Effects of Zebra Mussel, *Dreissena polymorpha*, Infestation on Lake Dardanelle Water Quality

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ABSTRACT: Zebra mussels recently invaded southern waterways including the Arkansas River. Exponential population growth and high filtration capacity of dense populations could alter reservoir ecosystem function. Furthermore, they attach to hard surfaces; thus, threatening normal operations of many artificial structures. We designed this study to provide baseline data prior to high population levels of zebra mussels in Lake Dardanelle. The characterization of spatial and temporal variability in water quality, zooplankton, phytoplankton, and macrophytes will allow testing of several hypotheses. We sampled zebra mussel density and zooplankton at four fixed sites and the other key variables at three of these sites biweekly from August 1994 through June 1995. Turbidity was high, averaging 22.5 NTU and Secchi disk depths were typically less than 0.8 m. The main lake had the highest average turbidity and the Illinois Bayou bay of the lake had the lowest (29.0 and 16.4 NTU, respectively). Chlorophyll a was the dominant chlorophyll type (mean of 15.8 ug/L) and it was lowest in winter (< 8 ug/L) when water temperatures and solar infiltration were the lowest. Turbidity was high during this period due to above average flows and higher loading of sediments. Total suspended solids were also high (mean of 16.7 mg/L) and followed the same pattern as turbidity. Concentrations of major ions increased during fall and declined sharply in early winter. In the bay areas, these ions were somewhat diluted by tributary flow compared to those in the main lake (e.g., conductivity was 318 verses 420 uS/cm, respectively). Rotifers numerically dominated the zooplankton community. Their density was similar among sites and often exceeded 40/L. Mean density of larval zebra mussels in 1993 remained less than 0.1/L; whereas, in 1994 density was over 10/L for much of the summer and exceeded 50/L on two sampling dates. The 1995 summer peak in larval zebra mussel density may still be in progress and our most recent samples analyzed (July 9) document a mean density exceeding 32/L. We found only 2.5 to 37.5% coverage of emergent vegetation (especially water willow) in shoreline sample areas and no submergent vegetation. Increased light penetration (resulting from high filtration rates) could allow dense beds of emergent and submergent vegetation, which could drastically influence fish population dynamics and negatively impact boating. The study will be continued to test this and related hypotheses.

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ACKNOWLEDGEMENTS: We appreciate the assistance of ATU students Jeffrey Herod, Shannon Shook, Coburn Howell, and Jason Phillips in the collection of field samples, entry of data, and preparation of this report. Portions of this project were funded by the U.S. Department of the Interior, Entergy Operations, Inc., and Arkansas Tech University.

INTRODUCTION

The zebra mussel, Dreissena polymorpha, was discovered in September 1992 in Lake Dardanelle, a 13,800 hectare impoundment on the Arkansas River. It could have a marked impact on the water quality and ecology of the reservoir. Based on samples we have collected, the zebra mussel population is increasing dramatically; densities of zebra mussel larvae (veligers) in our samples increased one-hundred-fold from 1993 to 1994. During the first half of 1995, veliger densities have been intermediate between the previous two years. We are beginning to see an increase in the density of settling juveniles and expect to see a significant increase in the adult population within the next few years.

In western Lake Erie, adult zebra mussels increased 325% between 1988 and 1990, and the population of juvenile mussels increased greater than 900% (Leach 1993). Adults larger than 10 mm in length reached a mean density of 18,457/m2 on reefs. Assuming an average filtration rate of 100 mL/h for typical (10 mm) zebra mussels (Kryger and Riisgard 1988), a population density of 18,457/m2 would filter 1.8 m^3 of lake water per hour. Filtration rates this high would result in the filtration of the entire volume of a shallow reservoir like Lake Dardanelle over 20 times per day. No ordinary lake community could exist in a lake filtered 20 times per day.

Clearly, high densities of zebra mussels can alter the water quality, and consequently, the ecology of infested waters. Effects of zebra mussels on water quality and ecology of Lake Dardanelle are difficult to predict, because it is a different system (i.e., has different water chemistry, thermal regimes, aquatic community structure, etc.) from those that have been previously studied.

