REGIONAL COPPER-NICKEL STUDY

LAKE ZOOPLANKTON

MINNESOTA ENVIRONMENTAL QUALITY BOARD
REGIONAL COPPER-NICKEL STUDY

Authors: Steve Piragis
Mark Johnson
Judith Baxter
Jeffery McCulloch

March 3, 1978

TABLE OF CONTENTS

TABLE OF CONTENTS (contd.)

PAGE

ABSTRACT

Zooplankton communities in Regional Copper-Nickel Study Area (Study Area) lakes were studied during 1976 and 1977. Clear, deep lakes generally contain less dense zooplankton communities than shallow, stained lakes. Maximum densities appeared in late summer and early fall.

All lakes were characterized by a small group of zooplankton species which are usually the dominants (comprising >10 percent of the ice-free seasonal means) and present throughout the ice-free season. Rare taxa were scattered among the lakes.

Study Area lakes were compared to lakes of the Experimental Lakes Area Canada and found to contain similar zooplankton communities.

PURPOSE

This regional characterization is intended to describe the dominant taxa of the region and their relationships, as well as the similarities and differences between the sites sampled. It provides a basis for assessing the potential impacts of copper-nickel development. It does not, in general, provide the baseline data necessary to detect impacts of development at particular sites. Techniques for developing such a baseline and ways in which these data might be used in planning a baseline monitoring program are discussed in a separate report, Biological Monitoring of Aquatic Ecosystems (Regional Copper-Nickel Study 1978).

INTRODUCTION TO THE REGIONAL COPPER-NICKEL STUDY

The Regional Copper-Nickel Environmental Impact Study is a comprehensive examination of the potential cumulative environmental, social, and economic impacts of copper-nickel mineral development in northeastern Minnesota. This study is being conducted for the Minnesota Legislature and state Executive Branch agencies, under the direction of the Minnesota Environmental Quality Board (MEQB) and with the funding, review, and concurrence of the Legislative Commission on Minnesota Resources.

A region along the surface contact of the Duluth Complex in St. Louis and Lake counties in northeastern Minnesota contains a major domestic resource of copper-nickel sulfide mineralization. This region has been explored by several mineral resource development companies for more than twenty years, and recently two firms, AMAX and International Nickel Company, have considered commercial operations. These exploration and mine planning activities indicate the potential establishment of a new mining and processing industry in Minnesota. In addition, these activities indicate the need for a comprehensive environmental, social, and economic analysis by the state in order to consider the cumulative regional implications of this new industry and to provide adequate information for future state policy review and development. In January, 1976, the MEQB organized and initiated the Regional Copper-Nickel Study.

The major objectives of the Regional Copper-Nickel Study are to characterize the region in its pre-copper-nickel development state: 1) to identify and describe the probable technologies which may be used to exploit the mineral resource and to convert it into salable commodities; 2) to identify and assess the impacts of primary copper-nickel development and secondary regional growth; 3) to conceptualize alternative degrees of regional copper-nickel development; and 4) to assess the cumulative environmental, social, and economic impacts of such hypothetical developments. The Regional Study is a scientific information gathering analysis effort and will not present subjective social judgements on whether, where, when, or how copper-nickel development should or should not proceed. In addition, the Study will not make or propose state policy pertaining to copper-nickel development.

The Minnesota Environmental Quality Board is a state agency responsible for the implementation of the Minnesota Environmental Policy Act and promotes cooperation between state agencies on environmental matters. The Regional Copper-Nickel Study is an ad hoc effort of the MEQB and future regulatory and site specific environmental impact studies will most likely be the responsibility of the Minnesota Department of Natural Resources and the Minnesota Pollution Control Agency.

INTRODUCTION

Zooplankton are small, free-swimming animals and are an important component of river and lake ecosystems. They cannot maintain their position in swift current and rarely are an important component of stream communities.

Zooplankton occupy several levels at the bottom of the animal food chain and act primarily as herbivores and detritivores and only occasionally as carnivores. Grazing zooplankton remove particles from the water by filtration. As a result, primary producers (i.e. phytoplankton) are assimilated into animal biomass and nutrients are excreted back into the water for use by other phytoplankton. Other zooplankton, insects, and fish prey on the grazers to support their own growth, thus environmental changes having deleterious effects on the zooplankton will have effects on the entire food chain of a lake.

Because of the importance of zooplankton in the food chain, a survey of the zooplankton communities in the Regional Copper-Nickel Study Area (Study Area) was conducted during 1976 and 1977. This survey provided data for characterization of Study Area lakes on the basis of zooplankton species composition, number of dominant zooplankton species, and density of zooplankton groups. By relating these biological parameters to physico-chemical parameters, it is possible to generally describe lakes in which no zooplankton data are available. This characterization then provides a basis for the prediction of impacts on lake ecosystems in the Study Area.

METHODS

Study Area

The Study Area includes 2130 sq mi of Lake and St. Louis counties in northeastern Minnesota (Figure 1). This area is divided into two major watersheds by the Laurentian Divide. Water north of this divide flows to Hudson Bay and water south of this divide flows to Lake Superior. Lakes within the Study Area range from shallow and bog-stained to deep and clear. In most cases they could probably be classified as mesotrophic or meso-entrophic.

Study Lakes

Zooplankton were sampled from lakes located in the portion of the Study Area closest to the mineral potential zone. Lakes sampled were located north and south of the Laurentian Divide (Figure 1). These lakes had various morphometric and chemical characteristics (Table 1).

In 1976 lakes were classified as primary or survey to indicate sampling intensity (Table 2). Lakes were selected on the basis of their potential for impact. Five primary lakes, one lake with high potential for impact and one lake with low potential for impact from both north and south of the Laurentian Divide were chosen. In addition, Birch Lake was chosen as a primary lake because of its high potential for impact and its importance in the Study Area. A further criteria for primary lakes was that their ecological classification by the Minnesota Department of Natural Resources (MDNR) be similar. All primary lakes were soft water walleye lakes except for Colby Lake which was a centrarchid-walleye lake. Two stations were located on primary lakes except Birch Lake, which had four stations because of its length.

Survey lakes were selected from twelve watersheds to include lakes of varying sizes, depths, and surrounding soil types (Table 1). Single stations were located on these lakes.

In 1977 14 of the original 25 lakes were chosen for repeated sampling (Table 2). The lakes retained represented a range of values of pH, alkalinity, and total organic carbon (factors affecting susceptibility to impacts) and morphometrics. Single stations were located on all lakes except Birch Lake where two stations were sampled.

Field Methods

Zooplankton samples were collected with a wisconsin-style plankton net with 80μ mesh. The net was towed from .5 m above the bottom to the surface. Samples were preserved in 5 to 10 percent formalin.

In 1976 two replicate tows from each station were analyzed. In 1977 one composite sample consisting of three individual tows from each station was analyzed. Detailed methods can be found in another report (see Regional Copper-Nickel Study 1977).

