A survey of lentic waters with respect to dissolved and particulate lead: A final report

A SURVEY OF LENTIC WATERS WITH RESPECT TO DISSOLVED AND PARTICULATE LEAD

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A FINAL REPORT

by

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INTRODUCTION

Some of the strongest temperature inversions in the world occur at Fairbanks, Alaska. Benson (1970) has reported that a temperature gradient of 10 to 30C/100 m is common in the winter inversions that form at Fairbanks. Air pollution is especially severe during these inversions when it is accompanied by the formation of ice crystals in the air, a condition known as ice fog. This phenomenon occurs when the temperature drops below -20F (-35C) (Benson, 1970), and it intensifies with time if the inversion is not broken.

The ice crystals in this fog have been found to adsorb dust and gasses, including the lead halides which are present in the air as a result of the combustion of tetraethyl lead and/or other lead-hydrocarbon compounds used as anti-knock additives in automotive gasoline. Lazrus *et al.* (1970) have found lead concentrations in precipitation to be highly significantly correlated with the amount of gasoline used in the area sampled.

There are two factors that bring the concentration of lead to high levels in ice fogs. Evaporation of the ice crystals tends to concentrate pollutants in the air mass, especially over the core area of the city where precipitation is retarded by the heating effect of the city. Also, during the extreme cold weather accompanying this phenomenon, many people allow their cars to idle when they are parked to increase performance and for reasons of personal comfort.

Eventually, much of the pollutants suspended in the ice fog is precipitated and causes unnaturally high levels of lead in the snow. (Winchester *et al.*, 1967). It is suspected that some of this particulate lead collected in the snow may be carried along with the associated surface runoff into lentic (standing) surface waters during thawing. The objectives of this project were:

1. to measure the amount of dissolved and particulate lead in a number of selected lentic waters in the Fairbanks area, and
2. to measure the amount of lead that has been incorporated into net plankton organisms located in the selected lentic waters.

Description of Study Area

Fig. 1 is a map of the distribution of ice fog over the city of Fairbanks. The central area, within the heavy, solid line, is covered with ice fog whenever it forms. After several days, the ice fog extends out to cover the area enclosed by the dashed line, and some of the worst ice fogs observed have covered the area indicated by the lighter, solid line.

The lentic waters chosen for this study (coded alphabetically) are distributed within these areas as shown in Fig. 1. Twenty-three are located within the core area of ice fog formation, sixteen more are within the additional area covered after several days of ice fog, and eight more are in the area rarely covered by ice fog. In addition, three lakes were studied outside the ice fog area (not shown in Fig. 1). These were Harding Lake, located approximately at 64° 25' North and 146° 50' West; an unnamed lake near Prudhoe Bay, at 70° 15' 30" North and 148° 35' West; and "Chick's Lake" in Goldstream Valley, just northwest of Fairbanks at approximately 64° 55' North, 147° 52' West.

Fig. 2 is a map of the state of Alaska and shows the interior locations of the City of Fairbanks and Harding Lake and the arctic coast locations of Prudhoe Bay.

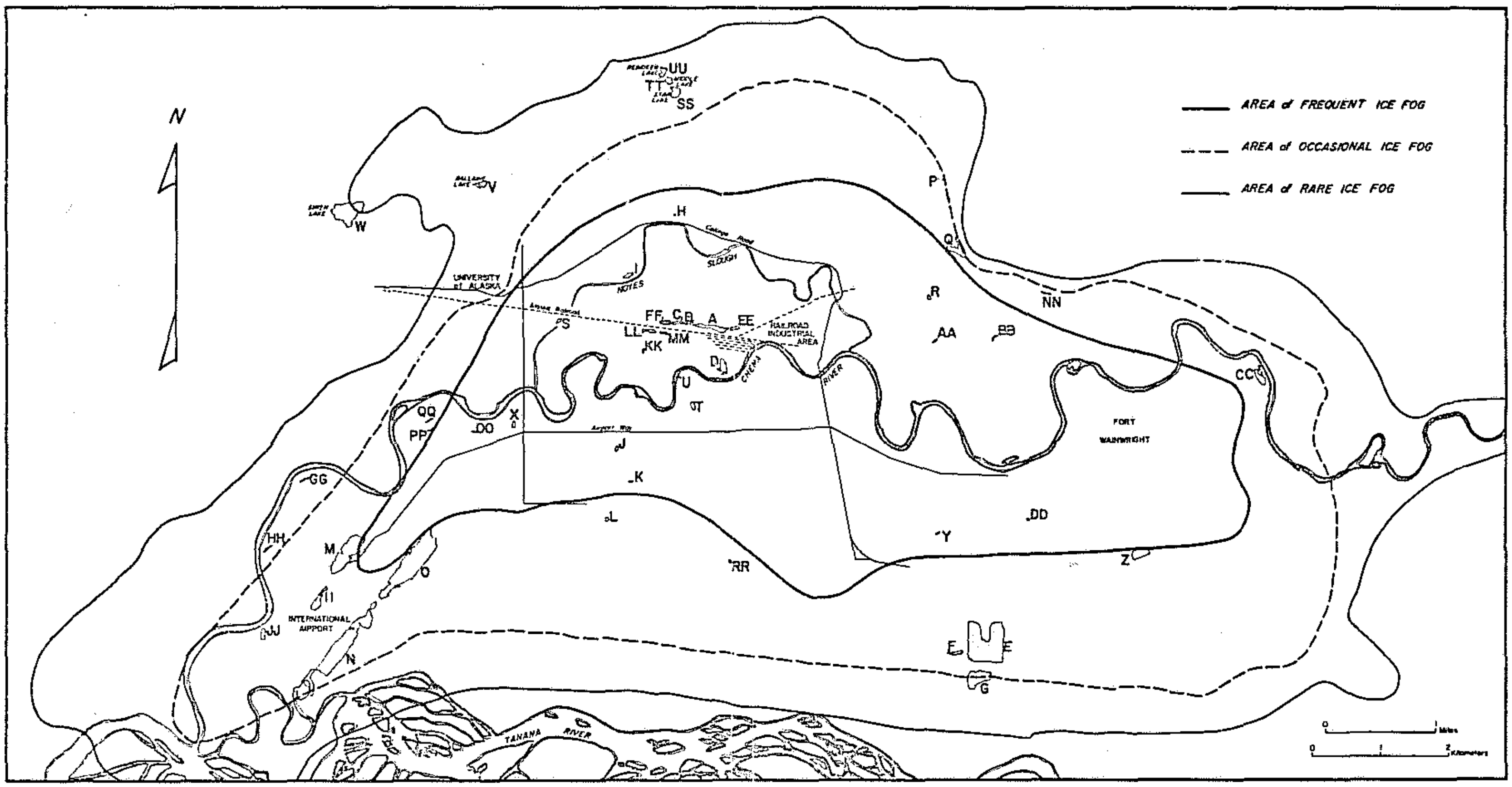

Fig. 1. Extent of observed ice fogs over the City of Fairbanks, Alaska (after Benson) and distribution of the lentic waters studied (coded alphabetically).