OBJECTIVES

This field-oriented study was designed to sample key aquatic variables at three fixed stations. The goal was to establish rigorous baseline data prior to establishment of a high density population of zebra mussels in Lake Dardanelle. The ongoing study is focused on spatial and temporal variability in water quality, zooplankton, phytoplankton (as a function of chlorophyll), and macrophytes. As zebra mussel populations increase over the next few years, we will be able to test several working hypotheses:

1) Water filtration by feeding zebra mussels will lead to decreases in phytoplankton and zooplankton densities (and probably changes in species composition toward larger forms);

2) Water filtration by feeding zebra mussels will lead to decreased suspended solids and turbidity, and subsequently, to increased water clarity;

3) Total phosphorous will decrease, because it is largely associated with suspended material that is susceptible to filtration by zebra mussels; however, phosphate and other inorganic nutrients will increase during the exponential growth phase of the zebra mussel population, because uptake by phytoplankton will decrease;

4) Increased water clarity and availability of inorganic nutrients is expected to lead to proliferation of rooted macrophytes, furthermore, if a proliferation of rooted macrophytes does occur, the dominant substrate for zebra mussel attachment will shift from rocks to macrophytes because Lake Dardanelle is shallow (mean depth of ≈ 4.3 m);

5) The effects listed above will be most dominant at times and places least influenced by Arkansas River flow (e.g., summer, and in the Illinois Bayou Bay of Lake Dardanelle).

RELATED RESEARCH

Larval, juvenile, and adult zebra mussel samples have been collected in Lake Dardanelle since July, 1993 as part of a separate, but related study funded by Entergy Operations (operations management of Arkansas Nuclear One). The larval and juvenile stages were sampled at four, fixed sites (Figure 1) which correspond to zooplankton and water chemistry sample sites in the present study. Adults were