Laboratory Methods

All 1976 samples were analyzed by staff of Ecology Consultants, Incorporated, Fort Collins, Colorado, using a Borgoreu counting chamber and a 50-70X dissecting microscope. Some rotifers and copepods were removed and identified with a compound microscope at 100-400X. A sufficient subsample was analyzed so that approximately 300 organisms were counted.

All 1977 samples were analyzed by project staff. Rotifers and protozoa were counted in a Sedgewick-Rafter cell with a 100-200X compound microscope. Cladocerans and copepods were counted under a dissecting scope. Copepods were differentiated to suborder only (i.e. Calanoida, Cyclopoida) because most individuals were immature and could not be further identified.

Detailed analysis procedures are described in another report (Regional Copper-Nickel Study 1977).

Sampling Frequency

Sampling frequency is shown in Table 2. In 1976 primary lakes were sampled five times and survey lakes sampled twice. In 1977 lakes were sampled twice.

RESULTS AND DISCUSSION

Temporal Patterns of Zooplankton Densities

The mean numbers of rotifers, cladocerans, and copepods found in primary lakes in 1976 are plotted in Figures 2 through 4. Rotifers (Figure 2) generally increased in numbers from ice-out to their October maximum. Seven Beaver Lake was not sampled later than August but had very large population at that time. Only Gabbro Lake was not at its peak density in October, having peaked a month earlier.

The cladocerans (Figure 3) reflect a similar pattern. Total density was greatest in September, followed by a decline in October. Again, Seven Beaver stands out because of its unusually high densities of animals. As with rotifers, the cladacerans in Gabbro Lake reach peak density and begin to decline one month earlier than the other lakes.

The seasonal pattern for copepods (Figure 4) was much less synchronous between lakes than the rotifers and cladocerans. Birch, Gabbro, and White Iron lakes reached their maxima early in the summer and decreased through the fall. Seven Beaver and Colby lake populations increased steadily throughout the year. Overall, the density of copepods varied less between the five lakes than did rotifers and cladocerans.

Several years of data would be needed to confirm these seasonal patterns since few data exist on the seasonal dynamics of zooplankton.

<u>Overall Mean Densities and Number of Taxa</u>

The mean density and the number of rotifer and cladoceran taxa from all samples in each lake are shown in Table 3. The number of copepod taxa is not presented because so few individuals were identified past suborder. Because of the unequal sampling effort between lakes, comparisons of mean densities and number of taxa from Table 3 only suggests trends.

Highest rotifer densities occurred in Seven Beaver, Pine, Sand, and Long lakes, all shallow, bog-stained lakes. Lowest densities of rotifers occurred in Tofte, Bass, Bear Island, and Clearwater lakes, all deep and clear lakes, and in Wynne Lake and Whiteface Reservoir, which are deep but bog-stained. The highest cladoceran density occurred in Seven Beaver and Cloquet, both shallow and bog-stained, while the lowest densities occurred in Triangle, Clearwater, and Bear Island lakes, all deeper and clearer than the average lake studied. Copepod density varied less over the Study Area than rotifer and cladoceran densities. Birch Lake had the highest copepod density while Seven Beaver Lake had the second highest density.

The data generally indicate that deep, clear lakes have lower zooplankton populations than the shallow, colored lakes. In order to statistically test this statement, data were compiled from thirteen lakes sampled during the same four time periods (Group A lakes) [1]. Table 4 presents the mean rotifer, cladoceran, and copepod abundances in the Group A lakes averaged over four sampling periods: June/July, 1976; October, 1976; April, 1977; and July, 1977. Two clear, deep lakes (Tofte and Base lakes) and two shallow, colored lakes (Seven Beaver and Sand lakes) were included in the Group A lakes. Clear, deep lakes were defined as having a mean depth exceeding 5 meters and color less than 50 Pt-Co units; shallow, colored lakes were defined as having a mean depth of less than 3 meters and color greater than 80 Pt-Co units. Another set of subgroups of lakes in Group A was developed based on the Trophic State Index (TSI) values found in Table 1. The TSI provides a measure of potential productivity based on the median phosphorus concentrations in the lake (Regional Copper-Nickel Study 1978).

The t-statistic was calculated for three comparisons of rotifer, cladoceran, and copepod densities in Group A lakes using a pooled estimate of within-lakes variance based on all the data in Table 4. First, lakes with low TSI values (Tofte, Bass, Bearhead, and Bear Island) were compared to the remaining Group A lakes; second, the low TSI lakes were compared to the

---

[1]Seven Beaver Lake was not sampled in October, 1976, so data from Seven Beaver Lake were averaged over three dates.

high TSI lakes (Sand and Seven Beaver); and finally, the clear deep lakes (Tofte and Bass) were compared to the two shallow, colored lakes (Seven Beaver and Sand). All contrasts were significant for each zooplankton group (Table 4). Thus, the data from the lakes sampled more frequently support the trends suggested by the mean zooplankton densities presented in Table 3.

Trends in the number of rotifer and cladoceran taxa in each lake (Table 3) also suggest that the deep, clear lakes have fewer taxa and thus lower diversity than the shallow, colored lakes. The number of taxa was found to be highly correlated with the number of sampling dates in a lake. The correlation coefficients for numbers of taxa and number of sampling dates are 0.80 for rotifers ($n=25$, $p<.01$) and 0.75 for cladocerans ($n=25$, $p<.01$). Thus, a comparison of the number of taxa found in each lake was made for Group A lakes (Table 5). On the average, the Group A lakes contain 17 rotifer and 8 cladoceran taxa, but there is no clear pattern relating the number of zooplankton taxa and lake types.

Most Frequently Occurring and Dominant Zooplankton

Tables 6, 7, and 8 list the taxa collected in each major zooplankton group, their frequency of occurrence, and the percentage of lakes in which a taxa occurs as a seasonal dominant. "Dominant" taxa, by definition, comprised ten percent or more of the ice-free seasonal mean for their group. Dominant copepods are not given because so few individuals were identified past the suborder level. Tables 6 and 7 indicate that a small group of taxa dominate the rotifer and cladoceran communities. Only six rotifers and eight cladocerans from 46 rotifers and 19 cladocerans taxa appeared as a dominant in a Study Area lake. If those taxa which occur in at least 20 percent of the pooled samples (Tables 6 and 7) are included with the dominants the number of "important" taxa is expanded to 15 rotifers and 10 cladocerans.

Because only a few copepods were identified beyond the suborder level, no calculations of dominance are possible. However, the frequency of occurrence of copepod taxa in the 1976 samples (Table 8) serves to indicate which taxa are typically present in the region. Three copepods (Tropocyclops prasinus, Cyclops bicuspidatus thomasi, and Diaptomus oregonensis) are present in more than 72 percent of the lakes and more than 68 percent of the samples. These species probably dominate the copepod community. Three other species, Epischura lacustris, Cyclops vernalis, and Mesocyclops edax, are present in more than twenty percent of the samples.