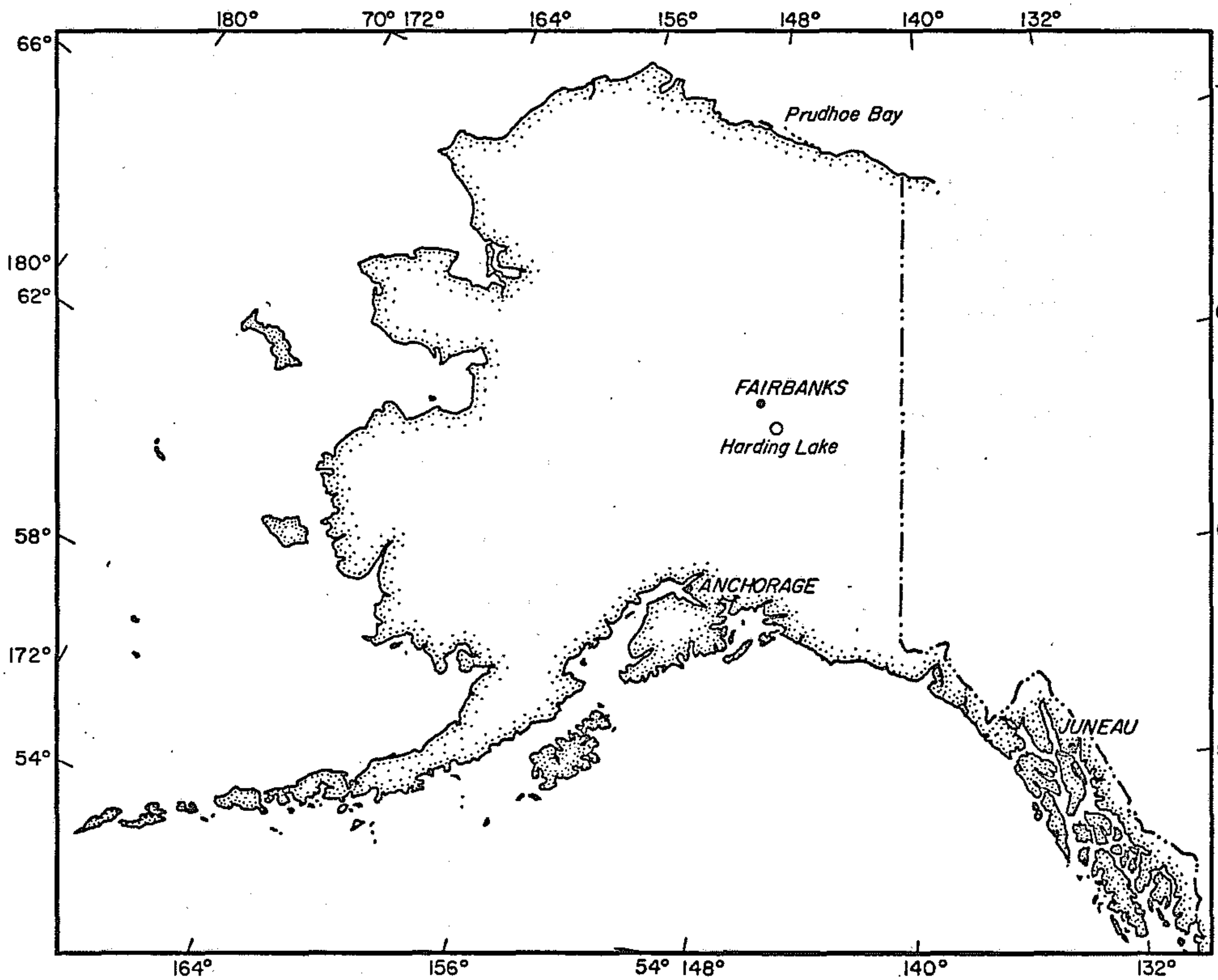

Fig. 2. Map of the State of Alaska showing the locations of Fairbanks, Harding Lake, and Prudhoe Bay.

EXPERIMENTAL METHODS

Sampling

Each body of lentic water in this study was sampled for dissolved and particulate lead and for lead concentrations in the muds, plankton, and aquatic plants. Sampling was done during July and August, 1971, at a time of year when shallow bodies of water in the area are usually sharply stratified (Barsdate, 1967). During the subsequent winter, snow samples were taken from the sites of each of the waters sampled and analyzed for lead.

Duplicate water samples were taken with a five-liter, non-metallic Van Dorn water bottle just below the surface and just off the bottom. These were immediately filtered through a 20-mesh (0.076 mm) screen to isolate the plankton samples. The plankton samples were fixed with a buffered, 10% formalin solution and placed in vials. Upon return to the laboratory, the water samples were again filtered through HA Millipore membrane filters (47μ) to isolate the particulate lead. Especially colored and/or turbid samples were pre-filtered through a glass-fiber filter to speed filtration. It was assumed that the remaining filtrate contained only the dissolved form of lead. All filters and aliquots of the filtered water were frozen for later analysis for lead.

The mud samples were taken with a small (15.24 cm) Ekman dredge, placed in a plastic bag and frozen until analyzed.

Plants were taken by hand from visible shallow water assemblages or removed from the dredged mud samples and frozen for later analysis.

Analysis

Frozen water samples were thawed into acid-washed beakers and acidified slightly by the addition of 2 drops of concentrated HCl. Analyses were carried out by the "sampling boat" method using a Perkin-Elmer Model 303 atomic absorption spectrophotometer. Analyses were conducted according to the conditions specified in the instrument methods manual.

The membrane filters and glass-fiber filter pads used to separate the particulate fraction were placed in acid-washed, 250-ml beakers. Then 5 mls of concentrated HNO_3 was pipetted onto the filters, and the beakers were covered with a watch glass and heated gently on a hot plate for several hours until the acetate filters were completely dissolved. The acid digestates were rinsed from the beakers with doubly distilled water and brought to volume in a 50-ml volumetric flask. These solutions were then analyzed by the sampling boat techniques using standards in acid solution. Blanks were prepared from clean filters with each digestion batch and evidenced negligible absorption upon analysis.

Plankton samples were filtered through a membrane filter. The filters were digested and analyzed in the above manner.

Mud samples were homogenized with a plastic spatula. A portion of the homogenate was placed in a tared, acid-washed, 50-ml beaker. The sample was dried overnight at 60C and the dry weight determined. The dried samples were treated with 5 mls of concentrated HNO_3 and heated gently on a hot plate (80C) for several hours to near dryness. Approximately 10 mls of doubly distilled water was added and the samples again warmed to dissolve all the acid-soluble lead. The slurries were filtered through prewashed Whatman #1 filter paper into a 25-ml volumetric flask. These samples were then analyzed by direct aspiration rather than boat sampling because of their apparent higher lead content.

Plant samples were treated in the same manner, except that the material was rinsed before it was dried in order to remove any adhering sediment. Heating time was extended to more than 24 hours to allow complete solution of the plant material.

RESULTS AND DISCUSSION

Dissolved and Particulate Lead

The t test for paired observations was applied to the data in order to determine whether the concentrations of lead found in surface and bottom samples from a given lake were significantly different. For both the dissolved and particulate lead (Tables 1 and 2), the hypothesis that the mean of the differences was zero could not be rejected; therefore, the surface and bottom lead concentrations did not differ significantly. Thus, the data used in the correlation analyses are averages of the surface and bottom sample values for a particular form of lead. The mean concentration of dissolved lead was 2.0 μg/l for all fifty lakes; that for particulate lead was 4.5 μg/l.

