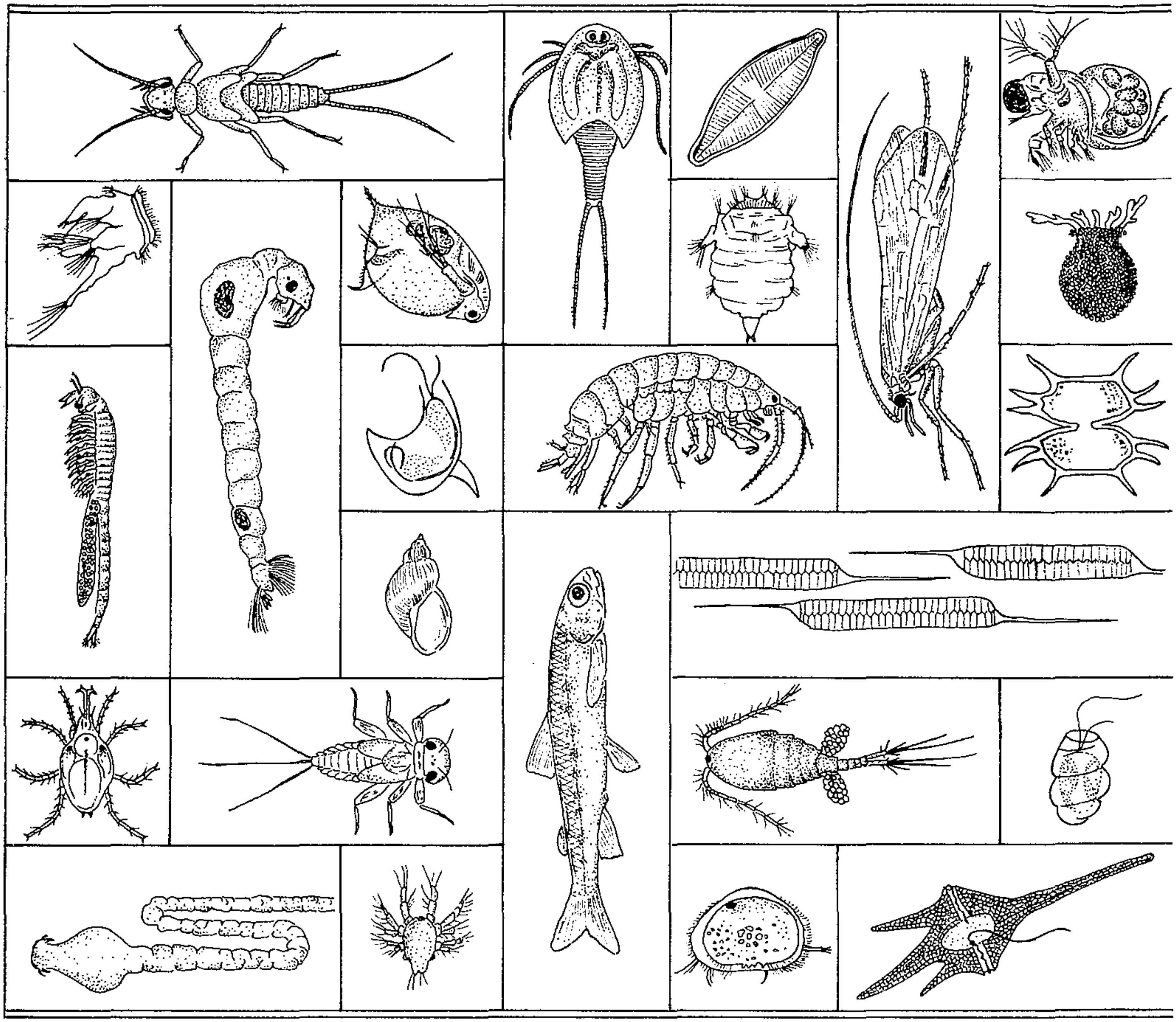
BANFF NATIONAL PARK



Prepared for
PARKS CANADA

by

CANADIAN WILDLIFE SERVICE
Calgary, Alberta

1978

Limnological Survey of some small Lakes in the Vicinity of the Cascade Trail, Banff National Park

R.S. ANDERSON and D.B. DONALD

Environment Canada Environnement Canada

Environmental Management Gestion de l'environnement

Canadian Wildlife Service Service canadien de la faune

Your file Votre dossier

Our file Notre dossier WLJ 300

#1110, 10025 Jasper Avenue
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T5J 1S6

15 March, 1978

Mr. W.C. TURNBULL, Director
Western Region, Parks Canada
131 Customs Building
134 - 11 Avenue S.E.
Calgary, Alberta T2G 0X5

Dear Mr. Turnbull:

I am pleased to transmit herewith a report entitled "A limnological survey of some small lakes in the vicinity of the Cascade Trail, Banff National Park" by R.S. Anderson and D.B. Donald.

Principal funding of the project was by Parks Canada under the EMS/Parks-Canada agreement, although much of the report is based on collections and studies dating back to 1966.

Yours sincerely,

M.R. Robertson, Director

A LIMNOLOGICAL SURVEY OF SOME SMALL LAKES IN THE VICINITY OF THE CASCADE TRAIL, BANFF NATIONAL PARK

R.S. Anderson

and

D.B. Donald

1978

prepared for PARKS CANADA

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Plate I

Dolly Varden char, *Salvelinus malma* (Walbaum), or bull trout, from Harrison Lake, Banff National Park, August 1977.

(photo R.B. Green)

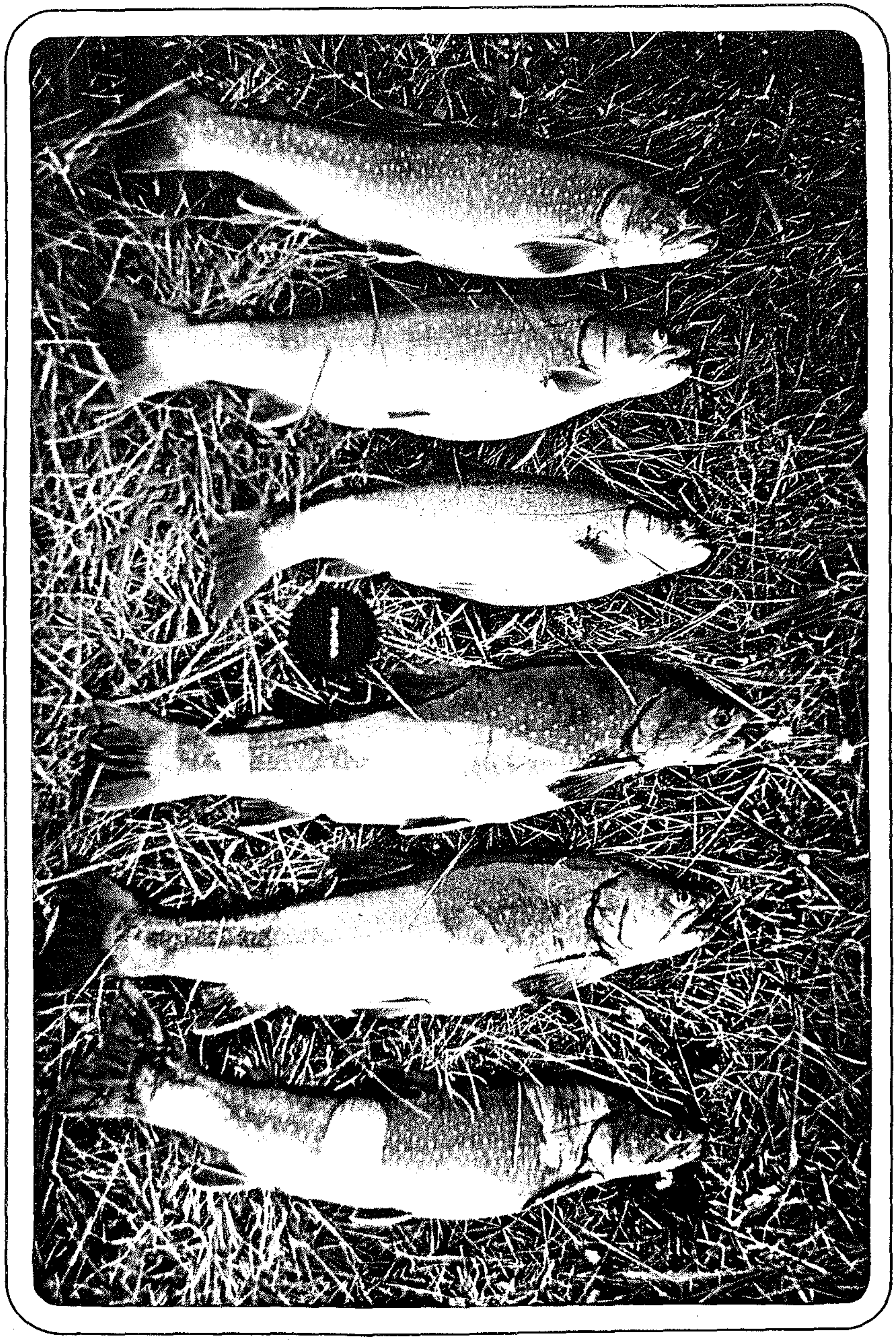
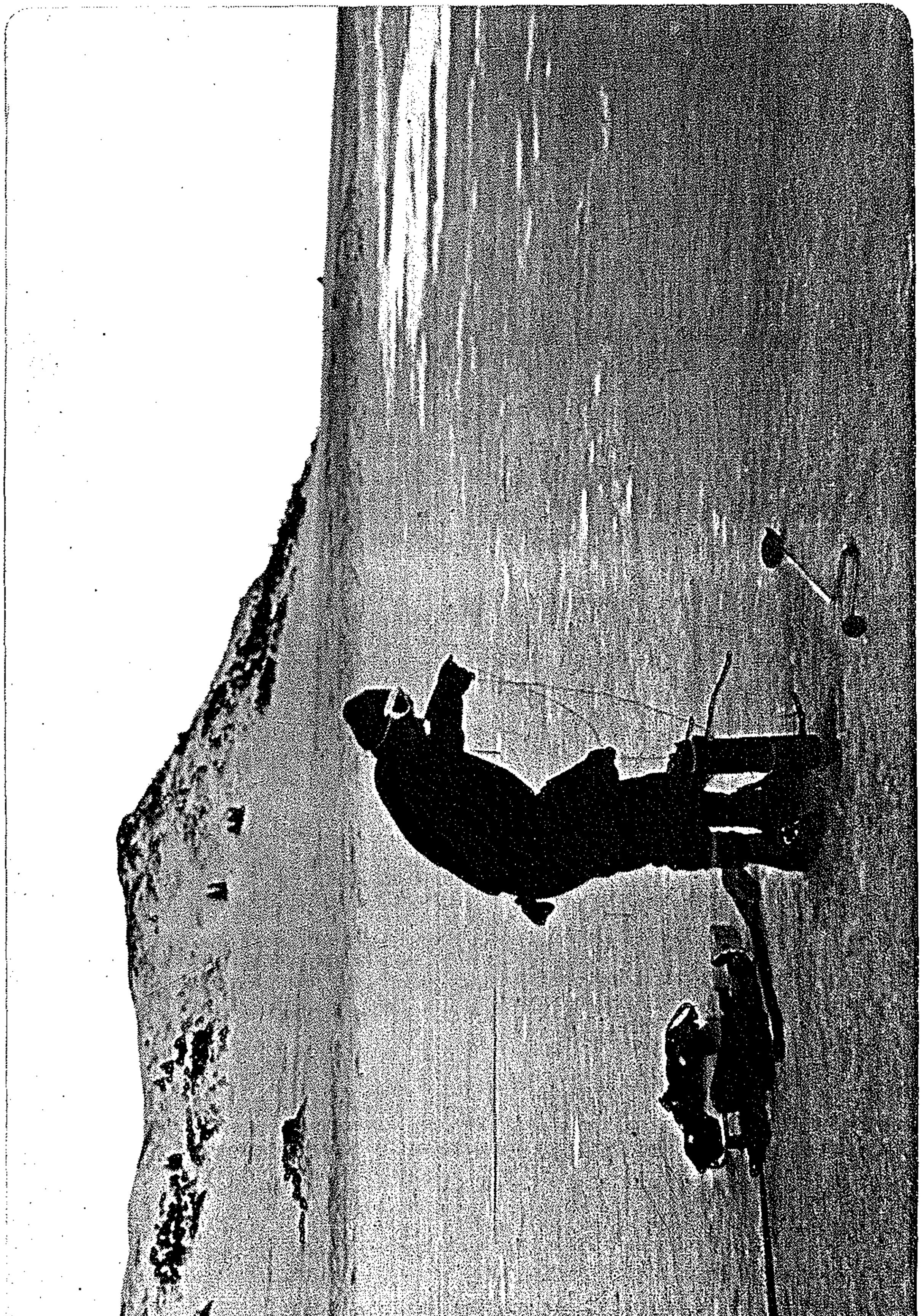


Plate II

Late afternoon sampling in winter at Snowflake Lake, Banff National Park, December 1967.

(photo R.S. Anderson)

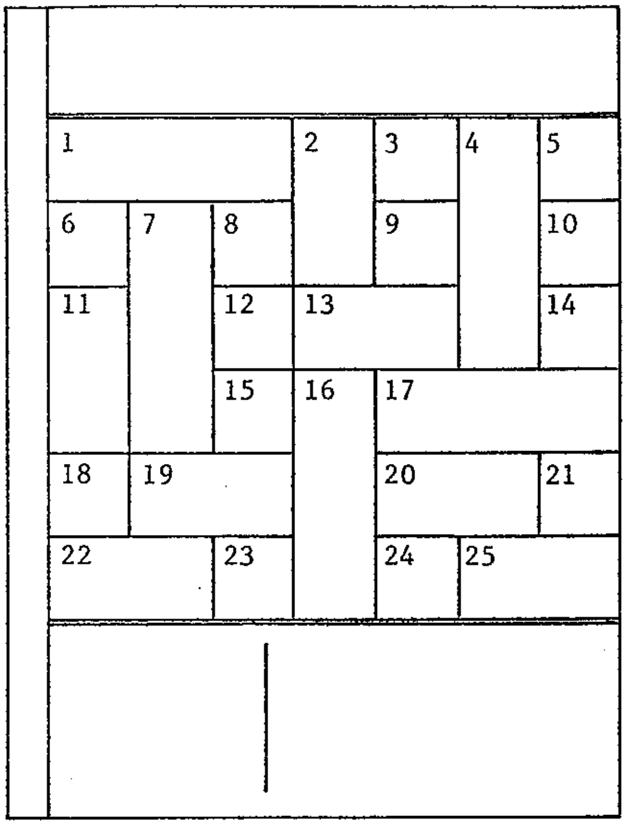


ABSTRACT

This report is a summary of aquatic studies which have been carried out with varying degrees of intensity in ten small lakes and ponds of the Cascade Trail area, Banff National Park, from 1966 to 1977. It includes detailed analyses of the physical and chemical limnology of some of the waters, the zooplankton and phytoplankton communities, and the benthic communities of these lakes. The studies also included an assessment of the fish populations in the lakes. From the inventory data, calculations of annual zooplankton and zoobenthos production were made. The potential maximum sport-fish production was estimated from these calculations of food-organism production.

Populations of native Dolly Varden char (*Salvelinus malma*) occur in two of the waters studied. Rainbow trout (*Salmo gairdneri*), eastern brook trout (*Salvelinus fontinalis*), cutthroat trout (*Salmo clarki*), and Atlantic salmon (*Salmo salar*) have been stocked at one time or another in one or more of six of the waters studied, and small populations of brook trout or rainbow trout survive in four of them. In the six lakes which presently support fish populations, one contains a Dolly Varden population which shows reasonably good growth, four have populations of brook, Dolly Varden or rainbow trout which show only fair growth, and one contains brook trout which are up to 14 years old and show one of the slowest growth rates on record.

It is suggested that the two Dolly Varden populations and one brook trout population may be capable of sufficient natural recruitment to enable them to maintain their numbers under moderate fishing pressure. There is no point in stocking the one lake where growth potential is so poor. One lake has been rather well studied as a representative alpine lake in this region and it is suggested that it would be very valuable to retain it as a study lake and to cease stocking it with hatchery-reared fish. The remaining lake could be stocked with moderate numbers of rainbow trout or cutthroat trout and retained as a back-country fishing lake with a small but not unacceptable production potential.



THE COVER

The cover design attempts to portray representative organisms from many of the major taxa occurring in the waters of the Canadian mountain National Parks. Some of the sketches are rather generalized. The approximate maximum dimension for each organism is given.

1. Plecopteran (stonefly) nymph - usually 1 to 3 cm
2. *Lepidurus* sp. (tadpole shrimp) - about 2 cm
3. *Navicula* sp. (a diatom) - 0.03 mm
4. Trichopteran (caddisfly) adult - usually 1 to 2 cm
5. *Polyphemus pediculus* (a cladoceran or water flea) - 0.15 cm

6. *Hexarthra* sp. (a rotifer) - 0.4 mm
7. *Chaoborus* sp. (non-biting midge) larva - 1.5 cm
8. *Daphnia* sp. (water flea) adult female - 1.5 to 2.5 mm
9. *Synchaeta* sp. (a rotifer) - 0.4 mm
10. *Difflugia* sp. (a protozoan) - 0.25 mm

11. *Branchinecta paludosa* (fairy shrimp) adult female - 2.5 cm
12. *Chrysolykos planctonicus* (a chrysophyte) - 0.02 mm
13. *Gammarus lacustris* (amphipod or scud) - 2.5 cm
14. *Xanthidium* sp. (a desmid) - 0.03 mm
15. *Lymnaea* sp. (a snail) shell - 1 cm

16. *Prosopium coulteri* (pygmy whitefish) - 10 to 13 cm
17. *Rhizosolenia eriensis* (a diatom) - 0.07 mm
18. *Lohmanella* sp. (water mite) - 0.6 mm
19. Ephemeropteran (mayfly) nymph - 3 to 15 mm
20. *Eucyclops agilis* (a copepod) adult female - 1.5 mm

21. *Pseudokephyrion pseudospirale* (a chrysophyte) - 0.008 mm
22. *Triaenophorus* sp. (a fish tapeworm) - 1 to 10 cm
23. *Diaptomus* sp. (copepod) nauplius or larva - 0.05 to 0.1 mm
24. *Cyclocypris* sp. (an ostracode) - 0.5 mm
25. *Ceratium hirundinella* (a dinoflagellate) - 0.4 mm

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ACKNOWLEDGMENTS

Because this study was conducted over a period of several years, many people have assisted on one or two occasions, and to these people we extend our sincere thanks. We are especially indebted to the following for assistance in the field or in the laboratory: Stephen Anderson, Art Colbeck, Rod Findlater, Rod Green, Don Cadman, Dennis Krochak, Dave Mayhood, Elizabeth Neil, Bob Saunders, George Scarlett, and Greg Scott. For help with identifications, we are indebted to Rod Green (algae), Dwight Mudry (parasites), and Agnes Ruttner-Kolisko (rotifers). Lois Green assisted with much of the typing. Water analyses were performed by the Calgary laboratory of the Water Quality Branch, Inland Waters Directorate.

This project was carried out by the Canadian Wildlife Service for Parks Canada under the EMS/Parks-Canada agreement. Funding was mainly by Parks Canada.

INTRODUCTION

The main purpose of this study is to provide a general limnological inventory (physical, chemical, and biological) of a group of small lakes in the northern Cascade Trail region (namely, Bighorn, Cuthead, Grouse, Harrison, Pipit, Snowflake, and Wigmore lakes) in Banff National Park, to assess general productivity, including potential fish productivity, and to provide a general consideration of management policies as they relate to both productivity potentials and general parks policies. The approach taken is basically the same as that taken in previous recent studies in the mountain national parks (Mudry and Anderson 1975; Anderson and Donald 1976a and other reports in the series; Mayhood and Anderson 1976a and other reports in the series; Anderson and Donald 1977 and other reports in the series).

The need for a reassessment of productivity, especially from the point of view of fisheries, arises out of apparent conflicts between expectations, which are not always based on thorough investigations, and factual realities. Although attempts will be made in this study to provide bases for the resolution of these conflicts, there is not room enough for explanations and arguments of sufficient length and breadth to satisfy every critic, especially when some hear only that which they want to hear. Historically, false expectations have been raised by judgments such as those by Rodd (1930). Popular accounts of fishing (e.g. Thornberry and Grimwood, undated) and unrestrained commercial advertising over the years may lead the uninitiated to have unrealistically high hopes. And there are always enough of those who come close to realizing their hopes to raise the hopes of the less successful --- part of the reason why fishermen's stories always find a ready ear. Some of the reasons for unrealistic expectations of productivity have been suspected for many years. The phenomenon of high initial growth after the first stocking of previously fishless waters, followed by declines varying from gradual to precipitous, was documented as early as 1940 (Mottley 1940). However, such accounts have not deterred the hopeful from predicting recovery (Rawson 1940, 1947; Ward 1972), which has occurred to some extent in some waters and very little in others. Because so many factors are involved in the whole matter of lake productivity (i.e. everything from the conditions during the previous winter, the amount of sunlight and rainfall, winds and the times of freezeup and breakup, to the many activities of man, including stocking, fishing, manipulating, polluting, and so on), it is virtually impossible to predict what will happen in a given year, although realistic long-term estimates can be made on the basis of detailed measurements, tempered by the knowledge of past performance in the lakes in question and modified by results and conclusions drawn from other studies of similar waters in the mountain national parks. Such is the purpose of the present study.

Although many detailed physical and chemical limnological investigations have been conducted in the mountain lakes of other regions of the world (e.g. Löffler 1968; Pechlaner 1966; Pennak 1955, 1968; and others), comparatively few studies have been conducted on small, high-altitude mountain lakes in Western Canada, especially winter studies of alpine lakes. Rawson (1940, 1942, 1953) conducted limnological investigations in some of the high mountain lakes in Western Canada, and more recently, there have been a number of studies by Anderson (1967, 1968a, 1968b, 1970a, 1970b, 1971, 1972, 1974a, 1974b, 1975, 1977), Anderson and Dokulil (1977), Anderson and Green (1975, 1976), and Anderson and Raasveldt (1974).

This report is based on some of the results of limnological investigations carried out on seven small alpine and subalpine lakes and three ponds in Banff National Park, Alberta, between 1966 and 1977. The term "alpine" is used here in the sense of Pechlaner (1966) and refers to the altitudinal zone above treeline. The "subalpine zone" corresponds to the "subalpine forest region" as described in "Forest Regions of Canada" (Rowe 1972). These terms are discussed in more detail below.

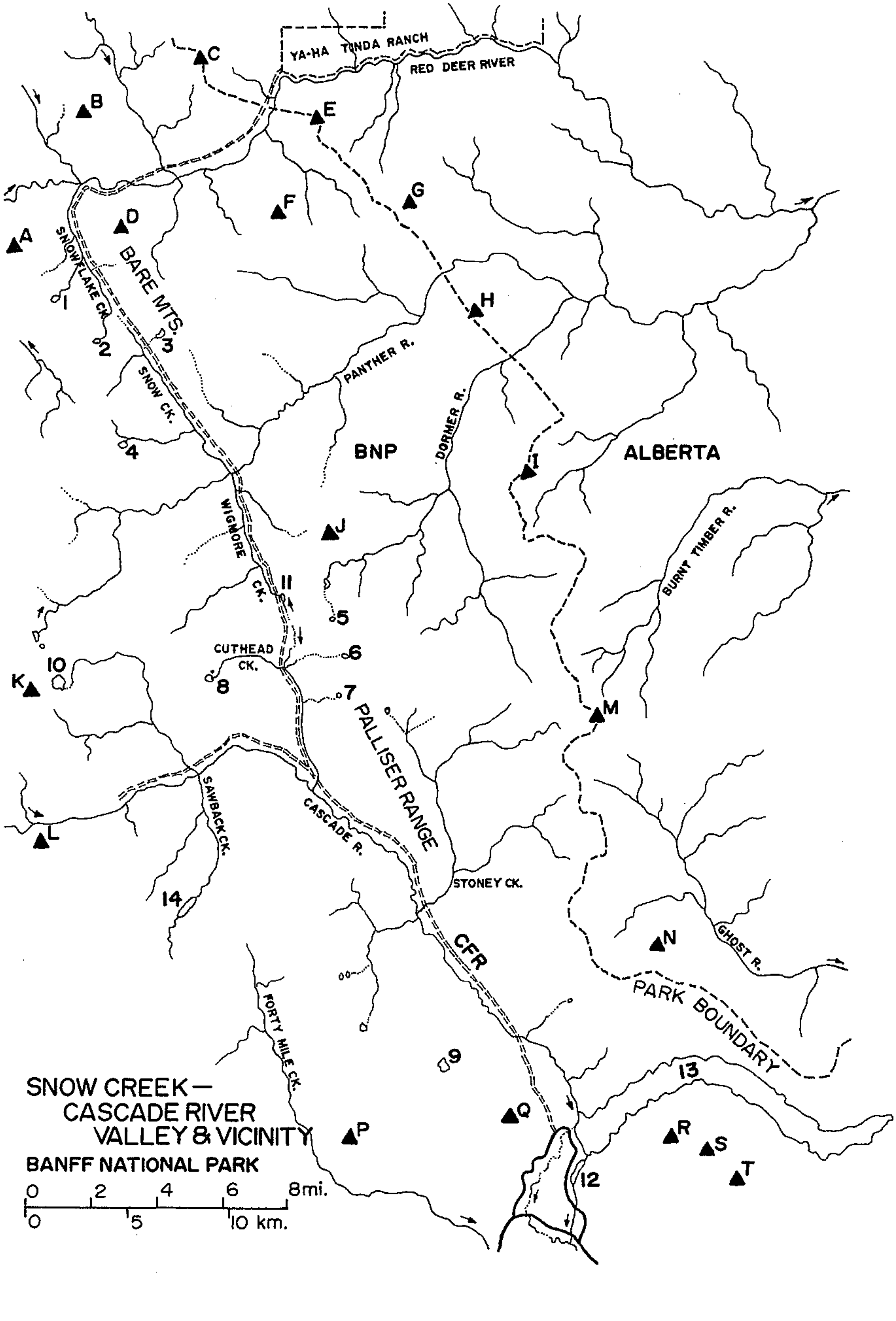
Figure 1. - Lakes and mountains in the vicinity of the Cascade Fire Road.

1.	Pipit Lake (2217m)	A.	Prow Mtn. (2905m)
2.	Snowflake Lake (2320m)	B.	Mt. Tyrrell (2717m)
3.	Grouse Lake (2271m)	C.	Wapiti Mtn. (3027m)
4.	Harrison Lake (2243m)	D.	Mt. White (2755m)
5.	Lost Horse Lake (2323m)	D.	Warden Rock Peak (2694m)
6.	Bighorn Lake (2347m)	F.	Gable Mtn. (2933m)
7.	Little Bighorn Lake (2420m)	G.	Barrier Mtn. (2963m)
8.	Cuthead Lake (2210m)	H.	Dormer Mtn. (2768m)
9.	Cascade Lake (2332m)	I.	Otuskwan Peak (2529m)
10.	Goat Lake (2438m)	J.	Panther Mtn. (2942m)
11.	Wigmore Pond (1996m)	K.	Bonnet Peak (3235m)
12.	Two Jack Lake (1476m)	L.	Block Mtn. (2935m)
13.	Lake Minnewanka (1474m)	M.	Mt. Oliver (3010m)
14.	Sawback Lake (2026m)	N.	Mt. Aylmer (3164m)
		P.	Mt. Brewster (2858m)
		Q.	Cascade Mtn. (3000m)
		R.	Mt. Inglismaldie (2965m)
		S.	Mt. Girouard (2993m)
		T.	Mt. Peechee (2933m)

TCH - Trans-Canada Highway

CFR - Cascade Fire Road

BNP - Banff National Park



SNOW CREEK —
CASCADE RIVER
VALLEY & VICINITY
BANFF NATIONAL PARK

THE STUDY AREA

Geography

An examination of maps and aerial photographs of the 7 Mountain National Parks of Western Canada indicates that the number of alpine and subalpine lakes and tarns is approximately 300, although some of them are known to be intermittent or too shallow to qualify as "lakes". Few of these lakes exceed 100 ha in area and most are between 1 and 25 ha. They occur over a total area of about 22,300 km^2, which means that there is about 1 alpine or subalpine lake for every 75 km^2 of National Park. About 80% of the total number of these high lakes are in Banff and Jasper, between which they are about evenly divided.

With the exception of the relatively sterile alpine lakes fed directly by glaciers, the high lakes in the vicinity of the fire road from Lake Minnewanka to the Ya-Ha Tinda Ranch are fairly representative of the high lakes of the Mountain Parks. This fire road (hereafter called the Cascade Trail) extends approximately 65 km through parts of the valleys of the Cascade River, Cuthead Creek, Wigmore Creek, Panther River, Snow Creek, Snowflake Creek, and the Red Deer River. In an area of 770 km^2 there are approximately 38 small alpine and subalpine lakes within 8 km of the Cascade Trail or the short branch trail through "Flint's Park". Sixteen of these have been stocked with trout or char at some time, and native populations of fish, though all but one of these have since been changed or supplemented with hatchery stock. About 20 of the 38 lakes are pristine lakes, barren of fish. Fig. 1 is a map of the study area.

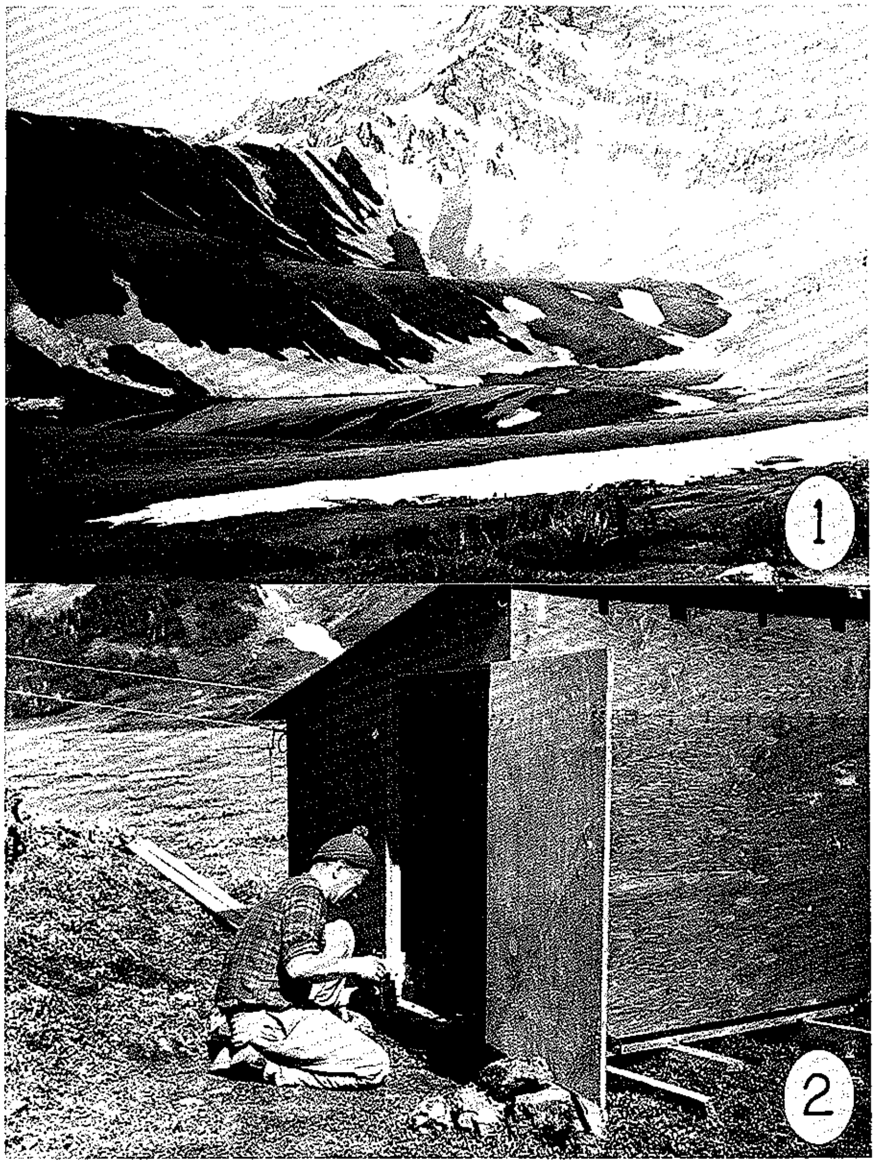


PLATE III

1. SNOWFLAKE LAKE, BANFF NATIONAL PARK, 12 JULY 1967.

2. FIELD WORK AT THE TEMPORARY CABIN NEAR SNOWFLAKE LAKE, 12 JULY 1967.

The Cascade Trail region is not well known scientifically, although a number of recent botanical (e.g. Porsild 1959, Beder 1967, Baptie 1968), geological (e.g. Rutter 1966, Ogilvie and Baptie 1967), and mammalian (e.g. Banfield 1958, Flook 1967) studies have been conducted partly or entirely in the area. The overall valley of the Cascade Trail varies from about 5 to 10 km in width from ridge to ridge. The tree line is generally at 2130 m or more. The interval between 2130 m and 2290 m is often characterized by krummholz or concentrations of rather stunted trees, often in small valleys or sheltered areas. The tree line is not clearly defined along the Cascade Trail. This may be because some portions of the area were burnt-over as recently as 40 years ago and that most of the forest area has been burnt within the past 300 years (Beder 1967, Baptie 1968), and to the fact that some of the area is in a rain shadow (Porsild 1959).

Seven of the lakes of the Cascade Trail region were sampled or observed on two or more occasions during 1966-77 (some data for 3 small ponds are also included). Of the seven lakes, Snowflake Lake (Plate III) was studied in much more detail than the others. From 1966 to 1977, inclusive, a total of 89 sampling trips were made to Snowflake Lake. The elevation, area, mean depth, and maximum depth of Snowflake Lake (2320 m, 7.13 ha, 6.12 m, 13.0 m) are close to the average for six of the seven lakes, excluding Wigmore and the small ponds (2268m, 6.36 ha, 5.81 m, 11.56 m, respectively). Excluding the small ponds, all seven lakes are rather small (2.0 ha to 10.6 ha) alpine or subalpine (1996 m to

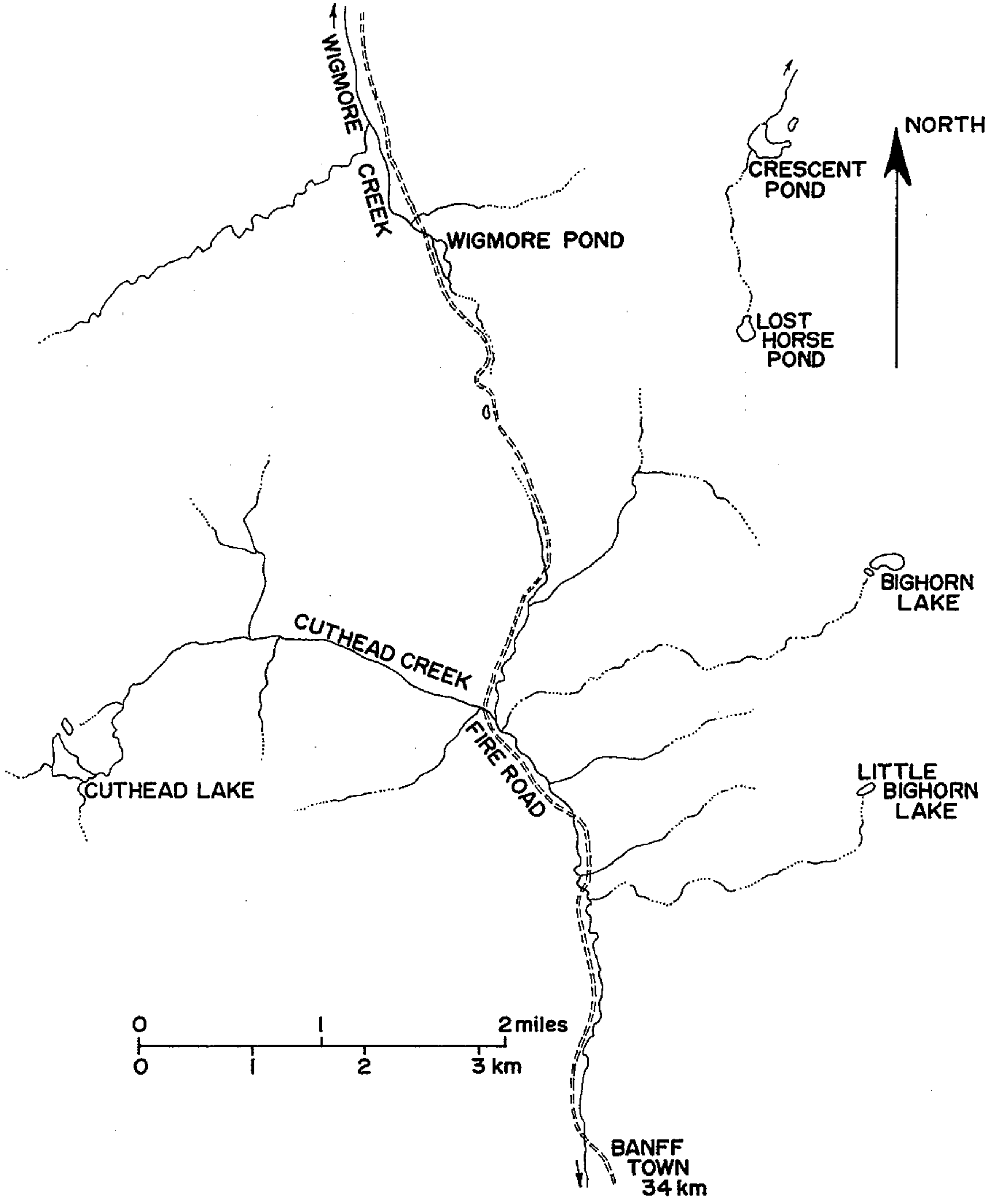


Figure 2.

LAKES IN THE VICINITY OF WIGMORE SUMMIT

BANFF NATIONAL PARK

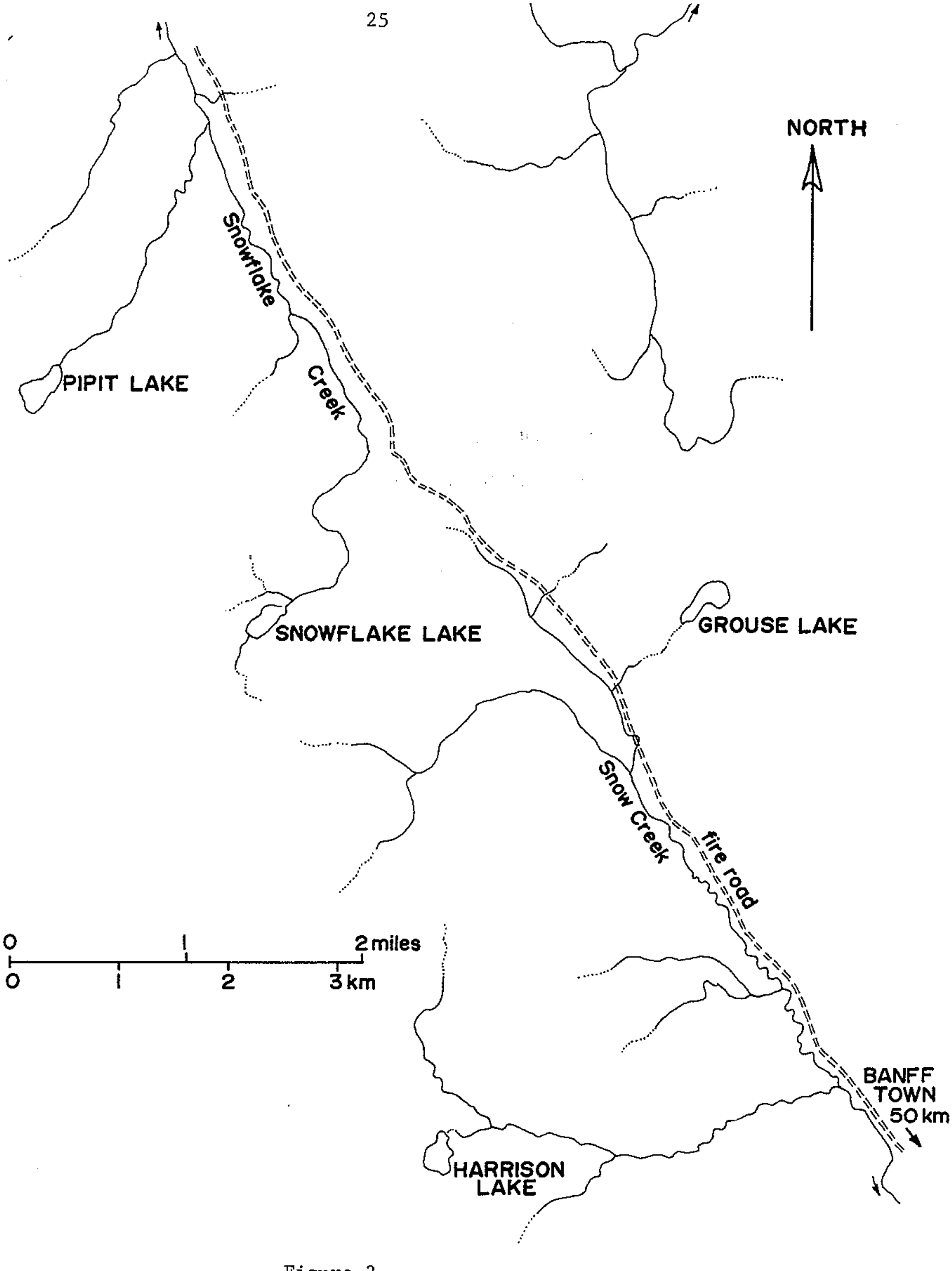


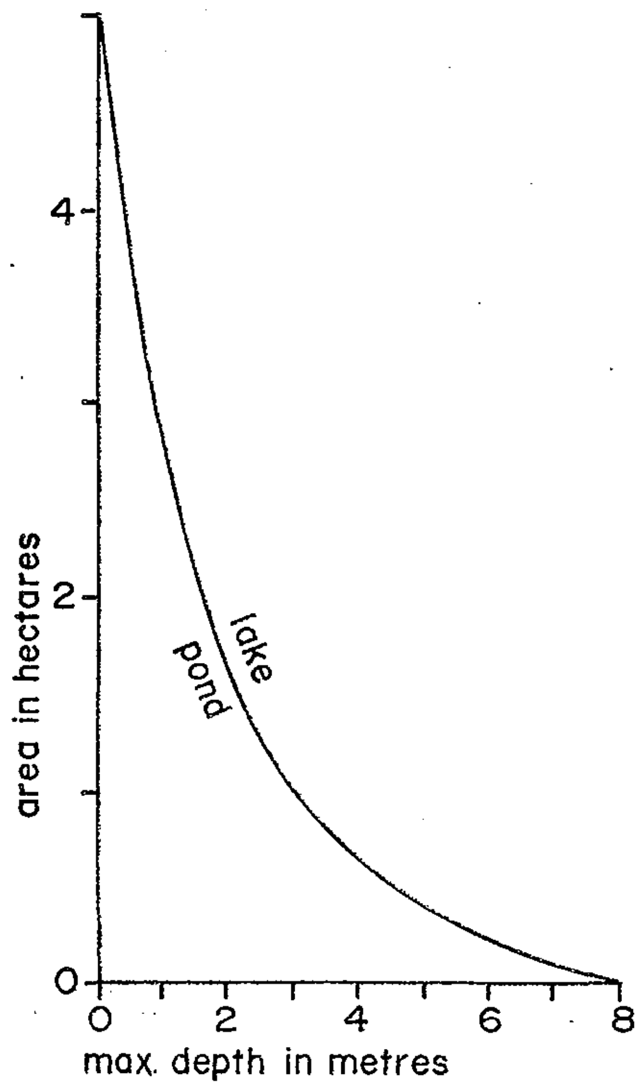
Figure 3.

