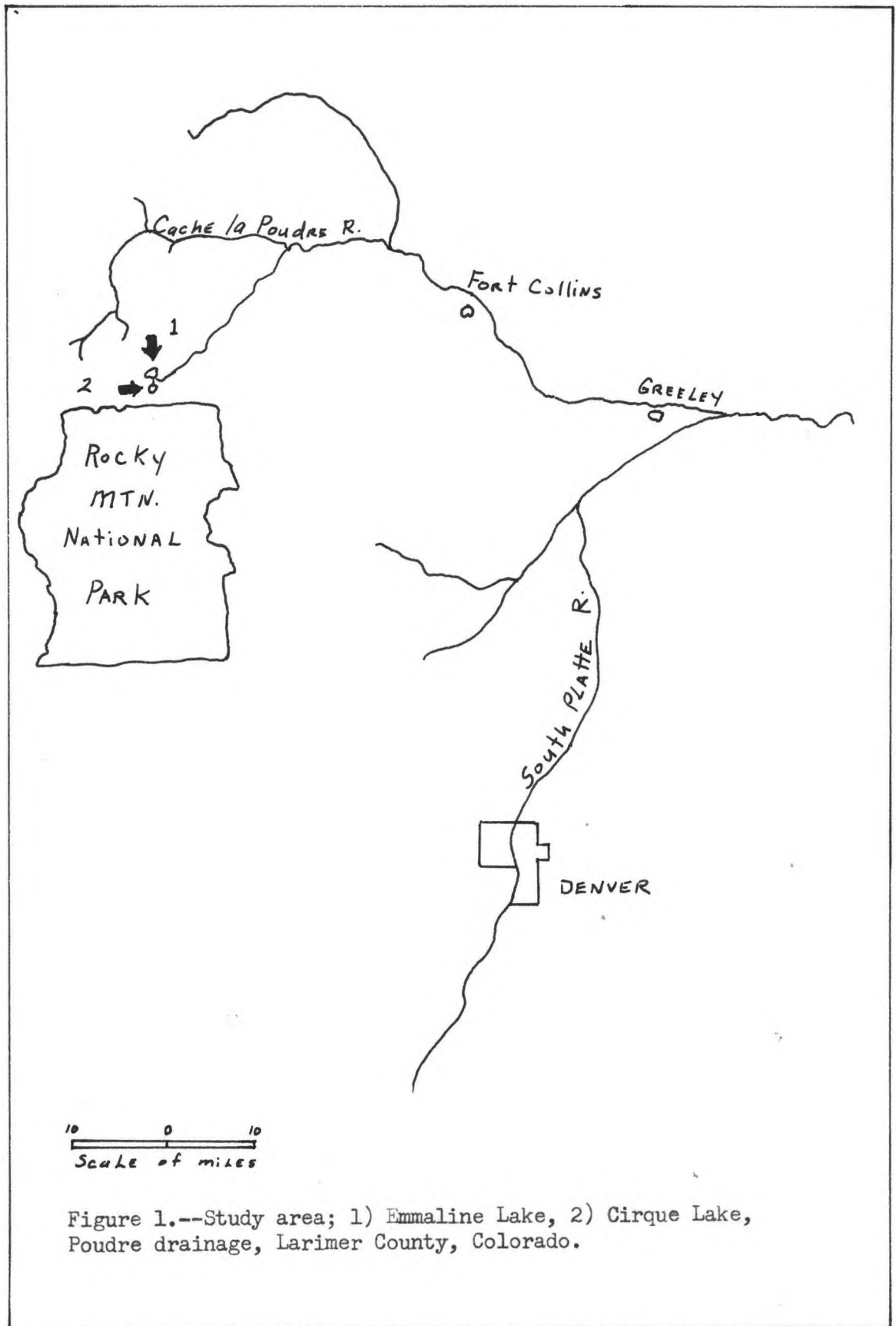
The lakes lie at 3,350 m above sea level (S. 26, T 7 N., R. 74 W., 6th p. Mer.). Pennak (1958) designated the lower limit of the alpine limnological zone in Colorado to be 3,200 m above sea level. According to Hutchinson (1957), both lakes are classified as cirque lakes; they probably resulted from late Pleistocene (Richmond, 1960) or post-Pleistocene glaciation (Matthes, 1940) that ranged from 7,200 to 4,000 years B. P.

#### Physical Features

Emmaline Lake is pear-shaped (Fig. 2); the outlet is at the northeast end. Cirque Lake is more circular with the outlet located similar to that of Emmaline Lake. A temporary outlet at the southern tip of Emmaline Lake joins the north shore of Cirque Lake; during the period of study, a snowbank persisted in this area. Cirque Lake is approximately 200 ft lower in elevation than Emmaline Lake. Both lakes are fed directly by snow-melt. Morphometric data appear in Table 1.

Water transparency was measured by a 10 cm Secchi disk. The bottom of Cirque Lake was visible throughout the study. The mean reading for Emmaline Lake during 1964 and 1965 was 3.4 and 4.3 m respectively.

A mean temperature cycle for the lakes appears in Fig. 3.



10 0 10  
Scale of miles

Figure 1.--Study area; 1) Emmaline Lake, 2) Cirque Lake, Poudre drainage, Larimer County, Colorado.

Table 1.--Physical and chemical features\* of Emmaline and Cirque lakes.

	Emmaline		Cirque	
	1964	1965	1964	1965
Mean depth	2.5 m	-	2.3 m	-
Max. depth	6.4 m	-	3.9 m	-
Surface area	2.3 acres	-	1.0 acres	-
Volume	18.6 acre ft	-	7.4 acre ft	-
Total alkalinity	9-10 ppm	9-10 ppm	9 ppm	9 ppm
Total dissolved	12-15 mohm	12-15 mohm	9-10 mohm	9-10 mohm
pH	6.8-7.0	6.8-7.0	6.8-7.0	6.8-7.0
Mean Secchi disk	3.4 m	4.3 m	bottom visible	bottom visible
Mean temperature range	39-49 F	36-48 F	36-43 F	34-44 F
Dissolved oxygen range	8-10 ppm	8-10 ppm	8-10 ppm	8-10 ppm

\*Ice-free period

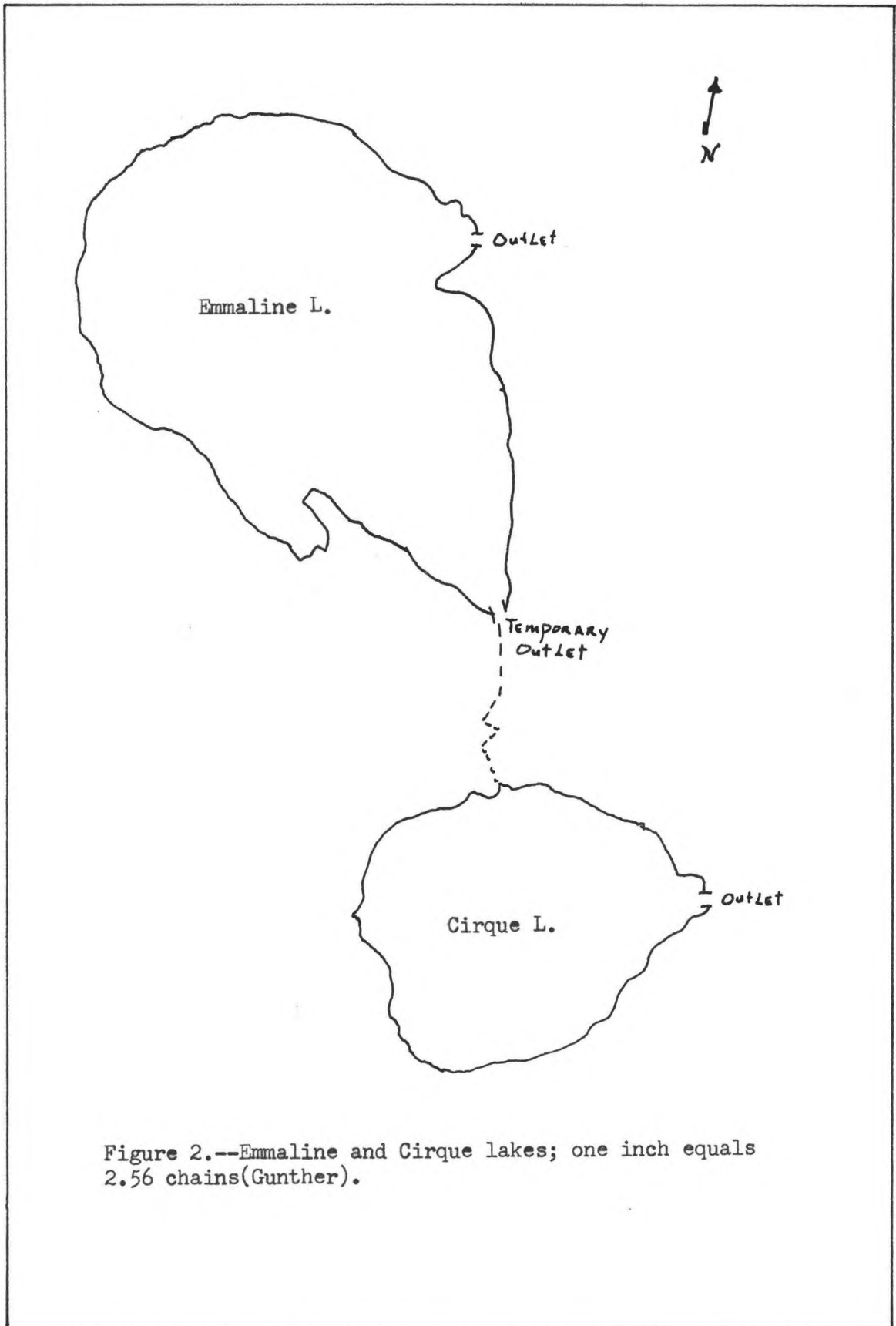


Figure 2.--Emmaline and Cirque lakes; one inch equals 2.56 chains(Gunther).