Plankton Lead Concentrations

Lead concentrations in the plankton (Table 3) were measured as mg Pb per five liters of sample filtered. Although this type of measurement is not adequate to quantitatively define what portion of the available lead is tied up by the zooplankton, it does give some indication of the lead in that particular trophic level. A table listing identifications and numbers of zooplankton can be found in the Appendix.

As regards the plankton data, not only were there surface and bottom samples, but these were replicated. Again, the t test indicated that the replicates could be averaged and that the surface and bottom lead concentrations could again be averaged to give one plankton lead concentration for each lake which could then be used in the correlation analysis.

Lead Concentrations in the Bottom Muds

The lead concentrations in the bottom muds, in mg Pb per gram of soil, on a dry weight basis, are shown in Table 4. The mean concentration for all lakes was found to be 0.025 mg/g.

Lead Concentrations in Aquatic Plants

Approximately half of the frozen plant samples were lost in storage. The lead levels in the remaining samples, in mg Pb per gram, dry weight, of plant material, are given in Table 5. A table listing the plants collected can be found in the Appendix.

Lead Concentrations in Snow

The lead concentrations in the snow samples taken in the spring of 1972 at each lake are shown in Table 6. The mean lead concentration for the fifty lakes was 0.13 mg/l.

Correlation Analyses

The results of the correlation analyses are diagrammed in Fig. 3. The correlation between the dissolved and particulate forms of lead at each

TABLE 1. DISSOLVED LEAD CONCENTRATIONS

Lake	mg/l	Average	Lake	mg/l	Average	Lake	mg/l	Average
A1	----		R1	.010		II1	.003	
2	----	0.	2	----	.005	2	.004	.004
B1	.003		S1	----		JJ1	----	
2	----	.001	2	----	0.	2	----	0.
C1	----		T1	----		KK1	----	
2	----	0.	2	----	0.	2	----	0.
D1	----		U1	----		LL1	----	
2	.012	.006	2	----	0.	2	----	0.
E1	.006		V1	.008		MM1	----	
2	----	.003	2	----	.004	2	----	0.
F1	----		W1	----		NN1	.010	
2	----	0.	2	.005	.002	2	----	.005
G1	.016		X1	----		OO1	----	
2	----	.008	2	----	0.	2	----	0.
H1	----		Y1	.016		PP1	----	
2	.003	.002	2	.006	.011	2	----	0.
I1	.006		Z1	----		QQ1	.014	
2	----	.003	2	----	0.	2	.010	.012
J1	.005		AA1	.004		RR1	.008	
2	----	.002	2	.002	.003	2	----	.004
K1	.010		BB1	----		SS1	----	
2	.008	.009	2	.003	.002	2	----	0.
L1	----		CC1	.004		TT1	----	
2	----	0.	2	.006	.005	2	.004	.002
M1	no sample		DD1	.008		UU1	----	
2	no sample		2	.001	.004	2	----	0.
N1	----		EE1	----		VV1	----	
2	----	0.	2	----	0.	2	----	0.
O1	----		FF1	----		WW1	----	
2	----	0.	2	.008	.004	2	----	0.
P1	.003		GG1	----		XX1	----	
2	.002	.002	2	.008	.004	2	.004	.002
Q1	----		HH1	----				
2	.005	.002	2	.004	.002			

a dash indicates no lead detected
1 - near surface
2 - near bottom

TABLE 2. PARTICULATE LEAD CONCENTRATIONS

Lake	µg	µg/l	Average	Lake	µg	µg/l	Average	Lake	µg	µg/l	Average
A1	18	4.3		T1	16	4.1		MM1	7	1.8	
2	24	6.3	5.3	2	14	3.7	3.9	2	9	2.3	2.0
B1	6	1.4		U1	10	4.4		NN1	32	8.2	
2	11	2.7	2.0	2	12	4.8	4.6	2	75	18.8	13.5
C1	10	2.6		V1	7	1.7		OO1	28	7.9	
2	20	5.1	3.8	2	4	1.0	1.4	2	14	3.9	5.9
D1	6	1.5		W1	8	2.0		PP1	11	3.1	
2	18	4.3	2.9	2	15	4.1	3.0	2	10	2.7	2.9
E1	26	6.7		X1	15	4.1		QQ1	26	7.1	
2	18	4.2	5.4	2	7	2.0	3.0	2	19	5.2	6.2
F1	18	4.4		Y1	50	12.3		RR1	21	5.7	5.7
2	17	4.1	4.2	2	108	30.4	21.4	2	--		
G1	11	3.0		Z1	15	4.0		SS1	12	3.1	
2	12	3.0	3.0	2	8	2.1	3.0	2	13	3.4	3.2
H1	15	3.6		AA1	145	36.3		TT1	9	2.3	
2	25	6.1	4.8	2	130	31.9	34.1	2	7	1.8	2.0
I1	14	3.7		BB1	45	11.4		UU1	20	5.2	
2	10	2.8	3.2	2	15	3.8	7.6	2	20	4.9	5.0
J1	18	4.2		CC1	18	4.9		VV1	14	4.1	
2	14	3.5	3.8	2	14	3.8	4.4	2	10	3.0	3.6
K1	11	2.6		DD1	6	1.7		WW1	5	1.4	
2	10	2.4	2.5	2	8	2.2	2.0	2	5	2.4	2.0
L1	10	2.5		EE1	8	2.3		XX1	4	1.5	
2	10	2.4	2.4	2	18	4.8	3.6	2	3	0.8	1.2
M1	6	1.6		FF1	10	2.6					
2	6	1.6	1.6	2	22	5.9	4.2				
N1	4	1.0		GG1	4	1.0					
2	4	1.1	1.0	2	4	1.0	1.0				
O1	4	1.1		HH1	4	1.2					
2	3	0.8	1.0	2	4	1.2	1.2				
P1	2	0.5		II1	18	5.0					
2	7	1.8	1.2	2	16	4.3	4.6				
Q1	2	6.5		JJ1	29	7.6					
2	4	1.2	0.9	2	13	3.2	5.4				
R1	26	6.8		KK1	9	2.3					
2	33	8.8	7.8	2	9	2.4	2.4				
S1	6	1.5		LL1	15	5.9					
2	10	2.6	2.0	2	11	2.9	4.4				