LAKES IN THE VICINITY OF SNOW CREEK SUMMIT
BANFF NATIONAL PARK

2347 m) cirque lakes or tarns (Figs. 2 and 3). Some of the smaller lakes should be considered ponds perhaps, but as Reid (1961) and Macan and Worthington (1962) suggest, the terms "lake" and "pond" defy precise definition. Morphometry is discussed in more detail in the Discussion section.

Definitions

In these studies, the terms "lake" and "pond" will be used according to the scheme established by Anderson (1971). Although the categories are somewhat arbitrary, the use of such a scheme avoids some of the problems of definitions and provides these common descriptive terms with some precision. The accompanying graph (taken from Anderson 1971) establishes the approximate limits applied to these terms.



In limnological literature, there is often inconsistency in the terminology used in classifying lakes on the basis of elevation (see Rawson 1942, 1953, 1955: Pennak 1958, 1963, 1968; Reed and Olive 1958; Findenegg 1964, 1965, 1966; Pechlaner 1967). It is more meaningful to use general zones based on terrestrial plant communities as described by plant ecologists, although here, too, there is some inconsistency in the use of the terms (e.g. Shelford 1963) and in interpretation (e.g. Shiffers 1960).

Although the precise categorization of lakes altitudinally is difficult, it is proposed here to use a classification based on elevation and on surrounding terrestrial plant communities where elevational zones may vary laterally from valley to valley and from mountainside to mountainside, depending on exposure and other factors. Zones may be unclear in certain areas due to comparatively recent forest fires or to the existence of a "rainshadow" (e.g. Porsild 1959). For limnological purposes, three main zones are recognised: alpine, subalpine, and montane. However, because so many lakes in the mountain national parks occur at the "treeline", a fourth zone, the treeline zone, is proposed, where "treeline" refers to the transitional zone between the alpine and subalpine zones. The following discussion of the alpine and subalpine zones is based primarily on the classifactions of Rowe (1972). The reader is also referred to Ogilvie (1969) for a useful discussion of the topic of forest zones.

1. Alpine Zone

Above treeline (Pechlaner 1967; Hughes and Dunning 1949); the alpine meadow and heath zone, herbs and low shrubs but no trees (cf. Shiffers 1960); the region including the "alpine tundra" (Weaver and Clements 1938; Daubenmire 1943); a region in which occasional patches of permafrost may be encountered (e.g. Ogilvie and Baptie 1967). In the Cascade Trail study area, this zone occurs generally above 2200 m. Here, lakes usually freeze over early in October and ice breakup occurs from late June to mid-July. These times may vary considerably with lake depth or with exposure to sun and winds.

2. Treeline Zone

This is a transitional zone between the alpine and subalpine zones, a region characterized by scattered stunted and contorted trees and patches of "Krummholz". The treeline becomes progressively lower in elevation the further north or south of the equator it occurs. For instance, it occurs at about 3500 m in northern Colorado (Pennak 1963) and at about 2200 m in Banff National Park. The treeline zone usually occurs between elevations of 2130 m and 2290 m in the Cascade Trail study area.

3. Subalpine Zone

In western Canada, this zone corresponds closely to the "subalpine forest region" as described in "Forest Regions of Canada" (Rowe 1972). It is the highest of the forest zones, occupying approximately a 600-metre elevational band immediately below the alpine zone. The dominant tree species of this zone vary regionally: in the northern Rocky Mountains, the dominants are *Picea engelmannii* (Engelmann spruce) and *Abies lasiocarpa* (alpine fir). For other regions and discussions, see also Daubenmire (1943), Hughes and Dunning (1949), Rowe (1972), Shiffers (1960), Weaver and Clements (1938), and others.

Two subzones are distinguishable in the subalpine zone:

(a) Upper Subalpine - more open forest; stands often with additional treeline species: in the northern Rockies, *Pinus albicaulis* (whitebark pine) and *Larix lyallii* (alpine larch) occur in addition to *Picea engelmannii* and *Abies lasiocarpa*; high winds; freezing temperatures at any season of the year; deep snow; wide range of seasonal and diurnal temperatures.

(b) Lower Subalpine - dense, continuous closed-forest stands. In the northern Rocky Mountains, the dominant tree species are *Abies lasiocarpa*, *Picea engelmannii*-x-*Picea glauca* (white spruce) hybrids, and the fire-successional *Pinus contorta* (lodgepole pine) and *Populus tremuloides* (aspen). Lakes often less exposed to the high-velocity winds which characterize the upper subalpine and alpine zones.

In Banff National Park, the subalpine zone generally occurs between 1400 m and 2200 m. Lakes usually freeze over in mid-October, and ice usually breaks up between mid-May and mid-June. Here, too, dates may vary with lake depths and wind velocities. Late freezing or early breakup is more likely to occur in the subalpine than in the alpine zone.

Six of the lakes have no rooted vegetation, but Wigmore has extensive patches of sedges on the south and east sides, and has scattered *Potamogeton* sp. and *Ranunculus* sp. plants. All of the lakes except Bighorn have a meadow area in the immediate vicinity. Five of the lakes (Pipit, Grouse, Harrison, Cuthead and Wigmore) are subalpine; the other two are alpine. Although the water level in Bighorn Lake may fluctuate by about 2 metres, only Grouse Lake is subject to a large water level fluctuation and, although it is not known to dry up completely, it may go dry in years of unusually low precipitation or freeze to the bottom regularly or occasionally. All seven lakes are characterized by a short summer season, and the breakup and freezeup dates for Snowflake Lake are probably fairly representative of all the lakes.

Geology

General descriptions of the physiography, stratigraphy, soil structure, and alpine terrestrial vegetation of the area can be found in Mackay (1952), D.J. McLaren (1955), Porsild (1959), Belyea (1964), Baird (1967), Beder (1967), and Baptie (1968). The following geological description is based on these accounts and on discussions with Dr. L.V. Hills, Department of Geology, University of Calgary.

The Cascade Trail follows a valley in the Front Ranges, the easternmost division of the three main structural divisions of the Rockies. The mountains of the Front Ranges are stratified sedimentary rocks (limestone, shale, sandstone), deposited during or since the Cambrian Period and uplifted principally during the Cretaceous Period. The Second Front Range forms the east side of the valley and is made up of the Bare Mountains, elevations to 2770 m between the Red Deer and Panther Rivers, and the Palliser Range, elevations to 2940 m between the Panther River and Lake Minnewanka. The west side of the valley is part of the Third Front Range, an unnamed range extending 48 km from the Red Deer River to Forty-mile Creek near Banff townsite and having maximum elevations over 3280 m. Cascade Mountain (3000 m) is situated between the Second and Third Ranges at the south end of the Cascade Trail.

Although outwashes indicated possible older glaciation (Rutter 1966; L.V. Hills, personal communication) the oldest definite glaciation in the Cascade Trail valley was about 20,000 to 25,000 years before the present(B.P.) when ice almost filled Snow Creek Valley. The second oldest glaciation was probably 12,000 to 20,000 B.P., and the youngest major glaciation was about 9,300 B.P., although this last glaciation may have been restricted to the Snowflake and Harrison cirques. There is evidence of limited recent glaciation which may be part of the Neoglacial stades common to the Cordilleran Region of North America, one ending approximately 2500 to 3000 B.P. and the other about 750 to 120 B.P. (Porter and Denton 1967). Volcanic ash at the east end of Snowflake cirque is estimated to be between 6600 (possible Mazama origin) and 2500 to 3500 (Bridge River or St. Helen's Y ash) years old (Westgate and Dreimanis 1967, Baptie 1968). The cirque above Snowflake Lake may have contained glacial ice as recently as 100 years ago (L.V. Hills, personal communication).

With these figures as a basis, it is estimated that the lake basins of Pipit, Snowflake, Harrison, and Cuthead Lakes are the oldest of the lakes studied (maximum age between 2500 and 6600 yr) and that the others are probably younger (between 120 and 2500 years old).

Frost action is a significant factor in churning soils and surface strata in the main valley as well as in the small cirques. A small area of permafrost has been found to occur in the immediate vicinity of Snowflake Lake (Ogilvie and Baptie 1967).

Climate

The summary of climatic conditions which follows is based on the data of Beder (1967), Baptie (1968), and observational notes summarized in Anderson (1968b).

The summers in the valley are cool, and snow is often retained in limited areas as late as August or September. During 1967, in the Snow Creek Valley, north of the Panther River, temperatures over 21°C were uncommon. There were 21 days over 21°C in 1965 and 5 days over 21°C in 1966. The highest recorded temperatures were 27°C in 1965, 26°c in 1966, and 27°C in 1967. Mean daily temperatures for the June to September period were in the 5 to 10°C range. The daily means for the winter periods were in the -4 to -12°C range with records as low as -38°C in January 1966. Temperatures well above freezing have been noted in all months of the year, and an occasional frost was noted on the ground during some nights in July and August, 1967. Temperature inversions have been noted frequently in the main valley.

The alpine climate in the valley is variable. From May to October, short rain showers, snow flurries, hailstorms or thunderstorms may occur suddenly and be followed by calm, sunny periods. Total precipitation near the Snow Creek summit was 52.3 cm (20.59 in) from May to December, 1966. Although records are incomplete, there is no evidence for a winter maximum (Baptie 1968). There were 3 weeks of dry weather in 1965, and 5 weeks during 1966 when total precipitation was less than 1.3 cm (0.5 in). Although complete records are not available, the dry spell was probably more extensive in 1967.

Winds in the valley can be strong. Hand anemometer records go as high as 80 km/hr (50 mph) and higher velocities probably occur (Anderson 1968b). The temporary cabin (Plate III) erected at Snowflake Lake, tied down and loaded with rocks and equipment, had withstood winds up to 80 km/hr on several occasions during the summer of 1967, but was found overturned and moved 20 m to the NW during October. Trees 20 cm or more in diameter were snapped off by winds at this time in the lower valley, In general, winds are minimal in early summer, increase through autumn, and reach peak strengths in winter. The temporary cabin at Snowflake Lake has often been buried in drifted snow during the winters from 1967 to 1977.

METHODS

Although the main laboratory and field methods are summarized here, the reader is referred to Appendix B (green pages), General and Technical References (pages B-1 to B-7), for information sources giving more details on various methods, Appendix C (also green pages C-1 to C-7) includes the prinicpal taxonomic references used in this study. Appendix A (pink pages) is a glossary of terms.

1. Lake areas were determined by planimetry from bathymetric maps prepared from 1:50,000 map sheets and aerial photos, onto which sounding data were incorporated.
2. Lake volumes, mean depths, and shoreline developments were calculated according to Welch (1948). Sounding was done with a Fish-Lo-k-tor portable sounder, or with a leaded line.
3. Temperatures were measured with a Yellow Springs Instrument Co. transistorized thermistor calibrated against a glass-stem mercury thermometer at each use.
4. Light penetration was estimated with a black and white Secchi disc 20 cm in diameter. When the disc could be seen to the lake bottom, "+" is used to indicate that water clarity was sufficient to have allowed the disc to be seen at even greater depths than actually existed.
5. Break-up data were compiled from personal observations.
6. Field analyses of water were made using Hach Kit techniques (alkalinity and hardness), a Dionic 3 Conductivity meter, and a Hellige Pocket Comparator (pH). Laboratory water analyses were done by the Calgary laboratory of the Inland Waters Directorate, Water Quality Branch, Environment Canada.
7. Phytoplankton was identified by R.B. Green using the inverted microscope technique (Wild M40) and settling chambers (1972-77) and by R.S. Anderson using filter and immersion oil clearing technique (1966-71). Keys and taxonomic literature are listed in the taxonomic reference section Appendix C (green pages) of Part 1 of this report series.

8. Primary production was estimated using the techniques of Steemann-Nielsen (1952) with some variation as outlined elsewhere (Anderson 1974b; Anderson and Dokulil 1977).

9. Zooplankton was collected with a #20 mesh (aperture approx. 64 micrometres) Wisconsin-style plankton net. In some samples which were not adequately quantitative, estimates of abundance were made according to the following scale:

x	one to very few		$<$ 0.1/litre
xx	few	approx.	0.1-1.0/litre
xxx	several	"	1.0-10 /litre
xxxx	many	"	10/100 /litre
xxxxx	very abundant	"	100-1000/litre
xxxxxx	extremely abundant	"	$>$ 1000/litre

The efficiency of the plankton net was assumed to be 17 to 25%, depending on numbers of net phytoplankton and rotifers, (Anderson 1970a and unpublished data) and calculations of biomass were based on this assumption.

10. Benthic invertebrates were collected with a 15x15 cm Ekman-style dredge. Samples were sieved through a screen-bottom bucket (mesh aperture: 0.36 x 0.52 mm), and the sample residue was hand picked in the field. Identification, counting and weighing were done in the laboratory.

11. Benthic mud was collected with an Ekman grab at one or two stations (usually one littoral and one from near the deepest spot). Six or more samples were dried for 24 h @ 100°C, weighed, ashed 2 h @ 650°C and reweighed. Ignition loss was assumed to represent organic content (no correction was made for carbonate or bicarbonate transformation).

12. Fish from lakes were collected with monofilament-survey nets of mixed mesh sizes (10 yards of each of 1, $1\frac{1}{2}$, 2, 3, and 4 inch stretched-measure apertures).[1] Freshweights were determined to the nearest gram and fork-lengths to the nearest millimetre. Stomachs and otoliths were retained for laboratory analysis. From each collection, a few specimens were quick-

---

1. Manufacturer's dimensions, which are approximately equal to 9.14 metres of each of 2.54 cm., 3.81 cm., 7.62 cm. and 10.16 cm. stretched-mesh apertures.

frozen and stored for total analysis (including parasites) later. Up to five fish of each species of fish from Snowflake Lake were examined for parasites. Details of analysis are described by Mudry and Anderson (1977). Only fresh-frozen specimens were used for parasite examination.

Stomach contents were preserved in dilute formaldehyde in the field. Content volume was determined volumetrically, where each stomach content was given a total of 10 points and according to the fraction of total volume occupied by the food-item. This method is similar to the "points method" which Hynes (1950) found to be the most satisfactory in studying the food of sticklebacks. Points scored by each food-item category in a sample of fish were summed and then expressed as a percentage of the total points assigned to the sample of fish. No special consideration was given to differences in stomach size. Empty stomachs were not included in calculations.

Fish were aged from otoliths which were preserved in glycerin. These were either read directly or, if the annuli were indistinct, they were first smoked (Christensen 1964) or polished. All fish were aged to the nearest number of summers' growth completed, and are recorded in this report as such, rather than as the true chronological age. Most of the fish samples were collected near the beginning or end of the summer season, so that age was more clearly determined with respect to the number of summers's growth completed. The advantage of this method of age determination is that growth rates of fish can be compared without having to make adjustments for the time of year when the fish were collected. For example, the chronological age of a rainbow trout from an alpine lake might be nearer to 3 years in September and 4 years in July of the following year, even though the weight of the fish would remain about the same. By aging the fish to the nearest number of summers' growth completed, this fish would be aged as 4 years in both cases.

In several lakes, we have observed that introduced trout quickly form what appears to be a normal annulus, probably within a few days of the stocking. Trout which are raised in a hatchery to fingerling size (usually about two or three months old), and are then introduced into a lake, are about the same size as one-year-old wild trout. In some oligotrophic waters in the mountain national parks in fact, introduced fingerlings are close to three-year-old wild trout in size. In general, therefore, the time a fingerling spends in the hatchery is equivalent to one year's growth. Consequently, an unmarked, hatchery-reared fish would be aged nearly one year over the true chronological age as a result of the presence of the "stocking annulus". In the past, all hatchery-reared fish (marked or unmarked) may have been aged this way. Therefore, to make our estimates of growth comparable to previous growth estimates, and to age marked and unmarked hatchery-reared fish consistently, we have treated the "stocking annulus" as a true annulus in this report. Thus, fingerling trout stocked in a lake in June are aged at one year at that time, and by the end of the summer's growth (i.e. usually about October) they are aged to two years, because of the method of aging fish described in the above paragraph, even though they have been in the lake for less than one calendar year.

There is normally no false "stocking" annulus in wild trout, so the age will be the true number of summer's growth completed. In the lakes of this study, most of the brook and rainbow trout are stocked. Many of these hatchery-reared fish are unmarked and, therefore, would be aged according to the above scheme. The growth curves are based on the combined data from all fish examined, and consequently may be displaced to the right by up to one year (depending on the percentage of stocked fish in the total). Because the hatchery-reared fish seem to have about one year's growth advantage on the average over the wild trout in most of these lakes, we feel that it is satisfactory to age the fish uniformly according to this scheme, and that no unrealistic bias occurs in interpretation as a result.

RESULTS

General Comments

The morphometric and other physical data, zooplankton and phytoplankton data, benthic data, and fisheries data are summarized lake-by-lake in the following order:

*Bighorn
*Cuthead
Grouse
*Harrison
*Pipit
*Snowflake
Wigmore
ponds (Cuthead North, Cuthead South, and Snowflake)

For the five marked with an asterisk (*), studies have been carried out with varying intensity since 1966, although many more collections and other studies were made for Snowflake Lake than for the other four. The data for Wigmore Pond are less consistent than for the five noted above. It is a completely different sort of "lake" but, because it has supported a sport-fishery of sorts for a number of years, it was decided that whatever data existed should be included in this report. Grouse Lake is really little more than a very large temporary pond and, although it has been studies several times, it is not included in the production calculations. It would not support a sport fishery from year to year, because it usually dries up or freezes solid each year. The three small ponds are included partly because they are biologically interesting and some data had been collected, and partly because they provide and interesting faunal contrast to the lakes nearby.

Water chemistry is treated comparatively rather than on a lake-by-lake basis, because it is the comparative aspects that are most useful. Primary production data were collected for only two of the waters. The data are of little direct application to sport fisheries at this time, but they are useful as indicators of production potentials at lower trophic levels. Following the lake-by-lake summaries of general limnological data, results of water analyses for the lakes and primary production for two of the lakes are summarized:

Lake-by-lake summaries
Water chemistry summary
Primary production summary.

Fig.4. Growth curve for fish (upper) and temperature profiles and Secchi disc readings (lower) for Bighorn Lake.

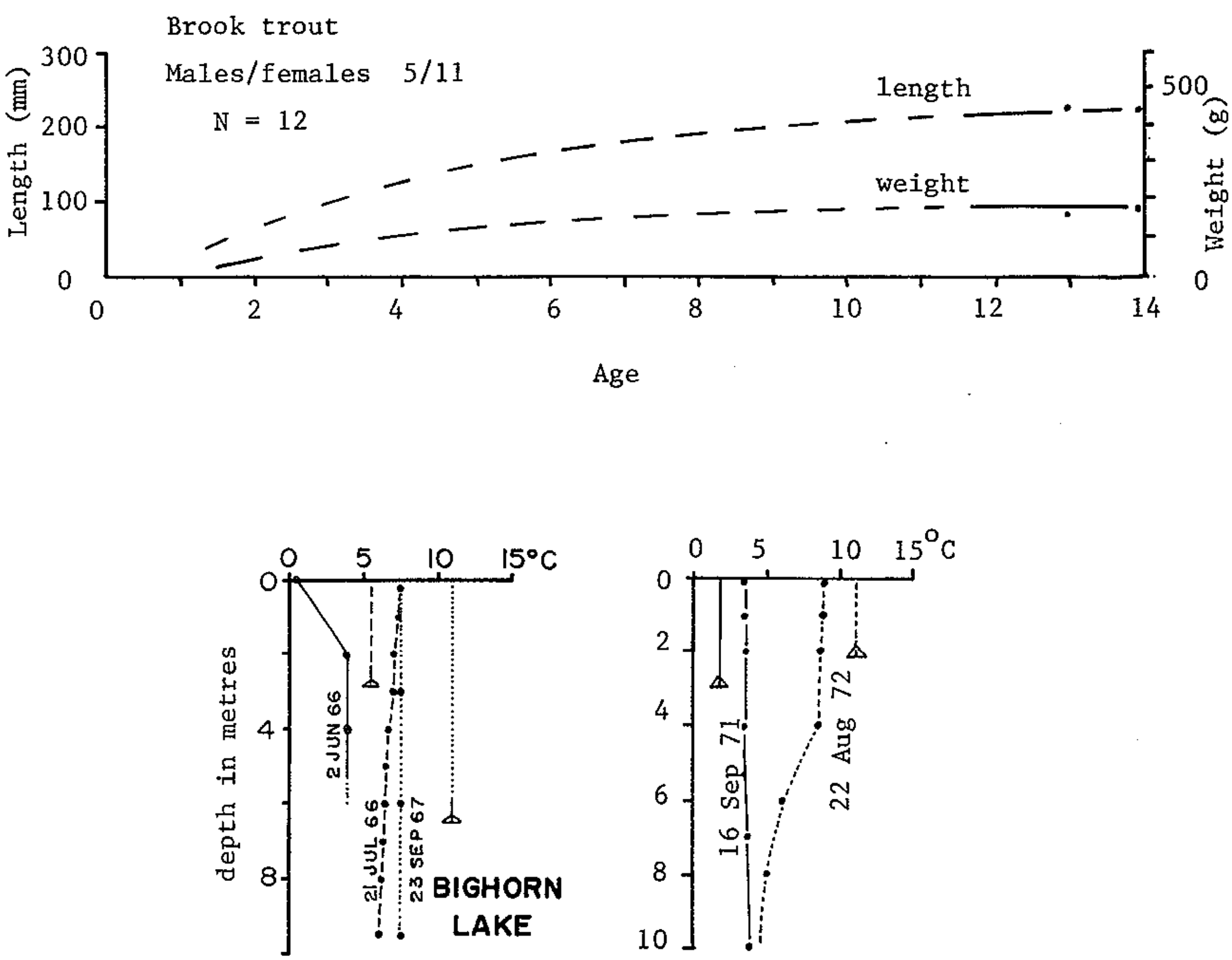
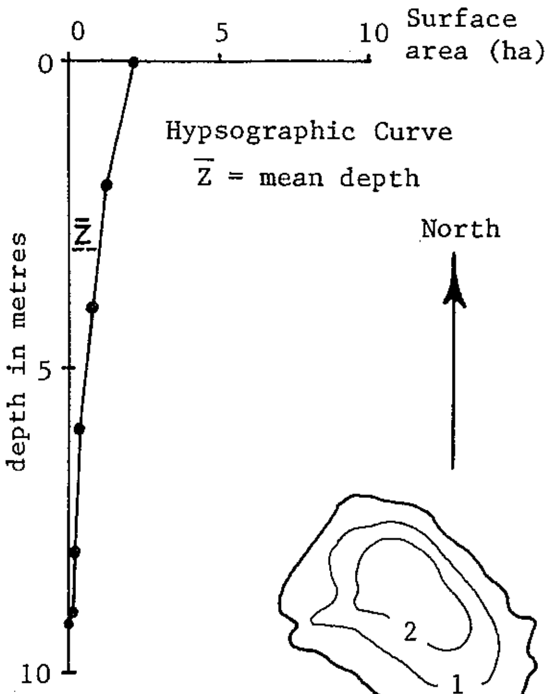
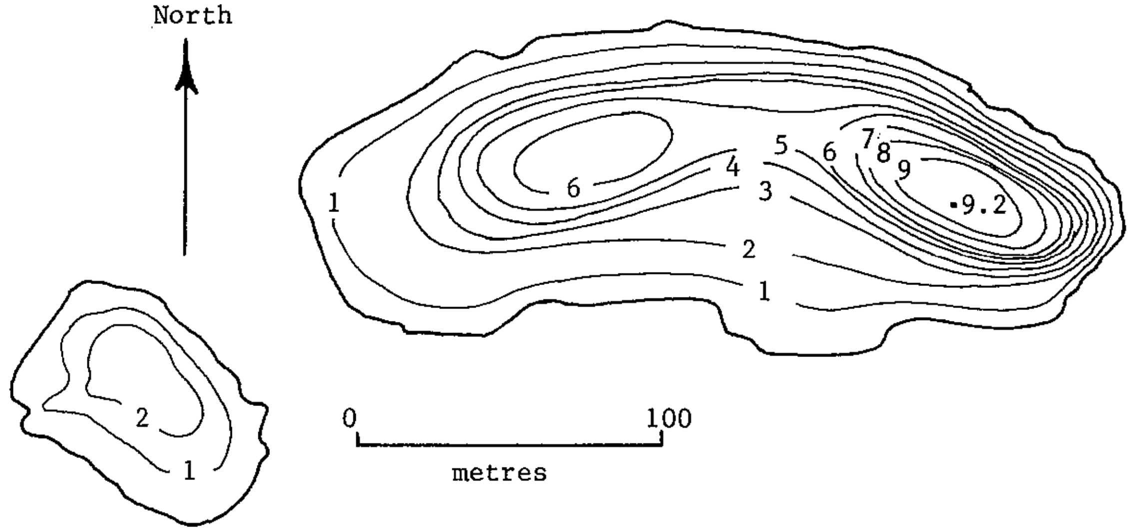


Fig.5. BIGHORN LAKE - B233

Grid ref. - 11U/NH939021
Altitude asl - 2347 m
(depths in metres at high water)





Volume X 10^4	6.65 m^3	Water level fluctuation	2.0 m
Surface area	2.15 ha	Drainage basin area	107.3 ha
Mean depth	3.09 m	Specific conductance((μS)	146
Maximum depth	9.20 m	pH	8.3
Shoal area (% <5 m deep)	77 %	Break-up	early June
Shoreline development	1.34	Freeze-up	October

Table 1. Phytoplankton data for Bighorn Lake, 1977.
(all entries as cells/ml)

	18/8/77 0.5m
Chlorophyta	
Ankistrodesmus cf. setigerum	683
Dictyosphaerium elegans	14
Chrysophyta	
Class Chrysophyceae	
Chromulina spp.	21
Chrysochromunlia parva	14
Chrysolykos planctonicus	17
Kephyrion spp.	21
Mallomonas tonsurata var. alpina	28
Ochromonas spp.	7
Class Bacillariophyceae	
Cyclotella spp.	21
Cymbella minuta	7
Synedra acus var. radians	897
Total cells/ml	1720.0

	Percent Composition of Major Groups
Chlorophyta	40.5 (697)*
Chrysophyceae	6.7 (98)
Bacillariophyceae	53.8 (925)

* Note denotes the total cells/ml for each major group.

Table 2 . Limnetic zooplankton and other net plankton, Bighorn Lake (mean nos. organisms /litre).

Year	1966		1968	1971	1972	1977
Date	2/6	21/7	9/8	16/9	22/8	18/8
No. samples for mean	2	2	3	4	2	4
Copepoda						
Diaptomus arcticus	-	0.42	0.01	-	-	-
Diacyclops bicuspidatus thomasi	-	-	0.08	0.03	-	0.27
Acanthocyclops vernalis	-	-	-	-	0.42 ?	0.70
Cladocera						
Chydorus sphaericus	-	-	-	-	-	0.01
Total Crustacea (x̄ no./litre)	0	0.42	0.09	0.03	0.42	0.98
Rotifera						
Polyarthra (dolichoptera?)	-	-	xxx	xxx	-	xxx
Filinia longiseta	-	-	-	x	-	xxx
Kellicottia longispina	-	-	xx	-	-	x
Keratella cochlearis	-	-	xx	-	-	-
Notholca sp.	-	-	xx	-	x	x
Synchaeta (oblonga?)	-	-	xxxxx	xxx	xxx	xxxxx
Lecane sp.	-	-	-	-	-	x
Euchlanis (lucksiana?)	-	-	-	x	-	-
Lepadella ovalis	-	-	xx	-	xx	-
Mytilina (mucronata?)	-	-	-	xxx	-	-
Trichotria (tetractis?)	-	-	-	xx	-	-
Other net plankton						
Tardigrades	-	-	-	xx	-	-
Dipteran larvae	-	-	-	xx	x	xxx
Fragilaria sp.	-	-	-	xxxx	xx	-
Dinobryon sp.	-	-	xxx	xxxxx	-	-
Ceratium hirundinella	-	-	xxx	-	-	-
Campylodiscus sp.	-	-	x	xx	-	-

Table 3. Benthic data for Bighorn Lake, 1977.

MACROINVERTEBRATES

Order Family* Genus species	Numbers collected Benthos per m^2
Oligochaeta	37
Ostracoda	221
Chironomidae	5000
*Sphaeriidae	1095
total numbers	6353
total weight (grams)	16.8
total number of samples (N)	7
sampling date	18-8-77

MACROPHYTES

- no macrophytes present

Table 4. Fisheries data for Bighorn Lake, 1977.

FISH SPECIES

	date collected
- *Salvelinus fontinalis* (brook trout)	18-8-77

CATCH DATA

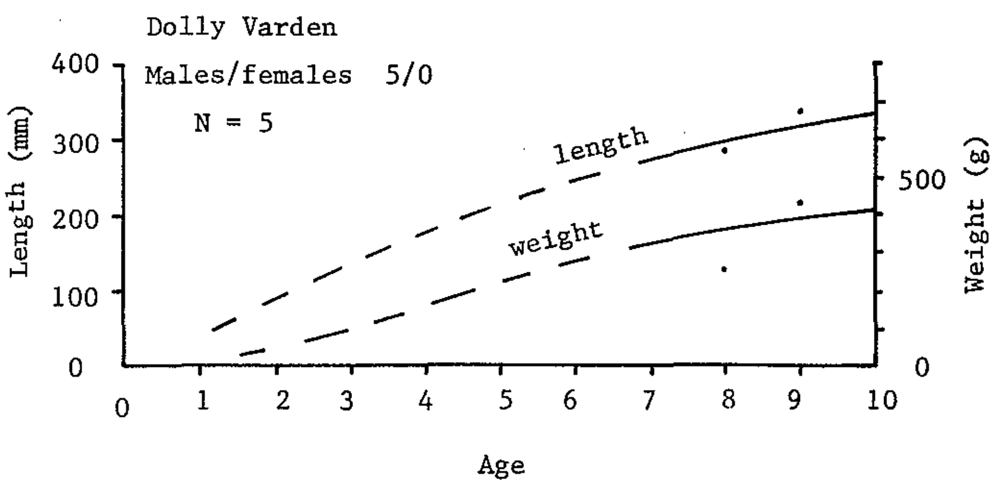
Age	Length (mm)		Weight (g)		
	Mean	Standard Deviation	Mean	Standard Deviation	Number Examined
13	248.75	12.55	168.50	29.77	4
14	248.00	11.15	178.88	30.93	8

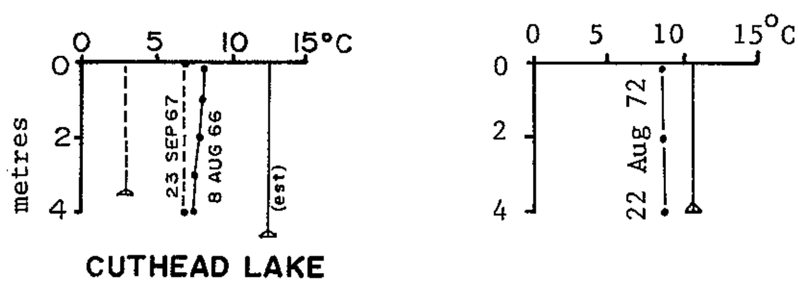
STOMACH ANALYSES

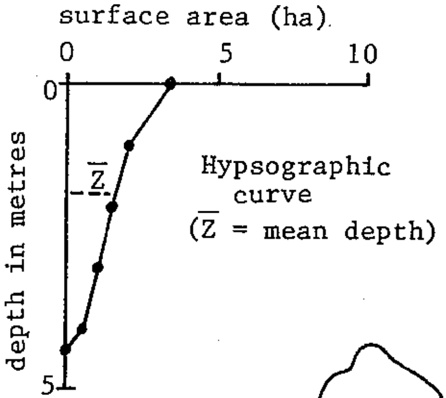
Date collected	18-8-77
Stomachs examined	16
Number empty	0

Food	Percent by volume
Terrestrial insects	43
Corixidae	25
Coleoptera (terrestrial)	17
Chironomidae	9
Notonectidae	4
Trichoptera	2
Acarina	+

Fig. 6. Fish growth curve (upper) and temperature profiles and Secchi disc light readings (lower) for Cuthead Lake.







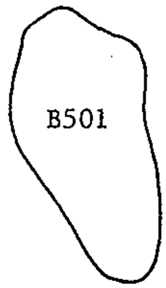


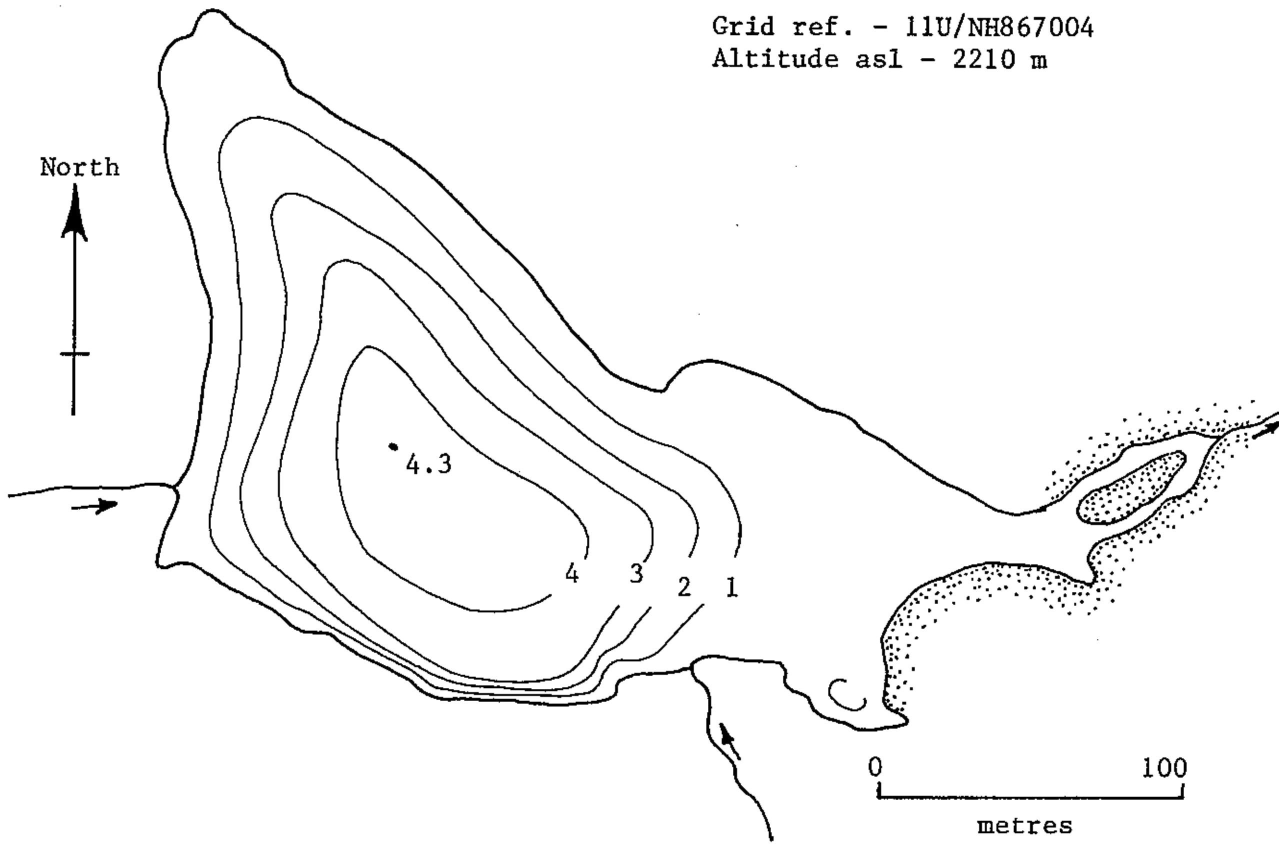
Fig.7. CUTHEAD LAKE - B227

Grid ref. - 11U/NH867003
Altitude asl - 2210 m

(depth contours in metres)

N. CUTHEAD POND - B501

Grid ref. - 11U/NH867004
Altitude asl - 2210 m



Volume X 10^4	6.38	m^3	Water level fluctuation	< 0.5	m
Surface area	3.47	ha	Drainage basin area	158.5	ha
Mean depth	1.84	m	Specific conductance (μS)	160	
Maximum depth	4.30	m	pH	8.5	
Shoal area (% <5 m deep)	100	%	Break-up	late June - early July	
Shoreline development	1.69		Freeze-up	October	

Table 5. Phytoplankton data for Cuthead Lake, 1977.
(all entries as cells/ml)

	17/8/77 0.5
Chlorophyta	
Chlamydomonas spp.	3
Chrysophyta	
Class Chrysophyceae	
Chromulina spp.	218
Chrysochromulina parva	218
Ochromonas spp.	14
Pseudopedinella erkensis	48
Class Bacillariophyceae	
Achnanthes minutissima	3
Cymbella minuta	3
Fragilaria construens var. venter	11
Navicula gregaria	3
Navicula spp.	3
Pyrrophyta	
Gymnodinium sp.	3
Cryptophyta	
Rhodomonas minuta	20
Total cells/ml	337.0

Percent Composition of Major Groups

Chlorophyta	0.9 (3)
Chrysophyceae	85.5 (288)
Bacillariophyceae	6.8 (23)
Pyrrophyta	0.9 (3)
Cryptophyta	6.0 (20)

Table 6 . Limnetic zooplankton and other net plankton, Cuthead Lake (mean nos. organisms/litre).

Year	1966		1967	1968	1972	1977
Date	22/6	8/8	23/9	24/8	22/8	19/8
No. samples for mean	1	1	1	2	2	2
Copepoda						
Diaptomus tyrrelli	xxx	10.00	18.98	10.86	16.67	30.20
Diacyclops bicuspidatus thomasi	xxx	.15	0.19	6.29	4.44	0.05
Acanthocyclops vernalis	x	-	-	-	1.00	-
Eucyclops agilis	xx	-	-	0.01	-	-
Cladocera						
*Daphnia (middendorffiana?)**	xx	-	0.07	0.29	0.12	0.65
Chydorus sphaericus	-	0.05	0.20	-	0.02	0.11
Total Crustacea ($\bar{x}$ no./litre)	-	10.20	19.44	17.45	22.25	31.01
Rotifera						
Notholca sp.	-	-	xxx	-	-	-
Euchlanis sp.	-	-	-	-	-	x
Other net plankters						
Dipteran larvae	xx	x	xx	-	-	-
Pediastrum sp.	x	-	-	-	-	-
Peridinium sp.	x	-	-	-	-	-

* great variation in the *Daphnia* from year to year.

Table 7. Benthic data for Cuthead Lake.