Both the number of dominant taxa and frequency of occurrence of widespread taxa have been used to characterize zooplankton communities (Patalas 1971). However, since dominance is based on seasonal means, determination of dominant taxa should be based on samples collected at comparable times. For this reason, the seasonal mean densities of the 25 most "important" taxa were calculated for Group A lakes and summarized in Tables 9 and 10.

Among the rotifers, Keratella cochlearis was dominant in all Group A lakes and was present in every lake at all four sampling times. Polyarthra vulgaris was present in 98 percent of all samples. Only four other rotifers, Keratella longispina, Conochilius sp., Synchaeta sp., and Kellicottia bostoniensis were ever dominant, although they were frequently collected.

Thirteen or more of the fifteen frequently collected rotifer taxa appear in seventy percent of the Group A lakes. All Group A lakes had two to four dominant rotifers.

Patterns of dominance in the cladocerans are similar to those of rotifers. Bosmina longirostris is dominant in 10 of 13 lakes and Daphnia galeata mendotae in 8 of 13 lakes. Only Pine Lake has only one dominant cladoceran, while the rest of the Group A lakes have two or three. Seven of the 10 frequently collected cladocerans were collected in 77 percent of the Group A lakes.

Tables 9 and 10 include the total mean density of the most frequently occurring taxa and the total mean density of all taxa collected for rotifers and cladocerans. In Group A lakes the total density for the most frequently occurring taxa account for greater than 85 percent of the total mean density for rotifers and cladocerans. Thus, those taxa which are rarely collected contribute very little to the overall density of rotifers and cladocerans. Group A lakes are generally representative of Study Area lakes; therefore, Tables 9 and 10 present an overview of the cladoceran and rotifer communities found in the Study Area.

Comparison With Other Lakes

Shagawa Lake, located within the Study Area, has been intensively sampled by the Environmental Protection Agency over the past few years. Shagawa Lake has supported dense algal blooms since early in this century as a result of municipal sewage effluent. Since 1973 an advanced tertiary wastewater treatment plant has removed more than 99 percent of the phosphorus in the effluent. Late summer blue-green algae still persist, however, probably utilizing nutrients stored in the sediments.

The summer means of zooplankton collected weekly from June 23, 1976, to September 15, 1976, are presented in Table 11. As expected, Shagawa Lake has much higher densities of zooplankton than any of the other lakes sampled in the Study Area. Rotifers are an order of magnitude more dense in Shagawa than in Seven Beaver Lake, a lake with very high rotifer densities. Keratella cochlearis and Polyarthra vulgaris are the dominant rotifers in Shagawa Lake as they are in most Study Area lakes. Fifteen rotifer taxa were recorded from Shagawa Lake during the summer of 1976 of which ten can be found in the most frequently collected group (Table 9). Only one genus, Anuraeopsis, is found in Shagawa but no other Study Area lake sampled.

The cladoceran fauna observed in Shagawa Lake is also characteristic of the Study Area lakes. A mean summer density of 76,000 animals/m^3 is not much higher than in Seven Beaver Lake (60,000 animals/m^3). Piragis and Piragis (1978) suggest that high predation rates on large cladocerans may maintain the low densities in Shagawa Lake.

Copepods like rotifers are much less common in other Study Area lakes than in Shagawa Lake. Thus, while Shagawa Lake may be more productive than other Study Area lakes, composition of the zooplankton community is similar.

Patalas (1971) studied the crustacean plankton (copepods and cladocerans) in 45 lakes of the Experimental Lakes Area (ELA) of northwestern Ontario. Twenty-eight species were recorded by Patalas of which only six were not found in the Study Area lakes. Of the 31 crustaceans identified from Study Area lakes, only eight were not found in ELA lakes. Based on this information, the zooplankton crustacean community in ELA lakes is very similar to that in the Study Area.

SUMMARY

Study Area lakes are characterized by similar zooplankton communities. Some pattern does exist as clear, deep lakes are generally less productive than shallow, stained lakes. Zooplankton productivity also appears to be related to the Trophic Status Index of a lake. Zooplankton densities in Study Area lakes appear to reach their maxima in late summer and early fall.

A small group of taxa are common in Study Area lakes. These taxa are usually the dominants and are present throughout the ice-free season. The rare taxa, which are never seasonally dominant, are present in only a small number of lakes. All lakes have the most common taxa, the rotifers, Keratella cochlearis and Polyarthra vulgaris, and the cladocerans, Bosmina longirostra and Daphnia galeata mendotae, which are the most abundant and widespread taxa in the Study Area.

Based on the zooplankton species, Study Area lakes are similar to lakes in the ELA.

REFERENCES CITED

Patalas, K. 1971. Crustacean plankton communities in forty-five lakes in the Experimental Lakes Area, northwestern Ontario. J. Fish. Res. Board Canada 28:231-244.

Piragis, S.J. and N.E. Piragis. 1978. Report to the EPA on zooplankton densities and grazing rates in Shagawa Lake, Minnesota, during the summer of 1976. EPA inhouse report. In Press.

Regional Copper-Nickel Study. Johnson, M.D. et al. 1977. Operations manual-aquatic biology. Minnesota Environmental Quality Board, St. Paul, MN.

Regional Copper-Nickel Study. Mustalish, R. 1978. Water Quality. Minnesota Environmental Quality Board, St. Paul, MN.

Table 1. Physical and chemical characteristics of lakes sampled biologically and reasons for sampling.

LAKE	WATERSHED	SURFACE AREA-Km^2	DEPTH (m)	pH[a]	COLOR[a]	ALKALINITY[a]	CONDUCTIVITY[a]	TSI[b] (P)	POTENTIAL FOR CU-NI IMPACTS DIRECT[c]	INDIRECT[d]	REASON FOR SAMPLING[e]
Birch	Birch	25.62	4.15	7.1	54.9	23.4	68.6	49	high	high	1
Colby	Partridge	2.24	3.13	7.1	133.75	33.0	152.65	51			
Gabbro	Isabella	3.63	3.66	7.25	100.25	17.75	48.25	48	low	low	2, 10
Seven Beaver	St. Louis	5.63	1.46	6.5	172.5	13.67	47.75	54	med	med	1, 3
White Iron	Kawishiwi	13.85	6.00	6.95	73.75	17.15	51.25	49	high	med	1
Bass	Range	.68	5.51	8.15	6.5	32.0	79.5	47	low	low	3
Bearhead	Vermilion	2.74	4.49	7.85	26.0	23.5	68.0	40	low	low	3, 9
Bear Island	Bear Island	8.64	8.74	7.4	39.5	15.5	44.25	47	low	low	3
Big	Partridge	3.21	--	7.6	14.0	25.0	62.0	61	med	med	3, 4, 7
Clearwater	Kawishiwi	2.61	7.44	6.7	2.0	16.0	39.0	54	low	low	4, 7
Cloquet	Cloquet	0.74	.85	7.2	90.0	21.0	54.0	55	low	low	3
Fall	Fall	8.93	3.99	6.7	45.0	16.0	43.0	51	med	low	3, 5
Greenwood	Stony	5.06	1.27	6.65	170.0	8.0	50.0	60	low	med	3
Long	St. Louis	1.79	.50	7.1	30.0	14.0	46.0	46	low	med	4, 7
One	Kawishiwi	3.55	3.14	6.7	27.0	15.0	27.0	52	low	low	3, 4
Perch	Bear Island	0.44	2.30	6.5	82.5	7.5	28.5	51	low	low	4, 7
Pine	St. Louis	1.77	2.34	7.8	102.5	18.0	59.5	52	low	med	4, 7
Sand	Stony	2.05	1.45	7.25	80.0	21.5	63.5	60	low	med	3
Slate	Stony	0.93	1.51	6.8	180.0	21.0	51.0	--	low	med	4
South McDougal	Stony	1.12	.51	6.7	260.0	11.0	36.0	55	low	med	4
Tofte	Moose Lake	0.47	10.73	8.55	3.0	70.5	147.5	38	low	low	4, 9, 10
Triangle	Moose Lake	1.32	3.99	7.7	2.0	34.0	65.0	46	low	low	9
Turtle	Isabella	1.36	1.13	6.85	30.0	8.5	26.0	50	low	low	4, 9
Whiteface Res.	Whiteface	17.22	3.15	7.05	137.5	19.75	57.5		low	low	1, 3, 5
Wynne	Embarrass	--	11.1	7.2	110.0	42.5	139.0	43	low	low	3