TABLE 3. PLANKTON LEAD CONCENTRATIONS

Lake	mg/5l	Average
A1	2.7	
2	0.9	1.8
B1	1.8	
2	1.6	1.7
C1	3.4	
2	0.8	2.1
D1	1.8	
2	1.6	1.7
E1a	0.7	
b	0.2	
2a	1.0	
b	1.6	0.9
F1a	0.4	
b	0.4	
2a	0.6	
b	0.2	0.4
G1a	0.6	
b	0.6	
2a	0.8	
b	0.2	0.6
H1a	1.2	
b	3.1	
2a	6.3	
b	---	4.0
I1a	2.9	
b	1.4	
2a	0.4	
b	---	1.6
J1a	1.1	
b	1.8	
2a	0.4	
b	0.6	1.0
K1a	0.1	
b	1.2	
2a	0.4	
b	1.8	0.9
L1a	1.2	
b	1.2	
2a	1.2	
b	1.8	1.4
M1a	1.4	
b	1.4	
2a	0.4	
b	0.6	1.0
N1a	1.0	
b	---	
2a	0.2	
b	0.2	0.5
O1a	0.4	
b	0.6	
2a	0.4	
b	0.4	0.4
P1a	0.5	
b	0.1	
2a	0.2	
b	0.8	0.4
Q1a	1.4	
b	0.6	
2a	1.2	
b	1.0	1.0
R1a	0.6	
b	0.4	
2a	0.4	
b	0.8	0.6
S1a	1.8	
b	0.8	
2a	2.8	
b	1.8	1.8
T1a	0.8	
b	1.6	
2a	2.0	
b	2.1	1.6
U1a	7.6	
b	---	
2a	0.8	
b	0.6	3.0
V1a	0.6	
b	0.8	
2a	1.6	
b	1.2	1.0
W1a	8.2	
b	2.6	
2a	2.0	
b	3.5	
c	8.4	4.9
X1a	0.8	
b	4.2	
2a	0.8	
b	---	1.9
Y1a	7.8	
b	7.0	
2a	1.07	
b	1.15	4.2
Z1a	.22	
b	.16	
2a	.06	
b	.06	0.3

TABLE 3. PLANKTON LEAD CONCENTRATIONS, Continued

Lake	mg/5l	Average	Lake	mg/5l	Average	Lake	mg/5l	Average
AA1a	19.0		KK1a	2.0		UU1a	6.4	
b	14.0		b	1.9		b	9.6	
2a	18.4		2a	0.2		2a	7.2	
b	12.4	16.0	b	0.8	1.2	b	2.5	6.4
BB1a	10.5		LL1a	1.0		VV1a	1.2	
b	16.6		b	1.0		b	---	
2a	1.6		2a	1.8		2a	0.6	
b	1.0	7.4	b	1.8	1.4	b	0.6	0.8
CC1a	3.2		MM1a	2.0		WW1a	1.6	
b	1.7		b	2.0		b	2.3	
2a	2.9		2a	1.8		2a	1.6	
b	2.7	2.6	b	1.8	1.9	b	0.0	1.4
DD1a	0.5		NN1a	0.2				
b	1.6		b	1.0				
2a	1.1		2a	2.8				
b	0.9	1.0	b	2.2	1.6			
EE1a	0.8		OO1a	1.0				
b	0.9		b	1.0				
2a	0.4		2a	1.6				
b	1.2	0.8	b	1.6	1.3			
FF1a	2.0		PP1a	5.7				
b	0.4		b	5.7				
2a	1.2		2a	3.1				
b	1.0	1.2	b	3.1	4.4			
GG1a	7.9		QQ1a	2.6				
b	6.7		b	6.4				
2a	7.1		2a	---				
b	3.8	6.4	b	25.0	11.3			
HH1a	3.7		RR1a	9.6				
b	---		b	9.1				
2a	3.5		2a	3.8				
b	9.3	5.5	b	9.2	7.9			
II1a	1.8		SS1a	2.1				
b	1.8		b	9.0				
2a	1.2		2a	7.0				
b	0.4	1.3	b	8.8	6.7			
JJ1a	5.8		TT1a	4.1				
b	3.1		b	2.3				
2a	0.4		2a	5.3				
b	0.6	2.5	b	7.4	4.8			

TABLE 4. LEAD CONCENTRATIONS IN BOTTOM MUDS

Lake	mg/l	mg/25ml	Sample wt (dry)	mg/g (dry)
A	2.2	.05	3.792	.013
B	4.0	.10	5.516	.018
C	3.8	.10	5.631	.018
D	3.6	.09	6.694	.013
E	3.4	.08	5.085	.016
F	2.1	.05	5.102	.010
G	3.0	.08	4.055	.020
H	3.4	.08	2.640	.030
I	3.9	.10	8.840	.011
J	2.6	.06	6.602	.009
K	7.3	.18	7.700	.023
L	10.8	.27	4.394	.061
M	2.4	.06	4.363	.014
N	2.6	.06	4.121	.014
O	---------------------no sample------------------			
P	1.8	.05	4.713	.011
Q	1.5	.04	0.866	.046
R	1.5	.04	1.466	.027
S	4.2	.11	4.736	.023
T	4.6	.11	2.618	.042
U	2.8	.07	5.014	.014
V	6.2	.16	3.458	.046
W	1.5	.04	1.824	.022
X	2.4	.11	4.402	.025
Y	2.6	.06	2.037	.029
Z	5.0	.12	2.752	.044

TABLE 4. LEAD CONCENTRATIONS IN BOTTOM MUDS, Continued

Lake	mg/l	mg/25ml	Sample wt (dry)	mg/g (dry)
AA	16.7	.42	4.745	.088
BB	6.20	.16	3.509	.045
CC	2.3	.06	3.442	.017
DD	3.8	.10	1.660	.060
EE	3.6	.09	3.917	.022
FF	3.0	.08	4.270	.018
GG	3.4	.08	5.271	.015
HH	9.9	.25	2.424	.103
II	6.1	.15	7.376	.020
JJ	4.5	.11	5.931	.018
KK	6.5	.16	6.804	.023
LL	4.7	.12	5.645	.021
MM	2.5	.06	3.822	.016
NN	1.7	.04	3.044	.013
OO	3.9	.10	14.976	.006
PP	3.5	.09	7.265	.012
QQ	8.8	.22	8.689	.025
RR	2.9	.07	5.140	.014
SS	1.3	.03	1.5606	.019
TT	0.6	.02	.922	.022
UU	2.3	.06	2.413	.024
VV	0.9	.02	3.082	.006
WW	1.2	.03	14.597	.002
XX	4.7	.12	9.848	.012

TABLE 5. LEAD CONCENTRATIONS IN AQUATIC PLANTS

Lake	mg/l	mg/25ml	Sample wt	mg/g
E	.6	.02	1.249	.016
H	.6	.02	2.030	.010
I	1.4	.04	1.037	.038
O	.6	.02	1.613	.012
P	.1	.01	1.046	.010
T	3.2	.08	1.432	.056
V	.1	.01	1.184	.008
X	5.4	.14	3.768	.037
AA	11.6	.29	3.117	.093
DD	1.8	.04	3.196	.012
EE	2.8	.07	3.076	.023
FF	.1	.01	1.144	.009
GG	.2	.01	0.576	.017
II	3.8	.10	4.377	.023
JJ	2.6	.06	2.194	.027
LL	2.1	.05	2.379	.021
MM	3.4	.08	2.582	.031
NN	.2	.01	1.302	.008
PP	1.2	.03	1.460	.020
QQ	2.8	.07	1.718	.041
RR	1.1	.03	1.376	.022
SS	.6	.02	4.761	.004
WW	.4	.01	2.483	.004