MACROINVERTEBRATES

Order Family* Genus species	Numbers collected Benthos per m^2
Oligochaeta	1988
Ostracoda	129
Trichoptera	36
*Chironomidae	11904
*Sphaeriidae	1908
total number	15965
total weight (grams)	66.53
total number of samples (N)	6
sampling date	19-8-77

MACROPHYTES

- no macrophytes present

Table 8. Fisheries data for Cuthead Lake.

FISH SPECIES

- *Salvelinus malma* (Dolly Varden)

	date collected
Salvelinus malma (Dolly Varden)	19-8-77

CATCH DATA

Age	Length (mm)		Weight (g)		
	Mean	Standard Deviation	Mean	Standard Deviation	Number Examined
8	282.5	27.63	259.75	70.08	4
9	337	-	428	-	1

STOMACH ANALYSES

Date collected	19-8-77
Stomachs examined	6
Number empty	0

Food	Percent by volume
Daphnia	31
Pisidium	19
Terrestrial insects	19
Trichoptera	11
Chironomidae	6
Coleoptera	5
Oligochaeta	5
Corixidae	2
Notonectidae	1

GROUSE LAKE - B240

Grid ref. - 11U/NH848168

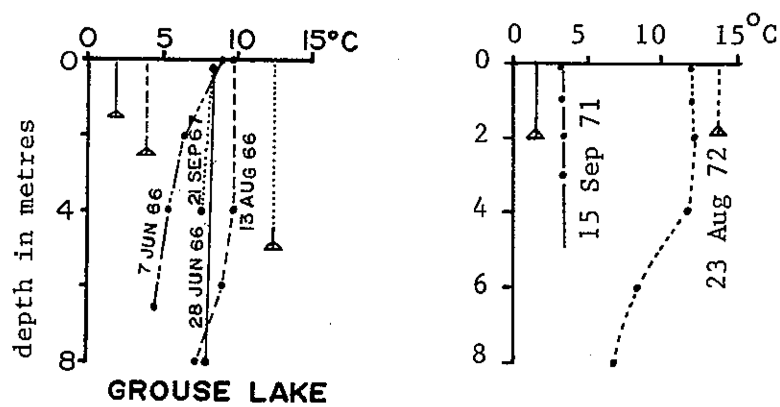
Altitude asl - 2271 m

No fish present

No macrophytes

No benthic sample taken

No adequate maps or aerial photos to enable the production of a suitable bathymetric map.



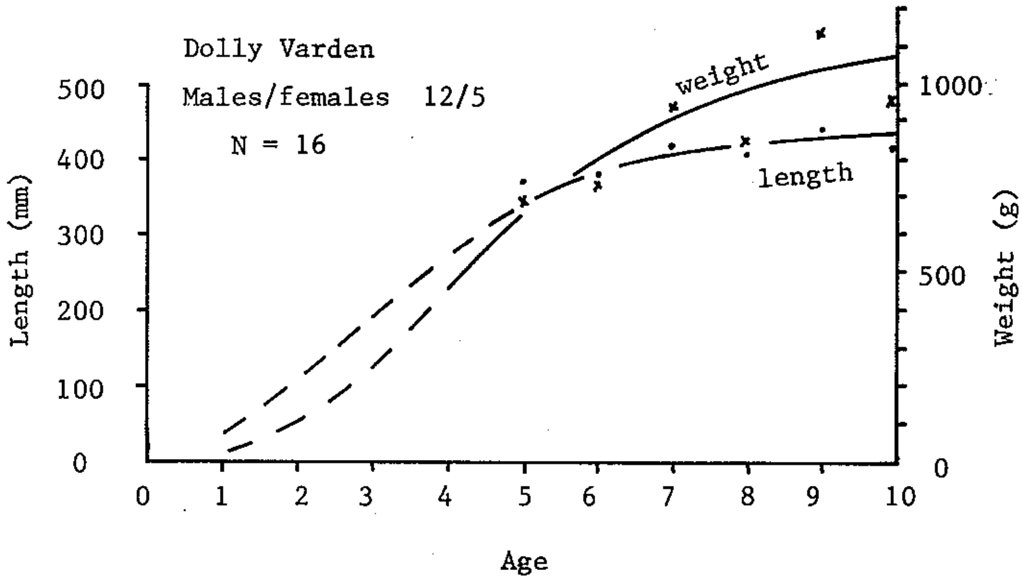
Temperature profiles and Secchi disc readings for Grouse Lake.

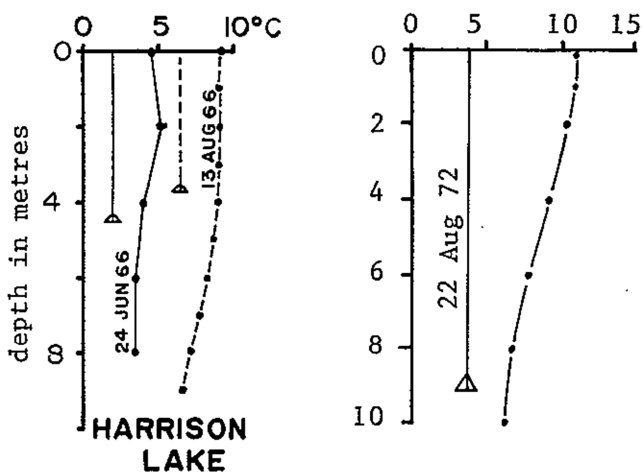
Table 9 . Limnetic zooplankton and other net plankton, Grouse Lake (mean nos. organisms/litre).

Year	1967		1968		1969	1970	1971	1972	1977
Date	27/7	21/9	3/7	11/7	12/8	23/6	15/9	23/8	26/8
No. samples for mean	1	1	1	1	2	2	3	2	2
Copepoda									
Diaptomus tyrrelli	xxxxx**	91.48	xxxx	17.78	xxxx	0.49	76.49	8.78	2.73
Macrocyclops albidus	-	-	-	-	-	-	-	-	0.01
Diacyclops bicuspidatus thomasi	xx	2.82	xx	3.56	xxx	0.23	0.28	0.07	1.90
Acanthocyclops vernalis	x	-	-	-	-	0.01	-	0.10	-
harpacticoid nauplii	x	-	-	-	-	-	-	-	-
Cladocera									
Daphnia middendorffiana	xxx	0.15	-	0.67	xxxx	0.10	1.52	0.43	3.09
Chydorus sphaericus	xxx	0.22	-	0.01	xxx	0.01	0.37	0.11	0.06
Alona sp.	-	-	-	-	-	-	-	0.02	0.03
Macrothrix hirsuticornis	-	-	-	-	-	-	-	0.01	-
Anostraca									
Branchinecta paludosa	xx	-	x	0.01	xx	0.15	-	0.01	-
Total Crustacea ($\bar{x}$ no./litre)	-	94.67	-	22.03	-	0.99	78.66	9.53	7.82
Rotifera									
*Hexarthra bulgarica canadensis**	xxx	-	-	xxxx	-	-	xx	x	-
Lecane (luna?)	-	-	-	-	-	x	-	-	-
Lepadella sp.	-	-	-	-	x	-	-	-	-
Euchlanis sp.	x	-	-	-	-	-	-	-	-
Kellicottia longispina	x	-	-	-	-	-	-	-	-
Other net plankters									
Diptera larvae	xx	xxx	xx	xx	-	x	-	-	x
Mesostoma sp.	-	-	-	-	-	x	-	-	-

* described as a new subspecies (Dumont, Coussement, and Anderson 1978).
** predominantly nauplii

Fig. 8. Fish growth curve (upper) and temperature profiles and Secchi disc light readings (lower) for Harrison Lake.

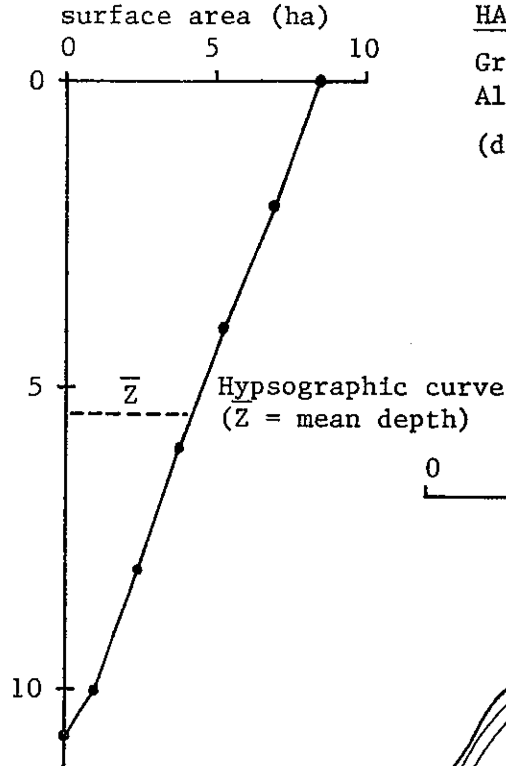


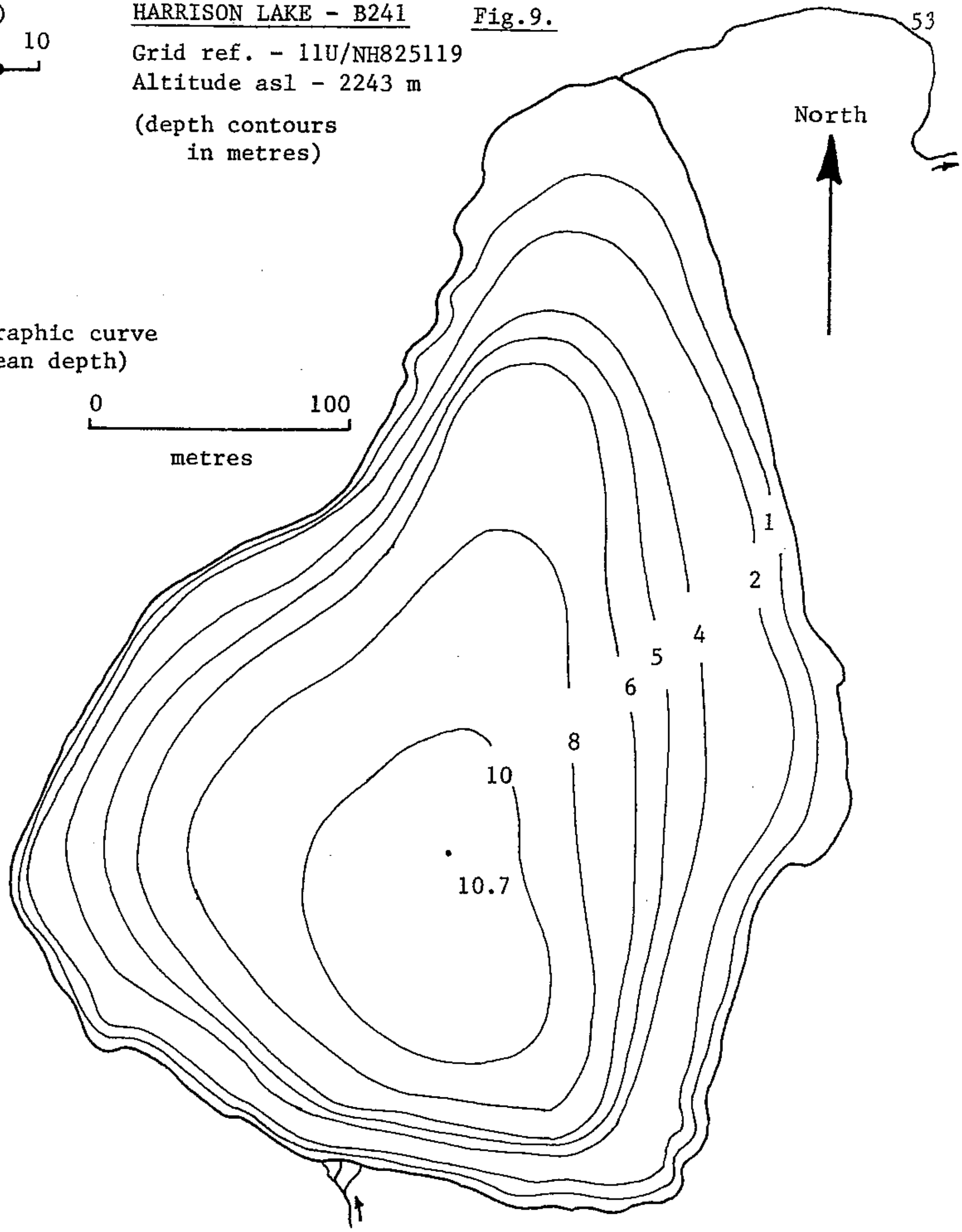


HARRISON LAKE - B241 Fig.9.

Grid ref. - 11U/NH825119
Altitude asl - 2243 m

(depth contours in metres)





Volume X 10^4	45.8 m^3	Water level fluctuation	<0.5 m
Surface area	8.4 ha	Drainage basin area	117.1 ha
Mean depth	5.4 m	Specific conductance (µS)	249
Maximum depth	10.7 m	pH	8.1
Shoal area (% <5 m deep)	46 %	Break-up	late June - early July
Shoreline development	1.22	Freeze-up	October

Table 10. Phytoplankton data for Harrison Lake.
(all entries as cells/ml)

	17/8/77 0.5m
Chlorophyta	
Ankistrodesmus falcatus	120
Chlamydomonas spp.	14
Quadrigula lacustris	22
Chrysophyta	
Class Chrysophyceae	
Chrysochromulina parva	62
Chromulina spp.	115
Mallomonas akrokomos	14
Monosiga varians var. vagans	8
Ochromonas spp.	45
Pseudokephyrion cf. hyalinum	381
Pseudopedinella erkensis.	22
Spiniferomonas bourrellii	8
Class Bacillariophyceae	
Achnanthes cf. sublaevis var. crassa	3
Cyclotella cf. atomus	3
Cyclotella comta	135
Cyclotella ocellata	17
	3
Synedra cyclopum	3
Cryptophyta	
Cryptomonas spp.	6
Rhodomonas minuta	39
Total cells/ml	1020.0

Percent Composition of Major Groups

Chlorophyta	15.3 (156)
Chrysophyceae	64.2 (655)
Bacillariophyceae	16.1 (164)
Cryptophyta	4.4 (45)

*Notes denote the total cells/ml for each major group.

Table 11. Limnetic zooplankton and other net plankton, Harrison Lake (mean nos. organisms/litre).

Year	1966		1967	1972	1977
Date	24/6	13/8	26/7	22/8	17/8
No. samples for mean	2	2	2	2	2
Copepoda					
Macrocyclops albidus	-	-	0.02	-	-
Diacyclops bicuspidatus thomasi	150.00*	150.00*	164.00	64.00	76.80
Acanthocyclops vernalis	-	-	-	-	0.70
Eucyclops speratus	-	-	-	-	0.02
Cladocera					
Daphnia pulicaria	4.00	0.10	1.78	5.16	7.26
Total Crustacea ($\bar{x}$ no./litre)	154.00*	150.10*	165.80	69.16	84.78
Rotifera					
Kellicottia longispina	-	-	x	-	-
Keratella cochlearis	-	-	-	x	-
Keratella quadrata	-	-	xxx	-	-
Other net plankters					
Diptera larvae	x	x	x	-	-
Sphaerocystis sp.	-	-	-	-	xxxxx
Actinastrum sp.	xxxx	xx	-	-	-
Gyrosigma sp.	-	-	x	-	-

* estimated values

Table 12. Benthic data for Harrison Lake.

MACROINVERTEBRATES

Order Family* Genus species		Number collected Benthos per m^2
Oligochaeta		529
Amphipoda	*Gammarus lacustris*	148
Trichoptera		25
*Chironomidae		9767
*Sphaeriidae		615
total number		11083
total weight		61.17
total number of samples		7
sampling date		17-8-77

MACROPHYTES

- no macrophytes present

Table 13 . Fisheries data for Harrison Lake.

FISH SPECIES

	date collected
- *Salvelinus malma* (Dolly Varden)	17-8-77

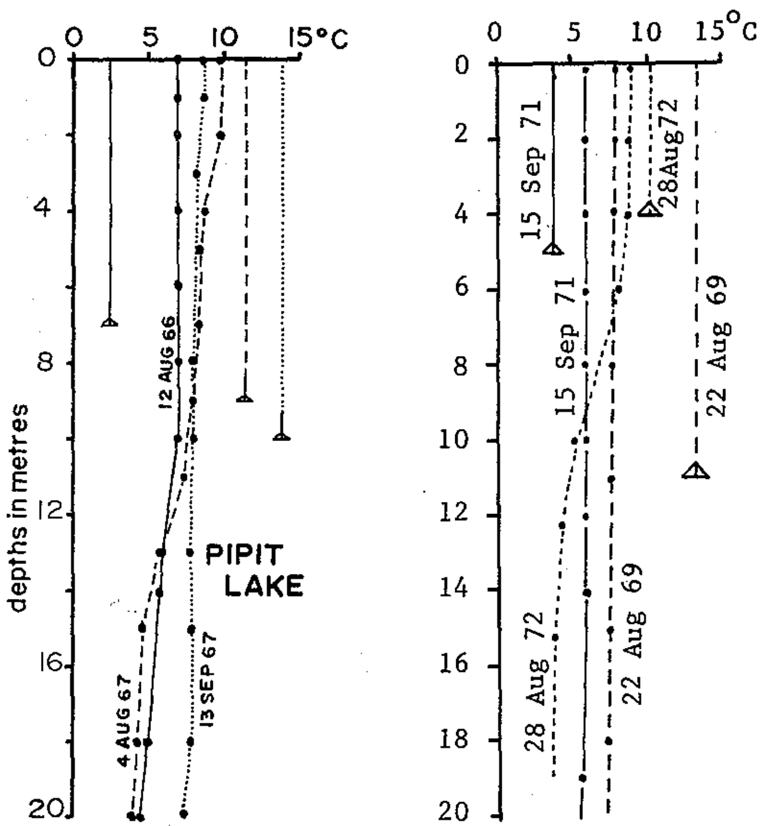
CATCH DATA

Age	Length (mm)		Weight (g)		
	Mean	Standard Deviation	Mean	Standard Deviation	Number Examined
5	371.33	9.02	692.33	64.75	3
6	379.00	30.17	738.20	209.28	5
7	419.00	14.02	943.50	62.96	4
8	405.50	6.36	860.00	53.74	2
9	440.00	-	1132.00	-	1
10	411.00	-	956	-	1

STOMACH ANALYSES

Date collected	17-8-77
Stomachs examined	18
Number empty	0

Food	Percent by volume
Daphnia	59
Gammarus lacustris	24
Pisidium	11
Oligochaeta	4
Chironomidae	1
Plecoptera	1
Trichoptera	+



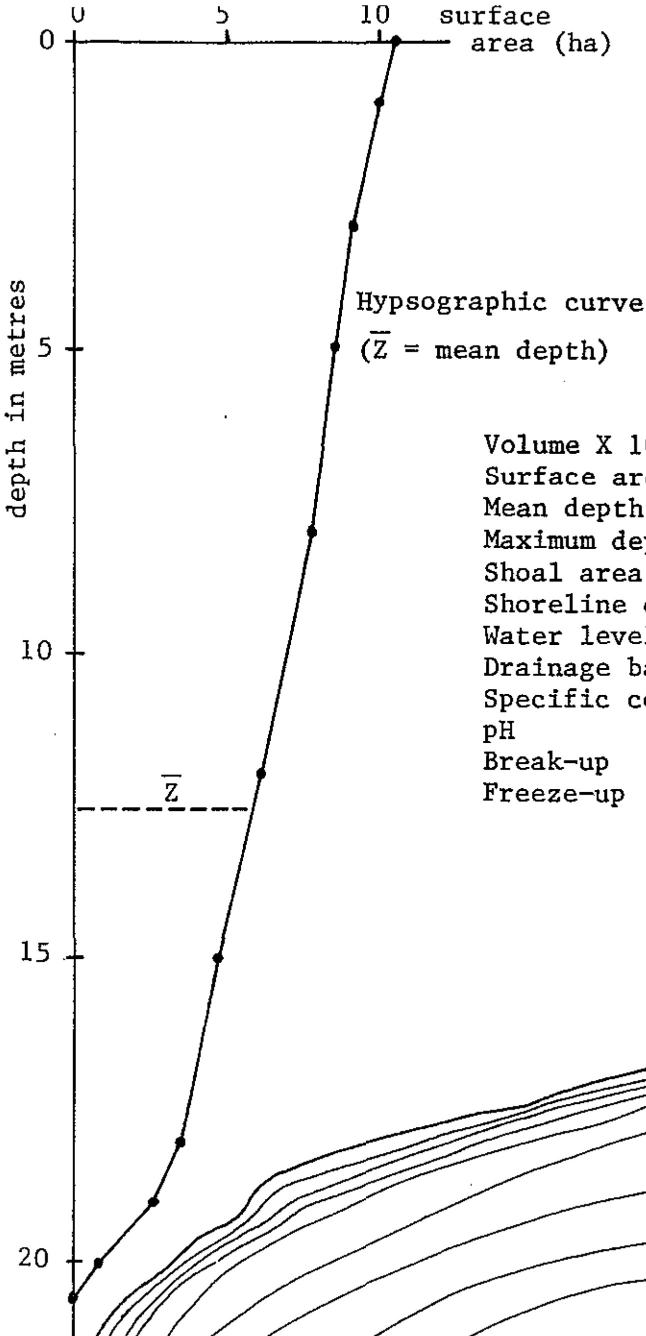
Temperature profiles and Secchi disc light readings for Pipit Lake.

NOTE: too few fish were caught to permit us to draw a growth curve.

Fig.10. PIPIT LAKE - B244

Grid ref. - 11U/NH788188
Altitude asl - 2217 m

(depth contours in metres)



Volume X 10^4	133.7	m^3
Surface area	10.6	ha
Mean depth	12.6	m
Maximum depth	13.0	m
Shoal area (% < 5 m deep)	19 %	
Shoreline development	1.29	
Water level fluctuation	< 0.5	m
Drainage basin area	253.7	ha
Specific conductance (uS)	174.0	
pH	8.1	
Break-up	late June - early July	
Freeze-up	October	

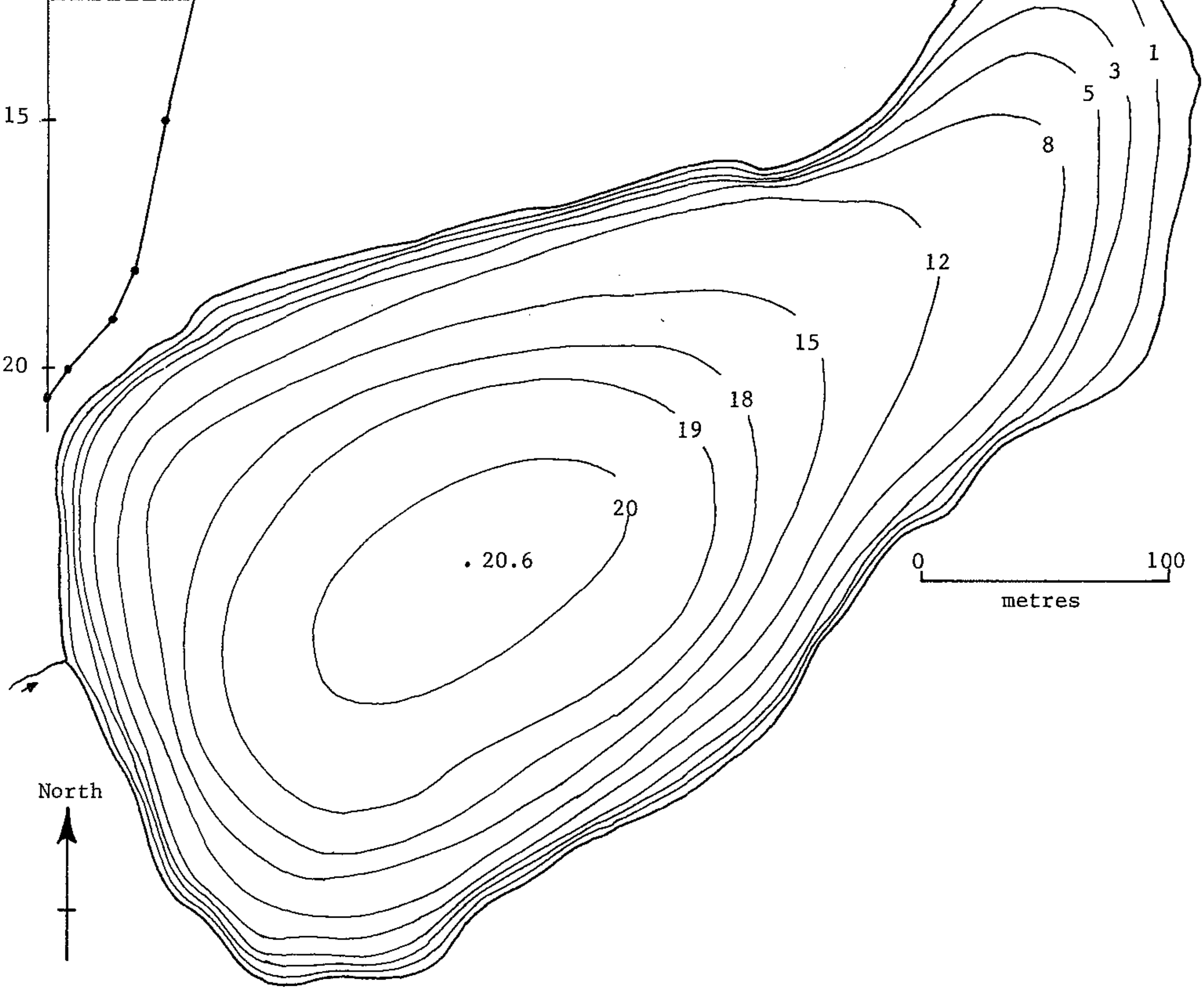


Table 14. Phytoplankton data for Pipit Lake, 1977.
(all entries as cells/ml)

	20/8/77 0.5m
Chlorophyta	
Cosmarium bioculatum	48
Oocystis parva	48
Tetraedron minimum	28
Chrysophyta	
Class Chrysophyceae	
Bitrichia chodatii	21
Chromulina spp.	28
Chrysochromulina parva	642
Dinobryon cylindricum	7
Dinobryon sociale	21
Mallomonas sp.	7
Pseudopedinella erkensis	41
Pseudokephyrion cf. hyalinum	35
Ochromonas spp.	48
Salpingoeca frequentissima	21
Kephyrion sp.	14
Class Bacillariophyceae	
Synedra acus var. radians	8218
Gomphonema sp.	7
Total cell/ml.	9262.0

Percnet Composition of Major Groups

Chlrorphyta	1.6 (152)*
Chrysophyceae	9.5 (885)
Bacillariophyceae	88.9 (8225)

*Notes denotes the total cells/ml for each major group.

Table 15. Limnetic zooplankton and other net plankton, Pipit Lake (mean nos. organisms/litre).

Year	1966	1967		1968	1969	1971	1972	1977
Date	12/8	4/8	13/9	25/8	22/8	15/9	22/8	20/8
No. samples for mean	2	2	2	3	2	4	2	2
Copepoda								
Diaptomus arcticus	1.00	0.60	0.09	-	-	-	-	-
Acanthocyclops vernalis	-	0.20*	0.13*	0.10	0.28	0.06	0.52	0.20
Cladocera								
Daphnia middendorffiana	0.10	-	-	-	-	-	-	-
Chydorus sphaericus	-	-	-	-	-	-	-	0.01
Alona rectangula	-	-	-	-	-	0.01	-	-
Total Crustacea ($\bar{x}$ no./litre)	1.10	0.80	0.22	0.10	0.28	0.07	0.52	0.21
Rotifera								
Keratella cochlearis	-	x	-	-	x	-	-	xxxx
Kellicottia longispina	xx	xxxx	xxxx	xxxx	xxx	xxxx	-	-
Notholca sp.	-	x	xx	-	xx	-	-	-
Filinia longiseta	-	-	-	-	-	xxxx	xxx	x
Polyarthra (dolichoptera?)	-	-	-	-	-	xxxxx	xx	x
Synchaeta oblonga	-	-	-	-	-	xx	-	-
Euchlanis (lucksiana?)	-	-	-	-	-	x	-	-
Lepadella sp.	-	-	-	-	x	-	-	-
Trichotria sp.	-	-	-	-	-	x	-	-
Other net plankters								
Dipteran larvae	xx	-	-	-	-	-	-	x
Campylodiscus sp.	-	xx	x	-	-	-	-	-

* nauplii predominate

Table 16. Benthic data for Pipit Lake.

MACROINVERTEBRATES

Order Family* Genus species	Numbers collected Benthos per m^2
Ostracoda	133
Trichoptera	4
*Chironomidae	1894
Acarina	4
*Sphaeriidae	1662
total number	3694
total weight (grams)	12.8
total number of samples (N)	10
sampling date	20-8-77

MACROPHYTES

- no macrophytes present

Table 17. Fisheries data for Pipit Lake.

FISH SPECIES	date collected
- *Salmo gairdneri*	25-8-77

CATCH DATA

- A single specimen was collected during 8 h of fishing with 120 m of net.

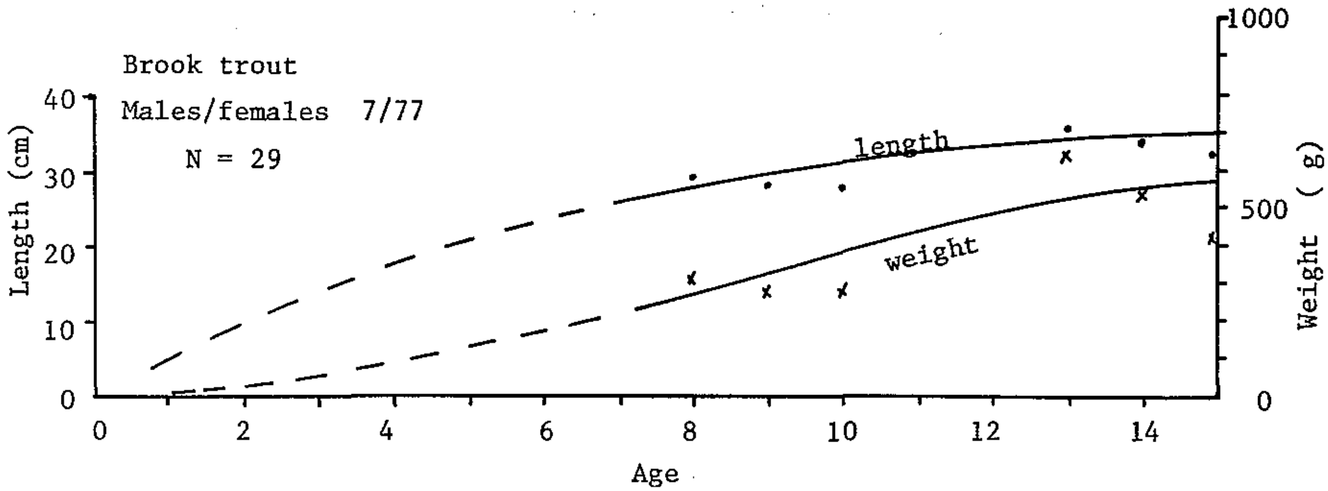
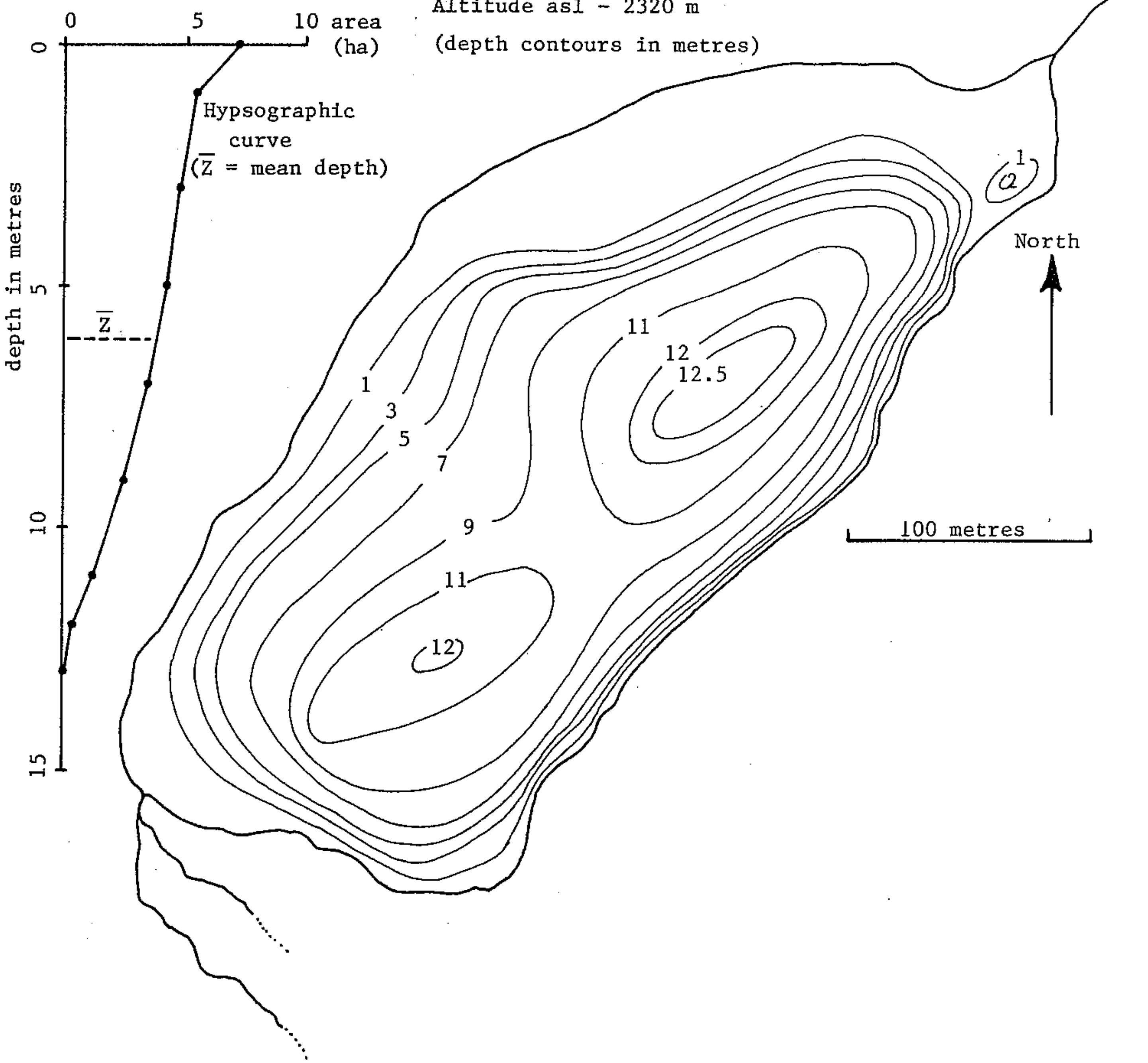


Fig. 11. Fish growth curve for Snowflake Lake.

Fig.12. SNOWFLAKE LAKE - B242

Grid ref. - 11U/NH808167
Altitude asl - 2320 m
(depth contours in metres)



Volume X 10^4	43.6 m^3	Water level fluctuation	< 0.5 m
Surface area	7.13 ha	Drainage basin area	147 ha
Mean depth	6.1 m	Specific conductance (uS)	234
Maximum depth	20.6 m	pH	8.0
Shoal area (% < 5 m deep)	40 %	Break-up	mid June - early July
Shoreline development	1.28	Freeze-up	October

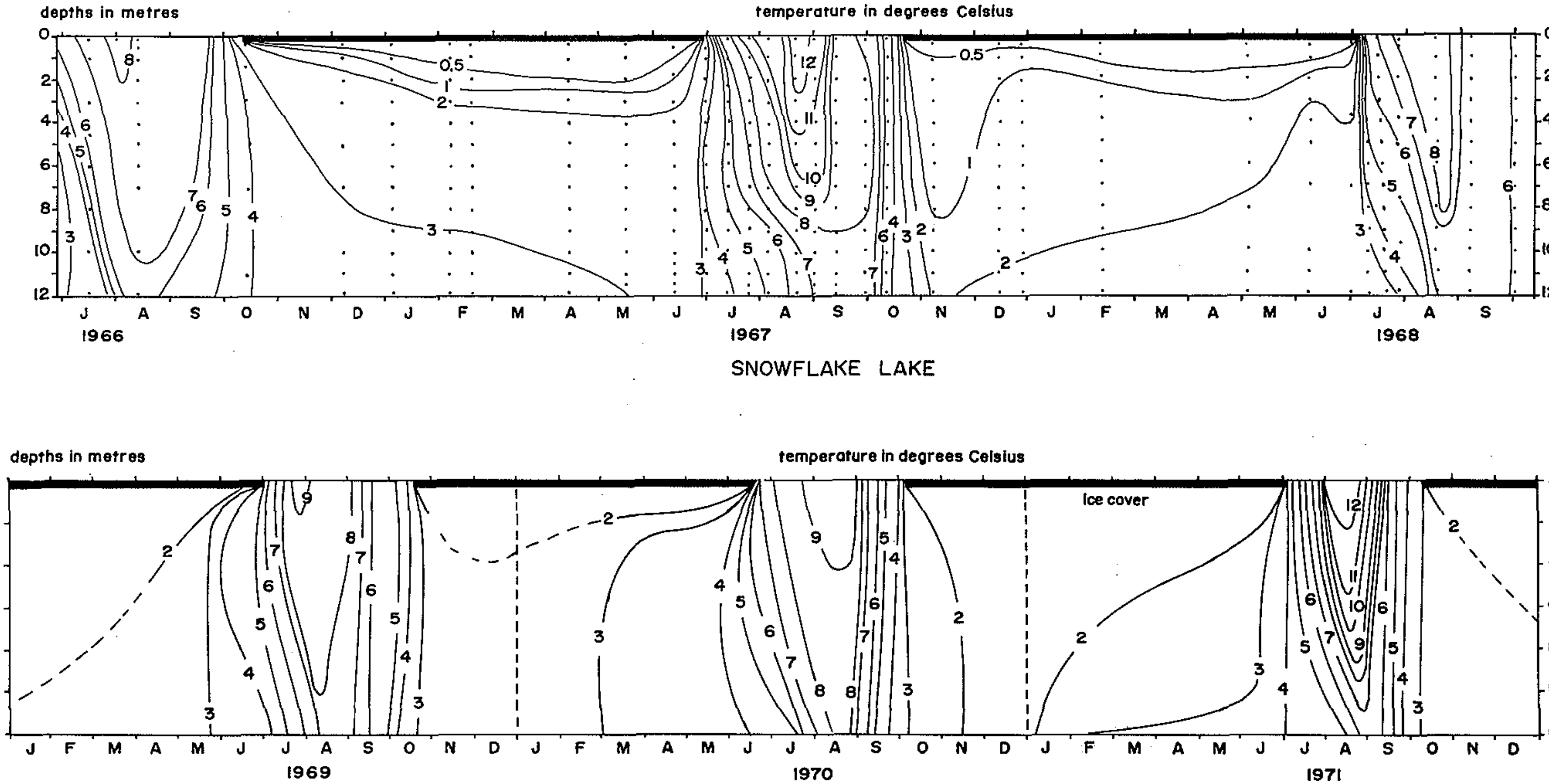
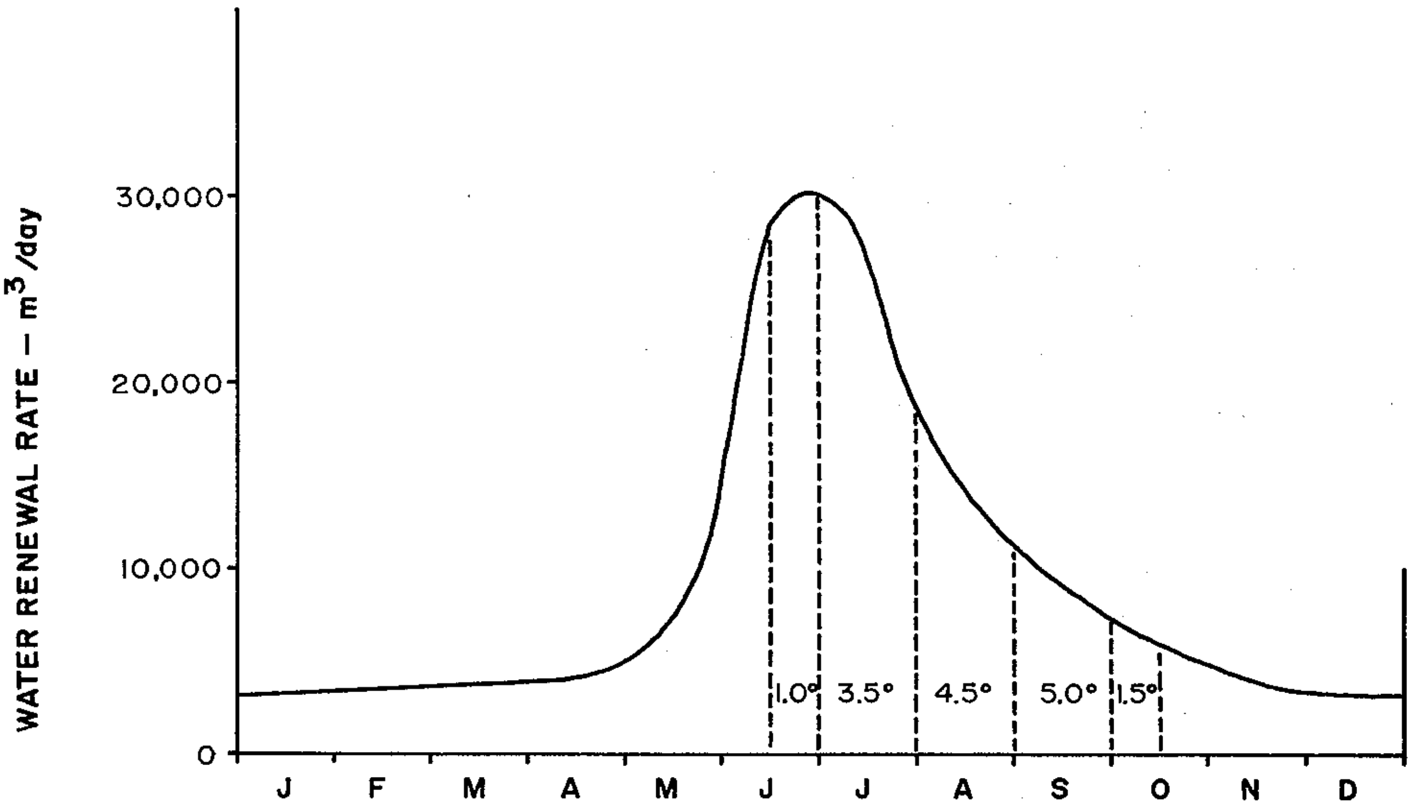


Fig.13. Temperature isopleths for Snowflake Lake, 1966-1971.



