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AN ASSESSMENT OF THE AQUATIC INVERTEBRATE COMMUNITY IN IMPACT AND NON-IMPACT ZONES OF CAMP RIPLEY MILITARY RESERVATION

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AN ASSESSMENT OF THE AQUATIC INVERTEBRATE COMMUNITY IN IMPACT AND NON-IMPACT ZONES OF CAMP RIPLEY MILITARY RESERVATION

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Executive Summary

Aquatic macroinvertebrates, zooplankton, water chemistry, sediment chemistry and sediment cores were collected from six lakes on Camp Ripley Military Reservation from May through September 1993 - 1995 to determine if impact zone lakes were being affected by military training activities. Lakes were chosen to present a spectrum of impacts occurring in the training area, ranging from completely enclosed within an impact area (Muskrat) to remote from impact areas (Bass). Impact lakes were Muskrat, Mud and Ferrell, while non-impact lakes were Fosdick, Bass and Coon Stump.

None of the parameters measured consistently separated impact lakes from non-impact lakes, and none showed significant negative impacts on the invertebrate communities. Sediment chemistry indicated increased levels of copper in Ferrell (an impact lake), and Fosdick and Coon Stump lakes (two non-impact lakes). Sedimentation rate analysis indicated that Ferrell had increased levels of sedimentation, while Bass and Fosdick rates had returned to pre-settlement levels. Construction activities and amphibious vehicle training use at Ferrell leading to erosion at access sites are likely the cause of the increased sedimentation, and use of copper sulfate by the MDNR could explain elevated copper levels.

A total of 80 macroinvertebrate taxa were collected during the study, of which 13 were non-insect, predominantly Mollusca. Of the insect taxa, most were Chironomidae (33 separate taxa). Total number of taxa per lake per year varied from a low of 4 (Coon Stump) to a high of 33 (Fosdick). The two smallest lakes (Bass, Coon Stump) had the lowest number of taxa for the study period (1993-1995). Fosdick had the highest, and the other lakes showed numbers similar to one another. Ten species of adult Odonata (dragonflies) were collected in one sampling trip, with several of the taxa not having been sampled previously as nymphs in Camp Ripley lakes.

A total of 11 species of copepods and 22 species of cladocerans were collected during the study. Total zooplankton densities were lower in 1995 than they were in the previous two years. Muskrat and Ferrell lakes (two impact lakes) had the highest zooplankton densities while Coon Stump and Mud lakes had the lowest. The assessment of the zooplankton communities using correspondence analysis showed Mud Lake to be the only impact lake that might be different from the other lakes but this difference was probably not due to military activities.

Major recommendations

1. None of the parameters sampled distinguished impact zone lakes from non-impact zone lakes. There were no consistent negative impacts on the aquatic invertebrate community that could be attributed to training activities. Routine sampling for monitoring does not seem to be indicated by these results. However, if training activities or levels increase markedly consideration should be given to additional sampling to evaluate possible impacts from these increases.
2. Ferrell Lake bottom fauna may be impacted by the use of the lake for amphibious vehicle training. It was not possible to determine the nature or duration of these impacts as there was no such training during the course of the study. In the future samples could be collected just prior to and after any such training to document if any impacts to the invertebrate community occur.
3. Training and use records for Fosdick and Coon Stump lakes and surrounding areas should be examined to try and determine why these two lakes showed an increase in copper in the surface sediments similar to that seen in Ferrell Lake.

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Introduction

The aquatic macroinvertebrates and zooplankton of Minnesota are relatively unknown, with distribution, densities and general ecological information lacking. Most aquatic studies have been focussed on fish or water chemistry in lakes or streams. Very few studies have been conducted examining invertebrate communities over a large area, or involving different habitats.

While there has been considerable interest and effort over the recent years in using aquatic invertebrates for biological monitoring, most of the effort has focussed on flowing waters and the communities associated with streams and rivers. Very little attention has been placed on the benthic fauna in lakes and its use in monitoring the ecosystem. In lentic systems, monitoring has mainly been focussed on using chironomids to distinguish trophic status (Ward 1992, Wiederholm 1984). This information gap prevents the routine bioassessment of lentic waters at Camp Ripley.

Camp Ripley Military Reservation in central Minnesota is used by the Minnesota National Guard for training. Most of the reservation is undeveloped and contains a variety of aquatic habitats. There has been increasing concern by the environmental staff at the facility that training activities might be impacting the natural resources. A number of lakes are located within designated 'impact zones' - areas which receive fire during training exercises. Under a cooperative agreement between the Minnesota Department of Natural Resources (MDNR) Ecological Services Section and the Department of Military Affairs, a study was conducted to sample benthic macroinvertebrates, zooplankton, water chemistry, and sediment chemistry in lakes within and outside of these impact zones. The goals of the study were to determine if these parameters could be used to document changes in lake ecosystems due to military activities, and to recommend which parameters should be monitored over longer time intervals.

Study Area

Camp Ripley Military Reservation is located in Morrison County in central Minnesota, approximately 16 km north of Little Falls (Fig. 1). The reservation covers approximately 20,235 hectares and is used by the Minnesota National Guard for training exercises. Within Camp Ripley are numerous lakes, ponds, wetlands, and small streams. No major rivers are included in the reservation, although the Mississippi River borders Camp Ripley on the east and the Crow Wing River forms part of the northern boundary. There are two large areas contained within the reserve which are designated as "impact zones"(Fig. 2). These are the areas that fire is directed into during training exercises.

Lakes sampled in this study were: Bass, Coon Stump, Fosdick, Muskrat, Mud , and Ferrell (Fig. 2). The study lakes are representative of the majority of the lakes located on the reservation as they are small (ranging from 4-42 hectares) and shallow (less than 3 m deep). Mud Lake is the only study lake which is significantly larger (121 hectares) than most of the Camp Ripley lakes; however, it is also shallow (1.5-2 m deep). Muskrat Lake is completely surrounded by one of the impact areas, while Mud Lake borders the northern impact site. Ferrell Lake is used by MDNR Fisheries as a walleye rearing pond, and is also the site for amphibious vehicle training. The remaining study lakes are not subject to these impacts, and served as reference lakes for the study.

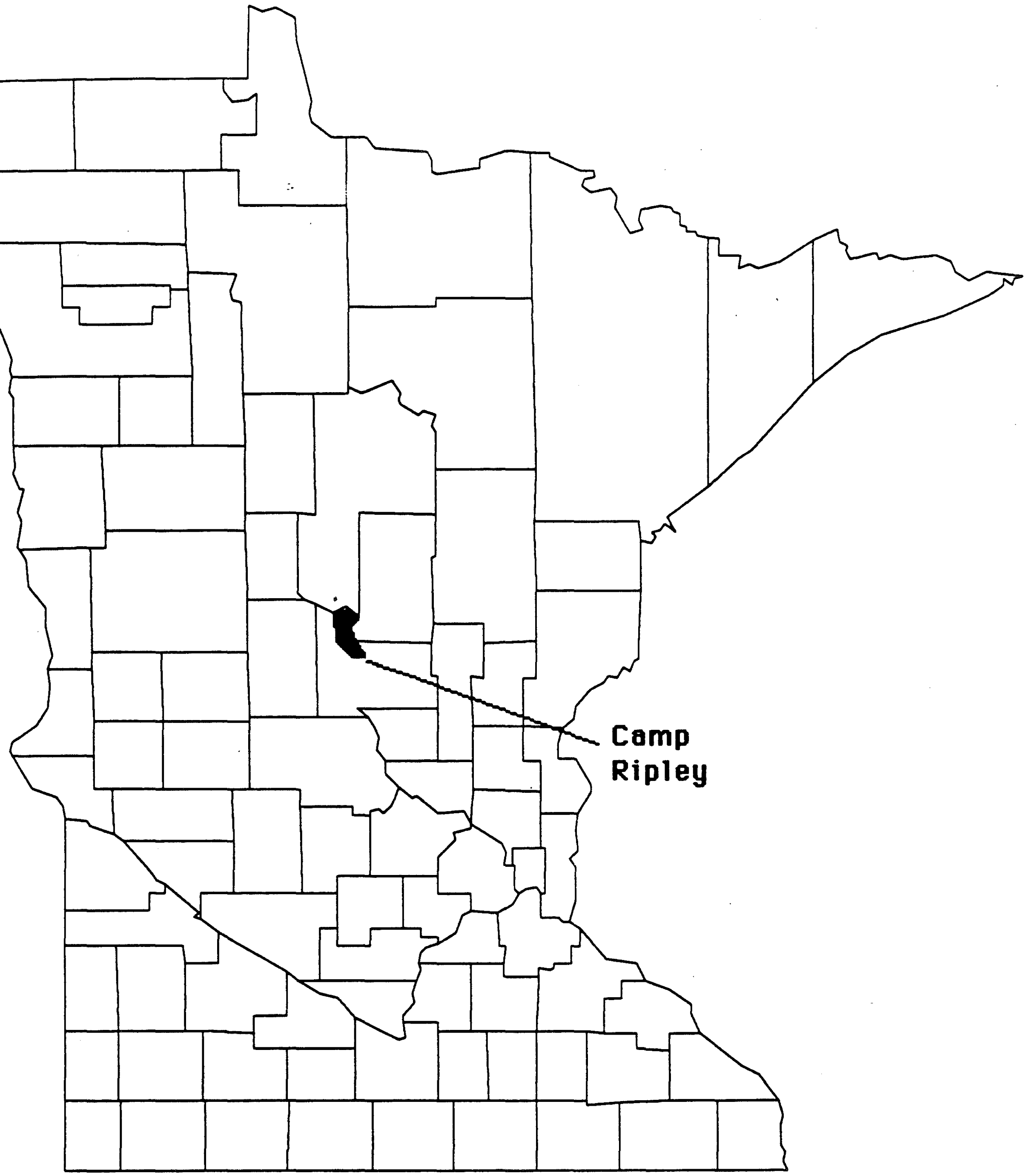


Figure 1. Location of Camp Ripley Military Reservation, Morrison County, Minnesota

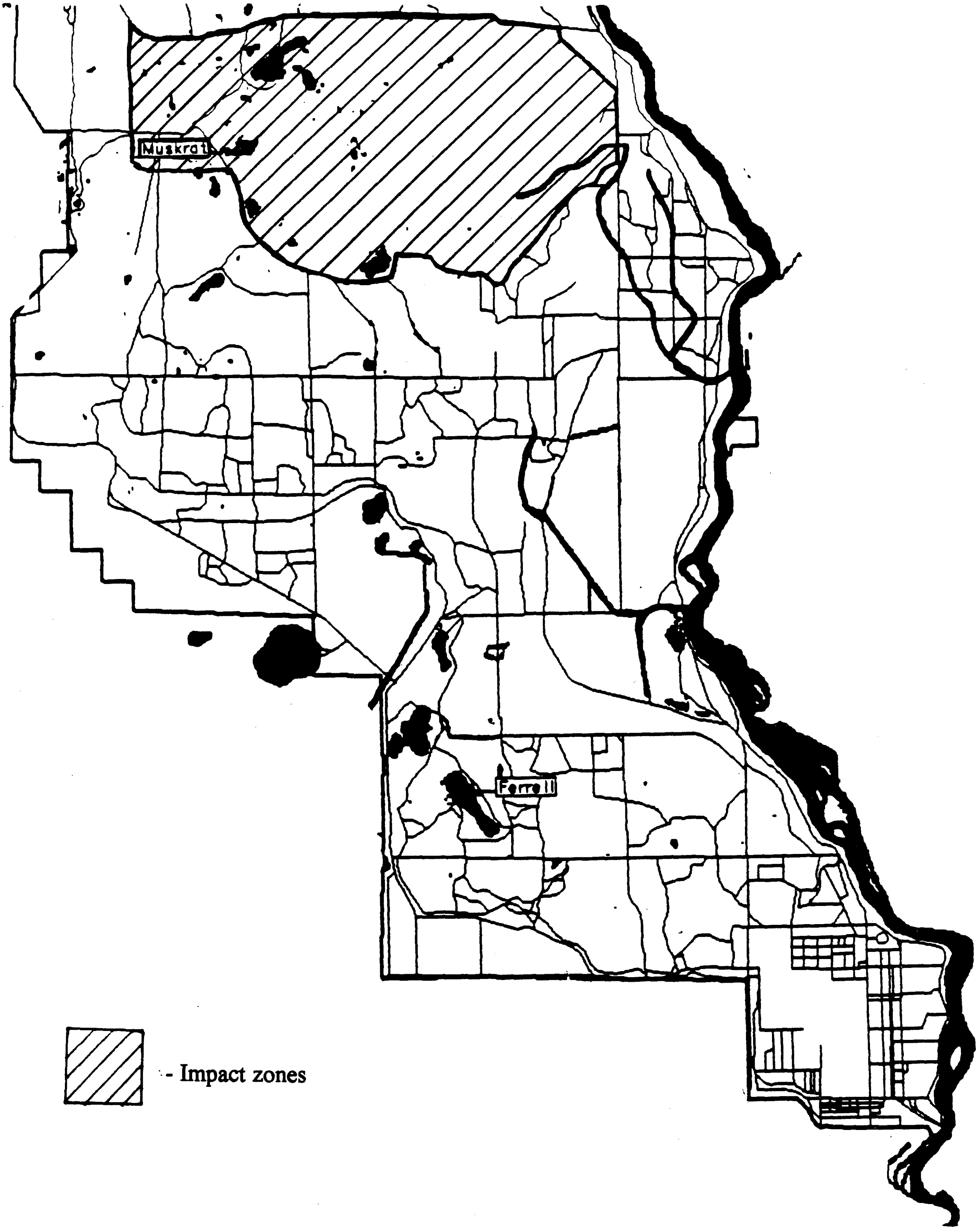


Figure 2. The location of the six study lakes (Bass, Coon Stump, Fosdick, Mud, Muskrat, and Ferrell) in Camp Ripley Military Reservation.

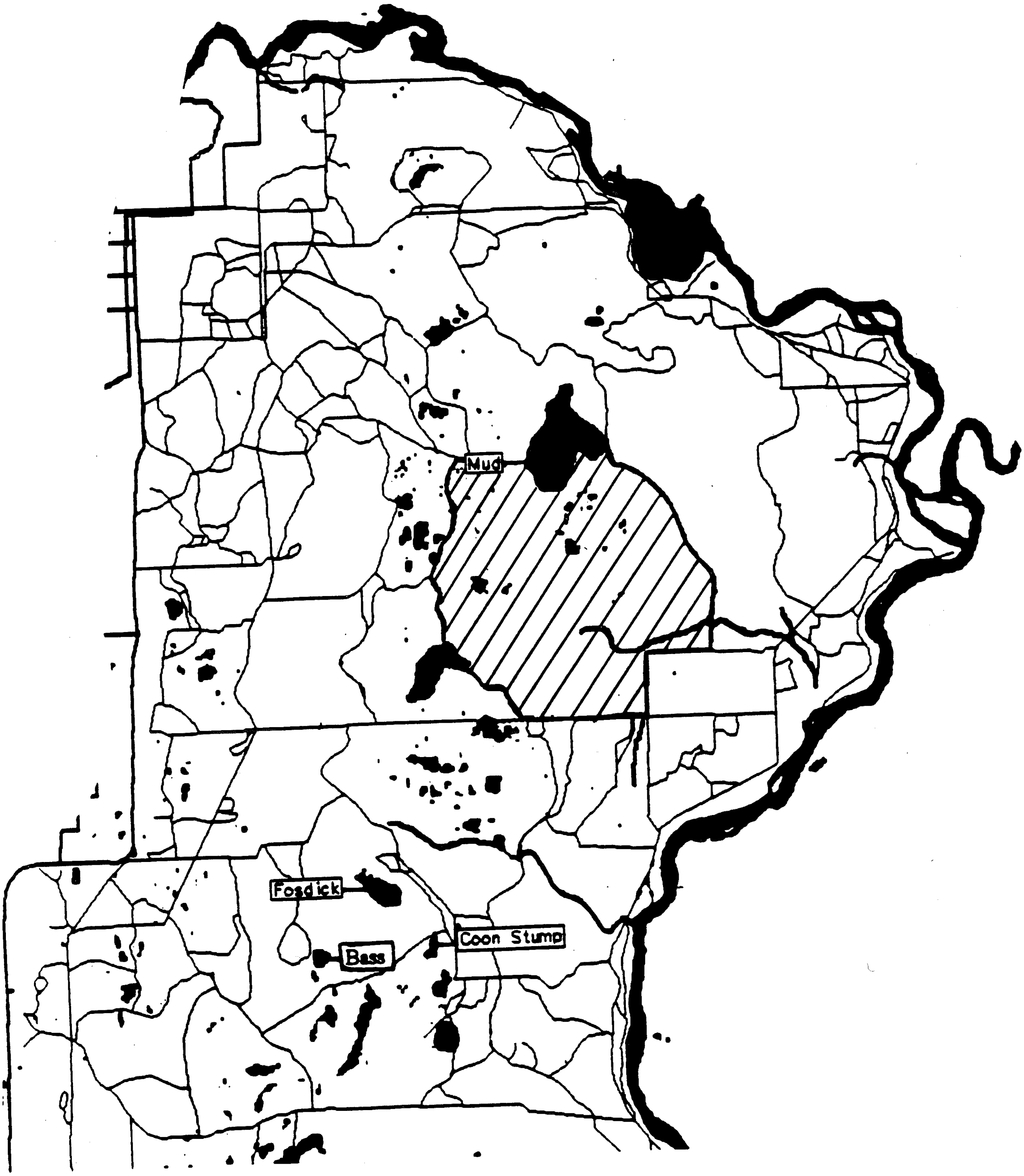


Figure 2. (continued) The location of the six study lakes (Bass, Coon Stump, Fosdick, Mud, Muskrat, and Ferrell) in Camp Ripley Military Reservation.

Methods

a. Benthos - Quantitative samples for benthic invertebrates were collected using a petite Ponar grab (15.25 cm x 15.25 cm; 232 cm^2 total area). Samples were collected in June and August for all three years of the study. Number of sites per lake varied according to lake size and were: Bass and Coon Stump, 2 each; Fosdick, 3; Mud and Muskrat, 4 each; Ferrell, 5. Three replicate grab samples were collected at each site. Samples were sieved through a 590μm mesh sieve. The sieved material was placed in Whirl-Paks, preserved with ethanol and transported back to the Biology Laboratory. Invertebrates were sorted from the samples under a dissecting microscope using 10X magnification. Invertebrates were counted and identified to the lowest practical level using the following taxonomic keys: insects, Hilsenhoff 1981, Merritt and Cummins 1996; Chaoboridae, Cook 1956; other taxa, Eddy and Hodson 1982. The Chironomidae were identified by mounting head capsules in CMC mounting media, followed by examination under a compound microscope. Large numbers of Chironomidae were subsampled before mounting.

b. Zooplankton - Zooplankton were collected quantitatively from set stations on all of the lakes. Horizontal tows (30 meters) were taken at each station using a Clarke-Bumpus plankton sampler (mesh size 80 µm). The number of sampling stations per lake varied according to the size and shape of the basin. Samples were collected four times per season: early May, late June/early July, early August and late August/early September. Samples were not collected during the early August period in 1994 due to scheduling conflicts. In addition to the routine sampling, night zooplankton tows (shortly after sunset) were conducted on Mud Lake during July 1994 and 1995 and on Fosdick Lake during July 1994. Activity traps were also used to collect zooplankton in Mud Lake during July 1995. The traps consisted of a funnel and bottle attached to a pole which was anchored into the bottom sediment. The trap was positioned between the vegetation and the water surface to collect any vertically migrating zooplankters. Activity traps were set for two consecutive nights and contents collected each morning. All zooplankton samples were preserved in ethanol and returned to the laboratory for analysis.

Additional zooplankton tows were conducted on Ferrell Lake in September of 1993 and 1995 during the week of walleye fingerling harvest to assess the impact of copper sulfate on the zooplankton community. (A complete report on the copper sulfate study is attached to this report.)

Zooplankton samples were processed using the following protocol. Sample volumes were adjusted to a known volume by filtering through 80µm mesh netting and rinsing specimens into a graduated beaker. Water was added to the beaker to a volume that would provide at least 200 organisms per 5 ml aliquot. The beaker was swirled in a figure-eight motion to ensure thorough mixing. Two 5 ml aliquots were withdrawn from each sample using a bulb pipet and transferred to a counting wheel and zooplankton samples were counted at 30X magnification under a dissecting microscope. Identification to species (or the lowest taxonomic group possible) was done with the use of a compound microscope. Taxonomic keys used for identification included Pennak (1989) for cladocerans other than daphnids, Brooks (1957) for daphnids and Smith and Fernando (1978) for copepods. Permanent slides were made of all species identified for a reference collection.

The 1995 zooplankton samples were processed using a computerized image analysis system running the "ZCOUNT" software program. This program provided individual length measurements in addition to counts. Using length/weight regression coefficients for individual taxa (Culver et al. 1985, Dumont et al. 1975) biomass was estimated for the 1995 samples in addition to densities.

In order to detect any differences among the six study lakes with respect to their zooplankton communities, correspondence analysis (CA) was run with the use of the Fortran program CANOCO (ter Braak 1988). CA is an ordination technique which identifies sites that are similar to each other in respect to their biological communities. Site scatter plots were constructed for the July sampling periods for all three years based on percent composition of zooplankton species excluding rare species (those that represented less than 5% of the community).

c. Water Chemistry - The following measurements were collected from each lake each sample period: pH, water temperature, turbidity and conductivity. Turbidity was measured with a Hach 16800 Tubidimeter, conductivity and temperature with a YSI Conductivity meter, and pH was measured with a Beckman Φ 21 pH meter.

One water sample was collected from each lake in the initial sample period to use for analysis for anions and cations. Additionally, core samples were collected mid-basin in each lake and were analyzed for metal contamination as well as comparisons of sedimentation rates (Engstrom 1994).

Results and Discussion

a. Macroinvertebrates- A total of 80 macroinvertebrate taxa were collected from the six study lakes over the course of the three year study (Tables 1 and 2). Thirteen were non-insect, with those dominated by the Mollusca. Of the insect taxa, 33 were different Chironomidae genera. These numbers are lower than reported in an earlier study on Camp Ripley lakes (Montz and Hirsch 1993) where some of the same study lakes were sampled in April and September. However, that study also included qualitative samples from shoreline areas, whereas the present study examined the mid-lake benthic community. The numerical dominance of the chironomid community is not surprising, as this group often dominates the benthic off-shore community.

The lowest taxa totals were seen consistently in Coon Stump Lake, while Bass Lake was the next lowest. Both of these lakes are small lakes without fish, and much of the invertebrate production may be shifted to either the zooplankton fauna or the large, free swimming invertebrate fauna, such as the Odonata (dragon- and damselflies) or the Hemiptera (true bugs). In contrast, Muskrat Lake also lacks fish but annually had some of the higher totals of taxa. Fosdick, Mud, Muskrat and Ferrell lakes all showed increases in total taxa over the course of the study, while Bass and Coon Stump declined over the three year period. Fosdick Lake had the highest total of taxa over the three year period, with Mud, Muskrat and Ferrell having similar totals. Coon Stump was significantly lower than all the other lakes, with only 16 different taxa recorded throughout all sample periods.

Table 1. Aquatic mcroinvertebrates collected with Ponar grab samples from Camp Ripley study lakes, 1993 - 1995. The first three lakes (BA, CS, FS) are non-impact lakes.
BA - Bass Lake, CS - Coon Stump Lake, FS - Fosdick Lake, MD - Mud Lake, MS - Muskrat Lake, FL - Ferrell Lake

Taxa	BA	CS	FS	MD	MS	FL
EPHEMEROPTERA						
Caenidae						
Caenis sp.			X	X	X	X
Baetidae						
Baetis sp.						X
TRICHOPTERA						
Phryganeidae		X	X		X	X
Leptoceridae						
Oecetis sp.			X	X		X
Triaenodes sp.			X			
Triaenodes tarda			X			
Mystacides sp.						X
Mystacides sepulchralis				X		
Mystacides longicornis				X		
Limnephilidae						
Limnephilus sp.						X
Hydroptilidae						
Oxyethira sp.					X	
Orthotrichia sp.			X			
Polycentropodidae						
Polycentropus sp.						X
Molannidae						
Molanna sp.						X
ODONATA						
Coenagrionidae		X				
Amphiagrion sp.					X	
Lestidae						
Lestes sp.			X		X	X
Corduliidae						
Cordulia sp.				X		
Epitheca sp.			X	X		
Libellulidae						
Leucorrhinia sp.				X		
HEMIPTERA						
Corixidae						
Hesperocorixa sp.			X			
Palmacorixa sp.		X				
Sigara sp.			X			
Cenocorixa sp.			X			
Notonectidae						
Notonecta sp.	X					
COLEOPTERA						
Gyrinidae						
Dineutus sp.		X				X
Curculionoidae		X			X	
Chrysomelidae						
Donacia sp.		X				
LEPIDOPTERA					X	

Table 1. (continued)

Taxa	BA	CS	FS	MD	MS	FL
DIPTERA						
Chironomidae	X	X	X	X	X	X
Chaoboridae						
Chaoborus americanus	X	X			X	
Chaoborus punctipennis		X	X		X	X
Chaoborus albatus	X	X	X	X	X	X
Chaoborus flavicans	X					
Ceratopogonidae						
Bezzia/Palpomyia grp.	X	X	X	X	X	X
Nilobezzia sp.	X	X	X		X	X
Sphaeromais sp.				X	X	X
Probezzia sp.			X			
CRUSTACEA						
Hyalella azteca			X	X		X
Crangonyx richmondensis grp.	X				X	X
NEMATOMORPHA				X	X	
TRICLADIDA				X		
ACARINA	X	X	X	X	X	X
HIRUDINEA	X	X	X	X	X	X
MOLLUSCA						
Sphaeriidae	X	X	X	X	X	X
Gastropoda	X	X		X		X
Amnicola sp.			X	X		
Physa sp.			X			
Helisoma sp.			X	X		
Feressia sp.			X			
Stagnicola sp.			X			
TOTAL NUMBER OF TAXA	12	16	26	20	19	22

Table 2. Chironomidae collected and identified from Ponar grab samples from Camp Ripley study lakes, June and August 1993 - 1995. The first two lakes (BA, FS) are non-impact lakes. Chironomidae were collected in only one sample period from Coon Stump Lake and are not included.
BA - Bass Lake, FS - Fosdick Lake, MD - Mud Lake, MS - Muskrat Lake, FL - Ferrell Lake

	June					August				
Taxa	BA	FS	MD	MS	FL	BA	FS	MD	MS	FL
Tanypodinae										
Procladius sp.	X	X	X	X	X	X	X	X	X	X
Ablabesmyia sp.		X	X		X		X			X
Thienemannimyia sp.		X					X	X		
Clinotanypus sp.					X					X
Coeltanypus sp.										X
Larsia sp.	X	X	X					X		
Labrundinia sp.		X	X							
Chironominae										
Chironomini										
Chironomus sp.	X	X	X	X		X	X	X	X	X
Microtendipes sp.	X	X		X	X	X			X	X
Glyptotendipes sp.		X		X	X	X	X		X	X
Cladopelma sp.	X			X	X	X	X		X	
Dicrotendipes sp.		X	X	X	X	X	X	X	X	X
Polypedilum sp.		X	X				X		X	
Parachironomus sp.	X	X	X	X			X	X	X	X
Phaenopsectra sp.			X						X	
Pseudochironomus sp.			X		X			X		X
Einfeldia sp.	X	X		X	X	X			X	X
Cryptochironomus sp.				X	X		X			
Nilothauma sp.	X	X					X			X
Tribelos sp.			X	X						
Stempelinella sp.					X					
Xenochironomus sp.										X
Lauterborniella sp.		X								
Endochironomus sp.		X								
Paracladopelma sp.	X									
Zavreliella sp.			X							
Tanytarsini										
Tanytarsus/Micropsectra sp.	X	X	X	X	X	X	X	X	X	X
Cladotanytarsus sp.	X	X	X	X	X				X	X
Paratanytarsus sp.		X	X				X	X		
Tanytarsus sp.	X		X		X		X	X	X	X
Orthocladiinae										
Psectrocladius sp.			X	X			X	X		X
Corynoneura sp.		X	X				X		X	
Nanocladius sp.								X	X	
TOTAL NUMBER OF TAXA	12	19	18	13	14	8	16	12	15	17

Preliminary examination indicated that benthic densities at sites within a lake did not differ significantly from one another over time, so densities from all replicates from all sites were combined to give a whole lake mean (#/m^2) for each sample period. The results (Fig. 3) indicate only Muskrat Lake seemed to be distinct from the other study lakes throughout the course of the study. The densities in Muskrat were consistently higher throughout the study, with the exception of August 1993, when Mud Lake had higher mean benthic densities. While lakes had widely varying densities in June 1993, by late 1994 most of the study lakes had similar densities, while numbers in Muskrat remained about twice that of other lakes.

The taxa totals and benthic densities do not seem to show any consistent impacts on the treatment lakes. Mud Lake borders the northern impact area, but showed no evidence of negative impacts to the benthic diversity or density. Muskrat Lake, however, is enclosed within an impact area and could reasonable be expected to have the highest level of disturbance of the study lakes; however, it had consistently high taxa diversity and density among the study lakes. The impact area is burned every spring to reduce fire hazards associated with training activities. It is possible that runoff is flushing higher levels of nutrients into the lake, and this is increasing the productivity. However, it does not appear that benthic macroinvertebrates are negatively affected by training activities at the scale of sampling done in this study.

b. Zooplankton- A total of 11 species of copepods and 22 species of cladocerans were collected among the six study lakes during 1993-1995 (Table 3). Both calanoid and cyclopoid copepods were found in all lakes with one or two dominant species. In lakes where two species of calanoids were present, they generally did not coexist during the same time period. In contrast, some cyclopoids appeared to coexist in lakes where more than one species of cyclopoids were present. These coexisting cyclopoids are littoral species that dwell among the vegetation where more niche space is available. The dominant copepods varied among lakes but all calanoids belonged to the family Diaptomidae. Cladocerans were present in all lakes. The most common cladocerans appeared to be *Bosmina longirostris* and *Diaphanosoma sp.* which were present in all lakes. Bass was the only lake where *Daphnia spp.* were not found. The phantom midge larvae *Chaoborus americanus* was present only in Bass, Muskrat and Coon Stump lakes.

Coon Stump and Mud lakes generally had the lowest zooplankton densities throughout the sampling seasons whereas Ferrell and Muskrat appeared to have the highest (Figs. 4-8). Total densities in all lakes were lower in 1995 than in the previous two years, which may be a result of higher water levels in 1995. The 1995 zooplankton biomass estimates are summarized along with 1995 density estimates (Fig. 9). In general, the biomass estimates follow the same pattern as the density estimates throughout the year with the exception of Mud Lake in May. Very high densities of naupllii and copepodites were estimated for Mud Lake in May which contributed very little to the total biomass.