Temperatures were usually recorded between 10 AM and 12 PM. Seldom was there a difference of more than two degrees between surface and bottom. High winds were frequent both years.

#### Chemical Features

Total dissolved solids (measured by conductance) in Emmaline and Cirque lakes ranged from 12 to 15 mohm to 9 to 10 mohm, respectively (Table 1). One mohm NaCl at 25 C is equivalent to 0.65 ppm total dissolved solids (McKee and Wolf, 1963). This somewhat lower than the minimum of 25 ppm reported for alpine lakes in the region (Pennak, 1941; Olive, 1954). Phenothalein alkalinity did not exist. Dissolved oxygen ranged from 8 to 10 ppm in each lake. Corrected for altitude, these concentrations were equal to or greater than 100 per cent saturation. The pH of both lakes was 6.8 to 7.0.

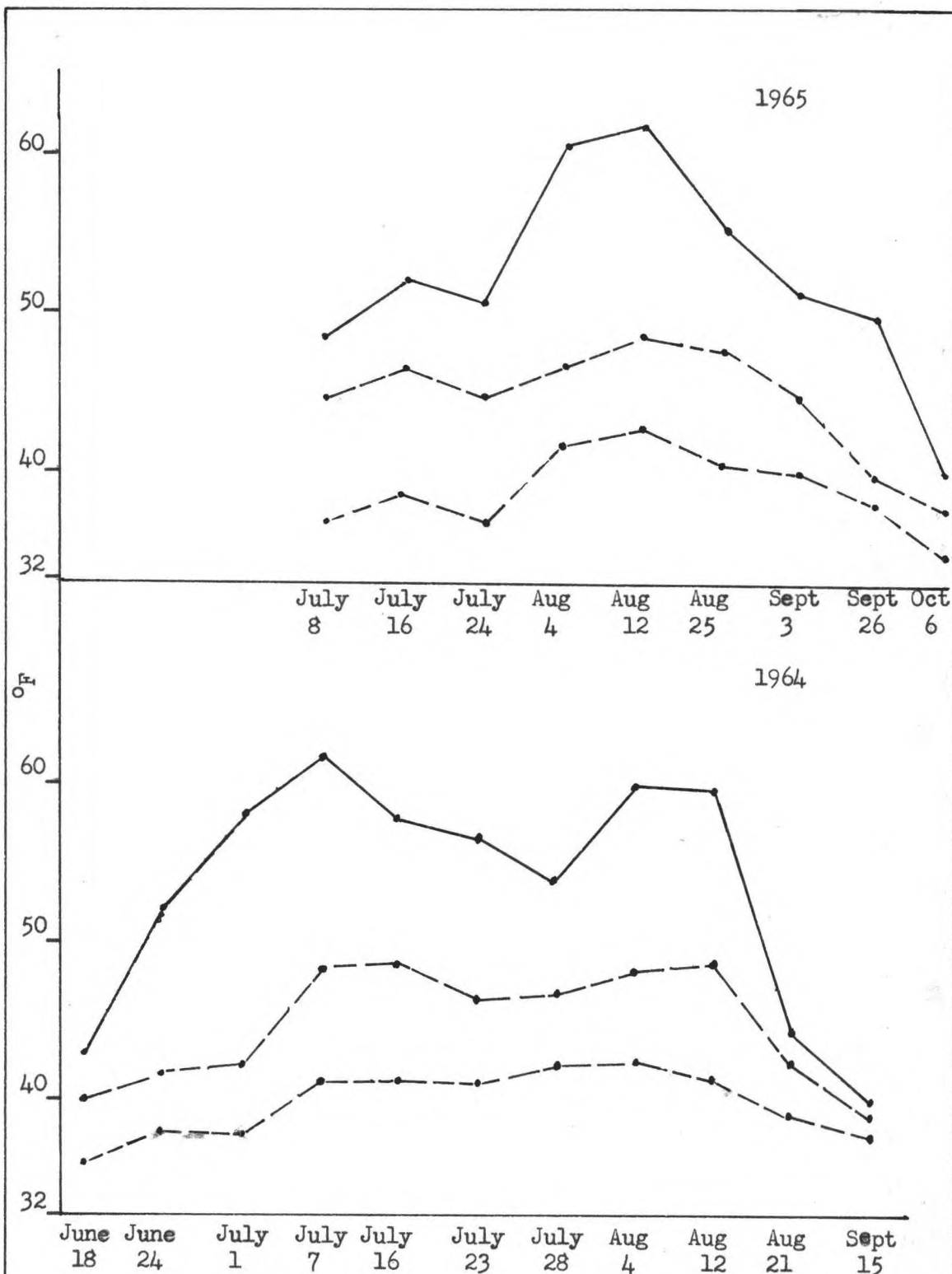


Figure 3.--Mean temperature cycle(Fahrenheit) for Emmaline and Cirque lakes, 1964 and 1965.

Standing crop, before removal, was maximum during August through mid-September (Fig. 5). Afterward there was no definite peak of abundance. However, a sharp increase in the number of rotifers appeared during the summer of 1965 (Table 3). The compensating reduction was in Daphnia rosea.

Zooplankton standing crop in Cirque Lake was not significantly different in 1964 and 1965 (Fig. 6). Fluctuations in standing crop were minor both years. Fig. 7 and Fig. 8 show the comparative decline of summer standing crop in Emmaline Lake from 1964 to 1965.

#### MACROSCOPIC BOTTOM ORGANISMS

Bottom organisms were collected by two methods. Multi-plate samplers were used in the shallow rocky areas, and an Ekman dredge was used in the deeper mud bottom areas.