Temperatures=(outlet—inlet)°C for the summer period

Fig.14 — WATER RENEWAL RATES, SNOWFLAKE LAKE, 1967.

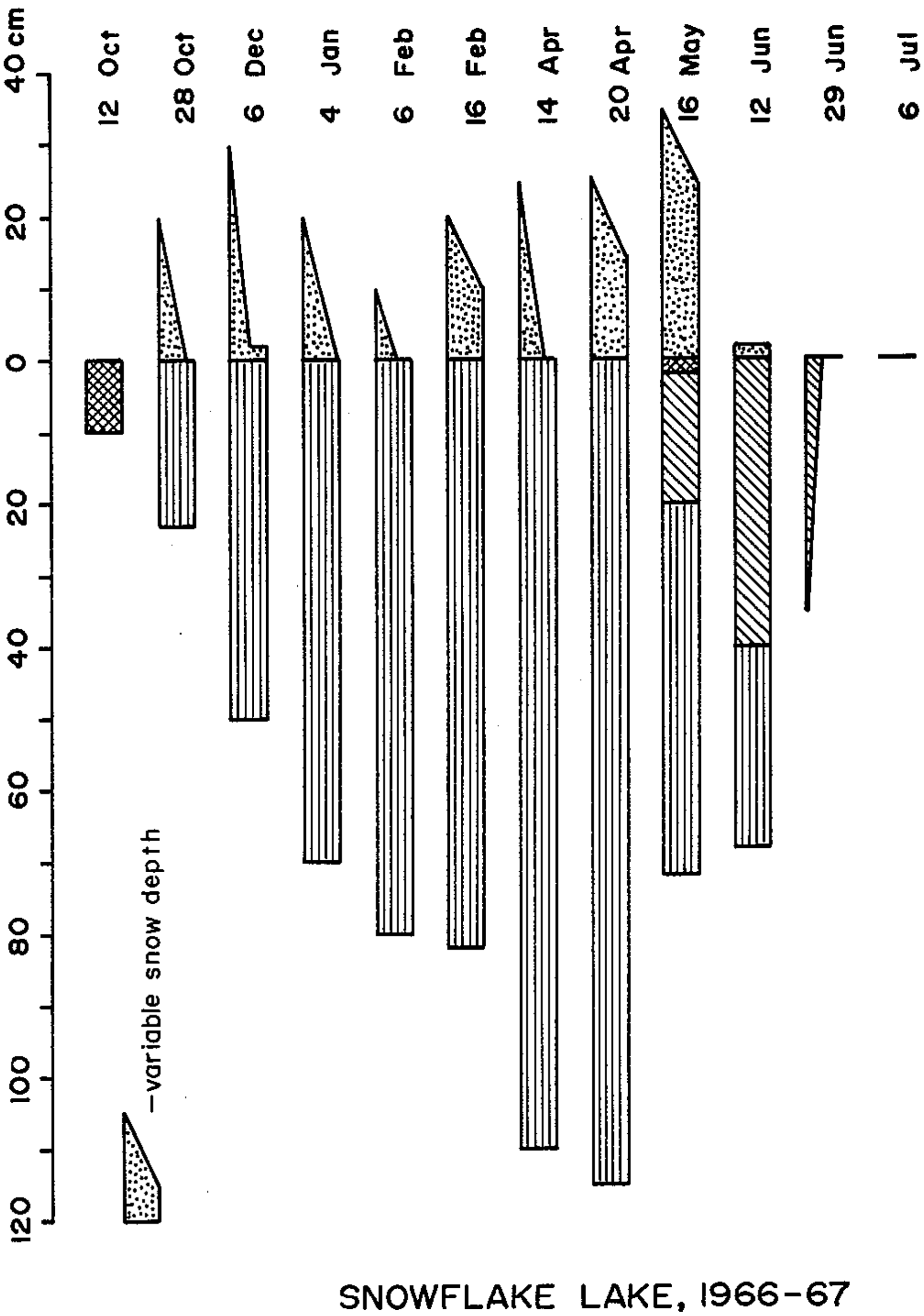


Fig.15A. Ice and snow cover, Snowflake Lake, 1966-1967.

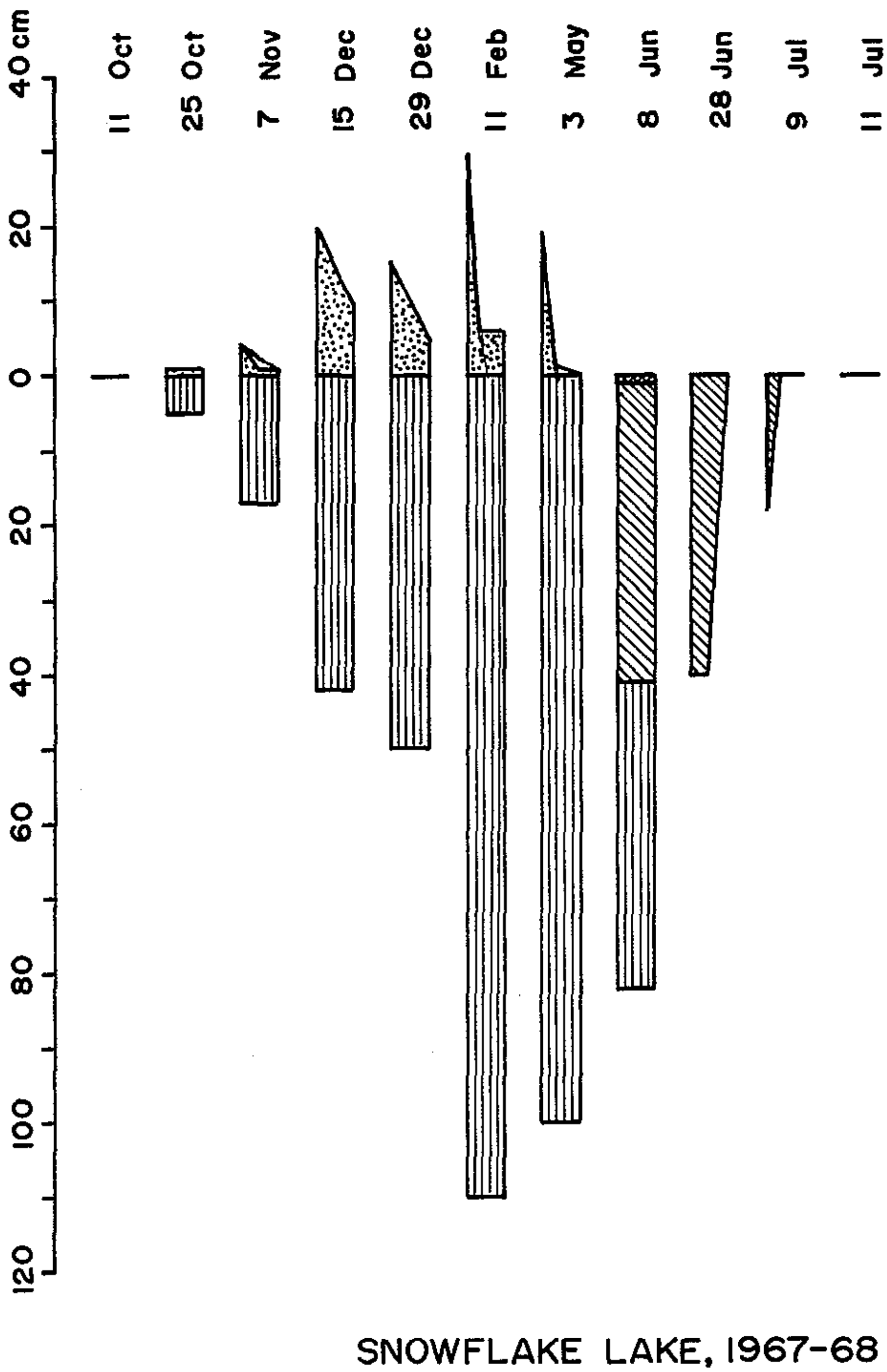


Fig.15B. Ice and snow cover, Snowflake Lake, 1967-1968.

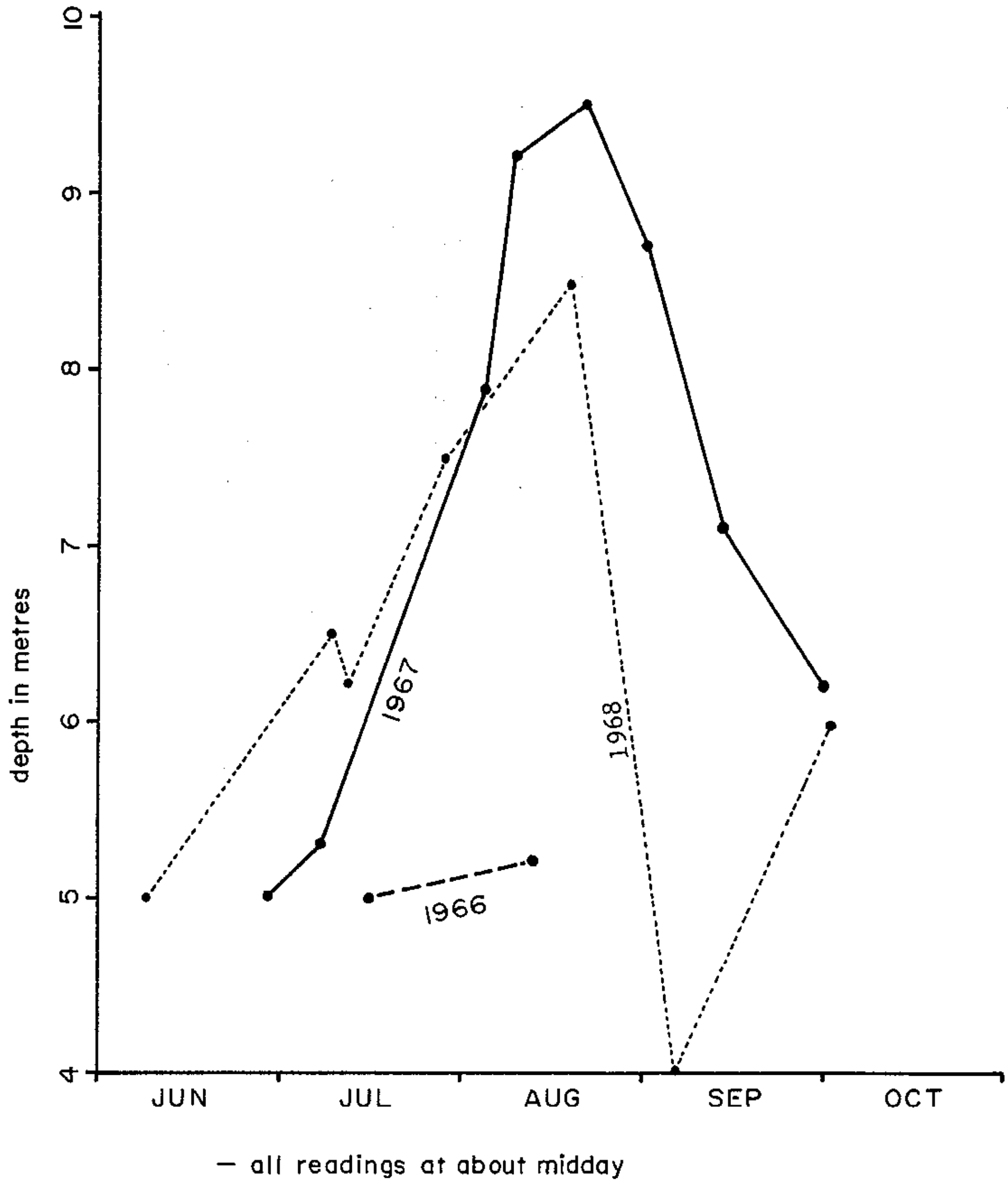


Fig. 16A- SECCHI DISC MEASUREMENTS OF LIGHT PENETRATION, SNOWFLAKE LAKE.

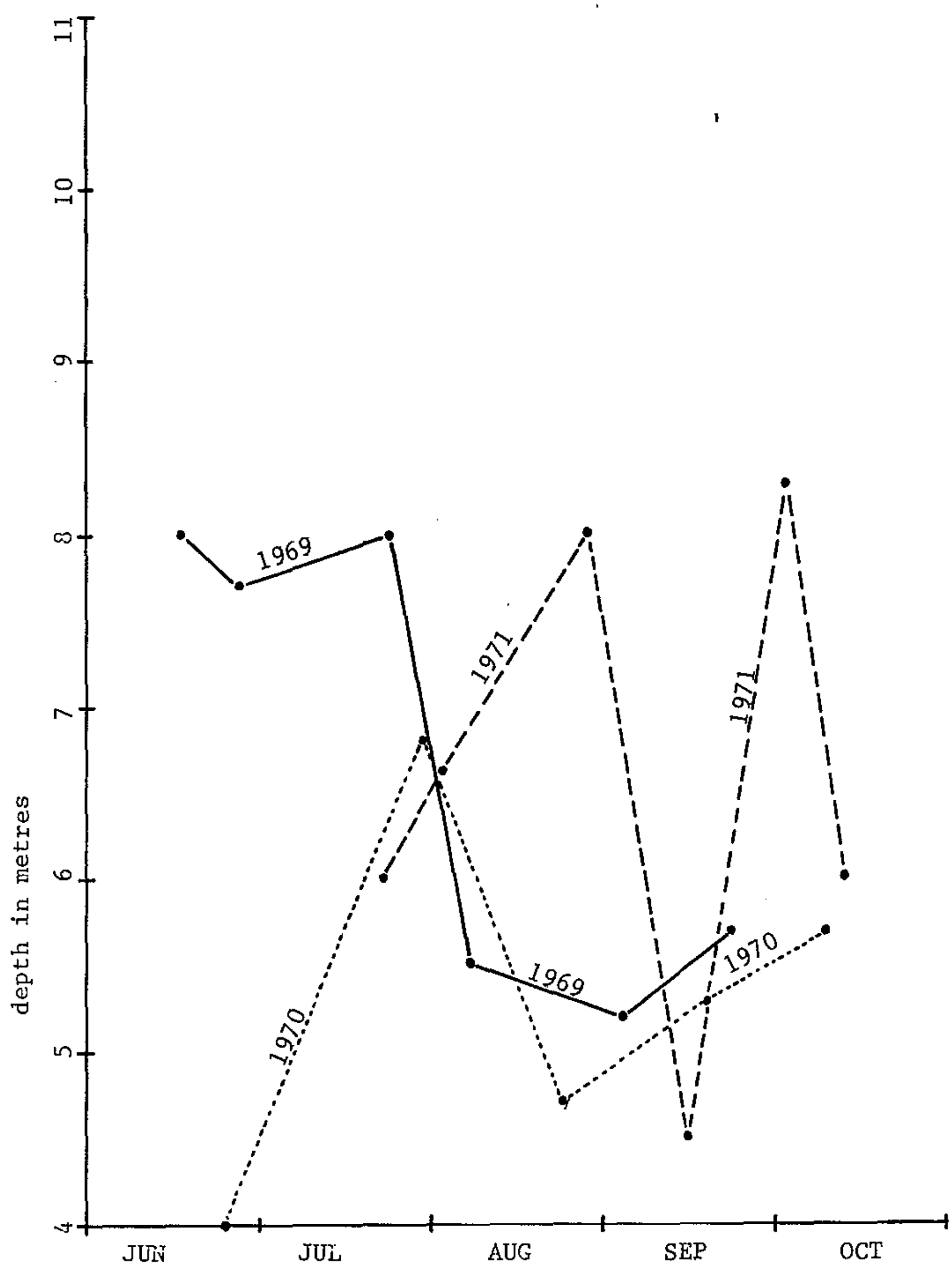


Fig. 16B. Secchi disc measurements of light penetration, Snowflake Lake.

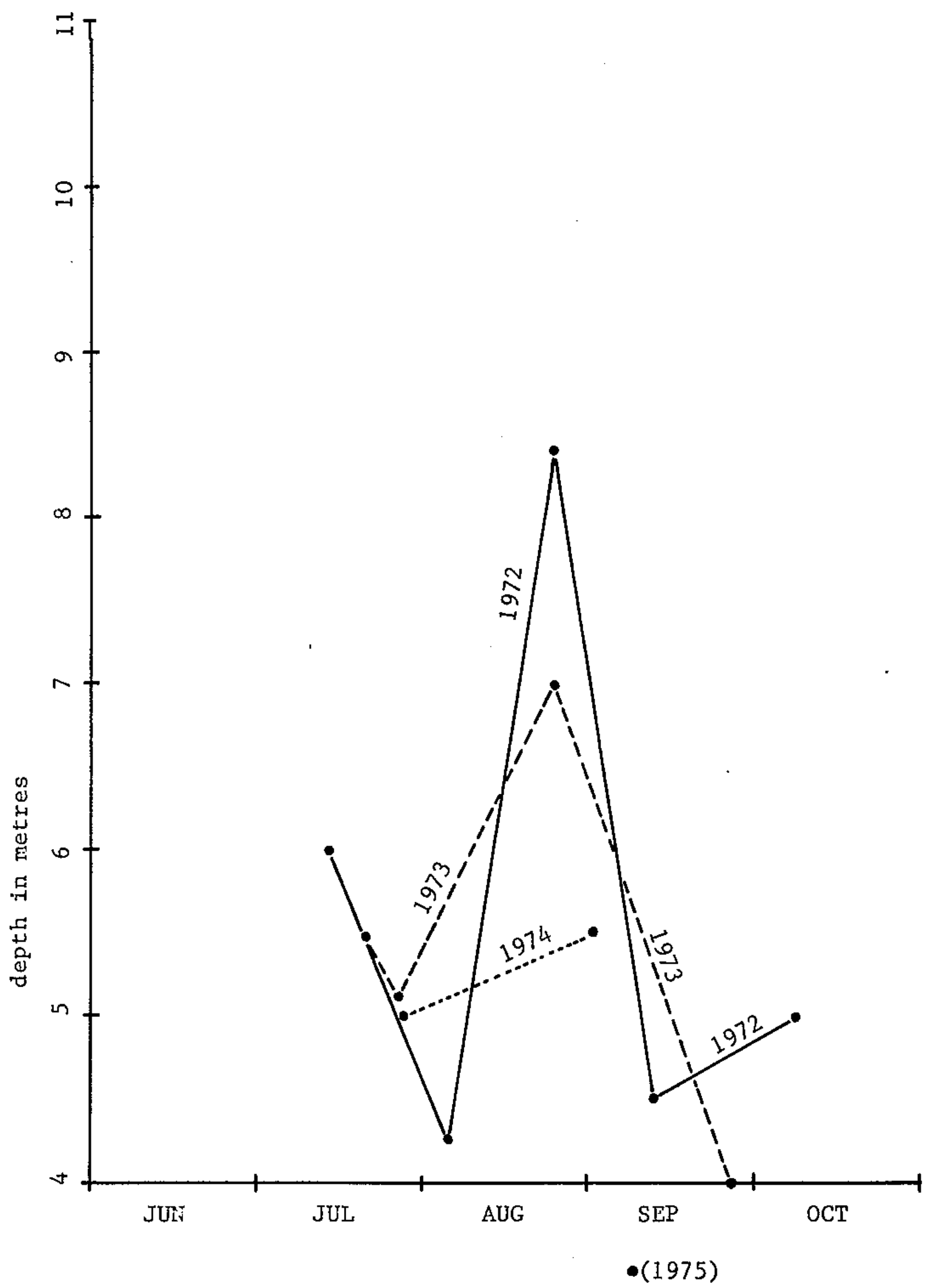


Fig. 16C. Secchi disc measurements of light penetration, Snowflake Lake.

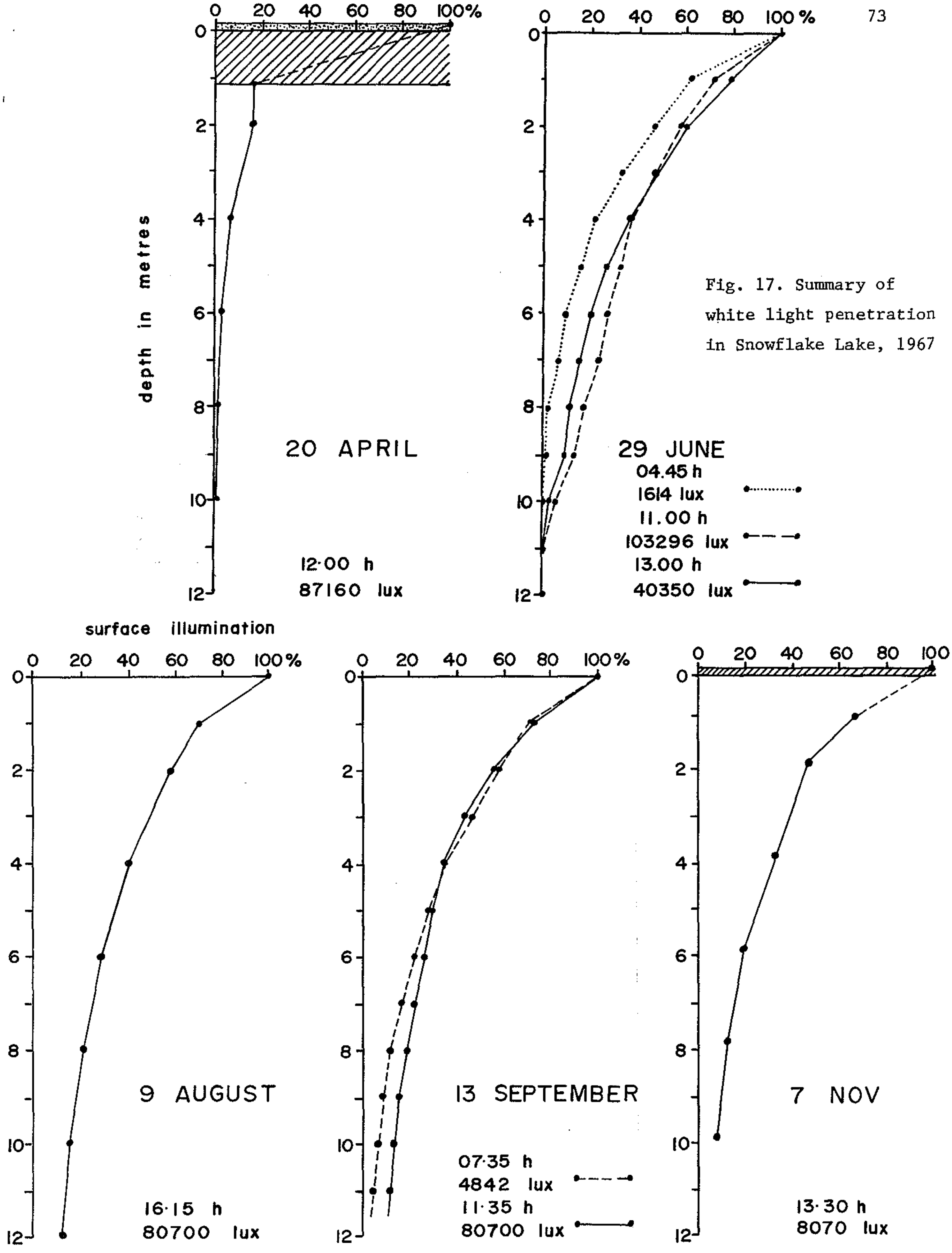
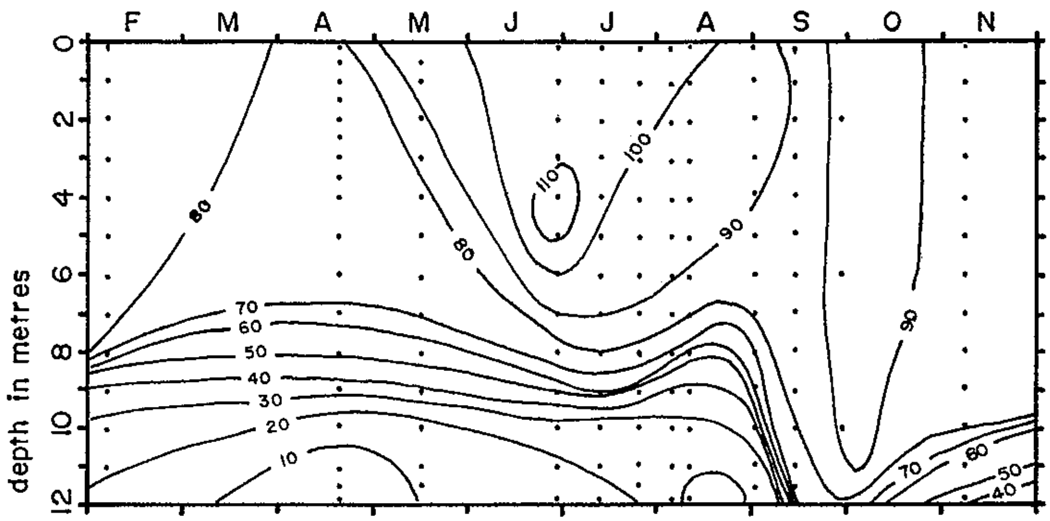


Fig. 17. Summary of white light penetration in Snowflake Lake, 1967



— dissolved oxygen isopleths in percentage saturation corrected for temperature and elevation

Fig. 18 — DISSOLVED OXYGEN ISOPLETHS, SNOWFLAKE LAKE, 1967.

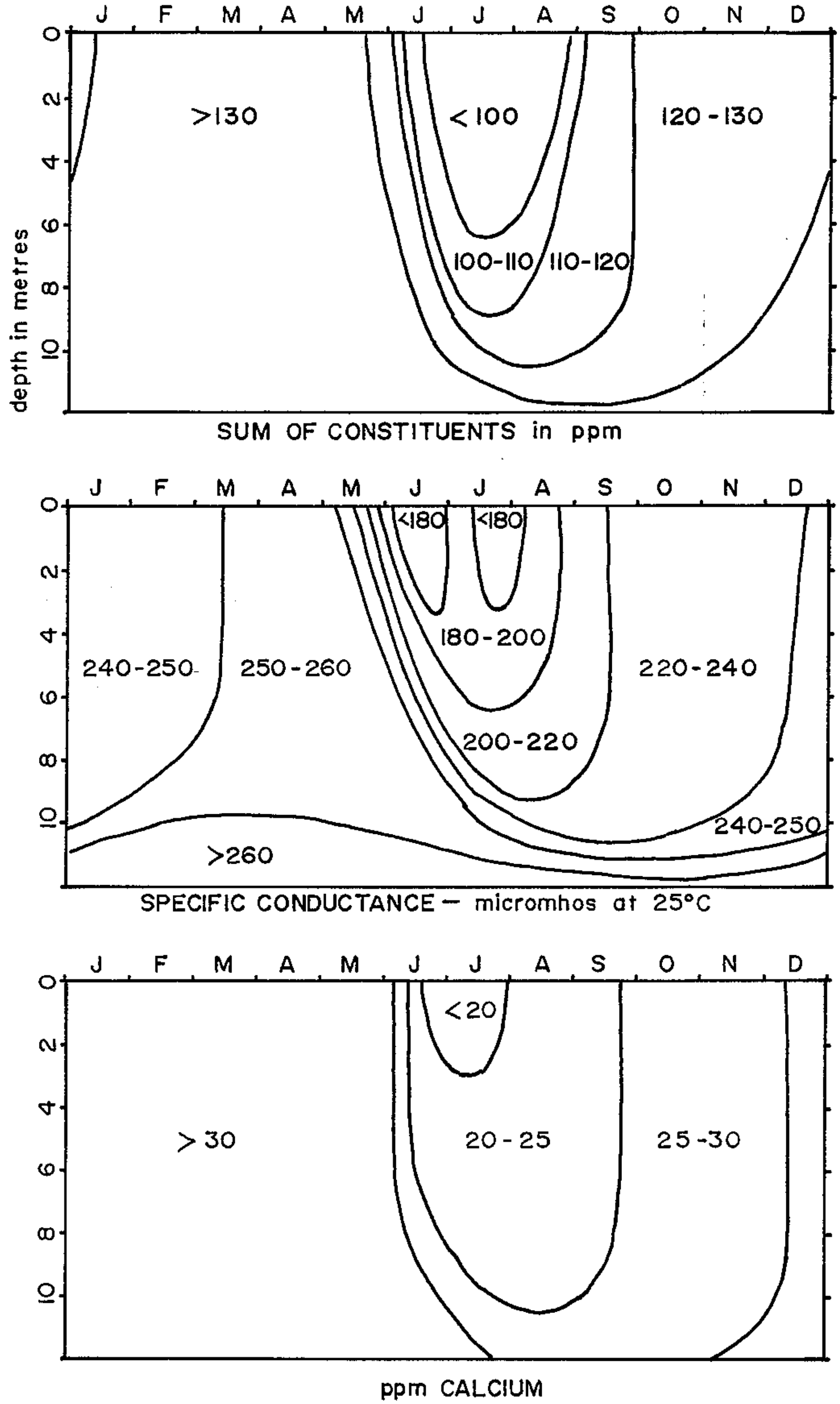


Fig. 19–SUM OF CONSTITUENTS, SPECIFIC CONDUCTANCE, AND CALCIUM ISOPLETHS, SNOWFLAKE LAKE, 1967

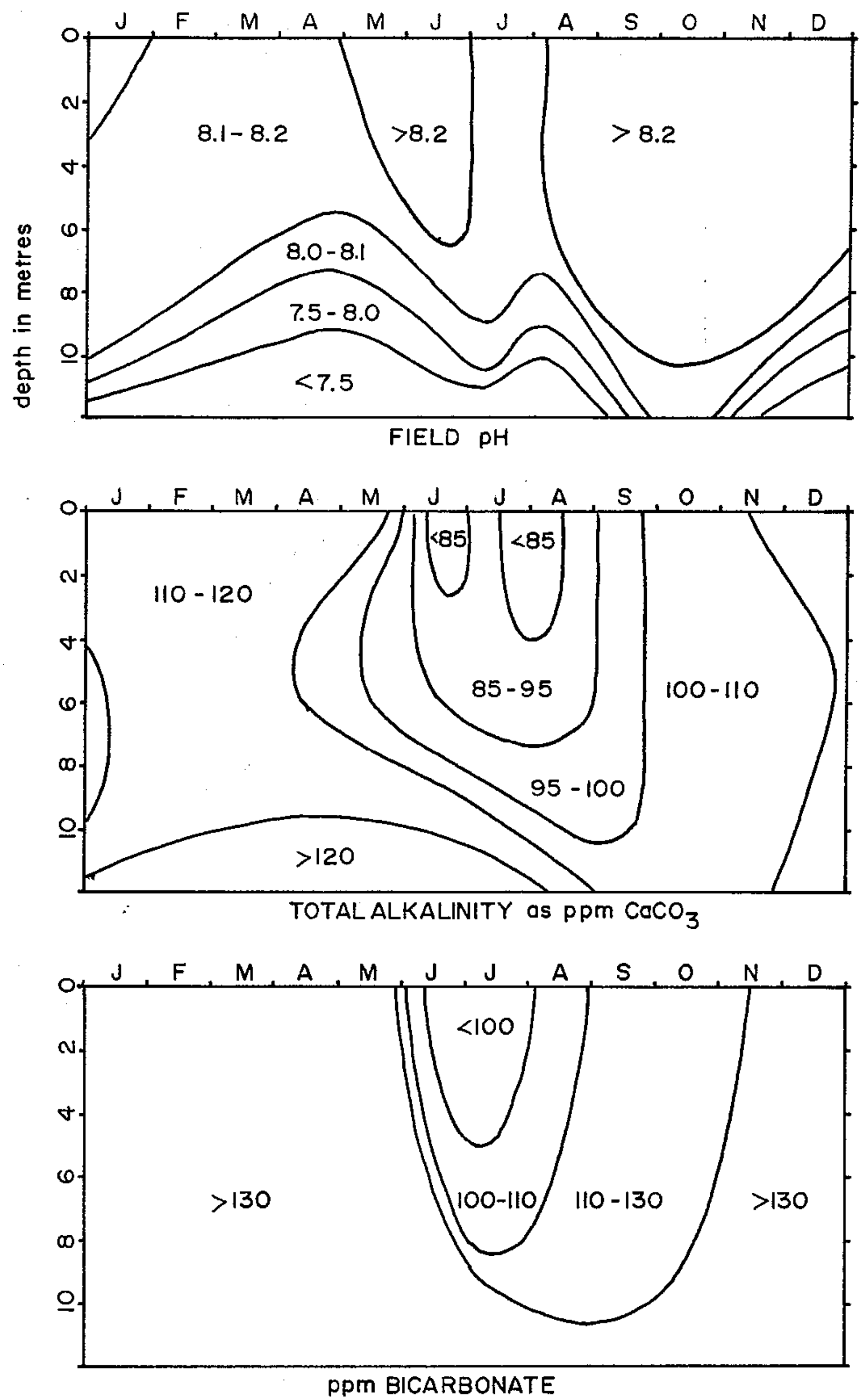


Fig. 20— pH, ALKALINITY, AND BICARBONATE ISOPLETHS, SNOWFLAKE LAKE, 1967.

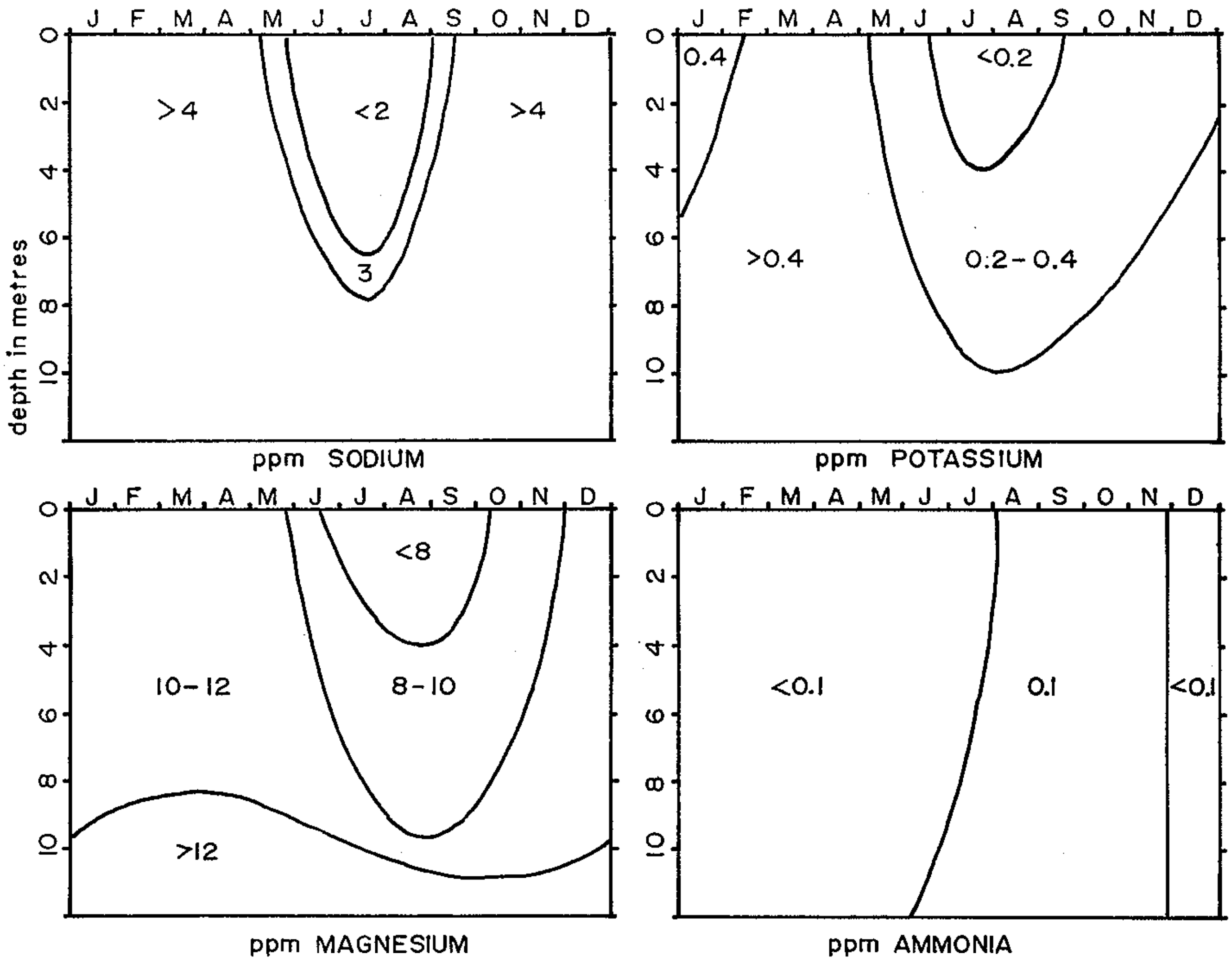


Fig. 21—SODIUM, POTASSIUM, MAGNESIUM, AND AMMONIA ISOPLETHS, SNOWFLAKE LAKE, 1967.

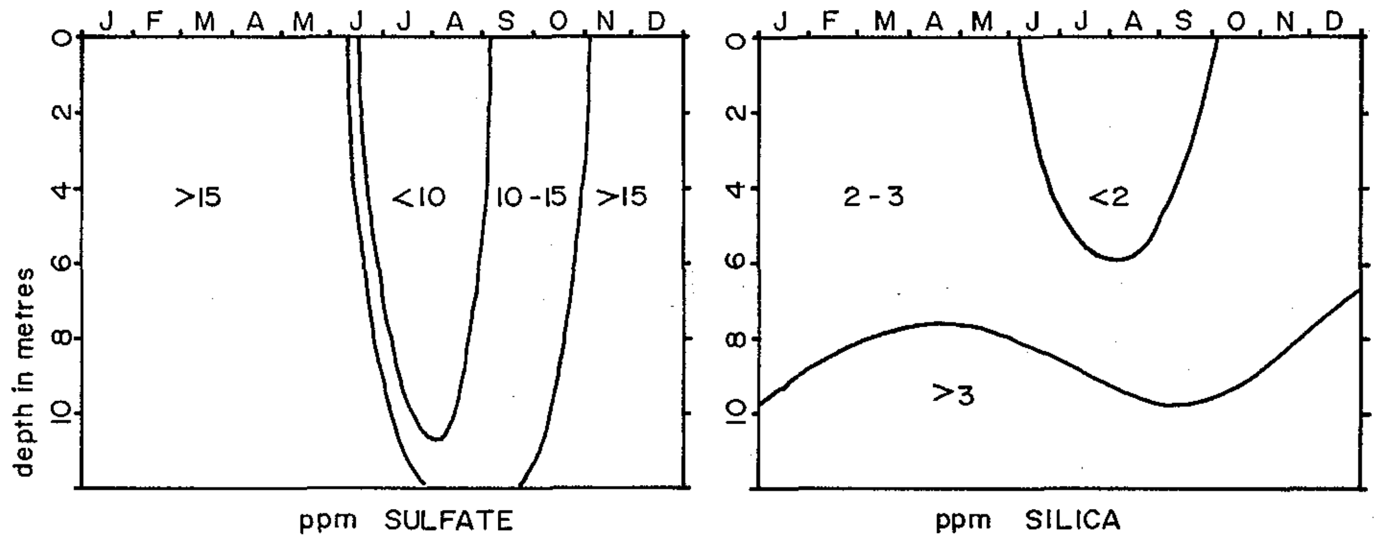


Fig.22 — SULFATE AND SILICA ISOPLETHS, SNOWFLAKE LAKE, 1967.