Muskrat Lake had relatively high zooplankton densities with large numbers of immature copopods (nauplii and copepodites) appearing early in the 1993 and 1994 season while the adult copepods and cladocerans reached the highest densities during mid-summer (Fig. 5). Muskrat Lake is located in a military impact area and was considered as one of the three impact lakes. Every spring (usually late April) the land surrounding Muskrat Lake is burned. This activity could

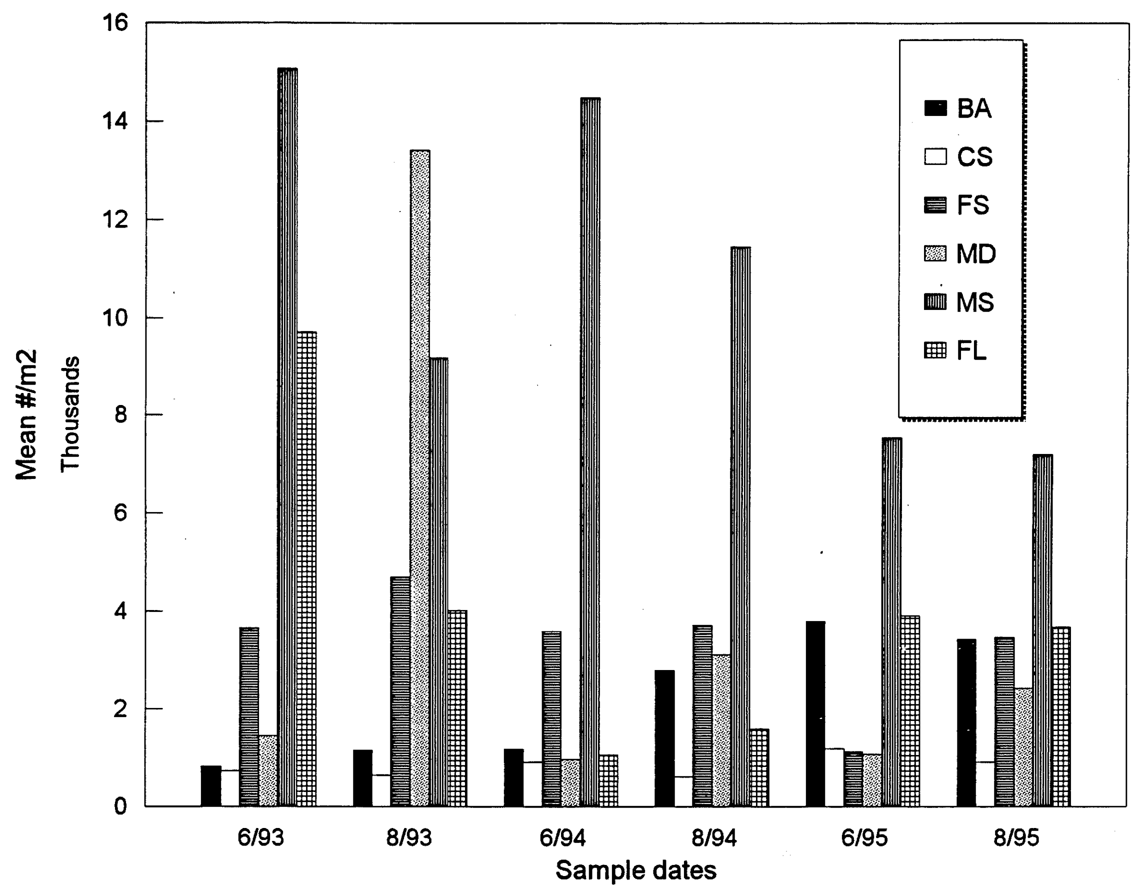
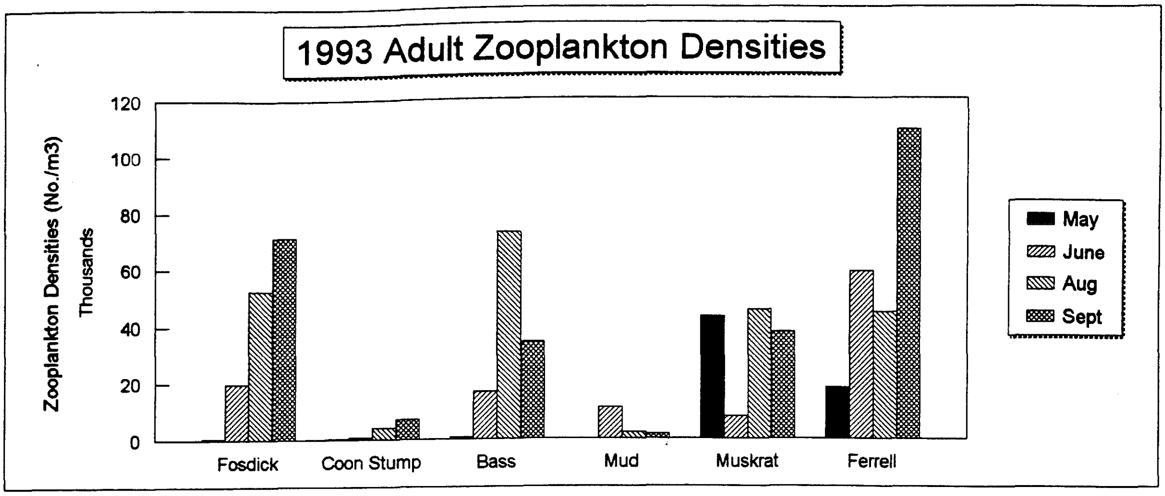


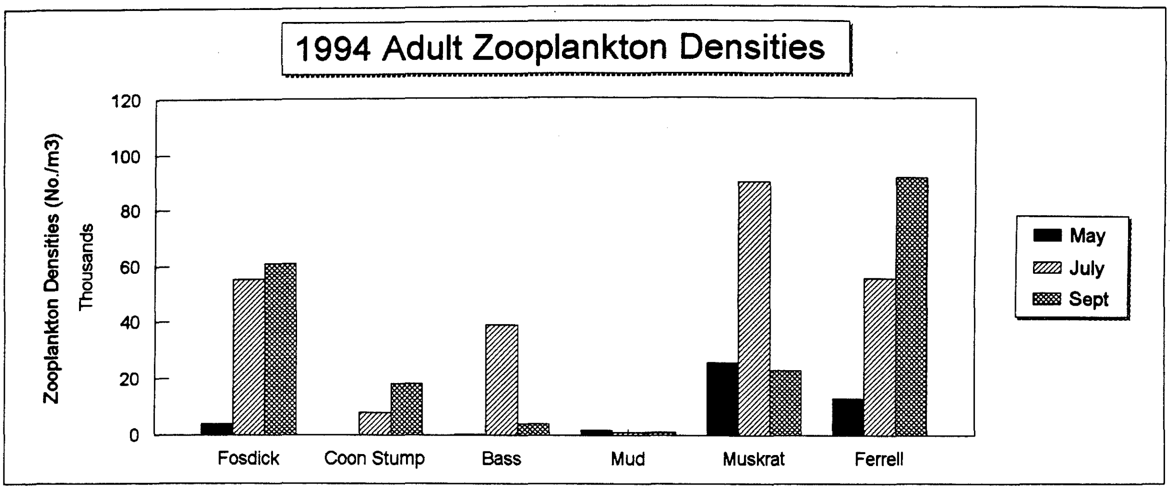
Figure 3. Mean whole lake benthic densities from Camp Ripley study lakes from sample periods 1993 - 1995. All reps and sites included in means. BA - Bass Lake; CS - Coon Stump; FS - Fosdick Lake; MD - Mud Lake; MS - Muskrat Lake; FL - Ferrell Lake
The non-impact lakes are the three bars on the left of each set, while the three bars on the right are the impact lakes.

Table 3 . Summary of zooplankton taxa collected from Camp Ripley study lakes, 1993-1995.

	Mud	Bass	Fosdick	Ferrell	Muskrat	Coon Stump
COPEPODS						
Skistodiaptomus oregonensis	X			X		
Skistodiaptomus pallidus			X			
Leptodiaptomus siciloides				X		
Aglaodiaptomus leptopus		X				
Aglaodiaptomus saskatchewanensis		X			X	X
Mesocyclops edax	X		X	X	X	X
Diacyclops bicuspidatus thomasi	X		X	X		X
Tropocyclops prasinus mexicanus	X	X	X	X		
Eucyclops serrulatus			X		X	
Eucyclops speratus	X*					
Acanthocyclops vernalis						X
CLADOCERANS						
Daphnia pulex				X	X	X
Daphnia laevis			X	X		
Daphnia ambigua			X	X		
Daphnia rosea	X					
Holopedium gibberum		X	X		X	X
Bosmina longirostris	X	X	X	X	X	X
Diaphanosoma birgei	X	X	X	X		X
Diaphanosoma brachyurum	X	X			X	
Ceriodaphnia lacustris	X		X			
Ceriodaphnia reticulata				X	X	
Chydorus sphaericus	X			X	X	
Simocephalus serrulatus	X					
Streblocerus serricaudatus		X				
Scapholeberis sp.	X*					
Alona guttata			X			
Alona circumfimbriata	X*				X	
Alona quadrangularis						X
Ilyocryptus spinifer	X			X		
Eurycercus lamellatus	X*					
Sida crystallina	X*					
Camptocercus rectirostris	X*					
Polyphemus pediculus					X	
OTHER						
Chaoborus americanus		X			X	X

* collected only from night tows and/or activity traps





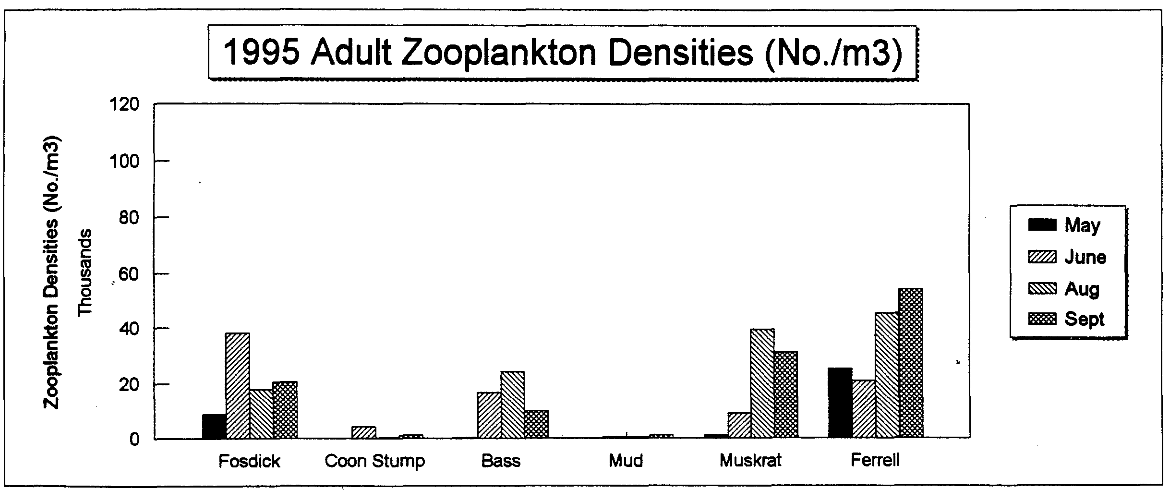


Figure 4. Total Adult zooplankton (excluding nauplii and copepodites) densities (No./m3) from the six Camp Ripley study lakes, (Fosdick, Coon Stump, and Bass: non impact lakes; Mud, Muskrat, and Ferrell: impact lakes), 1993-1995.

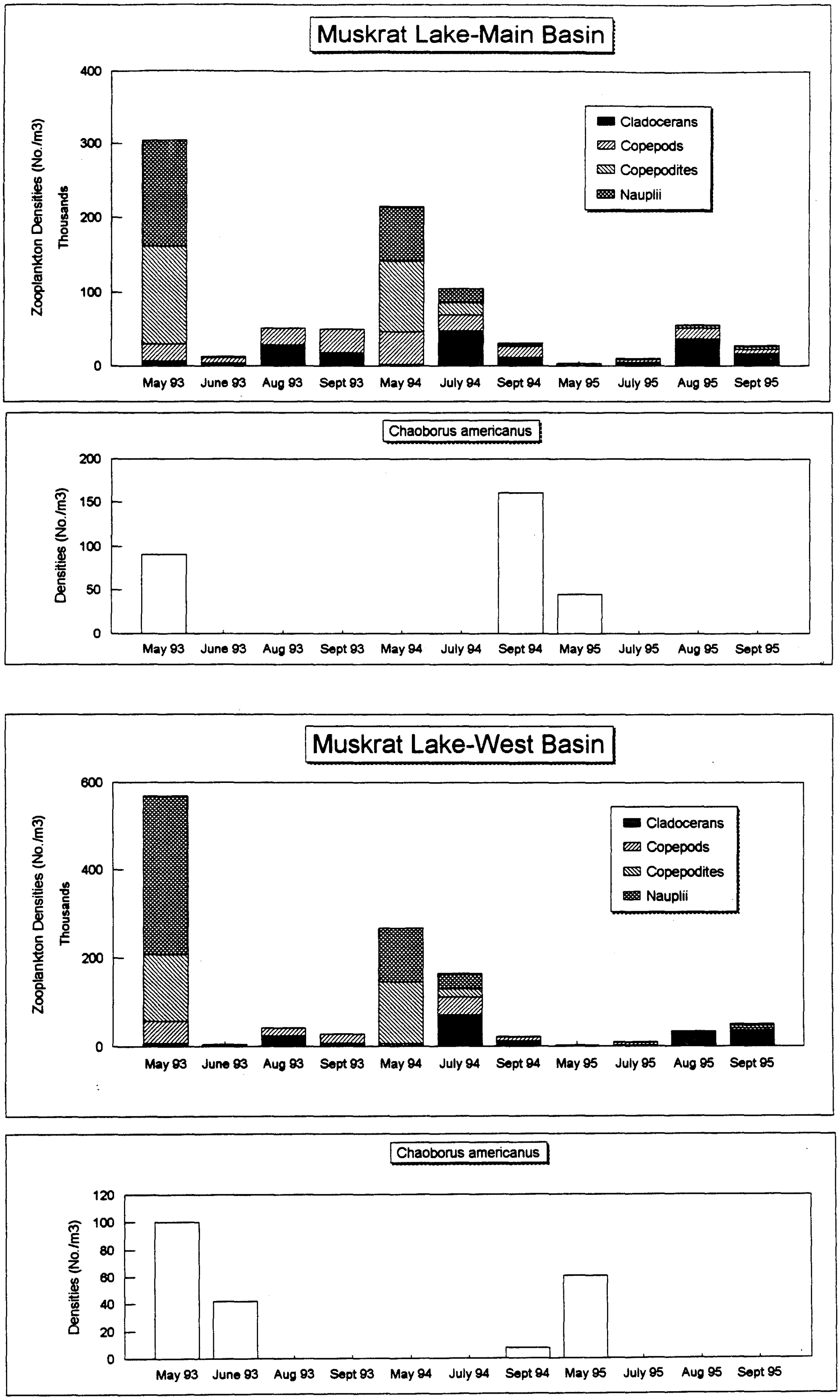


Figure 5. Densities (No./m3) of the major groups of zooplankton (cladocerans, copepods, nauplii and copepodites) and Chaoborus americanus in Muskrat Lake, 1993-1995.

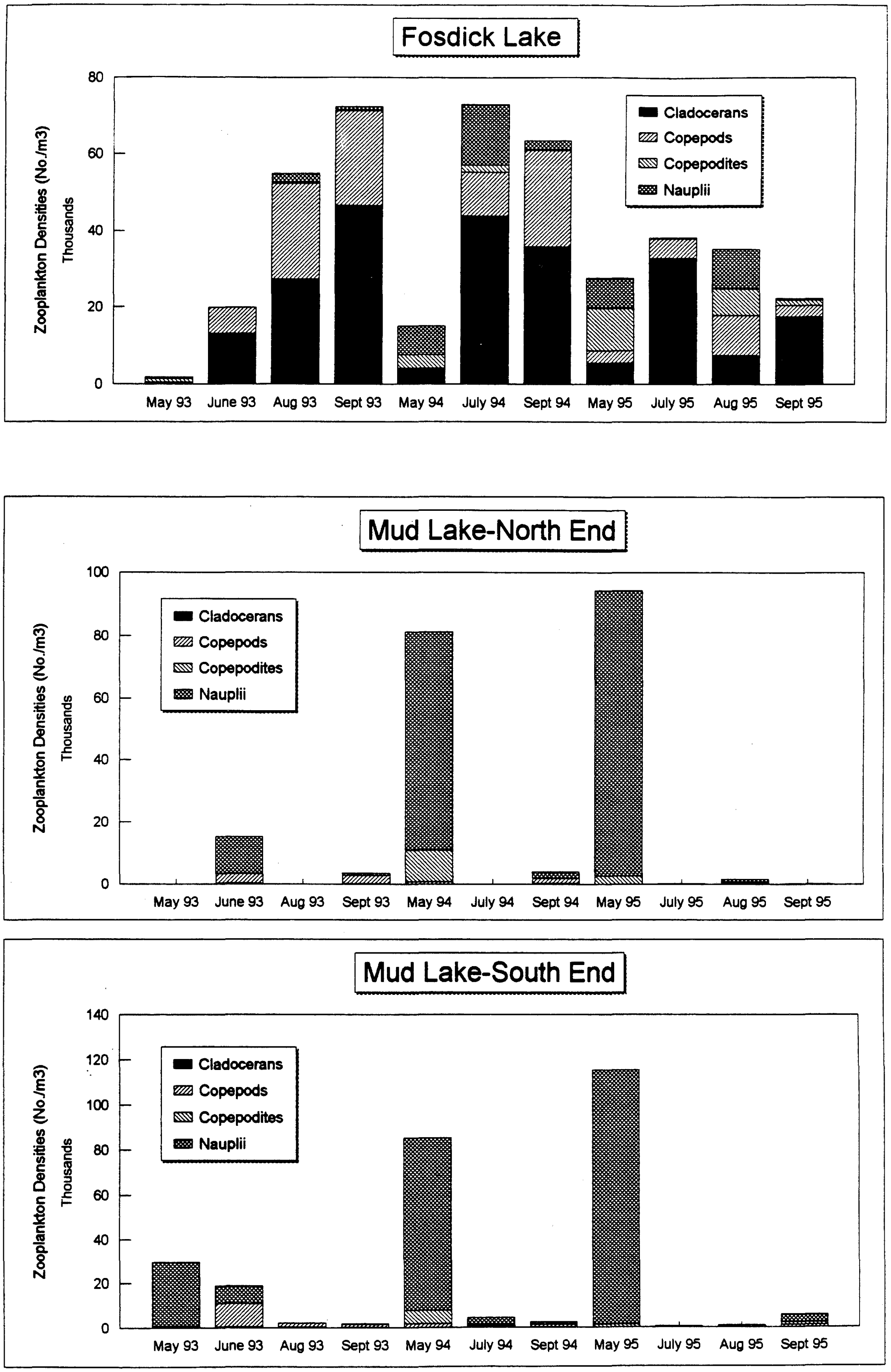
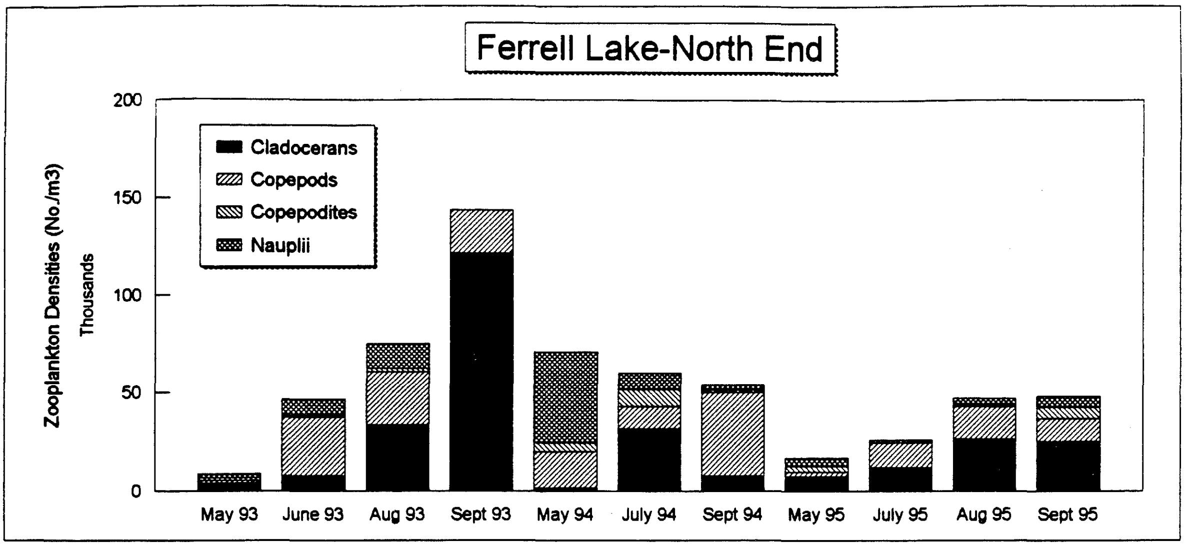
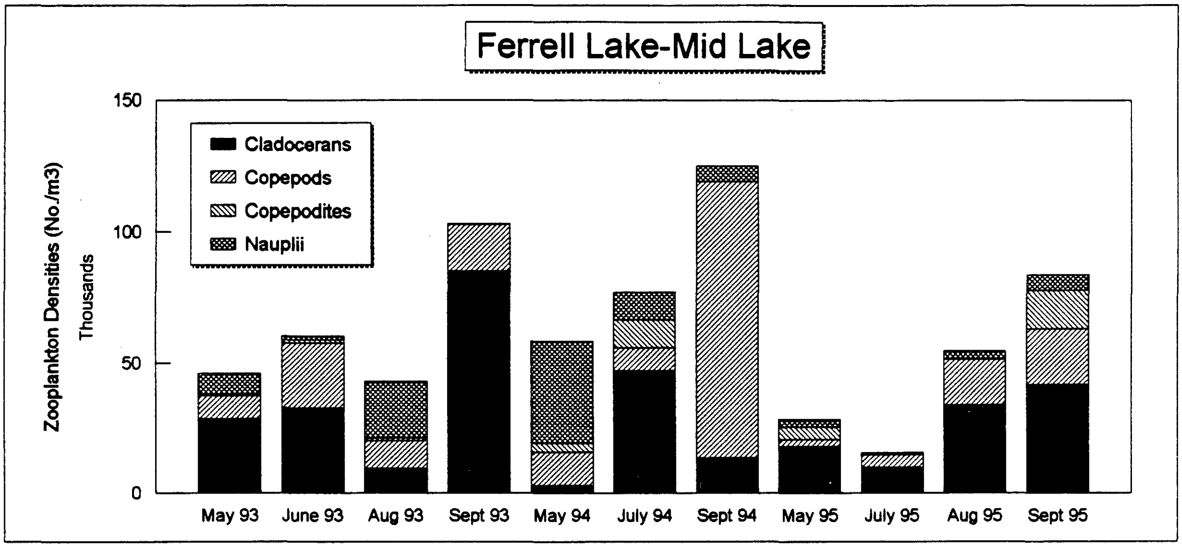


Figure 6. Densities (No./m3) of the major groups of zooplankton (cladocerans, copepods, nauplii and copepodites) in Fosdick and Mud lakes, 1993-1995.





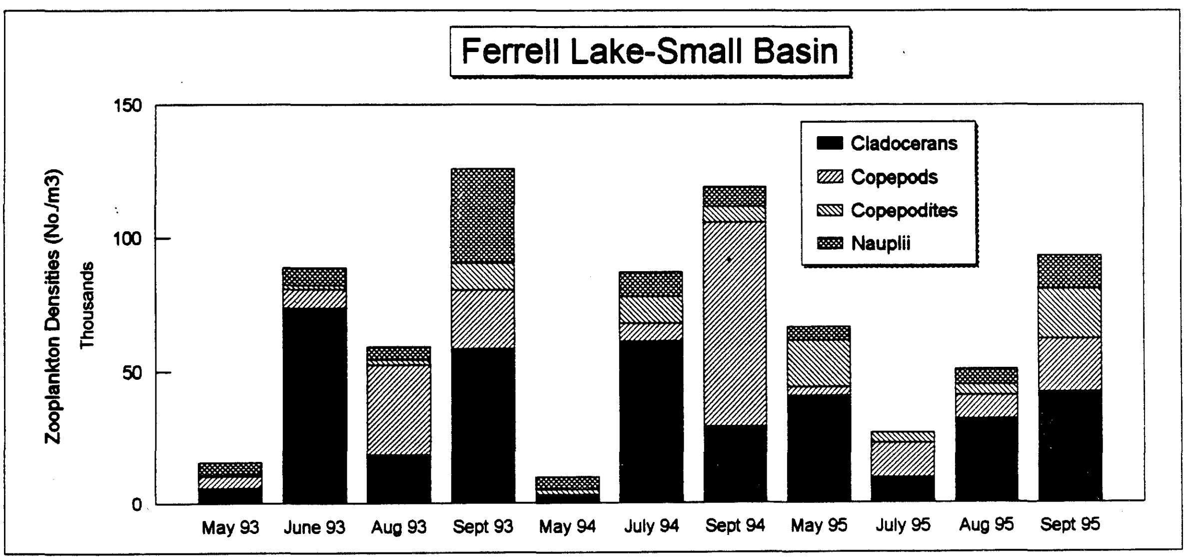


Figure 7. Densities (No./m3) of the major groups of zooplankton (cladocerans, copepods, nauplii and copepodites) in Ferrell Lake, 1993-1995.

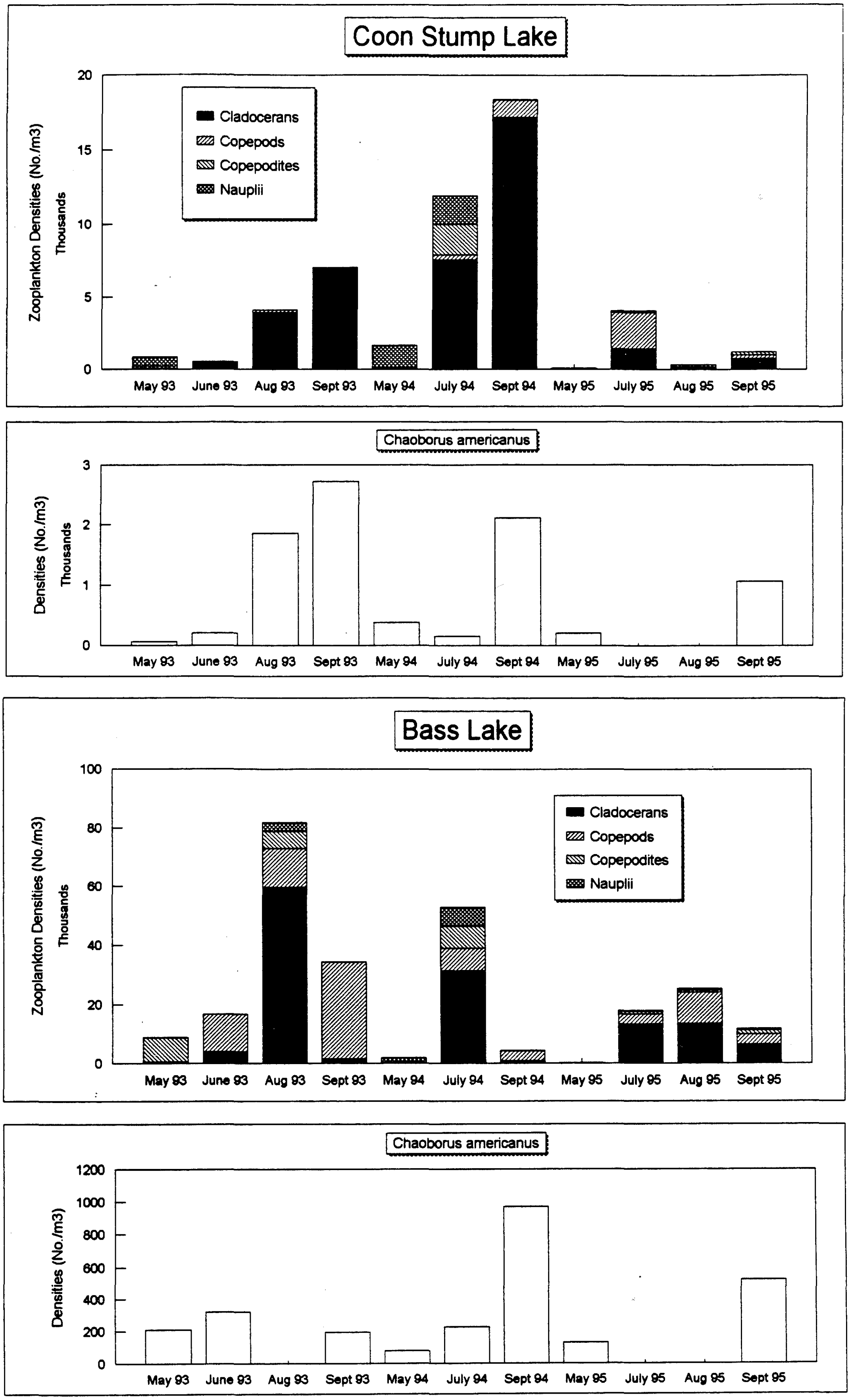
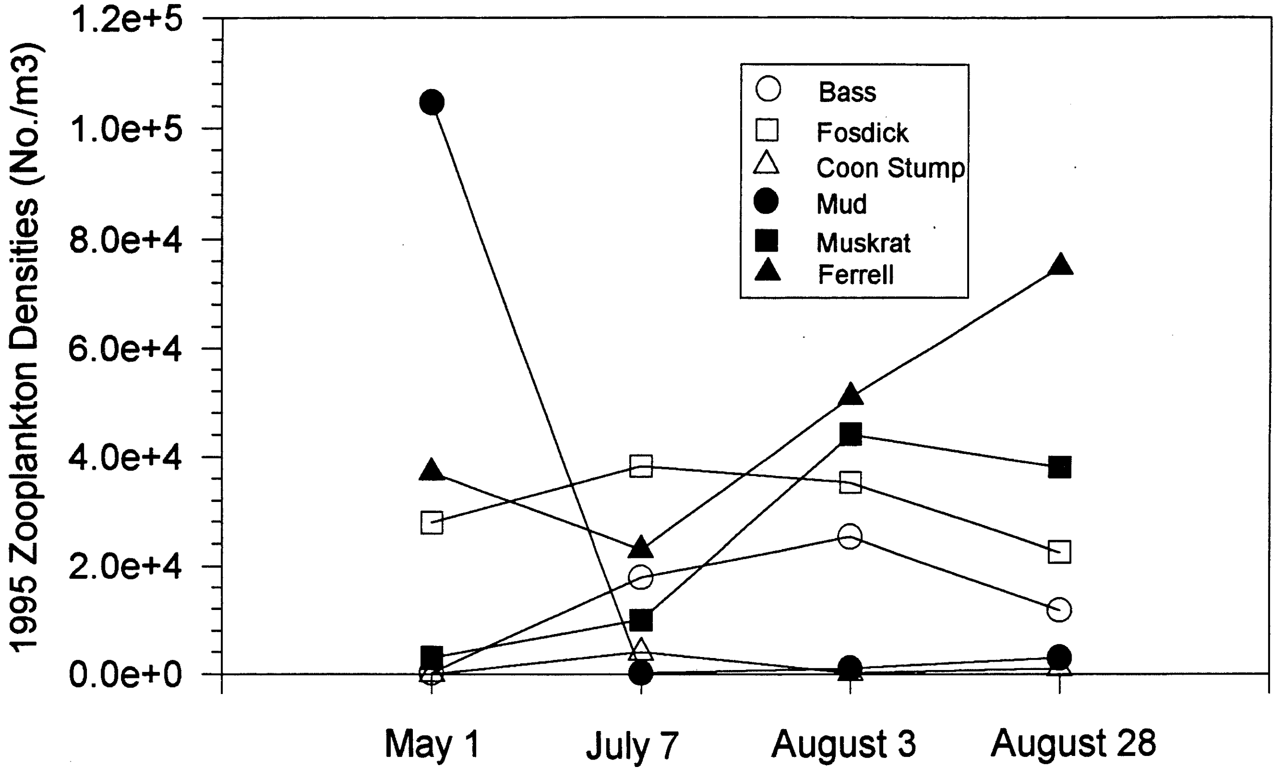


Figure 8. Densities (No./m3) of the major groups of zooplankton (cladocerans, copepods, nauplii and copepodites) and Chaoborus americanus in Coon Stump and Bass lakes, 1993-1995



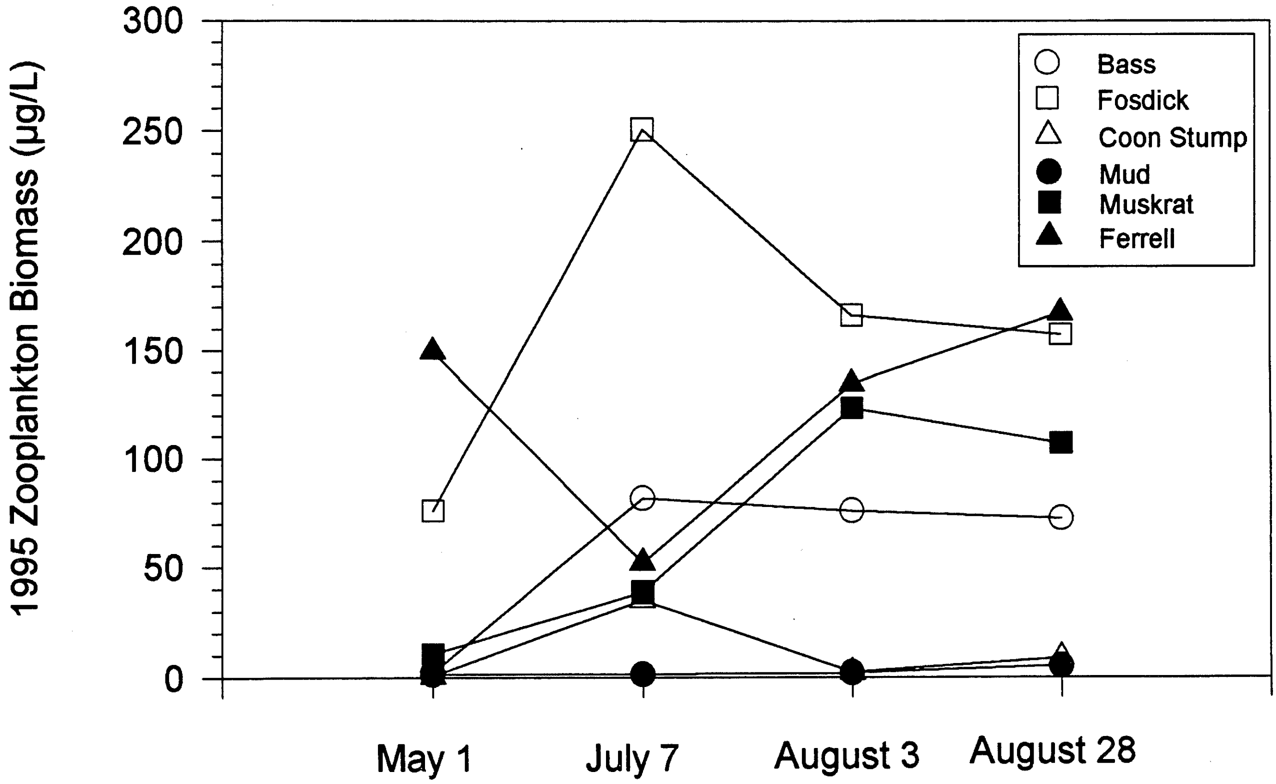


Figure 9. The 1995 zooplankton densitites (No./m3) and biomass (µg/l) from the Camp Ripley study lakes, (Bass, Coon Stump, and Fosdick: non-impact lakes; Mud, Muskrat, and Ferrell: impact lakes).

account for the high zooplankton densities found in Muskrat Lake as nutrients are released from the watershed and flushed into the lake each year. This spring "bloom" of nauplii and copepodites was not apparent in 1995 but it may have occurred after the May sampling period since it was a late spring with cooler water temperatures (Fig. 15) and the burning activity occurred later than in the previous two years.