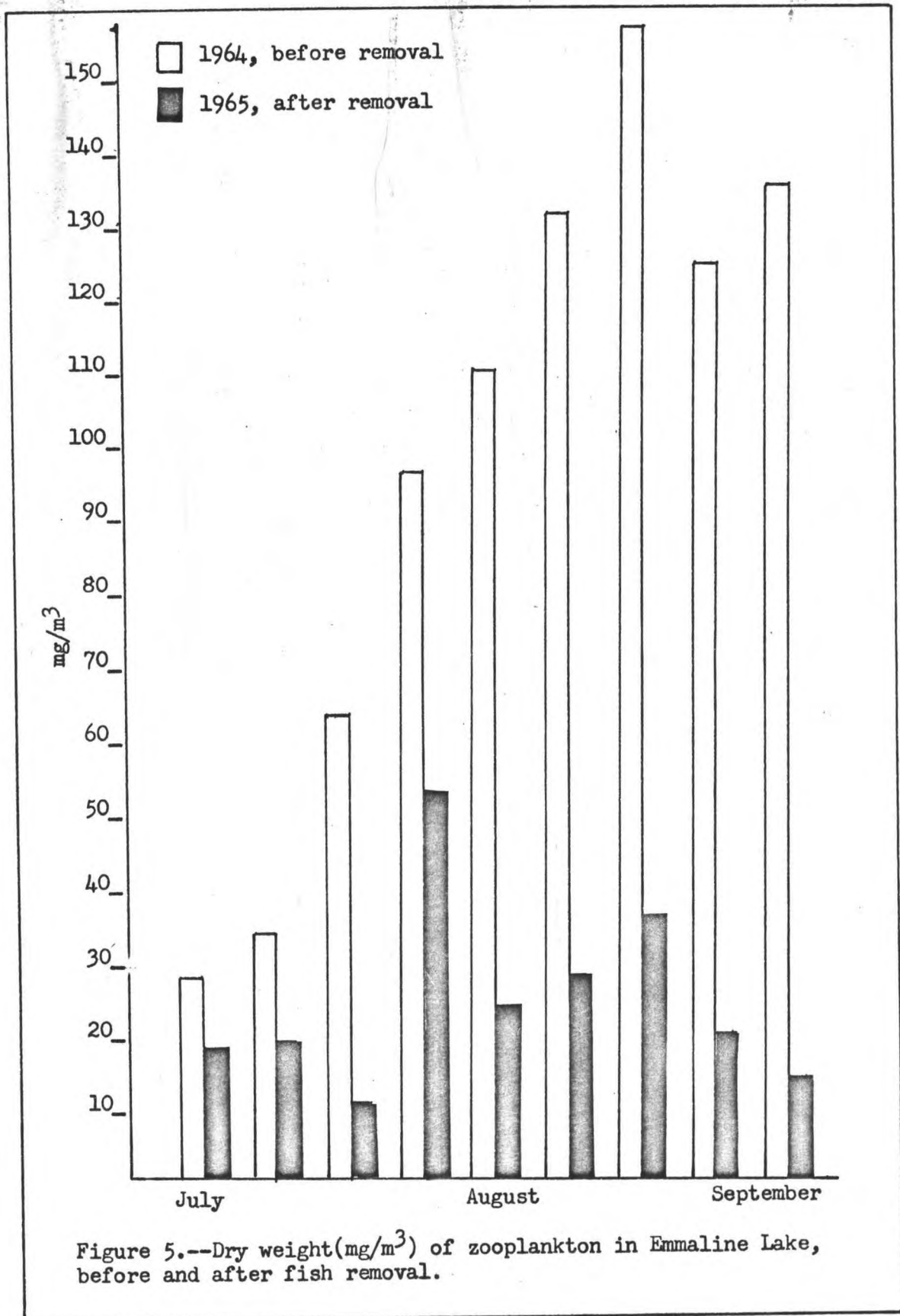
##### Multi-plate Samplers

Multi-plate samplers had a total area of 1.5 sq m. No statistical comparison was made between the 1964 and 1965 samples. It became apparent that the area sampled by multi-plate samplers was insufficient to compute an estimate of standing crop.

In Emmaline Lake, Isogenus sp. (Plecoptera) was collected only from plates and only in 1964. Tendipes sp. (Diptera) was collected most frequently from the plates in Emmaline Lake.

In Cirque Lake, Tricladida (Turbellaria) was collected from the plates. Other organisms collected in Cirque Lake were: Ameletus sp. (Ephemeroptera), Leuctra augusta and Isogenus sp. (Plecoptera) and Micrasema sp. (Tricoptera). Tricoptera were collected most frequently.

Plecoptera, Tricoptera and Ephemeroptera were often collected while



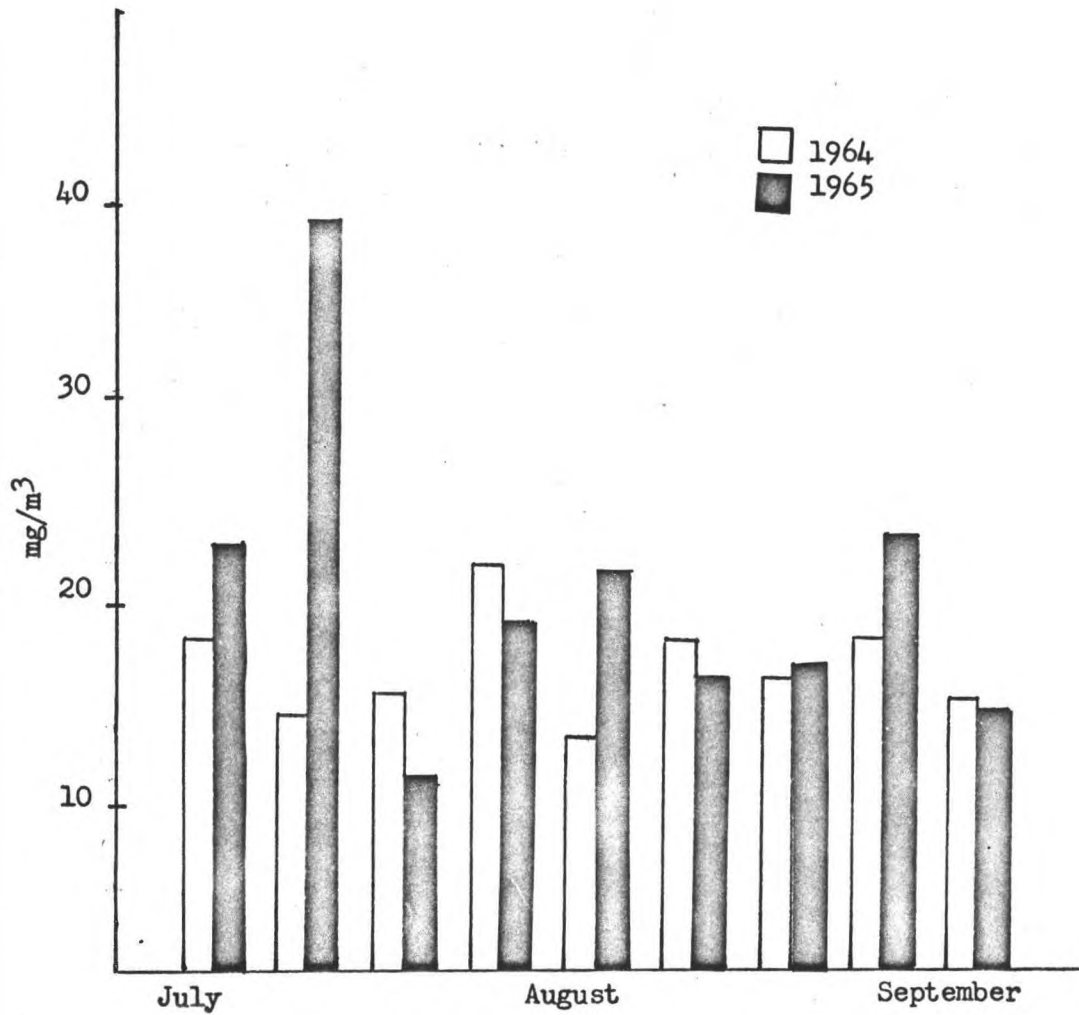


Figure 6.--Dry weight (mg/m<sup>3</sup>) of zooplankton in Cirque Lake.

## CHAPTER IV

### PRESENTATION OF DATA

Phytoplankton, zooplankton and macroscopic bottom organism data are analyzed qualitatively and quantitatively. Comparison of organisms that were collected to those utilized by fishes is also presented.

#### PHYTOPLANKTON

Qualitative composition of phytoplankton in Emmaline and Cirque lakes was similar; however, there was a variation in both lakes between 1964 and 1965. Staurastrum sp. (Desmidiaceae) was dominant throughout 1964. It was found only in the first sample (July 8) in 1965 (Table 2). In 1965 the diatom Asterionella sp. (Bacillariophyceae) and Chlorella sp. (Chlorophyceae) were dominant.

There was no significant difference in standing crop (Cells/liter) of the two lakes in either 1964 or 1965 (Table 3). Summer standing crop was greater both years in Emmaline Lake than in Cirque Lake. Similar seasonal fluctuations of summer standing crop occurred in both lakes (Fig. 4).

#### ZOOPLANKTON

Zooplankton in Emmaline Lake were Keratella quadrata (Rotifera), Cyclops vernalis (Copepoda), Daphnia rosea and Chydorus sphaericus (Cladocera). There was no qualitative change after removal of brook trout. The same species were in both lakes with the exception that Cirque Lake had an additional population of a large red Diaptomus shoshone (Copepoda).

There was a significant reduction in the zooplankton standing crop (dry weight) in Emmaline Lake after treatment with rotonone (Table 3).

Table 2.—Qualitative composition of phytoplankton in Emmaline and Cirque lakes.