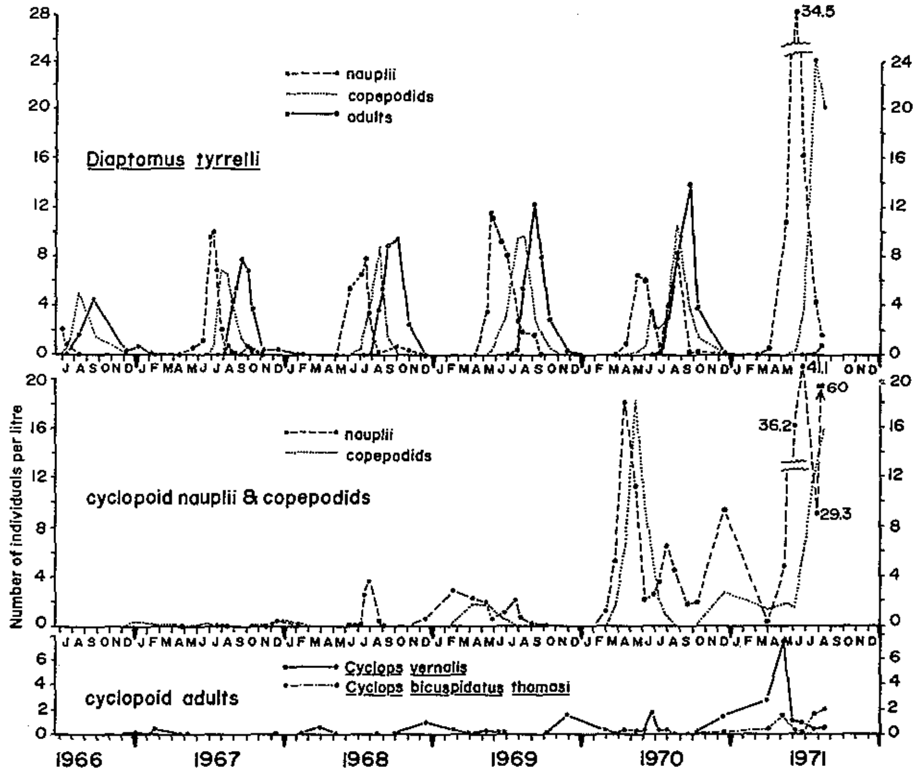
Table 18. Phytoplankton data, Snowflake Lake, 1972-1977.

(all entries as cells/ml)

Species	7/10/72 0.5	19/7/73 0.5	24/8/73 0.5	27/9/73 0.5	6/10/77 0.5
Chlorophyta					
Chlamydomonas botrys	--	-	-	-	10
Chalmydomonas frigida	-	-	-	-	114
Chlamydomonas spp.	25	-	8	73	222
Carteria Klebsii	-	-	-	-	5
Dictyosphaerium pulchellum	-	-	-	50	-
Tetraedron minimum	-	22	10	31	14
Cyanophyta					
Chroococcus spp.	41	42	34	-	-
Chrysophyta					
Class Chrysophyceae					
Bitrichia chodatii	-	-	-	-	109
Chromulina spp.	-	-	-	-	62
Chrysoikos skujae	-	1	-	-	-
Chrysolykos planctonicus	-	-	-	-	52
Chrysochromulina parva	-	-	-	-	43
Dinobryon elegantissimum	-	-	-	-	43
Dinobryon sociale	-	-	-	-	28
Kephyrion spp.	26	-	-	-	24
Kephyriopsis spp.	-	31	29	132	-
Ochromonas spp.	-	-	-	-	57
Pseudopedinella erkensis	-	-	-	-	255
Unidentified	6	-	-	-	-
Class Bacillariophyceae					
Achnanthes clevei var. rostrata	-	-	-	-	5
Achnanthes microcephala	-	3	-	-	-
Achnanthes spp.	-	4	4	15	14
Amphora ovalis	-	-	-	1	-
Caloneis sp.	1	-	-	-	-
Cyclotella cf. atomus	-	-	-	-	114
Cyclotella comta	60	-	-	41	-
Cyclotella spp.	28	19	60	36	-
Cymbella minuta	-	-	1	4	-
Diatoma vulgare	1	-	-	-	-
Fragilaria capucina	1	-	-	-	-
Fragilaria pinnata	-	-	-	1	-
Gomphonema spp.	-	-	-	-	5
Hannaea arcus	1	-	-	-	-
Navicula spp.	4	6	3	8	5
Nitzschia spp.	-	-	-	1	-
Synedra acus var. radians	-	-	-	-	47
Synedra spp.	1	-	-	-	-
Pyrrophyta					
Glenodinium sp.	-	1	3	8	-
Gymnodinium helveticum	-	-	-	1	-
Wolosynzkia sp.	1	7	10	13	-

Table 18. (cont'd.)

Cryptophyta					
Cryptomonas spp.	51	-	4	73	52
Rhodomonas minuta	41	1	10	105	33
Total cells/ml	288.0	135.0	176.0	593.0	1313.0
<u>Percent Composition of Major Groups</u>					
Chlorophyta	8.7 (25)	16.3 (22	10.2 (18)	26.0 (154)	27.8 (365)
Cyanophyta	14.2 (41)	31.1 (42)	19.3 (34)	-	-
Chrysophyceae	11.1 (32)	23.7 (32)	16.5 (29)	22.3 (132)	51.3 (673)
Bacillariophyceae	33.7 (97)	23.7 (32)	38.6 (68)	18.0 (107)	14.5 (190)
Pyrrophyta	0.3 (1)	0.7 (1)	7.4 (13)	3.7 (22)	-
Cryptophyta	31.9 (92)	4.4 (6)	-	30.0 (178)	6.5 (85)



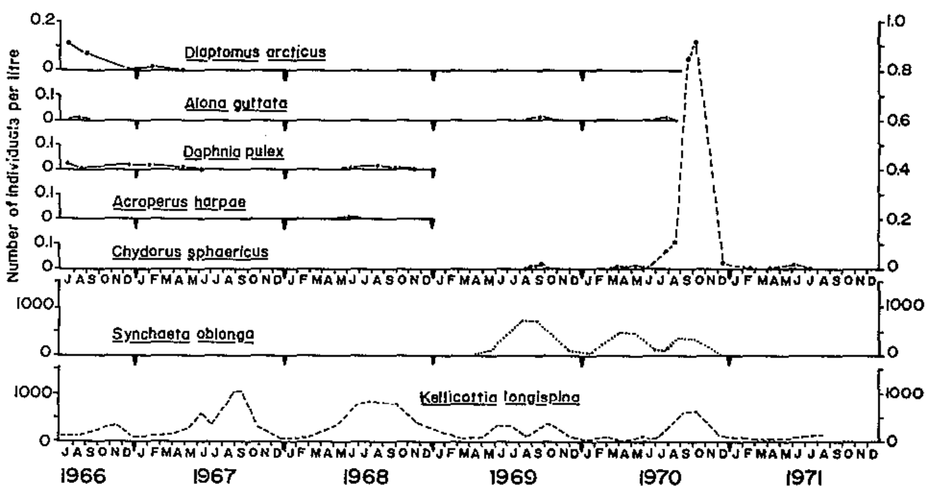


Fig.23. Zooplankton data, Snowflake Lake, 1966-1971.

Table 19. Zooplankton from Snowflake Lake (mean nos. organisms/litre) for the years 1972-1977.

Year	1972						1973			
Date	21/6	13/7	4/8	23/8	17/9	7/10	19/7	27/7	24/8	22/9
No. samples for mean	4	2	2	2	2	2	2	2	2	2
Copepoda										
Diaptomus tyrrelli	2.08*	1.14*	0.77*	0.05	0.64	0.46	1.13*	0.03	0.33*	0.90
Acanthocyclops vernalis	0.21	-	-	-	-	-	0.02	-	-	-
Diacyclops bicuspidatus thomasi	11.54	24.84	63.24*	59.91*	154.09*	84.93*	50.68	60.87*	91.84*	123.41*
Cladocera										
Alona (guttata?)	-	-	-	-	.02	-	-	-	-	-
Total Crustacea (x̄ nos./litre)	13.83	25.98	64.01	59.96	154.75	85.36	51.83	60.90	92.17	124.31

Rofitera
(no assessments made in 1972-73.

Year	1974		1975	1977
Date	26/7	1/9	9/9	26/8
No. samples for mean	2	2	3	3
Copepoda				
Diaptomus tyrrelli	0.25*	0.61*	0.36	0.07
Diacyclops bicuspidatus thomasi	29.43	45.80	70.06	9.21*
Cladocera				
Daphnia (pulex?)	-	-	0.03	0.01
Chydorus sphaericus	-	-	0.01	0.01
Alona (guttata?)	-	-	0.03	0.01
Total Crustacea (x̄ nos./litre)	29.68	46.41	70.49	9.31
Rotifera				
Polyarthra dolichoptera	-	-	xxxxx	xxxxxx
Euchlanis sp.	-	-	-	x

*predominantly nauplii.

Table 20. Benthic data, Snowflake Lake.

MACROINVERTEBRATES

Order Family* Genus species		Numbers collected Benthos per m^2
Turbellaria		4
Nematoda		30
Oligochaeta		95
Ostracoda		73
Amphipoda	*Gammarus lacustris*	9
Trichoptera		9
*Dolichopodidae		4
*Chironomidae		3393
Acarina		47
*Sphaeriidae		3009
total number		6673
total weight (grams)		19.4
total number of samples (N)		10
sampling date		26-8-77

MACROPHYTES

- no macrophytes present

Table 21. Fisheries data, Snowflake Lake.

FISH SPECIES

	date collected
- *Salmo gairdneri* (rainbow trout)	28-7-73
- *Salvelinus fontinalis* (brook trout)	28-7-73 & 26-8-77

CATCH DATA

- brook trout

	Age	Length (mm) Mean	Length (mm) Standard Deviation	Weight (g) Mean	Weight (g) Standard Deviation	Number Examined
1973	8	294.78	8.89	318.78	37.36	9
1973	9	284.13	19.03	281.88	60.67	8
1973	10	280.00	-	281.00	-	1
	11	-	-	-	-	-
	12	-	-	-	-	-
1977	13	357.67	21.54	631.00	135.07	3
1977	14	335.14	15.99	533.57	72.27	7
1977	15	323.00	-	420.00	-	1

STOMACH ANALYSES

Fish species	brook trout		
Date collected	1-9-67	28-7-73	26-8-77
Stomachs examined	8	20	14
Number empty	0	0	0
Food	**Percent by volume**		
Chironomidae	16	90	17
Pisidium	6	4	-
Ephemeroptera	-	3	-
Corixidae	8	1	10
Diptera	-	1	-
Trichoptera	18	1	44
Terrestrial insects	24	+	-
Gammarus lacustris	-	+	26
Saldidae	-	+	-
Gyrinidae	-	+	-
Coleoptera (aquatic)	-	+	-
Dytiscidae	9	-	1
Mammal	19	-	-
Plecoptera	-	-	2

Table 21. (cont'd.)

PARASITES	
- rainbow trout	- *Crepidostomum farionis*
- brook trout	- *Crepidostomum farionis* - *Rhabdochona milleri*

Table 22. Some morphometric data and location data for Wigmore Pond and the three small ponds.

Site	Lake No.	Grid Reference	Elevation (m)	Maximum Depth(m)	Surface Area(ha)
Cuthead Pond (N)	B501	11U/NH867004	2210	0.5	0.2
Cuthead Pond (S)	B502	11U/NH868003	2210	0.5	0.2
Snowflake Pond	B504	11U/NH817176	2299	0.5	0.1
Wigmore Pond	B228	11U/NH900048	1996	1.0	2.0

Site	Type of sample collected			
	Phytoplankton	Zooplankton	Benthos	Fish
Cuthead Pond (N)	-	+	-	-
Cuthead Pond (S)	-	+	-	-
Snowflake Pond	-	+	-	-
Wigmore Pond	-	+	-	-

Table 23 . Limnetic zooplankton and other net plankton, Wigmore Lake (mean nos. organisms/litre).

Year	1970		1974	1977
Date	3/6	23/6	26/7	19/8
No. samples for mean	1	1	2	1
Copepoda				
Macrocyclops albidus	-	-	-	0.02
Acanthocyclops vernalis	xxx	xx	0.40	0.60
Eucyclops agilis	-	-	0.04	-
Cladocera				
Daphnia (rosea?)	-	-	-	0.02
Ceriodaphnia (affinis?)	x	xx	-	6.67
Simocephalus vetulus	x	-	-	-
Bosmina longirostris	x	xxx	110.26	116.67
Total Crustacea ($\bar{x}$ nos./litre)		(est)12	110.70	123.98
Rotifera				
Synchaeta (oblonga?)	xx	xx	xxx	xxxxx
Keratella cochlearis	-	xx	-	-
Monostyla sp.	x	-	-	-
Trichotria sp. (?)	-	x	-	-
Other net plankton				
Dipteran larvae	xx	x	xx	-
Water mites	xx	x	-	xx
Sphaerocystis sp.	xxx	-	-	-
Fragilaria sp.	-	-	-	-
Closterium sp.	xx	xx	x	-
Pediastrum sp.	x	-	-	-
Eudorina sp.	-	-	xxx	-
Dinobryon	-	xxxx	-	-
LRGT's*	-	-	xxxx	xxxxxx

* Little Round Green Things (see paper by Paerl and Mackenzie 1977).

Table 24. Limnetic zooplankton and other net plankton, Cuthead ponds.

	N. Cuthead Pond	S. Cuthead Pond
Year	1968	1968
Date	24/8	24/8
No. samples for mean	1	1
Copepoda		
Diaptomus tyrrelli	xxxxx	-
Diacyclops bicuspidatus thomasi	-	xxx
Cladocera		
Ceriodaphnia reticulata	xx	xxx
Scapholeberis kingi	xxx	xxxx
Anostraca		
Branchinecta paludosa	xxx	xxx
Rotifera		
nil	-	-
Other net plankters		
Dipteran larvae	xx	-
Volvox sp.	xxx	-
Ceratium hirundinella	-	x
Cosmarium sp.	x	-
Spirogyra sp.	xx	xxx
Estimated total no. crustacea/litre (Copepoda, Cladocera, Anostraca)	60	50

Table 25. Limnetic zooplankton and other net plankton, Snowflake Pond.

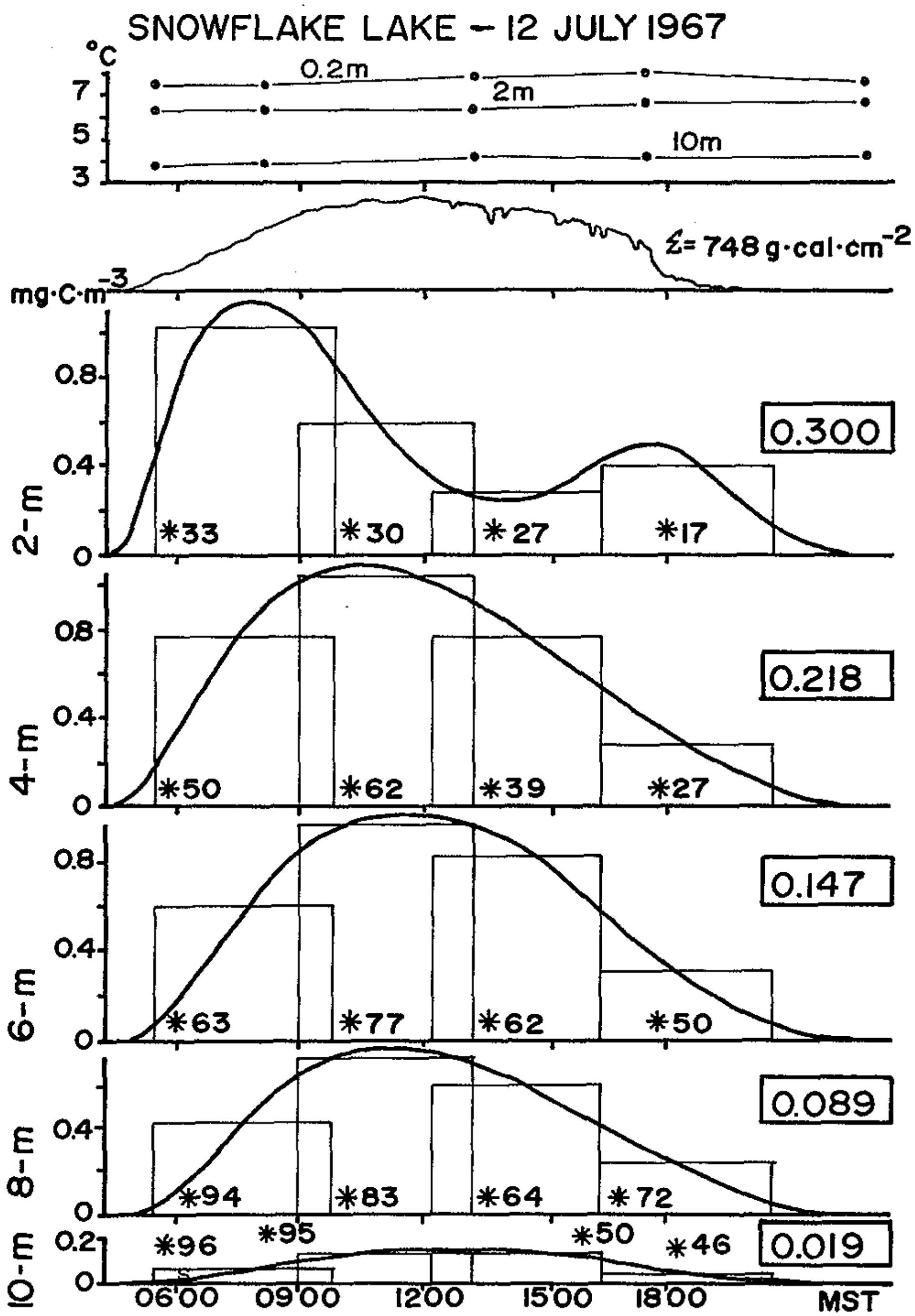
Year	1968				1969			1970		
Date	9/7	11/7	26/7	17/8	23/7	12/8	5/9	23/6	9/7	22/8
Copepoda										
Diaptomus nudus	–	–	xxx	xx	–	–	–	–	–	x
Acanthocyclops vernalis	xxxx	xxxxx	xx	xxx	xxx	xxx	xxx	xx	xxxx	xx
Diacyclops navus	–	–	–	–	–	–	–	xxx	–	–
harpacticoid nauplii	–	–	–	–	–	–	xx	–	–	–
Cladocera										
Daphnia pulex	xxxxx	xxxxx	xxx	xxxx	xxx	xxxx	xxxx	xxxx	xxx	xx
Ceriodaphnia (affinis?)	xx	xx	xxx	xxxx	xxx	xxxx	xxx	xxx	xxxx	xxxx
Simocephalus vetulus	–	–	–	–	–	xx	xxx	–	x	xxx
Chydorus sphaericus	–	–	x	xxx	xxx	xxxx	xxx	xxx	xx	xxx
Anostraca										
Branchinecta paludosa	–	–	xxxx	xxx	xxx	xxx	xxx	xx	xxx	xxx
Estimated total Crustacea (nos./litre)	70	80	50	70	50	90	75	60	75	70
Rotifera										
Euchlanis (lucksiana?)	–	–	–	–	xx	xx	–	–	xx	x
Other net plankters										
Mesostoma sp.	x	x	–	–	–	–	–	–	–	–
Diptera larvae	xxx	xx	–	–	–	xx	xx	xxx	x	xx
Coleopterans	–	xx	–	–	–	–	–	–	–	x
Corixids	–	–	–	–	–	xx	–	–	–	–
Water mites	–	–	–	–	–	–	–	–	–	x
Nostoc (microscopicum?)	–	–	–	–	xxx	xx	xx	–	xx	xx

PRIMARY PRODUCTION

This term refers to the conversion of inorganic carbon (chemically combined with hydrogen and oxygen) into carbohydrates via the chemical process called photosynthesis, a process which requires light as the energy source (solar radiation in nature). Oxygen is produced as a biproduct of this reaction. Almost all of the photosynthesis on the earth occurs in green plants. In most mountain lakes, the microscopic algae in the water (sometimes millions in a litre of water) are the principal photosynthesizers. Macrophytes are rarely very abundant in mountain waters of the Canadian mountain national parks, if they are present at all, and their photosynthetic activity per unit of biomass is much less than that of phytoplankton. Therefore, their photosynthetic production is usually only a fraction of that of the phytoplankton. In some shallow alpine waters, periphyton may account for a large proportion of a lake's production. In the seven lakes of this study, it is likely that 80 to 90% of total photosynthetic production is due to phytoplankton. Experiments were conducted on only two of the lakes (Snowflake and Wigmore). Because of the great difficulties in assessing production by periphyton or macrophytes, only production by phytoplankton was measured.

Figs. 24 and 25 are graphic summaries of the primary production experiments conducted on two of the seven lakes which were studied in some detail. Annual primary production in these two lakes was estimated to be:

lake	$mgC \cdot m^{-2} \cdot year^{-1}$
Snowflake Lake	7,640 (Anderson 1975)
Wigmore Pond	15,000 (estimated, this study)



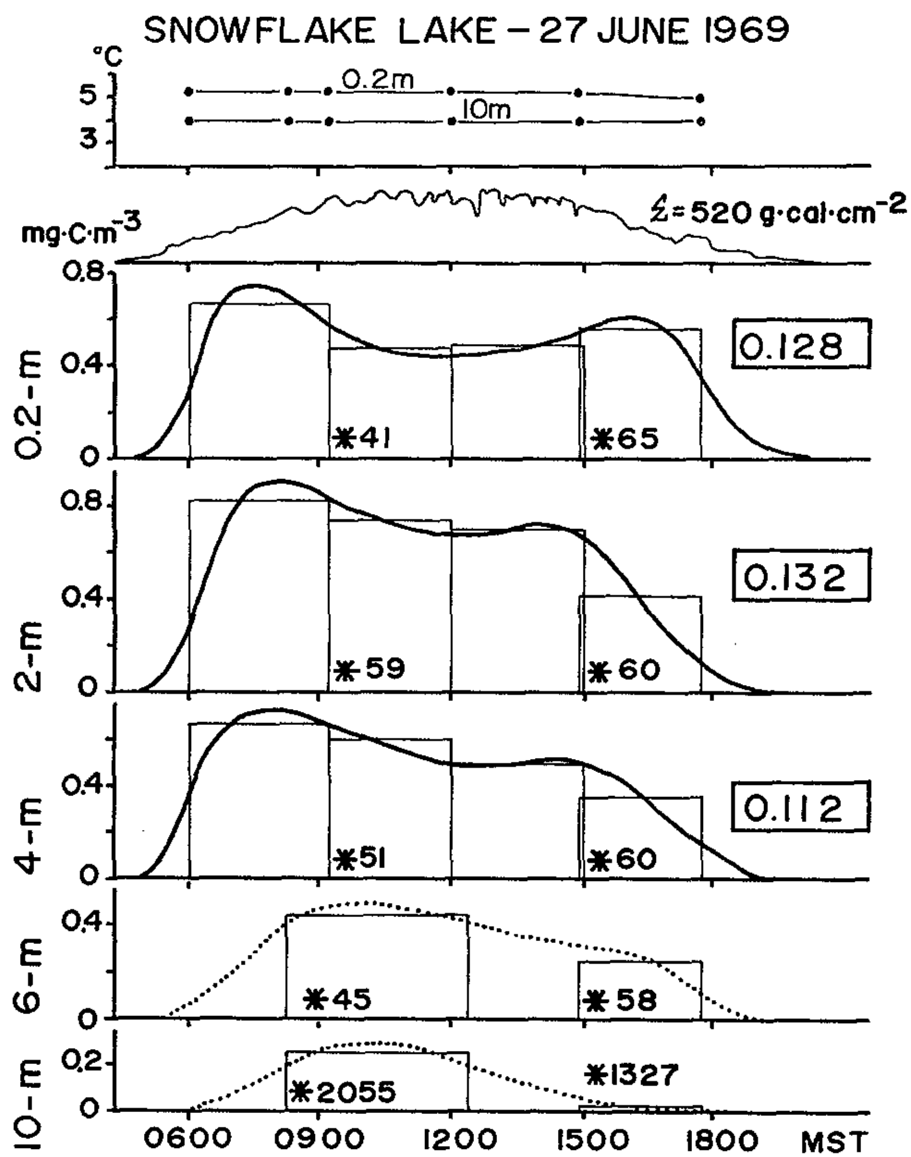


Fig. 24. Diurnal primary production patterns for Snowflake Lake, Banff National Park (from Anderson 1974a).

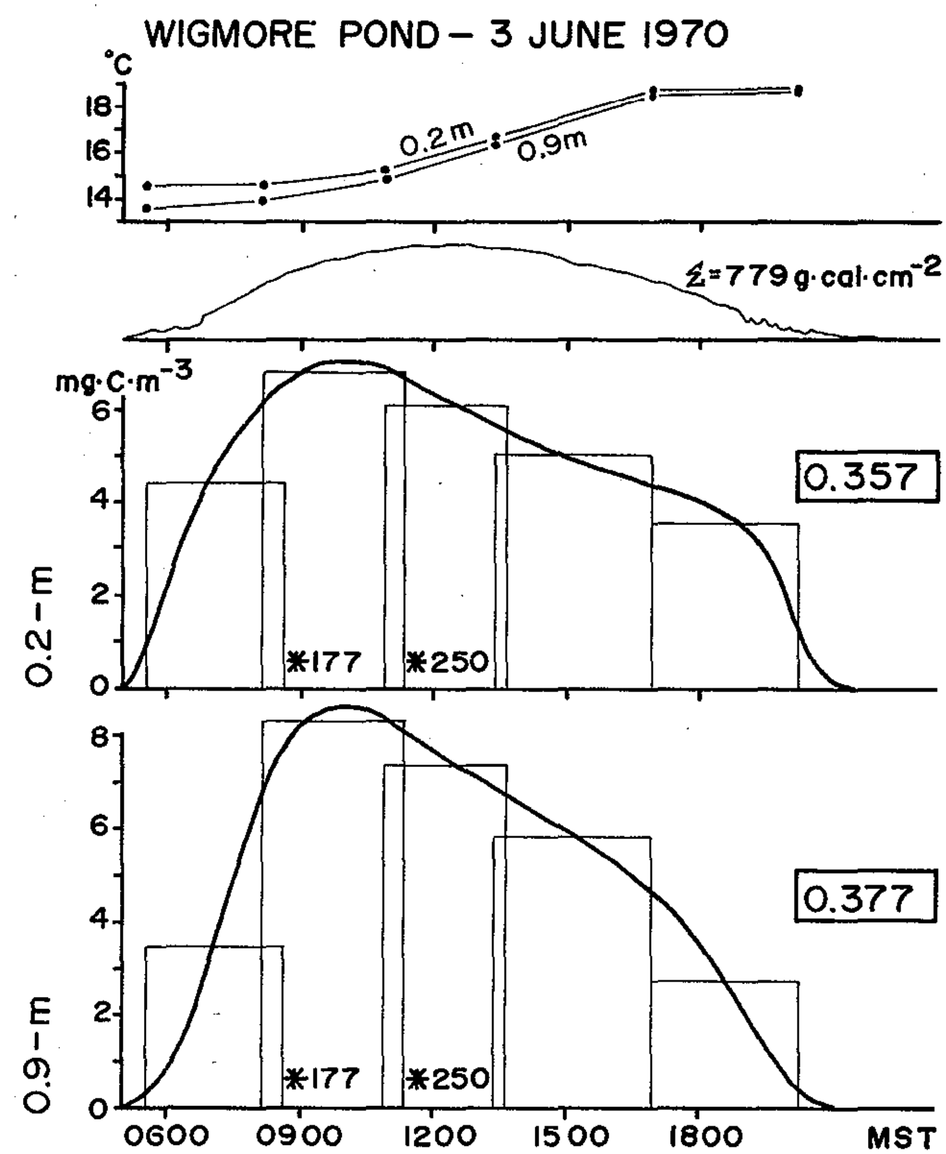


Fig. 25. Diurnal primary production pattern for Wigmore Pond, Banff National Park (from Anderson 1974a).

WATER CHEMISTRY

The majority of water samples taken for chemical analysis were collected at the times when primary production experiments were being carried out. Consequently, there are nearly twice as many analyses for Snowflake Lake as for the other six lakes combined. Isopleths have been plotted for some parameters for the Snowflake Lake analyses, These were included in the section on Snowflake Lake earlier in the general Results section. All detailed analyses were performed by the Calgary laboratory, Water Quality Branch, Inland Waters Directorate, Environment Canada. These results should be available through the Naquadat data retrieval system. The results of 64 analyses for the seven lakes are summarized in Table 26.

Table 26. Summary of water analyses for seven lakes of the Cascade Trail region of Banff National Park.

Lake	SNOWFLAKE				GROUSE	PIPIT	HARRISON	BIGHORN	CUTHEAD	WIGMORE
Sample date	Spring	Summer	Fall	Winter		Aug-Sep	Jun-Aug	Jun-Aug	Jun-Aug	June
Year (s)		1966 - 1972			1966-72	1966-72	1966-72	1966-72	1966-72	1970
Number of samples	14	20	8	4	5	3	2	4	3	1
Conductivity (μS @ 25^{o}C)	246	210	229	250	161	174	249	146	160	238
Alkalinity **	111.2	96.2	105.8	117	73.7	83.2	86.8	54.4	77.0	109
Total Hardness **	121	98.4	111.8	126.5	81.3	89.2	127	72.3	83.1	123
Silica *	2.9	2.5	2.6	3.0	1.7	1.9	2.9	1.0	2.3	4.0
Carbonate *	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bicarbonate *	135.3	117.2	128.9	142.0	90.1	101.4	105.7	65.7	94.0	133
Sulphate *	16.9	10.8	14.3	16.9	6.2	7.2	36.2	17.7	4.3	13.9
Chloride *	0.2	0.1	0.1	0.1	0.2	0.2	0.3	0.2	0.2	0.2
Fluoride *	0.06	0.06	0.06	0.09	0.06	0.04	0.07	0.09	0.03	0.07
Nitrate *	< 0.20	0.1	0.1	< 0.1	< 0.2	< 0.05	< 0.01	0.03	< 0.10	<0.01
Hydroxide *	0.0	0.0	-	-	-	0.0	0.0	0.0	0.0	-
Calcium *	30.5	24.5	28.8	31.5	23.2	25.7	34.9	19.6	23.0	32.4
Magnesium *	10.9	9.1	9.7	11.7	5.7	6.0	9.7	5.7	6.2	10.2
Sodium *	4.4	4.5	4.6	3.1	0.2	1.2	0.6	0.2	0.4	1.6
Potassium *	0.4	0.3	0.4	0.5	0.3	0.2	0.3	0.2	0.2	0.9
Carbon dioxide *	2.24	2.52	1.50	1.40	1.69	1.07	1.91	0.98	1.31	2.1
Stability Index (pH units)	7.80	8.16	7.93	7.5	8.39	7.96	7.92	8.63	8.24	-
pH (field)	8.0	7.9	7.8	8.2	8.2	8.1	8.1	8.3	8.5	8.2
pH (laboratory)	8.0	8.0	8.1	8.2	8.0	8.2	8.1	8.2	8.1	8.0
Turbidity (J.T.U.'s)	1.4	0.7	0.5	2.5	1.5	0.4	0.4	1.6	0.4	2.7
Color (Hazen units)	6.5	3.3	3.8	5.0	3.6	2.7	5.0	3.0	3.0	2.0
Zinc (dissolved) *	< 0.007	< 0.008	< 0.005	< 0.009	< 0.004	< 0.005	0.003	0.003	< 0.003	< 0.005
Copper (dissolved) *	< 0.003	< 0.005	< 0.005	< 0.006	< 0.003	0.003	< 0.001	< 0.001	< 0.001	< 0.001
Iron (dissolved) *	0.010	< 0.015	< 0.010	< 0.010	< 0.04	< 0.07	< 0.02	< 0.02	< 0.04	0.13
Lead (dissolved) *	< 0.007	< 0.006	-	< 0.010	< 0.006	< 0.006	< 0.006	< 0.006	< 0.006	< 0.010
Manganese (dissolved) *	< 0.008	< 0.015	< 0.003	< 0.008	< 0.008	< 0.020	< 0.020	< 0.008	< 0.010	< 0.001
Phophate (ortho) *	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.003	< 0.003	< 0.003	< 0.003	< 0.01
Phophate (inorganic) *	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.003	< 0.003	< 0.003	< 0.003	< 0.01
Carbon (total organic) *	2	4	-	-	3	4	2	9	3	-
Carbon (total inorganic)*	29	17	-	-	12	8	11	8	12	-
Ammonia *	< 0.1	< 0.1	0.1	< 0.1	< 0.1	< 0.1	0.0	< 0.1	0.0	< 0.1
Non carbonate hardness**	9.8	5.8	6.0	9.5	7.6	6.0	40.3	17.9	6.0	14
Sum of contituents *	132.4	109.7	124.8	136.7	82.1	92.6	137.0	77.5	82.9	128.5

* mg/litre ** mg/litre as $CaCO_3$

DISCUSSION OF RESULTS

1. Chemistry

Low oxygen concentrations in Snowflake Lake were confined to the bottom 2 m in the year of intense studies (1967) and are unlikely to be much different from this most years (see Fig. 18). The absence of anaerobic conditions was probably due to the accumulation of only small amounts of organic matter in the bottom sediments. The oxygen deficit under the ice in alpine lakes is usually closely related to both the depth of the lake and the depth of snowcover, where the shallower lakes have a lower oxygen reserve and the deep snowcover inhibits renewal of oxygen from the atmosphere. The increase in dissolved oxygen under the ice in May coincided with the spring phytoplankton maximum (i.e. oxygen is a by-product of photosynthesis).

The concentrations of most dominant ions (Figs. 19-22) followed the general pattern of salinity (sum of constituents) and conductivity (Fig. 19), where lowest values occurred during the period of greatest flow-through or water renewal (see Fig. 14) and highest concentrations occurred during the period of ice-cover, especially near lake bottom. Ions at low concentration (e.g. ammonia) showed a less distinct pattern, and trace elements often showed no clear pattern.

Table 26 shows the general similarity among the seven lakes in regard to water chemistry. There is little difference in pH or color. Nutrients (esp. nitrates and phosphates) were usually at

Table 27. Relationship between total salinity and elevation for some Banff and Jasper national parks lakes.

Lake group	No. of lakes	Mean elevation ASL (metres)	Elevation Range (metres)	Mean Salinity (mg/litre)	Salinity Range
1	8	2191	2087 - 2287	20	6 - 55
2	7	2229	1996 - 2347	104	77 - 137
3	16	2221	1887 - 2424	65	27 - 128
4	2	1956	1945 - 1967	30	26 - 34
5	3	1641	1498 - 1750	110	101 - 124
6	9	1542	1384 - 1732	124	75 - 194
7	6	1112	1024 - 1230	180.2	114.5- 371.5
8	4	1001	1000 - 1003	233	209 - 285

1. Lake groups: 1.- 8 small alpine lakes in the Maligne River watershed east of the Maligne River (Anderson 1974b).
2. 7 alpine and subalpine lakes of this study.
3. 16 alpine and subalpine lakes in Banff National Park near the Continental Divide (Anderson 1969a).
4. Amethyst and Moat lakes, Tonquin Valley (Anderson & Donald 1978b).
5. Maligne, Mona, and Beaver lakes (Donald & Anderson 1978)
6. 9 montane lakes in Banff National Park in the vicinity of the Trans-Canada Highway (Anderson 1969a, 1974b).
7. Annette, Beauvert, Edith, Horseshoe, Patricia, and Pyramid lakes (Anderson & Donald 1978a).
8. 4 low altitude lakes and ponds in the lower Athabasca Valley (Anderson 1970c).

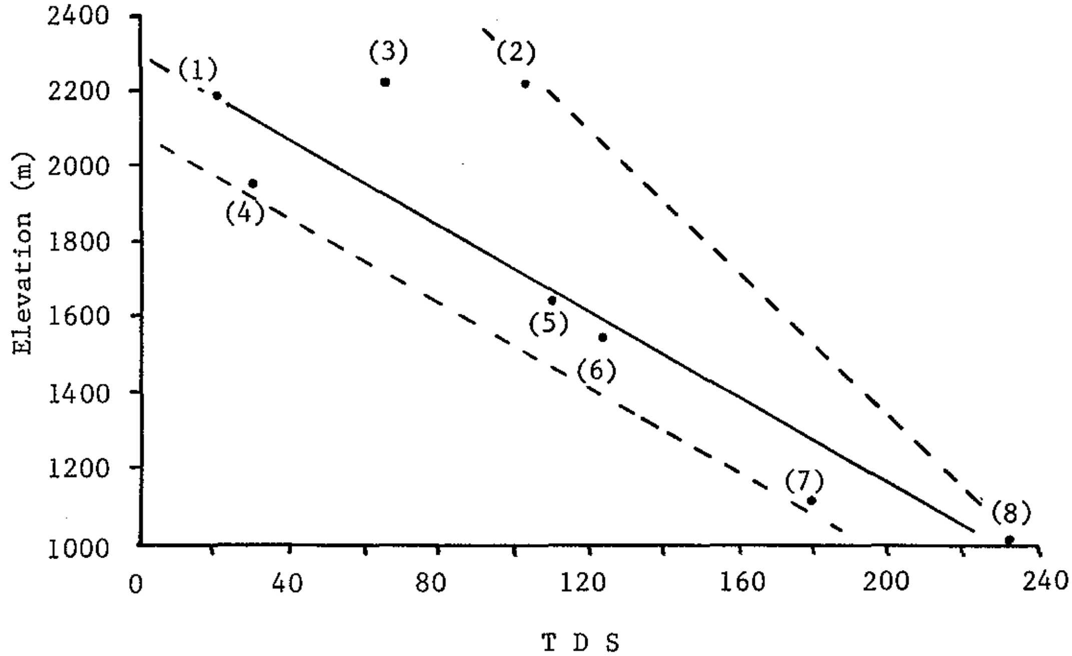


Fig. 26. Relationship between total salinity (mg/l) and elevation (metres) for some Banff and Jasper National Parks lakes (number in parenthesis is lake group - see Table 27).

Table 28. Comparison of means and ranges for some analyses features for the seven waters of this study with a large number of other Jasper Park waters and some Banff Park waters.

	This study			Banff waters (Anderson 1969a)			Jasper waters (Anderson 1969b)		
Feature*	$\bar{\bar{x}}$	(N/n)	range	$\bar{x}$	(n)	range	$\bar{x}$	(n)	range
sum of constituents (mg/l)	104.3	(64/7)	77.5-137.0	79	(21)	27-194	49.1	(24)	2.4-149.0
Specific conduct. at 25 C (uS)	194.6	(64/7)	146 -249	150	(21)	54-369	91.8	(24)	2.8-268
Ratio: sum of constits. / specif. conduct.	.530	-	.509-.550	0.522	(21)	0.488 - 0.583	0.53	(24)	.045-0.86
Total alkalinity as mg/l $CaCO_3$	84.5	(64/7)	54.4-109.0	69	(21)	22 - 174	30.9	(24)	0.2-115.0
Ratio: total alkalinity / sum of constits.	0.822	-	.633-.928	0.874	(21)	0.715-0.984	-	-	-
Total hardness as mg/l $CaCO_3$	98.6	(64/7)	72.3-123.0	76	(21)	27 - 188	45.1	(24)	0.8-137.0
Field pH	8.2	(64/7)	8.0-8.5	8.1	(21)	7.5-8.7	7.9	(22)	7.3-8.3

* $\bar{x}$ = mean; (n) = no. of lakes; (N/n) = no. of samples/no. of lakes; $\bar{\bar{x}}$ = mean of means

very low concentrations, as were heavy metals. In all, bicarbonate followed by sulfate were the dominant anions, and calcium followed by magnesium were the dominant cations. The only obvious difference was in the total concentration of salts as measured by total salinity (or sum of constituents) and specific conductance. Here, the lakes at highest altitudes (probably also having fastest renewal times) had the lowest salinity. This is a feature generally applicable to mountain lakes and reflects the amount of contact time the water has with the rocks and soils. For a large group of alpine, subalpine and montane lakes in Banff and Jasper National Park, this pattern tends to previal (Fig. 26 and Table 27), although the Banff lakes are more saline at a given altitude probably reflecting the greater proportion of limestone in the rocks.

Table 28 compares the general water analyses for these lakes to some Banff alpine and subalpine waters nearer the Continental Divide and to a large number of high altitude lakes in Jasper National Park. The greater prevalence of limestone rocks in the Front Ranges where the Cascade Trail lakes are situated shows in the greater salinity. Similarly, the greater percentage of quartzite rocks in many of the high altitude formations in Jasper shows in their lower average salinity. The pH of the Cascade Trail lakes is slightly higher, as might be expected, but the ratios between salinity and specific conductance remain remarkably constant.

2. Physical Data

a) Morphometry and Water Renewal

Table 29 summarizes some morphometric features of the lakes.

Table 29 - Selected morphometric features of seven lakes of the Cascade Trail area.