The seasonal shift from the winter cyclopoid *Diacyclops bicuspidatus thomasi* in the spring samples to the dominant calanoid *Aglaodiaptomus saskatchewanensis* in the summer samples was apparent in Muskrat Lake (Fig. 10). *D.bicuspidatus thomasi* is a winter cyclopoid, encysting in the bottom sediment as a copepodid stage during the summer (Birge and Juday 1908, Balcer et al. 1984) whereas *A. saskatchewanensis* generally do not appear in large numbers until mid-summer. The common cladocerans present in Muskrat Lake included *Daphnia pulex*, *Holopedium gibberum* and *Diaphanosoma spp.* (Fig. 11).

The phantom midge larvae, *Chaoborus americanus* was present in Muskrat Lake. This species is abundant only in fishless lakes. Most chaoborids stay in the bottom sediment during the day to avoid predation by fish and migrate into the water column at night to feed. *C. americanus* however, stays in the water column permanently so they are highly susceptible to predation. *C. americanus* was present only intermittently throughout the sampling periods in very low densities (Fig. 5). The low density of *C. americanus* in Muskrat Lake could be due to the presence of an undetected fish population however, minnow traps and small mesh (1/4") trapnets were set in Muskrat Lake to document any presence of forage fish which could account for the low densities of *C. americanus*, but no minnows were caught.

Mud Lake had very low zooplankton densities throughout most of the sampling seasons (Fig. 6). This lake was also considered an impact lake because it borders an impact area on the military reservation. Similar to Muskrat Lake, Mud appeared to produce a "spring bloom" of nauplii and copepodites but in contrast to Muskrat Lake, it had very low densities during the remainder of the season. The only common species present in Mud Lake was the calanoid *Skistodiaptomus oregonensis* which was most abundant during July (Fig. 10). Very few cladocerans were collected from Mud Lake during routine sampling, although five different species of cladocerans were collected from night tows and/or activity traps during July. These cladocerans were littoral/vegetative dwelling species that live in the dense mats of vegetation present in Mud Lake. Of these five species, *Sida crystallina* were found in highest densities whereas *Eurycercus lamellatus*, *Camptocercus rectirostris*, *Alona circumfimbriata* and *Scapholeberis sp.* were found in lower densities. One copepod, *Eucyclops speratus* was also collected only in the night tows. The low zooplankton densities found in Mud Lake are probably not due to any military activities but rather due to the lake's water chemistry and the presence of large numbers of forage fish.

Ferrell Lake had high zooplankton densities throughout most of the sampling periods (Fig. 7). *Skistodiaptomus oregonensis* appeared to be the dominant calanoid copepod with densities peaking in September (Fig. 10). Of the cyclopoids, *Diacyclops bicuspidatus thomasi* was abundant during the spring and the small cyclopoid *Tropocyclops prasinus mexicanus* appeared to be dominant later in the season. *Daphnia pulex* and *Daphnia laevis* were the dominant cladocerans in the spring but disappeared in the large basin by August (Fig. 11). Predation by stocked walleye fry is the most likely explanation for the disappearance. Ferrell

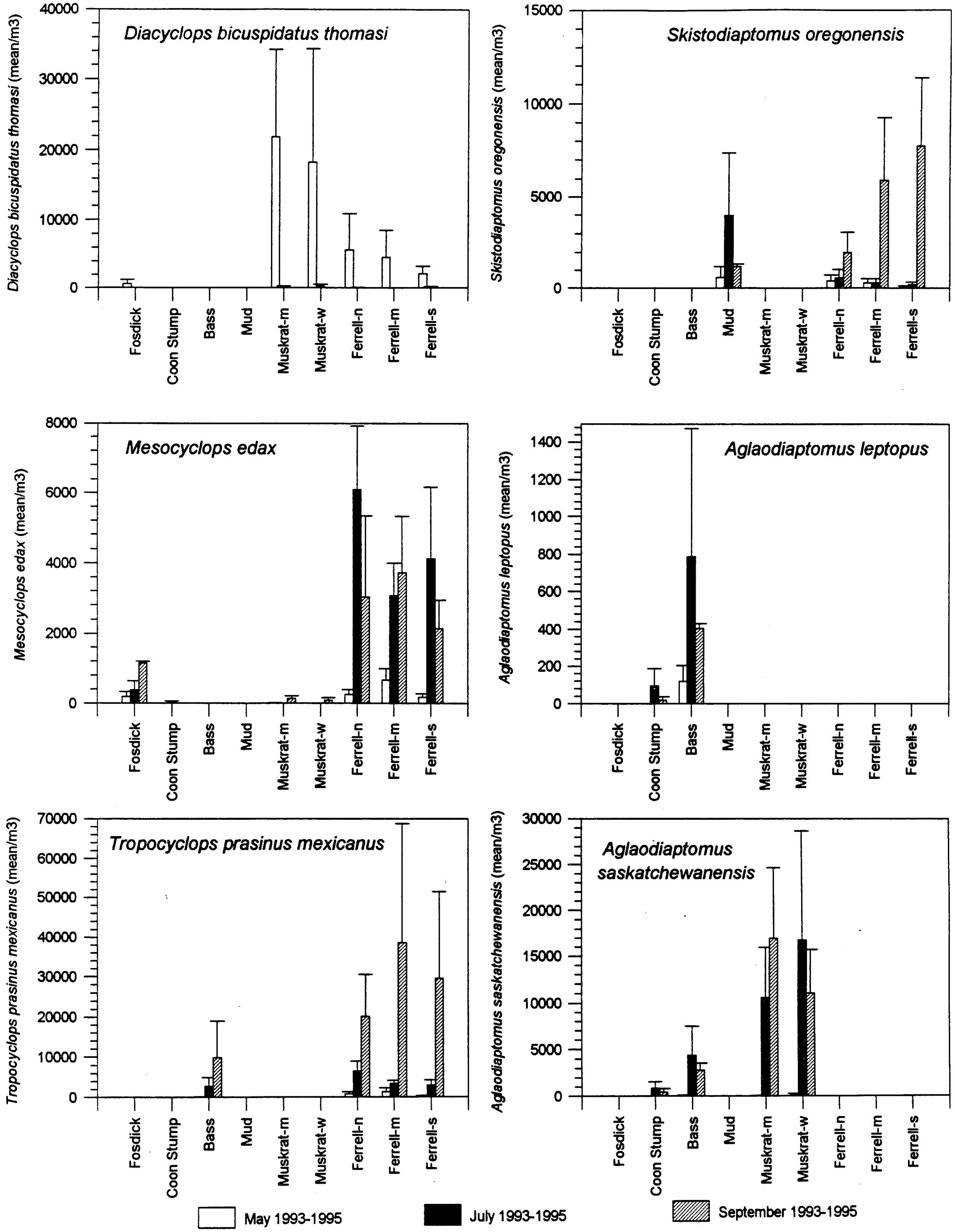


Figure 10. Mean monthly densities (No./m3) for the years 1993-1995, with standard error bars, of selected copepod species in the six Camp Ripley study lakes.

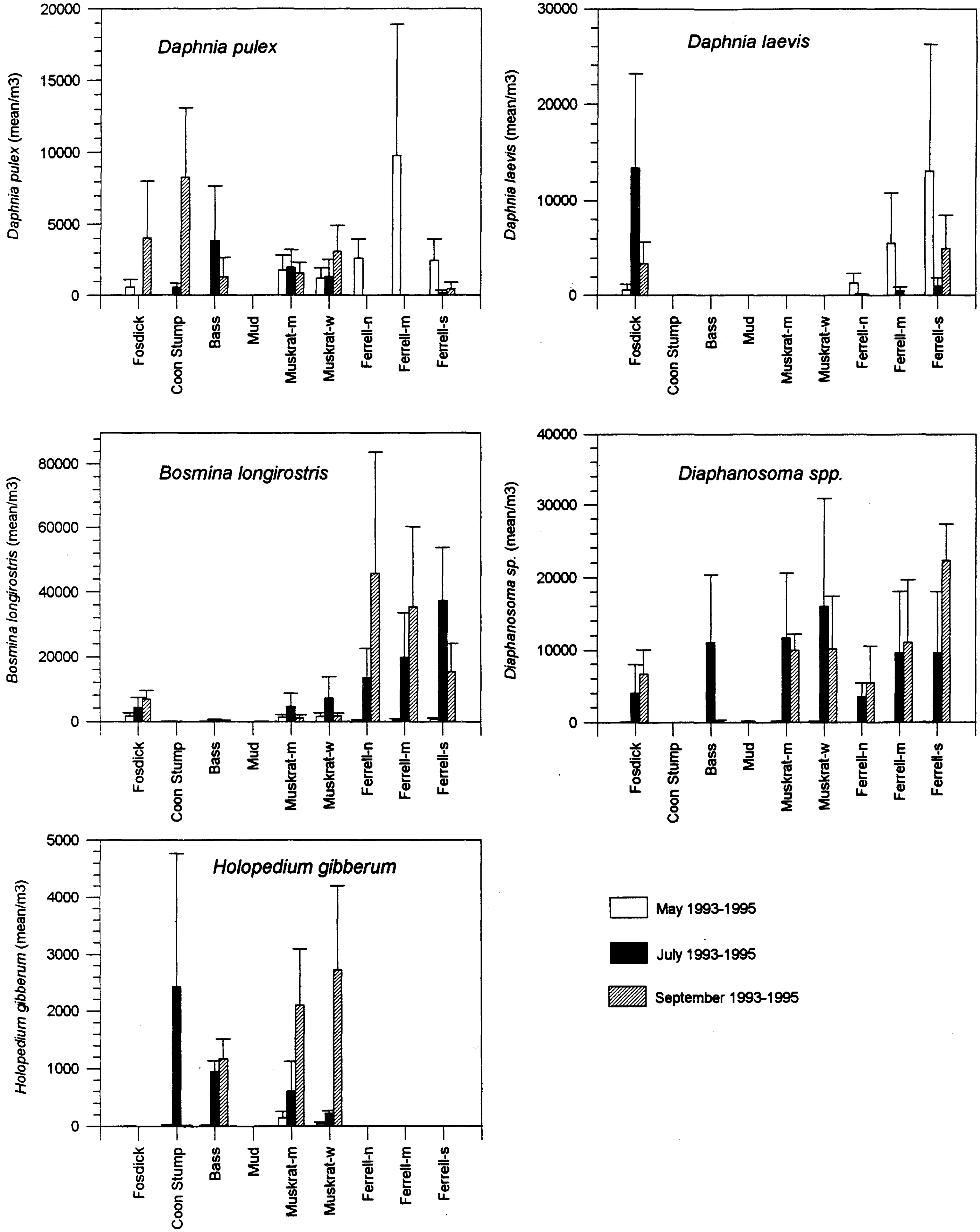


Figure 11. Mean monthly densities (No./m3) for the years 1993-1995, with standard error bars, of selected cladoceran species in the six Camp Ripley study lakes.

Lake was considered a military impact lake only because of its occasional use for amphibious vehicle training. In this study, the impacts on Ferrell Lake's zooplankton community were not due to military activities, but due to the MN DNR walleye rearing activities. These impacts were restricted to the cladoceran portion of the zooplankton communities and only short term. (See attached report).

Fosdick Lake also had relatively high zooplankton densities throughout most of the sampling seasons (Fig. 6). The dominant calanoid was *Skistodiaptomus pallidus* which was not found in any of the other study lakes. Similar to Ferrell Lake, *Daphnia pulex* and *Daphnia laevis* were the dominant cladocerans but these species did not disappear in Fosdick by September as they did in Ferrell Lake (Fig. 11). Fosdick Lake has forage fish present but it is not used as a walleye rearing pond.

Zooplankton densities in Bass Lake were low in the spring samples and were represented mainly by immature copepods but by August densities of adult copepods and cladocerans were relatively high (Fig. 8). The dominant calanoids in Bass Lake were *Aglaodiaptomus saskatchewanensis* and *Aglaodiaptomus leptopus* (Fig. 10). These two species have a considerable size difference and therefore can most likely co-exist because of different food size preferences. The dominant cyclopoid was *Tropocyclops prasinus mexicanus* which was most abundant during September. *Diaphanosoma birgei* appeared to be the dominant cladoceran in Bass Lake with *Holopedium gibberum* and *Daphnia pulex* present in lower densities (Fig. 11). The phantom midge larvae, *Chaoborus americanus* was present in Bass Lake throughout the season with densities peaking in September.

Coon Stump Lake had very low zooplankton densities throughout the sampling seasons (Fig 8). *Aglaodiaptomus saskatchewanensis* was the dominant copepod while *Daphnia pulex* and *Holopedium gibberum* were common cladocerans (Figs. 10 and 11). *Chaoborus americanus* were very abundant during all sampling periods with densities peaking in September. Similar to Bass Lake, the presence of *C. americanus* throughout the season suggests the absence of fish in the lake.

The zooplankton communities from the six study lakes were described using correspondence analysis (CA) and site scatter plots for July 1993-1995 are summarized in Figures 12, 13, and 14. For all three years, Mud Lake is significantly separated from the other lakes in respect to its zooplankton composition. This separation is due to the high percentage of the copepod *Skistodiaptomus oregonensis* in its community. The placement of the other two impact study lakes (Ferrell and Muskrat) were never a significant distance away from at least one of the non-impact lakes. In 1993 and 1995, Muskrat, Coon Stump and Bass lakes had a very close grouping. Although CA biplots show Mud Lake to be consistently different with respect to its zooplankton composition, as was stated earlier in this report, this difference is probably not caused by military actions.

c. Water Chemistry: Mean values and ranges for pH, conductivity, and turbidity (Table 4) show some differences among the lakes. The two smallest lakes (Bass and Coon Stump) were slightly more acidic and turbid. Mud had the highest pH and conductivity, indicating the possibility that groundwater may play a more important role in Mud than in the other lakes (Montz and Hirsch 1993).

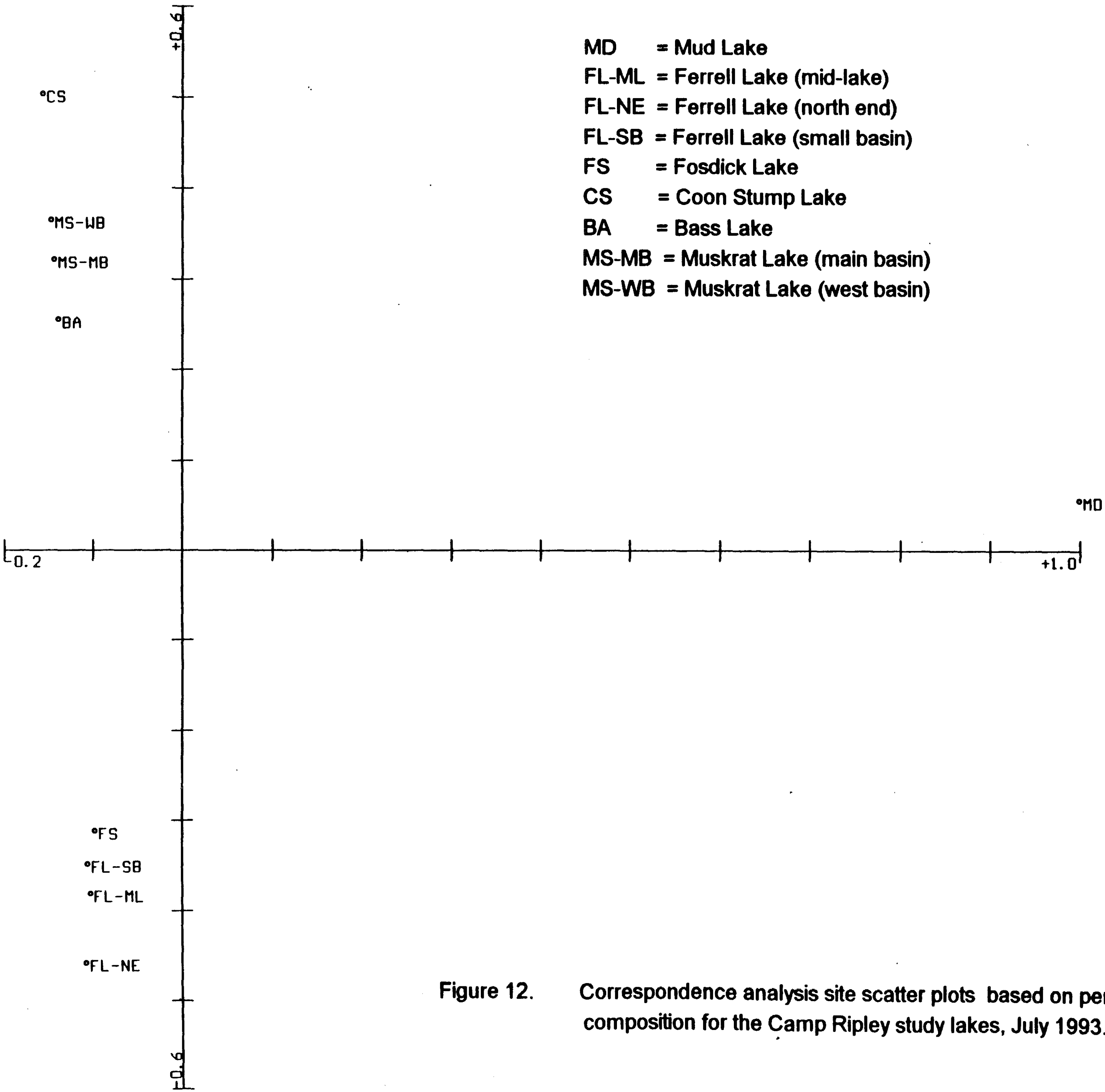


Figure 12. Correspondence analysis site scatter plots based on percent zooplankton composition for the Camp Ripley study lakes, July 1993.

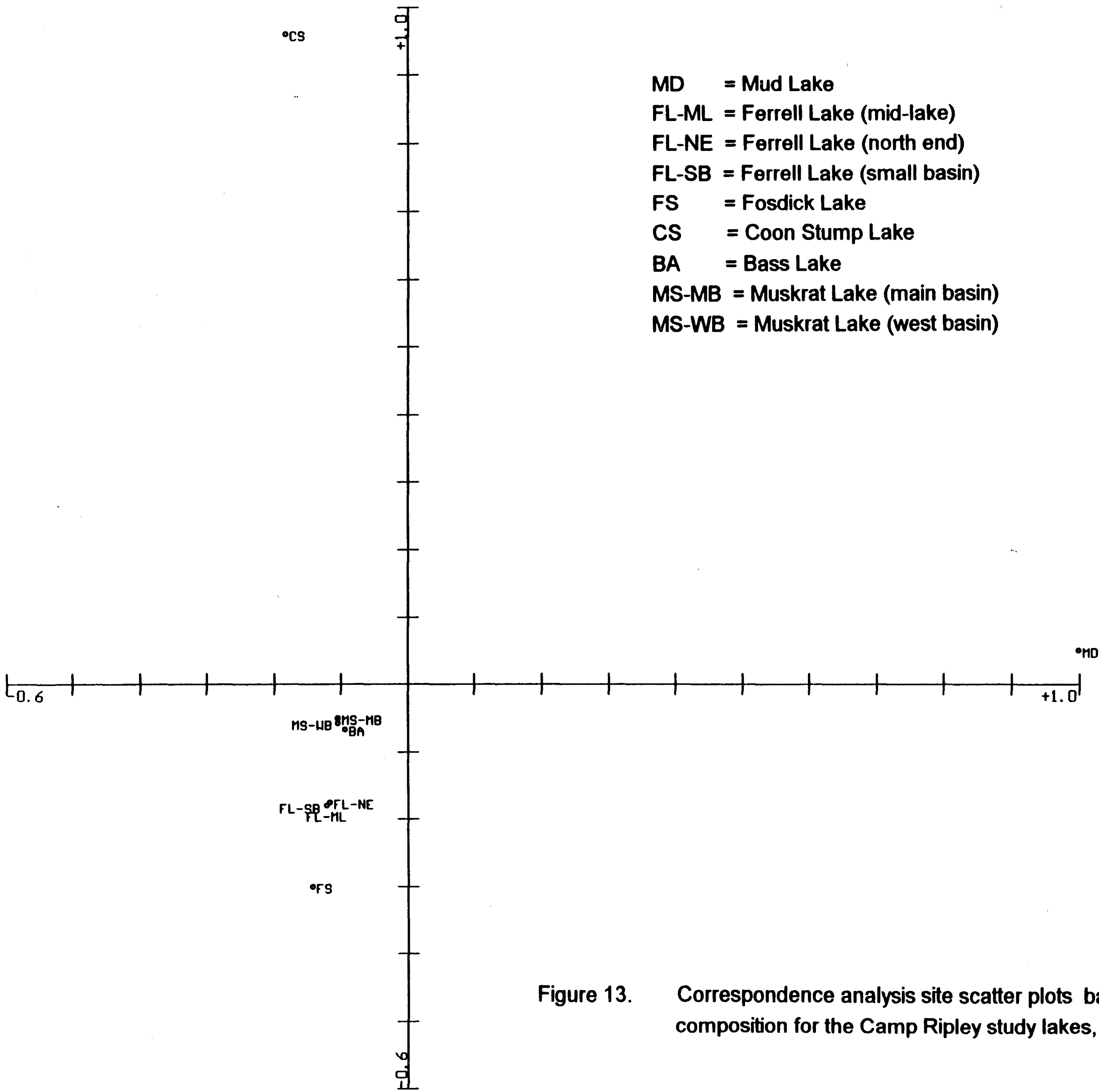


Figure 13. Correspondence analysis site scatter plots based on percent zooplankton composition for the Camp Ripley study lakes, July 1994.

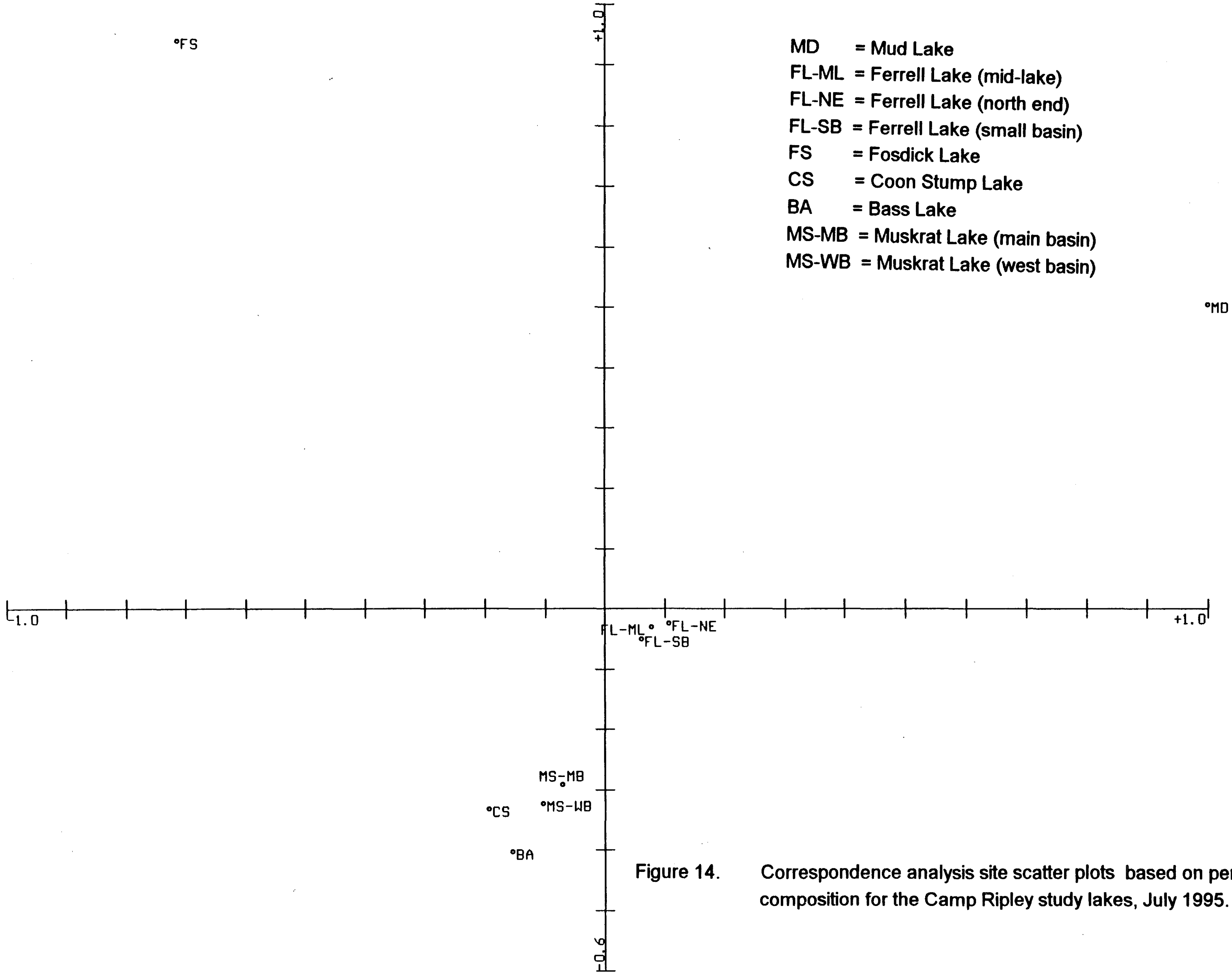


Figure 14. Correspondence analysis site scatter plots based on percent zooplankton composition for the Camp Ripley study lakes, July 1995.

Table 4. Mean water chemistry parameters and ranges (in parentheses) for pH, turbidity and conductivity as measured each sample period for the six Camp Ripley study lakes, 1993 - 1995. (conductivity - μmhos/cm^2; turbidity - nephalometer turbidity units)

Lake	pH	Conductivity	Turbidity
Bass	6.87	20.5	2.09
	(5.99 - 7.98)	(18 - 25)	(0.9 - 4.1)
Coon Stump	6.30	19.7	2.27
	(5.72 - 7.09)	(16 - 22)	(1.2 - 3.9)
Fosdick	8.07	38.1	1.83
	(6.86 - 9.02)	(31 - 48)	(1.0 - 3.2)
Mud	8.92	135	1.44
	(8.37 - 9.49)	(110 - 173)	(1.15 - 1.9)
Muskrat - large basin	6.90	24.5	1.34
	(6.38 - 7.68)	(19 - 32)	(0.85 - 2.1)
Ferrell - large basin	7.89	39.6	1.77
	(6.8 - 9.15)	(22 - 50)	(1.0 - 4.0)
Ferrell - small basin	7.76	37.7	1.42
	(6.77 - 9.71)	(30 - 49)	(0.6 - 3.1)

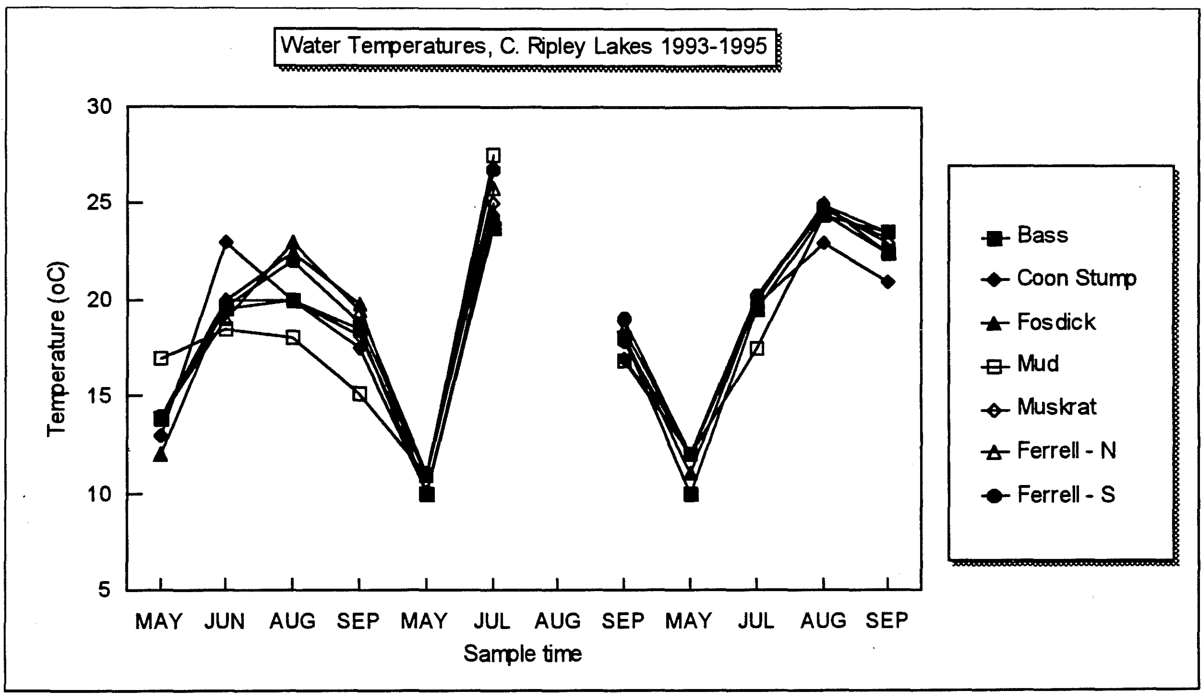


Figure 15. Water temperatures taken each sample period for the six Camp Ripley study lakes, 1993 - 1995

While temperatures showed some variation between lakes in the beginning of the study (Fig. 15), by the second year the pattern was consistent in all the lakes. The change in temperature patterns may be related to water levels in the lakes. The initial year of the study had lower water levels, likely due to the effects of a previous drought and water temperatures in the smaller lakes (such as Coon Stump) would have varied more dramatically on a daily basis. In contrast, lower water levels in Mud Lake would allow groundwater to play a larger role in temperature regulation, which could account for the cooler temperatures in the first year of the study. By the third year, water levels had risen dramatically in all of the lakes reducing the sensitivity of the lakes to daily variations and lessening the difference between Mud and the other lakes.

Water samples collected in August 1993 were analyzed for nutrients, pH, dissolved solids and other parameters. The results (Table 5) show very little differences between the lakes. Muskrat and Coon Stump have higher total phosphorus levels than the other lakes. Phosphorus levels in Muskrat could be somewhat elevated due to runoff of ash from the burning conducted every spring in the impact area. Total dissolved solids were higher in Ferrell and Mud lakes. During the first year of the study, construction activities on two landing areas on Ferrell Lake may have contributed to these levels. Overall, the values do not indicate consistent differences between impact and non-impact areas.

Coring in mid-lake areas was conducted to determine if sedimentation or metals were accumulating in impact area lakes faster than in the control lakes. Engstrom (1994) reported that Ferrell showed an obvious recent increase in sedimentation rates, while Bass and Fosdick have returned to sedimentation rates equivalent to pre-settlement periods. The other three lakes (Muskrat, Mud, Coon Stump) all show sustained low levels of sedimentation which are higher than pre-settlement levels and are likely due to use. However, in comparison to many other lakes in central Minnesota, the Camp Ripley lakes show much lower rates of post-settlement sedimentation (Engstrom 1994).

The following metals in the sediments showed increases of at least 2x over pre-settlement levels: iron, manganese, phosphorus, copper, cadmium, chromium, and arsenic. Most of the increases could be attributed to atmospheric deposition from regional sources rather than from local military use. However, coppper showed an increase attributed to local sources (Engstrom 1994) in three lakes (Ferrell, Fosdick, and Coon Stump). Copper levels in Ferrell could be attributed to the seasonal use of copper sulfate by the MDNR for harvesting walleyes reared in that lake. The elevated copper levels in the other two lakes are difficult to explain. These lakes are not used for fish rearing and are not in the impact areas.

d. Impact vs Non-Impact Lakes - It was not possible to distinguish lakes in the impact zones from those outside on a consistent basis with any of the components sampled in this study. None of the parameters indicated significant long-term negative impacts from training activities.

It is possible that impacts are occurring, but that the temporal or spatial scale of the study was not fine enough to distinguish these changes. For example, the impact of copper sulfate on the cladocerans in Ferrell Lake was documented only through repeated sampling at the time of the treatment. Additionally, this impact was short-term, as the cladocerans were present again in the zooplankton community the following season. Thus, more intensive sampling of the benthic

Table 5. Water chemistry parameters measured from single mid-lake samples collected in August 1993 from six Camp Ripley study lakes.

Sample Description	Ferrell Lake	Fosdick Lake	Bass Lake	Coon Stump Lake	Mud Lake	Muskrat Lake
SO_4 Ion (ppm)	1	<1	2	<1	<1	<1
P-Total (ppm)	0.017	0.012	0.016	0.032	0.021	0.037
P-Ortho (ppm)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cl Ion (ppm)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
NH_3-N (ppm)	0.031	0.029	0.025	0.023	0.033	0.039
NO_2-N (ppm)	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
NO_3-N (ppm)	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
TKN (ppm)	0.51	0.52	0.56	0.76	0.69	0.79
pH	7.28	7.73	6.46	6.09	8.55	6.65
Tot. Alk. (ppm)	15	16	4.5	7.0	84	10
Chloro. a (ppb)						
B.O.D.$_5$ (ppm)						
F^- (ppm)	0.10	0.06	0.04	0.04	0.12	0.05
Total Suspended Solids (ppm)						
Total Dissolved Solids (ppm)	108	48	42	52	128	52

community might document a short-term immediate impact. However, it can also be argued that these short-term impacts may not be as important, if the community remains stable over the longer time frame.

It is also possible that the effects of use occurred previous to the study, are permanent and thus the study recorded this 'altered' community as the existing 'un-impacted' fauna. The impact zones have been extablished far longer than the study duration, and there is no pre-impact baseline for comparisons. However, the high productivity of the micro- and macroinvertebrate communities in Muskrat Lake in comparison to non-impact zone lakes argues against this interpretation.