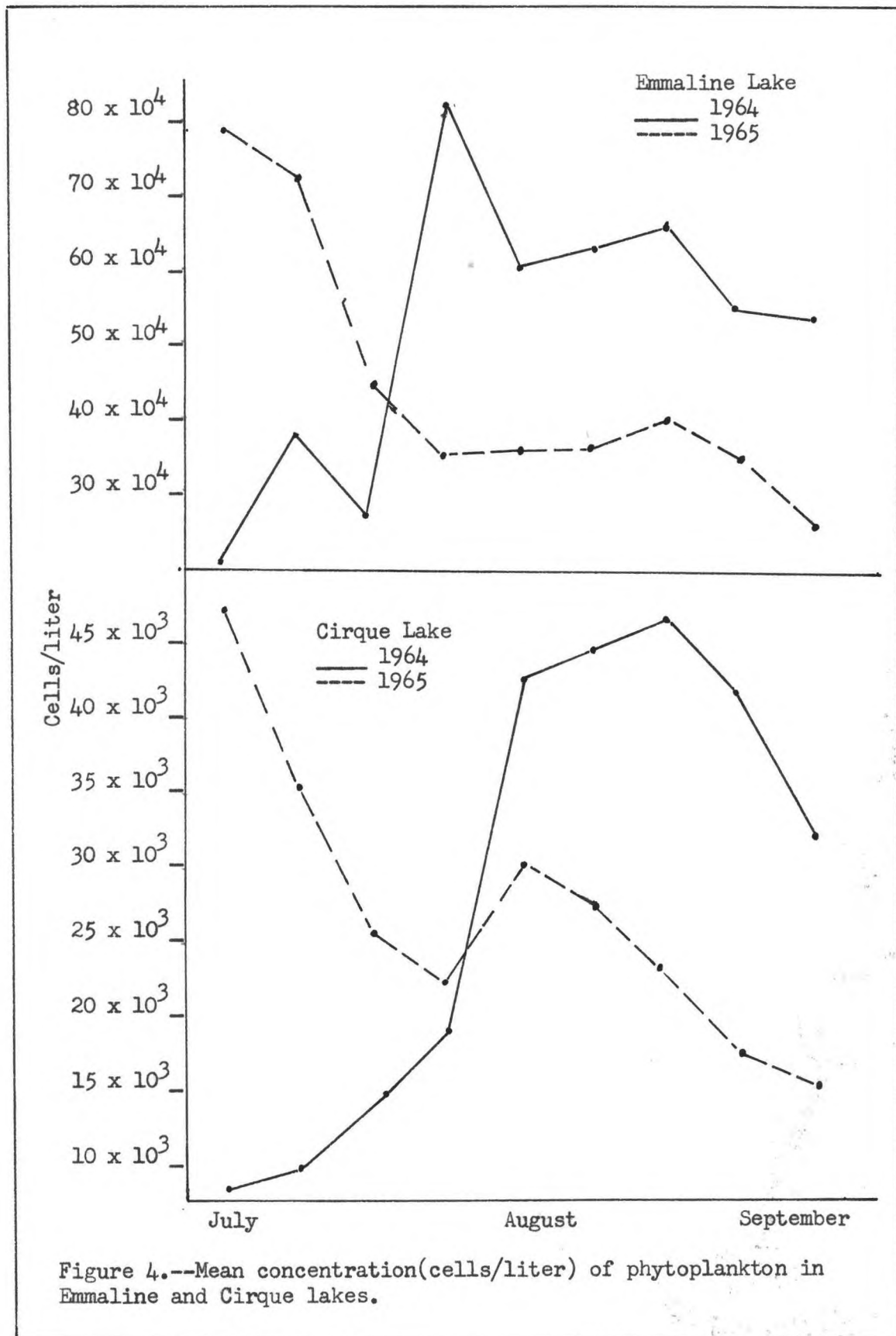
Genus	Emmaline Lake		Cirque Lake	
	1964	1965	1964	1965
<u>Staurastrum</u>	dominant	rare	dominant	rare
<u>Asterionella</u>	absent	dominant	absent	dominant
<u>Chlorella</u>	occ.*	dominant	occ.	dominant
<u>Cymbella</u>	rare	occ.	rare	occ.
<u>Diatoma</u>	rare	rare	absent	rare
<u>Stauroneis</u>	rare	rare	rare	occ.
<u>Synedra</u>	rare	rare	rare	rare
<u>Cyclotella</u>	rare	rare	rare	rare
<u>Pinnularia</u>	absent	absent	absent	rare
<u>Navicula</u>	rare	Occ.	absent	occ.

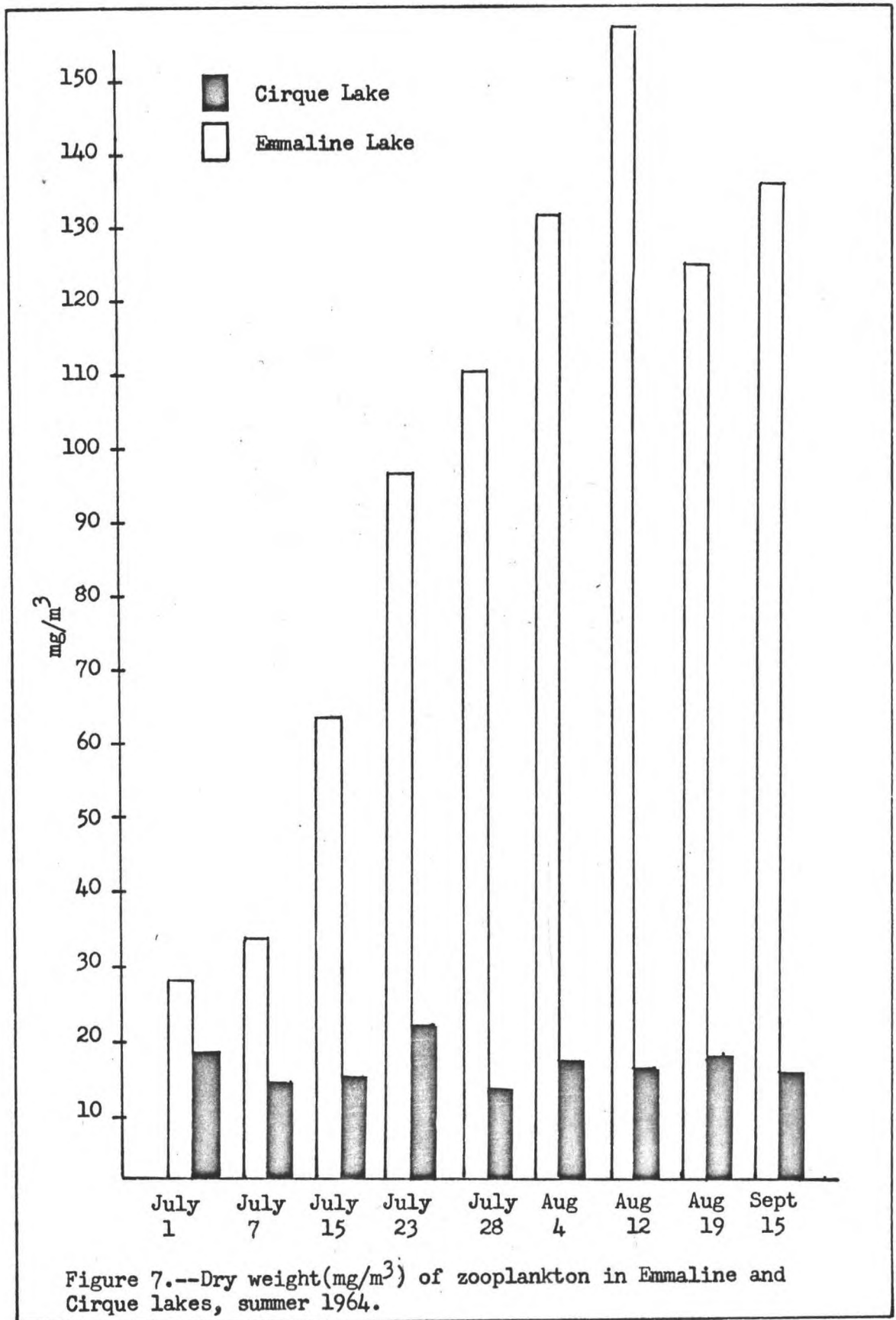
\*occasional

Table 3.--Comparison of phytoplankton and zooplankton in Emmaline and Cirque lakes (1964 to 1965) by paired t-test.