Lake	$\bar{z}$	z_m	A_o	V_L**	V_c	V_L/V_c	$\bar{z}/z_m$	$A_o/\bar{z}$	shoreline development	drainage basin (ha)
+Bighorn	3.09	9.20	2.15	6.65	6.59	1.009	0.336	0.695	1.34	107.3
+Cuthead	1.84	4.30	3.47	6.38	4.98	1.281	0.427	1.897	1.69	158.5
Grouse	x4.0	±9.0	±10.0	*	*	*	x0.44	x2.50	*	*
+Harrison	5.44	10.70	8.42	45.78	30.04	1.524	0.508	1.549	1.22	117.1
+Pipit	12.57	20.60	10.63	133.68	73.01	1.831	0.610	0.846	1.29	253.7
+Snowflake	6.12	13.00	7.13	43.59	30.88	1.417	0.471	1.165	1.28	147.0
Wigmore	*	1.0	2.0	*	*	*	*	*	*	*
+mean	5.81	11.56	6.36	47.22	29.10	1.412	0.470	1.230	1.36	156.7

+ means for these 5 lakes only
x estimated value
± subject to large water level fluctuations (figs. approx. for high water)
* no measurement or value available
** calculated according to Welch (1948)

$\bar{z}$ mean depth, metres
z_m maximum depth, metres
A_o total surface area, hectares
V_L volume of lake, $\text{metres}^3 \times 10^4$

$V_c = \frac{A_o z_m}{3}$ = vol. of cone of base area A_o, height z_m

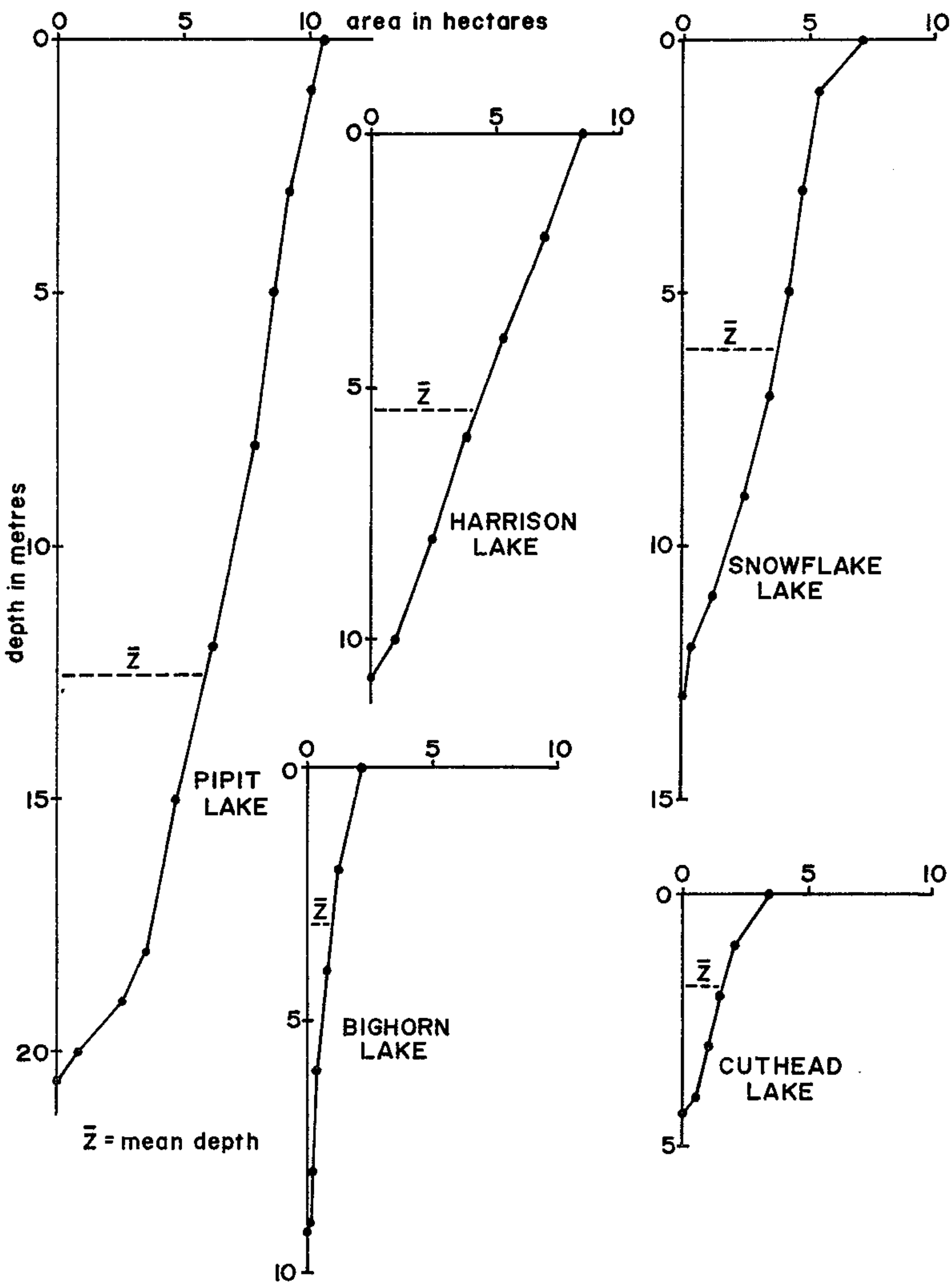


Fig. 27.

HYPSOGRAPHIC CURVES

5 LAKES IN THE CASCADE TRAIL AREA

As indicated, some of the figures are approximate since no data were available. Lake volumes were calculated according to Welch (1948). The "volume development" (V_L/V_c) is rarely less than unity for natural lakes (Hutchinson 1957), and when unity is approached, it indicates a cone-shaped lake (e.g. Bighorn Lake). A value less than unity indicates basin walls convex towards the water (Welch 1948). The hypsographic curves for five of the lakes (Fig. 27) indicate the cone-like basin of Bighorn Lake and the various degrees of concavity in the lake-basin walls of Harrison, Pipit, and Snowflake lakes.

The ratio of mean depth to maximum depth $(\bar{z}/z_m)$ is greater than 0.33 for most lakes (Hutchinson 1957), and a small ratio can be indicative of lakes having one or two very deep holes of relatively small area. Bighorn Lake at 0.336 and having no deep holes is the most exceptional in this regard. Snowflake Lake at 0.471 is very close to the values of 0.52 given by Pechlaner (1966) for two alpine lakes, the Finstertaler Seen, in Austria.

Gorham (1964) suggests a ratio of lake area to mean depth $(A/\bar{z})$ as an index of "basin shape". He notes that the shape effect is manifested mainly in small lakes and that large lakes generally have a higher heat budget when this ratio is low. He also notes that low $(A/\bar{z})$ ratios usually correlate with low lake volumes. For nine of the lakes for which this ratio could be calculated or estimated, the values are moderately low and fairly similar, much more so than figures obtained for some Yoho National Park lakes

(Anderson 1968d) where the smallest value was about the same, but the larger was nearly 4 times as large. A small ratio is also an indicator of "relative" deepness a feature already noted for Little Bighorn Lake ($A/\bar{z}$ = 0.16). Pipit ($A/\bar{z}$ = 0.846), the second deepest of the lakes in this group and also the second largest, is not unusually deep when considered from this point of view.

The drainage basin for Snowflake Lake is only about 147 ha and is about half what it would be if it were not for the low ridge which extends down the middle of the cirque and diverts much of the runoff into a small stream that joins Snowflake Creek just below the lake. The relative drainage basin for Snowflake Lake (about 20.6 times lake area) is about half the average relative figures given for 32 Italian alpine and subalpine lakes (average was 40.5 times lake area) by Ravera and Tonolli (1956). The average ratio for Bighorn, Cuthead, Harrison, Pipit, and Snowflake lakes was 31, with Bighorn having the highest ratio and Harrison having the smallest ratio.

An approximate water renewal rate of 7.7 times per annum (Fig. 14) was determined for Snowflake by estimating stream flow from average depth and width and from velocity gauged by means of a floating chip. Estimates of stream flow were made on a short stretch of Snowflake Creek which was characterized by a fairly uniform depth and width and a comparatively consistent bottom of sand and fine gravel. Most estimates of flow were made near midday. Estimates made in the early morning and late in the afternoon on a few days during the summer indicated that the flow was fairly constant throughout those days.

The estimated rate of 7.7 is in the same range as the values of 2.8 and 11.2 obtained for the Austrian Finstertaler lakes (Pechlaner 1966). The volume of Snowflake Lake is only about 10% larger than the smaller of the two Austrian lakes (Hinterer Finstertaler See) and this indicates a somewhat lower flow through Snowflake Lake. For a group of 14 alpine tarns in Italy, Tonolli (1954) estimated theoretical water renewals, based on the volumes of the tarns, the drainage basin sites, and precipitation intensity, to range between 10 and 100 times per year. It is estimated that Grouse, Harrison, and Pipit lakes would have renewal rates similar to Snowflake Lake. The renewal rates for Bighorn and Cuthead lakes are estimated to be higher than Snowflake Lake because of their smaller lake volumes relative to drainage basin areas.

b) Temperature; Ice and Snow Cover

Fig. 13 summarizes six years of temperature data for Snowflake Lake. A few features are notable. Thermoclines are only weakly developed, probably the result of a combination of frequent winds, relatively shallow depths, and moderately high water renewal rates. Under-ice temperatures in winter are usually less than the "text book" $4^{o}C$ from surface to bottom, due mainly to continued mixing in late fall by high winds and to low heat income in winter. Surface temperatures are usually less than $10^{o}C$ rarely exceed $12^{o}C$, and usually remain at the high point for less than one month.

Cooling and fall overturn usually begin in the last week of August. The temperature data given on the first page of the lake data for the other lakes of this study in the Results section suggest that Snowflake Lake water temperatures are probably quite typical of the group as a whole.

Figs. 15A and 15B summarize some of the data collected on snow and ice conditions on Snowflake Lake. These measurements are probably typical of lakes at this altitude which have a similar exposure to sun and wind. Freezeup and breakup dates are probably typical also. The main differences in the other lakes would be due mainly to exposure to wind. It would be expected, for example, that Bighorn and Pipit lakes would accumulate more snow on the ice surface and would, as a result, have thinner ice. Grouse Lake is known to have a much earlier "breakup" date, because most of its water is melt water. In fact, there may be no water in the lake some springs until melt water begins to accumulate. It is expected that Grouse, Cuthead and Wigmore lakes would usually freeze over earlier than the others, because they are shallower and could cool more quickly.

In a normal year, Snowflake Lake could be expected to freeze over about October 10 and remain frozen over until late June or early July. Snowflake Lake remained almost blown free of snow during most of the winters with the result that the ice layer tends to be rather thick. When an ice hole was cut at Snowflake Lake, the water level always remained a few centimeters below the

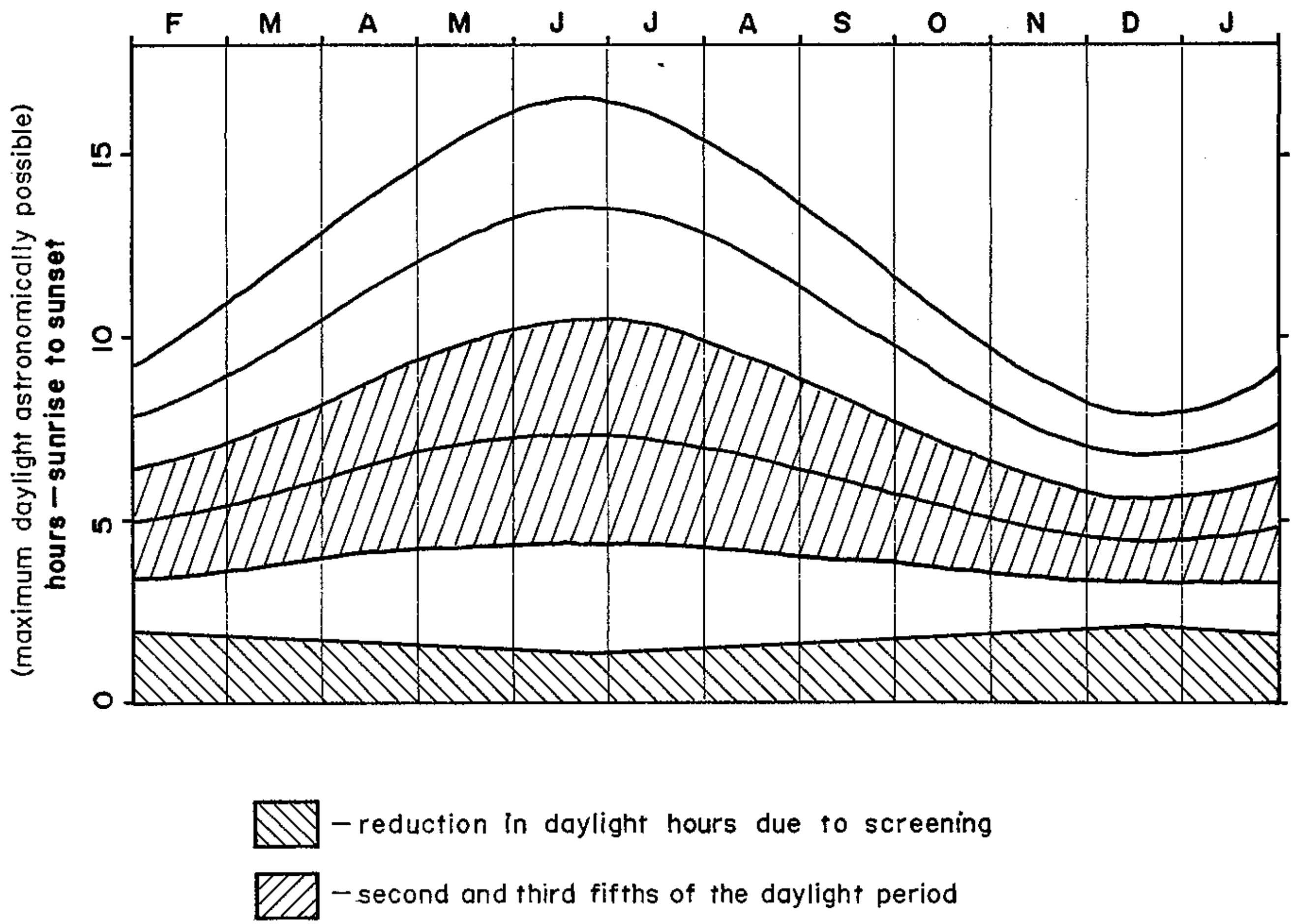


Fig. 28 — SEASONAL CHANGES IN THE DAYLIGHT PERIOD, SNOWFLAKE LAKE.

the upper ice surface. The ice reached its maximum thickness of 110 to 120 cm in March or April (Figs. 15A-15B). The ice was usually quite clear, although patches of the upper few centimeters consisted of translucent snow-ice. The phenomenon of the ice cracking followed by water welling up through the cracks to soak the snow did not occur on Snowflake Lake in 1966-1968 except for a small area to one side of the lake where 0.5 to 1 m of snow tended to accumulate. The water in the snow on the ice surface on 16 May 1967 appeared after a sudden heavy snowfall which occurred during an extremely mild spell. The ice cover diminishes in thickness from April until mid-June or later when "candling" occurs, and breakup can follow with dramatic suddenness if a strong wind strikes the lake at this time. As Nauwerck (1963) has suggested, the candling effect will enable a lake to break up under spring winds with a minimum of damage to shoreline or to shallow water sediments and organisms.

c) Light

The seasonal changes in daylight periods at Snowflake Lake during 1967 are shown in Fig. 28. The graph was drawn from figures taken from the Canada Department of Transport, Meteorological Service Sunrise-Sunset Tables for the Calgary International Airport and adjusted to the situation in Snowflake Lake from records of sunrise and sunset times observed at the lake or in the immediate vicinity. The upper curve indicates the maximum amount of sunshine astronomically possible and the lower hatched portion indicates the approximate minimum reduction of sunshine for the lake area due to screening by the mountains. In Fig. 28, the daylight period is divided into 5 equal parts; the second and third of these (hatched) represent the part of the day during which primary production rates have been found to be highest in some waters (Raymont 1966, Vollenweider and Nauwerck 1961).

No recording instruments were available during the 1966-68 Snowflake Lake investigations; therefore, Fig. 28 represents the best possible estimates made from available information. The screening effect is less in summer than in winter due to the position of the surrounding mountains and the angle of the sun. The percentage reduction of astronomically possible sunshine is between 8 and 26%, about half the screening effect noted by Pechlaner (1966) for the Finstertaler lakes. The mountains to the south of Snowflake Lake are rather low (2530 m) and about 1 km distant, and those to the east are several kilometres distant.

Secchi disc light penetration readings are given in the Results section for each of the lakes. Figs. 16A, 16B, and 16C summarize the Secchi disc light readings for Snowflake Lake for a 10-year period. In general, the water was clear at the time of breakup, sometimes turbid in July, usually very clear in August, turbid during the turnover period in September, and sometimes clear again before the ice formation, probably depending on the strength and duration of late autumn winds. The mean Secchi depth for the lakes as a group was about 5 m and the majority of readings were in the 2 to 4 m range. The maximum figure of 10 m was exceptional, and the lowest figure obtained on any occasion was 1.5 m. Snowflake, Pipt, and Harrison waters had the highest transparencies of the 7 lakes, which was to be expected since the color (Hazen units) and turbidity were among the lowest (Table 26). In Cuthead Lake, the Secchi disc could usually be seen on the lake bottom.

A more detailed determination of light penetration was made at Snowflake Lake using an underwater light meter. However, the value of the findings are limited due to the fact that selective light filters were not available at the time. The photometer output at each depth was related to total light energy at that depth, although the relationship is complex because different wavelengths are selectively filtered out by the water (Strickland 1958). The opal optical element was used for all readings (Strickland 1958, Westlake 1965) and a correction of 6% was applied to the subsurface readings made at less than 0.885 R from the surface where R is the radius of the opal. This correction was determined in the manner suggested by Westlake (1965). Whenever possible, measurements were made under consistent or no cloud cover in accordance with the recommendations of Strickland (1958).

Midday surface light intensities were found to range between 64,000 lux and 87,000 lux on clear, bright days. A maximum reading of 103,296 lux occurred in the morning of 29 June, 1967, under clear skies when the upper mountains were snowcovered and the sun was near the summer solstice. The second highest surface light was recorded on April, 1967 on a day of almost continuous hazy overcast, which indicates the diffusing effect of light cloud or haze. Similar intense light under continuous hazy overcast was also recorded during 1967 at Herbert Lake (51°28'N, 116°13'W, elev. 1615 m) in Banff National Park. Hutchinson (1957) suggests that a low sun angle together with partial white cloud cover can increase the total radiation on the earth's surface by 40%. The shielding effect of heavily overcast skies was most obvious on 16 May, 29 June (afternoon) and 7 November, 1967. Rodgers and Anderson (1961) note that cloud cover can reduce the total possible radiation by up to 50% in winter and 30% in summer.

Fig. 17 contains graphs showing the total light penetration in Snowflake Lake as indicated by the selenium cell. The curves are generally similar during the open-water period, although sets of readings (16 May, 29 June, 13 Sept.) showed a higher extinction during the low light intensity of the early morning due to the reduced amount of incoming light at the blue end of the visible light spectrum at this time and to the higher rate of attenuation of light at the red end of the spectrum (Hutchinson 1957), Sauberer 1962). The extinction coefficients for Snowflake Lake were estimated from the nomograph given by Sauberer (1962, p. 18) were found to fall between 0.32 and 0.47, indicating very little light absorbing material in the water and a small change in the amount present. The coefficients are much smaller than those reported by Kalff (1967) for an Arctic lake where more suspended material in a greater range of concentrations was present during the open-water season.

The Secchi disc readings (Fig. 16A) for Snowflake Lake over the summer of 1967 show a correlation with decreased phytoplankton biomass and reduced turbidity in midsummer due to less wind and reduced inflow, rather than with the angle of the sun or the total surface illumination. The increase in extinction at 9 to 10 m in June, 1967 (Fig. 17) correlates with the period of high surface runoff where cold meltwater slides down the sides to the lake bottom creating two or three metres of turbid water at the bottom.

Between 8 and 25% of total surface illumination was found to penetrate a combination of 0.6 or 1.1 m of ice and 25 or 5 cm of snow, respectively. Measurements were taken through a 15 cm ice-hole which was cut through the ice with a minimum disturbance of the snow cover. The small hole was then packed with snow and covered with a piece of dark, opaque rubber groundsheet. The percentage of short wave radiation immediately under the ice seems to be 4 to 15 times greater than that found by Rodhe (1962) or Pechlaner (1964), and is undoubtedly related to the higher transparency of the ice on Snowflake Lake, where there was less snow cover and no "slush" on top of the ice. These readings are in the same range of magnitude as readings obtained by Saijo and Sakamoto (1964) for some Japanese Lakes, although the ice was only half as thick on the latter lakes. These values are considerably greater than those reported by others in the past (Chandler 1942, Wright 1964), and indicate that a lake covered by ice and snow may not be the world of darkness it has often been held to be.

d) Bottom Sediments

The bottom material of Snowflake Lake is mostly fine gravel on the steep slopes, fine sand and coarse gravel in the flat shallows, and fine, black mud in the deepest parts. An analysis (1967) of the black mud from the deep holes indicated an organic content of about 20%, rather high for an alpine lake and possible reflecting a low turnover of organic material by organisms in the deep sediments. This could be due to conditions slightly too anaerobic for some organisms and too cold for others. An analysis of Wigmore bottom material indicated about 14% organics. Although analyses for the other lakes of the study were not done, it is believed that they would all be in a similar range, except perhaps for Grouse and Bighorn lakes, which would be much lower and slightly lower in organic content, respectively.

The ranges for other lakes in the mountain national parks suggest a loose correlation with trophic status, but more work must be done on the subject before firm conclusions can be drawn. Results from a few other lakes are summarized here for comparison (* from this study):

Lake	Park	% organic
Upper Waterton	WLNP	4.2
Louise	BNP	4.4
Boom	BNP	5.2
Lower Waterton (west)	WLNP	5.9
Moraine	BNP	7.0
Baker	BNP	11.8
Pyramid (centre)	JNP	12.0
*Wigmore	BNP	13.9
Eiffel	BNP	14.9
*Snowflake	BNP	20.1
Patricia (10m)	JNP	29.7
Linnet	WLNP	32.1
Lower Altrude	BNP	39.2
Herbert	BNP	47.5
Copper	BNP	66.1
Little Herbert	BNP	69.4

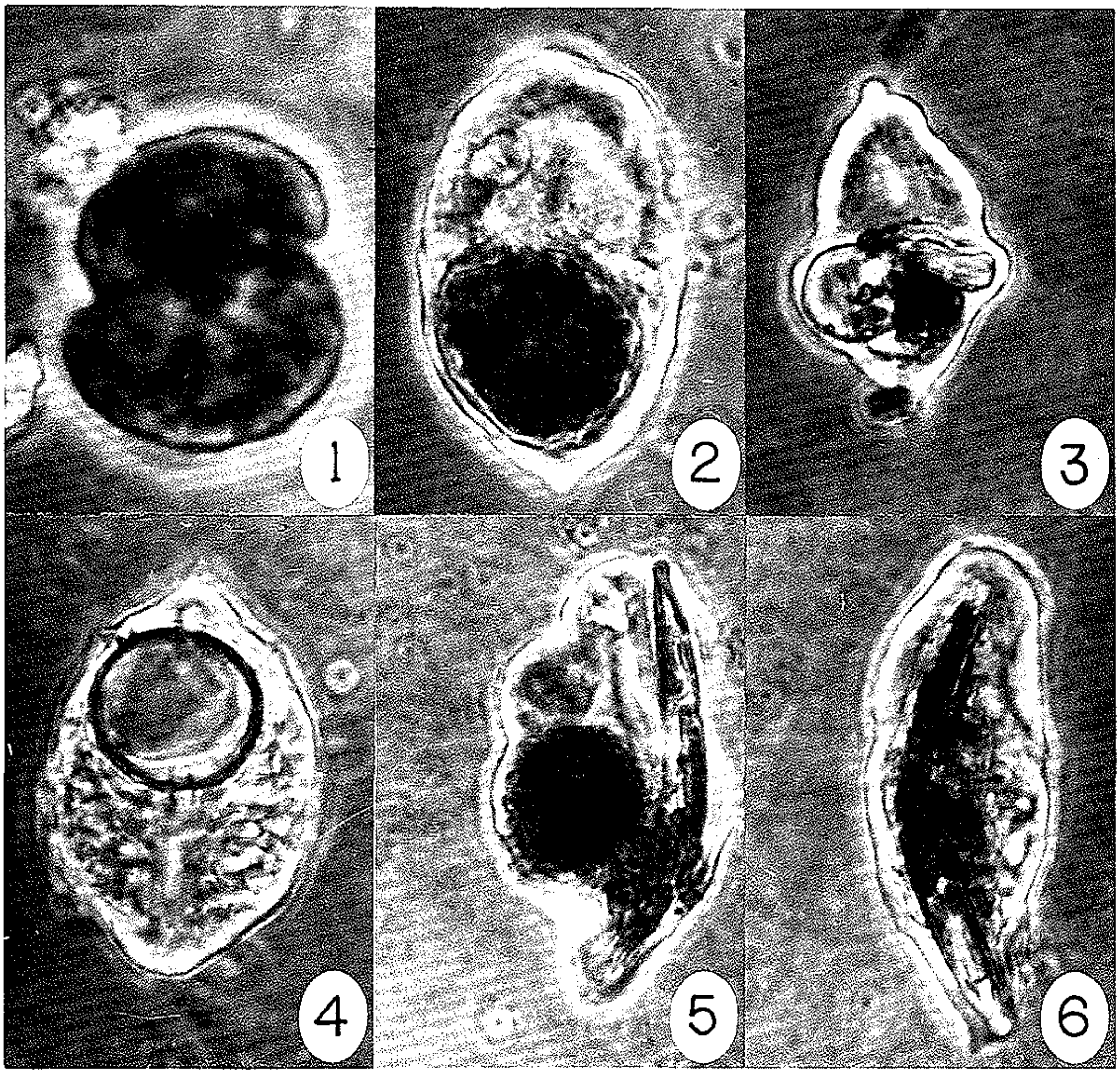


PLATE IV – THE PHYTOPLANKTON OF SNOWFLAKE LAKE

1. *Woloszynskia* sp., 11 Feb. 1968 (3000X)

2. *Gymnodinium helveticum* containing *Woloszynskia* sp., 12 July 1967 (1200X)

3. *G. helveticum* containing large *Cyclotella* sp. cells and *Woloszynskia* sp., 9 Aug. 1967 (1200X)

4. *G. helveticum* containing a chrysomonad, 26 July 1967 (1200X)

5. *G. helveticum* containing a large diatom and *Woloszynskia* sp., 26 July 1967 (1200X)

6. *G. helveticum* containing a large diatom, 26 July 1967 (1200X)

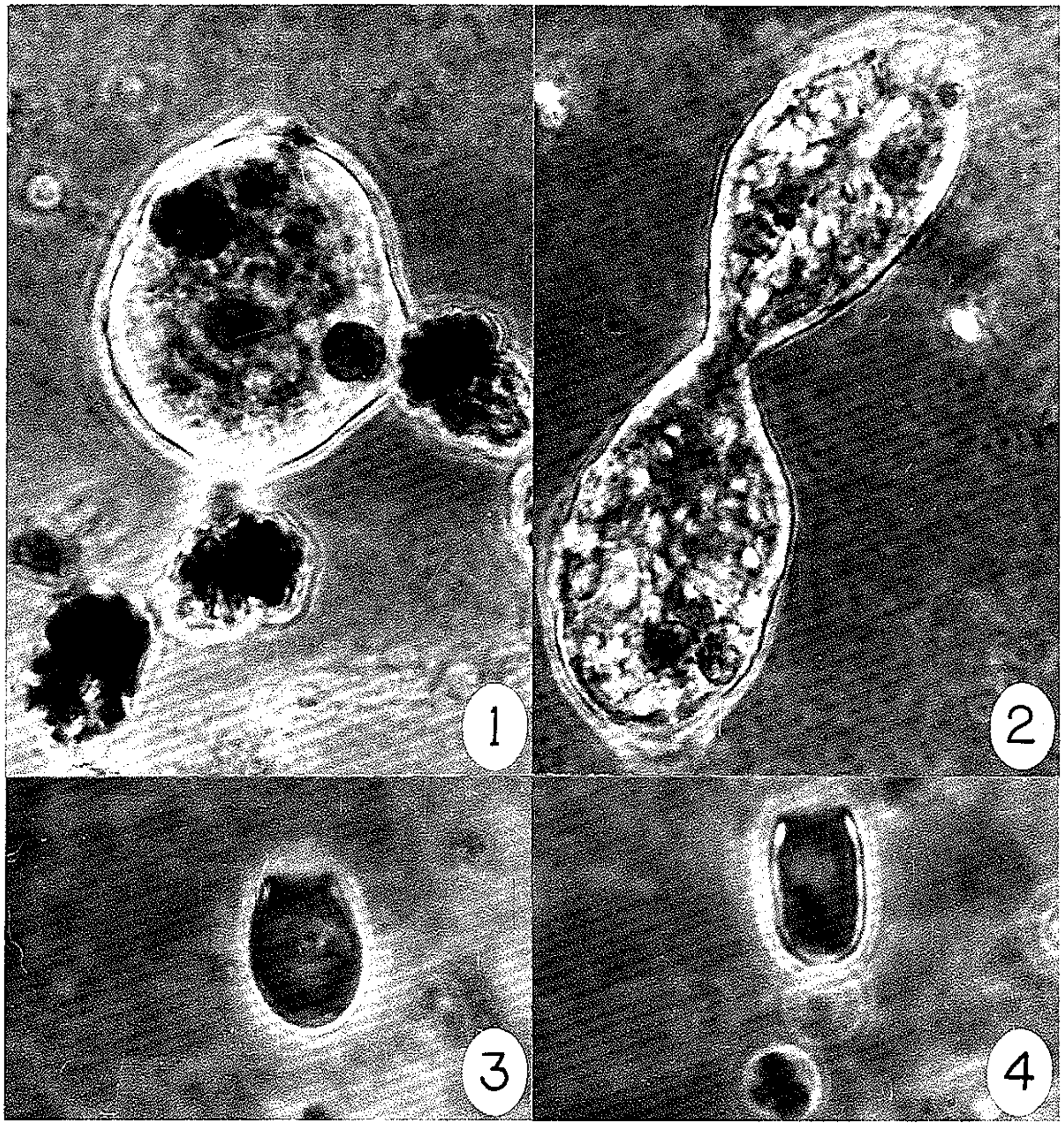


PLATE V — THE PHYTOPLANKTON OF SNOWFLAKE LAKE

1. Gymnodinium helveticum — preliminary stage of phagocytosis, 26 July 1967 (1200X)

2. G. helveticum — cell division, 29 June 1967 (1200X)

3. Kephyriopsis sp. , 7 November 1967 (3000X)

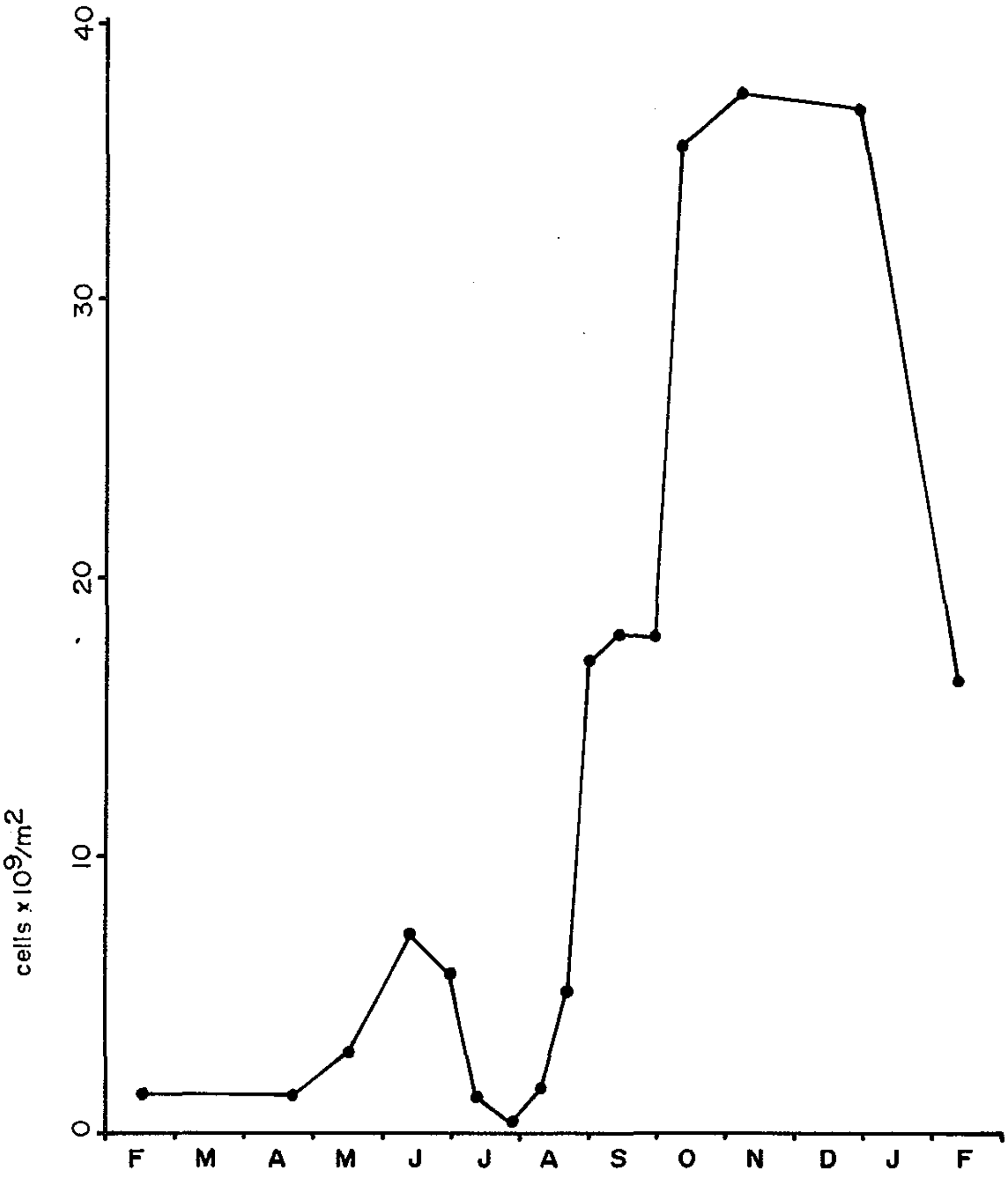
4. Kephyriopsis sp. , 7 November 1967 (3000X)

3. Phytoplankton

The phytoplankton communities in five of the lakes are summarized in Tables 1, 5, 10, 14, and 18. These data will be of use for comparative purposes in long-term studies. However, because phytoplankton communities in lakes such as these tend to differ from spring to summer, to autumn, a single analysis is useful only to indicate general similarities and to characterize the communities in a broad way.

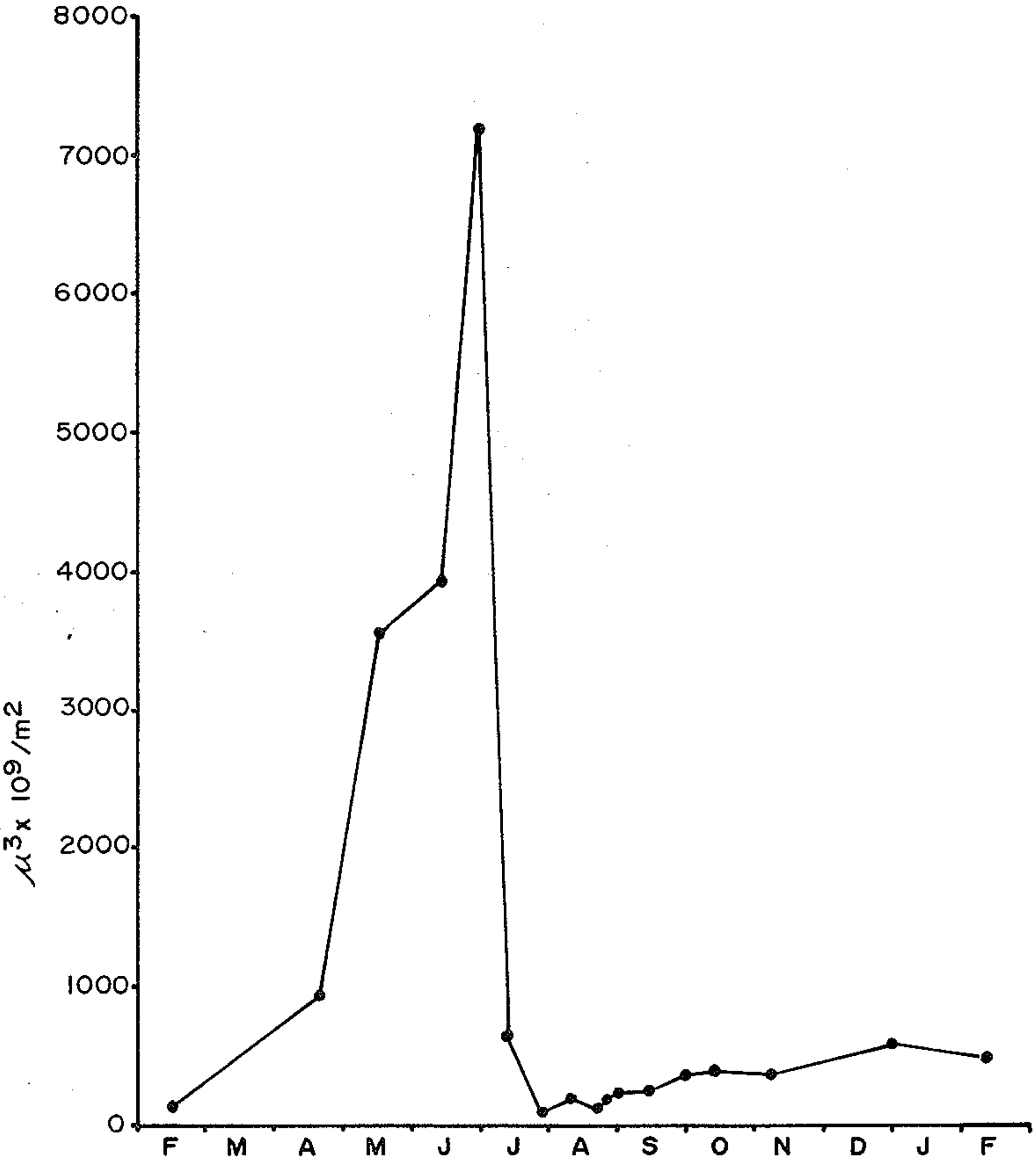
The seasonal changes that may be typical for most of the lakes of this study are shown in Figs. 29-32 (from Anderson 1968b). The plankton community which developed under the ice was comprised of smaller numbers (Fig. 29) of larger cells which resulted in a much larger biomass under the ice than later in the season (Fig. 30). The huge numbers of very small *Cyclotella* sp. which occurred in the fall (Figs. 29, 31, 32) made only a small contribution to the total biomass (Fig. 30). The complete change from the spring community to the summer and autumn community is shown in Figs. 31 and 32. In many lakes, there is a distinct community in each of spring, summer, and autumn (and sometimes winter as well). Here, the low temperatures and relatively short openwater season may be the main reasons why there are only two community types. It is possible, as well, that the communities can vary from year to year. The spring species especially seem to be very sensitive to light intensity and temperature change.

Plates IV and V show some of the larger spring phytoplankton species from Snowflake Lake. Here, at this microscopic level,



—numbers/m^2 for the top 10.5m at Stn.no.1

Fig. 29 - TOTAL PHYTOPLANKTON NUMBERS, SNOWFLAKE LAKE, 1967.



— volume/m^2 for the top 10.5m at Stn. no. 1

Fig. 30 - PHYTOPLANKTON VOLUME, SNOWFLAKE LAKE, 1967.