Table 1 (contd.)

[a]Summertime averages (June, July, and August data) from Water Quality Programs.

[b]TSI (P) = Carlson's Trophic State Index based on median total phosphorus concentrations.

[c]Potential direct impact: Lake may receive effluents either directly from mining operation or tailings basin, or receives water from a directly impacted watershed.

[d]Potential indirect impact: Lake may receive impacted water "second hand," or is in area likely to receive air-borne contaminates.

[e]1. Likely to be impacted by copper-nickel development
2. Not likely to be impacted ("control")
3. Represents a particular watershed
4. Chosen because of a prevailing soil type and/or percent predominant slope
5. Receives water from large watershed
6. Receives water from small watershed
7. No inlet
8. No outlet
9. Neither inlet nor outlet
10. Chosen because of greater maximum depth

Table 2. Frequency of zooplankton sampling during the Regional Copper-Nickel Study.

	YEAR	1976					1977		
LAKE	MONTH	V	VI/VII	VIII	IX	X	IV	VII	PRIMARY/SURVEY
Birch		X	X	X	X	X	X	X	Primary
Seven Beaver		X	X	X			X	X	"
White Iron		X	X	X	X	X	X	X	"
Colby		X	X	X	X	X	X	X	"
Gabbro		X	X	X	X	X			"
Pine			X			X	X	X	Survey
Bass			X			X	X	X	"
Bear Head			X			X	X	X	"
Perch			X			X	X	X	"
Sand			X			X	X	X	"
Greenwood			X			X		X	"
Tofte			X			X	X	X	"
Turtle			X			X	X	X	"
Wynne			X			X	X	X	"
Bear Island			X			X	X	X	"
Fall			X			X			"
Long			X						"
Big			X			X			"
Slate			X			X			"
So. McDougal			X			X			"
One			X			X			"
Cloquet			X			X			"
Triangle			X			X			"
Whiteface						X			"
Clearwater			X			X			"

Table 3. Mean density of rotifers, cladocerans, and copepods averaged over all sample dates and sites and number of taxa/lake in each group except copepods.

LAKE	#SAMPLE DATES	#ROTIFERA TAXA	$\overline{D}$ ROTIFERA	#CLADOCERA TAXA	$\overline{D}$ CLADOCERA	$\overline{D}$ COPEPODA (excluding Naupiii)
PRIMARY LAKES						
Birch	7	21	39,631	10	10,416	14,470
Colby	7	26	35,757	11	6,834	5,538
Gabbro	5	20	38,090	9	8,089	9,000
Seven Beaver	5	23	141,328	11	59,777	13,510
White Iron	7	21	30,619	9	8,410	9,444
SURVEY LAKES						
Bass	4	11	9,953	6	1,850	3,384
Bearhead	4	19	25,476	8	1,691	2,636
Bear Island	4	16	7,678	8	1,281	2,126
Big	2	12	16,294	6	7,858	3,950
Clearwater	2	10	4,788	7	1,119	2,448
Cloquet	2	11	35,906	8	39,930	7,346
Fall	2	12	32,426	9	2,166	6,009
Greenwood	3	12	45,573	5	3,625	3,824
Long	1	13	93,000	4	5,250	4,500
One	2	12	10,812	7	4,036	9,125
Perch	4	16	19,994	6	1,563	3,003
Pine	4	21	51,792	9	6,507	5,180
Sand	4	15	63,499	8	2,386	6,202
Slate	2	8	31,816	4	1,565	1,275
So. McDougal	2	11	39,645	5	6,349	4,178
Tofte	5	14	5,718	8	1,887	3,836
Triangle	2	14	18,515	4	600	3,162
Turtle	4	16	28,380	8	5,156	4,158
Whiteface Res.	1	7	9,216	5	3,699	4,284
Wynne	4	9	7,811	9	2,323	2,285
MEAN	4	17.7	36,123	8.6	8,440	6,055

Table 4. Mean rotifer, cladoceran, and copepod density for Group A lakes* averaged over four sampling periods in 1976 and 1977.

LAKE	MEAN TOTAL ROTIFERS	MEAN TOTAL CLADOCERANS	MEAN TOTAL COPEPODS (excluding nauplii)	COLOR/DEPTH	TSI
Tofte	5,177	2,215	3,312	Clear/deep	low
Bear Island	7,678	1,280	2,125		low
Wynne	7,812	2,323	2,287		med
Bass	9,951	1,850	3,384	Clear/deep	low
Perch	19,994	1,562	3,003		med
Bear Head	25,474	1,691	2,634		low
Turtle	28,393	5,155	4,158		med
White Iron	32,741	6,326	7,703		med
Colby	35,816	4,301	4,327		med
Birch	44,028	5,010	10,019		med
Pine	51,793	6,505	5,178		med
Sand	63,500	2,386	6,670	Colored/Shallow	high
Seven Beaver**	124,169	43,635	14,829	"	high

*Group A lakes were sampled in June/July, 1976, October, 1976, April, 1977, and October, 1977.
**Three dates only.

Levels of significance for t-test comparisons of Group A lakes.

CONTRAST	P VALUES		
	ROTIFERS	CLADOCERANS	COPEPODS
Low TSI Lakes vs. all others	.001	.003	.019
Low TSI Lakes vs. High TSI Lakes	.000	.000	.004
Clear, deep lakes vs. shallow, colored lakes	.000	.000	.020

Table 5. Total numbers of rotifer and cladoceran taxa found on four dates in Group A* lakes arranged by increasing TSI values.