	N	Mean difference	Sum of difference	Standard error	t
Zooplankton					
Emmaline	9	74.0	667.0	24.3	3.04*
Cirque	9	4.0	38.0	4.5	0.8
Phytoplankton					
Emmaline	9	0.8	7.2	0.68	1.7
Cirque	9	0.2	1.7	0.19	1.05

\*significant at 5 per cent





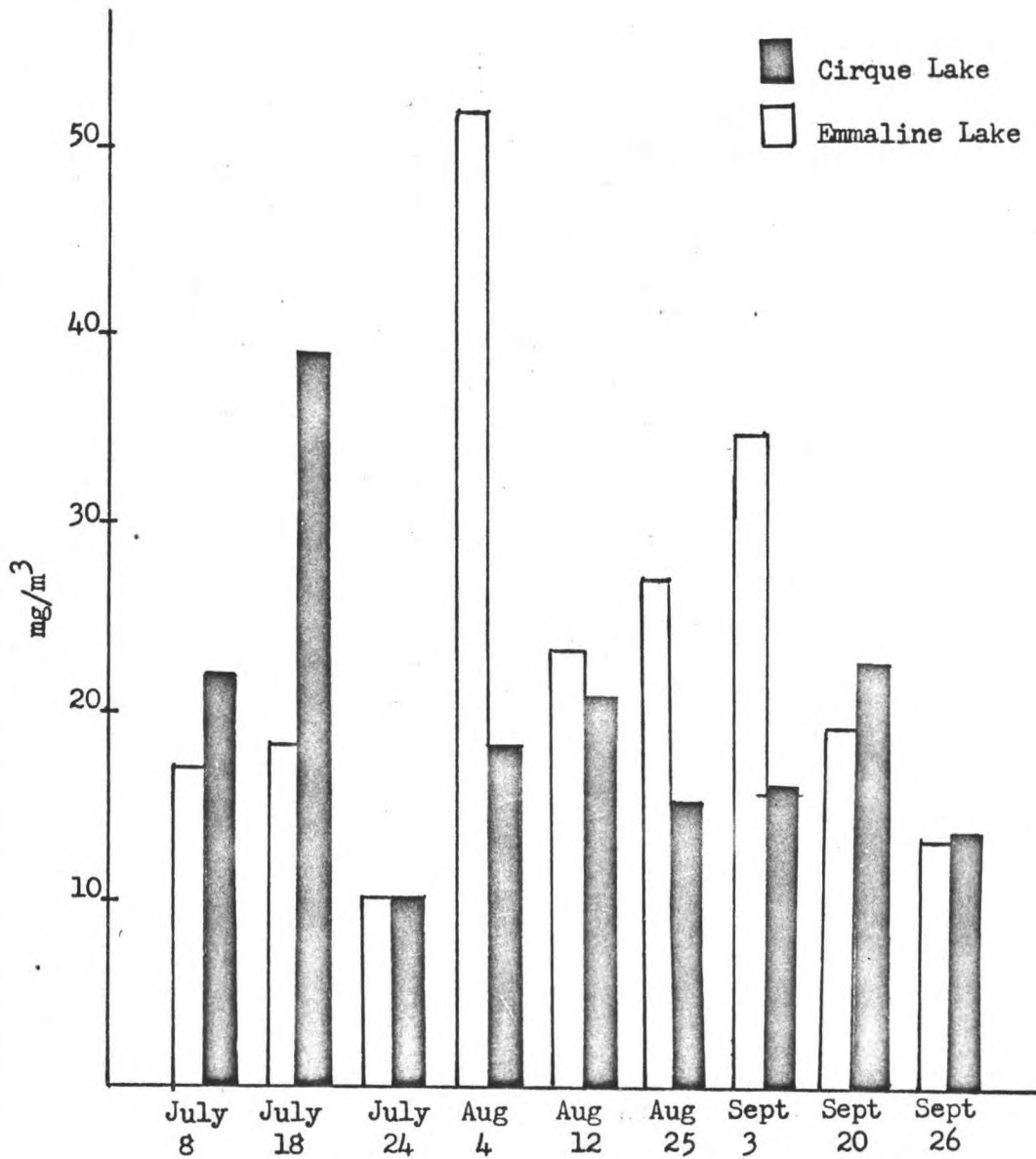


Figure 8.--Dry weight(mg/m<sup>3</sup>) of zooplankton in Emmaline and Cirque lakes, summer 1965.

wading the shoal areas in Cirque Lake. Four estimates of Tricoptera in the shoal areas ranged from 15 to 35/m<sup>2</sup>. Observation of the shoal areas in Emmaline Lake 1965 revealed Tricoptera and water boatmen (Corixidae) that were not observed the previous summer.

#### Ekman Dredge Samples

Qualitative composition of organisms collected with an Ekman dredge was similar for both lakes, with the exception that Tricoptera were collected only in Cirque Lake. A qualitative change between years was not observed. Organisms identified were: Tendipes sp., Micrasema sp., Pisidium sp., (Pelecypoda), Oligochaeta, and Nematoda.

There was a significant difference in standing crop of bottom organisms in Emmaline Lake between 1964 and 1965 (Table 4). Standing crop in 1965 was less than in 1964. (Fig. 9). There was not a significant difference in bottom organisms in Cirque Lake between 1964 and 1965 (Fig. 10). Sampling dates were likewise insignificant. Cirque Lake had the greater summer standing crop both years (Fig. 11 and Fig. 12).

Table 5 contains the numerical percentages of organisms sampled. Tendipedidae were dominant in both lakes in 1964; they were also dominant numerically in Emmaline Lake in 1965. Reduction of Tendipedidae is reflected in the weight loss (Fig. 9). Weight of Oligochaeta was considered as negligible.

#### STOMACH CONTENTS AND CONDITION OF BROOK TROUT

Stomach contents of brook trout were collected the first summer, (Table 7). Mean dry weight of contents per stomach was greatest during early summer. Aquatic Diptera (Tendipes sp.) aerial, and terrestrial insects composed most of the diet. Mean number of dipterans ranged from 9 to 86 per cent during the sampling period. Aerial and terrestrial

Table 4.--Analysis of variance of bottom organisms (blot-dry weight) from Emmaline and Cirque lakes.

Components	Degrees of freedom		Sum squares		Mean squares		F	
	Emmaline	Cirque	Emmaline	Cirque	Emmaline	Cirque	Emmaline	Cirque
Date	8	8	238.6	225.9	29.8	28.2	2.53*	0.29
Years	1	1	101.5	362.2	101.5	362.2	8.63*	3.84
Cells	17	17	379.4	1864.0	22.3	109.6	1.89	1.16
Interaction	8	8	39.3	1275.7	4.9	159.4	0.41	1.69
Within cells	72	54	846.8	5090.6	11.7	94.2		
Total	89	71	1226.3	6954.6	13.7	97.9		

\*significant at 5 per cent

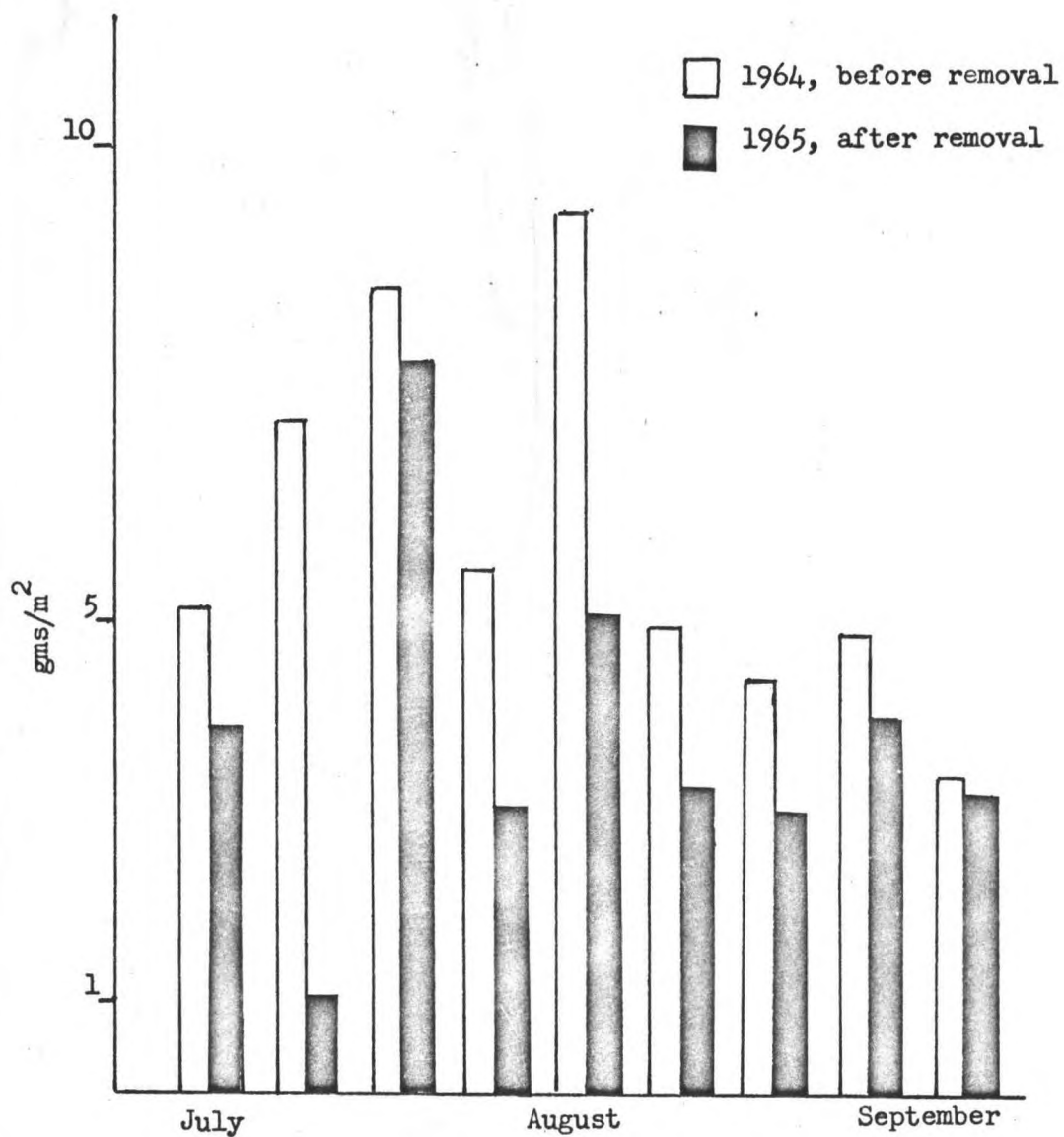


Figure 9.--Mean dry weight (gms/m<sup>2</sup>) of Ekman dredge samples from Emmaline Lake.

