THE UNIVERSITY OF MANITOBA

A COMPARISON OF THE CRUSTACEAN ZOOPLANKTON POPULATIONS OF FOUR MAN-MADE LAKES IN SOUTHERN MANITOBA

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF ZOOLOGY

WINNIPEG, MANITOBA

May, 1980

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IN MEMORY OF

DR. B. E. LOADMAN

ABSTRACT

Seasonal variations in the abundance of eight species of crustacean zooplankton in four small man-made lakes in southern Manitoba were studied from samples taken in a one year period from June of 1977 to June of 1978. Three stations on each lake were sampled at weekly intervals in summer, 1977 and the spring of 1978 and at approximately biweekly intervals in autumn. Winter samples were taken at one station per lake biweekly. Crustacean species shared by the four lakes were: Diaptomus siciloides, Cyclops bicuspidatus thomasi, Cyclops vernalis, Mesocyclops edax, Daphnia galeata mendotae, Daphnia parvula, Ceriodaphnia lacustris, and Bosmina longirostris. Lake I had the highest total numbers of animals per liter in all seasons as well as the greatest relative abundance of cyclopoids and cladocerans.

In each lake, the number of dominant species ranged from one to five on various sampling dates. Lake IV generally had the least complex community in that in 21 of a total 32 sampling dates, no cladoceran was dominant. In the other lakes, combinations of one diaptomid, one to two cyclopoids and one or more cladocerans dominated more often than in Lake IV. A comparison of relative abundance and dominance in June of 1977 and June of 1978 showed a large shift in community composition in each of the four lakes in favour of cyclopoid copepods which comprised over 60 percent of the total abundance of crustacean zooplankton by the spring of 1978.

The percent similarity of community index calculated for all possible lake pairs showed that the degree of similarity between the lakes changed in different seasons. Lake pairs I and IV and II and IV were least similar in autumn, 1977 (PSC = 46.0 and 40.6 respectively) and most similar in spring, 1978 (96.1 and 96.5 percent). Discriminant function analysis was performed on species abundance data from summer and fall, 1977. The analysis achieved good separation among Lakes I, II, and IV and poor discrimination between Lakes III and IV. Possible effects of differing environmental conditions on the abundance and timing of the seasonal maxima of some of the crustacean species were discussed.

ACKNOWLEDGEMENTS

I am indebted to my supervisor, Dr. F. J. Ward, first for suggesting this project and also for his constant support and encouragement and valuable criticism of the manuscript. I would like to thank A. Salki and Dr. K. Patalas for the initial identification of crustaceans and subsequent confirmations, and helpful advice on the methods of counting samples. R. Nero, G. Sinclair, L. Brownlie, G. Ginther, B. Cook, and R. Ratynski assisted with the sample collection and I thank them for their skill with boat motors and power augers. People at the Freshwater Institute kindly performed the chemical analysis of the water samples. B. O'Malley and D. Swain aided with computer manipulations. Financial support from the University of Manitoba and the National Research Council in scholarships to the author is gratefully acknowledged.

Finally, I am deeply indebted to my friends and family for their encouragement, particularly my husband, Tim Fultz, for his unfailing support and greatly appreciated patience and understanding.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES cont'd

LIST OF FIGURES cont'd

Figure | Page

LIST OF APPENDICES

INTRODUCTION

A number of studies have been undertaken to compare zooplankton populations of lakes with different limnological conditions in attempts to characterize lakes on the basis of their plankton communities. These studies have often led to the formation of community types according to the dominant species of zooplankton and the accompanying limnological characteristics of the group of lakes (Whittaker and Fairbanks 1958; Anderson 1974; Patalas 1971). In recent years this relationship between community and environment has been investigated using principle components and discriminant function analyses to demonstrate the use of zooplankton as indicators of limnological conditions (Sprules 1977; Green and Vascotto 1978; Janicki and DeCosta 1979). These studies point out that more regional information is needed and that species considered indicators of certain conditions in one area may be abundant under quite different conditions in other regions.

Relationships between certain environmental conditions and the total abundance of zooplankton have also been investigated. Patalas (1971) found that the total numbers of plankton per unit area increased with maximum depth. Patalas (1972, 1973) also observed an increase in crustacean abundance with increased heat and chlorophyll content of the St. Lawrence Great Lakes and the lakes of the Okanagan Valley.