LAKE	TSI	DEPTH/COLOR	NUMBER OF ROTIFER TAXA	NUMBER OF CLADOCERAN TAXA
Tofte	low	deep/low	14	8
Bass	low	deep/low	12	6
Bear Island	low	med	16	8
Bear Head	low	med	19	8
Wynne	med	med	9	9
Turtle	med	med	16	8
Perch	med	med	16	6
Pine	med	med	21	9
Colby	med	med	18	11
White Iron	med	med	20	8
Birch	med	med	20	20
Sand	high	high	16	8
Seven Beaver	high	high	23	10
MEAN			16.9	8.3
STANDARD DEVIATION			3.84	1.4

*Group A lakes were lakes sampled on four dates: June/July, 1976; October, 1976; April, 1977; and July, 1977. For Seven Beaver, August, 1976 data has substituted for missing October, 1976 data.

Table 6. Frequency of occurrence of rotifera taxa in study lakes, and in all pooled samples* and the percentage of lakes in which the taxa occurred as a dominant species.

TAXA	PERCENTAGE OF LAKES IN WHICH TAXA OCCURS	PERCENTAGE OF ALL POOLED SAMPLES IN WHICH TAXA OCCURS	PERCENTAGE OF LAKES IN WHICH TAXA OCCURS AS DOMINANT SPECIES
Keratella cochlearis	100	100	96
Polyarthra vulgaris	100	100	76
Synchaeta sp.	96	62	16
Conochilus sp.	92	87	44
Kellicottia congispina	88	86	24
Trichocera cylindrica	88	57	0
Kellicottia bostoniensis	68	48	0
Collotheca sp.	60	29	0
Trichocera similis	60	37	0
Filinia longiseta	52	26	0
Keratella quadrata	52	31	0
Ploesoma truncatum	48	15	0
Pompholyx sulcata	48	23	0
Trichocera porcellus	48	35	0
Hexathra sp.	44	15	0
Ploesoma lenticulare	44	15	0
Unidentified rotifers	44	14	0
Lecane sp.	36	15	4
Trichocera multicrinis	28	8	0
Asplanchna sp.	27	74	0
Lophochavis salpine	16	6	0
Trichocera weberi	16	5	0
Brachionus sp.	12	4	0

*Pooled samples are all replicates from all stations on one lake on one date

Table 6. Frequency of occurrence of Rotifera taxa in study lakes and in all pooled samples* and the percentage of samples in which the taxa occurred as a dominant species (contd.)

TAXA	PERCENTAGE OF LAKES IN WHICH TAXA OCCURS	PERCENTAGE OF ALL POOLED SAMPLES IN WHICH TAXA OCCURS	PERCENTAGE OF LAKES IN WHICH TAXA OCCURS AS DOMINANT SPECIES
Lophocharis sp.	12	6	0
Trichocera elongata	12	4	0
Trichocera longiseta	12	5	0
Ascomorpha sp.	8	4	0
Enchlanis dilatata	8	5	0
Hexarthra mira	8	4	0
Ploesoma hudsoni	8	2	0
Testudinella patina	8	4	0
Tnchocera sp.	8	2	0
Trichotria tetractis	8	4	0
Ascomorpha ovalis	4	1	0
A. saltans	4	1	0
Bdelloid sp.	4	1	0
Brachionus quadridentatus	4	1	0
Cephalodella intuda	4	1	0
Euchlanis sp.	4	1	0
Keritella hiemalis	4	2	0
K. paludosa	4	1	0
K. serrulata	4	1	0
K. taurocephala	4	1	0
Notholca acuminata	4	1	0
Notholca sp.	4	1	0
Rotaria peturia	4	1	0
Synchaeta stylata	4	1	0

*Pooled samples are all replicates from all stations on one lake on one date averaged.

Table 7. Frequency of occurrence of Cladocera taxa in study lakes and in all pooled samples* and the percentage of samples in which the taxa occurred as a dominant species. (contd.)

TAXA	PERCENTAGE OF LAKES IN WHICH TAXA OCCURS	PERCENTAGE OF ALL POOLED SAMPLES IN WHICH TAXA OCCURS	PERCENTAGE OF LAKES IN WHICH TAXA OCCURS AS DOMINANT SPECIES
Cladocera			
Bosmina longirostris	100	94	68
Daphnia galeata mendotae	84	75	52
Holopedium gibberum	84	61	12
Daphnia retrocurva	80	59	44
Diaphanosoma sp.	76	55	28
Chydorus sphaericus	72	46	24
Ceriodaphnia lacustris	48	27	0
Daphnia pulex	44	24	8
Leptodora kindtii	40	29	0
Daphnia shodleri	36	17	4
Alona circumfimbriata	20	6	0
Ceriodaphnia quadrangula	8	2	0
Alona guttata	4	1	0
Ceriodaphnia sp.	4	2	0
Chydorus bicornutus	4	1	0
Daphnia catawba	4	1	0
Daphnia longiremis	4	2	0
D. parvula	4	1	0
D. sp.	4	1	0

*Pooled samples are all replicates from all stations on one lake on one date averaged.

Table 8. Frequency of occurrence of Copepoda taxa in lakes and in pooled samples*.

TAXA	PERCENTAGE OF LAKES IN WHICH TAXA OCCURS	PERCENTAGE OF ALL POOLED SAMPLES IN WHICH TAXA OCCURS
Tropocyclops prasinus (Cyclopoida)	96	90
Cyclops bicuspidatus thomasi (Cyclopoida)	72	58
Diaptomus oregonensis (Calanoida)	72	68
Epischura lacustris (Calanoida)	48	31
Cyclops vernalis (Cyclopoida)	44	34
Mesocyclops edax (Cyclopoida)	40	35
Diaptomus minutus (Calanoida)	20	11
Ergasilis chautaquaensis (Cyclopoida)	16	10
Macrocyclops albidus (Cyclopoida)	16	6
Eucyclops agilis (Cyclopoida)	12	5
Orthocyclops modestus (Cyclopoida)	12	5
Diaptomus sicilis (Calanoida)	8	8

*Pooled samples are all replicates from all stations on one lake on one date averaged.

Table 9. sonal[a] mean density ($\bar{D}/m^3$) and frequency of occurrence (F) of the most frequently collected rotif s (FCR)[b] in Group A lakes. Density of dominant taxa for each lake is underlined.