TABLE 6. LEAD CONCENTRATIONS IN SNOW

Lake	Date	Temp.	Snow Depth	Equiv. Water Depth	Lead (mg/l)
A	Mar 13	+8	12"	2.0	.32
B	" "	+8	10 1/2"	1.6	.67
C	" "	+8	12"	2.0	.11
D	" "	+8	16"	3.0	.16
E	" 14	+4	17"	3.8	.06
F	" "	+4	11"	2.1	.12
G	" "	+4	15"	3.0	.03
H	" 13	+8	24"	4.5	.08
I	" 13	+8	19"	3.8	.10
J	" 9	+6	22"	4.1	.16
K	" "	+6	22"	4.1	.22
L	" "	+6	12"	2.0	.06
M	" "	+6	23"	4.2	.10
N	" "	+6	12"	2.0	.11
O	" "	+6	11"	1.8	.12
P	" 14	+4	17"	3.0	.04
Q	" "	+4	19"	3.6	.24
R	" "	+4	22 1/2"	4.3	.30
S	" 9	+6	15"	2.4	.12
T	" 13	+8	16"	4.0	.15
U	" 13	+8	27"	6.0	.25
V	" 14	+4	23"	5.3	.08
W	" 14	+4	13"	2.3	.04
X	" 9	+6	12"	1.8	.30
Y	" 14	+4	19"	4.7	.10
Z	" 14	+4	8"	1.5	.19

TABLE 6. LEAD CONCENTRATIONS IN SNOW, Continued

Lake	Date	Temp.	Snow Depth	Equiv. Water Depth	Lead (mg/l)
AA	Mar 15	+8	22"	4.2	.05
BB	" 15	+8	22"	4.2	.24
CC	" 14	+4	11"	1.6	.08
DD	" 14	+4	7 "	1.9	.29
EE	" 13	+8	12"	1.9	.14
FF	" 13	+8	24"	4.6	.06
GG	" 9	+6	20"	3.7	.03
HH	" "	+6	21"	4.0	.06
II	" "	+6	12"	1.7	.34
JJ	" "	+6	21"	4.0	N.D.
KK	" 13	+8	22"	4.1	N.D.
LL	" "	+8	20"	3.5	.36
MM	" "	+8	20"	3.6	.12
NN	" 15	+8	22"	4.2	.12
OO	" 9	+6	16"	2.6	.21
PP	" "	+6	19"	3.2	N.D.
QQ	" "	+6	22"	4.4	N.D.
RR	" "	+6	19"	3.5	N.D.
SS	" 17	+9	21"	3.6	N.D.
TT	" "	+9	21"	3.5	N.D.
UU	" "	+9	20"	3.1	.26
VV	" 22	+6	12"	1.9	.02
WW	" 25				N.D.
XX	Apr 3				N.D.

N.D. - no lead detected

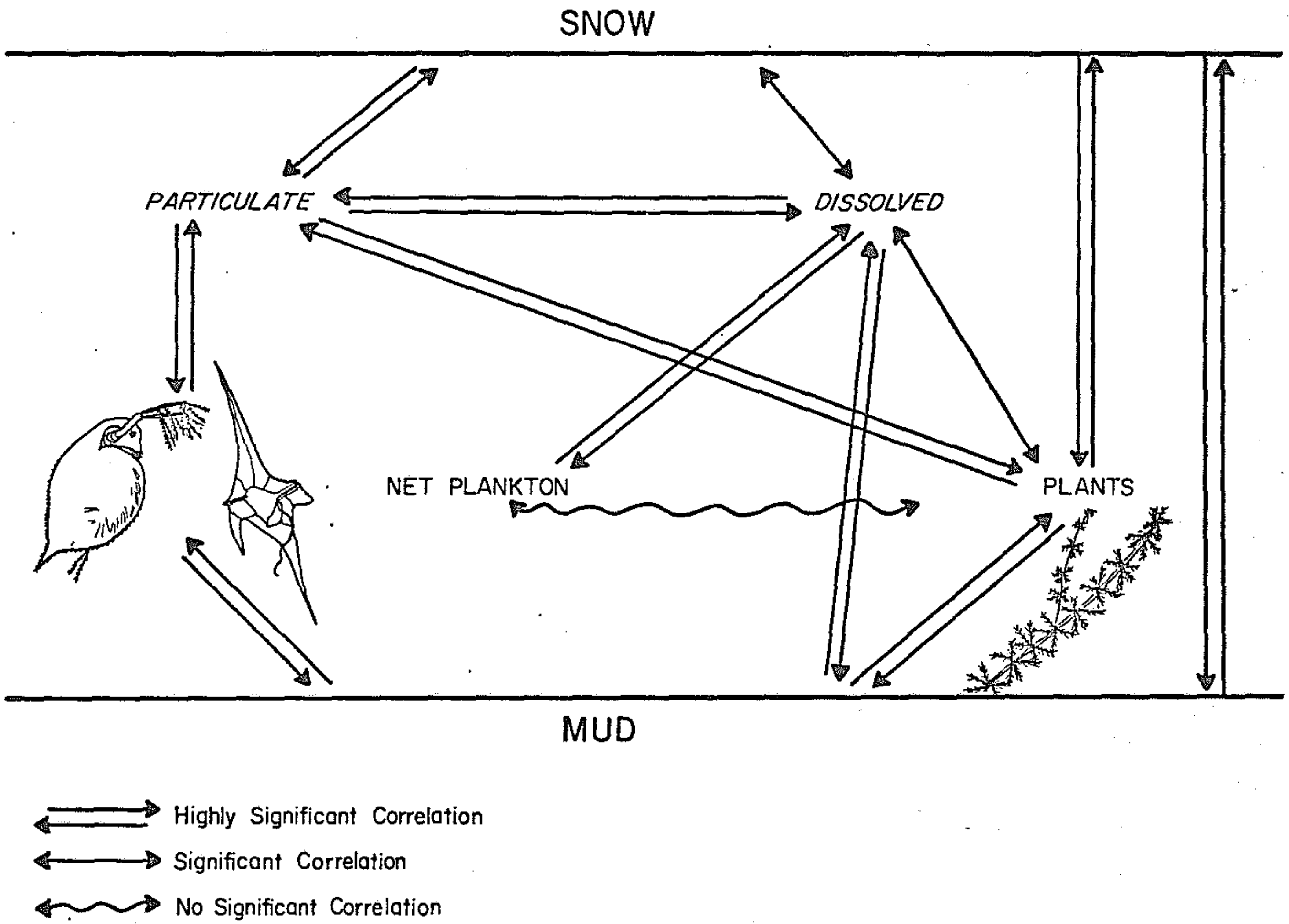

Fig. 3. Diagram of the relationships between lead concentrations in various portions of a lentic water ecosystem, as ascertained by correlation analysis.

site was highly significant (r = 0.59). The correlation between the dissolved lead concentrations and lead concentrations in associated snow was low but significant (r = 0.38). It should be noted that the lead in the water samples cannot be directly related to that in the snow samples, since the latter were taken in the winter following the sampling of the waters. However, the particulate lead concentrations and associated snow lead concentrations had a highly significant correlation (r = 0.44).

The correlation between lead in the muds and the dissolved lead was highly significant (r = 0.51) as were the correlation between the particulate lead and mud lead concentrations (r = 0.66) and the correlation between associated snow lead concentrations and the lead in the muds (r = 0.58).