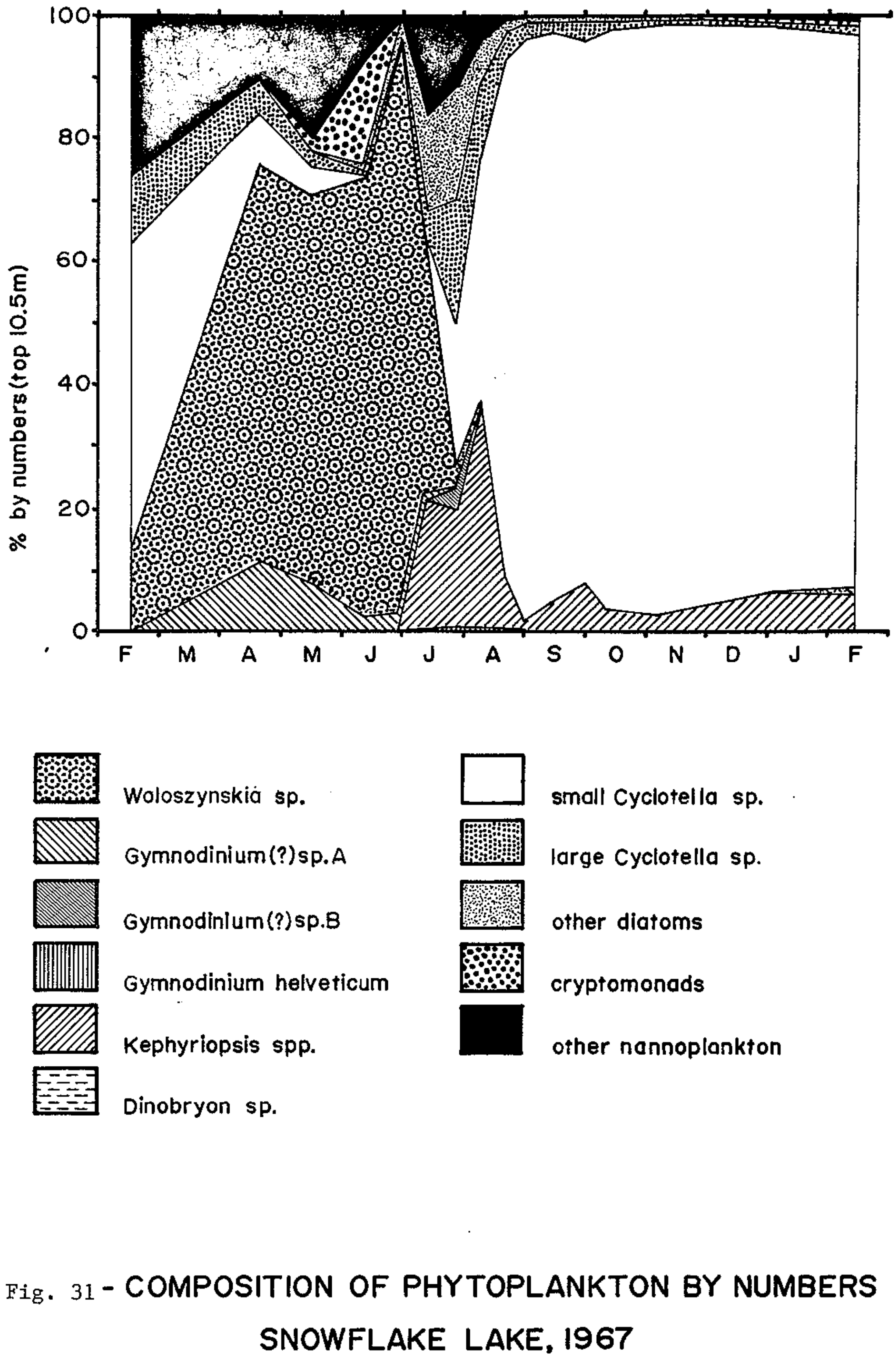


Fig. 31 - COMPOSITION OF PHYTOPLANKTON BY NUMBERS SNOWFLAKE LAKE, 1967

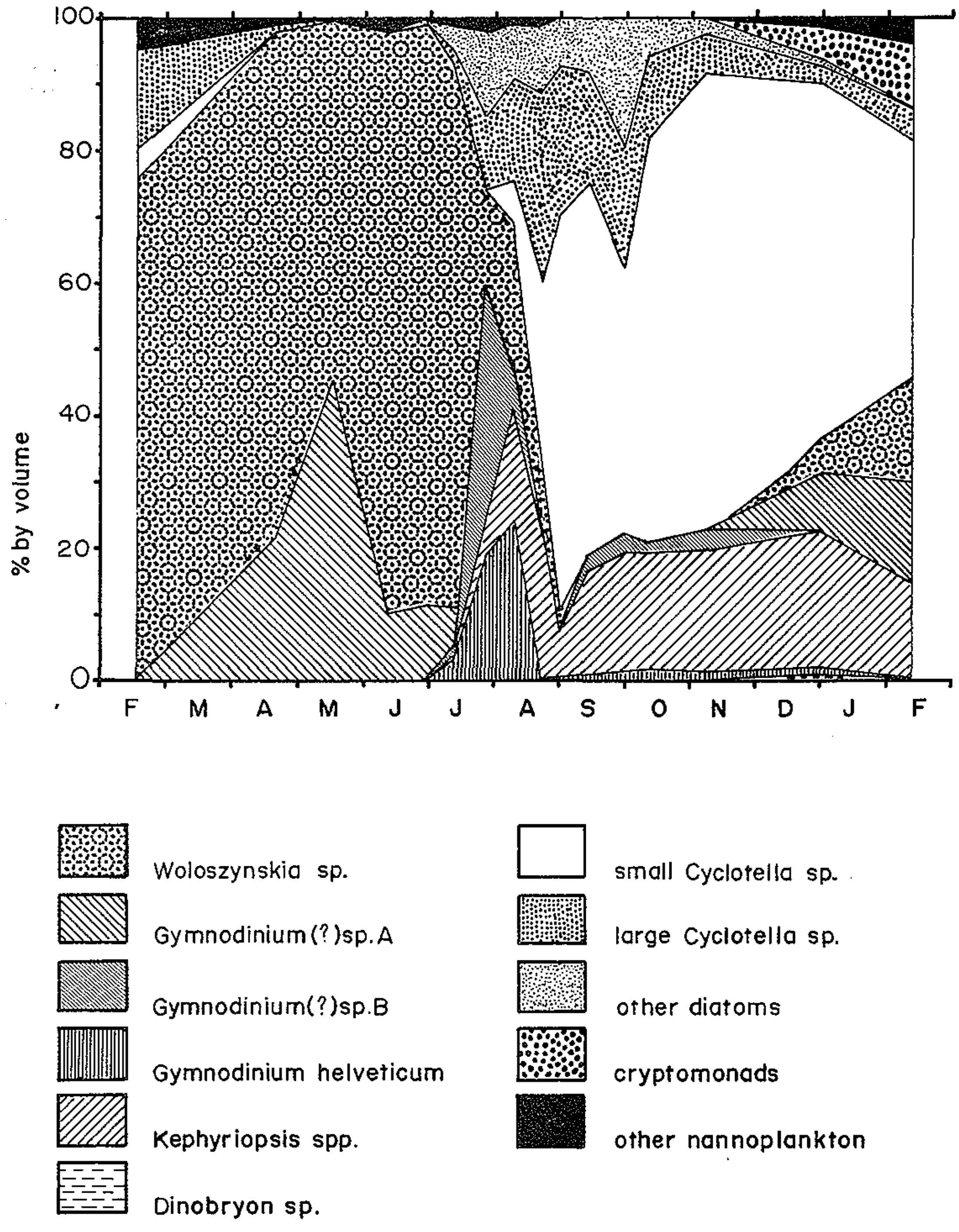


Fig. 32—COMPOSITION OF PHYTOPLANKTON BY VOLUME, SNOWFLAKE LAKE, 1967.

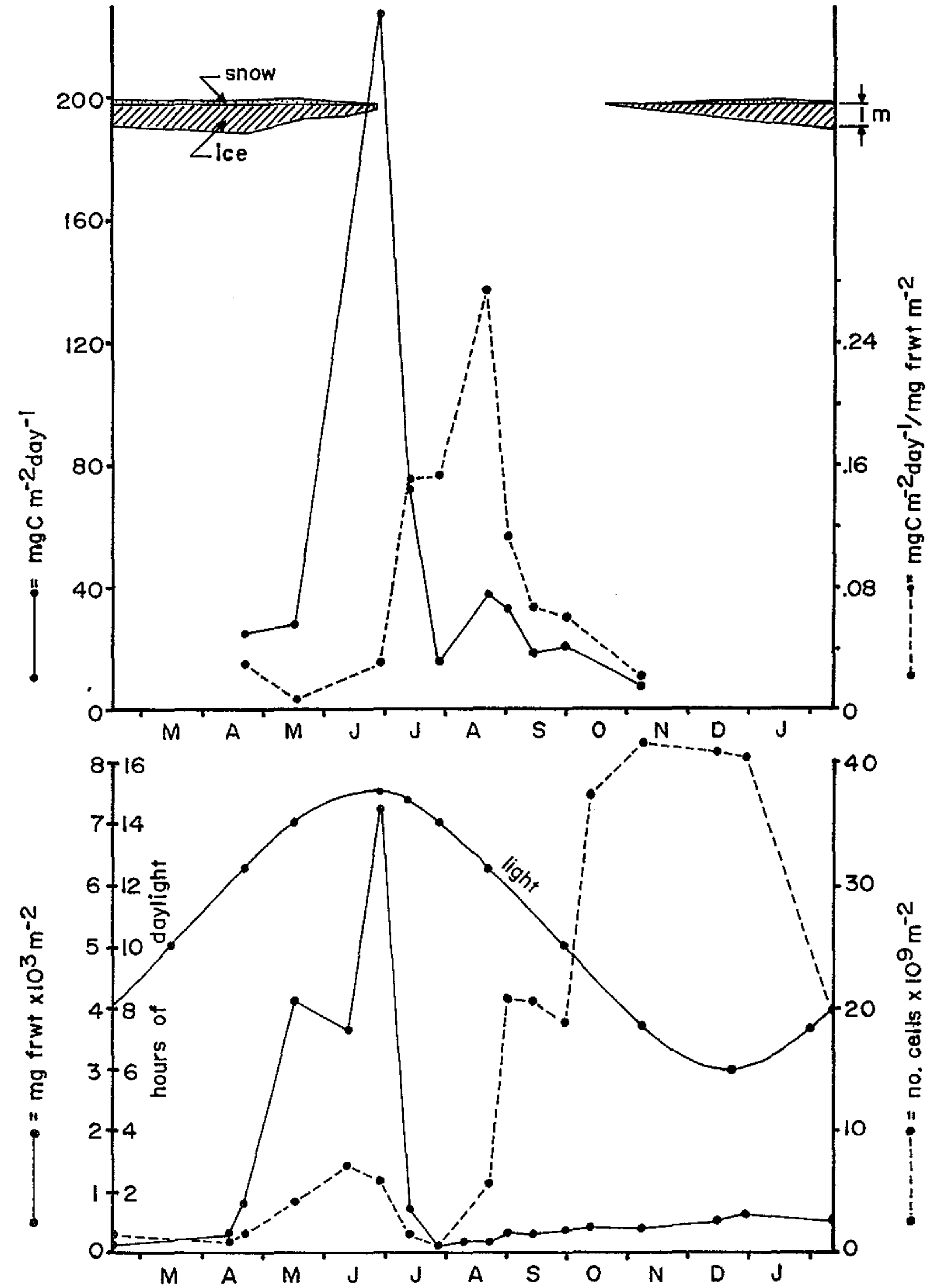


Fig. 33 - COMPARISON OF NET PRIMARY PRODUCTION RATES, ACTIVITY COEFFICIENTS, PHYTOPLANKTON BIOMASS AND NUMBERS, SNOWFLAKE LAKE, 1967

some interesting interactions take place. *Gymnodinium helveticum*, an alga, is shown in various stages of "predatory" feeding. The two smaller forms in Plate IV (probably *Kephyriopsis* spp.) are examples of the very small species that make up much of the summer phytoplankton in many alpine lakes in the mountain national parks.

4. Primary Production

As suggested above, there was a development of larger phytoplankton species under the ice in spring in Snowflake Lake. This development corresponded to the peak in primary production. However, the small peak in summer was proportionally greater than the small summer biomass. However, the summer phytoplankton was comprised of very small forms which photosynthesize at a much higher rate than larger cells. Although the peaks can vary in size, depending on the species present and on the numbers present, it is likely that the pattern shown in Fig. 33 is representative for most of the lakes of this study. In this figure, there is some indication of three production peaks - spring, summer, and autumn. Such a pattern was evident in some similar studies recently conducted in some montane lakes in Jasper National Park (Anderson and Donald 1978a).

The total production by the phytoplankton in Snowflake Lake seems to be close to enough to support the zooplankton (Anderson 1968b, 1975). It is possible that bacterial production and detritus are important factors in some lakes (Anderson and Dokulil 1977). Based on an assessment of the phytoplankton communities, the estimates of zooplankton production, and the primary production data available, it is likely that zooplankton communities in the present study are limited by phytoplankton production. The low dark-uptake in most primary production experiments in our alpine lake studies are indicative of low bacterial production. In Harrison Lake, however, the rather high zooplankton production suggests some additional food source (possible detritus and/or bacterial production). It would be useful to investigate this question at greater length, although it is not a high priority topic in terms of general studies in the mountain national parks.

Table 30 provides a comparison of primary production estimates for Snowflake and Wigmore lakes with some montane lakes in Jasper National Park and some arctic and alpine lakes elsewhere. In general, the two lakes of this study can be compared to arctic lakes in their primary production potentials. They seem to be about ½ to 1/10 as productive as the Jasper lakes on the basis of primary production, even though the potential fish production per unit area was determined to be potentially similar or even higher (see <u>Production Estimates</u> section later in this report).

5. Zooplankton

In general, the 6 lakes and 4 ponds[1] had one major zooplankton pulse per year when one or more crustacean plankton species developed and matured. The mean number of crustaceans per community (including the rare species) was 5 for the six

1. Here, for discussion purposes, Grouse Lake is included with the ponds, because of its temporary nature and because its zooplankton community is more like that of a pond.

Table 30. Comparison of annual primary production in two lakes of this study with four montane lakes in Jasper National Park and three arctic and alpine lakes elsewhere.

Lake	Location	Primary production $mgC \cdot m^{-2} \cdot y^{-1}$	Source
Snowflake L.	Banff National Park, Canada	7,640	Anderson (1975)
Wigmore Pond	Banff National Park, Canada	15,000 (est.)	this study
Edith Lake	Jasper National Park, Canada	40,359	Anderson and Donald (1978)
Horseshoe Lake	" "	64,547	" "
Pyramid Lake	" "	27,000	" "
Patricia Lake	" "	61,734	" "
Imikpuk Lake	Alaska, U.S.A.	8,400	Kalff (1967)
Vorderer Finstertaler See	Austria	18,250	Pechlaner (1967)
Marion Lake	B.C., Canada	8,000	Efford (1967)

Table 31. Summary of distribution of crustacean plankton species in the lakes and ponds of this study[1]:

	Bighorn Lake	Cuthead Lake	Grouse Lake	Harrison Lake	Pipit Lake	Snowflake Lake	Wigmore Lake	North Cuthead Pond	South Cuthead Pond	Snowflake Pond
Copepoda										
Diaptomus arcticus[2]	0?	–	–	–	0?	0?	–	–	–	–
Diaptomus tyrrelli	–	+	+	–	–	0	–	+	–	–
Diaptomus nudus	–	–	–	–	–	–	–	–	–	+
Diacyclops navus	–	–	–	–	–	–	–	–	–	+
Diacyclops bicuspidatus thomasi	0	+	+	+	–	+	–	–	+	–
Acanthocyclops vernalis	0	0	0	0	+	0	+	–	–	+
Eucyclops agilis	–	0	–	–	–	–	0	–	–	–
Eucyclops speratus	–	–	–	0	–	–	–	–	–	–
Macrocyclops albidus	–	–	0	0	–	–	0	–	–	–
harpacticoids (immature)	–	–	0	–	–	–	–	–	–	0
Cladocera										
Daphnia middendorffiana	–	0	+	–	0?	–	–	–	–	–
Daphnia pulicaria	–	–	–	+	–	–	–	–	–	–
Daphnia pulex	–	–	–	–	–	0	–	–	–	+
Daphnia (rosea?)	–	–	–	–	–	–	0	–	–	–
Ceriodaphnia spp.	–	–	–	–	–	–	+	+	+	+
Simocephalus vetulus	–	–	–	–	–	–	0	–	–	+
Scapholeberis kingi	–	–	–	–	–	–	–	+	+	–
Bosmina longirostris	–	–	–	–	–	–	+	–	–	–
Chydorus sphaericus	0	0	+	–	0	0	–	–	–	+
Alona spp.	–	–	0	–	0	0	–	–	–	–
Macrothrix hirsuticornis	–	–	0	–	–	–	–	–	–	–
Anostraca										
Branchinecta paludosa	–	–	+	–	–	–	–	+	+	+

1. + = abundant; 0 = rare; – = absent
2. for these species, "?" indicates once present, but current status conjectural.

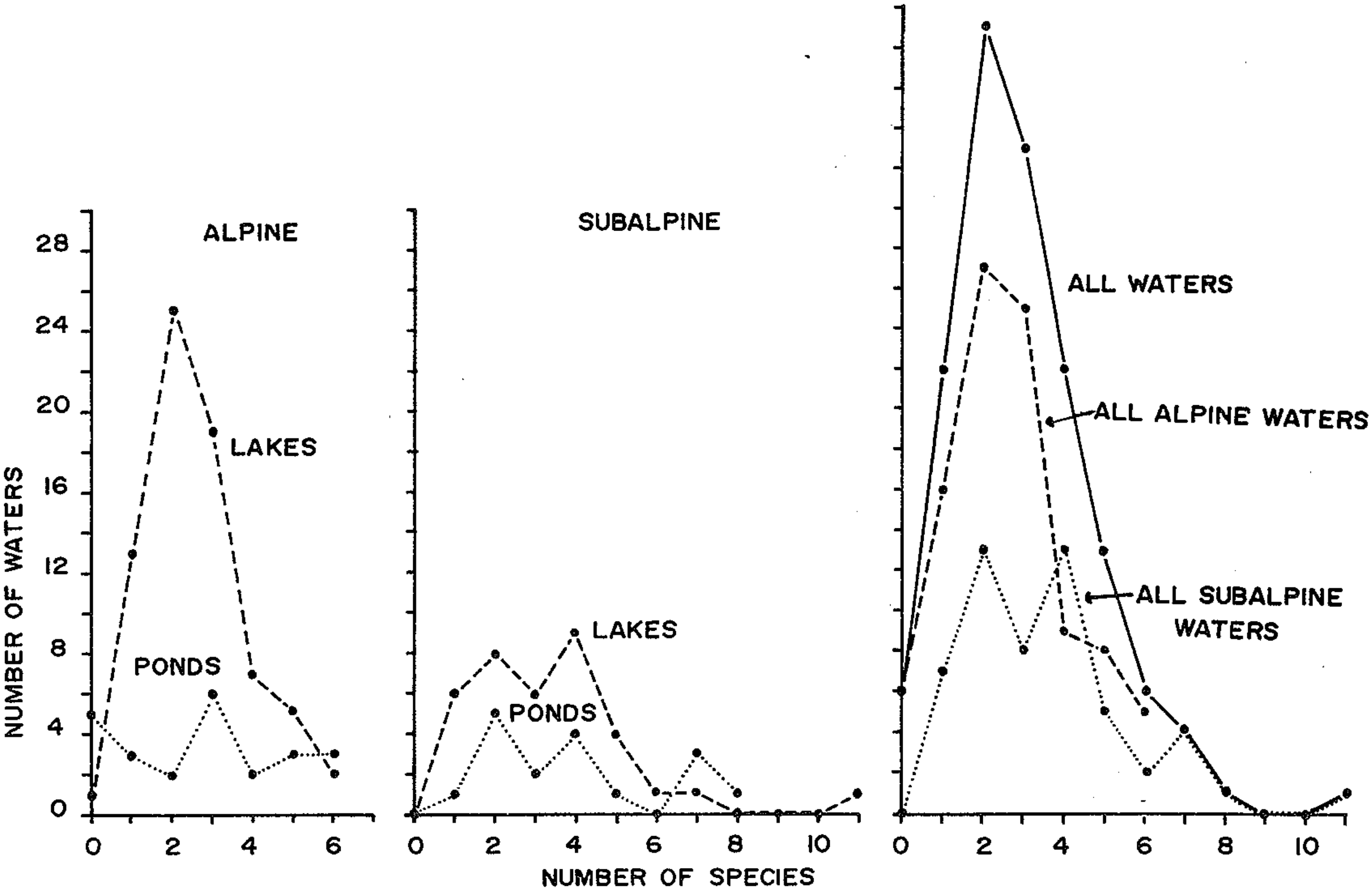


Fig. 34. Distribution of numbers of crustacean species per community in the various categories of mountain lakes and ponds. (from: Anderson 1971).

lakes and 6.75 for the four ponds (Table 31). In 4 of the 6 lakes, only 1 or 2 species were very abundant. In Wigmore, up to 3 small species were abundant at one time, but in Bighorn the plankton has remained extremely sparse since the introduction of fish. Only in Harrison Lake, did a zooplankton species occur which was large enough to be of potential significance in the trout diet (i.e. species greater than 1.5 mm in max. dimension), and these zooplankters (*Daphnia pulicaria*) did in fact constitute an important part of the Dolly Varden diet (see Table 13).

In comparison with a number of other waters in the mountain national parks, it can be seen that the number of species in the waters of this study is larger than the average (2.62 for alpine waters, and 3.53 for subalpine waters, Anderson 1971). The species diversity of 146 lakes is summarized in Fig. 34. However, in the lakes of this study, some of the crustacean plankton species are so sparsely represented or are so small that their contribution to the biomass is negligible. Fig. 35 is a summary of the zooplankton communities in 10 lakes of the Cascade Trail area in 1966 and 1967, where an adjustment has been made on the basis of body size. Again Harrison Lake has the only significant community among the "fishing" lakes. Grouse Lake has a similar biomass, but the lake cannot sustain a fish population, as evidenced by the occurrence of *Branchinecta paludosa* (Table 31), a fairy shrimp characteristic of temporary ponds and occurring in this study in ponds only.

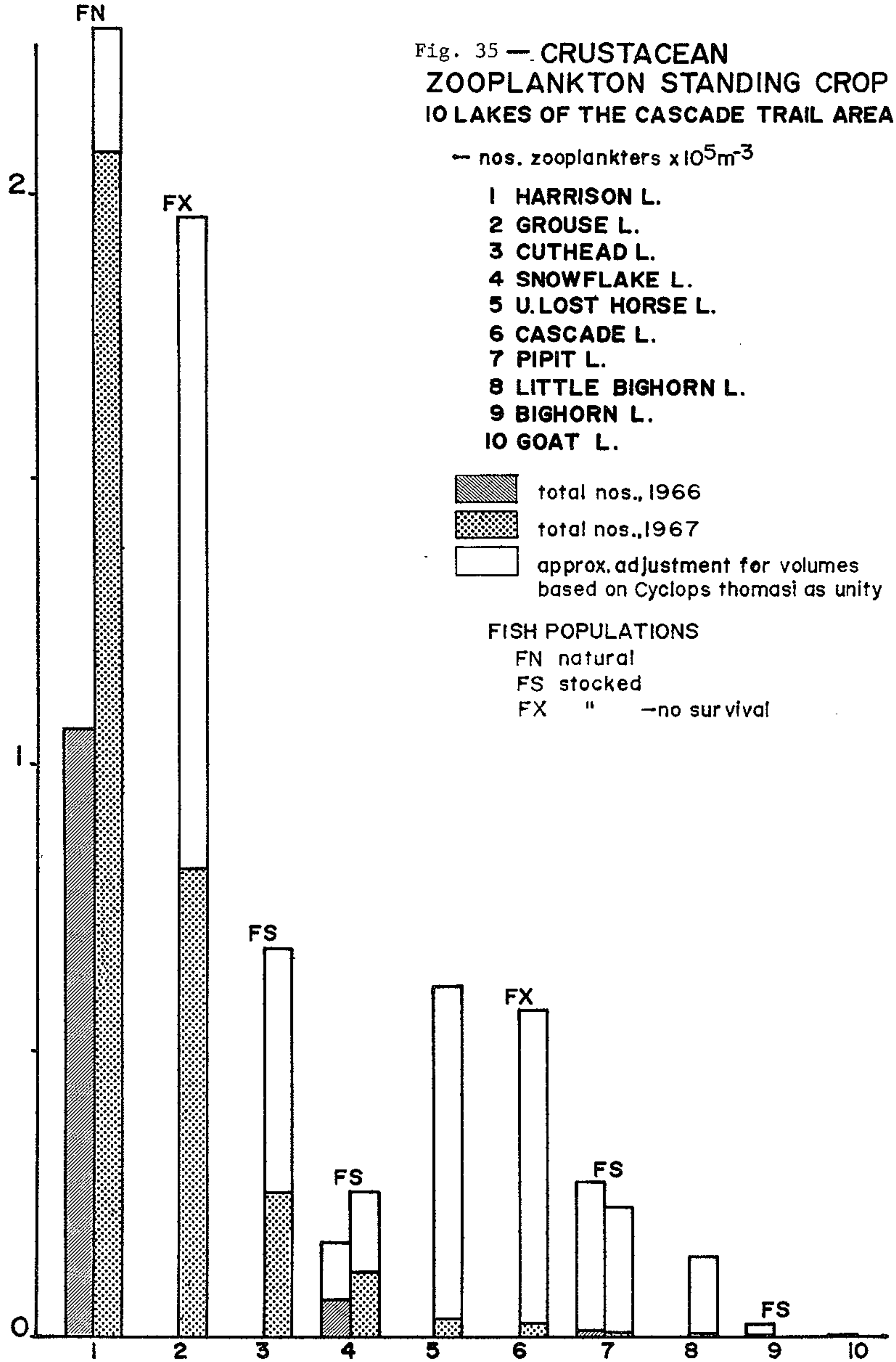


Fig. 35 — CRUSTACEAN ZOOPLANKTON STANDING CROP 10 LAKES OF THE CASCADE TRAIL AREA

Table 32 . Summary of distribution[2] of rotifer species in the lakes and ponds of this study[1].

	Bighorn Lake	Cuthead Lake	Grouse Lake	Harrison Lake	Pipit Lake	Snowflake Lake	Wigmore Lake	North Cuthead Pond	South Cuthead Pond	Snowflake Pond
Rotifera										
Kellicottia longispina	0	–	0	0	+	0	–	–	–	–
Keratella cochlearis	0	–	–	0	+	0	0	–	–	–
Keratella quadrata	–	–	–	0	–	–	–	–	–	–
Notholca sp.	0	+	–	–	0	–	–	–	–	–
Filinia (longiseta?)	+	–	–	–	+	–	–	–	–	–
Hexarthra bulgarica canadensis	–	–	+	–	–	–	–	–	–	–
Polyarthra dolichoptera	+	–	–	–	+	+	–	–	–	–
Asplanchna priodonta	–	–	–	–	–	–	–	–	–	–
Synchaeta oblonga	+	–	–	–	0	+	+	–	–	–
Euchlanis (lucksiana?)	0	0	0	–	0	0	–	–	–	0
Lecane (luna?)	0	–	0	–	–	–	–	–	–	–
Lepadella (ovalis?)	0	–	0	–	0	–	–	–	–	–
Mytilina (mucronata?)	0	–	–	–	–	–	–	–	–	–
Trichotria (tetractis?)	0	–	–	–	0	–	0	–	–	–
Monostyla sp.	–	–	–	–	–	–	0	–	–	–

1. + = abundant; 0 = rare; – = absent
2. Based on a long-term appraisal; many species are sporadic in occurrence.

It is interesting, too, that the ponds of this study tend to have few or no rotifers (Table 32). The only abundant rotifer in Grouse Lake was an unusual one which occurs sporadically, but sometimes in large numbers (*Hexarthra bulgarica canadensis* Dumont et al. 1978). It seems that the phenomenon of the occurrence of rotifers in conjunction with fish populations holds true here (Anderson 1972; Hrbáček and Novotnà-Dvořàkovà 1965, and a number of other papers). In fishless lakes, comparable otherwise to the lakes of the present study, large crustacean species out-compete or eliminate by predation nearly all of the rotifers (Anderson 1972, 1977). The introduction of fish usually results in the elimination of the large zooplankters and results in an increase in the numbers of rotifers present, the rotifers being much too small for any trout to prey on.

6. Benthos

Detailed taxonomic studies of the benthic invertebrates were not done. It was interesting that the standing crop biomass of zoobenthos was rather high in these lakes. For example, the total standing crop for five of these lakes (Bighorn, Cuthead, Harrison, Pipit, and Snowflake - Tables 3, 7, 12, 16, 20) was about four times as high as that found in six montane lakes in Jasper National Park (Anderson and Donald 1978a). However, many of the macroinvertebrates in the high lakes of this study seem to have a two-year life cycle, so their production-biomass ratio is very low compared to the montane lakes in Jasper.

In the five lakes (noted above) of this study, the zoobenthos was dominated by chironomid larvae. Sphaerid clams were usually subdominant, except for Cuthead Lake where oligochaetes were second in importance and sphaerids third. Amphipods were found in only two lakes. In Harrison Lake, they constituted a fairly important item in the Dolly Varden diet. In Snowflake Lake, a few amphipods were found in 1977 (in both benthic samples and fish stomachs), whereas they had not been found from 1966-74. It is likely that the large fish populations in earlier years kept the numbers of *Gammarus lacustris* very low. It is possible that the reappearance of *G. lacustris*, coinciding with reductions in numbers of fish present, is one reason for the increase in growth rates of the remaining brook trout in Snowflake Lake.

7. Shorelines

A small amount of shoreline damage (possible attributable to shoreline fishermen) occurred at Snowflake Lake a few years ago, mainly at the time when there were larger numbers of fish present (i.e. within a few years of the original stocking). However, more recently damage has been negligible, as it is along the shorelines of the other lakes of this study.

8. Fish

Table 33 is a summary of the fish stocking in lakes of the Cascade Trail study area. Native populations of Dolly Varden trout were known to occur in Harrison and Cuthead lakes, although the original population in Cuthead was poisoned in 1961. It has apparently been reestablished by immigrants from Cuthead Creek.

Table 33. Fish-Stocking Record for Some of the Lakes of the Cascade Trail Area.***

Lake	Native population	1959	1960	1963	1964	1965	1966	1967	1969
Pipit	-		-	-	4000R	4000R	4000R	-	-
Snowflake	-		1000E 1000R	1000E 500R	4000E 1000R	5000E 5000R 5000C	1000C 4000E	-	-
Grouse	-		-	-	-	1000E*	-	-	-
Harrison	D		-	-	-	-	-	-	-
Bighorn	-		-	-	2000E	2000E	-	-	-
Cuthead	D C?		-	2000A	-	-	10000C	-	-
Cascade	-		-	-	-	1000E* 2000C*	-	-	-
Wigmore	?	4000R**	-	-	2000E?	500E	-	1000E	75R

* No survival
R Rainbow trout - Salmo gairdneri Richardson
C Cutthroat trout - Salmo clarki Richardson
A Atlantic salmon - Salmo salar Linnaeus
D Dolly Varden - Salvelinus malma (Walbaum)
E Eastern Brook trout - Salvelinus fontinalis (Mitchill)
** stocked into Wigmore Creek.
*** based on official stocking records and personal records of D. McTrowe (personal communication).

Small numbers of Dolly Varden may have occurred in some of the other lakes as well, although there is no firm evidence of this. Our sampling in 1977 indicated rainbow trout only in Pipit Lake, Dolly Varden only in Cuthead and Harrison lakes, and brook trout only in Bighorn and Snowflake lakes. A few rainbow trout still remained in the last two of these lakes in 1973, but none was seen in 1977. Catch records are summarized in Tables 4, 8, 13, 17, and 21. No sampling was done in Wigmore Lake, although some brook trout probably still exist there.

The total standing crops of crustacean zooplankters in the lakes seem to bear no relationship to the presence or absence of fish populations. Both the largest standing crop of crustacean zooplankters in terms of numbers and biomass (Harrison Lake 1967) and the smallest standing crop (Bighorn Lake 1967, where virtually no crustacean zooplankters have been found) occurred with fish populations.

Of the 5 lakes presently having fish populations, only 2 had natural populations, and only 1 of these (Harrison Lake) has been left in its original condition. The fish species present in the lakes and the stocking histories are summarized in Table 33. Reported originally to have had small natural populations of Dolly Varden (*Salvelinus malma* Walbaum) and Cutthroat trout (*Salmo clarki* Richardson), Cuthead Lake was poisoned with Thiodan in 1961 prior to the attempt to establish a population of Atlantic salmon (*Salmo salar* Linnaeus) in the lake. The experiment failed and the lake has since been stocked with cutthroat trout in 1966, of which none seems to have survived.

Although total numbers or biomass of the crustacean zooplankton in the lakes bear no relationship to the presence or absence of fish, the sizes of the individual zooplankters do. A few specimens of *Diaptomus arcticus* were found in Bighorn Lake and Snowflake Lake in 1966, but none occurred during 1967. *Daphnia middendorffiana* was present in moderate numbers in Pipit Lake in 1966 but was absent in 1967, and *Diaptomus arcticus* had disappeared by 1968. In the other lakes with fish populations, copepods were small ($<$1.5 mm) and the rather small numbers of cladocerans present were generally found to be transparent and located in the deeper waters.

While these observations are too few to be conclusive, they conform with the general findings of the preliminary study of a large number of similar lakes in the mountain national parks cited above (Anderson 1968c). In 64 alpine and subalpine lakes including the 10 lakes of the Cascade Trail region, abundant copepods greater than 1.5 mm in length were not found in the presence of fish populations. When small numbers of large copepods did occur with fish, one of 3 conditions was found to prevail:

i. the lake was turbid.

ii. the lake contained large numbers of chironomid or caddis larvae or seemed to receive large numbers of terrestrial insects.

iii. the population of large zooplankters was sparse and often diminishing, especially in lakes stocked with fish within the previous 2 or 3 years.

Brooks and Dodson (1965), Reif and Tappa (1966), and Galbraith (1967,

1975) have shown that certain fish species, tend to eliminate crustacean zooplankters greater than 1.5 mm in length and that the larger zooplankters are gradually replaced by smaller species. Momot (1965), Keast (1965, 1966), and Keast and Webb (1966) have shown that smaller zooplankters may constitute a significant part of the diet of small fish species or of the young of larger fish species. However, in a clear mountain lake it is unlikely that fingerlings or fry would be able to utilize limnetic zooplankton without subjecting themselves to elimination by predation by the larger fish in the lake.

In the survey of 64 lakes mentioned above (Anderson 1968c), a strong correlation between dense or moderately dense rotifer populations[1] and the presence of fish was apparent. In only one lake (Grouse Lake) were rotifers found to be abundant in the absence of fish, and in this case no large copepods were present and fish which had been present the previous year had winter-killed. In no lake barren of fish and having an abundance of large copepods were rotifers found to be numerous. *Kellicottia longispina* was found to have increased considerably in Pipit Lake from 1966 to 1967, the *D. arcticus* present having decreased dramatically in number, and *Daphnia middendorffiana* having disappeared entirely by 1967. Pipit Lake was first stocked with rainbow trout in 1964.

The "antagonism" between rotifers and copepods discussed by D'Ancona (1955) for oligotrophic Italian lakes is evident in the 10 lakes of this study as well as in the other 54 lakes of

1. equally or more numerous than the crustacean zooplankters

the larger survey (Anderson 1968c), but it seems to be limited mainly to rotifers and copepods over 1.5 mm in length. In ponds having no fish, Grygierek et al. (1966) found that rotifers were abundant only in spring, but that in stocked ponds they were abundant in summer and autumn as well. From year-round zooplankton assessments determined before and after the introduction of fish, these authors found that the numbers of small-sized species of zooplankters increased and that the numbers of large-sized species decreased and became sparse after the introduction of fish. Hillbricht-Ilkowska (1964) has suggested that the increase in rotifers that accompanies the introduction of carp into newly-formed fish ponds seems to be linked to an increase in bacteria and particulate organic material which is available to the small filterers and sediment feeders such as rotifers, small cladocerans, and protozoans. Hence, it would seem possible that rotifer distribution and abundance is linked to control factors (such as competition and/or predation on one side) and limiting factors (such as abundance and/or availability of food) on the other.

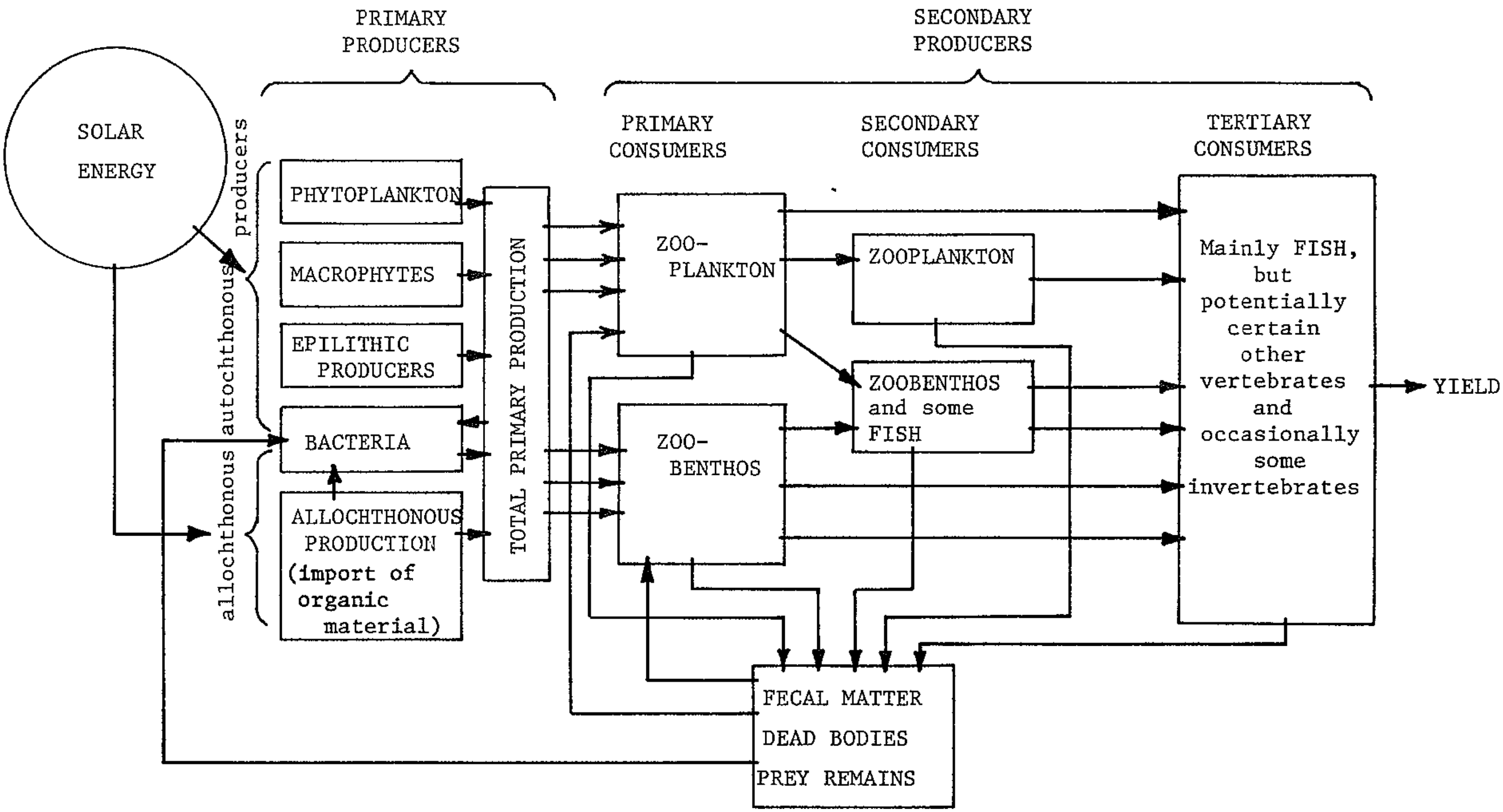


Fig.35: Simplified food web for an aquatic ecosystem.

PRODUCTION ESTIMATES

In order to obtain completely reliable estimates of the total lake production, it would be necessary to make detailed measurements of production at all trophic levels (simplified illustrations of the trophic levels in the food web are given in Fig. 35). Some such studies have been done, but with the exception of Teal's (1957) classic study and a few like it, they usually involve teams of investigations working over a period of years (e.g. I.B.P. Marion Lake study in British Columbia; the Experimental Lake Area, ELA, studies of the Freshwater Institute in Winnipeg; the I.B.P. Char Lake study in the Canadian Arctic; several European I.B.P. and M.A.B. studies). It is notable also that these studies involve both teams of investigators and a focus on one or two lakes. Clearly, the time and manpower involved are beyond the scope of routine national parks inventory and management studies.

Without firm data at all trophic levels, it is necessary to utilize results and conclusions from other studies, and to make estimates of production from the most appropriate biomass determinations and a knowledge of life cycles. The basic approach used in this study was similar to that used in other recent reports on mountain national parks studies cited elsewhere in the present report. Background and details are outlined in some detail in Mayhood and Anderson (1976b) and will not be repeated here. The rationale behind this approach was reviewed in the report just cited and in Anderson and Donald (1977).

In this study, primary production experiments were done in sufficient detail to obtain a good picture of total phytoplankton production for a full year in only one of the lakes (Snowflake Lake). Bacterial production studies were not done, although it is possible to obtain fairly good estimates of the magnitude of such production in Snowflake Lake by comparing the "dark uptake" values in primary production experiments to the production figures obtained by Anderson and Dokulil (1977). Although we did not use the results of primary production experiments in calculations of consumer productivity, the results were of value in verifying zooplankton estimates, which were deemed to be realistic by this test.

Although it was possible to calculate fairly reasonable values for zoöplankton production in these lakes, it was evident from fish stomach analyses that fish do not utilize the smaller forms, and that the larger forms were utilized in only one lake (Harrison Lake). While they must be taken into account in calculating maximum potential fish production, the larger zooplankton forms may be important only at certain times of the year, a factor that has been observed in mountain lakes (e.g. Anderson and Donald 1978b; Rawson 1953). Zoobenthos is the most important component in the trout diets in these lakes.

To estimate fish production, representative population tables were compiled for the six lakes with fish populations (Tables 34-36). These simplified population dynamics calculations were based on actual measurements of fish from the lakes, except for Wigmore Lake from which no fish were collected. Table 36 was used for Wigmore fish production estimates.

Table 34 . Table of survivorship, production, mortality, and mean sizes for a theoretical population of brook trout based on data from Bighorn Lake and assuming a constant mortality rate of 30%.