ROTIFERA	BIRCH D	f	SEVEN BEAVER D	f	WHITE IRON D	f	COLBY D	f	PINE D	f	BASS D	f	BEARHEAD D	f	PERCH D	f	SAND D	f	TOFTE D	f	TURTLE D	f	WYNNE D	f	BEAR ISLAND D	f
1) Asplanchna sp.	939	4	3,365	4	154	2	17	1	269	2	25	2	696	4	214	3	236	1	180	4	685	4	19	1	26	1
2) Collotheca sp.	222	2	990	1	14	1	22	1	334	2	60	1	87	1	132	2	0	0	42	2	1,082	2	0	0	24	1
3) Conochilus sp.	3,833	4	<u>32,002</u>	4	<u>9,092</u>	4	885	3	1,120	3	356	2	535	1	<u>6,050</u>	4	3,629	4	28	2	1,935	4	0	0	<u>925</u>	3
4) Filinia longiseta	426	1	898	2	60	3	0	0	561	1	243	2	0	0	47	1	238	2	20	2	204	2	0	0	5	1
5) Kellicottia bostoniensis	74	2	2,926	2	<u>4,268</u>	3	164	2	13	1	789	3	0	0	67	2	21	1	28	2	0	0	6	1	33	2
6) K. longispina	<u>9,820</u>	4	4,515	3	<u>2,632</u>	3	1,287	3	432	4	<u>1,261</u>	4	1,398	4	32	2	1,748	4	<u>1,483</u>	4	0	0	679	4	<u>2,985</u>	4
7) Keritella cochlearis	<u>14,357</u>	4	<u>92,912</u>	4	<u>9,586</u>	4	<u>23,666</u>	4	<u>31,497</u>	4	<u>4,471</u>	4	<u>9,348</u>	4	<u>7,760</u>	4	<u>49,842</u>	4	<u>792</u>	4	<u>18,486</u>	4	<u>4,719</u>	4	<u>2,162</u>	4
8) K. quadrata	1,072	2	826	1	51	2	615	4	46	1	90	1	69	2	118	1	31	1	28	3	306	1	0	0	45	2
9) Lecane sp.	2	1	0	0	0	0	22	1	65	1	0	0	161	1	0	0	0	0	0	0	638	2	6	1	0	0
10) Polyarthra vulgaris	<u>11,309</u>	4	10,861	4	<u>5,961</u>	4	<u>5,140</u>	4	12,974	4	<u>2,494</u>	4	<u>9,915</u>	4	<u>4,211</u>	4	5,075	4	<u>807</u>	3	2,986	4	<u>1,034</u>	4	<u>781</u>	4
11) Pompholyx sulcata	1,075	1	6,355	3	536	2	472	2	180	1	47	1	92	1	189	1	145	2	10	1	0	0	0	0	0	0
12) Synchaeta sp.	418	2	365	2	116	2	2,598	2	769	2	0	0	601	2	16	1	124	2	<u>1,726</u>	2	123	1	160	2	219	3
13) Trichocera cylindrica	219	3	2,756	4	3	1	18	1	741	3	0	0	500	3	16	1	152	2	4	1	400	3	18	1	88	2
14) T. porcellus	77	3	762	3	48	1	6	1	0	0	0	0	61	3	113	1	64	1	0	0	0	0	0	0	68	1
15) T. similis	14	1	2,472	3	130	1	0	0	362	1	77	2	329	2	0	0	33	1	0	0	0	0	0	0	14	1
Number "selected rotifera"	15/15		14/15		14/15		13/15		14/15		11/15		13/15		13/15		13/15		12/15		10/15		8/15		13/15	
Number other rotifera	5		9		6		5		7		1		6		3		3		2		6		1		3	
Total number of rotifera	20		24		21		20		22		16		21		18		18		17		21		16		18	
Mean density of FCR	43,857		162,005		32,661		34,912		49,363		9,913		23,792		18,965		61,338		5,148		26,845		6,641		7,375	
Overall mean density	44,028		164,371		32,741		35,816		51,793		950.5		.25474		19.994		63499.5		5177.3		28392		7811.8		7677.5	
FCR density as % of total	99.0		98.6		99.8		97.5		95.3				93.4		94.9		96.6		99.43		94.6		85.01		96.1	
Number of Dominants	3		2		5		2		2		3		3		3		1		4		2		2		4	

[a]Mean based on pooled samples from June/July, 1976; October, 1976; April, 1977; and July, 1977, except for Seven Beaver, where August, 1976 data has substituted for missing October, 1976 data.

[b]Frequently collected rotifers were present in at least 20 percent of pooled samples from all lakes, all dates.

Table 10. Seasonal[a] mean density ($\bar{D}/m^3$) and frequency of occurrence (F) of the most frequently collected cladocerans (FCC)[b] in Group A lakes. Density of dominant taxa for each lake is underlined.

CLADOCERA	BIRCH D	BIRCH f	SEVEN BEAVER D	SEVEN BEAVER f	WHITE IRON D	WHITE IRON f	COLBY D	COLBY f	PINE D	PINE f	BASS D	BASS f	BEAR HEAD D	BEAR HEAD f	PERCH D	PERCH f	SAND D	SAND f	TOFTE D	TOFTE f	TURTLE D	TURTLE f	WYNNE D	WYNNE f	BEAR ISLAND D	BEAR ISLAND f
1) *Bosmia longirostris*	587	4	13,062	4	518	4	2,072	4	6,154	4	54	4	434	3	748	4	624	4	24	2	1,208	2	1,593	2	327	4
2) *Ceriodaphnia locustris*	24	3	10	1	0	0	111	1	0	0	0	0	2	1	0	0	54	2	0	0	453	2	6	1	0	0
3) *Chydorus sphaericus*	364	1	38,938	1	1,266	1	95	1	0	0	47	1	55	3	26	2	0	0	0	0	511	3	6	1	65	2
4) *Daphnia galeata mendotae*	1,560	3	18,465	4	2,271	3	1,296	4	1	1	1,367	4	872	2	25	2	943	3	1,218	3	0	0	186	3	122	2
5) *D. pulex*	4	1	859	1	16	1	165	4	108	2	222	2	152	3	136	1	210	2	0	0	0	0	21	1	0	0
6) *D. retrocurva*	2,211	4	329	1	2,053	4	126	2	1	1	128	2	2	1	0	0	102	2	726	3	220	3	401	2	377	3
7) *D. shodleri*	5	1	0	0	0	0	189	2	0	0	0	0	0	0	0	0	0	0	113	1	0	0	0	0	0	0
8) *Diaphanosoma* sp.	159	3	686	1	152	2	138	3	4	1	32	1	38	2	45	2	38	2	0	0	1,662	2	97	2	195	3
9) *Holopedium gibberum*	91	3	574	4	42	3	53	1	177	2	0	0	0	0	583	2	361	3	0	0	1,062	3	6	1	90	3
10) *Leptodora kindtii*	7	2	68	1	7	2	41	3	36	1	0	0	0	0	0	0	0	0	4	1	20	1	0	0	13	2
Number "selected cladocera"	10/10		9/10		8/10		10/10		7/10		6/10		7/10		6/10		7/10		6/10		7/10		8/10		7/10	
Number Other taxa	0		1		0		1		2		0		1		0		1		2		1		1		1	
Total number cladocerans	10		10		8		11		9		6		8		6		8		8		8		9		8	
Mean density of FCC	5,012		72,991		6,325		4,286		6,480		1,850		1,555		1,563		2,332		2,085		5,136		2,316		1,189	
Overall mean density	5010.5		73003		6326.3		4301.3		6506		1850.3		1691.3		1562.0		2386.0		2215.5		5155.5		2323.5		1280.3	
FCC density as % total	100		99.98		99.98		99.6		99.6		100		91.9		100		97.7		94.1		99.6		99.7		92.9	
Number of dominants	3		3		3		2		1		2		2		2		3		2		3		2		3	