Others have observed relationships between the amount of zooplankton and total dissolved solids (Rawson 1942; Northcote and Larkin 1956), hypolimnetic oxygen deficits, (Rawson 1942) and epilimnetic temperature (Patalas 1975). An increasing proportion of cyclopoids and cladocerans and a reduction in calanoids has been observed with increasing productivity and eutrophy (Gannon 1972; Patalas 1972).

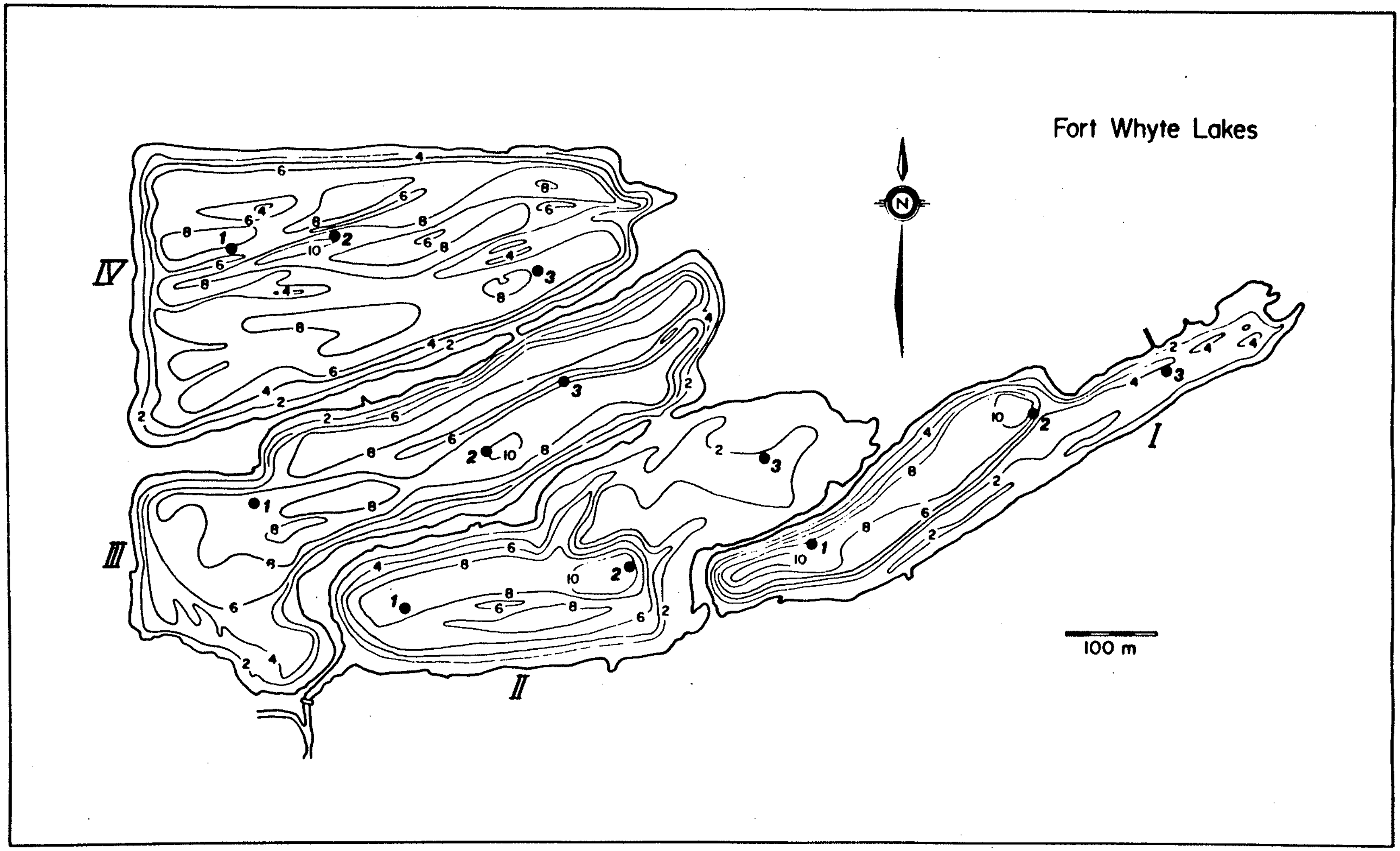
The primary objective of the present study was to provide an initial survey of the zooplankton populations of four small man-made lakes at Fort Whyte, Manitoba as part of an ongoing investigation into the limnology of these lakes. The zooplankton species present in these four lakes are common components of some of the large regional study areas previously mentioned and thus a description of the seasonal cycles and abundances of these species and the environmental conditions in which they are found adds to the information on regional differences. The four lakes are superficially very similar because of their origin and close physical proximity and, theoretically, their plankton communities should be very similar. Thus certain aspects of the abundance of the four zooplankton populations were compared and contrasted to observe their degree of similarity and an attempt was made to relate, in a qualitative way, the structure of the zooplankton communities with the limnological conditions prevailing in each of the lakes.