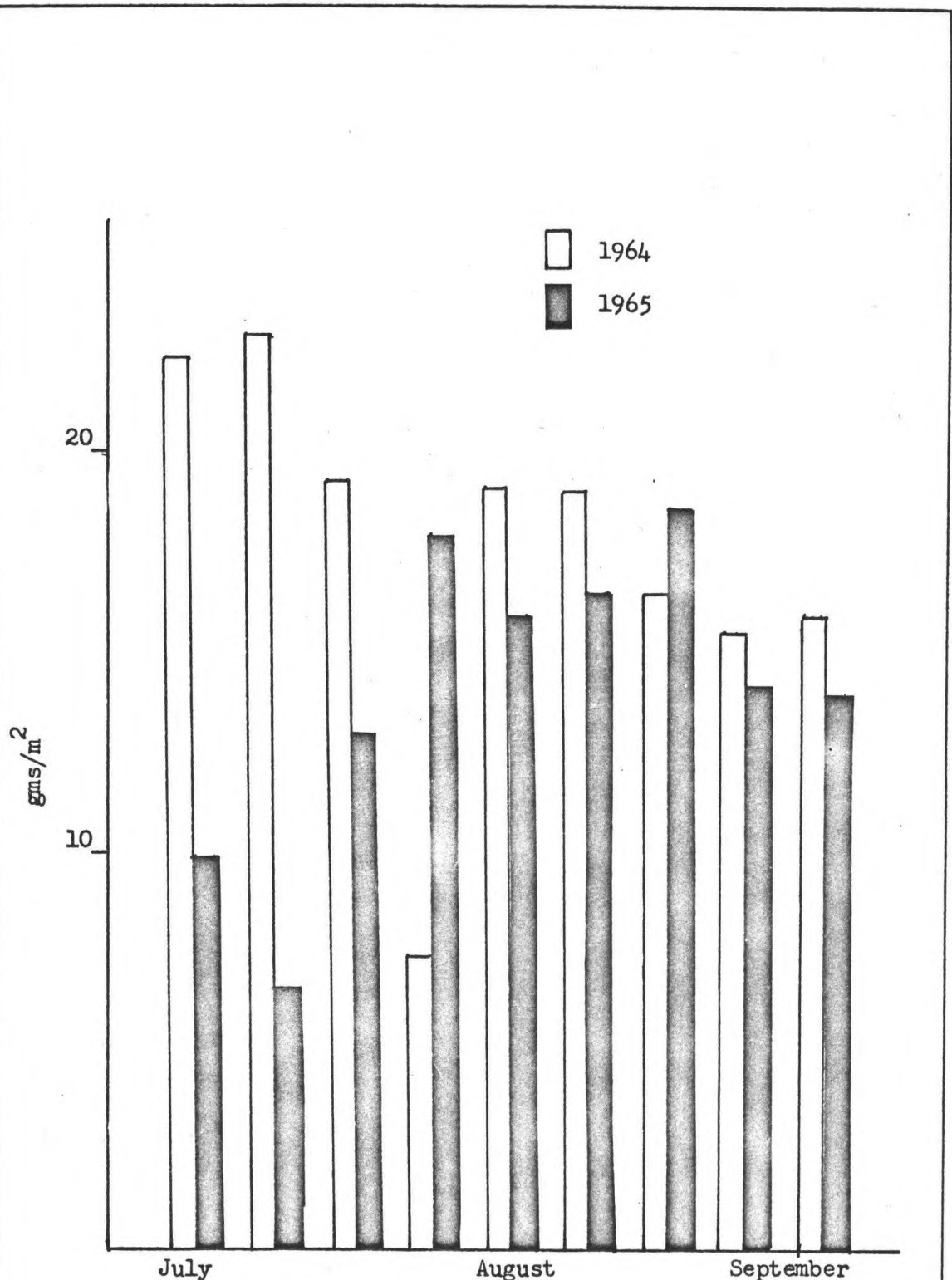
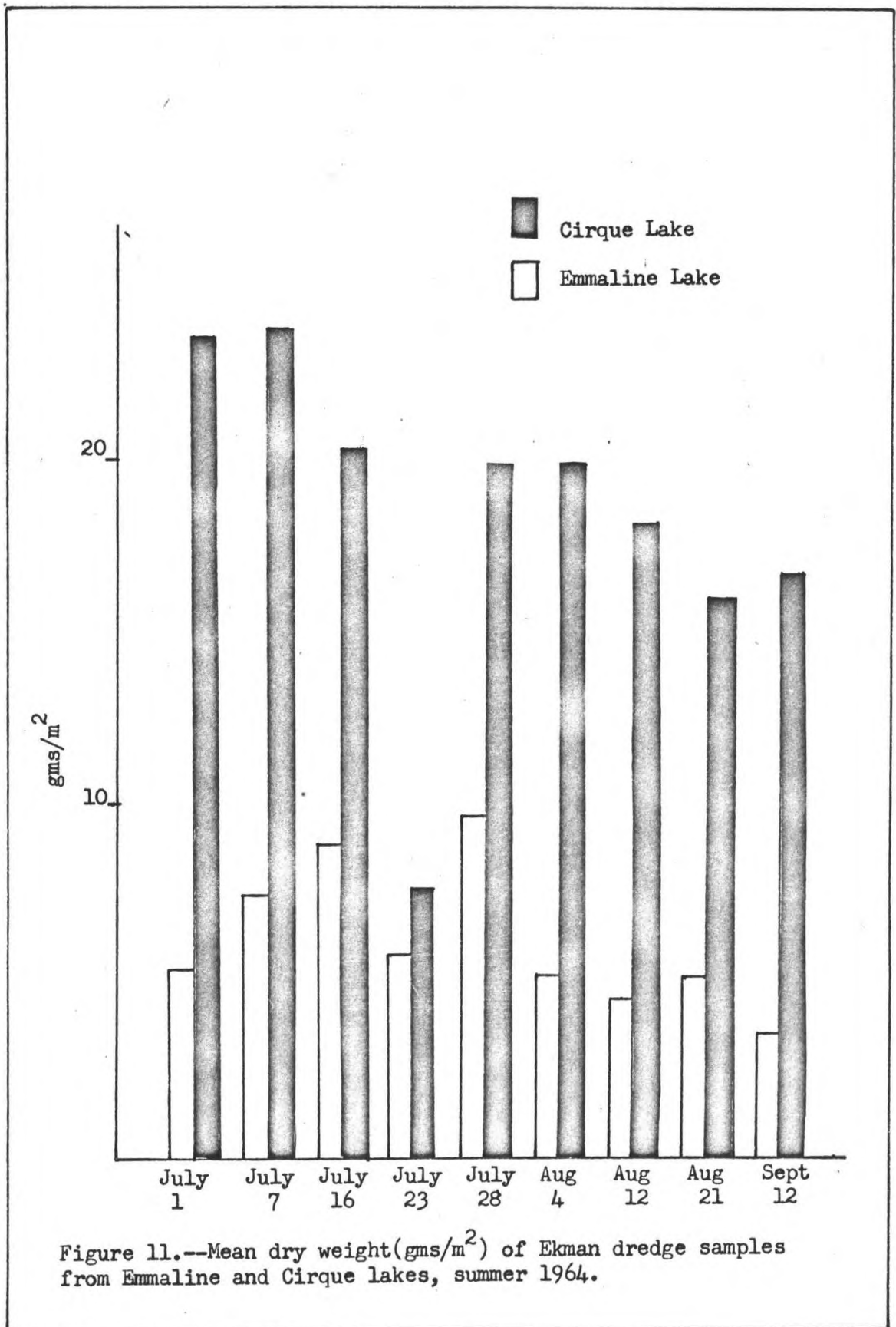


Figure 10.—Mean dry weight (gms/m<sup>2</sup>) of Ekman dredge samples from Cirque Lake.