	End of summer no.	No. of survivors per original 1000 ("unit")* year classes 1-10	Annual biomass production*** per fish (grams)	Total annual production per year class (grams) per unit (col 2 x col 3)	Mean size of fish per year class (grams)	Total standing crop per year class (grams) (col 2 x col 5)	Mortality per year class at end of growing season**	Total mortality as biomass per year class (grams) (col 5 x col 7)
column no.	1	2	3	4	5	6	7	8
	0	1000	-	-	1	-	300	300
	1	700	16	11200	17	11900	210	3570
	2	490	20	9800	37	18130	147	5439
	3	343	28	9604	65	22295	103	6695
	4	240	25	6000	90	21600	72	6480
	5	168	22	3696	112	18816	50	5600
	6	118	18	2124	130	15340	36	4680
	7	82	13	1066	143	11726	24	3432
	8	58	7	406	150	8700	18	2700
	9	40	3	120	153	6120	12	1836
	10	28	2	56	155	4340	8	1240
Totals (all year classes)	-	2267	-	44072	-	-	-	41972
Totals (year classes 4-10)	-	734	-	13468	-	86642	220	25968
Mean/fish (year classes 4-10)	-	-	-	-	-	118g	-	118g

* Table based on "units" of 1000 original (hatched or stocked) fry, and the survivors in all year classes from a constant annual recruitment.

** In this simplified calculation, mortality assumed to occur soon after hatching or stocking and following the main production period (i.e. September to May)

*** "Annual biomass production" here corresponds to "annual weight increment" used in some other references.

Table 35: Table of survivorship, production, mortality, and mean sizes for a theoretical population of Dolly Varden trout based on data from Harrison Lake and assuming a constant mortality rate of 30%.

	End of summer no.	No. of survivors per original 1000 ("unit")*	Annual biomass production*** per fish (grams)	Total annual production per year class (grams) per unit (col 2 x col 3)	Mean size of fish per year class (grams)	Total standing crop per year class (grams) (col 2 x col 5)	Mortality per year class at end of growing season**	Total mortality as biomass per year class (grams) (col 5 x col 7)
column no.	1	2	3	4	5	6	7	8
	0	1000	-	-	1	-	300	300
	1	700	19	13300	20	14000	210	4200
	2	490	20	9800	40	19600	147	5880
	3	343	100	34300	140	48020	103	14420
	4	240	185	44400	325	78000	72	23400
	5	168	215	36120	540	90720	50	27000
	6	118	180	21240	720	84960	36	25920
	7	82	135	11070	855	70110	24	20520
	8	58	95	5510	950	55100	18	17100
	9	40	35	1400	985	39400	12	11820
	10	28	15	420	1000	28000	8	8000
Totals (all year classes)	-	2267	-	177560	-	-	-	158560
Totals (year classes 3-10)	-	1077	-	154460	-	494310	323	148180
Mean/fish (year classes 3-10)	-	-	-	-	-	459g	-	459g

* Table based on "units" of 1000 original (hatched or stocked) fry, and the survivors in all year classes from a constant annual recruitment.

** In this simplified calculation, mortality assumed to occur soon after hatching or stocking and following the main production period (i.e. September to May).

*** "Annual biomass production" here corresponds to "annual weight increment" used in some other references.

Table 36 : Table of survivorship, production, mortality, and mean sizes for a theoretical population of rainbow, brook, and Dolly Varden "trout" based on data from Cuthead, Pipit, and Snowflake lakes and assuming a constant mortality rate of 30%.

	End of summer no.	No. of survivors per original 1000 ("unit")*	Annual biomass production per fish (grams)***	Total annual production per year class (grams) per unit (col 2 x col 3)	Mean size of fish per year class (grams)	Total standing crop per year class (grams) (col 2 x col 5)	Mortality per year class at end of growing season**	Total mortality as biomass per year class (grams) (col 5 x col 7)
column no.	1	2	3	4	5	6	7	8
	0	1000	-	-	1	-	300	300
	1	700	19	13300	20	14000	210	4200
	2	490	15	7350	35	17150	147	5145
	3	343	35	12005	70	24010	103	7210
	4	240	80	19200	150	36000	72	10800
	5	168	75	12600	225	37800	50	11250
	6	118	75	8850	300	35400	36	10800
	7	82	60	4920	360	29520	24	8640
	8	58	50	2900	410	23780	18	7380
	9	40	30	1200	440	17600	12	5280
	10	28	10	280	450	12600	8	3600
Totals (all year classes)	-	2267	-	82605	-	-	-	74605
Totals (year classes 4-10)	-	734	-	49950	-	192700	220	57750
Mean/fish (year classes 4-10)	-	-	-	-	-	263g	-	263g

* Table based on "units" of 1000 original (hatched or stocked) fry, and the survivors in all year classes from a constant annual recruitment.

** In this simplified calculation, mortality assumed to occur soon after hatching or stocking and following the main production period (i.e. September to May)

*** "Annual biomass production" here corresponds to "annual increment" used in some other references.

Table 37. Estimates of potential sport-fish production in Bighorn (B), Cuthead (C), Harrison (H), Pipit (P), Snowflake (S), and Wignore (W) lakes in the Cascade Trail region of Banff National Park, calculated from food-organism production.

	lake	biomass, $g \cdot m^{-2}$	P/B[1]	estimated annual production, $g \cdot m^{-2}$	"available"[2,3] production, $g \cdot m^{-2}$		total "available" production, $g \cdot m^{-2}$	factor[4]
		a	b	c (a x b)	d (2/3c)		e	f
macro-zoobenthos	B	16.80	1.25	21.00	14.00			
	C	66.53	1.25	83.16	55.44			
	H	61.17	1.25	76.46	50.97			
	P	12.80	1.25	16.00	10.67			
	S	19.40	1.25	24.25	16.17			
	W[8]	35.32	1.50	52.98	35.32			
Total zooplankton	B	0.25	2.50	0.63		B	14.00	1.17
	C	3.35	2.50	8.38		C	55.44	1.19
	H	41.58	2.50	103.95	[9]	H	88.77	1.00
	P	0.50	2.50	1.25		P	10.67	1.05[10]
	S	10.79	2.50	26.98		S	16.17	1.05
	W	2.24	3.00	6.72		W	35.32	1.18[10]
Macro-zooplankton	B	-		-	-			
	C	-		-	-			
	H	22.68	2.50	56.70	37.80			
	P	-		-	-			
	S	-		-	-			
	W	-		-	-			

1. Based mainly on the summary of Waters (1969) - see also Mayhood & Anderson (1976b) and Anderson (1975) for further comment. Many benthic species here have a two-year life cycle.

2. Based on a sieve size of 0.36 x 0.52 mm; 2/3P considered to be "available" to fish (i.e. of a size that fish could utilize, and assuming that a minimum of 1/3 of production could not be eaten because it goes to egg production or to mortality of immature and very small stages).

3. Species with a maximum dimension <1.5 mm, and 2/3P "available" to fish, as in #2 above.

4. Based on fish stomach content analysis and an estimate of the fraction of food eaten which originated outside the lake.

	adjusted total "available" production	lake area, ha	estimated maximum "available" invertebrate production per lake, kg	kg fish production[5] (whole lake)	"units" supported[6] at 100% feeding efficiency	potential maximum no. of "catchables"[7] at 30% annual mortality if all mortality due to fishing	maximum estimated fish production, $kg \cdot ha^{-1}$
	g	h	i	j	k	l	m
	(e x f)		(10xgxh)	(0.08xi)	(j÷ col.4)[6]	(kxcol.7)[7]	(j÷ h)
B	16.38	2.15	352.2	28.2	0.64	141	13.1
C	65.97	3.47	2289.2	183.1	2.22	488	52.8
H	88.77	8.42	7474.4	598.0	3.37	1089	71.0
P	11.20	10.63	1190.6	95.2	1.15	253	9.0
S	16.98	7.13	1210.7	96.9	1.17	257	13.6
W	41.68	2.00	833.6	66.7	0.81	178	33.4
							$\bar{x}$ = 32.15

5. At 100% utilization of "available" food, and assuming an ecological efficiency of 8%.
6. "units" of 1000 + all survivors (Table 34 - Bighorn; Table 35 - Harrison; Table 36 - all others)
7. 4th year class and older (except Harrison L. - 3rd and older).
8. No benthic data for Wigmore L.: mean of other 5 lakes is used.
9. Species of maximum dimension <1.5 mm not included in succeeding calculations.
10. No data; factor used is from similar lakes.

In a national parks setting, it is neither practical nor justifiable to obtain large catches of fish to determine production from real data only. However, for a number of reasons, we feel that the production estimates obtained are realistic. Tables 34 - 36 are based on population "units" of 1000 original stocked or naturally recruited fish plus the survivors in all year classes to 10 years, assuming a constant annual recruitment of 1000 and a constant mortality rate of 30%. Although some data indicate that 30% annual mortality is a realistic assumption, it may be too low in the younger year classes. If this is so, then a greater percentage of available production by food organisms would go into early year classes, and less into the "catchable" year classes, another reason why fish production estimates are likely to be near the maximum that can be expected. The production of each "unit" was calculated on the basis of the increase in biomass per year, and this was compared to the total "available" production by food organisms in each lake (i.e. the organisms large enough for the fish to prey on). From this, it was determined how many "units" each lake could support, taking into account growth rates applicable to the lake in question (Table 37). The maximum number of "catchable" fish per lake was determined from total mortality in "catchable" size classes (here assumed to be the 3rd year class and older for Harrison Lake, and 4th year class and older for the other 5 lakes), assuming that all mortality in these year classes could be due to fishing. Although this last assumption may not be true, it is accepted in order to determine a maximum number of harvestable fish.

DISCUSSION OF PRODUCTION

On the basis of production estimates, accepting the assumption that the 30% annual mortality in the 3rd or 4th to 10th year classes (or older) could be due to sportfishing, and basing calculations on growth rates close to those found in 1973 and 1977, the potential maximum numbers of "catchable" trout for the six lakes are estimated to be (these include all year classes[1], 3 or 4 to 10 or more years, inclusive):

Bighorn	141	Pipit	253
Cuthead	488	Snowflake	257
Harrison	1089	Wigmore	178

For comparison to other fishing waters, it is better to express potential production as biomass units per unit area. The above yields are equivalent to the following maxima:

Bighorn	13.1 kg/ha	Pipit	9.0 kg/ha
Cuthead	52.8 kg/ha	Snowflake	13.6 kg/ha
Harrison	71.0 hg/ha	Wigmore	33.4 kg/ha

These data are drawn from Table 37. In Table 38, we compare these data to production data for a number of other lakes. The average for the six lakes of this study are close to the average for 6 montane lakes in Jasper (Anderson and Donald 1978a) and approximately twice those for Amethyst and Moat lakes in Jasper Park (Anderson and Donald 1978b). Some other lakes are included in Table 38 for general comparison.

The total production for each of these lakes is low compared to the 6 Jasper montane lakes, because each of these lakes is very small compared to the Jasper lakes. Productivity per

1. About 1/3 of the total for each lake includes the smallest "catchable" year classes, or fish which are likely to be only 90 g in Bighorn Lake (1/5 lb.), 140 g in Harrison Lake (<1/3 lb.), and 150 g in the other 4 lakes (1/3 lb.).

Table 38: Comparison of estimated potential annual fish production in six lakes of this study with measurement of fish production in other waters.*

lake		$kg\ ha^{-1}$		source
Bighorn	Banff National Park	13.1	mean = 32.15	this study
Cuthead		52.8		
Harrison		71.0		
Pipit		9.0		
Snowflake		13.6		
Wigmore		33.4		
6 montane lakes, Jasper National Park		30.38 (mean)		Anderson and Donald (1978a)
Amethyst Lake	Jasper National Park	8.29	mean = 16.64	Anderson and Donald (1978b)
Moat Lake		24.98		
Waterton Lakes National Park				
- 15 alpine and subalpine lakes		12		Anderson and Donald (1976b)
- 3 mesotrophic montane lakes		39		
4 New York lakes (brook trout)		33 - 65		Hatch and Webster (1961) in Chapman (1967)
Cultus Lake, B.C. (sockeye) other spp. present, but not studied.		59		Ricker and Foerster (1948) in Chapman (1967)
Marion Lake, B.C. (rainbow and kokanee)		18.7		Sandercock (1969) in Hall and Hyatt (1974)
Char Lake, N.W.T. (arctic char) ultraoligotrophic, polar		3.2		Rigler (1974)
Konnevesi L., Finland (vendace)		20 - 25		Hakkari (1972)
5 dystrophic lakes, Minnesota (rainbow)		19 - 84		Johnson and Hasler (1954)
Reservoir, Oregon (chinook) eutrophic		156		Higley (1963), in Chapman (1967)
Reservoir, Oregon (steelhead)		53		Coche (1964), in Chapman (1967)

* In some waters, the production measurements may refer to one species in a community which includes some other species; the mountain-national-park-studies production estimates are for the total fish community.

unit area is high compared to the Jasper lakes because of the relative shallowness of the Cascade Trail area lakes. In most of the latter, half or more of the lake is 5 m deep or less. The standing crop of benthos in the Cascade Trail area lakes was unusually high. However, most of the species constituting the benthos of these lakes are slow growing, most having a two-year life cycle and some having a three year cycle. The large standing crop can be misconstrued as an indication of high productivity, whereas turnover is actually rather low. It is also possible that 1977 benthic standing crops are somewhat higher than would be the case if the lakes were supporting larger fish populations. For example, the standing crop in Snowflake Lake in 1977 was nearly twice that found in 1973 when fish numbers were higher, and fish numbers had been even higher in the immediately preceeding years.

If the findings of Chapman (1967)[1] and others are applicable to the six lakes of this study, and if the majority of anglers who come to these lakes are uninterested in the smallest year class of "catchables",[2] then the maximum realized yield is more likely to be as follows (numbers of fish caught):

Bighorn	25	Pipit	45
Cuthead	80	Snowflake	50
Harrison	185	Wigmore	30

Omitting the smallest year classes of "catchables" from the calculations, the mean sizes of these potential yields are: 132 g (about 0.29 lb) for Bighorn Lake; 608 g (about 1.10 lb.) for

1. In many sportfishing waters, only about 25% of the harvestable population is taken by angling.
2. Refer to footnote on previous page.

Harrison Lake; 317 g (about 0.70 lb.) for the other four lakes. These are estimates of the maximum average sizes to be expected. If more fish than indicated immediately above were caught, the average sizes would be smaller. Except for Cuthead Lake, where the estimate seems to us to be somewhat too high, we believe the yields indicated immediately above are reasonable and would be in line with an optimum productivity over a long period of time. However, theoretical estimates of production are no guarantee of fish in the creel. It is still necessary for the fisherman to pit his skill against nature.

If we accept the potential production figures as reasonably accurate, and until the estimate of 30% annual mortality is proven to be in error, the required annual recruitments to the fish communities of these six lakes are as follows (see Table 37):

lake	no. of "units"	required annual recruitment
Bighorn	0.64	640
Cuthead	2.22	2220
Harrison	3.37	3370
Pipit	1.15	1150
Snowflake	1.17	1170
Wigmore	0.81	810

Harrison Lake has a native population of Dolly Varden capable of sufficient natural recruitment to maintain the population as long as it is not overfished. Cuthead Lake, if left alone, may develop a similar population, although its small size may make survival of a naturally reproducing population tenuous. There might be some natural reproduction among the brook trout of Wigmore Lake, but a study would be necessary to determine this for certain, and it is not likely that such a small lake warrants much time and expense for such a study. The other three lakes apparently have no natural recruitment and, if a sport-fishery is to be maintained in these three lakes, stocking of hatchery-reared fish will be necessary.

SUMMARY

Bighorn Lake - According to stocking records, only eastern brook trout were stocked in this lake. However, one of us (RSA) caught some rainbow trout by angling in 1968. In any case, only brook trout appear to have survived and, by their age, represent survivors from the original stocking. Apparently, there is no natural reproduction. On the basis of the growth rate, the lake's production potential, and the expected maximum yield, it hardly seems worth while attempting to maintain a sportfishery in the lake. If, however, the management decision is to stock hatchery-reared fish, we recommend that only cutthroat trout be stocked (native to the general region, and thus in keeping with current national parks policies) and that the maximum number introduced per year should not exceed 640 fingerlings. If fishing pressure is very light, there may be no need to stock every year. A follow-up study should be done about every three years to assess growth and survival.

Cuthead Lake - Since the 1961 poisoning of this lake, only Atlantic salmon and cutthroat trout have been stocked. The first of these survived for a while, but none has survived until now as far as we know. Of the extremely high (much too high, we feel, for a lake of this size and volume) number of cutthroat trout introduced, none seems to have survived in the lake. However, some may have migrated into the outlet stream, or they may have been cannibalized by the Dolly Varden in the lake and outlet stream. In any case, some native Dolly Varden now occur in the lake, and in time a similar but smaller population to the one in Harrison Lake may develop. We feel that the Dolly Varden population should be left to develop on its own.

Grouse Lake - It is not a permanent lake, as evidenced by the presence of fairy shrimp. Therefore, it should not be stocked. It contains what may be a unique subspecies of the rotifer *Hexarthra bulgarica*, but this very small species would not be affected by fish stocking.

Harrison Lake - This lake contains a successfully reproducing population of native Dolly Varden. Growth rates are reasonably good, and the production potential of the lake is excellent for a lake of this size and elevation. The native population should not be tampered with from the point of view of stocking. However, the population should be monitored to make sure that it is not overfished. Because of the feeding habits of Dolly Varden, it would be possible for a small number of fisherman to overfish the lake in a short time.

Pipit Lake - Only rainbow trout have been stocked in this lake. Survival was fair, as was growth, but no natural recruitment seems to have occurred. The youngest surviving fish would now be twelve years old. In our estimation, stocking rates in the past were about four times too high. We feel that an annual introduction of no more than 1150 cutthroat (or possibly rainbow, to keep it as a rainbow lake) would result in a successful but small back-country fishery. The maximum realized yield is rather small, and there is some question as to the economic justification for stocking such a poor potential producer.

Snowflake Lake - According to various records, all of eastern brook trout, rainbow trout, and cutthroat trout have been stocked in this lake. The original rainbow grew well, but later stocking seems to have failed. There was apparently no natural reproduction in the species, although one of us (RSA) observed spawning activity in the outlet stream in 1966-68. The eastern brook trout have survived well, but growth has been poor, especially when numbers were high (we feel that stocking rates in this lake during the last 3 years of stocking were 5 to 15 times too high!). Apparently, there has been no natural reproduction of the brook trout, so in recent years numbers have declined and growth rates have increased. To our knowledge, no cutthroat trout have survived.

The long range effects of fish stocking on a lake have been studied in a few places, although few studies have continued for more than two or three years. What has seldom been done, is to study the opposite phenomenon in alpine lakes, that is, to study the long term "recovery" pattern in a lake where the fish population is in decline and will probably disappear with time. This is occurring in Snowflake Lake. Because there is a good accumulation of baseline data for this lake, we strongly

<u>recommend that the lake be left unstocked in future and that it be kept as a control and study site</u>.

If a sport-fishery is to be maintained in this lake, we suggest that no more than 1170 fingerlings per year be stocked and that these should be either cutthroat or rainbow and that all future stocking should be kept to a single species. At this rate of stocking, moderate growth and a consistent but small annual yield might be expected over the long term. It is our opinion, however, that the lake is more valuable for management purposes as a study site than as a rather insignificant sport-fishing lake.

<u>Wigmore Lake</u> - Both rainbow and brook trout have been stocked in this lake. There is a possibility that a small amount of natural recruitment occurs among the brook trout. If this can be shown to be true, then the population should be left to its own devices. If there is no survival of either species and the management decision is to stock, than we suggest that no more than 810 of either rainbow or cutthroat trout be introduced per year, and that all stocking in future should be kept to a single species.

RECOMMENDATIONS

Refer to page number:

1. Bighorn Lake:
   - it is not worthwhile to continue stocking this lake. 38
   - if the decision to continue stocking is made, then no more than 640 cutthroat fingerlings per year should be introduced. 134, 151

2. Cuthead Lake:
   - the native Dolly Varden population should be allowed to develop on its own. 44
   - no stocking is necessary. 134
   - no other fish species should be introduced into this lake. 150, 151

3. Grouse Lake:
   - no further stocking should be considered. 37, 50, 128, 152

4. Harrison Lake:
   - no stocking is necessary. 52
   - the native Dolly Varden population is self-sustaining. 128
   - no other species of fish should be introduced. 131
   - the lake should be carefully monitored to guard against overfishing, which could damage the native population. 132, 134, 152

5. Pipit Lake:
   - if a fishery is to be maintained, then a maximum of 1150 fingerlings per year should be introduced. These fingerlings could be either cutthroat or rainbow trout, but only one species should be stocked in future. 58, 135, 136, 152

6. Snowflake Lake:
   - we recommend no further stocking. Productivity potential is not high, and the lake offers a valuable resource as a control study lake. 64, 131-132, 149, 153-154

7. Wigmore Lake:
   - if there is a viable brook trout population in the lake, it should be allowed to maintain itself. 37, 128
   - if there is no survival of brook trout, and a decision is made to retain the lake as a fishing lake, then a maximum of 810 fingerlings per year of either rainbow or cutthroat trout could be introduced. All future stocking should be of the same single species. 150, 154

8. Only certified disease-free fish should be stocked.

9. Marked fish should be stocked whenever possible to facilitate monitoring studies of growth rates and survival.

10. No "reclamation" with fish toxins should be permitted in this group of lakes in future. 134

11. No food organism transplants are recommended.

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APPENDIX A.

GLOSSARY

Note: Only a basic selection of taxonomic and anatomic terms is included in the glossary. The reader is referred to any of the many standard taxonomic, basic limnology, or general biology references listed in the bibliography for assistance with taxonomic and anatomic terms.

Acarina - (see Hydracarina)

activity coefficient - ratio of inorganic carbon uptake by algal photosynthesis to biomass of the algae (expressed as carbon or as freshweight).

aerobic - refers to a condition where oxygen is present more or less abundantly.

affluents - tributaries; not to be confused with affluence; see also "effluents".

alkalinity - excess of bases over strong acids; in most Canadian waters, alkalinity comes from hydrolysis of bicarbonate ions.

Amphipoda - an order of Crustacea; common in marine and freshwater environments; most frequently benthic or meroplanktonic; one of many groups called "freshwater shrimps".

albedo - fraction of incident light that is reflected by a surface (e.g. by clouds or a field of snow).

alluvial - transported by water and subsequently deposited (i.e. as soils).

allochthonous - organic matter formed primarily by photosynthesis outside the system under consideration and coming into the system by some form of transport (usually air or water).

alpine - above tree-line; zone of the mountains roughly equivalent to the tundra of the arctic/subarctic.

anaerobic - refers to organisms which facultatively or by obligation thrive in the absence of oxygen; lacking in oxygen.

Anostraca - a group of Crustacea commonly called fairy shrimps and most commonly occurring in temporary waters.

anoxic - condition of inadequate oxygenation.

assimilation - the transformation of absorbed nutrient substances into body substances.

astatic waters - lakes of an endorheic region (outlet rivers lost in dry courses and do not reach the sea) usually having fluctuating water levels.

aufwuchs - microscopic plant and animal forms which encrust submerged surfaces of living organisms and non-living substrates.

autochthonous - organic matter originating within the system under consideration and primarily by photosynthesis.

autotrophic - refers to the nutrition of those organisms able to construct organic matter from inorganic (principally green plants).

autumnal circulation - the overturn or full-circulation during the period of homothermy in autumn; enhanced by wind.

bathymetric - concerning the science of deep-water sounding, especially the sea.

benthos - the association of species of plants and animals that live in or on the bottom sediments of a body of water.

biochemical oxygen demand - decrease in oxygen content in mg/litre of water in the dark over time period, brought about mainly by bacterial breakdown of organic matter.

biocoenosis - community of organisms whose composition and aspect is linked to environmental properties and by the relationships of the organisms to each other.

biomass - mass units of organic matter per unit surface area or per unit volume; mass of living material in an organism.

biota - the flora and fauna of a given habitat.

BOD - (see biochemical oxygen demand)

buffer - mixture of weak acids and their salts which minimizes effects of changes in hydrogen-ion concentration.

^{14}C-method - determination of assimilation or photosynthesis by "marking" the photosynthate with radioactive carbon (^{14}C), usually as bicarbonate.

catchment area or basin - the entire area from which drainage is received by a body of water; a watershed.

Chironomidae - the chironomids or midges; Diptera; larval stages are aquatic.

cirque - usually a circular valley with precipitous walls and usually formed by glaciation.

Cladocera - small planktonic, meroplanktonic, or epibenthic Crustacea often known as water fleas (e.g. Daphnia, Bosmina).

Coelenterata - jellyfish and their relatives; Hydra is one of the few freshwater forms.

cohort - groups of animals born at the same time.

Coleoptera - the beetles; larvae and adults of many species are aquatic; often highly predaceous; frequent in lakes and often very common in ponds.

coliform bacteria - all of the aerobic and facultative anaerobic gram-negative, non-spore-forming, rod-shaped bacteria which ferment lactose with gas formation within 48h at 35°C.

community - groups of organisms in a habitat, more closely related to each other ecologically than to other groups; the "biocoenosis".

compensation point - the depth at which assimilation and dissimilation are equal (i.e. where production approximately equals destruction).

competition - effect of one organism (or group of organisms) on another in the struggle for food, nutrients, living space, or other common needs.

Conchostraca - a group of bivalved meroplanktonic or epibenthic Crustacea known as "clam shrimps" (closely related to Anostraca).

conductivity - (see specific conductance).

congeneric - of the same genus; two species of the same genus are referred to as congeneric species.

convection - movements of particles of a fluid as a result of changes in density (usually as a result of heating or cooling).

Copepoda - the copepods; an order of Crustacea having 3 main free-living groups (Colanoida, Cyclopoida, Harpacticoida) and some parasitic forms.

Corixidae - water boatmen; family of Hemiptera; both nymphs and adults aquatic, although adults can fly for dispersal; common inhabitants of shallow-water habitats.

cosmopolitan – in biology, referring to world-wide distribution.

delta – triangular alluvial deposit at or in the mouth of a river.

detritus – finely divided settleable material suspended in the water; organic detritus = broken down remains of organisms.

dimictic – temperate lakes with spring and fall overturns; two periods of full circulation.

Diptera – two-winged insects, often with aquatic larvae; includes flies and mosquitoes (e.g. Chironomus, Aedes, Chaoborus).

drainage basin – area from which precipitation drains into a given lake or river.

drainage lakes – lakes with a consistent surface outlet through which most water loss (except by evaporation) occurs.

drift – the flora and fauna of running waters being transported passively downstream by the current.

dystrophic – brown-water lakes with low lime content and high humus content, often low in nutrients.

ecological efficiency – ratio (as percent) between energy flow at different points along the food chain; ratio of food consumed at one trophic level and food supplied to comparable point in preceding level.

ecology – the study of the relationships of organisms to their environment (from Greek oikos = house; logos = discourse).

ecosystem – an area of nature where living organisms and non-living substances interact to provide an exchange of materials between the living and the non-living parts.

effluent – the outflow; usually refers to sewage outflow after some form of treatment.

Ephemeroptera – an order of insects including the Mayflies; larvae are common inhabitants of lakes and rivers.

ephippium – resistant, often overwintering, egg form of Cladocera; usually formed by sexual reproduction.

epibenthic – superficially benthic organisms of the mud-water interface.

epilimnion – turbulent superficial layer of a lake above the metalimnion or thermocline.

euphotic zone - total illuminated stratum of a lake, including limnetic and littoral zones.

eutrophic - waters with a good supply of nutrients and, hence, a rich organic production.

eutrophication - enrichment of waters by nutrients either through man's activities or by natural means. Phosphorus and nitrogen are the 2 most important elements responsible for eutrophication.

extinction coefficients - mathematically and experimentally derived values describing the rates at which light of different wave lengths is extinguished by absorption and diffusion as it passes through natural water.

exuvia - (pl. exuviae) an animal's coat, skin, shell, or outer covering.

fetch - the distance that a wind blows across a lake surface; the longer the fetch, the higher the waves.

food chain - transfer of food energy from the plant source through a series of organisms with repeated eating and being eaten; the shorter the food chain, the greater the efficiency.

food web - interlocking patterns of food chains forming a complex pattern.

Gastropoda - the common single-shelled mollusks of freshwater; the snails.

glacial relict - survivors of the Pleistocene biota usually restricted to certain localities because of glacial history and temperature tolerance.

gradient - a change in a physical property related to a unit of length or height (e.g. temperature per metre).

habitat - the place where the organism lives; an organism's "address".

hard-water lakes - $>$ 60 p.p.m. as $CaCO_3$; 61-120 p.p.m. = medium hard; 121-80 p.p.m. = hard water; $>$ 180 p.p.m. = very hard water.

hardness - anti-lathering (soap) and scale-forming quality of water due to alkaline earth salts, mainly carbonates and bicarbonates of magnesium and calcium (most commonly calcium bicarbonate).

heat budget - balance between heat content and uptake (absorption and transfer) and heat loss (radiation, conduction, evaporation).

hectare - (ha) unit of square measure, 100 metres x 100 metres; approx. 2.47 acres.

Hemiptera - an order of insects; the true "bugs", including Corixidae and giant water bugs.

heterothermic - irregular temperature regulation in primitive mammals; usually considered equivalent to poikilothermic.

heterotrophic - refers to nutrition of plants and animals which are dependent on formed organic matter for food.

Hirudinoidea - leeches; members of phylum Annelida, the segmented worms.

holomictic - refers to lakes which circulate completely to the bottom, especially at the time of autumnal circulation.

homothermy - condition of uniform temperatures throughout, as at fall turnover which begins when water column uniform at 4^{o}C.

Hydracarina - water mites; groups of aquatic arachnids.

hypolimnion - deep layer of a lake lying below the metalimnion or thermocline and normally removed from surface influences.

imago - the "perfect insect" or adult form reached at the conclusion of metamorphosis.

insolation - incoming radiation from the sun; not to be confused with insulation.

interspecific - between species (e.g. competition between species).

intraspecific - within a species (e.g. competition between members of a single species).

internal seiche - standing wave within a lake; oscillations of the discontinuity layer in a thermally stratified lake.

ion - electrically charged particles in aqueous solution; anions are negatively charged ions which migrate to the anode; cations are positively charged ions which migrate to the cathode; molecules which dissociate in water form ions.

isotherms - a line of the same temperature value, usually referring to graphs.

kettle lakes - lakes forming in depressions in terminal moraine formations left by continental glaciers.

lacustrine - pertaining to lakes.

larva - early form of an animal unlike the parent (i.e. as in complete metamorphosis in insects).

lentic - referring to standing-water habitats (lake, swamp, pond, or bog).

limnetic - open water zones to the depth of effective light penetration.

limnology - study of inland waters; from Greek limne = lake, and logos = discourse.

littoral - the shoreward section of a body of water with light penetration to the bottom.

lotic - referring to running-water habitats (spring, stream, river).

Lugol's solution - 10 g pure iodine, 20 g KI, 200 cc distilled H_2O, 20 g glacial acetic acid; solution added to algal sample in 1:100 ratio.

macrobenthos - benthic organisms clearly visible to the naked eye.

macrophytes - vascular aquatic plants which may grow either free-floating, totally submerged, or emergent above the water surface.

meromictic - lakes undergoing only partial circulation due to thermal or salinity stratification.

meroplanktonic - temporarily planktonic; refers to animals planktonic during part of their lives or for part of the day.

metalimnion - (see thermocline).

micrometre - (μm) = 1/1000 of a millimetre, 1/1,000,000 of a metre.

micron - (see micrometre).

milliequivalents per litre = equivalent parts per million (e.p.m.) - one equivalent of any element will exactly combine with or be equivalent to one equivalent of any other element. Sum of all negative ions in natural waters must equal sum of positive ions in terms of equivalents.

Mollusca - the mollusks (snails and clams).

monomictic - a lake in which the water mass mixes or circulates completely once a year.

moraine - a ridge or mound of earth, stones, etc., carried or pushed by a glacier and deposited on adjacent ground.

morphoedaphic index - a productivity index for lakes based on morphometric and soil (or sediment) related factors such as water chemistry.

morphometry - measure of external form; branch of limnology dealing with morphologic measurements of lakes and their basins.

naiad - a nymph stage in the life cycle of certain insects exhibiting incomplete metamorphosis; resembles adult in many respects.

nannoplankton - portion of the open-water plankton too small to be collected with nets; usually accepted as those organisms under 60 µm in maximum dimension.

nekton - powerful swimmers among freshwater animals that are capable of moving about voluntarily from place to place.

nematodes - unsegmented roundworms; many free-living forms in the benthos and many parasitic forms.

neuston - community of the surface film of water.

niche - the position or status of an organism within the community or ecosystem; by analogy, the organism's "profession".

Notostraca - a group of epibenthic Crustacea commonly called tadpole shrimps; closely related to the Anostraca.

nymph - immature stage of insect which resembles the adult in many structural features; metamorphosis here involves gradual changes rather than the radical morphological changes of "complete metamorphosis".

Odonata - the dragonflies and damselflies; usually highly predaceous both as aquatic naiads and aerial adults.

Oligochaeta - a group of annelids mainly terrestrial and fresh-water; segmented worms with relatively few chaetae or bristles per segment.

oligotrophic - descriptive term for lakes which are characteristically deep, rich in oxygen, have little macrophyte vegetation around margins, are poor in dissolved nutrients, and have low rates of production.

Ostracoda - the ostracodes; small bivalved crustaceans usually on or in the benthic sediments.

otolith - mass of calcium carbonate crystals in the internal ear; in bony fishes tends to have characteristic shape for each species; forms annuli and, therefore, useful in age determination.

parthenogenesis - development of an egg without the entrance of a sperm.

pelagic - refers to region of free water in seas or inland lakes; of the open-water or limnetic zone; usually refers to the ocean.

Pelecypoda - bivalved mollusks (freshwater clams); common inhabitants of relatively stable substrates free from pollution and excessive silting.

periphyton - minute organisms (both plant and animal) attached to submersed substrates (living or non-living) which project above the sediments; usually accepted as equivalent to German term "Aufwuchs".

pH - a measure of the hydrogen ion concentration; pH of 0 to 7 indicates excess of hydrogen ions over hydroxyl ions = acidity; pH over 7 to 14 indicates excess of hydroxyl ions over hydrogen ions = alkalinity; pH of 7 = neutrality.

photosynthesis - synthesis of organic matter from inorganic carbon (as CO_2 or bicarbonate) with the aid of radiant energy.

phytoplankton - plant portion of the plankton (see plankton).

piscine - of fish.

piscivorous - fish-eating.

planimetry - measurement of surface area of plane figures by tracing their perimeters with a mechanical-mathematical device.

plankton - the total community of the free water (or limnetic zone of lakes); in a strict sense, only the non-motile forms drifting passively, but now usually extended to include all living forms in free water except vertebrates, larger insects and larger Crustacea.

Plecoptera - the stoneflies; nymphs common inhabitants of swift, cool streams and shores of oligotrophic lakes.

poikilothermic - refers to animals whose temperatures fluctuate with that of their environment.

pollution - contaminated, defiled, or degraded with unnatural material; degradation of a natural environment by the addition of foreign material.

polymictic - lakes with almost continuous circulation or very frequent overturns.

population - a group of individuals of one species closely associated with each other and forming a cohesive unit.

potamoplankton - true river plankton.

p.p.m. - parts per million = milligrams per litre (dissolved salts).

primary production - amount of energy stored as organic matter through photosynthetic activity of plants.

production - sum of growth increments of all individuals of a species population (survivors + non-survivors) in a discrete time period.

productivity - trophic nature of a water body or other habitat; a rate assessment often implying characteristics responsible for high or low productivity; approximately equivalent to "bioactivity".

profundal - of the deeper part of a lake; usually considered that deep zone beyond depth of effective light penetration.

proglacial lakes - occurring in front of, at or immediately beyond the margin of a glacier or ice-sheet.

protozoan - single-celled animal.

psammon - the community of the spaces between sand and fine gravel on the shores of lakes and rivers.

pseudoplankton - or "tychoplankton"; organisms "accidentally" in the plankton

pyrheliometer - a device for measuring and recording solar radiation.

rheophilic - referring to organisms which seek a running water habitat.

riffle - shallow section across the bed of a stream over which water flows quickly so that water surface is broken in waves; small wave or a succession of small waves.

Rotifera - the rotifers or "wheel animalcules", so-called because of their apparently-whirling ciliated structures; probably coenocytic; many epibenthic and planktonic forms.

saprobic - referring to dead or decaying organic material or organisms which depend on such material for food.

scree - steep sloping accumulation of rock fragments at the foot of cliffs; frost considered most important single agent creating this fragmented material.

Secchi-disc transparency - a measure of water transparency utilizing a white or black-and-white disc lowered to the point at which it disappears from sight.

secondary production - quantity of food or energy stored as biomass by consumers of primary producers (i.e. plants and some bacteria); third trophic level.

seepage lakes - a lake into which ground water enters and from which water leaves by seeping through the lake basin wall; no consistent surface inlet or outlet.

seiche - (see internal seiche).

seston - collectively, all particulate, free-floating matter, living or dead, and including zooplankton and phytoplankton.

shoreline development - ratio of the actual perimeter of a lake and circumference of a circle having same area.

soft-water lakes - waters with not more than 60 p.p.m. hardness as $CaCO_3$; little or no inhibition to soap lathering and little scale formation in boilers, etc.

specific conductance - the amount of electrical current conducted by water depends on the amount and nature of dissolved salts (ions); measured in micro-mhos (μmho), usually at 20 or 25 C. After 1975, the SI* unit is "Siemens" (=S). , umho = uS.

stagnation period - time period of thermal stratification where differences in water-mass densities prevent mixing of water mass.

standing crop - in limnology, the biomass present in a body of water at a particular time.

stenothermic - having a narrow temperature tolerance.

stratification - formation of layers exhibiting uniform and distinct physical or other qualities (e.g. thermal stratification in lakes).

stratum - a layer of any deposited substance; also a social or trophic level or grade.

stretched-mesh size - length of the opening in a gill net.

subimago - in Mayflies a "subadult" or apparently mature insect but dull in color with poor power of flight. A second moult occurs shortly after the first and the true adult emerges.

substrate - the material on or in which a plant or animal lives; the material or substance acted upon by an enzyme or ferment.

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* SI = the International System of units. SI is being phased into Canadian science and commerce on a gradual basis.

succession - ecological succession is the orderly process of community change usually involving a sequence of change in a given area.

sum of constituents - usually considered approximately equivalent to salinity or total dissolved solids (TDS); calculated total of quantitative analyses for individual dissolved constituents.

surplus production - in fisheries, production of new net weight by a fishable stock, plus recruits to the stock, minus losses by natural mortality; also called sustainable yield (see Ricker 1975).

talus - usually considered equivalent to scree (see scree).

taxon (pl. taxa) - a taxonomic division such as family, order, class, or species; in discussion, usually refers to the lowest level of identification employed in the study at hand.

TDS - total dissolved solids (see sum of constituents).

tertiary production - production by higher carnivores and insect hyperparasites; fourth trophic level.

thermistor - electronic device utilizing a thermocouple which measures temperature or temperature change as a result of changes in electrical resistance in the thermocouple at different temperatures; technically a resistance thermometer.

thermocline - region of greatest slope of the temperature gradients in a lake; zone is called the metalimnion.

Transeau's solution - for preserving plants; 6 parts water, 3 parts 95% ethanol, 1 part formalin; often with a small amount of copper sulfate.

transparency - (see Secchi-disc transparency).

Trichoptera - caddisflies; larval stages of these insects are common in running and standing waters; larvae of many species build cases of sand, detritus, etc.; some spin webs for trapping their food.

trophic level - "trophic" refers to food or nourishment; a level at which all organisms' food formed with same number of steps from plants.

turbidity - estimate of suspended matter density inhibiting passage of light.

turbulence - unorganized movement in liquids or gases.

turnover ratio (P/B) - in production, the relationship between production per time unit and mean standing-crop biomass during that time.

tychoplankton - (see pseudoplankton).

ultraviolet - region of short-wave radiation beyond the visible violet band of the visible spectrum.

vernal circulation - spring overturn or circulation at time of homothermy; may not occur if water stratifies.

voltine - number of generations in a year (i.e. univoltine, bivoltine).

volume development - ratio of a lake's actual volume and that of a cone with base area and height equal to lake area and maximum depth.

water renewal rate - (or flushing rate) - theoretical time required for total volume of water in a lake or its equivalent to be discharged via outlet stream or river.

yield - (see surplus production).

zoobenthos - animal portion of the benthic community.

zooplankton - animal portion of the plankton (see plankton).

$>$ - abbreviation used to express "greater than" (e.g. >25).

$<$ - abbreviation used to express "less than" (e.g. <25).

APPENDIX B

General and Technical References

This bibliography is not intented to be complete in all areas covered. Rather, it is intended to cover a selection of general references in each area as an aid to further reading for those wanting to pursue certain subjects further and not being familiar with the literature.

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APPENDIX C

Taxonomic References

In this section, no attempt is made to list all available general references or to list more than a few special references for certain groups. Additional special taxonomic reference papers will be listed in the appropriate sections of the report. The references listed here are intended to provide leads to the taxonomic literature and aids to preliminary identification. Because of continual taxonomic revision and the descriptions of new species, it is almost impossible to find thorough and complete keys to more than a few well-known groups.

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