It appears that Camp Ripley lakes are not seriously impacted by current use of the training area, but rather that the invertebrate communities are responding to differences in water chemistry, habitat and biological interactions (fish vs. no fish) in the lakes. The Camp Ripley Military Reservation with its large area shielded from direct urban and agricultural impacts presents a unique opportunity for biologists. The lakes, ponds, and wetlands could serve to help establish a database for invertebrates in Minnesota. For example, a recent compilation of Odonata records (Carroll and Gunderson 1995) lists only nine species of dragonflies from Morrison County. During June 1995, adult dragonflies were collected from only two of the current study locations and ten species were identified, of which seven were not recorded by Carroll and Gunderson. The variety of habitats such as lakes, ponds with or without fish, permanent and ephemeral wetlands, and small streams make it likely that a significant number of Odonata species exist in Camp Ripley. This potential diversity may also be found in other aquatic insect groups.

Recommendations

1. Monitoring: A routine invertebrate monitoring program does not appear warranted at this time. If the level of training significantly increases or specific acitvities are initiated that could present an increased risk to the aquatic communties, additional monitoring should be considered.
2. Copper loading: Records should be examined for Coon Stump and Fosdick lakes and the surrounding areas to try and determine why the copper levels in teh surface sediments showed dramatic increases similar to Ferrell Lake.
3. Ferrell Lake: One possible impact to the benthos of Ferrell Lake that could not be examined was the use of the lake for amphibious vehicle training. This activity has the potential to disturb bottom sediments and impact the benthic community as well as water chemistry. A short-term study to collect water chemistry and benthos immediately before and after such training activity could help answer the question of impacts. Defining the magnitude and duration of any impacts can help in future decisions regarding uses of this type. However, no evidence of long-term negative impacts were observed in this lake.

Additionally, Ferrell Lake should be the only lake used for fish rearing to prevent disruption of the invertebrate community in other lakes. The use of copper sulfate appears to have immediate short-term negative impacts on some of the zooplankton community and may be adding to the copper loading of the surface sediments. These impacts should be confined to Ferrell Lake.

4. Dragonfly survey: The variety of habitats contained in Camp Ripley may support an extremely diverse Odonata fauna. In only cursory collecting, 10 species of adults were taken in this study. Haarstad (1980) collected 45 species from a small area (Cedar Creek Natural History Area) in east-central Minnesota. While the fauna in Camp Ripley may not be this diverse, a survey of this group would be useful in helping define distribution and abundance of this fauna.

Conclusion

At the spatial and temporal scale examined in this study, the lakes in Camp Ripley do not appear to have suffered major negative impacts from military training activities. The invertebrate community is buffered from other impacts seen in many lakes throughout the state (nutrient and sediment loading, herbicide applications, overuse) and presents a valuable opportunity to examine this fauna in a relatively unimpacted setting. Camp Ripley and the scientific community could mutually benefit from the database which could be developed in this area.

Acknowledgments

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Appendix A - 1. Aquatic mcaroinvertebrates collected with Ponar grab samples from Camp Ripley study lakes, 1993. BA - Bass Lake, CS - Coon Stump Lake, FS - Fosdick Lake, MD - Mud Lake, MS - Muskrat Lake, FL - Ferrell Lake

Taxa	BA	CS	FS	MD	MS	FL
EPHEMEROPTERA						
Caenidae						
Caenis sp.				X	X	X
TRICHOPTERA						
Leptoceridae						
Triaenodes sp.			X			
Mystacides sp.						X
Hydroptilidae						
Oxyethira sp.					X	
Polycentropodidae						
Polycentropus sp.						X
Molannidae						
Molanna sp.						X
ODONATA						
Lestidae						
Lestes sp.					X	
Corduliidae						
Epitheca sp.			X	X		
Libellulidae						
Leucorrhinia sp.				X		
HEMIPTERA						
Corixidae						
Hesperocorixa sp.			X			
Palmacorixa sp.		X				
Notonectidae						
Notonecta sp.	X					
COLEOPTERA						
Gyrinidae						
Dineutus sp.		X				X
Curculionoidae		X			X	
Chrysomelidae						
Donacia sp.		X				
LEPIDOPTERA					X	
DIPTERA						
Chironomidae	X	X	X	X	X	X
Chaoboridae						
Chaoborus americanus	X	X			X	
Chaoborus punctipennis		X			X	
Chaoborus albatus	X		X	X		X
Ceratopogonidae						
Bezzia/Palpomyia grp.	X	X	X		X	X
Nilobezzia sp.		X			X	X
Sphaeromais sp.				X	X	X
CRUSTACEA						
Hyalella azteca						X
Crangonyx richmondensis grp.	X				X	
TRICLADIDA				X		
ACARINA		X	X	X	X	X
HIRUDINEA	X		X	X		X
MOLLUSCA						
Sphaeriidae	X	X		X	X	X
Gastropoda		X		X		
TOTAL NUMBER OF TAXA	8	12	8	11	14	14

Appendix A - 2. Chironomidae collected and identified from Ponar grab samples from Camp Ripley study lakes, June and August 1993.
BA - Bass Lake, FS - Fosdick Lake, MD - Mud Lake, MS - Muskrat Lake, FL - Ferrell Lake

	June					August				
Taxa	BA	FS	MD	MS	FL	BA	FS	MD	MS	FL
Tanypodinae										
Procladius sp.	X	X	X	X	X	X	X		X	X
Ablabesmyia sp.		X					X			
Thienemannimyia grp.		X					X			
Clinotanypus sp.					X					X
Chironominae										
Chironomini										
Chironomus sp.	X	X	X			X	X	X	X	X
Microtendipes sp.	X	X		X	X	X			X	X
Glyptotendipes sp.		X			X	X	X			X
Cladopelma sp.	X					X				
Dicrotendipes sp.						X	X	X		X
Polypedilum sp.		X	X				X		X	
Parachironomus sp.	X		X	X			X		X	
Phaenopsectra sp.									X	
Pseudochironomus sp.										X
Xenochironomus sp.										X
Lauterborniella sp.		X								
Einfeldia sp.		X		X						
Cryptochironomus sp.					X					
Tanytarsini										
Tanytarsus/Micropsectra grp.	X		X	X	X	X	X		X	
Cladotanytarsus sp.	X			X						
Paratanytarsus sp.		X	X				X			
Orthocladiinae										
Psectrocladius sp.							X	X		
Corynoneura sp.		X							X	
TOTAL NUMBER OF TAXA	7	11	6	6	6	7	11	3	8	8

Appendix A - 3. Aquatic mcaroinvertebrates collected with Ponar grab samples from Camp Ripley study lakes, 1994. BA - Bass Lake, CS - Coon Stump Lake, FS - Fosdick Lake, MD - Mud Lake, MS - Muskrat Lake, FL - Ferrell Lake

Taxa	BA	CS	FS	MD	MS	FL
EPHEMEROPTERA						
Caenidae						
Caenis sp.			X	X		X
Baetidae						
Baetis sp.						X
TRICHOPTERA						
Leptoceridae						
Oecetis sp.						X
Triaenodes sp.			X			
Limnephilidae						
Limnephilus sp.						X
Hydroptilidae						
Orthotrichia sp.			X			
ODONATA						
Coenagrionidae		X				
Amphiagrion sp.					X	
Corduliidae						
Epitheca sp.				X		
HEMIPTERA						
Corixidae						
Sigara sp.			X			X
Cenocorixa sp.			X			
DIPTERA						
Chironomidae	X	X	X	X	X	X
Chaoboridae						
Chaoborus americanus	X	X			X	
Chaoborus punctipennis			X		X	X
Chaoborus flavicans	X					
Chaoborus albatus	X		X	X	X	X
Ceratopogonidae						
Bezzia/Palpomyia grp.					X	X
Nilobezzia sp.	X		X		X	
Sphaeromais sp.						X
Probezzia sp.			X			
NEMATOMORPHA				X	X	
ACARINA	X	X	X	X	X	X
HIRUDINEA	X		X		X	X
CRUSTACEA						
Hyalella azteca			X			X
Crangonyx richmondensis grp.					X	
MOLLUSCA						
Sphaeriidae	X		X	X	X	X
Gastropoda						
Amnicola sp.			X	X		
Physa sp.			X			
Helisoma sp.			X	X		
Feressia sp.			X			
TOTAL NUMBER OF TAXA	8	4	18	10	12	14

Appendix A - 4 . Chironomidae collected and identified from Ponar grab samples from Camp Ripley study lakes, June and August 1994.
BA - Bass Lake, FS - Fosdick Lake, MD - Mud Lake, MS - Muskrat Lake, FL - Ferrell Lake

	June					August				
Taxa	BA	FS	MD	MS	FL	BA	FS	MD	MS	FL
Tanypodinae										
Procladius sp.	X	X	X	X	X	X	X		X	X
Ablabesmyia sp.		X	X		X		X			
Thienemannimyia sp.		X					X			
Clinotanypus sp.					X					X
Coeltanypus sp.										X
Larsia sp.								X		
Labrundinia sp.		X								
Chironominae										
Chironomini										
Chironomus sp.	X	X	X	X		X	X	X	X	X
Microtendipes sp.				X	X				X	X
Glyptotendipes sp.		X		X	X				X	X
Cladopelma sp.	X			X						
Dicrotendipes sp.		X	X	X	X		X		X	X
Polypedilum sp.		X	X				X		X	
Parachironomus sp.		X	X	X			X	X	X	
Phaenopsectra sp.			X							
Pseudochironomus sp.					X					X
Einfeldia sp.		X							X	X
Cryptochironomus sp.				X						
Nilothauma sp.		X					X			
Tribelos sp.			X	X						
Stempelinella sp.					X					
Tanytarsini										
Tanytarsus/Micropsectra sp.	X	X	X	X	X		X		X	X
Cladotanytarsus sp.					X				X	
Paratanytarsus sp.		X					X	X		
Tanytarsus sp.			X		X		X		X	X
Orthocladiinae										
Psectrocladius sp.								X		X
Corynoneura sp.							X			
Nanocladius sp.									X	
TOTAL NUMBER OF TAXA	4	13	10	10	11	2	12	5	12	12

Appendix A - 5. Aquatic macroinvertebrates collected with Ponar grab samples from Camp Ripley study lakes, 1995. BA - Bass Lake, CS - Coon Stump Lake, FS - Fosdick Lake, MD - Mud Lake, MS - Muskrat , FL - Ferrell Lake

Taxa	BA	CS	FS	MD	MS	FL
EPHEMEROPTERA						
Caenidae						
Caenis sp.				X		X
Baetidae						
Baetis sp.						X
TRICHOPTERA						
Phryganeidae		X	X		X	X
Leptoceridae						
Triaenodes tarda			X			
Oecetis sp.			X	X		X
Mystacides sepulchralis				X		
Mystacides longicornis				X		
ODONATA						
Lestidae						
Lestes sp.			X		X	X
Corduliidae						
Cordulia sp.				X		
Epitheca sp.				X		
COLEOPTERA						
Gyrinidae						
Dineutus sp.						X
DIPTERA						
Chironomidae	X	X	X	X	X	X
Chaoboridae						
Chaoborus americanus	X	X			X	
Chaoborus albatus	X	X	X	X	X	X
Chaoborus punctipennis			X		X	X
Ceratopogonidae						
Nilobezzia sp.					X	X
Bezzia/Palpomyia sp.			X	X	X	X
Probezzia sp.			X			
Sphaeromais sp.					X	X
CRUSTACEA						
Hyalella azteca				X		X
Crangonyx richmondensis grp.					X	X
ACARINA	X	X	X	X	X	X
HIRUDINEA		X	X		X	X
MOLLUSCA						
Sphaeriidae			X	X	X	X
Gastropoda	X			X		X
Amnicola sp.			X			
Physa sp.			X			
Stagnicola sp.			X			
TOTAL NUMBER OF TAXA	5	6	15	13	13	18

Appendix A - 6 . Chironomidae collected and identified from Ponar grab samples from Camp Ripley study lakes, June and August 1995.
BA - Bass Lake, FS - Fosdick Lake, MD - Mud Lake, MS - Muskrat Lake, FL - Ferrell Lake

	June					August				
Taxa	BA	FS	MD	MS	FL	BA	FS	MD	MS	FL
Tanypodinae										
Procladius sp.	X	X		X	X	X	X	X	X	X
Ablabesmyia sp.					X		X			X
Thienemannimyia sp.							X	X		
Clinotanypus sp.										X
Larsia sp.	X	X	X					X		
Labrundinia sp.			X							
Chironominae										
Chironomini										
Chironomus sp.	X	X	X	X		X	X	X	X	X
Microtendipes sp.				X	X				X	X
Glyptotendipes sp.				X	X				X	
Cladopelma sp.				X	X	X	X		X	
Dicrotendipes sp.		X	X	X	X		X	X	X	X
Polypedilum sp.		X	X				X		X	
Parachironomus sp.		X	X	X			X			X
Pseudochironomus sp.			X					X		
Einfeldia sp.	X	X			X	X			X	X
Cryptochironomus sp.				X			X			
Nilothauma sp.	X									X
Endochironomus sp.		X								
Paracladopelma sp.	X									
Zavreliella sp.			X							
Tanytarsini										
Tanytarsus/Micropsectra sp.		X	X	X	X		X	X	X	X
Cladotanytarsus sp.		X	X	X	X					X
Paratanytarsus sp.			X							
Tanytarsus sp.	X		X					X		
Orthocladiinae										
Psectrocladius sp.			X	X				X		
Corynoneura sp.			X							
Nanocladius sp.								X		
TOTAL NUMBER OF TAXA	7	10	14	11	9	4	10	10	9	11

Appendix A - 7. Mean densities(#/m2) for aquatic invertebrates collected in Petite Ponar grab samples from Bass Lake, June and August 1993 - 1995.

TAXA	June 1993 Site 1	June 1993 Site 2	June 1994 Site 1	June 1994 Site 2	June 1995 Site 1	June 1995 Site 2
DIPTERA						
Chironomidae	387	387	315	710	4744	2150
Chaoborus americanus	194	430	846	1,075	258	330
Chaoborus albatus	22	22			57	14
CRUSTACEA		22				
HIRUDINEA	22	22				
MOLLUSCA						
Sphaeriidae	108			22		
Gastropoda	43				29	
TOTAL	774	882	1,161	1,806	5088	2494

TAXA	August 1993 Site 1	August 1993 Site 2	August 1994 Site 1	August 1994 Site 2	August 1995 Site 1	August 1995 Site 2
DIPTERA						
Chironomidae	215	946	3,970	659	4673	401
Chaoborus americanus	201	186	158	659	788	702
Chaoborus albatus	229	57	14		86	115
Chaoborus flavicans				29		
Nilobezzia sp.			29	14		
Bezzia/Palpomyia grp.		29				
ODONATA						
Coenagrionidae	72	14				
HEMIPTERA						
Notonecta sp.	14					
CRUSTACEA						
Crangonyx richmondensis grp.	14					
ACARINA				14		14
HIRUDINEA	14			14		
MOLLUSCA						
Sphaeriidae	287	29	14		86	
TOTAL	1046	1261	4,185	1,390	5633	1233

Appendix A - 8. Mean densities (#/m2) for aquatic invertebrates collected in Petite Ponar grab samples from Coon Stump Lake, June and August 1993 - 1995

TAXA	June 1993 Site 1	June 1993 Site 2	June 1994 Site 1	June 1994 Site 2	June 1995 Site 1	June 1995 Site 2
DIPTERA						
Chironomidae	831	172		57	14	86
Chaoborus americanus	108	143	1,104	659	1261	946
Chaoborus punctipennis	14	14				
Bezzia/Palpomyia grp.		86				
Nilobezzia sp.	14	14				
COLEOPTERA						
Dineutus sp.	14					
Donacia sp.	14					
TRICHOPTERA						
Phryganeidae						14
Curculionidae						
ACARINA	29	43		14	14	43
TOTAL	1025	473	1,104	731	1290	1089

TAXA	August 1993 Site 1	August 1993 Site 2	August 1994 Site 1	August 1994 Site 2	August 1995 Site 1	August 1995 Site 2
DIPTERA						
Chironomidae		29				
Chaoborus americanus	573	272	530	645	645	774
Chaoborus punctipennis	14				158	244
Bezzia/Palpomyia grp.	14	14				
Nilobezzia sp.	14					
ODONATA						
Coenagrionidae		14	29			
HEMIPTERA						
Palmacorixa sp.		14				
Lepidoptera						
Pyralidae						14
Hirudinea						29
ACARINA	57		14	14		14
MOLLUSCA						
Sphaeriidae		172				
Gastropoda		100				
TOTAL	674	616	573	659	803	1075

Appendix A - 9. Mean densities (#/m2) for aquatic invertebrates collected in Petite Ponar grab samples from Fosdick Lake, June and August 1993 - 1995

	June 1993			June 1994			June 1995		
TAXA	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
DIPTERA									
Chironomidae	3,927	1,663	2,408	4,329	4,630	201	158	287	2293
Chaoborus albatus	100	86	43	158	358	444	43	57	29
Ceratopogonidae					29				
Nilobezzia sp.						43			
Bezzia/Palpomyia gr	14								
ODONATA								14	
Epitheca sp.	14								
Lestes sp.									14
TRICHOPTERA									
Phryganeidae								29	
Leptoceridea									
Triaenodes tarda								14	
CRUSTACEA									
Hyalella azteca					72				
ACARINA				57	14	29	43		14
HIRUDINEA		14	201	43				29	14
MOLLUSCA									
Sphaeriidae		14	2,494	29		29	14		14
Gastropoda									
Amnicola sp.				143		29			
Physa sp.				29	14		143	43	57
Helisoma sp.				14					
Feressia sp.				86					
Stagnicola sp.								57	
TOTAL	4,056	1,777	5,146	4,888	5,117	774	401	530	2437

	August 1993			August 1994			August 1995		
TAXA	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
DIPTERA									
Chironomidae	8,786	459	1,061	4,759	3,354	215	1032	1462	4802
Chaoborus albatus	760	1,304	1,347	158	1,204	645	588	917	932
Chaoborus punctipennis				43		86	29	229	201
Bezzia/Palpomyia gr	29	29	29				43	72	29
Probezzia sp.				129	143	14			14
ODONATA									
Epitheca sp.	14								
TRICHOPTERA									
Triaenodes sp.	14			14	29	14			
Orthotrichia sp.				29	14				
Oecetis sp.								14	
HEMIPTERA									
Hesperocorixa sp.	14	14		14	14				
Cenocorixa sp.				14					
EPHEMEROPTERA									
Caenis sp.				14	43				
CRUSTACEA									
Hyalella azteca				29	14				
ACARINA	57	86		29	14	43	14	14	
HIRUDINEA	14							14	
MOLLUSCA									
Sphaeriidae	43					29			
Gastropoda									
Amnicola sp.				14				14	
Physa sp.					14	14		14	
TOTAL	9,732	1,892	2,451	5,246	4,845	1,061	1706	2752	5977

Appendix A - 10. Mean densities (#/m2) for aquatic invertebrates collected in Petite Ponar grab samples from Mud Lake, June and August 1993 - 1995

	June 1993				June 1994				June 1995			
TAXA	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 4
DIPTERA												
Chironomidae	1,433	1,104	803	975		344	846	545	946	760	143	387
Chaoborus albatus				29		14	14	14		14		
Sphaeromais sp.	14			14								
ODONATA									43			29
Coenagrionidae												
Cordulia sp.										14		
Epitheca sp.								43		14	14	
EPHEMEROPTERA	43	14										
Caenis sp			14	57				172	14	14		14
CRUSTACEA												
Hyalella azteca												14
ACARINA			43			86	186	43	57	29	129	72
NEMATOMORPHA								14				
MOLLUSCA												
Sphaeriidae	430	14	745	29		86	29	129	201		57	57
Gastropoda			72			86	258		215	115	272	688
TOTAL	1,921	1,132	1,677	1,104		616	1,333	960	1,476	960	616	1,261

	August 1993				August 1994				August 1995			
TAXA	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 4
DIPTERA												
Chironomidae	35,131	3,641	9,259	4,443	3,540	2,494	2,451	3,196	1,276	2,981	1,290	1,562
Chaoborus albatus		72		14	14	29	14	14		29	100	43
Ceratopogonidae					244	43	29	57				
Bezzia/Palpomyia grp.	14		72						143	201	14	100
ODONATA												29
Coenagrionidae												
Epitheca sp.	14				14			43	158	14	14	129
Lestes sp.									43			
TRICHOPTERA					14							
Oecetis sp.											14	14
Mystacides sepulchralis?											14	
Mystacides longicornis?											57	
EPHEMEROPTERA												
Caenis sp.								29	14	115		43
TRICLADIDA	14											
ACARINA	43	86	29	14	29	72	14		29	29	43	14
MOLLUSCA												
Sphaeriidae	57	57	72	201			86	29	14	43	57	258
Gastropoda	330	43							201	86	301	258
Helisoma sp.					143	43	43					
Amnicola sp.					14		14					
TOTAL	35,604	3,899	9,431	4,673	3,870	2,637	2,594	3,368	1,878	3,497	1,906	2,451

Appendix A - 11. Mean densities (#/m2) for aquatic invertebrates collected in Petite Ponar grab samples from Muskrat Lake, June and August 1993 - 1995.

TAXA	June 1993 Site 1	June 1993 Site 2	June 1993 Site 3	June 1993 Site 4	June 1994 Site 1	June 1994 Site 2	June 1994 Site 3	June 1994 Site4	June 1995 Site 1	June 1995 Site 2	June 1995 Site 3	June 1995 Site4
DIPTERA												
Chironomidae	13,860	15,509	15,208	9,560	16,956	13,631	14,763	9,102	15,423	1,476	2,480	8,299
Chaoborus americanus		14	43	201	57	29	14	14	57	416	186	301
Chaoborus punctipennis		14	14	14	100	43	57	72	86	143		14
Chaoborus albatus									14			29
Bezzia/Palpomyia grp.	14	115	14	86	86	86	115				14	
EPHEMEROPTERA												
Caenis sp		14										
CRUSTACEA												
Crangonyx richmondensis grp.		57	29	29	158		330	86	272			
TRICHOPTERA												
Phryganeidae										14		
COLEOPTERA												
Donacia sp.							29					
Curculionidae	29											
NEMATOMORPHA						14						
ACARINA			14		43		14	43				14
HIRUDINEA	932	530	917	1,390	272	430	158	158	229	29	43	29
MOLLUSCA												
Sphaeriidae	72	573	401	588	43	186	129	674	201	57	201	186
TOTAL	14,907	16,827	16,641	11,868	17,716	14,419	15,609	10,148	16,283	2,136	2,924	8,872

TAXA	August 1993 Site 1	August 1993 Site 2	August 1993 Site 3	August 1993 Site 4	August 1994 Site 1	August 1994 Site 2	August 1994 Site 3	August 1994 Site 4	August 1995 Site 1	August 1995 Site 2	August 1995 Site 3	August 1995 Site4
DIPTERA												
Chironomidae	13,430	8,313	3,411	8,227	2,351	20,353	7,582	10,062	1,132	3,225	17,243	4,357
Chaoborus americanus					158	143	100	14	387	129	172	143
Chaoborus punctipennis		86	244	100	817	688	731	487	115	143	29	43
Chaoborus albatus					29				14			
Bezzia/Palpomyia grp.	158	14		143	57	72						29
Nilobezzia sp.	14						14					14
Sphaeromais sp.		29	14								14	
ODONATA												
Lestes sp.				14					29		14	100
Leucorrhinia sp.				14								
Amphiagrion sp.								14				
TRICHOPTERA												
Oxyethira sp.		14										
LEPIDOPTERA	14											
NEMATOMORPHA					14							
CRUSTACEA												
Crangonyx richmondensis grp	86			43	186	143	100	172	72	29	57	244
ACARINA	29	72	29	86		29	57	115	57	14	14	57
HIRUDINEA	287	459	72	1,190	158	201	129	143	29	29	43	
MOLLUSCA												
Sphaeriidae	43	29	29	100	29	430	100	129		86	459	301
TOTAL	14,061	9,016	3,798	9,919	3,798	22,059	8,815	11,165	1,835	3,655	18,046	5,275

Appendix A - 12. Mean densities (#/m2) for aquatic invertebrates collected in Petite Ponar grab samples from Ferrell Lake, June and August 1993 - 1995

	June 1993					June 1994					June 1995				
TAXA	Site 1	Site 2	Site 3	Site 4	Site 5	'Site 1	Site 2	Site 3	Site 4	Site 5	Site 1	Site 2	Site 3	Site 4	Site 5
DIPTERA															
Chironomidae	5,131	6,278	2,938	9,116	12,871	401	373	301	516	3,297	3798	1577	2809	4959	4415
Chaoborus albatus			14				14				29	72	14	29	
Bezzia/Palpomyia grp.				86	416				29	43					14
Sphaeromais sp.	14		14		14					43					
TRICHOPTERA	14				14										
Oecetis sp.										14	14			14	14
Limnephilus sp.						14									
Mystacides sp.				29											
CRUSTACEA															
Hyalella azteca	430	29	516	487	1,218									43	14
COLEOPTERA															
Dineutus sp.					14										14
ACARINA	14				14	14		29			29				
HIRUDINEA	860	1,691	1,362	57	86	14	14			72	229	129	602	14	473
MOLLUSCA															
Sphaeriidae	14	86	3,483		1,247		14	57		57	72	14	115		72
TOTAL	6,479	8,084	8,328	9,775	15,896	444	416	387	545	3,526	4171	1792	3540	5060	5017

	August 1993					August 1994					August 1995				
TAXA	Site 1	Site 2	Site 3	Site 4	Site 5	'Site 1	Site 2	Site 3	Site 4	Site 5	Site 1	Site 2	Site 3	Site 4	Site 5
DIPTERA															
Chironomidae	760	330	645	817	7,683	1,333	1,161	1,462	2,480	860	143	5662	4988	3813	43
Chaoborus albatus			43		14	43	115	129		14	72	201	143	86	86
'Chaoborus punctipennis							43	43		14	14	43	57	29	43
Ceratopogonidae										14					
Bezzia/Palpomyia grp.		14			14									129	
Nilobezzia sp.				315										14	
Sphaeromais sp.			14	29							14				
ODONATA															
Coenagrionidae					29										
Lestes sp.														14	57
TRICHOPTERA															
Polycentropus sp.					14										
Molanna sp.	14	14	43	14											
Oecetis sp.						14		14		29	14			29	72
Hemiptera															
Corixidae									14						
Sigara sp.									14						
EPHEMEROPTERA					29										
Caenis sp.										14				14	29
Baetis sp.										14				14	14
CRUSTACEA															
Crangonyx sp.														29	43
Hyalella azteca	29		29	14	2924					14	43			244	
ACARINA					14						14		14	14	
HIRUDINEA	315	516			143		43		14	43	229	143	158	57	115
MOLLUSCA															
Sphaeriidae	14	229			645			29			72	100	1233		
Gastropoda														14	29
TOTAL	1,132	1,104	774	1,190	11,510	1,390	1,362	1,677	2,523	1,018	616	6149	6593	4501	530

Appendix B-1. Zooplankton densities (No./m3) from Fosdick Lake, 1993-1995

Fosdick Lake	May 4 1993	May 3 1994	May 1 1995	June 28 1993	July 5 1994	July 6 1995	August 4 1993	August 3 1995	Sept. 7 1993	Sept. 6 1994	August 29 1995
Cladocerans											
Daphnia laevis	47.2	26.3	2850.4	0.0	32235.0	7986.0	0.0	1958.8	0.0	7455.0	3013.6
Bosmina longirostris	165.4	3550.5	941.8	997.5	10342.5	2109.5	11340.0	602.7	9363.2	9555.0	1506.8
Diaphanosoma birgei	68.2	52.6	0.0	11865.0	1260.0	0.0	10867.5	1808.2	12289.2	7140.0	452.0
Holopedium gibberum	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alona guttata	2.6	52.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ceriodaphnia lacustris	0.0	341.9	0.0	105.0	105.0	0.0	5250.0	0.0	25090.5	0.0	0.0
Daphnia ambigua	0.0	0.0	0.0	0.0	0.0	16122.7	0.0	0.0	0.0	9555.0	452.0
Daphnia rosea	0.0	0.0	0.0	0.0	0.0	6780.6	0.0	3164.3	0.0	2205.0	150.7
Daphnia pulex	0.0	0.0	1757.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12054.3
Total Cladocerans	**288.7**	**4023.9**	**5550.0**	**12967.5**	**43942.5**	**32998.8**	**27457.5**	**7534.0**	**46742.9**	**35910.0**	**17629.4**
Copepods											
Diacyclops bicuspidatus thomasi	10.5	0.0	1833.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tropocyclops prasinus mexicanus	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mesocylops edax	44.6	52.6	477.2	0.0	840.0	301.4	1050.0	6027.2	1170.4	1050.0	1205.4
Skistodiaptomus pallidus	126.0	131.5	828.8	6720.0	10605.0	4671.1	23992.5	4369.7	23481.2	23992.5	1808.2
Eucyclops serrulatus	0.0	0.0	0.0	157.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Adult Copepods	**186.4**	**184.1**	**3139.2**	**6877.5**	**11445.0**	**4972.5**	**25042.5**	**10396.9**	**24651.6**	**25042.5**	**3013.6**
copepodites	944.9	3445.3	11049.8	52.5	1732.5	301.4	210.0	7081.9	0.0	210.0	1506.8
nauplii	420.5	7337.7	8036.3	52.5	15960.0	0.0	2205.0	10246.2	951.0	2205.0	301.4
Total Zooplankton Adults	**475.1**	**4208.0**	**8689.2**	**19845.0**	**55387.5**	**37971.3**	**52500.0**	**17930.9**	**71394.4**	**60952.5**	**20643.0**
Total Zooplankton	**1840.4**	**14991.0**	**27775.3**	**19950.0**	**73080.0**	**38272.7**	**54915.0**	**35259.0**	**72345.4**	**63367.5**	**22451.2**

Appendix B-2. Zooplankton densities (No./m3) from Coon Stump Lake, 1993-1995.

Coon Stump Lake	**May 3 1993**	**May 2 1994**	**May 1 1995**	**June 28 1993**	**July 6 1994**	**July 6 1995**	**August 5 1993**	**August 3 1995**	**Sept. 7 1993**	**Sept. 7 1994**	**August 29 1995**
Cladocerans											
Daphnia pulex	18.4	39.4	0.0	257.2	353.7	1165.3	1639.0	40.2	6987.5	17193.7	663.0
Daphnia laevis	0.0	0.0	0.0	0.0	0.0	40.2	0.0	0.0	0.0	0.0	0.0
Daphnia ambigua	0.0	0.0	0.0	0.0	0.0	160.7	0.0	0.0	0.0	0.0	0.0
Bosmina longirostris	7.9	0.0	0.0	5.2	104.8	0.0	0.0	0.0	0.0	0.0	0.0
Holopedium gibberum	36.7	13.1	0.0	217.8	7087.1	0.0	2269.4	27.6	0.0	0.0	32.6
Diaphanosoma birgei	2.6	0.0	0.0	5.2	0.0	0.0	0.0	2.5	0.0	0.0	0.0
Chydorus sphaericus	0.0	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ceriodaphnia sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0
Scapholeberis sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.6
Total Cladocerans	**65.6**	**57.8**	**0.0**	**485.6**	**7545.6**	**1366.2**	**3908.5**	**70.3**	**6987.5**	**17193.7**	**713.2**
Copepods											
Aglaodiaptomus leptopus	0.0	0.0	0.0	0.0	0.0	281.3	0.0	57.8	0.0	0.0	57.8
Aglaodiaptomus saskatchewanensis	2.6	0.0	0.0	13.1	235.8	2290.3	31.5	47.7	37.5	1128.7	135.6
Mesocyclops edax	0.0	0.0	0.0	2.6	104.8	0.0	0.0	0.0	0.0	0.0	7.5
Acanthocyclops vernalis	0.0	0.0	0.0	0.0	0.0	0.0	141.8	0.0	0.0	0.0	0.0
Tropocyclops prasinus mexicanus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	55.2
Total Adult Copepods	**2.6**	**0.0**	**0.0**	**15.7**	**340.6**	**2571.6**	**173.4**	**105.5**	**37.5**	**1128.7**	**256.1**
copepodites	136.5	62.9	0.0	2.6	2122.2	80.4	0.0	128.1	0.0	26.2	190.9
nauplii	627.3	1490.8	73.7	2.6	1873.3	0.0	0.0	1.9	0.0	0.0	2.3
Total Zooplankton Adults	**68.2**	**57.8**	**0.0**	**501.3**	**7886.2**	**3937.8**	**4081.8**	**175.8**	**7025.0**	**18322.4**	**969.3**
Total Zooplankton	**832.0**	**1611.5**	**73.7**	**506.6**	**11881.7**	**4018.2**	**4081.8**	**305.8**	**7025.0**	**18348.6**	**1162.5**
Other											
Chaoborus americanus	60.4	370.1	200.0	196.9	150.0	0.0	1855.6	0.0	2730.0	2110.2	1064.0
Grand Total	**892.4**	**1981.6**	**273.7**	**703.4**	**12031.7**	**4018.2**	**5937.5**	**305.8**	**9755.0**	**20458.8**	**2226.5**

Appendix B-3. Zooplankton densities (No./m3) from Bass Lake, 1993-1995.