Plankton lead levels correlated well with dissolved lead (r = 0.48), but they did so more strongly with the particulate lead (r = 0.78), the snow lead concentrations (r = 0.36), and the mud lead concentrations (r = 0.74). All of these correlations were highly significant.

The lead levels in the aquatic plants analyzed correlated significantly with the dissolved lead concentrations in their respective lakes (r = 0.53), and the correlations with the particulate lead (r = 0.83), snow lead (r = 0.53), and mud lead concentrations (r = 0.86) were highly significant.

Analysis for Areal Differences in Lead Concentrations

As was stated above, there are four areas that can be delineated in relation to the severity of ice fog in the Fairbanks area (Benson, 1970): the central core of the city, where ice fogs are frequent; an outer area, where there are occasional ice fogs after several days of proper conditions; an area farther out where ice fog is a rare occurrence; and lastly, an area where ice fogs due to the presence of the city of Fairbanks do not occur.

When the bodies of lentic waters studied herein are aggregated according to which of these areas they belong, 23 are found to be in the core or frequent area, 16 in the area of occasional ice fog, 8 in the area where ice fogs are rare, and 3 in the area outside of ice fog formation at the present time.

When the lead analysis data are grouped according to this scheme and the t test is applied to determine significant differences between the areas, some additional information is obtained. However, because of the unevenness of the distribution of the bodies of water within the above areas, some of the differences cannot be said to be significant when in actuality they might well be significant. In Table 7, any two means joined by the same line are not significantly different. Thus, it can be seen that only with regard to the snow and mud lead concentrations were any significant differences between areas found. With regard to the mud lead concentrations, the only significant difference is between the lead in the core area and that in the area where ice fog does not form. The snow lead concentrations show the expected trend from high to low as one moves from the area of frequent ice fog to the area outside ice fog formation. However, no significant difference is seen between the average lead concentrations in the snow in the area of occasional ice fog and the lead in the snow in the area of rare ice fog. Also, there is no significant difference between the mean snow lead concentra-

TABLE 7. MEAN LEAD CONCENTRATIONS GROUPED ACCORDING TO ICE FOG AREA

Ice Fog Area	Frequent	Occasional	Rare	Outside
Dissolved	0.002 mg/l	0.003 mg/l	0.002 mg/l	0.001 mg/l
Particulate	5.95 μg/l	3.97 μg/l	2.38 μg/l	2.20 μg/l
Plankton	2.61 mg/5l	2.32 mg/5l	4.64 mg/5l	1.10 mg/5l
Mud	0.026 mg/g	0.020 mg/g	0.039 mg/g	0.007 mg/g
Plants	0.031 mg/g	0.020 mg/g	0.010 mg/g	0.004 mg/g
Snow	0.20 mg/l	0.10 mg/l	0.07 mg/l	0.01 mg/l

tions in the area of rare ice fogs and mean lead concentrations of those snow samples taken in the region outside the ice fog formation. This observation may be due to the sparsity of samples taken in the outer region.

The mean lead concentrations in the muds and plankton of the area which rarely experiences ice fogs are anomalously high and do not follow the expected trend. It may be that there are high background lead levels in this particular area. However, it should be noted that these levels are not significantly different from those of the area of occasional ice fog nor from those of the area outside the ice fog.

CONCLUSIONS

The results of this study do not conclusively show that lead from winter air pollution over the city of Fairbanks is finding its way into the lentic waters of the area. However, as Table 7 illustrates, the trends to be expected if this were occurring are present, even though the areas chosen are not delineated by significant differences in the lead levels. As has been mentioned, the fact that the differences between areas cannot be considered significant may be due to the fact that a small number of lakes were sampled both in the area of rare ice fog and in the area completely outside ice fog formation.

It is also likely that the ice fog areas identified by Benson (1970) may have changed as a result of the increased use of automobiles, oil heat, and other processes which contribute to ice fog. It is a common observation that ice fog in Fairbanks has been forming at higher temperatures and over wider areas as the population has increased.

The correlation analyses point to definite relationships between the lead deposited on snow near a lake and the levels that appear in the water and muds in that lake. These analyses also suggest that lead is taken into the zooplankton in the particulate form on which they feed, and that perhaps it is partially through this mechanism that lead is transferred to the muds. Tatsumoto and Patterson (1963) have stated in their study of lead in sea water, "It can be shown that biological material can serve as an adequate carrier for transporting lead from surface waters to sediment...." It can be observed that the dissolved lead concentrations in the lentic waters of this study are lower than the particulate lead levels, and this difference may be attributed to the fact that lead tends to precipitate out in fresh water (Lazrus *et al.*, 1970), another mechanism for transferring lead to the bottom muds. There is also some indication that rooted plants are exposed to lead mostly through the contact of their roots with the bottom muds. To actually prove these and other relationships, however, would require a detailed study of the lead cycle in these waters, which was beyond the scope of this project.

Because the lead was analyzed by atomic absorption, it is impossible to identify its source or to examine the changes in form that it undergoes in the aquatic system. Background and contamination levels were not measured and cannot be separated out from the data. Although the plankton data indicate that lead is biologically concentrated in this trophic level, zooplankton and phytoplankton were mixed in many samples, and thus specific lead concentrations in each could not be determined. Because the zooplankton were not separated from the phytoplankton and grit, and because of such factors as differential productivity and diurnal migration, it is impossible to relate the lead concentrations found in the zooplankton directly back to that deposited on snow by ice fog precipitation or even to the levels found in the water environment.

Another piece of information missing in our knowledge of the lead cycle is the amount of lead that becomes incorporated into the soil. This has been studied by Benson for certain stations in this area, and his results will soon be available.

To complete a study of the lead cycle in these lentic waters, it would also be necessary to measure the lead concentrations in the higher trophic levels. If the biological concentration of lead is occurring, it may reach levels that are dangerously high for these animals. Man, however, would probably not be affected by this potential source of lead as there is no viable fishery in any of the lentic bodies of water in the area nor is drinking water drawn from any of them.

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APPENDIX

TABLE A. ZOOPLANKTON COUNTS

	LAKE CODE									
	A1	A2	B1	B2	C1	C2	D1	D2	E1	E2
Hydra sp.										
Polyarthra sp.									2	
Karatella sp.					20				18	
Kellicottia sp.	1								14	
Trichocerca sp.										
Philodina sp.										
Horsehair worm										
Annelida										
Planaria										
Fairy Shrimps										
Daphnia sp.	1		117	50	3		48	12	16	152
Bosmina sp.									5	14
Leptodora sp.										
Calanoid copepods	28	3	2	3	19	42	64			10
Cyclopoid copepods	6		5	2	4	4	17		4	22
Nauplii	18	1	1			2	36	2	19	19
Scuds										
Mayflies										
Stoneflies										
Caddisflies										
Chaoborus sp.			7					2		
Chironomids										
Mosquitoes										
Mesovelia sp.										
Corixid beetles										
Dytiscid beetles										
Rat-tailed Maggots										
Aphids										
Mites										
Snails										
Anabaena sp.										
Aphanizomenon sp.										
Asterionella sp.										
Dinobyron sp.									*	Few
Gleotrichia sp.										
Pandorina sp.										
Spirogyra sp.		3046								
Tabellaria sp.										
Ulothrix sp.										
Volvox sp.										155
Zygnema sp.										
Ceratium sp.	1					58000	48000		412	125