MATERIALS AND METHODS

Water samples for chemical analysis were taken at the deepest (centre) station on each lake (Fig. 1) on the same date on which zooplankton samples were taken. Water temperature was also measured at the centre station with a thermistor thermometer at one meter intervals. Samples for oxygen, alkalinity, pH, and water chemistry were taken at each meter interval with a 1 liter van Dorn bottle. Oxygen samples were titrated according to the modified Winkler method and alkalinity was determined using the methyl orange indicator method (A.P.H.A. 1965). Water chemistry analysis was performed at the Freshwater Institute, Environment Canada, Winnipeg according to the standard procedures outlined in Stainton et al (1974). An initial description of the results of the water chemistry analysis is contained in Ward et al (unpublished).

From June to August, 1977, zooplankton samples were taken weekly at three stations on each of the four lakes (Fig. 1). One series of samples was taken in September and two were taken in October, 1977. Under ice cover, samples were taken at biweekly intervals at the deepest station on each lake except in January and April, 1978 when the lakes were visited once per month. In May and June, 1978, samples were taken weekly at all three stations on each lake.

Figure 1. Contour map of the four Fort Whyte lakes showing the location of the zooplankton sampling stations.


Fort Whyte Lakes
N
IV
III
II
I
100 m

The crustacean zooplankton were collected using an integrated tube sampler modified from Pennak (1962). The difference between the actual volume of sample contained within the sampling tube and the predicted volume calculated by multiplying the area of the tube by the depth to which it was lowered was less than 9% of the total volume in three trials. The contents of the sampler were filtered through a 64 μ screen mesh and the zooplankton preserved in 5% formalin. Samples were reduced to a volume of 25 ml by drawing off excess liquid with a syringe fitted with a 25 μ screen mesh. The contents of the sample vials were mixed vigorously in all directions and two one-half ml subsamples were withdrawn using a glass tube. The vial was mixed again before withdrawing the second subsample. Both subsamples were placed in a Sedgwick-Rafter cell and the entire crustacean zooplankton contents of the cell enumerated. To assess the adequacy of the subsampling technique, a variance-to-mean ratio test was performed on six subsamples from one sample and results are contained in Appendix A. The variance and mean were not significantly different for the dominant and largest species such as *Daphnia galeata* Sars *mendotae* Birge indicating that the subsampling method provided a representative random sample and that larger species were not selectively excluded from the glass tube.

Species of cladocerans were identified (Brooks 1957, 1959) and classified as immature, females, females with eggs, females with ephippia, or males. For *Bosmina longirostris* (O.F. Müller), only females with eggs were classified separately. Size measurements of at least fifty individuals of the three most abundant cladoceran species were taken as a further aid in classifying individuals as mature or immature (Appendix B). Measurements were made from the anterior margin of the head to the base of the caudal spine with the aid of an occular micrometer. Cyclopoid copepods were identified using Yeatman (1959) and adults were classified as females, females with eggs, or males. The copepodid stages of the various species were combined into two categories: copepodids I through III (CI-III) and copepodids IV and V (CIV-V). Nauplii were classified as either calanoid or cyclopoid. Cyclopoid nauplii were apportioned according to the copepodid ratio of the three cyclopoid copepods and were included in the calculations of total numbers and relative abundance of *Cyclops bicuspidatus thomasi* Forbes, *Cyclops vernalis* Fischer, and *Mesocyclops edax* Forbes. In samples where *C. vernalis* and *M. edax* were rare, cyclopoid nauplii were regarded as *C. b. thomasi*. The only diaptomid was identified according to Wilson (1959) and Comita and Tommerdahl (1960) and individuals were placed into the same life history categories as the cyclopoids.