Bass Lake	**May 4 1993**	**May 3 1994**	**May 1 1995**	**June 29 1993**	**July 5 1994**	**July 6 1995**	**August 5 1993**	**August 3 1995**	**Sept. 8 1993**	**Sept. 6 1994**	**August 28 1995**
Cladocerans											
Daphnia pulex	0.0	0.0	25.1	0.0	0.0	11522.1	0.0	2486.2	0.0	0.0	4068.3
Streblocerus serricaudatus	134.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diaphanosoma birgei	9.8	5.2	2.5	3045.0	29634.2	502.3	48030.2	6328.5	184.4	0.0	452.0
Diaphanosoma brachyurum	0.0	0.0	0.0	0.0	0.0	0.0	393.7	0.0	0.0	0.0	0.0
Holopedium gibberum	9.8	23.6	7.5	870.0	681.8	1305.9	328.1	4595.7	899.1	755.8	1858.4
Bosmina longirostris	0.0	10.5	0.0	60.0	944.1	0.0	10892.1	0.0	507.2	126.0	0.0
Total Cladocerans	**154.1**	**39.3**	**35.1**	**3975.0**	**31260.1**	**13330.3**	**59644.0**	**13410.4**	**1590.8**	**881.8**	**6378.7**
Copepods											
Tropocyclops prasinus mexicanus	62.3	133.8	20.1	0.0	7028.3	1305.9	6955.2	8136.7	27988.8	976.2	703.2
Aglaodiaptomus leptopus	291.8	21.0	40.2	2160.0	0.0	200.9	196.8	0.0	368.9	393.6	452.0
Aglaodiptomus saskatchewanensis	101.6	133.8	7.5	10545.0	681.8	1908.6	6102.2	2561.5	4311.3	1842.2	2260.2
Diacyclops bicuspidatus thomasi	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Adult Copepods	**455.7**	**288.6**	**72.8**	**12705.0**	**7710.1**	**3415.4**	**13254.2**	**10698.2**	**32668.9**	**3212.0**	**3415.4**
copepodites	7934.0	94.5	0.0	0.0	7447.9	803.6	5905.4	753.4	0.0	94.5	1456.6
nauplii	295.1	1438.3	145.7	0.0	6503.8	301.4	3149.5	382.8	0.0	141.7	401.8
Total Zooplankton Adults	**609.8**	**327.9**	**107.9**	**16680.0**	**38970.2**	**16745.7**	**72898.3**	**24108.6**	**34259.7**	**4093.8**	**9794.1**
Total Zooplankton	**8838.9**	**1860.7**	**253.6**	**16680.0**	**52921.9**	**17850.7**	**81953.1**	**25244.8**	**34259.7**	**4330.0**	**11652.5**
Other											
Chaoborus americanus	209.8	78.7	128.9	322.5	226.3	0.0	0.0	0.0	193.1	968.5	522.0
Grand Total	**9048.7**	**1939.4**	**382.5**	**17002.5**	**53148.2**	**18847.7**	**81953.1**	**25244.8**	**34452.8**	**5298.5**	**12174.5**

Appendix B-4. Zooplankton densities (No./m3) from Mud Lake, 1993-1995.

Mud Lake	**May 5 1993 South End**	**May 3 1994 North End**	**May 3 1994 South End**	**May 1 1995 North End**	**May 1 1995 South End**	**June 29 1993 North End**	**June 29 1993 South End**	**July 5 1994 South End**	**July 5 1995 North End**	**July 5 1995 South End**
Cladocerans										
Bosmina longirostris	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.1	0.0
Diaphanosoma birgei	0.0	0.0	0.0	0.0	0.0	275.6	330.8	23.6	5.0	7.5
Diaphanosoma brachyrurum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ceriodaphnia lacustris	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.8	0.0	0.0
Chydorus sphaericus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Simocephalus serrulatus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Daphnia rosea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.9	0.0	0.0
Total Cladocerans	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**275.6**	**330.8**	**47.3**	**30.1**	**7.5**
Copepods										
Diacyclops bicuspidatus thomasi	8.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	5.0
Mesocylops edax	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Skistodiaptomus oregonensis	0.0	736.8	1842.0	0.0	0.0	3055.5	10773.0	821.1	110.5	336.5
Tropocyclops prasinus mexicanus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Adult Copepods	**8.9**	**736.8**	**1842.0**	**0.0**	**0.0**	**3055.5**	**10773.0**	**821.1**	**113.0**	**341.5**
copepodites	897.9	10038.9	6170.7	2640.0	1406.4	196.9	78.7	189.5	12.6	7.5
nauplii	28860.0	70364.4	77271.9	91590.0	113737.7	11614.2	7716.5	3418.5	5.0	2.5
Total Zooplankton Adults	**8.9**	**736.8**	**1842.0**	**0.0**	**0.0**	**3331.1**	**11103.8**	**868.4**	**143.1**	**349.0**
Total Zooplankton	**29766.8**	**81140.1**	**85284.6**	**94230.0**	**115144.1**	**15142.1**	**18899.0**	**4476.4**	**160.7**	**359.0**

	August 5 1993 South End	**August 3 1995 North End**	**August 3 1995 South End**	**Sept. 8 1993 North End**	**Sept. 8 1993 South End**	**Sept. 7 1994 North End**	**Sept. 7 1994 South End**	**August 29 1995 North End**	**August 29 1995 South End**
Cladocerans									
Bosmina longirostris	7.9	0.0	0.0	0.0	0.0	78.5	165.4	0.0	0.0
Diaphanosoma birgei	47.3	0.0	0.0	0.0	0.0	0.0	23.6	0.0	0.0
Diaphanosoma brachyrurum	322.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ceriodaphnia lacustris	0.0	0.0	0.0	49.9	44.6	0.0	0.0	0.0	0.0
Chydorus sphaericus	7.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Simocephalus serrulatus	7.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Daphnia rosea	0.0	0.0	0.0	0.0	0.0	94.2	7.8	0.0	0.0
Total Cladocerans	**393.8**	**0.0**	**0.0**	**49.9**	**44.6**	**172.7**	**196.8**	**0.0**	**0.0**
Copepods									
Diacyclops bicuspidatus thomasi	0.0	0.0	0.0	0.0	5.2	2.9	0.0	0.0	0.0
Mesocylops edax	39.4	20.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Skistodiaptomus oregonensis	1669.5	421.9	241.1	2758.9	1469.8	1617.1	1015.9	22.6	1165.3
Tropocyclops prasinus mexicanus	0.0	0.0	0.0	0.0	0.0	0.0	15.8	0.0	0.0
Total Adult Copepods	**1708.9**	**442.0**	**241.1**	**2758.9**	**1475.1**	**1620.0**	**1031.7**	**22.6**	**1165.3**
copepodites	0.0	221.0	261.2	0.0	0.0	0.0	0.0	62.8	924.2
nauplii	0.0	803.6	221.0	623.3	349.1	2103.8	1157.6	0.0	3736.8
Total Zooplankton Adults	**2102.6**	**442.0**	**241.1**	**2808.8**	**1519.7**	**1792.7**	**1228.5**	**22.6**	**1165.3**
Total Zooplankton	**2102.6**	**1466.6**	**723.3**	**3432.0**	**1868.8**	**3896.5**	**2386.1**	**85.4**	**5826.3**

Appendix B-5. Zooplankton densities (No./m3) from Muskrat Lake (main basin), 1993-1995.

Muskrat Lake - Main Basin	**May 5 1993**	**May 3 1994**	**May 2 1995**	**June 28 1993**	**July 6 1994**	**July 5 1995**	**August 6 1993**	**August 3 1995**	**Sept. 8 1993**	**Sept. 6 1994**	**August 29 1995**
Cladocerans											
Daphnia pulex	3718.8	1600.0	120.5	1199.6	4421.2	452.0	346.1	1205.4	98.8	2263.9	2511.4
Ceriodaphnia reticulata	109.4	300.0	0.0	0.0	0.0	0.0	153.8	0.0	1432.0	0.0	0
Bosmina longirostris	2843.8	600.0	15.1	296.2	12632.0	452.0	1153.8	22752.6	3110.9	52.6	0
Chydorus sphaericus	218.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Diaphanosoma brachyurum	328.1	0.0	30.1	1318.1	29527.3	4068.3	26498.9	10396.9	12690.7	5633.5	11552.1
Holopedium gibberum	0.0	100.0	346.6	1643.9	0.0	150.7	0.0	1657.5	197.5	3580.2	2511.3
Polyphemus pediculus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	52.6	0
Alona circumfimbriata	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Total Cladocerans	**7218.8**	**2700.0**	**512.3**	**4457.8**	**46580.5**	**5123.0**	**28152.7**	**36012.4**	**17529.9**	**11582.8**	**16574.8**
Copepods											
Diacyclops bicuspidatus thomasi	22203.1	43200.0	105.5	0.0	473.7	0.0	0.0	0.0	0.0	0.0	0
Aglaodiaptomus saskatchewanensis	0.0	0.0	90.4	6916.3	21158.6	3691.6	21883.7	14625.9	31306.9	14478.7	5022.6
Eucyclops serrulatus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Mesocyclops edax	0.0	0.0	15.1	0.0	0.0	0.0	0.0	0.0	0.0	157.9	251.1
Total Adult Copepods	**22203.1**	**43200.0**	**211.0**	**6916.3**	**21632.3**	**3691.6**	**21883.7**	**14625.9**	**31306.9**	**14636.6**	5273.7
copepodites	131359.4	95100.0	150.7	88.9	16895.3	828.7	0.0	3164.3	0.0	421.2	3264.7
nauplii	143390.6	73800.0	2606.8	1199.6	19579.6	150.7	384.6	1054.8	0.0	3843.4	1757.9
Total Zooplankton Adults	**29421.9**	**45900.0**	**723.2**	**11374.1**	**68212.8**	**8814.6**	**50036.5**	**50638.3**	**48836.8**	**26219.4**	**21848.5**
Total Zooplankton	**304171.9**	**214800.0**	**3480.6**	**12662.6**	**104687.7**	**9794.0**	**50421.1**	**54857.4**	**48836.8**	**30484.0**	**26871.1**
Other											
Chaoborus americanus	90.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	160.5	0
Grand Total	**304262.5**	**214800.0**	**3480.6**	**12662.6**	**104687.7**	**9794.0**	**50421.1**	**54857.4**	**48836.8**	**30644.5**	**26871.1**

Appendix B-6. Zooplankton densities (No./m3) from Muskrat Lake (west basin), 1993-1995.

Muskrat Lake-West Basin	**May 5 1993**	**May 3 1994**	**May 2 1995**	**June 28 1993**	**July 6 1994**	**July 5 1995**	**August 6 1993**	**August 3 1995**	**Sept. 8 1993**	**Sept. 6 1994**	**August 29 1995**
Cladocerans											
Daphnia pulex	2763.2	300.0	632.9	189.1	3789.6	150.7	653.8	753.4	0.0	6265.3	3013.6
Ceriodaphnia reticulata	0.0	100.0	0.0	8.2	0.0	0.0	1076.9	0.0	246.9	0.0	0.0
Bosmina longirostris	3776.3	400.0	75.4	8.2	20369.1	602.7	7461.2	15821.3	2419.6	0.0	2511.3
Chydorus sphaericus	92.1	600.0	0.0	0.0	0.0	0.0	0.0	0.0	49.4	0.0	0.0
Diaphanosoma brachyurum	0.0	300.0	45.2	180.8	45948.9	1883.5	14461.0	6027.2	3604.7	2316.6	24610.9
Holopedium gibberum	0.0	0.0	105.5	197.3	315.8	150.7	0.0	3616.3	148.1	2737.8	5273.8
Polyphemus pediculus	0.0	0.0	0.0	8.2	0.0	0.0	38.5	0.0	0.0	0.0	0.0
Alona circumfimbriata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Cladocerans	**6631.6**	**1700.0**	**858.9**	**591.8**	**70423.4**	**2787.6**	**23691.4**	**26218.2**	**6468.8**	**11319.7**	**35409.6**
Copepods											
Diacyclops bicuspidatus thomasi	50381.4	4300.0	150.7	0.0	789.5	0.0	0.0	0.0	0.0	0.0	0.0
Aglaodiaptomus saskatchewanensis	0.0	0.0	452.0	3781.2	40580.3	5876.5	16883.9	1506.8	19998.9	8897.8	4269.2
Eucyclops serrulatus	0.0	200.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mesocyclops edax	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	251.1
Total Adult Copepods	**50381.4**	**4500.0**	**602.7**	**3781.2**	**41369.8**	**5876.5**	**16883.9**	**1506.8**	**19998.9**	**8897.8**	**4520.3**
copepodites	150131.2	141100.0	241.1	24.7	18632.2	1054.8	0.0	2410.9	0.0	368.5	5776.0
nauplii	362893.7	118100.0	783.5	24.7	35369.6	301.4	346.1	3164.3	0.0	684.4	3515.8
Total Zooplankton Adults	**57013.0**	**6200.0**	**1461.6**	**4373.0**	**111793.2**	**8664.1**	**40575.3**	**27725.0**	**26467.7**	**20217.5**	**39929.9**
Total Zooplankton	570037.8	265400.0	2486.2	4422.4	165795.0	10020.3	40921.4	33300.2	26467.7	21270.4	49221.7
Other											
Chaoborus americanus	100.0	0.0	60.5	41.7	0.0	0.0	0.0	0.0	0.0	7.9	0.0
Grand Total	**570137.8**	**265400.0**	**2546.7**	**4464.0**	**165795.0**	**10020.3**	**40921.4**	**33300.2**	**26467.7**	**21278.3**	**49221.7**

Appendix B-7. Zooplankton densities (No./m3) from Ferrell Lake (large basin), 1993-1995.

Ferrell Lake - Main Basin	**May 4 1993 North End**	**May 4 1993 Mid-Lake**	**May 3 1994 North End**	**May 3 1994 Mid-Lake**	**May 1 1995 North End**	**May 1 1995 Mid-Lake**	**June 29 1993 North End**	**June 29 1993 Mid-Lake**	**July 6 1994 North End**	**July 6 1994 Mid-Lake**	**July 7 1995 North End**	**July 7 1995 Mid-Lake**
Cladocerans												
Daphnia pulex	4466.6	28055.9	146.9	472.4	3365.2	766.0	0.0	0.0	0.0	0.0	0.0	0.0
Daphnia laevis	0.0	0.0	440.9	551.1	3566.1	16210.6	285.7	1345.6	0.0	0.0	0.0	150.7
Diaphanosoma birgei	0.0	183.7	0.0	0.0	0.0	0.0	6357.3	26452.9	0.0	0.0	4068.3	2410.9
Bosmina longirostris	0.0	288.7	73.5	183.7	703.2	1054.8	750.0	4594.8	31417.3	47322.7	7986.0	7534.0
Ceriodaphnia reticulata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chydorus sphaericus	0.0	0.0	0.0	0.0	0.0	0.0	357.2	525.1	0.0	0.0	0.0	0.0
Daphnia ambigua	0.0	0.0	1065.6	1522.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Cladocerans	**4466.6**	**28528.3**	**1726.9**	**2729.4**	**7634.4**	**18031.3**	**7750.2**	**32918.5**	**31417.3**	**47322.7**	**12054.3**	**10095.6**
Copepods												
Tropocyclops prasinus mexicanus	525.5	3359.4	1910.7	708.6	0.0	0.0	9678.8	2494.3	8188.9	4960.6	1657.5	2712.2
Diacyclops bicuspidatus thomasi	197.1	367.4	16020.8	12308.9	653.0	979.5	142.9	0.0	0.0	0.0	0.0	0.0
Mesocyclops edax	306.5	944.8	0.0	0.0	452.1	1029.7	5928.7	4201.0	2992.1	3779.5	9342.1	1205.4
Leptodiaptomus siciloides	219.0	4304.2	0.0	0.0	0.0	0.0	13786.0	18149.5	0.0	0.0	0.0	0.0
Skistodiaptomus oregonensis	0.0	0.0	220.5	157.5	1054.8	753.4	0.0	0.0	236.2	157.5	1506.8	753.4
Total Adult Copepods	**1248.0**	**8975.8**	**18152.0**	**13176.0**	**2159.8**	**2762.5**	**29536.3**	**24844.7**	**11417.2**	**8897.6**	**12506.4**	**4671.0**
copepodites	1051.0	472.4	4482.9	3464.3	3013.6	4545.5	1214.3	1214.3	8976.4	10551.2	1205.4	301.4
nauplii	2101.9	8083.5	46335.4	39236.3	3716.8	2963.4	7928.7	1476.9	8267.7	10157.5	0.0	602.7
Total Zooplankton Adults	**5714.6**	**37504.1**	**19878.9**	**15904.4**	**9794.1**	**20793.8**	**37286.5**	**57763.2**	**42834.5**	**56220.3**	**24560.7**	**14766.6**
Total Zooplankton	**8867.475**	**46059.98**	**70697.2**	**58605**	**16524.45**	**28302.6**	**46429.5**	**60454.44**	**60078.6**	**76928.98**	**25766.1**	**15670.7**

	August 4 1993 North End	**August 4 1993 Mid-Lake**	**August 3 1995 North End**	**August 3 1995 Mid-Lake**	**Sept. 7 1993 North End**	**Sept. 7 1993 Mid-Lake**	**Sept. 7 1994 North End**	**Sept. 7 1994 Mid-Lake**	**August 28 1995 North End**	**August 28 1995 Mid-Lake**
Cladocerans										
Daphnia pulex	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Daphnia laevis	0.0	36.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diaphanosoma birgei	29329.9	6503.9	17930.8	23204.6	78.8	52.5	630.0	4960.6	15670.6	28126.8
Bosmina longirostris	4068.1	2719.1	8287.4	10698.2	121668.8	85041.9	6929.1	7952.7	9191.4	13058.9
Ceriodaphnia reticulata	131.2	110.2	0.0	0.0	78.8	0.0	0.0	0.0	0.0	0.0
Chydorus sphaericus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	150.7	753.4
Daphnia ambigua	0.0	0.0	0.0	0.0	0.0	0.0	314.9	708.7	0.0	0.0
Total Cladocerans	**33529.3**	**9370.0**	**26218.2**	**33902.8**	**121826.3**	**85094.4**	**7874.0**	**13622.0**	**25012.7**	**41939.1**
Copepods										
Tropocyclops prasinus mexicanus	17781.7	3674.5	15369.3	16273.4	13623.8	12913.8	40472.4	98818.7	6177.8	3767.0
Diacyclops bicuspidatus thomasi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mesocyclops edax	3543.2	1616.8	150.7	301.4	7560.0	4829.5	0.0	551.2	1506.8	5776.0
Leptodiaptomus siciloides	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Skistodiaptomus oregonensis	5905.4	5548.5	1205.4	1205.4	393.8	157.5	1574.8	5905.5	4068.3	11803.2
Total Adult Copepods	**27230.2**	**10839.8**	**16725.4**	**17780.2**	**21577.5**	**17900.8**	**42047.2**	**105275.4**	**11752.9**	**21346.2**
copepodites	1837.2	1028.9	1054.8	0.0	0.0	0.0	1417.3	0.0	5725.8	14565.7
nauplii	12335.6	21973.5	3013.6	3314.9	0.0	315.0	2677.2	6063.0	5575.1	5776.0
Total Zooplankton Adults	**60759.5**	**20209.8**	**42943.6**	**51683.0**	**143403.8**	**102995.2**	**49921.2**	**118897.4**	**36765.6**	**63285.3**
Total Zooplankton	**74932.33**	**43212.12**	**47012**	**54997.9**	**143403.8**	**103310.2**	**54015.72**	**124960.4**	**48066.5**	**83627.0**

Appendix B-8. Zooplankton densities (No./m3) from Ferrell Lake (small basin), 1993-1995.

Ferrell Lake-Small Basin	**May 4 1993**	**May 3 1994**	**May 1 1995**	**June 29 1993**	**July 6 1994**	**July7 1995**	**August 4 1993**	**August 3 1995**	**Sept. 7 1993**	**Sept. 7 1994**	**August 28 1995**
Cladocerans											
Daphnia pulex	5066.3	2441.2	0.0	525.0	0.0	0.0	0.0	0.0	0.0	1417.3	0.0
Daphnia laevis	0.0	0.0	39377.5	2911.5	0.0	150.7	5879.4	0.0	11811.0	3307.1	0.0
Diaphanosoma birgei	170.6	105.0	0.0	25583.3	0.0	3314.9	9554.1	31039.9	14015.7	21496.0	31391.5
Bosmina longirostris	472.5	196.9	1318.5	44675.3	61259.7	6027.2	3097.2	1356.1	32598.4	3228.3	9794.1
Ilyocryptus spinifer	65.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ceriodaphnia reticulata	0.0	13.1	0.0	0.0	0.0	0.0	210.0	0.0	157.5	0.0	1004.5
Chydorus sphaericus	0.0	0.0	87.9	190.9	0.0	150.7	105.0	0.0	0.0	0.0	251.1
Total Cladocerans	**5775.0**	**2756.2**	**40783.9**	**73886.0**	**61259.7**	**9643.5**	**18845.7**	**32396.0**	**58582.6**	**29448.7**	**42441.2**
Copepods											
Tropocyclops prasinus mexicanus	433.1	288.7	175.8	1622.8	1574.8	5725.8	9606.6	7835.3	4173.2	73306.9	10798.7
Diacyclops bicuspidatus thomasi	3885.0	0.0	2461.1	0.0	314.9	0.0	0.0	0.0	0.0	0.0	0.0
Mesocyclops edax	170.6	0.0	351.6	286.4	4881.9	7232.6	5249.5	0.0	3307.1	629.9	2511.3
Leptodiaptomus siciloides	170.6	0.0	0.0	4963.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Skistodiaptomus oregonensis	0.0	52.5	175.8	0.0	157.5	452.0	18793.2	904.1	14566.9	2283.5	6529.4
Total Adult Copepods	**4659.4**	**341.2**	**3164.3**	**6873.1**	**6929.1**	**13410.4**	**33649.3**	**8739.4**	**22047.2**	**76220.3**	**19839.4**
copepodites	420.0	1890.0	17491.4	1622.8	9842.5	4068.3	1837.3	3917.7	9685.0	6062.9	18583.8
nauplii	4869.4	5079.4	5185.9	6204.9	8897.6	0.0	4934.5	5575.1	35354.3	7401.6	12305.5
Total Zooplankton Adults	**10434.4**	**3097.4**	**43948.1**	**80759.2**	**68188.8**	**23053.9**	**52495.0**	**41135.4**	**80629.8**	**105669.0**	**62280.6**
Total Zooplankton	**15723.8**	**10066.8**	**66625.4**	**88586.9**	**86928.9**	**27122.2**	**59266.9**	**50628.2**	**125669.0**	**119133.5**	**93169.9**

Appendix C-1. Zooplankton biomass estimates (µ/L) from Fosdick Lake, 1995.

Fosdick Lake	**May 1 1995**	**July 6 1995**	**August 3 1995**	**August 29 1995**
Cladocerans				
Daphnia laevis	26.81	68.53	16.32	25.04
Bosmina longirostris	2.23	3.13	0.80	2.16
Diaphanosoma birgei	0.00	0.00	6.21	1.92
Holopedium gibberum	0.00	0.00	0.00	0.00
Alona guttata	0.00	0.00	0.00	0.00
Ceriodaphnia lacustris	0.00	0.00	0.00	0.00
Daphnia ambigua	0.00	65.55	0.00	2.22
Daphnia rosea	0.00	80.36	24.16	0.76
Daphnia pulex	0.00	0.00	0.00	100.12
Total Cladocerans	**29.04**	**217.57**	**47.49**	**132.23**
Copepods				
Diacyclops bicuspidatus thomasi	9.11	0.00	0.00	0.00
Tropocyclops prasinus mexicanus	0.00	0.00	0.00	0.00
Mesocylops edax	5.87	1.01	70.95	8.55
Skistodiaptomus pallidus	3.25	31.38	31.79	13.98
Eucyclops serrulatus	0.00	0.00	0.00	0.00
Total Adult Copepods	**18.23**	**32.38**	**102.74**	**22.53**
copepodites	25.79	0.72	12.67	2.37
nauplii	3.03	0.00	3.39	0.09
Total Zooplankton Adults	**47.27**	**249.96**	**150.22**	**154.76**
Total Zooplankton	**76.09**	**250.67**	**166.29**	**157.21**

Appendix C-2. Zooplankton biomass estimates (μ/L) from Coon Stump Lake, 1995.

Coon Stump Lake	**May 1**	**July 6**	**August 3**	**August 29**
Cladocerans				
Daphnia pulex	0.00	5.52	0.23	4.72
Daphnia laevis	0.00	0.33	0.00	0.00
Daphnia ambigua	0.00	0.58	0.00	0.00
Bosmina longirostris	0.00	0.00	0.00	0.00
Holopedium gibberum	0.00	0.00	0.13	0.22
Diaphanosoma birgei	0.00	0.00	0.01	0.00
Chydorus sphaericus	0.00	0.00	0.00	0.00
Ceriodaphnia sp.	0.00	0.00	0.00	0.03
Scapholeberis sp.	0.00	0.00	0.00	0.05
Total Cladocerans	**0.00**	**6.43**	**0.36**	**5.03**
Copepods				
Aglaodiaptomus leptopus	0.00	7.35	1.38	1.81
Aglaodiaptomus saskatchewanensis	0.00	21.47	0.37	1.61
Mesocyclops edax	0.00	0.00	0.00	0.07
Acanthocyclops vernalis	0.00	0.00	0.00	0.00
Tropocyclops prasinus mexicanus	0.00	0.00	0.00	0.09
Total Adult Copepods	**0.00**	**28.82**	**1.75**	**3.59**
copepodites	0.00	0.10	0.12	0.23
nauplii	0.44	0.00	0.00	0.00
Total Zooplankton Adults	**0.00**	**35.25**	**2.11**	**8.61**
Total Zooplankton	**0.44**	**35.35**	**2.24**	**8.85**

Appendix C-3. Zooplankton biomass estimates (μ/L) from Bass Lake, 1995.

Bass Lake	**May 1**	**July 6**	**August 3**	**August 28**
Cladocerans				
Daphnia pulex	0.17	59.68	12.48	24.22
Diaphanosoma birgei	0.00	1.37	16.36	1.75
Holopedium gibberum	0.02	3.61	26.50	12.71
Bosmina longirostris	0.00	0.00	0.00	0.00
Total Cladocerans	**0.19**	**64.66**	**55.34**	**38.67**
Copepods				
Tropocyclops prasinus mexicanus	0.03	1.31	6.25	0.78
Aglaodiaptomus leptopus	1.67	4.33	0.00	13.92
Aglaodiptomus saskatchewanensis	0.09	10.25	13.64	17.18
Diacyclops bicuspidatus thomasi	0.02	0.00	0.00	0.00
Total Adult Copepods	**1.81**	**15.89**	**19.89**	**31.88**
copepodites	0.00	1.17	0.57	1.99
nauplii	0.03	0.08	0.38	0.12
Total Zooplankton Adults	**2.00**	**80.55**	**75.23**	**70.56**
Total Zooplankton	**2.03**	**81.80**	**76.18**	**72.66**

Appendix C-4. Zooplankton biomass estimates (μ/L) from Mud Lake, 1995.

Mud Lake	**May 1**	**May 1**	**July 5**	**July 5**	**August 3**	**August 3**	**August 29**	**August 29**
	North End	**South End**	**North End**	**South End**	**North End**	**South End**	**North End**	**South End**
Cladocerans								
Bosmina longirostris	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Diaphanosoma birgei	0.00	0.00	0.01	0.03	0.00	0.00	0.00	0.00
Total Cladocerans	**0.00**	**0.00**	**0.04**	**0.03**	**0.00**	**0.00**	**0.00**	**0.00**
Copepods								
Diacyclops bicuspidatus thomasi	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.00
Mesocylops edax	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00
Skistodiaptomus oregonensis	0.00	0.00	0.42	2.07	2.06	1.11	0.16	7.90
Total Adult Copepods	**0.00**	**0.00**	**0.43**	**2.09**	**2.15**	**1.11**	**0.16**	**7.90**
copepodites	0.01	0.01	0.01	0.01	0.28	0.33	0.11	2.25
nauplii	0.39	0.52	0.00	0.00	0.17	0.06	0.00	0.00
Total Zooplankton Adults	**0.00**	**0.00**	**0.47**	**2.12**	**2.15**	**1.11**	**0.16**	**7.90**
Total Zooplankton	**0.40**	**0.53**	**0.48**	**2.13**	**2.61**	**1.49**	**0.27**	**10.15**

Appendix C-5. Zooplankton biomass estimates (µ/L) from Muskrat Lake,1995.

Muskrat Lake	**May 2 Main**	**May 2 W. Basin**	**July 5 Main**	**July 5 W. Basin**	**August 3 Main**	**August 3 W. Basin**	**August 29 Main**	**August 29 W. Basin**
Cladocerans								
Daphnia pulex	2.09	7.35	1.24	0.85	7.36	6.98	1.97	13.38
Bosmina longirostris	0.00	0.15	0.63	0.77	27.77	18.21	0.00	2.42
Diaphanosoma brachyurum	0.05	0.15	9.46	5.76	30.06	14.71	34.42	67.30
Holopedium gibberum	1.06	0.40	0.44	1.11	6.20	14.73	15.57	20.06
Total Cladocerans	**3.20**	**8.05**	**11.77**	**8.49**	**71.39**	**54.63**	**51.95**	**103.16**
Copepods								
Diacyclops bicuspidatus thomasi	1.22	1.15	0.00	0.00	0.00	0.00	0.00	0.00
Aglaodiaptomus saskatchewanensis	1.85	3.89	16.74	36.99	101.98	10.41	25.30	19.49
Mesocyclops edax	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50
Total Adult Copepods	**3.07**	**5.04**	**16.74**	**36.99**	**101.98**	**10.41**	**25.80**	**19.99**
copepodites	0.33	0.35	0.98	2.22	4.49	2.81	4.25	7.38
nauplii	0.53	0.24	0.04	0.10	0.30	0.96	0.44	1.07
Total Zooplankton Adults	**6.27**	**13.09**	**28.51**	**45.48**	**173.37**	**65.04**	**77.75**	**123.14**
Total Zooplankton	**7.13**	**13.68**	**29.53**	**47.80**	**178.17**	**68.81**	**82.44**	**131.59**

Appendix C-6. Zooplankton biomass estimates (µ/L) from Ferrell Lake (large basin), 1995.

Ferrell Lake -Large Basin	**May 1**	**May 1**	**July 7**	**July 7**	**August 3**	**August 3**	**August 28**	**August 28**
	North End	**Mid-Lake**	**North End**	**Mid-Lake**	**North End**	**Mid-Lake**	**North End**	**Mid-Lake**
Cladocerans								
Daphnia pulex	39.24	11.83	0.00	0.00	0.00	0.00	0.00	0.00
Daphnia laevis	21.39	66.73	0.00	0.49	0.00	0.00	0.00	0.00
Diaphanosoma birgei	0.00	0.00	13.94	7.69	76.64	91.18	56.58	87.92
Bosmina longirostris	1.12	1.48	8.07	9.82	11.88	14.27	11.36	14.11
Chydorus sphaericus	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.79
Total Cladocerans	**61.75**	**80.04**	**22.01**	**18.01**	**88.52**	**105.45**	**68.08**	**102.82**
Copepods								
Tropocyclops prasinus mexicanus	0.00	0.00	1.71	3.62	20.51	19.14	5.78	2.58
Diacyclops bicuspidatus thomasi	5.11	2.31	0.00	0.00	0.00	0.00	0.00	0.00
Mesocyclops edax	3.63	12.20	41.33	5.21	0.49	2.28	5.83	17.73
Skistodiaptomus oregonensis	7.98	4.62	10.27	5.96	14.48	11.86	30.83	49.90
Total Adult Copepods	**16.72**	**19.13**	**53.31**	**14.79**	**35.48**	**33.28**	**42.44**	**70.21**
copepodites	4.54	4.82	1.32	0.41	1.19	0.00	7.01	15.69
nauplii	1.45	0.48	0.00	0.21	0.89	0.96	1.54	1.46
Total Zooplankton Adults	**78.47**	**99.17**	**75.31**	**32.80**	**124.00**	**138.73**	**110.52**	**173.03**
Total Zooplankton	**84.46**	**104.47**	**76.63**	**33.41**	**126.08**	**139.68**	**119.07**	**190.18**

Appendix C-7. Zooplankton biomass estimates (μ/L) from Ferrell Lake (small basin), 1995.

Ferrell Lake-Small Basin	**May 2**	**July7**	**August 3**	**August 28**
Cladocerans				
Daphnia laevis	215.65	0.44	0.00	0.00
Diaphanosoma birgei	0.00	8.78	115.32	99.96
Bosmina longirostris	3.81	5.02	1.73	9.47
Ceriodaphnia reticulata	0.00	0.00	0.00	2.61
Chydorus sphaericus	0.18	0.15	0.00	0.34
Total Cladocerans	**219.64**	**14.39**	**117.05**	**112.37**
Copepods				
Tropocyclops prasinus mexicanus	0.00	5.62	8.18	9.31
Diacyclops bicuspidatus thomasi	11.81	0.00	0.00	0.00
Mesocyclops edax	2.20	19.56	0.00	15.20
Skistodiaptomus oregonensis	3.59	1.20	7.89	37.86
Total Adult Copepods	**17.60**	**26.37**	**16.07**	**62.36**
copepodites	20.75	5.20	4.08	15.34
nauplii	1.56	0.00	1.50	2.85
Total Zooplankton Adults	**237.24**	**40.76**	**133.12**	**174.73**
Total Zooplankton	**259.55**	**45.96**	**138.71**	**192.93**

IMPACTS OF COPPER SULFATE ON THE ZOOPLANKTON COMMUNITY IN FERRELL LAKE

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ABSTRACT

Zooplankton samples were collected from a walleye rearing pond on the Camp Ripley Military Reservation prior to and during the week of walleye harvest to assess changes in the zooplankton community with respect to copper sulfate ($CuSO_4$) treatment. It appears the copper addition to Ferrell Lake did have an impact on the zooplankton community. One day after $CuSO_4$ treatment, the cladocerans decreased by more than 50% and one week post treatment, no cladocerans were collected. The abundance of copepods however, did not decline when $CuSO_4$ was added and one species increased in abundance after treatment.