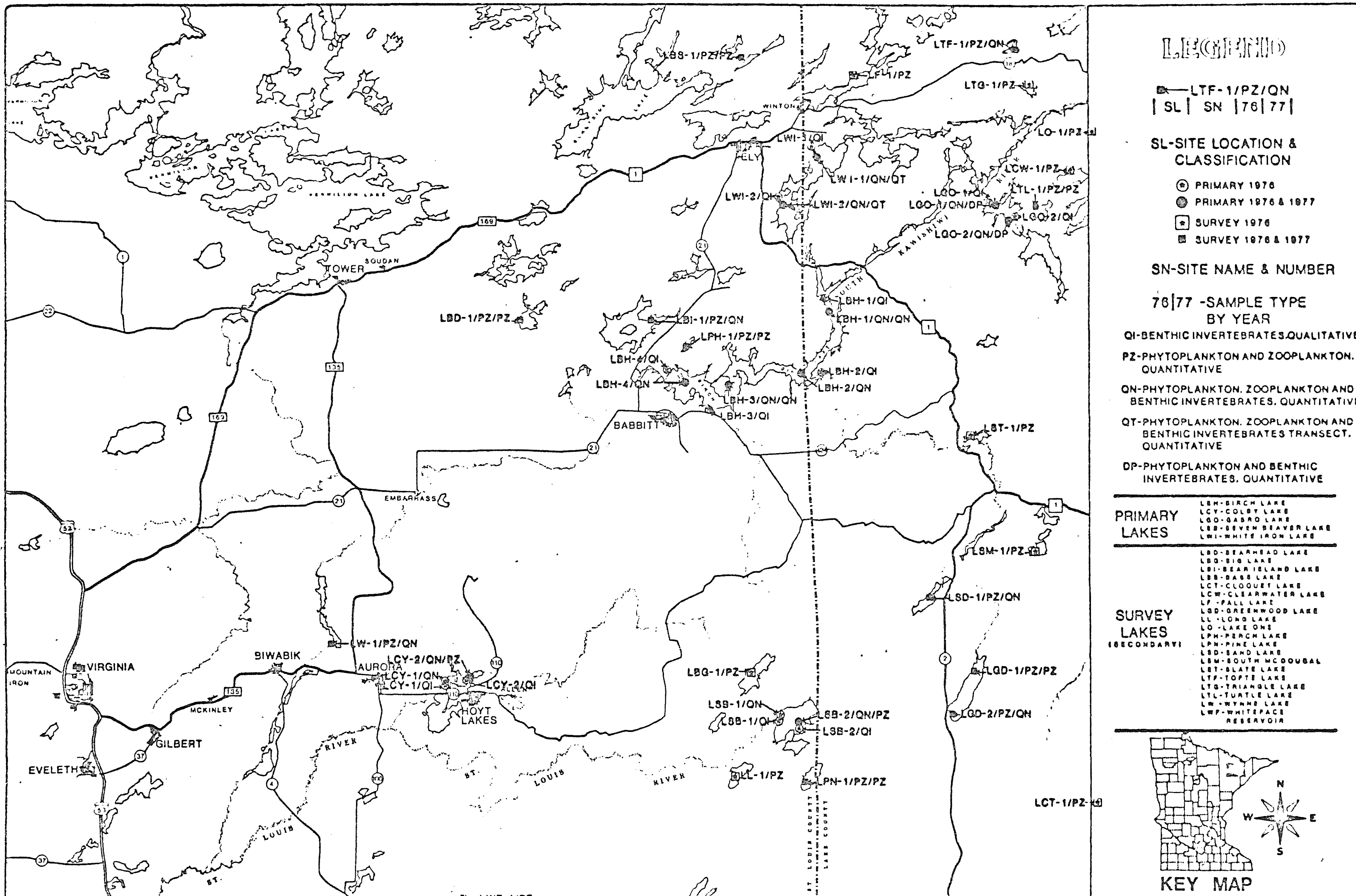
[a]Mean based on pooled samples from June/July, 1976; October, 1976; April, 1977; and July, 1977, except for Seven Beaver, where August, 1976, data has substituted for missing October, 1976, data.

[b]Frequently collected cladocerans were present in at least 20 percent of pooled samples from all lakes, all dates.

Table 11. Mean summer zooplankton density in Shagawa Lake in 1976*.

TAXA	ANIMALS M^{3}
Rotifera	
Anuraeopsis fissa	14,923
Ascomorpha orols	32,692
Conochilus sp.	36,154
Filinia longiseta	49,462
Kellicottia longispina	19,846
K. bostoniensis	4,615
*Keratella cochlearis***	1,098,846
Pompholyx sulcata	9,000
*Polyarthra vulgaris***	578,231
Trichocerca cylindrica	5,462
T. multicrinis	23,769
T. similis	36,846
T. porcellus	20,385
T. weberi	6,923
T. sp. (pusilla?)	15,615
Total Rotifera	1,952,769
Cladocera	
*Chydorus sphaericus***	59,208
Daphnia galeata mendotae	5,228
D. parvula	32
D. pulex	145
*D. retrocurva***	8,662
Diaphanosoma sp.	2,119
Holopedium gibberum	441
Leptodora kindtii	85
Total Cladocera	75,920
Protozoa	
Codonella sp.	248,769
Difflugia sp.	278,462
Copepoda	
Cyclopoida	64,608
Calanoida	2,935
Total Copepoda	67,543
Nauplii	174,615

*From Piragis and Piragis (1978).
**Dominants.



MEQB REGIONAL COPPER-NICKEL STUDY

Figure 1.

AQUATIC BIOLOGY LAKE STUDY SITES

Figure 2. Abundance of rotifers in primary lakes during 1976.