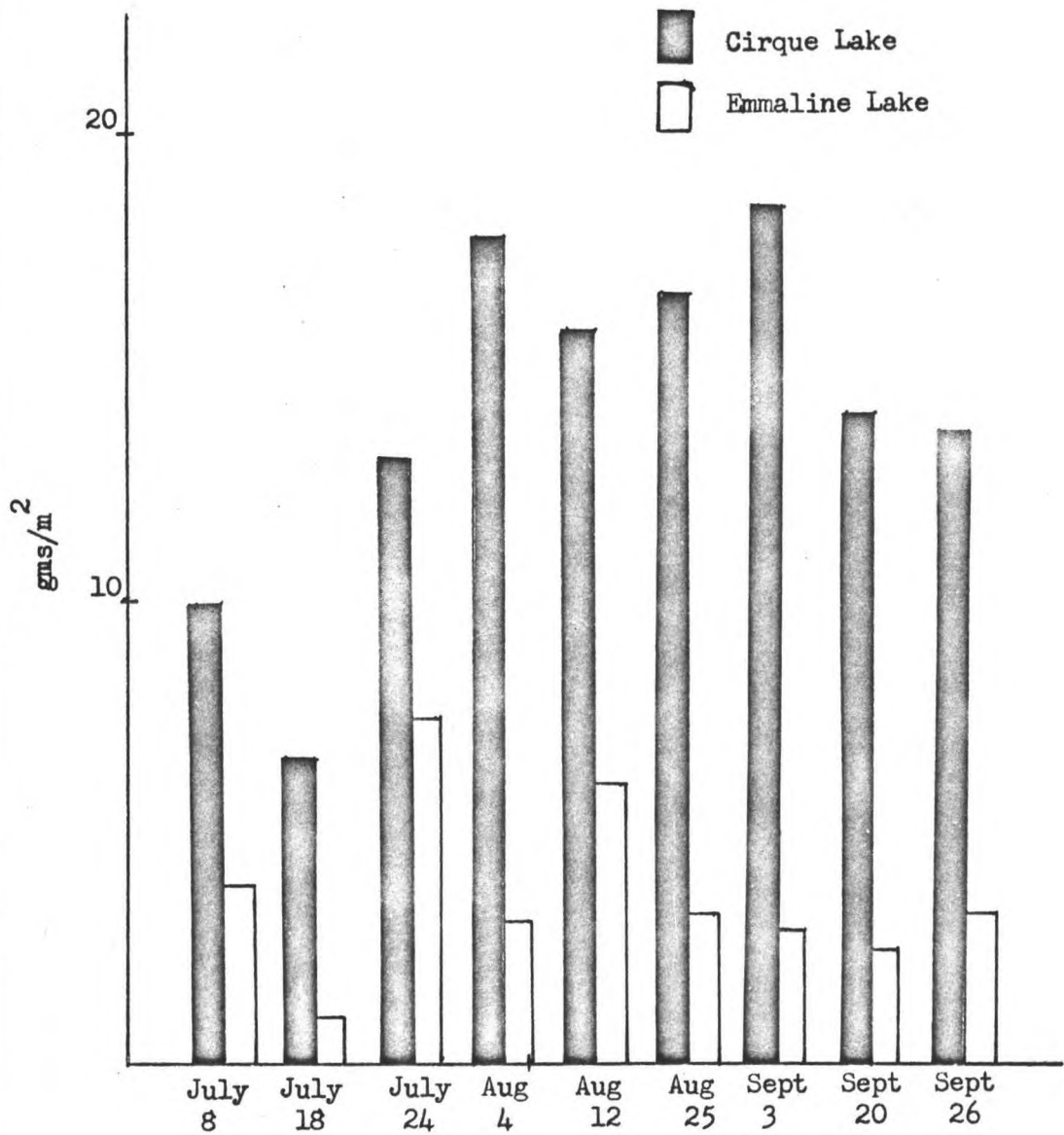


Figure 12.--Mean dry weight(gms/m<sup>2</sup>) of Ekman dredge samples from Emmaline and Cirque lakes, summer 1965.

Table 5.-- Number of zooplankters per cubic meter in Emmaline and Cirque lakes.

Order	Emmaline Lake							
	1964				1965			
	June 24	July 15	Aug 4	Sept 15	July 8	July 24	Aug 12	Sept 3
Rotatoria	23,500	15,750	10,500	2,000	11,500	22,500	237,750	182,500
Cladocera	15,000	31,750	83,500	79,500	2,000	325	875	320
Copepoda								
Adult	2,250	2,000	2,970	250	650	250	305	180
Nauplii*	1,500	3,250	250	82	50	175	100	12
	Cirque Lake							
Rotatoria	750	493	758	256	1,250	266	1,897	975
Cladocera	493	379	-	315	114	50	35	-
Copepoda								
Adult	289	266	20	24	65	15	26	48
Nauplii	-	-	-	-	-	14	37	-

\*nauplii and copepodites

Table 6.--Percentage abundance and summer standing crop of bottom organisms collected by Ekman dredge in Emmaline and Cirque lakes.

	Average percentage of total number by:				Summer standing crop	
	Diptera	Mollusca	Annelida	Other*	Mean dry weight, gms/m <sup>2</sup>	Number/m <sup>2</sup>
<b>Emmaline</b>						
1964	60	5	34	1	5.9	2,850
1965	35	6	54	5	3.7	2,660
<b>Cirque</b>						
1964	52	42	5	1	17.6	4,950
1965	45	35	15	2	10.9	4,500

\*Nematoda, Plecoptera, Tricoptera, and Ephemeroptera

insects ranged from 8 to 66 per cent, these included leaf hoppers (Hemiptera), wasps (Hymenoptera), beetles (Coleoptera), and adult dipterans. Leaf hoppers and wasps were most numerous.

Zooplankton were present in small numbers throughout the summer. An individual stomach contained either mainly copepods or mainly cladocerans. Leaves of subalpine fir (Abies lasiocarpa) were observed often in the stomach contents. Diatoms and desmids were also present but minor in number and weight. It was impossible to determine a difference in the qualitative composition of aquatic organisms in stomach samples compared with organisms collected from the lake.

Fifty brook trout recovered during eradication were used in determining the coefficient of condition (Lagler, 1956). Length in centimeters (total length) and weight in grams were used in the calculations. Mean length of fifty brook trout was 19.3 cm; mean weight was 81.8 gms. Mean condition factor was 1.12. This is better than the average condition factor reported for brook trout in the Convict Creek Basin (Reimers, Maciolek, and Pister, 1955).

Table 7.--Analysis of stomach contents of brook trout from Emmaline Lake, 1964.

Item	June 30	July 7	July 15	July 23	July 28	August 4	August 29	September 15
Number of stomachs	17	14	14	15	15	6	14	8
Mean dry weight of contents(gms)	0.17	0.11	0.14	0.10	0.17	0.11	0.05	0.06
Range in weight of contents	.07-.43	.06-.25	.02-.30	.03-.24	.03-.36	.03-.18	.01-.14	.01-.13
Mean numerical percentage of contents by:								
Aquatic diptera								
Tendipedidae	86	48	43	9	16	30	43	33
Zooplankton								
Copepoda	1	1	1	0	0	1	10	1
Cladocera	1	1	0	1	3	1	5	12
Aerial and terrestrial insects	8	24	42	66	52	60	10	26
Plants(fir leaves and diatoms)	1	1	0	5	1	6	8	2
Detritus and unidentifiable organisms	4	25	6	16	23	4	24	14

## CHAPTER V

### DISCUSSION

Emmaline and Cirque lakes are alpine lakes that have chemical, physical, and biological features typical of alpine lakes in the northern Colorado lake district (Pennak, 1941, 1958 and 1963). Rooted aquatics are absent from both lakes. The lakes were ice-free for approximately 120 days in 1964 and 105 days in 1965. Cirque Lake, barren of fish, was not an ideal control; a lake that supported fish would have been better.

#### PHYTOPLANKTON

Desmidiaceae and Bacillariophyceae were dominant in both lakes during 1964 and 1965, respectively. Olive (1954) found desmids and diatoms to be dominant in other high mountain lakes of Colorado. No significant difference was observed in the summer standing crop, but the peak of abundance varied. In 1964 phytoplankton was most abundant in the latter part of summer; in 1965 the peak was in early July (Fig. 4). There was an abrupt decline of Staurastrum and an increase of diatoms and Chlorella in 1965. Neither of the above observations could be related to McCombie's (1953) discussion of phytoplankton growth. Chemical and physical conditions that were measured were relatively constant both years.

Effect of rotenone on phytoplankton appeared negligible since the same change occurred in the control lake. Application of Pro-Noxfish in a cold-water pond in Montana, which had a number of phytoplankton species, affected only Dinobryon. The Dinobryon population decreased immediately and was absent two weeks after application, but returned to former abundance one month later (Wollitz, 1962).

## ZOOPLANKTON

Dry weight of zooplankton summer standing crop in Emmaline Lake was significantly less in 1965 (Fig. 5), approximately eight months after removal of brook trout. Daphnia rosea, dominant in 1964, was notably reduced.