Count data from three stations on each lake were combined to produce a weighted mean for each lake on each sampling date, with weights corresponding to the depth of the stations. For each lake on a particular sampling date during the ice free period, at least 200 individuals were counted. At least 64 individuals of each dominant cyclopoid, calanoid, and cladoceran were enumerated. Counting at least 64 individuals set the 95% confidence limits at a maximum of ±25% (Elliot 1971), assuming a Poisson distribution where the variance approximates the mean. Edmondson (1971) suggested that counting at least 40 animals of the major species would adequately represent the population. In this study, a 1 ml subsample from each station was usually sufficient to achieve this minimum number. After calculating the total number of each species in the whole sample, the number of individuals per liter was found by dividing by the volume of water in the integrated sampler. The number of animals per liter thus represented an average for the entire water column.

The percent similarity of community index was calculated for each season according to the formula

$$PSC = 100 - 0.5 \sum |a-b|$$

where a and b are, for a given species, the percentages of the total animals of samples A and B which that species represents (Whittaker and Fairbanks 1958).

Discriminant function analysis (DFA) was performed on log-abundance of the eight zooplankton species as well as cyclopoid nauplii in an attempt to distinguish between the lakes (groups) on the basis of their planktonic communities. Abundance data from the centre station of each lake for sixteen sampling dates representing summer and autumn, 1977 were used in the analysis. Discriminant analysis weights and linearly combines the discriminating variables so that the groups are as statistically distinct as possible, using the equation:

$$D_i = d_{i1}Z_1 + d_{i2}\ Z_2 + \ldots d_{ip}Z_p$$

where D_i is the score on the discriminant function, d_{ij} are the weighted coefficients, and the Z's are the standardized values of the p discriminating variables (Nie et al 1975). Once the discriminant functions were derived and each sampling date was given a score on each function, the population data were entered into the classification phase. The classification of the data from each sampling date originally used to derive the functions and the comparison of the predicted and actual group membership resulted in a measure of the success of discrimination. A graph of the discriminant scores for each sampling date and the group means was constructed to aid in visualizing the separation of the four lakes achieved through the analysis. A packaged computer programme (SPSS-DISCRIMINANT) was used to perform the analysis (Nie et al 1975).

THE LAKES

The four small study lakes are located in the southwestern section of the City of Winnipeg adjacent to the Canada Cement LaFarge Company (Fig. 1). The lakes were formed by dredging in order to extract the mud and clay used in the cement product.

Historical records from the cement plant indicate that excavation began at the shallow east ends of Lakes I and II in the early part of the second decade of this century using a horse-drawn shovel. A steam driven dragline was used to complete excavation of the western portion of Lakes I and II. By 1920 most of the first basin had been dug, thus making Lake I the oldest of the four lakes. Lake II was completed in the late 1940's. Lake III was first dug in 1951 and completed in 1962. Excavation of Lake IV began in the latter part of 1962 and this lake is currently being dredged with a diesel-powered dragline. Thus, in age, the lakes form a sequence: Lake I is over 50 years old, and Lake IV, the youngest lake, is less than twenty years old and has yet to be completed.

Lakes II, III, and IV are now connected by shallow trenches (Fig. 1). The formation of the channel between Lakes II and III, whether by intent or simple erosion, occurred between 1957 and 1967. The channel connecting

Lakes III and IV appeared between 1967 and 1977. Although no direct connection exists between Lakes I and II, surface water is pumped from Lake II to the west end of Lake I to raise the level in that lake. Water is pumped from and returns to the east end of Lake I via the cement plant where it is used in the manufacturing process.