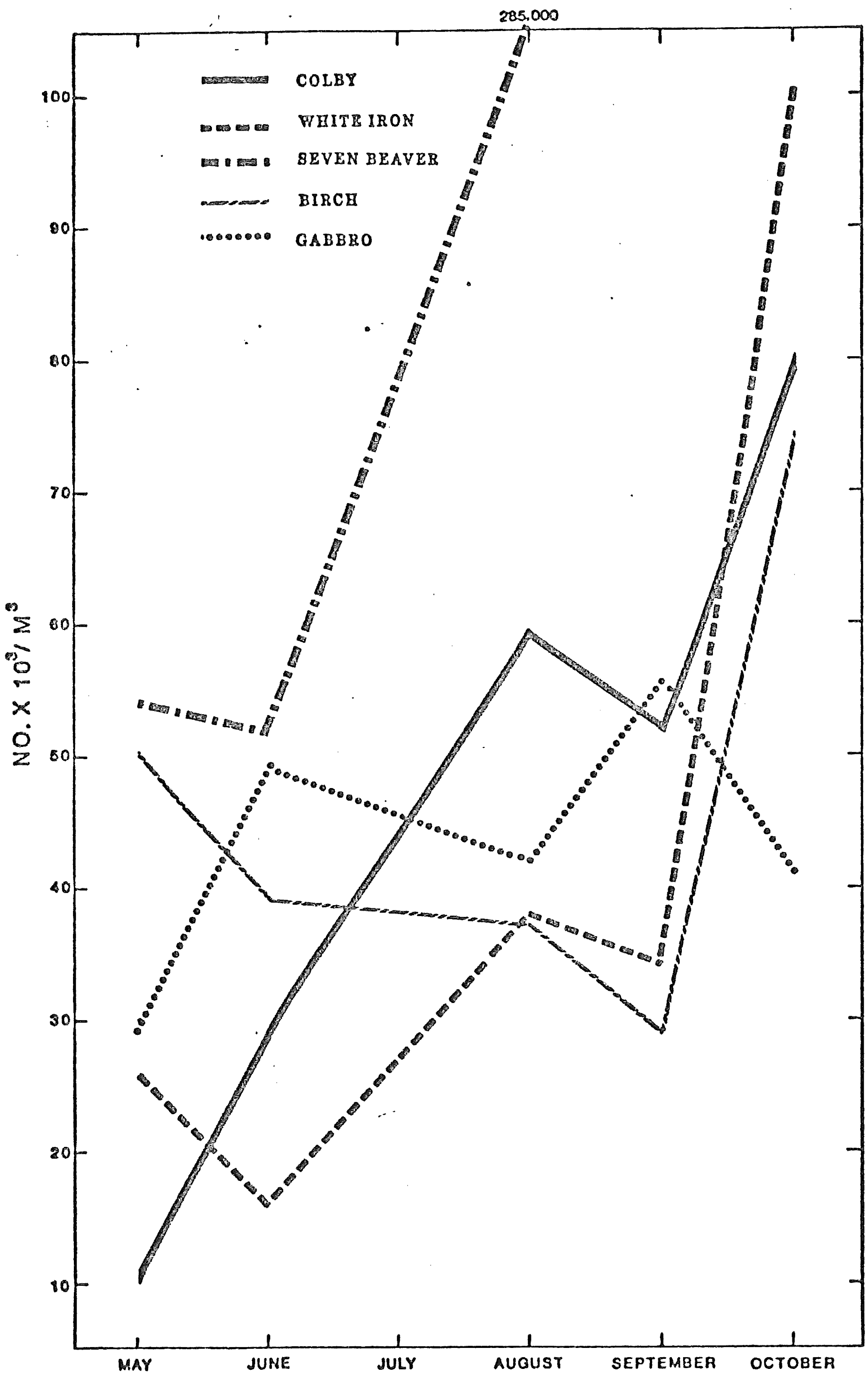


Figure 3. Abundance of cladocerans in primary lakes during 1976.

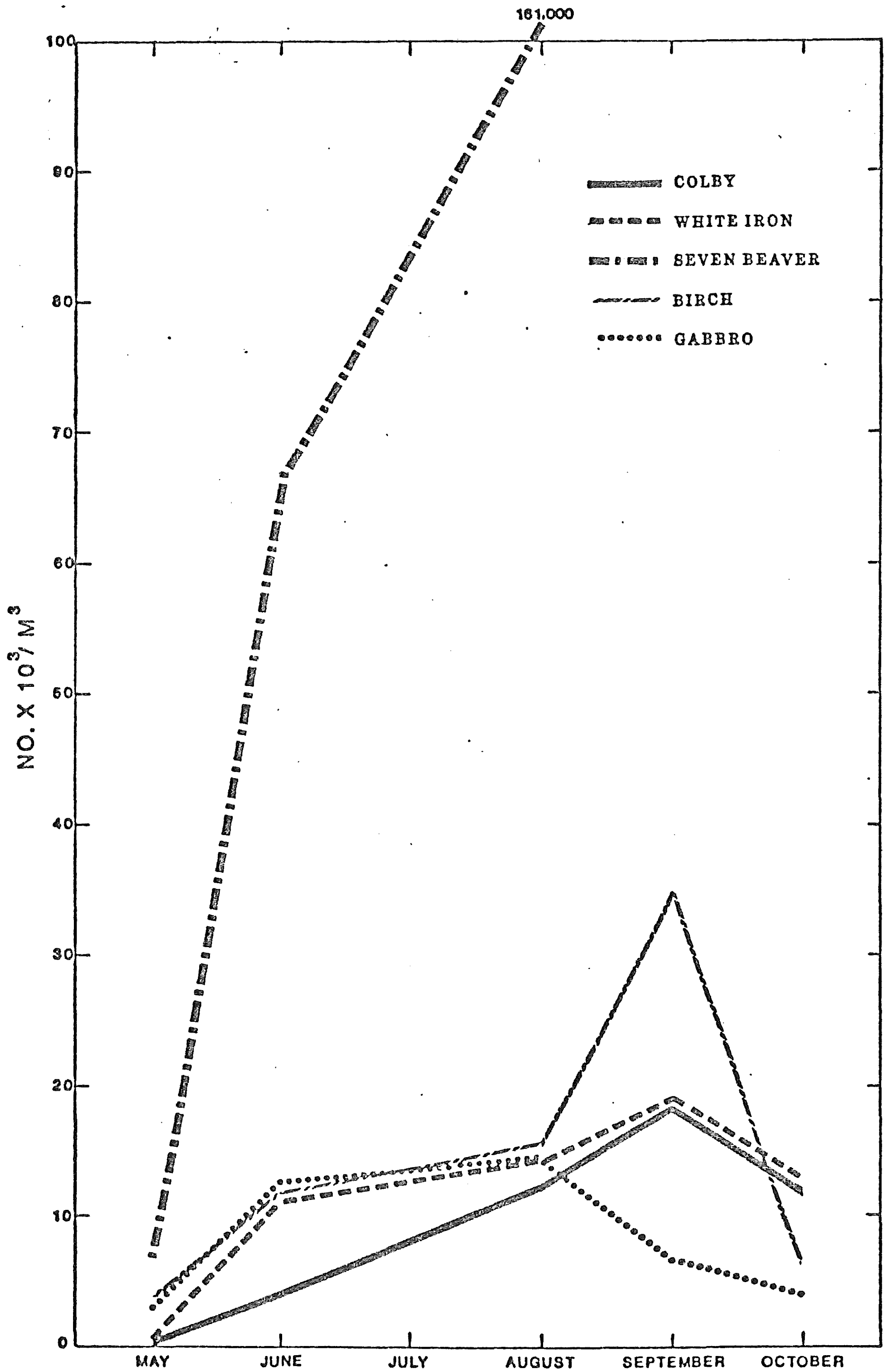


Figure 4. Abundance of copepods in primary lakes during 1976.