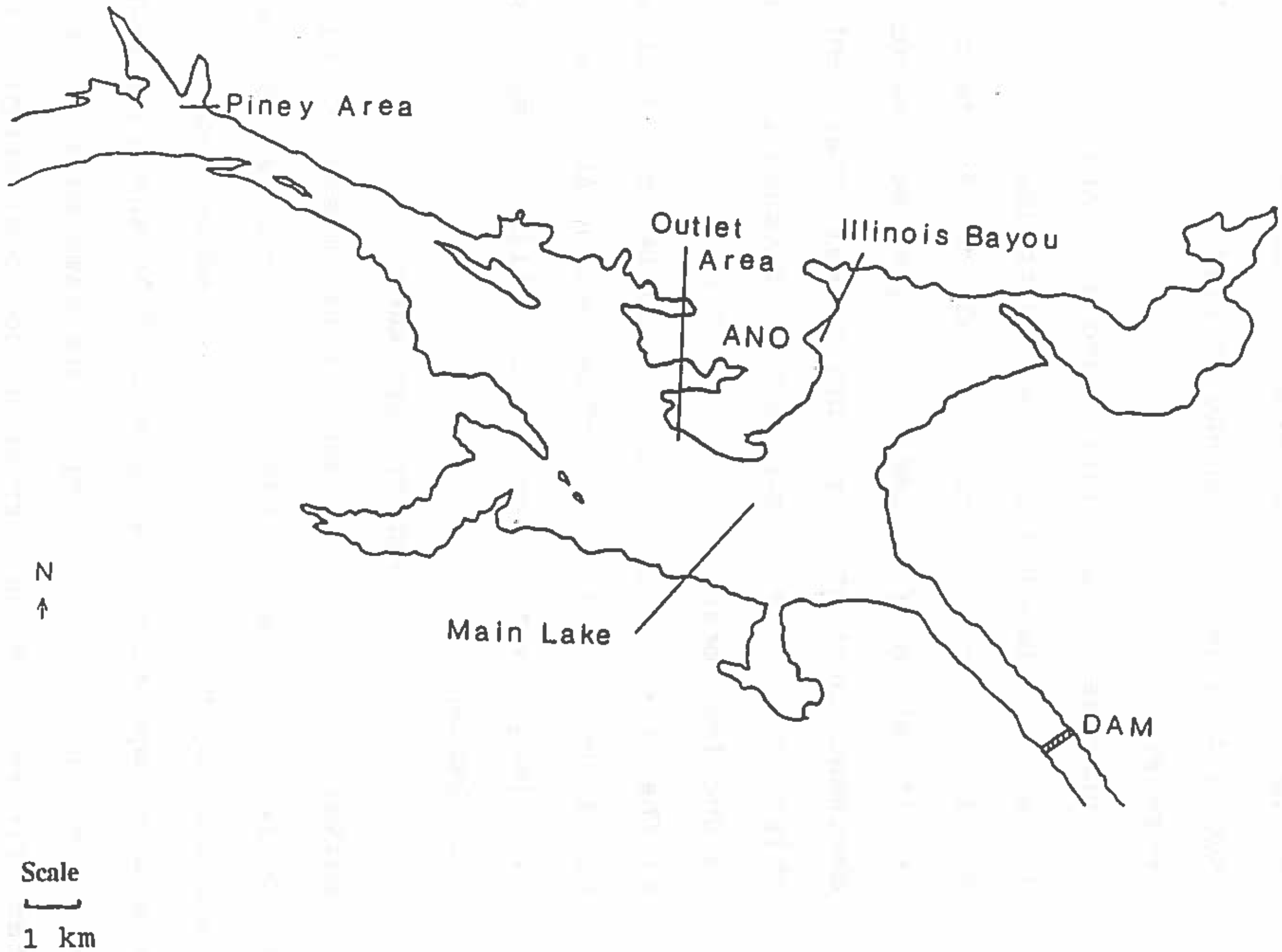

Figure 1. Map of Illinois Bayou, Main Lake, Piney Area, and Outlet Area sampling locations on Lake Dardanelle, AR. Only zooplankton, zebra mussels, and associated data were collected at Outlet Area.

sampled at random sites along the shoreline. Larval zebra mussels were collected in a 64-micron mesh Nitex net towed vertically from a depth of three meters to the surface and by pumping water from a depth of three meters through the net. Except during periods of equipment malfunction, both techniques were used and samples were enumerated separately. Larval zebra mussels were identified and counted in these samples under polarized light. PVC-plate samplers with attached glass slides (Marsden, 1992) were used to sample settling juvenile zebra mussels.

Another related and long-standing research project involved sampling larval fish at night biweekly. Unfortunately, this contract was not renewed for 1995 (we are exploring ways to fund this important aspect).

Zebra mussel densities have increased substantially since they were first found in Lake Dardanelle by Charlie Adams (Entergy Operations) in September, 1992. For example, 0 to 45 adult zebra mussels were found per hour of effort in 1993, 0 to 58 in 1994, and 0 to 139 so far in 1995. The highest mean settling rates (mean for two, 15-cm^2 plates) of juvenile zebra mussels increased from 0 in 1993 to 3.5 in 1994 and 8.0 in 1995. Density of larval zebra mussels from pumped samples was positively correlated with density from towed samples (Figure 2). Mean density of larval zebra mussels in 1993 remained less than 0.1/L; whereas, in 1994 density was over 10/L for much of the summer and exceeded