The draw-down from Lake I has been estimated at 946 m^3 day^{-1}. The rate of return is not known but is considerably less than the draw-down. In the summer of 1977 the water levels in the lakes affected by pumping varied as much as 1 meter. The lakes are essentially a closed system; though they are connected, there is no outflow.

Water levels in all four lakes were unusually low in the spring of 1977 because of reduced precipitation during the preceding winter and a warm, dry spring. By August of 1977, the channel between Lakes III and IV was dry. Lake II received nutrient rich water in spring, 1977 from the ditch at the west end which drained farmland from the north and west. Lake I received an effluent from an impoundment of ducks and geese on the south shore of the lake.

None of the lakes have any true littoral zone. For their size, the lakes are relatively deep and the basin slopes are steep, dropping quickly to two meters just offshore (Fig. 1). As a result of excavation, the lakes share a similar basin morphometry although maximum width, area, and volume are all greater in the younger lakes (Table 1). The lakes all have a maximum depth of 10 m but the mean depth of Lakes I and II are somewhat lower as a result of their shallow eastern ends.

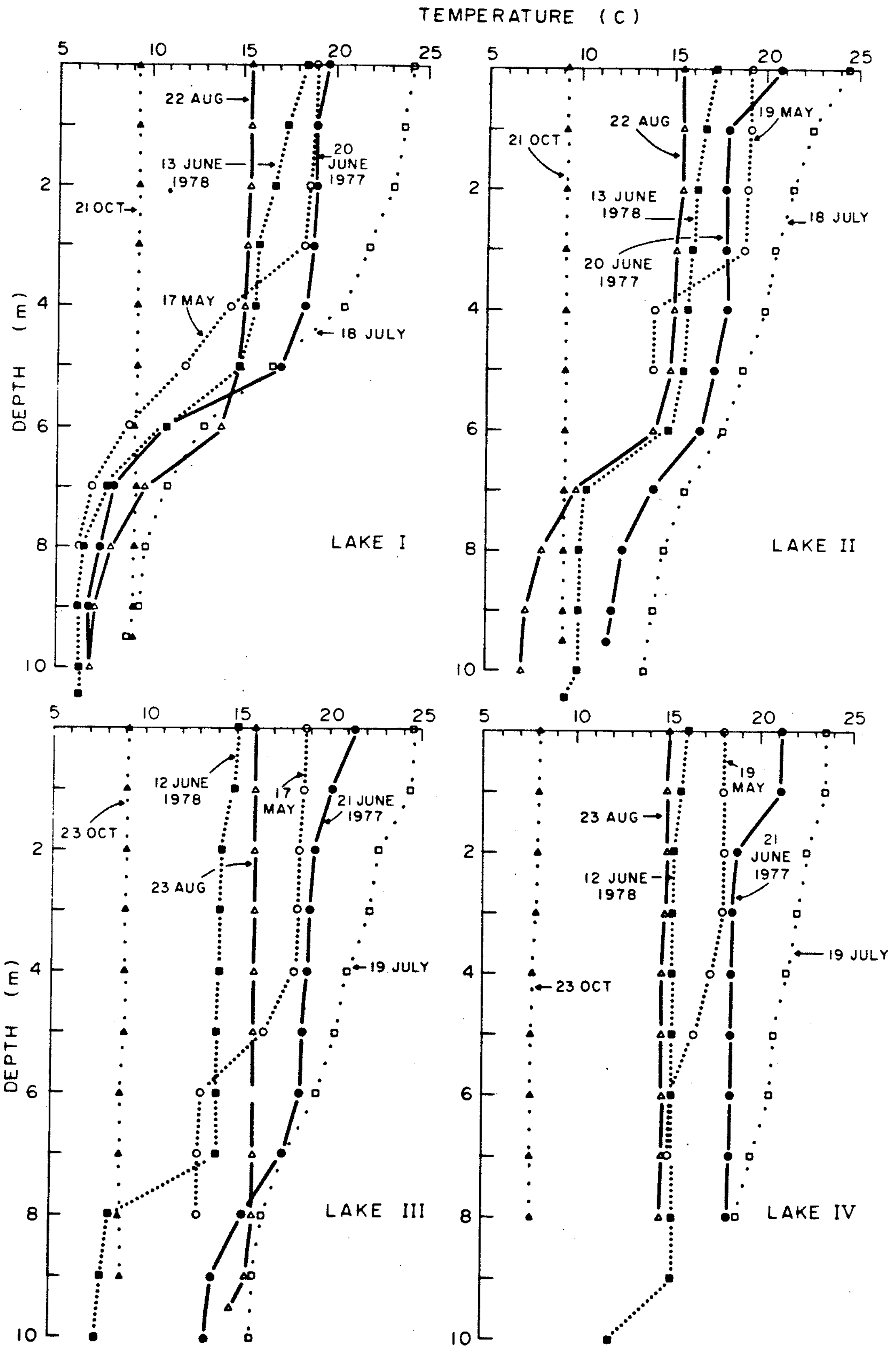
Lake I was already thermally stratified by May, 1977 (Fig. 2). The temperature of the epilimnion was about 20C to a depth of 3 m. The metalimnion extended from 3 to 7 m and the temperature dropped from 20 to 7C at the lower limit (Ward *et al* unpublished). The hypolimnion extended below 7 m. Thermal stratification became more complete in July. The epilimnion dropped to 4 m and the surface temperature was 24C. By the end of August the epilimnion had begun to cool and by October the entire water column was 9C, at which time mixing could have occurred. Ice formed in November and reached a maximum thickness of one meter by March.