* Too many to count

TABLE A. ZOOPLANKTON COUNTS, Continued

	LAKE CODE									
	F1	F2	G1	G2	H1	H2	I1	I2	J1	J2
Hydra sp.										
Polyarthra sp.			22							
Karatella sp.			19	58					2853	5100
Kellicottia sp.	192	350	1							
Trichocerca sp.										
Philodina sp.										
Horsehair worm										
Annelida										
Planaria										
Fairy Shrimps										
Daphnia sp.	12	2	24	180	59	19	14	16	149	287
Bosmina sp.					2	7				
Leptodora sp.										
Calanoid copepods	72	66	4	17	516	507	18	19	12	
Cyclopoid copepods	294	227	23	120	51	34	1	3	9	2
Nauplii	594	584	58	2753	86	31	14	2	74	92
Scuds										
Mayflies										
Stoneflies										
Caddisflies										
Chaoborus sp.										7
Chironomids					7	1				
Mosquitoes										
Mesovelia sp.										
Corixid beetles										
Dytiscid beetles										
Rat-tailed Maggots										
Aphids										
Mites										
Snails					1					
Anabaena sp.							*	*	*	*
Aphanizomenon sp.										
Asterionella sp.										
Dinobyron sp.										
Gleotrichia sp.										
Pandorina sp.										
Spirogyra sp.										
Tabellaria sp.										
Ulothrix sp.										
Volvox sp.										
Zygnema sp.										
Ceratium sp.	65	19	1709	4547	8		*	*	806	252

TABLE A. ZOOPLANKTON COUNTS, Continued

	LAKE CODE									
	K1	K2	L1	L2	M1	M2	N1	N2	O1	O2
Hydra sp.										1
Polyartha sp.							12	10	13	30
Karatella sp.	18	2	4	4			63	36	11	40
Kellicottia sp.								31	51	22
Trichocerca sp.										
Philodina sp.										
Horsehair worm										
Annelida										
Planaria										
Fairy Shrimps										
Daphnia sp.	1	4	9	10	276	81	48	235	2609	532
Bosmina sp.										
Leptodora sp.										
Calanoid copepods	24	51	7	7	10	10	30	71	111	65
Cyclopoid copepods	5		2		5	10	8	18	36	84
Nauplii	22		7	5	5	6	69	78	140	88
Scuds										
Mayflies										1
Stoneflies										
Caddisflies										
Chaoborus sp.					9	4				
Chironomids										1
Mosquitoes										
Mesovelia sp.										
Corixid beetles										
Dytiscid beetles										
Rat-tailed Maggots										1
Aphids										
Mites										
Snails										
Anabaena sp.						*				
Aphanizomenon sp.										
Asterionella sp.										
Dinobyron sp.										
Gleotrichia sp.										
Pandorina sp.										
Spirogyra sp.										
Tabellaria sp.										
Ulothrix sp.										
Volvox sp.	25				794	569				30
Zygnema sp.										
Ceratium sp.	74	117	41	80	1908	3520	5298	1827	2420	1612

TABLE A. ZOOPLANKTON COUNTS, Continued

	LAKE CODE									
	P1	P2	Q1	Q2	R1	R2	S1	S2	T1	T2
Hydra sp.							2	1		1
Polyarthra sp.					20		117	67		
Karatella sp.			6	5	3699	6512	69	16	200	48
Kellicottia sp.								1		
Trichocerca sp.										
Philodina sp.							456			
Horsehair worm										
Annelida							3			
Planaria										
Fairy Shrimp										
Daphnia sp.	447	68	61	69	12	36	145	133	8	21
Bosmina sp.				3	1					
Leptodora sp.										
Calanoid copepods	13		430	213	2	1	132	21	29	15
Cyclopoid copepods	15		13	27	23	23	6	12	155	193
Nauplii	8		173	220	56	228	4	20	152	45
Scuds										
Mayflies										
Stoneflies										
Caddisflies						1				
Chaoborus sp.		10								
Chironomids				2	1			12	2	
Mosquitoes										
Mesovelia sp.			1							
Corixid beetles				1						
Dytiscid beetles										
Rat-tailed Maggots										
Aphids										
Mites		1								
Snails										
Anabaena sp.										
Aphanizomenon sp.										
Asterionella sp.										
Dinobyron sp.										
Gleotrichia sp.										
Pandorina sp.					106					
Spirogyra sp.										
Tabellaria sp.										
Ulothrix sp.										
Volvox sp.							9	27	17	228
Zygnema sp.										
Ceratium sp.	115		31	1	89	2	4334	791	16400	14960

TABLE A. ZOOPLANKTON COUNTS, Continued

	LAKE CODE									
	U1	U2	V1	V2	W1	W2	X1	X2	Y1	Y2
Hydra sp.										
Polyarthra sp.										
Karatella sp.	1728			1835	4					
Kellicottia sp.							3			
Trichocerca sp.										
Philodina sp.										
Horsehair worm										
Annelida										
Planaria										
Fairy Shrimp								2		
Daphnia sp.	78		3	136	26	10	22	25	667	410
Bosmina sp.					2		2	5		
Leptodora sp.										
Calanoid copepods	7		176	79	174	634	5	5	45	41
Cyclopoid copepods	10	1	97	72	37	15	13	26	7	61
Nauplii	46	2	166	486	12	7	7			
Scuds										1
Mayflies								1		
Stoneflies										
Caddisflies										
Chaoborus sp.				3					14	8
Chironomids						3		1		1
Mosquitoes										
Mesovelia sp.										
Corixid beetles										2
Dytiscid beetles										
Rat-tailed Maggots										
Aphids									2	
Mites										
Snails										
Anabaena sp.	*			Few			Few	*		
Aphanizomenon sp.					*	*				
Asterionella sp.										
Dinobyron sp.										
Gleotrichia sp.										
Pandorina sp.										
Spirogyra sp.		4								
Tabellaria sp.										
Ulothrix sp.							189	Few		
Volvox sp.	576									
Zygnema sp.										
Ceratium sp.	22	2	7	301			44			

TABLE A. ZOOPLANKTON COUNTS, Continued

	LAKE CODE									
	Z1	Z2	AA1	AA2	BB1	BB2	CC1	CC2	DD1	DD2
Hydra sp.										
Polyarthra sp.	89	178								
Karatella sp.	1850	1232					7	11	84	207
Kellicottia sp.									1	
Trichocerca sp.										
Philodina sp.										
Horsehair worm										
Annelida			1		1					
Planaria	1									
Fairy Shrimps										
Daphnia sp.	4		236	554	109	277	87	45	47	37
Bosmina sp.				4				17		1
Leptodora sp.										
Calanoid copepods	55	187				1	249	6	43	80
Cyclopoid copepods	45	87	1	1	3	9	4	2	20	16
Nauplii	112	70				5	9	8	21	36
Scuds										
Mayflies										
Stoneflies										
Caddisflies										
Chaoborus sp.			13	10	2					1
Chironomids	2				6					
Mosquitoes					1					
Mesovelia sp.										
Corixid beetles									1	
Dytiscid beetles										
Rat-tailed Maggots										
Aphids										
Mites										
Snails				1						
Anabaena sp.										
Aphanizomenon sp.					*					
Asterionella sp.										
Dinobyron sp.										
Gleotrichia sp.										
Pandorina sp.							992	3385		
Spirogyra sp.			*	*			Few			
Tabellaria sp.										
Ulothrix sp.										
Volvox sp.										
Zygnema sp.										
Ceratium sp.	48204	11444				8	60		14	