INTRODUCTION

Approximately 287 wetlands and small lakes (7,405 ha) throughout the state of Minnesota are used by the Minnesota Department of Natural Resources, (MDNR) Section of Fisheries, for walleye rearing. In addition, 1859 wetlands (18,449 ha) are licensed for private fish rearing. In many of these water bodies, copper sulfate $CuSO_4$ is applied prior to walleye harvesting as part of the management operation to aid in herding the fish toward the shoreline and into trapnets. $CuSO_4$ is also applied to some lakes as an herbicide to control nuisance blue-green algae growth (Whitaker et al. 1978) and as a molluscicide to control the vectors of swimmers itch. According to the MDNR Ecological Services 1992 Aquatic Plant Management Report, 519 lakes in the state were treated that year with $CuSO_4$ to control algae, leeches and/or snails.

Copper is a metal that is highly toxic to many aquatic animals and plants. However, the impact that $CuSO_4$ applications have on freshwater communities in lakes and wetlands is not completely understood or well documented. This is partially due to the fact that copper toxicity varies with water chemistry parameters (temperature, pH, alkalinity and hardness) exposure time, and the presence of chelating agents (Andrew et al. 1977, Hale undated). *In vitro* studies show that direct toxicity is related to the activities of the cationic cupric forms of copper which precipitate rapidly in natural waters (Andrew et al. 1977).

Zooplankton communities play an integral role in freshwater ecosystems as they are vital links in the aquatic food web. From a fisheries management viewpoint, zooplankton provide food for the growth of stocked walleye fry in rearing ponds. Therefore, the toxicity of $CuSO_4$ to zooplankton is an issue of interest.

Many *in vitro* studies have shown that $CuSO_4$ is toxic to zooplankton at relatively low concentrations. Mitra and Thakurta (1973) found $CuSO_4$ to be lethally toxic to *Daphnia* sp. at a concentration as low as 0.02 mg/l in 2 hours. Ferrando et al (1992) found the 24 hr LC50 value for *Daphnia magna* to be 0.34 mg/l $CuSO_4$. Acute copper toxicity testing of *D. magna* resulted in a 48 hr LC50 of 40 μg\l Cu^{2+} while more subtle responses such as reproductive impairment resulted from 22 μg/l Cu^{2+} after 3 weeks (Biesinger and Christensen 1972). Anderson (1950) has argued that *D. magna's* response to toxins is representative of most freshwater microfauna.

In contrast to *in vitro* studies, literature on field studies on the impact of zooplankton to $CuSO_4$ applications are limited. Most of the *in situ* studies involve examining the phytoplankton response to $CuSO_4$ treatment and look only at zooplankton as non-target organisms which are minor aspects of the studies (McKnight 1981, Swain et al. 1985).

In this study, zooplankton samples were collected from a walleye rearing pond on the Camp Ripley Military Reservation immediately prior to and during the week of walleye harvesting in 1993 and 1995 to assess changes in the zooplankton community with respect to $CuSO_4$ addition. This sampling was part of a larger aquatic baseline monitoring study at Camp Ripley.

STUDY SITE

Ferrell Lake is a small, mesotrophic lake (approximately 24 hectares) located on the Camp Ripley Military Reservation, in Morrison County, Minnesota. The lake is divided into two basins. The small basin is approximately one quarter the size of the main basin and the two are connected by a shallow channel. The lake has an average depth of 2.4 meters and a maximum depth of 4.3 meters. This lake was dominated by a bullhead and fathead minnow population, but was chemically reclaimed in 1983 with rotenone. Since then it has been used by MDNR, Section of Fisheries as a walleye rearing pond. *Daphnia pulex* were stocked into the lake in 1983 and 1984 as forage and brewers yeast has been added to increase early populations of zooplankton.

METHODS

Zooplankton were collected quantitatively from three stations in Ferrell Lake on September 7, 1993 as part of the baseline monitoring study. One station was located on the north end of the main basin, one in the mid-lake region, and one near the center of the small basin. Horizontal tows (30 meters in length at 0.5 meters depth) were taken at each station using a Clarke-Bumpus plankton sampler (mesh size 80 μm). Samples were preserved in ethanol and returned to the laboratory for analysis. On September 8, $CuSO_4$ was added to both basins of the lake at a rate of 3.6 Kg/ha (3.3 lbs/acre). Approximately one hour later, zooplankton were collected using the same procedures as described above. Zooplankton were collected on September 9, 10 and 13 by MDNR Fisheries and Camp Ripley staff using the same procedures as before, except that a Wisconsin plankton net (mesh size 80 μm) was used for collection.

Zooplankton sampling was conducted again in 1995 during the week of walleye harvest using the same procedures as in 1993, although only the mid-lake station was sampled.

Zooplankton samples were counted and identified using the following protocol. Sample volumes were adjusted to a known volume by filtering through 80 μm netting and rinsing specimens into a graduated beaker. Water was added to the beaker to a volume that would provide at least 200 organisms per 5 ml aliquot. The beaker was swirled in a figure-eight motion to ensure thorough mixing. Two 5 ml aliquots were withdrawn from each sample using a bulb pipet and transferred to a counting wheel and zooplankton were counted at 30X magnification under a dissecting microscope. Identification to species (or the lowest taxonomic group possible) was done with the use of a compound microscope and various taxonomic keys (Brooks 1957, Smith and Fernando 1978, Pennak 1989). Zooplankton densities were calculated and reported as number of animals/liter.

RESULTS AND DISCUSSION

Addition of $CuSO_4$ to Ferrell lake was followed by more than a 50% decrease in cladocerans after one day and a 100% decrease in cladocerans after one week for both years. In contrast, it appears the $CuSO_4$ addition had no negative affects on the copepods and one species actually increased in abundance after the $CuSO_4$ addition. In 1993, the only cladoceran numerous enough to calculate densities for in the large basin was *Bosmina longirostris*. Prior to $CuSO_4$ addition, *B. longirostris* densities were at 114/L and 80/L at the north and mid-lake sampling sites, respectively (Figs. 1 and 2). One day after treatment, *B. longirostris* densities were at 24/L and 9/L at north and mid-lake sites, respectively. One week post treatment, no cladocerans were observed in the samples. Similar results were found in the small basin where there were three dominant cladocerans present, *B. longirostris* (31/L), *Daphnia laevis* (11/L) and *Diaphanosoma birgei* (13/L) before $CuSO_4$ addition (Fig. 3). No organisms from these taxa were observed in the samples two days after treatment.

In 1993, the two species of cyclopoid copepods present in the large basin were *Mesocyclops edax* and *Tropocylops prasinus mexicanus*. These two species were also present in the small basin along with the calanoid *Skistodiaptomus oregonensis*. One week after the addition of $CuSO_4$, *T. prasinus mexicanus* showed a two-fold increase at all three sampling sites whereas *M. edax* and *S. oregonensis* densities did not change (Figs. 1, 2 and 3). In the small basin, immature copepods were abundant enough to calculate densities. The addition of $CuSO_4$ did not appear to change the densities of either the copepodites or nauplii (Fig. 3).

Prior to $CuSO_4$ addition in 1995, *Bosmina longirostris* and *Diaphanosoma birgei* were present in the large basin of Ferrell Lake at densities of 22/L and 2/L respectively (Fig. 4). One day after treatment, densities of *B. longirostris* were at 3/L and *D.birgei* at less than 1/L. Three days post treatment no cladocerans were collected. Similar to the 1993 results, the addition of $CuSO_4$ did not appear to negatively affect the copepods and *Tropocyclops prasinus mexicanus* had a two-fold increase in density by day three (Fig.4).

The impact of added copper on the zooplankton community in Ferrell Lake was similar to a study by McKnight (1981) where $CuSO_4$ was added to a reservoir to control a nuisance bloom of algae. *Daphnia* and *Bosmina spp*. were abundant prior to $CuSO_4$ treatment but disappeared after treatment and were not observed again until the following spring. The only large zooplankton species that appeared to survive was an unidentified cyclopoid copepod. Effler et al. (1980) also observed that the only zooplankton species to decrease in abundance with low level treatments of $CuSO_4$ in a study lake was *Daphnia pulex*. Havens (1994) found that copper selectively eliminated herbivorous zooplankton species (*Daphnia galeata* and *Eubosmina coregoni*) and left the assemblage dominated by the predator *Mesocylops edax*. These studies do not offer an explanation why cladocerans are negatively affected by the copper more than the copepods, and if the impact is due to direct toxicity or indirect responses associated with alterations at lower trophic levels. The rapid rate of response and severity suggests that direct copper toxicity is the most likely cause for the change in zooplankton densities in Ferrell Lake.

Whether the impact is direct or indirect, the disappearance of the cladoceran assemblage in Ferrell Lake appears to be short term because, after years of $CuSO_4$ treatment in the fall, these species are present again every spring. *Daphnia laevis*, *Bosmina longirostris* and *Diaphanosoma birgei* produce resting eggs in autumn that overwinter in the sediment and hatch in the spring (Balcer et al 1984). This life history trait may explain why annual $CuSO_4$ treatments do not permanently eliminate these species from the community.

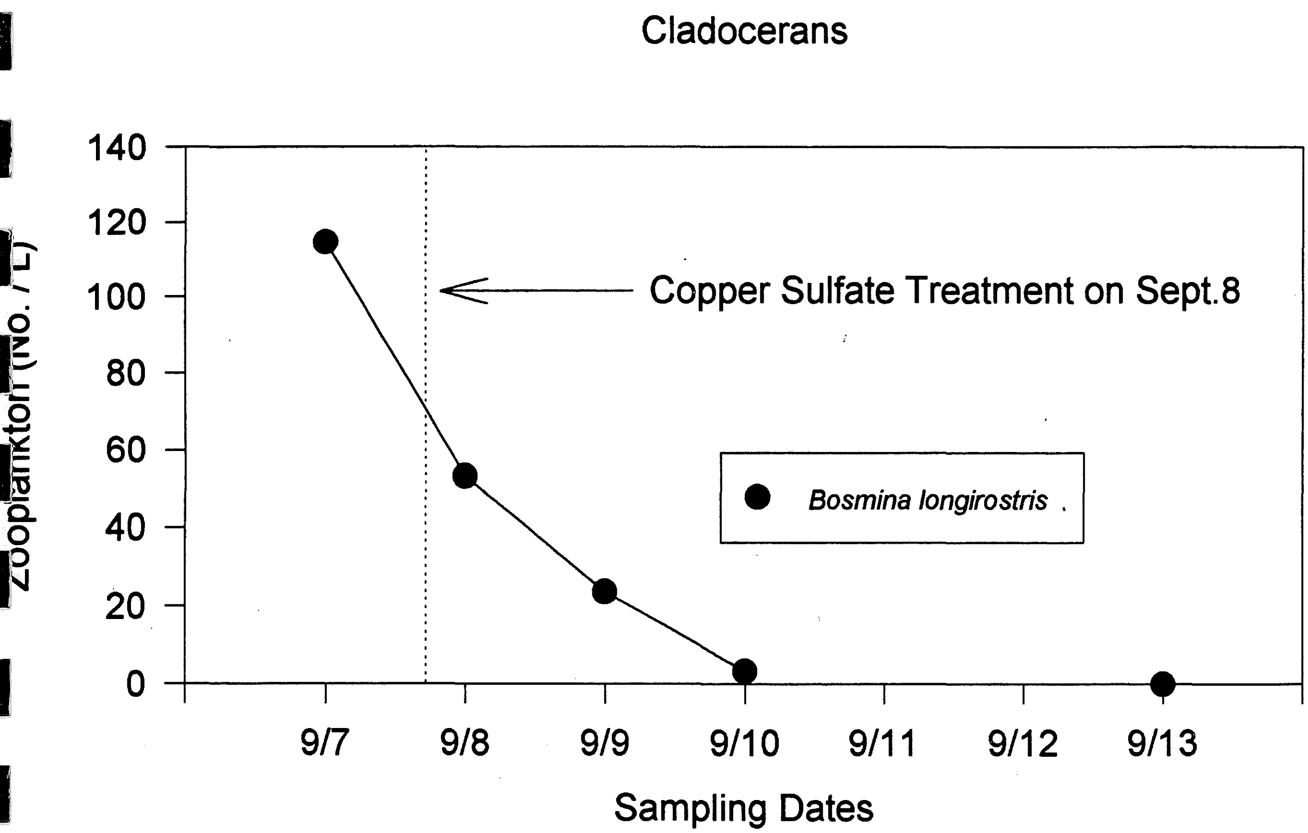
Long term impacts on the zooplankton community are more difficult to assess. Havens (1994) used low level $CuSO_4$ treatments to assess the effects of stress on aquatic ecosystems and found that significant declines in species richness and community diversity occurred with the treatments. Whether the zooplankton community in Ferrell Lake would be more diverse without $CuSO_4$ applications is speculative, but it is possible that annual $CuSO_4$ treatments may have eliminated certain zooplankton species that do not form resting eggs.

RECOMMENDATIONS

Since the addition of $CuSO_4$ appears to have immediate short-term negative impacts on a component of the zooplankton community, its use in fish rearing should be kept to a minimum. Specifically, in Camp Ripley, Ferrell Lake should be the only lake used for walleye harvesting to prevent disruption of the zooplankton communities in other lakes on the reservation.

Ferrell Lake-Large Basin (North End)

Zooplankton Densities-September 7-13,1993



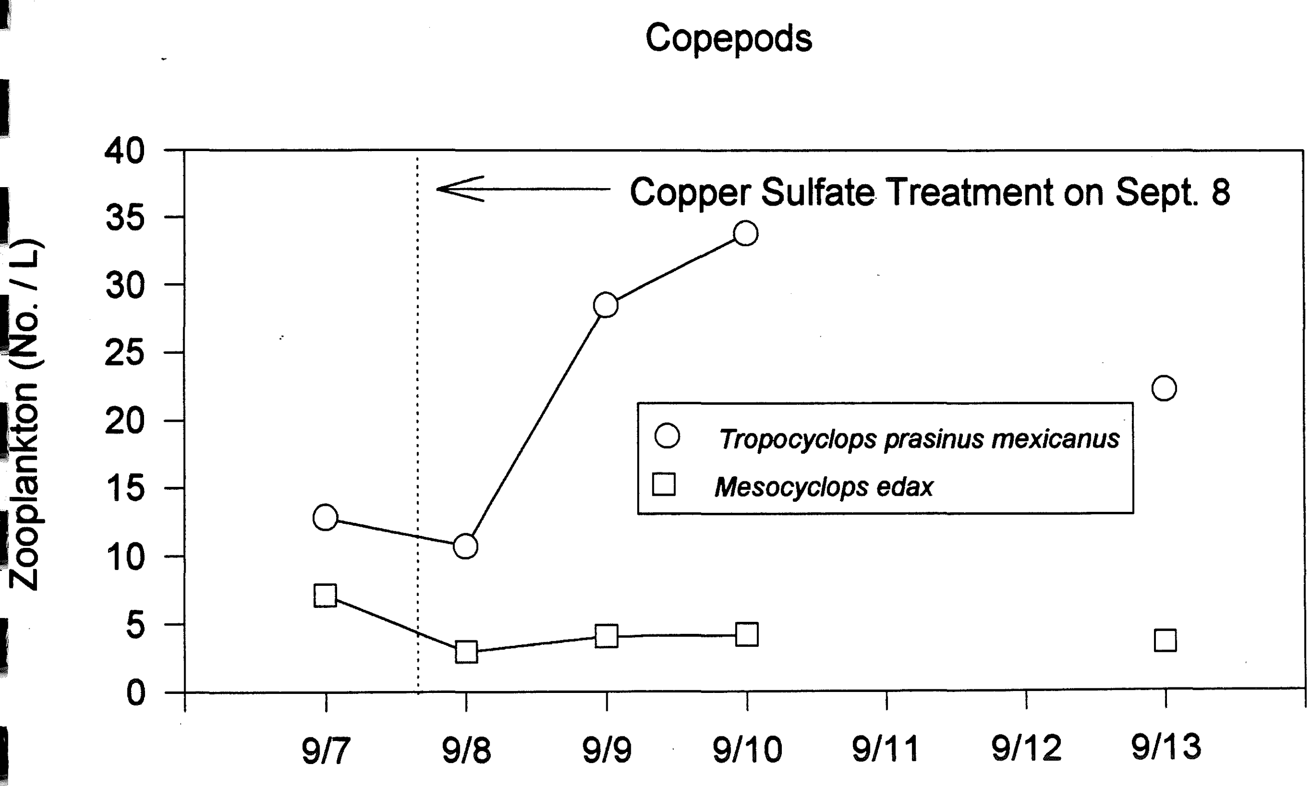


Figure 1. Zooplankton densities (No./L) in the large basin of Ferrell Lake (north end) during the week of walleye harvest, September 7-13, 1993.

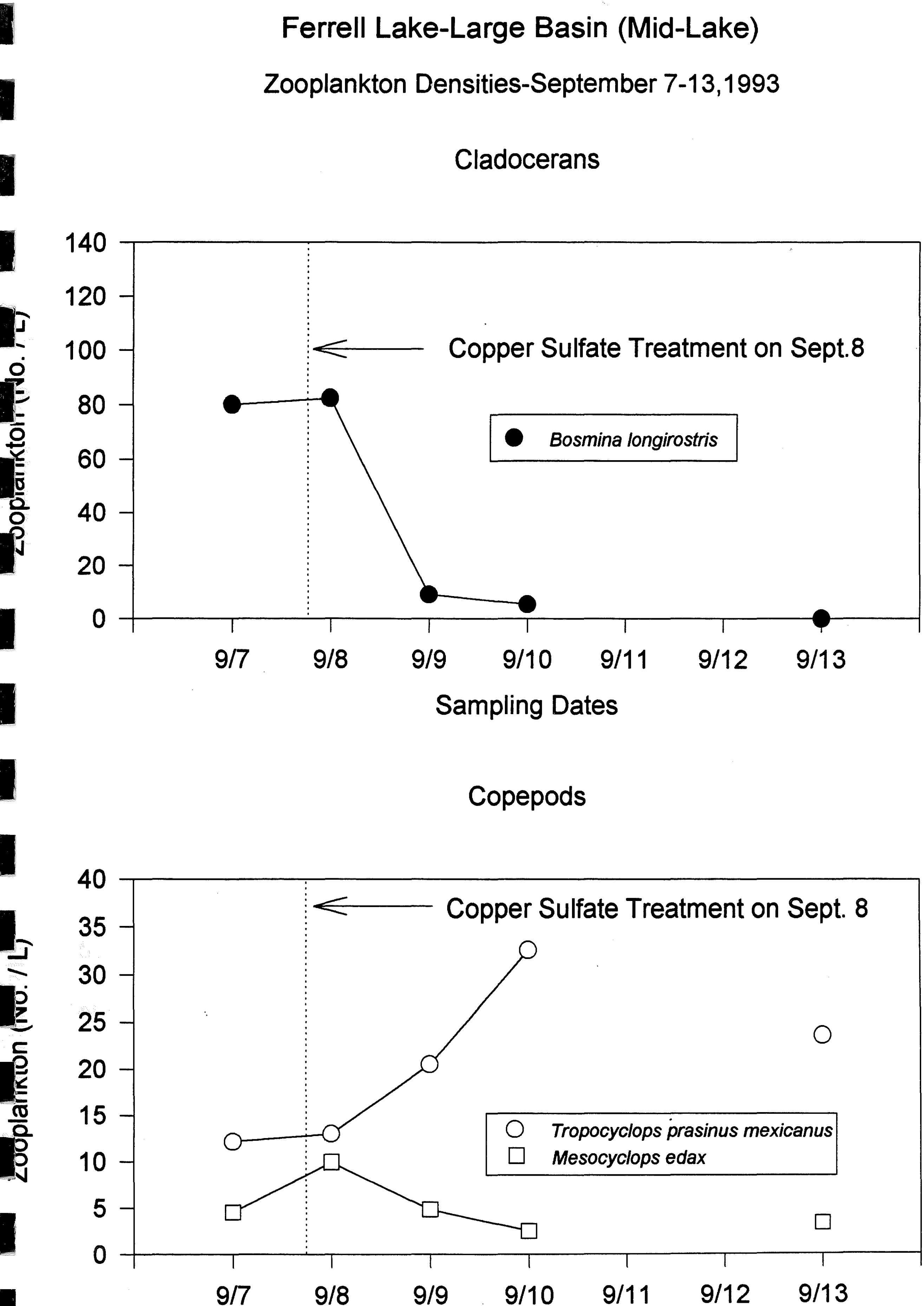


Figure 2. Zooplankton densities (No./L) in the large basin of Ferrell Lake (mid-lake) during the week of walleye harvest, September 7-13, 1993.

Ferrell Lake-Small Basin

Zooplankton Densities-September 7-13,1993

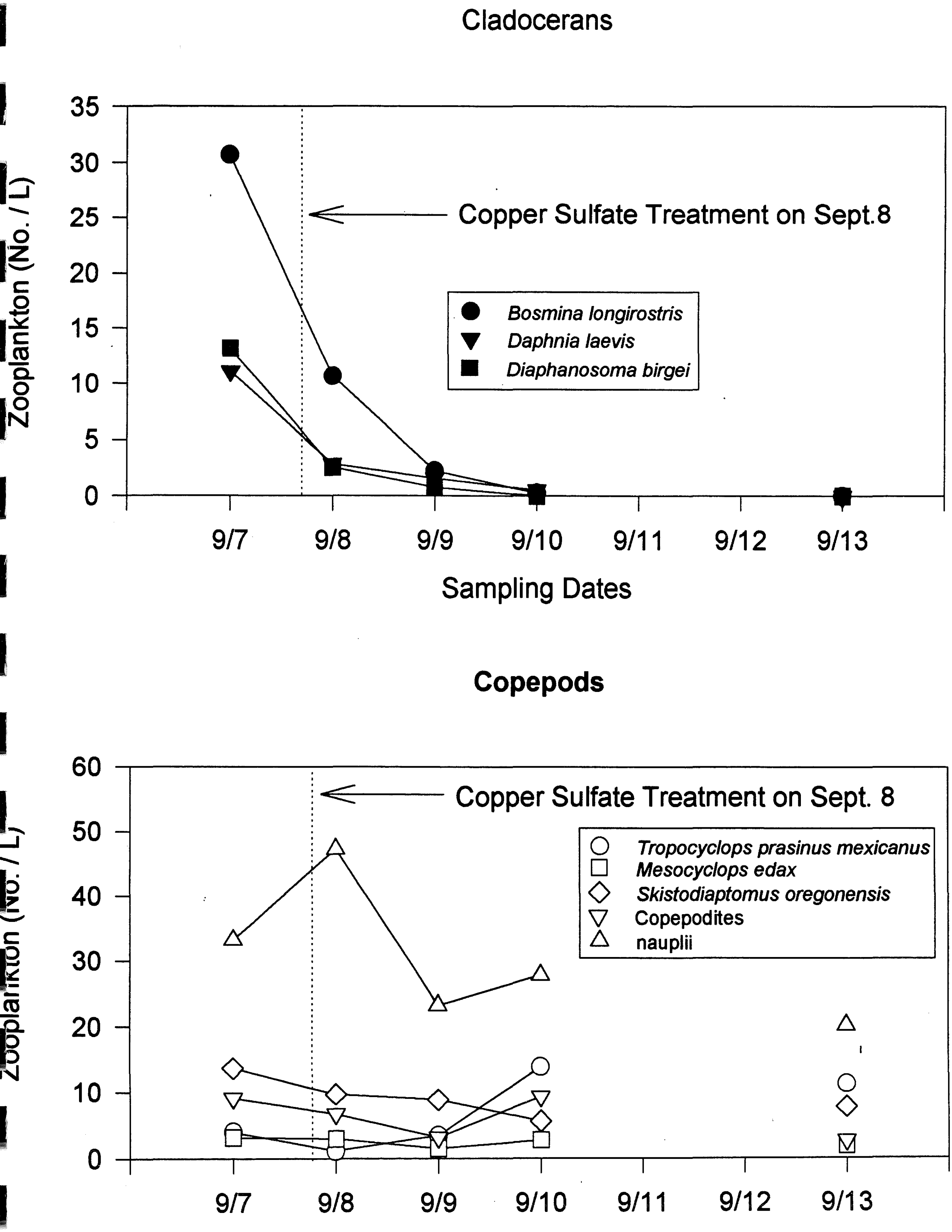
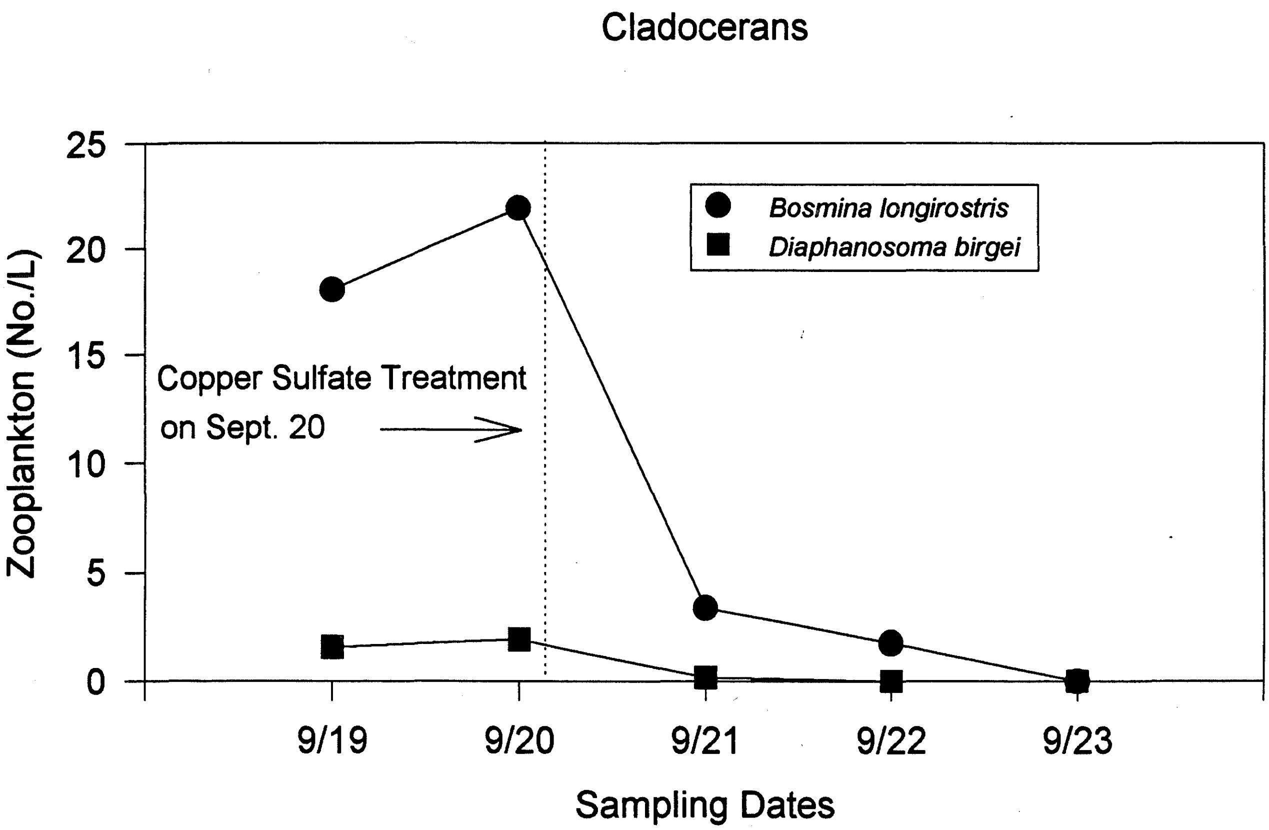


Figure 3. Zooplankton densities (No./L) in the small basin of Ferrell Lake during the week of walleye harvest, September 7-13, 1993.

Ferrell Lake

Zooplankton Densities - September 19-23, 1995



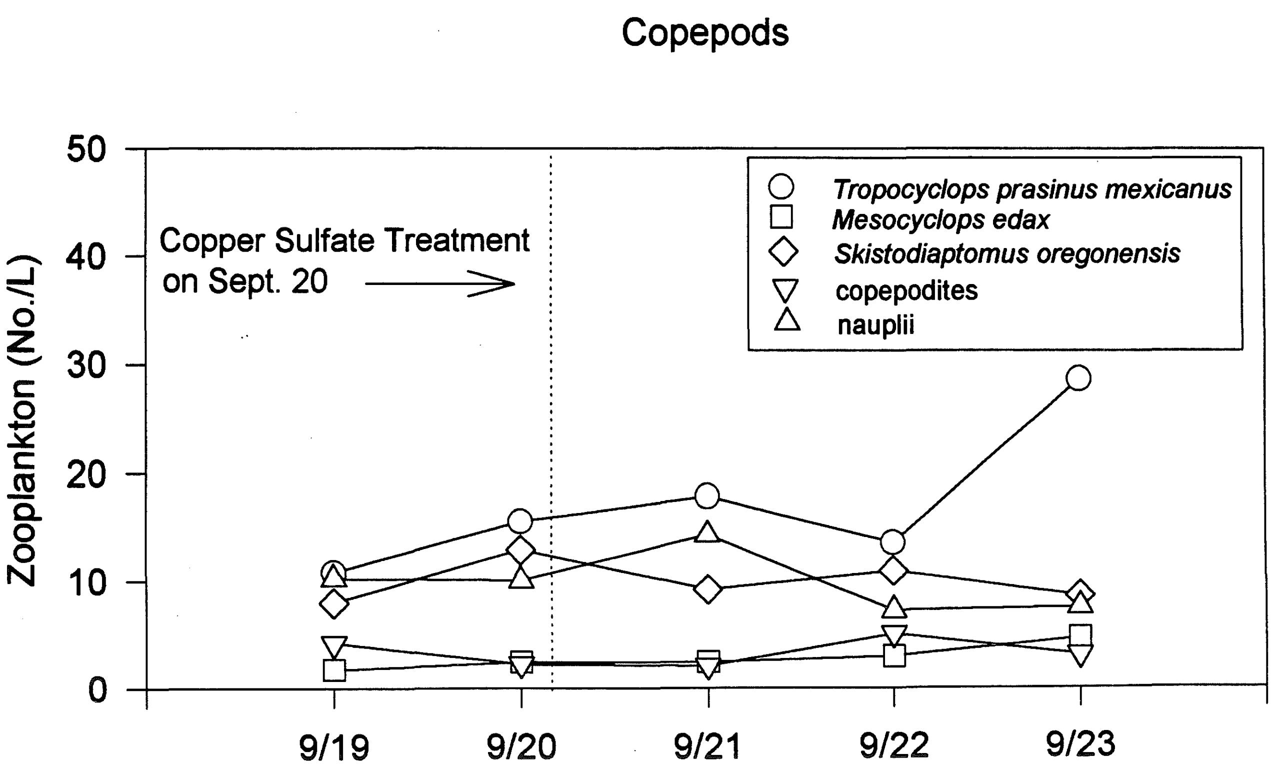


Figure 4. Zooplankton densities (No./L) in the large basin of Ferrell Lake during the week of walleye harvest, September 19-23, 1995.

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Human Impacts on the Aquatic Environments of Camp Ripley

Final Research Report

prepared for the

Minnesota Department of Natural Resources

by

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August 1994

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Summary

1. A single sediment core was collected from each of six lakes in the Camp Ripley Military Reservation to evaluate the long-term impacts of military activities on sediment accumulation and composition. The cores were dated at high resolution by ^{210}Pb and analyzed for lithological composition by loss-on-ignition methods to reconstruct historic trends in soil erosion and lake productivity.

2. All lakes show an increase in sediment accumulation commencing around the time of European settlement in the region (c. 1880). At the same time, sedimentary inorganic content increases by 10-25% in all but two lakes due to increased inputs of silts and clays from erosion of catchment soils.

3. In contrast to these earlier trends, most of the lakes show no changes or only a modest response to subsequent military activities at Camp Ripley. One lake (Ferrell) has sustained recent impacts (increase erosion and nutrient loading) from amphibious vehicle training, while two lakes remote from direct military activity (Bass, Fosdick) have recovered to pre-settlement conditions. The other study lakes, Coon Stump, Mud, and Muskrat (the later two located on artillery ranges) reflect a condition of sustained low-level impact similar to that following European settlement.

Introduction

Camp Ripley is a military reserve of the Minnesota National Guard occupying 53,000 acres (21,400 ha) of Morrison County along the west bank of the Mississippi River in central Minnesota. The camp was established in 1931 on State and private lands that had been extensively logged and partially homesteaded in the late 1800s. With the creation of a military reservation, certain areas were set aside for training exercises, while other areas were allowed to revert to a mosaic of second-growth forest and old fields. Subsequent impacts on lands within the reservation have shifted over time with changes in military technology and training needs.

In 1991 the Department of Defense commissioned an ecological study of Camp Ripley by the Minnesota Department of Natural Resources to assess unique ecological features of the reservation with the expressed aim of mitigating human impacts on the most sensitive sites. Several small lakes were chosen for study to assess possible military impacts on aquatic habitats. Because little in the way of baseline data exist for these lakes, a paleolimnological study was initiated to reconstruct limnological conditions prior to the creation of Camp Ripley and before the time of European settlement in central Minnesota. This report summarizes the results of that study.

The primary objectives of the investigation were to: (1) establish baseline criteria for undisturbed conditions existing prior to European settlement (2) determine whether limnological conditions have changed following the establishment of Camp Ripley, and (3) explore limnological trends in lakes exposed to contrasting levels of current military activity. This limnological history was reconstructed from meter-long sediment cores collected from the deeper regions of each of six lakes. The cores were dated at high resolution by ^{210}Pb and analyzed for lithological composition by loss-on-ignition methods. The ecological impacts that these methods should reveal include increased erosion of catchment soils and lake eutrophication associated with enhanced nutrient inputs (Engstrom *et al.*, 1991; Charles *et al.*, 1994).