Thermal stratification was not as intense in Lake II. In July, the boundary of the epilimnion and metalimnion was obscure, thus indicating that the hypolimnion was not as isolated from the overlying waters as in Lake I (Fig. 2). Stratification occurred only briefly in Lake III in May, 1977 (Fig. 2) and mixing probably occurred near the bottom in summer because the temperature of the hypolimnion always exceeded 12C. Lake IV showed the least evidence for

Table 1. Morphometry of the Fort Whyte Lakes (1977-1978).

	Lake			
	I	II	III	IV
Maximum length (km)	.72	.64	.75	.65
Maximum width (km)	.14	.22	.28	.32
Maximum depth (m)	10	10	10	10
Area (ha)	6.43	9.26	11.27	13.35
Mean depth (m)	4.31	4.12	6.07	6.07
Volume (m^3)	276,000	383,000	686,000	807,000

Figure 2. Temperature profiles of the Fort Whyte lakes, 1977-1978. All profiles are from 1977 except where indicated.



TEMPERATURE (C)
DEPTH (m)
LAKE I
22 AUG
13 JUNE 1978
20 JUNE 1977
21 OCT
17 MAY
18 JULY
LAKE II
22 AUG
19 MAY
21 OCT
13 JUNE 1978
18 JULY
20 JUNE 1977
LAKE III
12 JUNE 1978
17 MAY
21 JUNE 1977
23 OCT
23 AUG
19 JULY
LAKE IV
19 MAY
23 AUG
21 JUNE 1977
12 JUNE 1978
19 JULY
23 OCT

stratification and there was little difference between surface and bottom temperatures (Fig. 2). Aided by wind action and the constant dredging operation, this lake was mixed throughout the summer.

The oxygen regimes of the four lakes reflected the degree and duration of thermal stratification as described above. Lake I showed summer and winter oxygen deficits in the hypolimnion (Fig. 3). Lakes II and III had reduced hypolimnial oxygen concentrations in summer but deficits were less severe than those in Lake I (Fig. 3). Except for a brief period in May, 1977, the constant mixing in Lake IV ensured high oxygen levels at all depths. In Lakes I and II in particular, mixing appeared to be incomplete in the spring of 1978 and the lakes were not fully recharged with oxygen.

The annual mean concentration of total dissolved phosphorus in 1977-1978 in Lake I was twice that of Lake II and more than seven times the mean level in Lake IV (Table 2). Particulate phosphorus levels in Lakes I and II were similar and higher than those in Lakes III and IV.

Particulate carbon values were highest in Lake I but the concentration in all the lakes exceeded 1000 mg m^{-3}. On an annual basis, Lakes I, III, and IV had similar values of chlorophyll-a (Table 2) but the level in Lake II was

Figure 3. Monthly mean epilimnion and hypolimnion values for oxygen in the Fort Whyte lakes, 1977-1978.