TABLE A. ZOOPLANKTON COUNTS, Continued

	LAKE CODE									
	EE1	EE2	FF1	FF2	GG1	GG2	HH1	HH2	II1	II2
Hydra sp.										
Polyarthra sp.	2	4								
Karatella sp.	228	60	403	400			7			
Kellicottia sp.	3	49	3							
Trichocerca sp.										
Philodina sp.										
Horsehair worm			1							
Annelida										
Planaria										
Fairy Shrimps										
Daphnia sp.	5	5			436	236	152	299	22	355
Bosmina sp.										
Leptodora sp.										
Calanoid copepods	83	31	28	79				1	28	4
Cyclopoid copepods		14	2	6	90	77	9		29	
Nauplii	32	20	2	6	5	8	6			2
Scuds										
Mayflies										
Stoneflies										
Caddisflies										
Chaoborus sp.		1				3		2	2	4
Chironomids						143				
Mosquitoes										
Mesovelia sp.										
Corixid beetles										
Dytiscid beetles										
Rat-tailed Maggots										
Aphids						1				
Mites										
Snails					1	1				
Anabaena sp.										
Aphanizomenon sp.										
Asterionella sp.										
Dinobyron sp.										
Gleotrichia sp.										
Pandorina sp.										
Spirogyra sp.				Few	*	*	*	*		
Tabellaria sp.										
Ulothrix sp.										
Volvox sp.										
Zygnema sp.										
Ceratium sp.	6670	1828	*	22400			5		162029	37

TABLE A. ZOOPLANKTON COUNTS, Continued

	LAKE CODE									
	JJ1	JJ2	KK1	KK2	LL1	LL2	MM1	MM2	NN1	NN2
Hydra sp.										
Polyarthra sp.		8						19		
Karatella sp.		1	2	2				2		
Kellicottia sp.								9		
Trichocerca sp.								5		
Philodina sp.										
Horsehair worm										
Annelida										
Planaria										
Fairy Shrimps										
Daphnia sp.	6	63	5			2		3	220	283
Bosmina sp.										
Leptodora sp.										
Calanoid copepods	12	63	19	112	14	67	26	42		
Cyclopoid copepods	2	18	8	63	24	11	31	103	3	10
Nauplii	4	63	19	78	6	12	5	78		
Scuds										
Mayflies										
Stoneflies										
Caddisflies										
Chaoborus sp.										2
Chironomids									2	1
Mosquitoes										
Mesovelia sp.										
Corixid beetles										
Dytiscid beetles										
Rat-tailed Maggots										
Aphids										
Mites										
Snails										
Anabaena sp.										
Aphanizomenon sp.									Few	
Asterionella sp.										
Dinobyron sp.										
Gleotrichia sp.							1			
Pandorina sp.										
Spirogyra sp.										
Tabellaria sp.										
Ulothrix sp.						1				
Volvox sp.					261	203				
Zygnema sp.										
Ceratium sp.	2545	4164	73	128	35			83		

TABLE A. ZOOPLANKTON COUNTS, Continued

	LAKE CODE									
	001	002	PP1	PP2	QQ1	QQ2	RR1	RR2	SS1	SS2
Hydra sp.								1		
Polyarthra sp.	8	21	9							
Karatella sp.	4	21	17	8					18	
Kellicottia sp.				24						
Trichocerca sp.										
Philodina sp.										
Horsehair worm										
Annelida						6		1		
Planaria										
Fairy Shrimps										
Daphnia sp.		136	1		32	49	109	37	5	7
Bosmina sp.										
Leptodora sp.										
Calanoid copepods	14	21	5	131	2		23	12	323	194
Cyclopoid copepods	1		2	74	228	186	4	5	1	10
Nauplii	10	4	13	18	20		1	2		
Scuds										1
Mayflies										
Stoneflies										
Caddisflies							1			
Chaoborus sp.								1		
Chironomids					1	13	6			
Mosquitoes					1					
Mesovelia sp.										
Corixid beetles										
Dytiscid beetles						1				
Rat-tailed Maggots										
Aphids										
Mites										
Snails										
Anabaena sp.										
Aphanizomenon sp.										
Asterionella sp.										
Dinobyron sp.										
Gleotrichia sp.										
Pandorina sp.										
Spirogyra sp.							Few			*
Tabellaria sp.										
Ulothrix sp.										
Volvox sp.	844						*	*		
Zygnema sp.								*		
Ceratium sp.	1235	2119	184	2184	1			26	75	

TABLE A. ZOOPLANKTON COUNTS, Continued

	LAKE CODE									
	TT1	TT2	UU1	UU2	VV1	VV2	WW1	WW2	XX1	XX2
Hydra sp.										
Polyarthra sp.										
Karatella sp.	53	274	9			1				11
Kellicottia sp.									7	
Trichocerca sp.										5
Philodina sp.										
Horsehair worm										
Annelida										
Planaria										
Fairy Shrimps										
Daphnia sp.	2	2	10	15	67	4	12	11	53	70
Bosmina sp.			2							
Leptodora sp.										
Calanoid copepods	794	1007	349	369	197	37	162	113	24	37
Cyclopoid copepods	3		14	8	5	11	1		16	15
Nauplii	41		9	12	3	3			19	22
Scuds										1
Mayflies										
Stoneflies										
Caddisflies										
Chaoborus sp.										
Chironomids										
Mosquitoes										
Mesovelia sp.										
Corixid beetles										
Dytiscid beetles										
Rat-tailed Maggots										
Aphids										
Mites				1						
Snails										
Anabaena sp.									10	41
Aphanizomenon sp.					*					
Asterionella sp.									3116	764
Dinobyron sp.										
Gleotrichia sp.										
Pandorina sp.										
Spirogyra sp.							Few			
Tabellaria sp.										2
Ulothrix sp.								Few		
Volvox sp.										
Zygnema sp.										
Ceratium sp.	62			7	1004		51	20	18	318

TABLE B. PLANTS COLLECTED

Lake	
E	Utricularia sp.
H	Sparganium sp., Najas sp., Potomogeton natans
I	Potomogeton diversifolius
O	Chara sp., Potomogeton longiligulatus
P	Myriophyllum sp.
T	Potomogeton sp. (marl encrusted)
V	Myriophyllum sp., Potomogeton sp.
X	Chara sp.
AA	Myriophyllum sp.
DD	Potomogeton sp.
EE	Potomogeton sp. (2)
FF	Potomogeton foliosus, Potomogeton sp.
GG	Equisetum fluviatile, Ranunculus sp.
II	Vallisneria americana, Utricularia sp.
JJ	Chara sp.
LL	Potomogeton sp.
MM	Chara sp.
NN	Potomogeton sp.
PP	Potomogeton amplifolius
QQ	Ranunculus sp., Najas sp.
RR	Potomogeton sp.
SS	Ceratophyllum demersum
WN	Najas sp., Potomogeton sp.