Study Sites

The lakes selected for study occupy small (4 -100 ha) shallow (Z_{max} = 1.0-3.5 m) depressions in gently undulating ground moraine (Fig. 1). Lakes are not particularly numerous in Camp Ripley, especially large deep ones. Three of the lakes (Bass, Coon Stump, and Fosdick) occupy forested catchments that today receive little or no military use, while the other three (Ferrell, Mud, and Muskrat) are located in areas with high military activity. Mud and Muskrat lakes are situated in or near target ranges for heavy artillery, while Ferrell Lake straddles a training course for amphibious vehicles.

Methods

Core Collection A single sediment core was obtained from the central region of each basin during two days of field sampling in October, 1993. The cores were collected with a 5-cm diameter polycarbonate tube fitted with a piston and operated from the lake surface by rigid drive-rods. This device recovers even the very loose uncompacted sediment surface without disturbance. The cores were extruded vertically from the top of the tube and sectioned at fixed depth intervals into polypropylene jars. The outer smear was removed from each sample during the extrusion process, and sediment texture and color were recorded. The upper half-meter of each core was sectioned at 2-cm intervals, while deeper strata were integrated into 4-cm sections. Cores were at least one meter in length except for Mud Lake where only 76 cm were recovered.

Loss-on-Ignition: Bulk density, organic matter, and carbonate content of sediment samples were determined by standard loss-on-ignition techniques (Dean, 1974). Approximately 1-cm^3 aliquots of fresh wet sediment were dried at 110° C, and burned at 550° and 1000° C; samples were weighed wet and between each heating on an electronic analytical balance.

Lead-210 Dating Sediment cores were analyzed for excess ^{210}Pb activity to determine age and sediment accumulation rates for the past 150-200 years. Lead-210 was measured through its grand-daughter product ^{210}Po with ^{208}Po added as an internal yield tracer. The polonium isotopes were distilled from 0.5 - 2.0 g dry sediment at 550° C following pre-treatment with concentrated HCl and plated directly (without HNO_3 oxidation) onto silver planchets from a 0.5 N HCl solution (modified from Eakins & Morrison, 1978). Activity was measured for 1-6 x 10^5 s with Si-depleted surface barrier detectors and an Ortec Adcam alpha spectroscopy system. Unsupported ^{210}Pb was calculated by subtracting supported activity from the total activity measured at each level; supported ^{210}Pb was estimated from the asymptotic activity at depth (the mean of the lowermost samples in a core). Dates and sedimentation rates were determined according to the c.r.s. (constant rate of supply) model (Appleby & Oldfield, 1978) with confidence intervals calculated by first-order error analysis of counting uncertainty (Binford, 1990).

Results

Sediment Dating

Stratigraphic profiles for total ^{210}Pb exhibit reasonably monotonic declines from surface activities of 11-21 pCi/g to background (supported) values of 0.2-1.2 pCi/g at core depths ranging from 25 to almost 110 cm (Fig. 2). Despite the substantial range in profile length, five of the six cores (excluding Mud L.) contain roughly the same inventory of unsupported ^{210}Pb (12-18 pCi cm^{-2}); Mud Lake is somewhat lower with 7 pCi cm^{-2} (Table 1). These inventories are equivalent to a mean annual ^{210}Pb flux of 0.37-0.45 pCi cm^{-2} yr^{-1}, and are similar to the atmospheric ^{210}Pb flux for the region 0.5 pCi cm^{-2} yr^{-1} (Urban *et al.*, 1990). Supported ^{210}Pb values are well-defined in all cores by at least two levels with near-constant activity in the lower part of the profiles. All of the ^{210}Pb profiles exhibit changes in slope that represent changing rates of sediment accumulation. Dates and sedimentation rates from such non-exponential decay curves are most appropriately calculated by the c.r.s. (constant rate of supply) model, which assumes a constant flux of ^{210}Pb to the core site, but allows sediment input to vary.

The age/depth curves calculated by the c.r.s. model (Fig. 3) show that most of the cores can be reliably dated back to 125-150 years. Beyond this point (5-6 half-lives for ^{210}Pb) unsupported ^{210}Pb is barely discernible above background (supported ^{210}Pb) and dating error increases markedly. The dating results for these cores are quite robust, because surface activities are high and the break to supported levels at depth is clearly defined. In all cases, there are at least three dated levels that precede the time of European settlement in central Minnesota (c. 1880). These strata are particularly important because they provide the predisturbance sedimentation rates against which all subsequent human impacts in the Camp Ripley area may be compared.

Sediment accumulation rates derived from c.r.s. modeling (Fig. 4) show two periods of increasing sediment flux in the Camp Ripley cores. All lakes show an increase in sediment accumulation commencing shortly after the region was homesteaded (between 1880 and 1900). In two of these lakes (Bass and Fosdick) accumulation rates return to pre-settlement levels in the early 1900s, whereas in the others (Coon Stump Ferrell, Mud, and Muskrat) sediment accumulation rates increase further, though somewhat asynchronously, in recent decades. The increase is most dramatic in Ferrell Lake and begins around 1970; it is also clearly defined in Coon Stump but starts earlier (c. 1950); In Mud and Muskrat the increase and its inception are less distinct because of variable sedimentation rates during the first half of this century.

Mean sediment accumulation rates during two time windows (pre-1880 and post-1910) have been calculated from the detailed accumulation profiles to smooth short-term variation and provide a basis for comparing the cumulative impact of land-use change among basins (Table 1). This summary again illustrates the major increase in sediment accumulation that followed settlement: roughly a 2x increase (except for Bass Lake which shows no long-term trend). However, it should be noted that even the modern rates (0.007-0.037 g cm^{-2} yr^{-1}) are 1-2 orders of magnitude lower than those of most culturally impacted lakes in agricultural and urban landscapes.

Sediment Composition

The proximate composition of sediments varies greatly among the six study lakes and shows marked changes over time in several of the cores (Fig. 5). Organic content ranges from 10 to 75% with the remainder composed largely of inorganic (presumably clastic) materials; carbonate content is low and consistently exceeds 5% only in Mud Lake. The high carbonate content of Mud Lake (30-65%) represents calcite encrustations that form on benthic macrophytes (principally *Chara*) during photosynthetic uptake of CO_2. The organic matter represents algal and macrophyte production within the lake as well as inwash of organic detritus from the watershed, although in-lake organic sources are likely dominant. The deeper sediments from several of the shallower lakes are rich in coarse plant detritus and in Muskrat are generally peaty in texture; all other sediments are fine grained.

In all cores except those from Bass and Coon Stump there is a clear increase in inorganic content that corresponds to the time of European settlement (c. 1880). Pre-settlement sediments tend to be richer in organic matter (or carbonate in Mud Lake), except in Fosdick Lake where alternating bands of silty inorganic sediments re-occur many times down core. The inorganic fraction consists mostly of silts and clays eroded from the watershed along with a substantial component of biogenic silica from diatom production. Thus the coincident increase in sediment accumulation and inorganic content around the turn of the century provides strong evidence for increased soil erosion in the Camp Ripley area following European settlement and land clearance.

In contrast to these earlier trends, sediment composition changes relatively little during the second interval of increasing sedimentation in Ferrell and Muskrat lakes. Coon Stump sediments are slightly more inorganic after 1950 (but no more so than those at the bottom of the core), whereas Mud Lake sediments become less inorganic just prior to 1970 (when sedimentation rates increase at these site). The lack of systematic lithologic changes associated with recent sedimentation increases makes these recent trends more difficult to interpret. It is possible that they represent higher rates of organic production (along with increased erosion) so that sediment composition does not change appreciably. It is also possible that the more subtle increases in sediment accumulation (e.g. Mud, Muskrat) are simply the result of changing patterns of sediment deposition within the basin, and that lake-wide sediment deposition has not increased, at least at these sites (Engstrom *et al.*, 1991).

Discussion and Conclusions

Stratigraphic trends in sediment composition and accumulation provide only limited evidence that military operations at Camp Ripley have had a direct impact on lakes within the reservation. While there is a clear and synchronous increase in watershed erosion at the time of European settlement, discerning more recent human impacts against long-term environmental variability is quite difficult. Only Ferrell Lake shows an unequivocal five-fold increase in sediment deposition in recent decades. This increase, which begins around 1970 appears in both the organic and inorganic fractions, so that sediment composition does not shift appreciably from that of the early 1900s. These recent sediments are clearly more inorganic than those at the base of the core, however. The fact that organic constituents have increased in concert with inorganic inputs implies that both organic productivity and soil erosion are greater in recent times. Military use of Ferrell Lake is manifest in the recent construction of an amphibious landing approach on both sides of the lake and its routine use for amphibious vehicle exercises. This lake thus provides a clear end-member along a continuum of military impacts where the paleolimnological signals are unequivocal.

At the other extreme are remote lakes such as Bass and Fosdick. Both lakes today receive little human disturbance, their watersheds are forested, and from the appearance of their sediments they are not appreciably different what they were prior to European settlement. Both lakes experienced a brief period of increased erosion around the turn of the century, from which they have largely recovered. Present-day sedimentation rates in Bass Lake are virtually indistinguishable from pre-settlement rates and are only slightly elevated above background in Fosdick. Sediment composition is complacent throughout the

Bass Lake core but is highly variable in the Fosdick profile. The large shifts in organic content in the Fosdick core are probably related to periodic desiccation of this shallow basin throughout its history.

The other three lakes, Coon Stump, Mud, and Muskrat, lie somewhere along the continuum from heavy to no impact. Mud and Muskrat lakes are both located in the heavy artillery range of Camp Ripley, and their watersheds are maintained as open fields by periodic burning to prevent artillery shells from igniting forest fires. Muskrat Lake also has an active military road along one shoreline. Nonetheless, there is only weak sedimentary evidence that these activities have appreciably altered conditions within the lakes. Sedimentation rates in Muskrat Lake have increased very gradually over that last 90 years, but sediment composition has not changed, so the exact nature of this trend is difficult to discern. In Mud Lake increasing sedimentation rates are accompanied by higher carbonate and lower inorganic content. As carbonate precipitation is governed both by macrophyte production and groundwater hydrology, the exact cause of this modest trend cannot be determined. The most one can say about these sites is that they have not returned to pre-settlement conditions (as have Bass and Fosdick) because of continuous military impacts in their catchments.

Although the recent increase in sediment accumulation in Coon Stump Lake is more pronounced than that in Mud or Muskrat, its cause is not directly related to military activity, which is minimal in the area. However, there is evidence for recent logging activity within a short distance of the lake shore, and the higher sediment flux and more inorganic sediments after 1950 may signal greater erosion from this source.

Such limited positive response stands in sharp contrast to the long-term rise in sediment accumulation that occurred in all six lakes around the time of settlement. One lake (Ferrell) has sustained obvious recent impacts, two lakes have recovered to conditions approaching those prior to settlement, and three lakes reflect a condition of sustained low-level impact. Nutrient loading and soil erosion from farming and lake-shore development have greatly enhanced sediment accumulation in lakes throughout central Minnesota, and against this background the Camp Ripley lakes are in relatively good shape.

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Figures and Tables

Figure 1. Location of study lakes in the Camp Ripley Military Reservation.

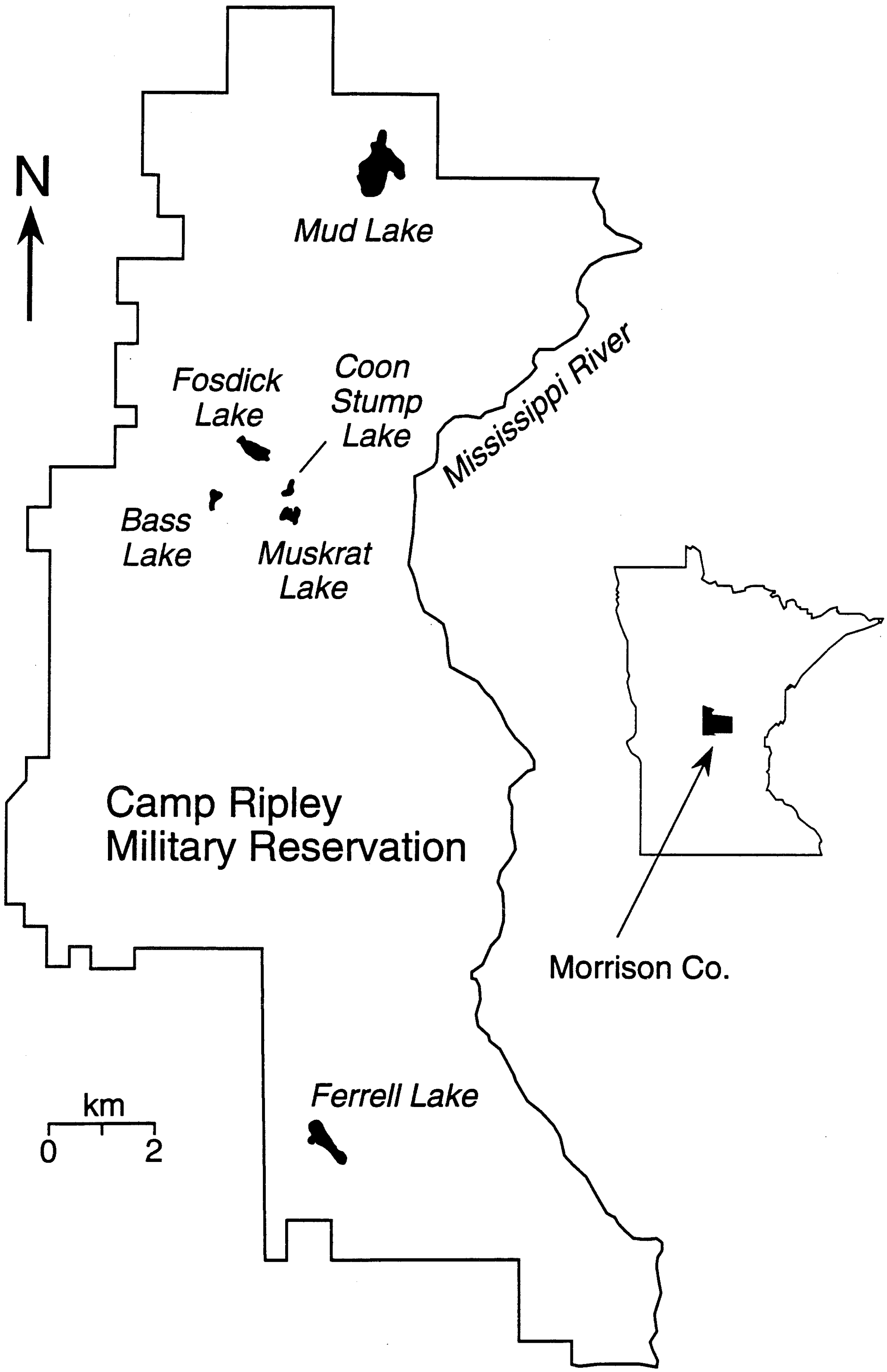
Figure 2. Total ^{210}Pb activity profiles for each of the study lakes; error bars represent ± 1 SD propagated from counting uncertainty.

Figure 3. Age/depth relationships derived from ^{210}Pb dating; error bars as in Figure 2.

Figure 4. Sediment accumulation rates based on ^{210}Pb dating; error bars as in Figure 2.

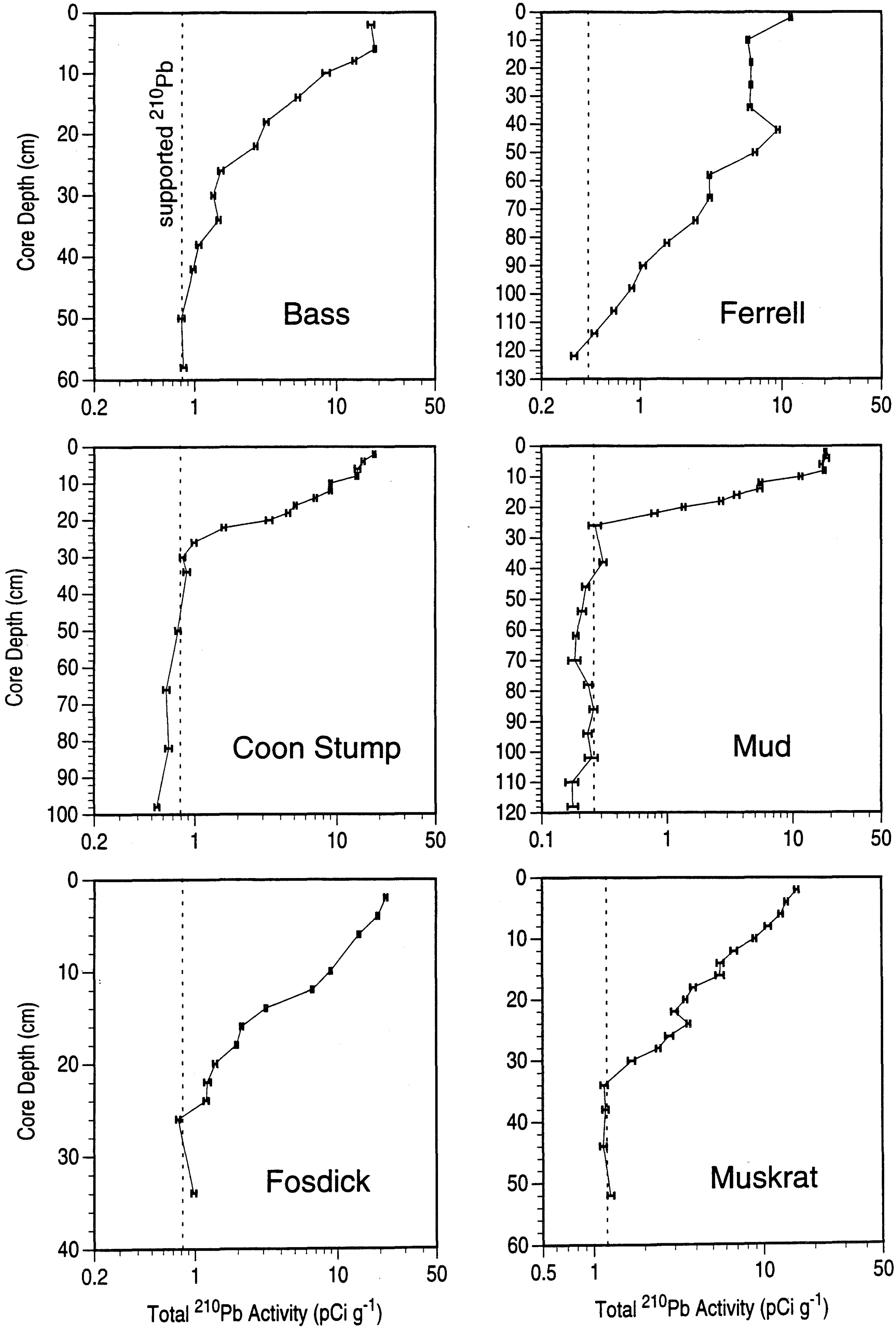
Figure 5. Loss-on-ignition profiles for the six study lakes showing the 1880 settlement horizon and dates marking secondary increases in sediment accumulation.

Fig. 1



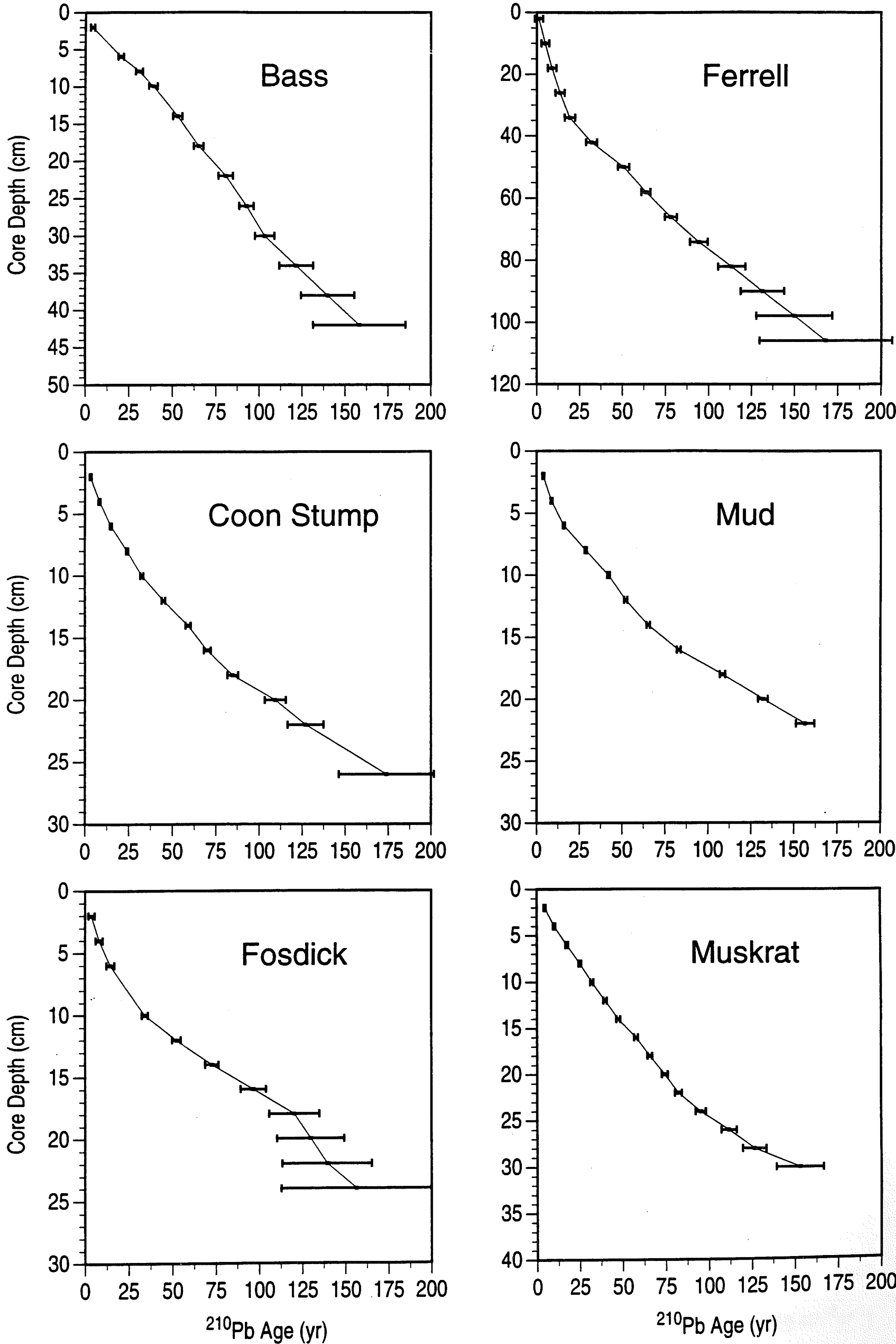
N
Mud Lake
Fosdick Lake
Coon Stump Lake
Mississippi River
Bass Lake
Muskrat Lake
Camp Ripley Military Reservation
Morrison Co.
Ferrell Lake
km
0
2

Fig. 2



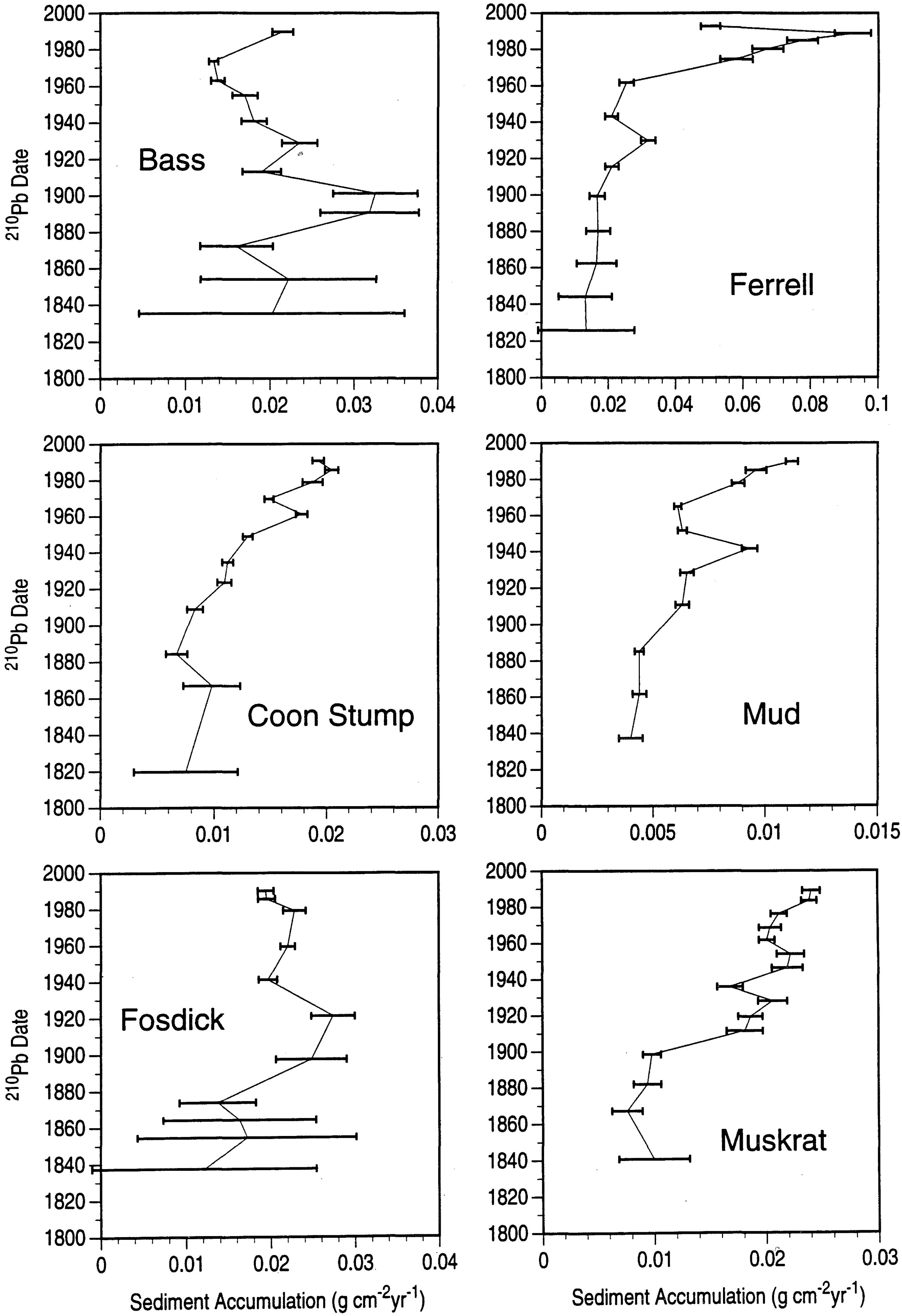
Bass
Ferrell
Coon Stump
Mud
Fosdick
Muskrat
supported ^{210}Pb
Core Depth (cm)
Total ^{210}Pb Activity (pCi g^{-1})

Fig. 3



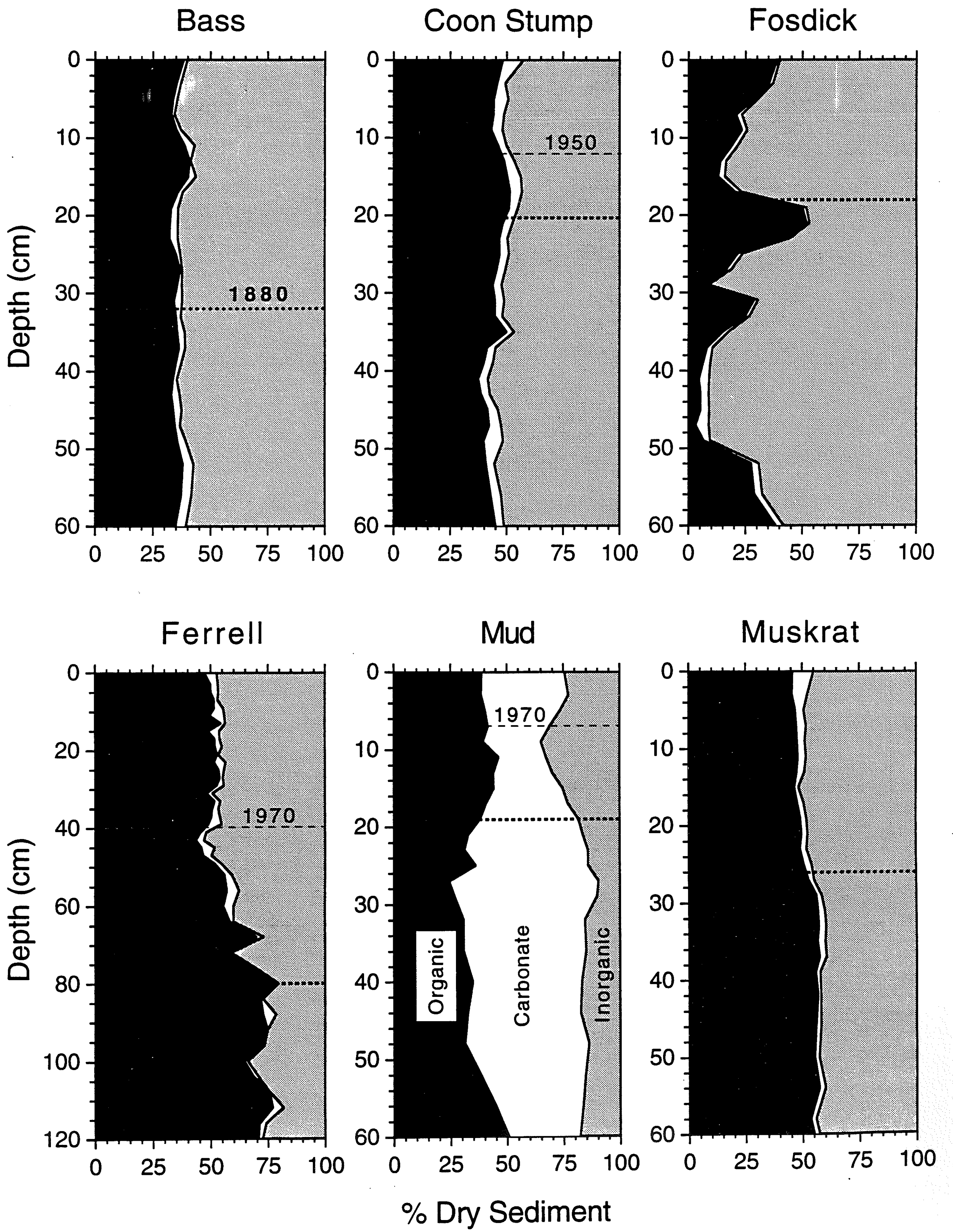
Bass
Ferrell
Coon Stump
Mud
Fosdick
Muskrat
Core Depth (cm)
^{210}Pb Age (yr)
0
25
50
75
100
125
150
175
200

Fig. 4



Bass
Ferrell
Coon Stump
Mud
Fosdick
Muskrat
210Pb Date
2000
1980
1960
1940
1920
1900
1880
1860
1840
1820
1800
0
0.01
0.02
0.03
0.04
0.06
0.08
0.1
0.005
0.015
Sediment Accumulation (g cm-2yr-1)

Fig. 5


Bass
Coon Stump
Fosdick
1880
1950
Ferrell
Mud
Muskrat
1970
1970
Organic
Carbonate
Inorganic
Depth (cm)
Depth (cm)
0
10
20
30
40
50
60
0
20
40
60
80
100
120
0
25
50
75
100
% Dry Sediment

^{210}Pb parameters and sediment-accumulation rates for cores from Camp Ripley.