There was no significant difference in standing crop in Cirque Lake. Daphnia rosea was present but rare both years. Diaptomus shoshone was dominant.

Removal of fish did not increase the invertebrate standing crop the succeeding summer. Possible causes for reduction of standing crop in Emmaline Lake were: (1) Absence of fish, (2) effect of rotenone, or (3) natural fluctuation. Interaction between brook trout and zooplankton may have benefited zooplankton, but this is doubtful. Banta (1939) stated in a footnote that predators (fish) living on cladocerans are limiting the cladoceran populations.

Effect of rotenone on zooplankton has been variable. It is generally accepted that open-water cladocerans and copepods are initially eliminated for several weeks, that rotifers are less sensitive, and that complete elimination of a species is unlikely (Smith, 1939; Brown and Ball, 1942; Hooper, 1948; and Kiser, Donaldson, and Olson, 1963). Zooplankton in Emmaline Lake were limnetic, and one week after application a reduced number of rotifers (Keratella) was the only zooplankton present.

Zooplankton in two Washington State lakes were affected but not permanently eliminated by 0.5 and 1.0 ppm rotenone (Kiser, et al. 1963). All limnetic Entomostraca disappeared for approximately four weeks. Littoral-species were dominant in open water after the fourth

week. After 12 weeks, the original dominant limnetic species returned to previous abundance. Rotenone application in the spring and early summer, during zooplankton population pulses, appears to have more severe and lingering effects than when used in autumn months. When rotenone was applied to Emmaline Lake on September 15, 1964, zooplankton was at a peak abundance.

Wollitz (1962) concluded that treatment with rotenone had little apparent effect on most groups of zooplankton. Bosmina was the only organism which decreased after treatment. Other zooplankton included Ceriodaphnia, Chydorus, Daphnia (Cladocera); Cyclops, and Diaptomus (Copepoda).

It was impossible to determine how long cladocerans and copepods were absent or how long it required for the rotenone to dissipate in Emmaline Lake. Water temperature was 38 F when rotenone was applied; at this temperature it would require approximately 45 to 50 days (Post, 1957) to dissipate. Low water temperatures and an autumn zooplankton pulse may have contributed to a lingering effect of the rotenone that subsequently reduced the standing crop in 1965.

Natural changes in dominant species composition of limnetic Entomostraca have been observed in a Colorado alpine lake. Daphnia longispina was absent from samples collected in August, 1940 and in July to September, 1950; in September, 1954 it was abundant. Other cladocerans and copepods demonstrated similar changes in densities (Pennak, 1955). Since standing crop in Cirque Lake was stable in 1965, it would indicate that an abrupt decline was unlikely in Emmaline Lake. However, Daphnia rosea was not dominant in Cirque Lake

It seems most probable that rotenone was the major cause for the zooplankton decline in 1965. Recovery of zooplankton populations in alpine lakes such as Emmaline must require an extended period of time.

In Emmaline Lake, brook trout utilized small numbers of zooplankton throughout the summer of 1964. Survey of lakes in Convict Creek Basin showed that brook trout consumption of zooplankton varied from 0.12 per cent of total stomach volume to 17.75 per cent. There seemed to be no apparent relationship between amounts of plankton present in the environment and amounts eaten by trout (Reimers, et al. 1955).

#### MACROSCOPIC BOTTOM ORGANISMS

Standing crop of bottom organisms in Emmaline Lake was significantly reduced in 1965, while that of Cirque Lake did not change. Tendipedidae composed the bulk (dry weight) of Ekman dredge samples from both lakes. As in the case of zooplankton, rotenone probably caused the reduction. However, sample size was not large and should be reconsidered in future analysis of the lake.

Reports on the effects of rotenone on benthonic organisms are likewise variable. One ppm Pro-Noxfish (0.025 ppm rotenone) and 1 ppm Noxfish (0.05 ppm rotenone) did not cause a decrease in chironomid midge larvae following treatment (Penick and Co., 1963).

Benthonic animals are less sensitive than fish to 0.5 ppm rotenone emulsives and after eradication of fish, sufficient numbers of organisms remain to restore the population. Mud was considered a protection factor (Lindgren, 1960). However, Cushing and Olive (1957) noted disappearance of tendipedids for a week following treatment with 1 ppm of 5 per cent rotenone in a Colorado reservoir. Tendipedidae were reduced in Emmaline

Lake in 1965 (Table 5).

Tendipedid larvae and pupae, and terrestrial insects each composed approximately one-half the diet of brook trout in Emmaline Lake. General conclusions concerning food habits of brook trout in alpine and subalpine lakes is that they are variable, but that brook trout feed on the most available food. Midge larvae and pupae were high in most diets (Hazzard, 1935; Needham and Summer, 1941; Reimers, 1958; and Royer, 1960).

Aquatic insects, numerous in shoal areas of Bunny Lake prior to the introduction of brook trout, were absent one year later (Reimer, 1958). Caddis larvae and water boatman (Corixidae), which were absent prior to fish removal, were observed in Emmaline Lake the following summer. Plecoptera were rare before fish removal, but were absent afterwards. Either rotenone killed the Plecoptera, or the sample was not large enough to detect the low number. Apparently larger insects in shoal areas are consumed readily but return when fish are absent.

Conditions observed in the summer of 1965 were: (1) standing crop of phytoplankton did not change in either the control or experimental lake, (2) standing crop of zooplankton was significantly less in the experimental lake, (3) standing crop of macroscopic bottom fauna was also significantly less in the experimental lake, but not in the control; rotenone may have been a reduction factor, but limitations in sampling are also possible. (4) Aquatic insects appeared in shoal areas of the experimental lake.

One season was not sufficient time for invertebrate populations to reach natural levels after the effect of rotenone. Prolonged effect of rotenone masked predator prey relationships within the lake.

## CHAPTER VI

### SUMMARY

This study was to consider the effect of fish predation upon aquatic invertebrates in Emmaline Lake, a small alpine lake in northern Colorado. Cirque Lake, adjacent to Emmaline Lake but barren of fish, served as a control.

Summer standing crop of phytoplankton, zooplankton, and macroscopic bottom organisms of both lakes was sampled nine times before (1964) and after (1965) removal of brook trout from Emmaline Lake. Brook trout were removed by rotenone (1 ppm) in September, 1964. Stomach samples of the trout were collected during the summer prior to removal. Physical and chemical properties of both lakes were similar in 1964 and 1965.

Phytoplankton standing crop (cells/liter) did not change significantly in either the treated or untreated lake. Qualitative composition of phytoplankton was similar. The desmid, Staurastrum sp., was dominant in both lakes during 1964. Diatoms were dominant during 1965.

Zooplankton standing crop (dry weight) in Emmaline Lake declined significantly after removal of brook trout. Reduction of Daphnia rosea was the most noticeable. Rotenone, natural fluctuation, or lack of predation are possible causes of reduction. As standing crop in Cirque Lake remained constant, rotenone is the most probable cause. Cladocera were dominant in Emmaline Lake, copepods, in Cirque Lake.

Based on wet weight (blot-dry) of Ekman dredge samples, standing crop of bottom organisms in Emmaline Lake was significantly reduced after fish removal. Rotenone appears to have caused this decline, but sample size may be questioned. The greater standing crop in Cirque Lake

remained stable. Tricoptera were observed in the shoal areas of Emmaline Lake after removal of brook trout, but not before. Tendipedidae were dominant in both lakes.

Tendipedid larvae and pupae, and terrestrial or aerial insects were the chief organisms in the stomachs of brook trout. Zooplankton were eaten in small quantities throughout the summer.

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ABSTRACT

EFFECT OF REMOVAL OF THE FISH POPULATION ON THE INVERTEBRATE  
FAUNA AND PHYTOPLANKTON OF EMMALINE LAKE, COLORADO

Summer standing crop of phytoplankton, zooplankton, and macroscopic bottom organisms was sampled before (1964) and after (1965) removal of brook trout from Emmaline Lake, an alpine lake. Cirque Lake, adjacent to Emmaline Lake but barren of fish, served as a control. Brook trout were removed by rotenone (1 ppm) in September, 1964. Stomach samples of the trout, collected during the summer prior to removal, indicated that the trout consumed approximately 50 per cent aquatic and 50 per cent terrestrial organisms. Tenedipidid larvae and pupae were the most abundant aquatic organisms in the stomachs.

After fish removal, standing crop of phytoplankton did not change in either the control or experimental lake. Standing crop of zooplankton and macroscopic bottom fauna was significantly less in the experimental lake but was stable in the control lake. One season was not sufficient time for invertebrate populations to reach natural levels after the effect of rotenone. Prolonged effect of rotenone masked predator-prey relationships within Emmaline Lake.

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