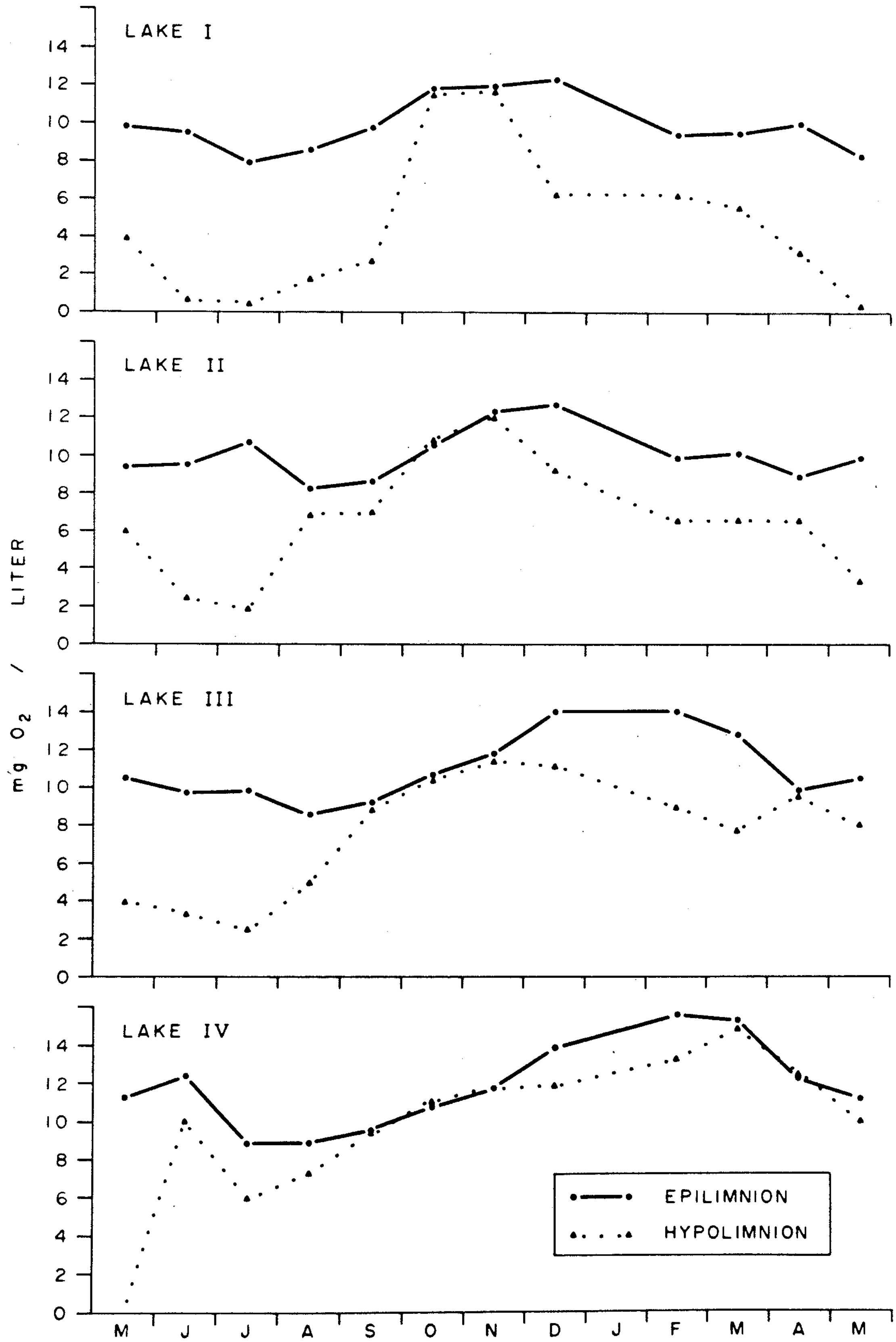

LAKE I
LAKE II
LAKE III
LAKE IV
mg O2 / LITER
0
2
4
6
8
10
12
14
M
J
J
A
S
O
N
D
J
F
M
A
M
EPILIMNION
HYPOLIMNION

Table 2. Annual mean values for chemical parameters in the Fort Whyte Lakes, May 1977 to May 1978.