Lake Site	Cumulative unsup. ^{210}Pb (pCi cm^{-2})	Unsup. ^{210}Pb conc. at surface (pCi g^{-1})	Supported ^{210}Pb (pCi g^{-1})	Number of supported samples	Mean sed. rate before 1880 (g cm^{-2} yr^{-1})	Mean sed. rate since 1910 (g cm^{-2} yr^{-1})	Mean ^{210}Pb flux (pCi cm^{-2} yr^{-1})
Bass	12.31	16.69	0.83	2	0.020	0.018	0.40
Coon Stump	11.59	17.86	0.67	6	0.008	0.015	0.37
Fosdick	13.97	21.24	0.83	2	0.015	0.023	0.45
Ferrell	18.19	11.07	0.39	2	0.015	0.037	0.58
Mud	6.89	18.03	0.18	13	0.004	0.007	0.22
Muskrat	12.19	14.68	1.18	4	0.009	0.022	0.39

Top	Base	Wet (g/cc)	Dry (g/cc)	Dry/Wet	Org/Wet	% Organic	% CaCO3	% Inorg.
0	2	1.0232	0.0451	0.0441	0.0169	38.36	1.51	60.13
2	4	1.0373	0.0639	0.0616	0.0218	35.37	1.78	62.85
4	6	1.0399	0.0668	0.0642	0.0217	33.83	1.70	64.47
6	8	1.0440	0.0727	0.0696	0.0231	33.15	1.25	65.60
8	10	1.0349	0.0675	0.0652	0.0229	35.11	2.02	62.87
10	12	1.0330	0.0576	0.0558	0.0216	38.72	4.34	56.94
12	14	1.0350	0.0597	0.0577	0.0236	40.87	0.38	58.75
14	16	1.0350	0.0621	0.0600	0.0242	40.26	3.30	56.45
16	18	1.0370	0.0675	0.0651	0.0232	35.70	2.02	62.27
18	20	1.0415	0.0759	0.0729	0.0240	32.94	3.00	64.07
20	22	1.0453	0.0826	0.0790	0.0256	32.45	3.30	64.25
22	24	1.0483	0.0859	0.0819	0.0264	32.25	3.44	64.31
24	26	1.0416	0.0804	0.0772	0.0271	35.07	1.70	63.23
26	28	1.0402	0.0790	0.0759	0.0279	36.71	0.86	62.43
28	30	1.0456	0.0850	0.0813	0.0289	35.53	1.87	62.60
30	32	1.0466	0.0889	0.0849	0.0290	34.08	3.58	62.34
32	34	1.0469	0.0881	0.0842	0.0295	35.07	1.81	63.12
34	36	1.0381	0.0879	0.0847	0.0301	35.49	3.10	61.40
36	38	1.0459	0.0885	0.0846	0.0307	36.27	2.57	61.16
38	40	1.0484	0.0907	0.0865	0.0301	34.84	2.26	62.90
40	42	1.0512	0.0981	0.0933	0.0314	33.64	1.62	64.74
42	44	1.0534	0.0976	0.0927	0.0306	32.99	3.49	63.51
44	46	1.0499	0.0981	0.0934	0.0316	33.84	3.48	62.68
46	48	1.0512	0.0961	0.0914	0.0315	34.44	2.13	63.43
48	50	1.0474	0.0964	0.0920	0.0327	35.48	3.77	60.75
50	54	1.0504	0.1008	0.0960	0.0365	38.00	4.51	57.49
54	58	1.0527	0.1116	0.1060	0.0395	37.28	4.28	58.44
58	62	1.0578	0.1228	0.1161	0.0405	34.85	4.26	60.89
62	66	1.0481	0.1099	0.1049	0.0398	37.94	4.14	57.92
66	70	1.0460	0.1002	0.0958	0.0387	40.42	3.40	56.18
70	74	1.0307	0.0746	0.0724	0.0360	49.73	3.35	46.92
74	78	1.0237	0.0628	0.0613	0.0326	53.16	4.28	42.56
78	82	1.0302	0.0821	0.0796	0.0383	48.05	4.15	47.81
82	86	1.0325	0.0872	0.0845	0.0359	42.50	3.38	54.12
86	90	1.0387	0.1030	0.0992	0.0368	37.15	4.97	57.88
90	94	1.0482	0.1291	0.1232	0.0397	32.22	3.41	64.37
94	98	1.0429	0.1140	0.1093	0.0391	35.81	3.59	60.61
98	102	1.0565	0.1498	0.1418	0.0451	31.81	3.24	64.95
102	106	1.0576	0.1538	0.1454	0.0483	33.20	2.80	64.00
106	110	1.0450	0.1194	0.1143	0.0451	39.47	2.68	57.84
110	114	1.0348	0.0922	0.0891	0.0455	51.11	2.13	46.75
114	118	1.0390	0.1027	0.0989	0.0499	50.51	2.59	46.90
118	122	1.0377	0.1016	0.0979	0.0452	46.17	3.60	50.23

Top	Base	Wet (g/cc)	Dry (g/cc)	Dry/Wet	Org/Wet	% Organic	% CaCO3	% Inorg.
0	2	1.0117	0.0300	0.0297	0.0143	48.18	9.01	42.81
2	4	1.0195	0.0531	0.0521	0.0239	45.81	3.39	50.80
4	6	1.0227	0.0619	0.0605	0.0269	44.41	6.18	49.42
6	8	1.0260	0.0691	0.0674	0.0297	44.14	4.55	51.31
8	10	1.0286	0.0751	0.0731	0.0315	43.18	4.77	52.05
10	12	1.0299	0.0798	0.0774	0.0357	46.04	3.66	50.30
12	14	1.0301	0.0799	0.0776	0.0380	48.95	4.49	46.56
14	16	1.0222	0.0600	0.0587	0.0295	50.25	5.99	43.76
16	18	1.0233	0.0619	0.0604	0.0311	51.53	5.13	43.34
18	20	1.0310	0.0815	0.0790	0.0404	51.19	3.86	44.95
20	22	1.0325	0.0860	0.0833	0.0403	48.42	4.08	47.50
22	24	1.0385	0.1027	0.0989	0.0463	46.83	3.50	49.67
24	26	1.0362	0.0966	0.0933	0.0438	46.97	4.09	48.95
26	28	1.0365	0.0980	0.0946	0.0430	45.52	3.82	50.66
28	30	1.0354	0.0957	0.0924	0.0406	43.88	3.83	52.29
30	32	1.0347	0.0917	0.0886	0.0398	44.87	3.98	51.15
32	34	1.0327	0.0879	0.0851	0.0383	44.96	3.07	51.96
34	36	1.0369	0.0983	0.0948	0.0474	49.94	3.32	46.74
36	38	1.0341	0.0910	0.0880	0.0365	41.44	3.61	54.94
38	40	1.0362	0.0980	0.0946	0.0377	39.82	4.02	56.15
40	42	1.0402	0.1065	0.1024	0.0384	37.45	4.11	58.44
42	44	1.0381	0.1028	0.0991	0.0382	38.60	3.86	57.54
44	46	1.0354	0.0935	0.0903	0.0376	41.64	4.46	53.90
46	48	1.0355	0.0937	0.0905	0.0383	42.30	5.19	52.51
48	50	1.0362	0.0954	0.0920	0.0367	39.91	8.46	51.63
50	54	1.0369	0.0990	0.0955	0.0390	40.85	3.72	55.43
54	58	1.0396	0.1059	0.1019	0.0439	43.07	4.37	52.56
58	62	1.0357	0.0960	0.0927	0.0418	45.07	3.61	51.32
62	66	1.0326	0.0880	0.0852	0.0444	52.04	4.22	43.74
66	70	1.0352	0.0930	0.0899	0.0451	50.23	3.46	46.30
70	74	1.0387	0.1043	0.1004	0.0450	44.87	3.04	52.10
74	78	1.0413	0.1091	0.1047	0.0457	43.62	3.37	53.01
78	82	1.0473	0.1266	0.1208	0.0487	40.33	3.55	56.12
82	86	1.0490	0.1306	0.1245	0.0453	36.37	3.04	60.59
86	90	1.0684	0.1817	0.1701	0.0562	33.02	3.46	63.52
90	94	1.0740	0.1964	0.1828	0.0589	32.22	3.01	64.77
94	98	1.0847	0.2252	0.2076	0.0614	29.59	3.21	67.20
98	102	1.0718	0.1931	0.1802	0.0636	35.30	3.39	61.30
102	106	1.0782	0.2099	0.1947	0.0634	32.55	3.08	64.37

Top	Base	Wet (g/cc)	Dry (g/cc)	Dry/Wet	Org/Wet	% Organic	% CaCO3	% Inorg.
0	2	1.0306	0.0356	0.0345	0.0134	38.76	1.28	59.96
2	4	1.0306	0.0429	0.0416	0.0147	35.43	1.59	62.98
4	6	1.0396	0.0738	0.0710	0.0206	29.00	1.54	69.46
6	8	1.0950	0.1525	0.1393	0.0291	20.92	2.39	76.70
8	10	1.0828	0.1234	0.1140	0.0266	23.34	2.21	74.45
10	12	1.1091	0.1782	0.1607	0.0306	19.02	2.55	78.42
12	14	1.1647	0.2777	0.2384	0.0332	13.94	2.46	83.61
14	16	1.1781	0.2957	0.2510	0.0327	13.02	2.92	84.06
16	18	1.0853	0.1618	0.1491	0.0305	20.46	2.81	76.73
18	20	1.0294	0.0779	0.0757	0.0378	49.92	1.84	48.24
20	22	1.0583	0.0830	0.0784	0.0406	51.81	1.32	46.87
22	24	1.0746	0.1035	0.0963	0.0413	42.84	1.59	55.57
24	26	1.0734	0.1686	0.1570	0.0338	21.52	2.28	76.21
26	28	1.1086	0.2271	0.2049	0.0337	16.45	2.29	81.26
28	30	1.2905	0.5081	0.3937	0.0272	6.90	1.94	91.16
30	32	1.0288	0.1247	0.1212	0.0347	28.60	1.76	69.64
32	34	1.0884	0.1758	0.1615	0.0400	24.74	1.87	73.39
34	36	1.1341	0.2647	0.2334	0.0351	15.02	2.69	82.29
36	38	1.3659	0.6440	0.4715	0.0382	8.10	2.47	89.43
38	40	1.3335	0.5984	0.4488	0.0283	6.30	3.20	90.49
40	42	1.4507	0.7830	0.5397	0.0247	4.57	4.48	90.95
42	44	1.3741	0.6722	0.4892	0.0257	5.25	3.55	91.20
44	46	1.2737	0.5597	0.4394	0.0232	5.29	3.66	91.05
46	48	1.6355	1.0111	0.6182	0.0184	2.98	5.87	91.15
48	51	1.3484	0.6007	0.4455	0.0292	6.56	2.80	90.64
51	54	1.0451	0.1482	0.1418	0.0390	27.48	3.33	69.19
54	58	1.0673	0.1659	0.1554	0.0450	28.98	3.47	67.56
58	62	1.0264	0.1278	0.1245	0.0477	38.27	3.43	58.30
62	66	1.0469	0.1566	0.1496	0.0411	27.46	3.15	69.39
66	70	1.0616	0.1755	0.1654	0.0421	25.46	2.65	71.88
70	74	1.0925	0.2222	0.2034	0.0431	21.20	3.33	75.47
74	78	1.0357	0.1404	0.1355	0.0498	36.74	3.51	59.75
78	82	1.0436	0.1437	0.1377	0.0508	36.88	3.81	59.31
82	86	1.0586	0.1672	0.1580	0.0509	32.20	3.77	64.03
86	90	1.0558	0.1673	0.1585	0.0517	32.61	3.11	64.28
90	94	1.0487	0.1599	0.1525	0.0497	32.63	3.60	63.77
94	98	1.0571	0.1482	0.1402	0.0524	37.40	3.33	59.27
98	102	1.0367	0.1431	0.1381	0.0545	39.48	2.87	57.65
102	106	1.0639	0.1676	0.1575	0.0536	34.00	2.94	63.05
106	110	1.0946	0.2216	0.2024	0.0487	24.03	2.60	73.37
110	114	1.0808	0.2347	0.2171	0.0458	21.10	2.57	76.33
114	118	1.0624	0.1620	0.1525	0.0552	36.21	3.21	60.58
118	122	1.0728	0.1802	0.1680	0.0517	30.75	3.65	65.60

Top	Base	Wet (g/cc)	Dry (g/cc)	Dry/Wet	Org/Wet	% Organic	% CaCO3	% Inorg.
0	2	1.0187	0.0304	0.0298	0.0141	47.37	5.24	47.40
2	4	1.0223	0.0353	0.0345	0.0172	49.86	3.22	46.92
4	6	1.0194	0.0295	0.0289	0.0145	50.17	3.08	46.75
6	8	1.0170	0.0307	0.0302	0.0155	51.47	1.48	47.05
8	10	1.0187	0.0363	0.0356	0.0184	51.52	3.76	44.73
10	12	1.0200	0.0363	0.0356	0.0176	49.59	6.26	44.15
12	14	1.0178	0.0343	0.0337	0.0183	54.23	1.99	43.78
14	16	1.0235	0.0343	0.0335	0.0164	48.98	4.64	46.38
16	18	1.0230	0.0438	0.0428	0.0221	51.60	2.08	46.33
18	20	1.0202	0.0378	0.0371	0.0192	51.85	3.01	45.14
20	22	1.0200	0.0374	0.0367	0.0193	52.67	0.61	46.72
22	24	1.0210	0.0375	0.0367	0.0189	51.47	*4.85*	43.68
24	26	1.0217	0.0404	0.0395	0.0211	53.47	2.25	44.28
26	28	1.0198	0.0393	0.0385	0.0208	53.94	1.16	44.90
28	30	1.0208	0.0425	0.0416	0.0218	52.47	3.21	44.32
30	32	1.0267	0.0493	0.0480	0.0232	48.28	2.31	49.42
32	34	1.0265	0.0451	0.0439	0.0227	51.66	2.52	45.82
34	36	1.0225	0.0431	0.0422	0.0213	50.58	2.64	46.78
36	38	1.0238	0.0376	0.0367	0.0185	50.27	3.63	46.11
38	40	1.0247	0.0469	0.0458	0.0223	48.83	5.82	45.35
40	42	1.0259	0.0595	0.0580	0.0263	45.38	2.68	51.95
42	44	1.0309	0.0606	0.0588	0.0256	43.56	3.38	53.06
44	46	1.0291	0.0584	0.0567	0.0260	45.89	5.84	48.27
46	48	1.0299	0.0526	0.0511	0.0239	46.77	3.46	49.77
48	50	1.0249	0.0483	0.0471	0.0244	51.76	2.82	45.42
50	54	1.0200	0.0434	0.0425	0.0238	55.99	3.14	40.87
54	58	1.0209	0.0436	0.0427	0.0244	57.11	5.22	37.67
58	62	1.0262	0.0432	0.0421	0.0234	55.56	4.21	40.23
62	66	1.0246	0.0417	0.0407	0.0237	58.27	1.64	40.09
66	70	1.0183	0.0363	0.0356	0.0249	69.97	3.13	26.90
70	74	1.0232	0.0338	0.0330	0.0191	57.69	1.35	40.96
74	78	1.0161	0.0420	0.0413	0.0278	67.41	2.16	30.44
78	82	1.0156	0.0425	0.0419	0.0330	78.81	0.64	20.54
82	86	1.0128	0.0352	0.0347	0.0249	71.85	0.84	27.31
86	90	1.0123	0.0344	0.0340	0.0248	72.91	5.44	21.66
90	94	1.0136	0.0375	0.0370	0.0277	74.83	0.00	25.17
94	98	1.0116	0.0309	0.0305	0.0221	72.43	0.94	26.64
98	102	1.0135	0.0347	0.0343	0.0221	64.48	1.57	33.95
102	106	1.0106	0.0300	0.0297	0.0204	68.66	2.10	29.24
106	110	1.0108	0.0298	0.0295	0.0223	75.66	0.00	24.34
110	114	1.0125	0.0322	0.0318	0.0245	76.95	4.68	18.37
114	118	1.0122	0.0331	0.0327	0.0233	71.31	2.80	25.89
118	122	1.0135	0.0370	0.0365	0.0258	70.80	1.66	27.54
122	126	1.0183	0.0485	0.0476	0.0247	51.80	1.76	46.44
126	130	1.0132	0.0338	0.0333	0.0230	68.94	3.45	27.62

Top	Base	Wet (g/cc)	Dry (g/cc)	Dry/Wet	Org/Wet	% Organic	% CaCO3	% Inorg.
0	2	1.0198	0.0224	0.0220	0.0085	38.84	36.55	24.61
2	4	1.0230	0.0230	0.0225	0.0087	38.70	38.56	22.75
4	6	1.0240	0.0317	0.0310	0.0125	40.38	33.00	26.62
6	8	1.0335	0.0390	0.0377	0.0157	41.54	27.40	31.06
8	10	1.0332	0.0425	0.0411	0.0162	39.29	25.68	35.02
10	12	1.0257	0.0463	0.0451	0.0209	46.22	21.12	32.66
12	14	1.0355	0.0429	0.0414	0.0183	44.06	25.97	29.97
14	16	1.0352	0.0561	0.0542	0.0240	44.21	30.40	25.39
16	18	1.0343	0.0565	0.0546	0.0222	40.71	36.22	23.07
18	20	1.0249	0.0518	0.0505	0.0192	38.03	43.46	18.51
20	22	1.0270	0.0485	0.0472	0.0155	32.78	50.64	16.58
22	24	1.0340	0.0435	0.0421	0.0132	31.26	54.37	14.37
24	26	1.0298	0.0425	0.0413	0.0149	36.00	49.76	14.24
26	28	1.0447	0.0657	0.0629	0.0153	24.35	66.11	9.54
28	30	1.0430	0.0622	0.0596	0.0160	26.85	62.88	10.27
30	34	1.0374	0.0583	0.0562	0.0174	30.87	53.44	15.69
34	38	1.0443	0.0649	0.0621	0.0192	30.82	53.96	15.22
38	42	1.0392	0.0639	0.0615	0.0215	34.90	48.04	17.06
42	46	1.0428	0.0694	0.0666	0.0217	32.56	49.81	17.63
46	50	1.0473	0.0801	0.0765	0.0240	31.34	54.79	13.87
50	54	1.0387	0.0704	0.0678	0.0260	38.35	46.19	15.46
54	58	1.0362	0.0585	0.0565	0.0254	44.96	38.48	16.56
58	62	1.0295	0.0594	0.0577	0.0292	50.67	31.39	17.93
62	66	1.0363	0.0622	0.0600	0.0289	48.23	35.46	16.31
66	70	1.0316	0.0564	0.0547	0.0312	57.09	24.19	18.72
70	74	1.0274	0.0524	0.0510	0.0317	62.21	18.66	19.13
74	78	1.0235	0.0540	0.0528	0.0322	61.11	17.27	21.62
78	82	1.0264	0.0482	0.0470	0.0325	69.29	6.13	24.57
82	86	1.0857	0.0475	0.0438	0.0307	70.11	6.22	23.67
86	90	1.0284	0.0495	0.0481	0.0307	63.84	16.54	19.62
90	94	1.0283	0.0545	0.0530	0.0319	60.18	14.19	25.63
94	98	1.0227	0.0471	0.0461	0.0296	64.33	11.59	24.08
98	102	1.0245	0.0539	0.0526	0.0304	57.70	17.72	24.58
102	106	1.0405	0.0708	0.0680	0.0303	44.49	35.01	20.50
106	110	1.0339	0.0657	0.0635	0.0330	51.90	24.92	23.18
110	114	1.0240	0.0614	0.0600	0.0244	40.72	54.44	4.84
114	118	1.0278	0.0739	0.0719	0.0374	52.00	23.88	24.12
118	122	1.0398	0.1055	0.1015	0.0346	34.11	48.54	17.35
122	126	1.0490	0.1309	0.1248	0.0320	25.68	64.18	10.14
126	130	1.0448	0.1202	0.1151	0.0351	30.50	53.35	16.15
130	134	1.0572	0.1535	0.1452	0.0322	22.16	63.48	14.36

Top	Base	Wet (g/cc)	Dry (g/cc)	Dry/Wet	Org/Wet	% Organic	% CaCO3	% Inorg.
0	2	1.0250	0.0562	0.0548	0.0251	45.73	9.31	44.96
2	4	1.0288	0.0660	0.0642	0.0293	45.61	6.55	47.85
4	6	1.0315	0.0774	0.0750	0.0353	47.03	3.53	49.45
6	8	1.0357	0.0788	0.0761	0.0362	47.59	4.04	48.37
8	10	1.0344	0.0695	0.0672	0.0322	47.91	3.27	48.81
10	12	1.0376	0.0863	0.0832	0.0401	48.20	3.43	48.37
12	14	1.0358	0.0834	0.0805	0.0384	47.72	3.27	49.01
14	16	1.0360	0.0872	0.0842	0.0392	46.56	1.83	51.61
16	18	1.0431	0.0824	0.0790	0.0379	47.94	2.76	49.30
18	20	1.0303	0.0798	0.0775	0.0381	49.25	2.56	48.19
20	22	1.0299	0.0721	0.0700	0.0349	49.79	2.52	47.68
22	24	1.0278	0.0632	0.0615	0.0302	49.05	2.88	48.07
24	26	1.0371	0.0778	0.0750	0.0380	50.64	3.51	45.85
26	28	1.0227	0.0560	0.0548	0.0288	52.68	2.44	44.88
28	30	1.0498	0.1326	0.1264	0.0711	56.26	2.23	41.51
30	32	1.0594	0.1577	0.1488	0.0848	56.95	2.91	40.14
32	34	1.0536	0.1419	0.1347	0.0771	57.28	3.13	39.58
34	36	1.0529	0.1424	0.1352	0.0767	56.75	3.26	39.99
36	38	1.0589	0.1570	0.1483	0.0855	57.66	2.94	39.41
38	40	1.0649	0.1716	0.1611	0.0901	55.92	1.91	42.17
40	44	1.0704	0.1885	0.1761	0.1001	56.84	1.28	41.88
44	48	1.0739	0.1970	0.1835	0.1028	56.00	2.17	41.83
48	52	1.0764	0.2027	0.1883	0.1041	55.27	1.89	42.84
52	56	1.0759	0.2011	0.1869	0.1073	57.41	2.52	40.07
56	60	1.0839	0.2234	0.2061	0.1103	53.54	2.36	44.09
60	64	1.0861	0.2279	0.2098	0.1185	56.46	2.46	41.08
64	68	1.0815	0.2158	0.1995	0.1157	57.97	2.23	39.80
68	72	1.0623	0.1676	0.1577	0.1027	65.10	1.66	33.24
72	76	1.0674	0.1782	0.1669	0.0928	55.61	2.18	42.20

Top of Interval (cm)	Base of Interval (cm)	Cum. Dry Mass (g/cm2)	Unsup. Activity (pCi/g)	Error of Unsup. Act. (±s.d.)	Cum. Act. below Int. (pCi/cm2)	Age: Base of Int. (yr)	Error of Age (±s.d.)	Date A.D.	Sediment Accum. (g/cm2 yr)	Error of Sed. Accum. (±s.d.)
0	2	0.0902	16.6869	0.9114	10.8080	4.19	1.18	1989.6	0.0215	0.00123
4	6	0.3357	17.8206	0.4002	6.4975	20.53	1.60	1973.2	0.0133	0.00055
6	8	0.4811	12.5296	0.4300	4.6757	31.09	2.03	1962.7	0.0138	0.00080
8	10	0.6161	7.6062	0.5121	3.6489	39.06	2.45	1954.7	0.0170	0.00149
12	14	0.8627	4.5121	0.1942	2.3619	53.03	2.70	1940.7	0.0181	0.00149
16	18	1.1249	2.3602	0.1202	1.6238	65.06	2.81	1928.7	0.0235	0.00211
20	22	1.4402	1.8736	0.0803	0.9981	80.69	4.27	1913.1	0.0190	0.00229
24	26	1.7640	0.7099	0.0750	0.6866	92.70	4.21	1901.1	0.0325	0.00502
28	30	2.0994	0.5269	0.0522	0.4952	103.19	5.66	1890.6	0.0318	0.00587
32	34	2.4487	0.6501	0.0613	0.2791	121.61	9.77	1872.2	0.0160	0.00430
36	38	2.8023	0.2510	0.0558	0.1579	139.90	15.48	1853.9	0.0222	0.01043
40	42	3.1851	0.1587	0.0499	0.0888	158.38	26.93	1835.4	0.0203	0.01572

Supported Pb-210: 0.827 ± 0.0316 pCi/g

Number of Supported Samples: 2

Cum. Unsup. Pb-210: 12.3132 pCi/cm2

Unsup. Pb-210 Flux: 0.3973 pCi/cm2 yr

Coon-Stump Lake, Camp Ripley, MN: Coring Date: 10/11/1993

Top of Interval (cm)	Base of Interval (cm)	Cum. Dry Mass (g/cm2)	Unsup. Activity (pCi/g)	Error of Unsup. Act. (±s.d.)	Cum. Act. below Int. (pCi/cm2)	Age: Base of Int. (yr)	Error of Age (±s.d.)	Date A.D.	Sediment Accum. (g/cm2 yr)	Error of Sed. Accum. (±s.d.)
0	2	0.0600	17.8614	0.4270	10.5164	3.12	0.60	1990.7	0.0193	0.00051
2	4	0.1662	14.7205	0.4095	8.9526	8.29	0.64	1985.5	0.0205	0.00060
4	6	0.2899	13.4351	0.6733	7.2905	14.88	0.63	1978.9	0.0188	0.00089
6	8	0.4281	13.2575	0.3310	5.4583	24.18	0.71	1969.6	0.0149	0.00040
8	10	0.5784	8.3879	0.2046	4.1976	32.61	0.83	1961.2	0.0178	0.00052
10	12	0.7379	8.3733	0.2138	2.8618	44.91	1.07	1948.9	0.0130	0.00043
12	14	0.8977	6.4073	0.1909	1.8379	59.13	1.51	1934.6	0.0112	0.00049
14	16	1.0178	4.4462	0.1373	1.3040	70.15	2.05	1923.6	0.0109	0.00064
16	18	1.1415	3.8962	0.1602	0.8220	84.97	3.12	1908.8	0.0083	0.00070
18	20	1.3044	2.6866	0.1859	0.3843	109.39	6.12	1884.4	0.0067	0.00095
20	22	1.4765	0.9394	0.0796	0.2227	126.91	10.37	1866.9	0.0098	0.00252
24	26	1.8525	0.3243	0.0661	0.0513	174.05	27.75	1819.7	0.0075	0.00458

Supported Pb-210: 0.6668 ± 0.0536 pCi/g

Number of Supported Samples: 6

Cum. Unsup. Pb-210: 11.5881 pCi/cm2

Unsup. Pb-210 Flux: 0.3706 pCi/cm2 yr

Top of Interval (cm)	Base of Interval (cm)	Cum. Dry Mass (g/cm2)	Unsup. Activity (pCi/g)	Error of Unsup. Act. (±s.d.)	Cum. Act. below Int. (pCi/cm2)	Age: Base of Int. (yr)	Error of Age (±s.d.)	Date A.D.	Sediment Accum. (g/cm2 yr)	Error of Sed. Accum. (±s.d.)
0	2	0.0712	21.2443	0.5788	12.4601	3.68	1.83	1990.1	0.0194	0.00093
2	4	0.1570	18.5533	0.4740	10.8682	8.07	1.99	1985.7	0.0195	0.00100
4	6	0.3046	13.4197	0.3583	8.8875	14.53	2.26	1979.2	0.0228	0.00134
8	10	0.7486	8.1520	0.1902	4.8083	34.26	1.77	1959.5	0.0220	0.00086
10	12	1.1050	5.8082	0.1660	2.7383	52.34	2.46	1941.4	0.0197	0.00109
12	14	1.6604	2.3070	0.1197	1.4570	72.60	3.92	1921.2	0.0274	0.00258
14	16	2.2518	1.2903	0.1160	0.6939	96.42	7.25	1897.4	0.0248	0.00420
16	18	2.5754	1.1189	0.1116	0.3318	120.11	14.57	1873.7	0.0137	0.00449
18	20	2.7312	0.5482	0.1135	0.2464	129.67	19.46	1864.1	0.0163	0.00901
20	22	2.8972	0.3849	0.1221	0.1825	139.31	26.00	1854.5	0.0172	0.01291
22	24	3.1042	0.3629	0.1146	0.1074	156.34	43.58	1837.4	0.0122	0.01319

Supported Pb-210: 0.8306 ± 0.1034 pCi/g

Number of Supported Samples: 2

Cum. Unsup. Pb-210: 13.9727 pCi/cm2

Unsup. Pb-210 Flux: 0.4468 pCi/cm2 yr

Ferrell Lake, Camp Ripley, MN: Coring Date: 10/11/1993

Top of Interval (cm)	Base of Interval (cm)	Cum. Dry Mass (g/cm2)	Unsup. Activity (pCi/g)	Error of Unsup. Act. (±s.d.)	Cum. Act. below Int. (pCi/cm2)	Age: Base of Int. (yr)	Error of Age (±s.d.)	Date A.D.	Sediment Accum. (g/cm2 yr)	Error of Sed. Accum. (±s.d.)
0	2	0.0608	11.0716	0.2621	17.5181	1.21	2.40	1992.6	0.0502	0.00290
8	10	0.3335	5.3211	0.1661	15.5909	4.95	2.31	1988.8	0.0924	0.00536
16	18	0.6614	5.6357	0.1269	13.7815	8.92	2.46	1984.9	0.0775	0.00461
24	26	0.9948	5.6196	0.1524	11.9059	13.61	2.67	1980.2	0.0672	0.00464
32	34	1.3415	5.5053	0.1918	9.9826	19.27	2.99	1974.5	0.0579	0.00480
40	42	1.7743	8.9201	0.2868	6.7187	31.99	3.21	1961.8	0.0253	0.00215
48	50	2.1943	6.0273	0.2279	3.7629	50.60	3.33	1943.2	0.0209	0.00190
54	58	2.5525	2.6789	0.1083	2.5076	63.64	2.59	1930.1	0.0318	0.00216
62	66	2.8899	2.6964	0.1256	1.5993	78.08	3.49	1915.7	0.0210	0.00198
70	74	3.1761	2.0574	0.1032	0.9650	94.30	5.08	1899.5	0.0166	0.00231
78	82	3.4990	1.1532	0.0881	0.5315	113.46	7.80	1880.3	0.0169	0.00361
86	90	3.7904	0.6593	0.0828	0.3050	131.29	12.66	1862.5	0.0164	0.00593
94	98	4.0444	0.4775	0.0741	0.1724	149.61	22.02	1844.2	0.0131	0.00795
102	106	4.2860	0.2599	0.0711	0.0973	167.98	38.50	1825.8	0.0134	0.01435

Supported Pb-210: 0.3916 ± 0.066 pCi/g
Number of Supported Samples: 2

Cum. Unsup. Pb-210: 18.1913 pCi/cm2
Unsup. Pb-210 Flux: 0.5797 pCi/cm2 yr

Mud Lake, Camp Ripley, MN: Coring Date: 10/12/1993

Top of Interval (cm)	Base of Interval (cm)	Cum. Dry Mass (g/cm2)	Unsup. Activity (pCi/g)	Error of Unsup. Act. (±s.d.)	Cum. Act. below Int. (pCi/cm2)	Age: Base of Int. (yr)	Error of Age (±s.d.)	Date A.D.	Sediment Accum. (g/cm2 yr)	Error of Sed. Accum. (±s.d.)
0	2	0.0448	18.0294	0.3975	6.0797	4.01	0.59	1989.8	0.0112	0.00027
2	4	0.0908	18.2892	0.9396	5.2384	8.79	0.58	1985.0	0.0096	0.00047
4	6	0.1542	16.6025	0.5285	4.1858	15.99	0.61	1977.8	0.0088	0.00028
6	8	0.2322	17.5695	0.4530	2.8154	28.73	0.70	1965.0	0.0061	0.00016
8	10	0.3172	11.3043	0.3826	1.8545	42.13	0.77	1951.6	0.0063	0.00020
10	12	0.4098	5.3517	0.1895	1.3589	52.12	0.90	1941.7	0.0093	0.00035
12	14	0.4956	5.3091	0.2583	0.9034	65.23	1.00	1928.5	0.0065	0.00030
14	16	0.6078	3.4141	0.1777	0.5203	82.95	1.10	1910.8	0.0063	0.00030
16	18	0.7208	2.5227	0.1065	0.2352	108.45	1.62	1885.3	0.0044	0.00020
18	20	0.8244	1.1808	0.0525	0.1129	132.01	2.92	1861.8	0.0044	0.00031
20	22	0.9214	0.6195	0.0500	0.0528	156.42	5.46	1837.4	0.0040	0.00053

Supported Pb-210: 0.1814 ± 0.0172 pCi/g

Number of Supported Samples: 13

Cum. Unsup. Pb-210: 6.8874 pCi/cm2

Unsup. Pb-210 Flux: 0.2187 pCi/cm2 yr

Muskrat Lake, Camp Ripley, MN: Coring Date: 10/12/1993

Top of Interval (cm)	Base of Interval (cm)	Cum. Dry Mass (g/cm2)	Unsup. Activity (pCi/g)	Error of Unsup. Act. (±s.d.)	Cum. Act. below Int. (pCi/cm2)	Age: Base of Int. (yr)	Error of Age (±s.d.)	Date A.D.	Sediment Accum. (g/cm2 yr)	Error of Sed. Accum. (±s.d.)
0	2	0.1124	14.6823	0.4690	10.5382	4.67	0.65	1989.1	0.0241	0.00079
2	4	0.2444	12.5986	0.3364	8.8752	10.19	0.70	1983.6	0.0239	0.00069
4	6	0.3992	11.6361	0.3767	7.0739	17.47	0.77	1976.3	0.0212	0.00072
6	8	0.5568	9.5768	0.4764	5.5646	25.18	0.80	1968.6	0.0204	0.00098
8	10	0.6958	7.7680	0.2265	4.4848	32.11	0.92	1961.7	0.0201	0.00070
10	12	0.8684	5.5944	0.3039	3.5192	39.89	1.01	1953.9	0.0222	0.00121
12	14	1.0352	4.4472	0.2787	2.7774	47.49	1.11	1946.3	0.0219	0.00137
14	16	1.2096	4.3958	0.3151	2.0108	57.87	1.18	1935.9	0.0168	0.00114
16	18	1.3744	2.6884	0.1569	1.5678	65.86	1.38	1927.9	0.0206	0.00130
18	20	1.5340	2.3044	0.0985	1.2000	74.44	1.71	1919.3	0.0186	0.00109
20	22	1.6782	1.8264	0.1446	0.9366	82.40	2.04	1911.4	0.0181	0.00161
22	24	1.8046	2.4479	0.0996	0.6272	95.28	2.94	1898.5	0.0098	0.00080
24	26	1.9602	1.6201	0.1581	0.3751	111.79	4.40	1882.0	0.0094	0.00123
26	28	2.0722	1.2337	0.0845	0.2369	126.54	6.83	1867.2	0.0076	0.00136
28	30	2.3375	0.5019	0.0900	0.1037	153.07	13.71	1840.7	0.0100	0.00315

Supported Pb-210: 1.1805 ± 0.0364 pCi/g

Number of Supported Samples: 4

Cum. Unsup. Pb-210: 12.1885 pCi/cm2

Unsup. Pb-210 Flux: 0.3936 pCi/cm2 yr