Parameter	Units	Lake I	Lake II	Lake III	Lake IV
Oxygen	g/m^3	7.1	7.9	8.9	10.7
pH		8.1	8.1	8.2	8.4
Alkalinity	g/m^3	202	172	171	180
Ammonia	mg/m^3	813	293	162	45
Nitrate	mg/m^3	84	200	124	33
Particulate Nitrogen	mg/m^3	154	170	141	128
Total Dissolved Phosphorus	mg/m^3	95	44	17	12
Particulate Phosphorus	mg/m^3	23	22	17	17
Particulate Carbon	mg/m^3	1218	1096	1129	1087
Chlorophyll	mg/m^3	5.1	8.2	5.7	5.1
Total Dissolved Solids	g/m^3	674	335	390	473
Conductivity	x10 mS/m	11.0	5.4	6.2	7.2
Temperature	^{o}C	10.6	11.3	12.8	13.4

somewhat higher (8.2 mg m^{-3}). In Lake II in July, 1977, chlorophyll-a values reached 22 mg m^{-3} likely caused by a bloom of blue-green algae. This bloom also affected Lake III to a lesser extent (Ward et al unpublished).

Nitrate levels were considerably higher in Lake II, possibly because of the addition of fertilizer enriched runoff. High particulate nitrogen levels in this lake may have been associated with the blue-green algal bloom. The very high levels of ammonia in Lake I as compared to the other lakes were, in part, caused by the isolation of the anoxic hypolimnion in summer but the major source of this ammonia is thought to be the effluent from the wildfowl impoundment (Ward et al unpublished). High ammonia levels also occurred in winter in this lake when oxygen concentrations near the bottom were low.

Alkalinity values were quite high in all the lakes but were highest in Lake I (202 mg l^{-1}). pH values also indicate that all the lakes were slightly alkaline (Table 2).

Total dissolved solids and conductivity were highest in Lake I and second highest in Lake IV (Table 2). The retention of elements in the sediments with some return to the overlying waters, as well as the continuous effluent from the waterfowl enclosures may have contributed to the high T.D.S. values in Lake I. Constant dredging, resulting in high levels of suspended inorganic matter may have elevated T.D.S. values in Lake IV above those found in Lakes II and III (Ward et al unpublished).

In summary, the four man-made lakes, though superficially similar, showed differences in age, morphometry, thermal stratification, oxygen deficits, and nutrient levels. Lake I, the smallest and oldest lake, had the highest levels of most dissolved substances, the greatest degree of thermal stratification, and the largest and most prolonged hypolimnial oxygen deficit. These characteristics indicate that this lake is the most eutrophic. Lake II had relatively high nutrient levels and the highest chlorophyll-a values also indicating a certain degree of eutrophy. Lakes III and IV, the youngest lakes, lacked the direct nutrient input known for Lake I, have had less time to accumulate nutrients in the sediments, and circulated more frequently. Lake IV seemed the least productive of the four lakes, and was shown to have the lowest levels of phosphorus, nitrogen, and chlorophyll-a.

RESULTS

The four lakes shared eight species of crustacean zooplankton: *Diaptomus siciloides* Lilljeborg, *Cyclops bicuspidatus thomasi* Forbes, *Cyclops vernalis* Fischer, *Mesocyclops edax* Forbes, *Daphnia galeata* Sars *mendotae* Birge, *Daphnia parvula* Fordyce, *Ceriodaphnia lacustris* Birge, and *Bosmina longirostris* (O. F. Müller). *Scapholeberis* sp. was found on only one occasion in June, 1978 in Lake I.

The average annual total number of crustacean zooplankton per liter (June 1977-June 1978) decreased substantially from Lake I to Lake IV, the latter having an annual average of slightly more than half that in Lake I (Table 3). This same pattern of decreasing abundance from Lake I to Lake IV was evident for the mean values in summer (June 1977-August 1977) and autumn (September and October 1977). The winter populations (November 1977-April 1978) of the lakes were quite low with Lake I having the highest total numbers per liter and Lakes II, III, and IV having lower and similar total numbers. All four lakes showed a large increase in average total numbers in spring (May-June 1978), but the same relationship from Lake I to Lake IV was evident.