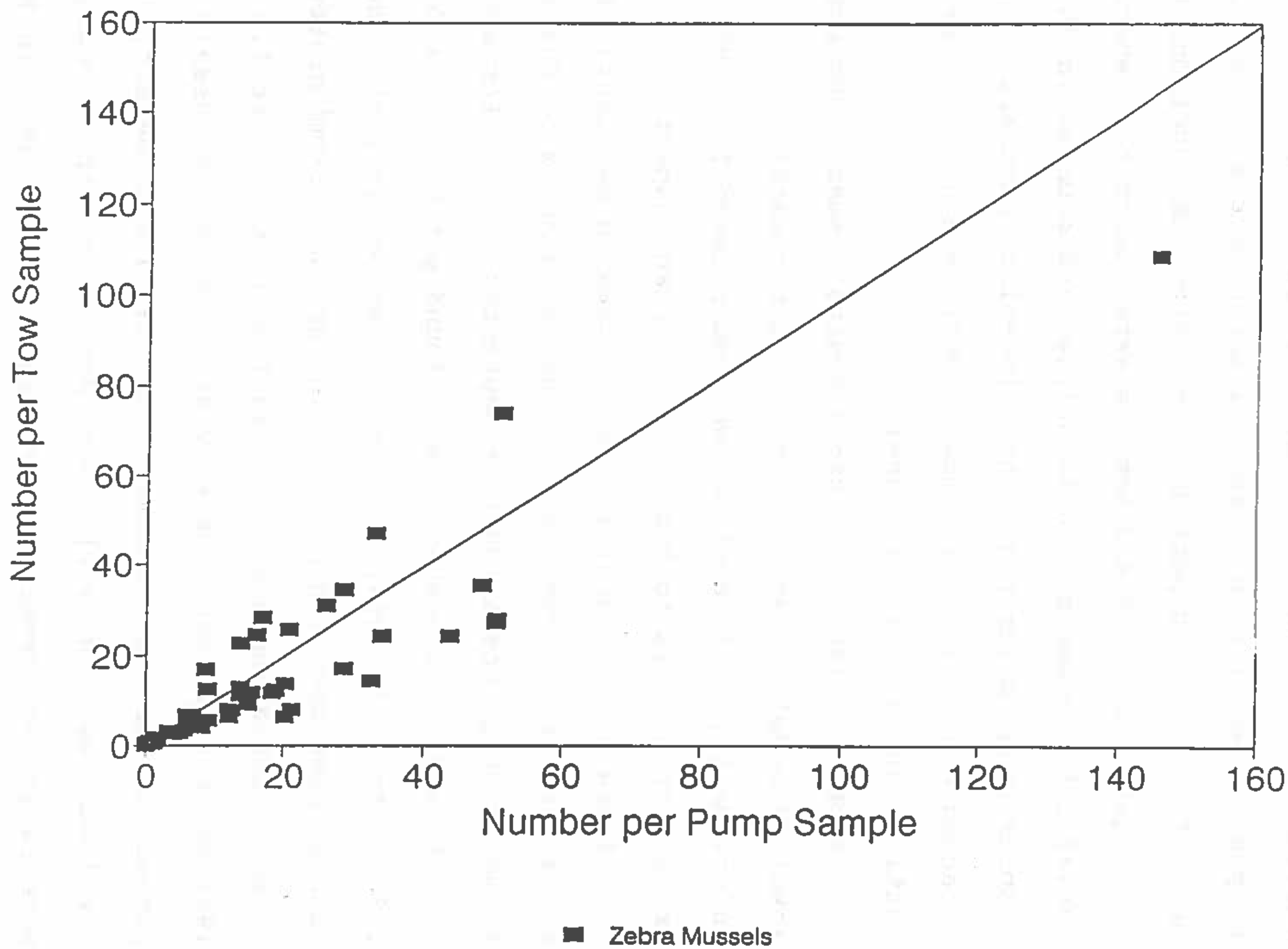

Figure 2. Scatter plot of number of zebra mussels per liter collected in pump samples versus number of zebra mussels collected per liter in vertical tow samples.

50/L on two sampling dates (Figure 3). Through June 1995, larval zebra mussel density has remained intermediate relative to these extremes.

MATERIALS AND METHODS

We collected water biweekly from a depth of 1 m in a polycarbonate sampler to analyze selected water chemistry parameters and chlorophyll levels at three sites in Lake Dardanelle (Figure 1). Lake Dardanelle does not stratify for an extended period in summer, therefore, stratified sampling was unnecessary. Secchi disk depth and dissolved oxygen and temperature profiles were also recorded when water samples were collected. Refrigerated water samples were transported to the Arkansas Water Resources Center Water Quality Laboratory for analysis by EPA accepted methods. Analyses included: total phosphorous, chlorophylls a, b, c, ammonia, nitrate, chloride, calcium, magnesium, phosphate, pH, nitrite, sulfate, turbidity, conductivity, and suspended solids. All 16 parameters were measured for half the sample dates; whereas, only the first six were measured for the other half (Table 1).

The percentage of bottom area covered by submerged and emergent macrophytes in 100 m by 25 m areas near each of the three sample sites was estimated visually with the aid of a rake and SCUBA. These seasonal samples were in water up to 2 m deep and within 25 m of shore.

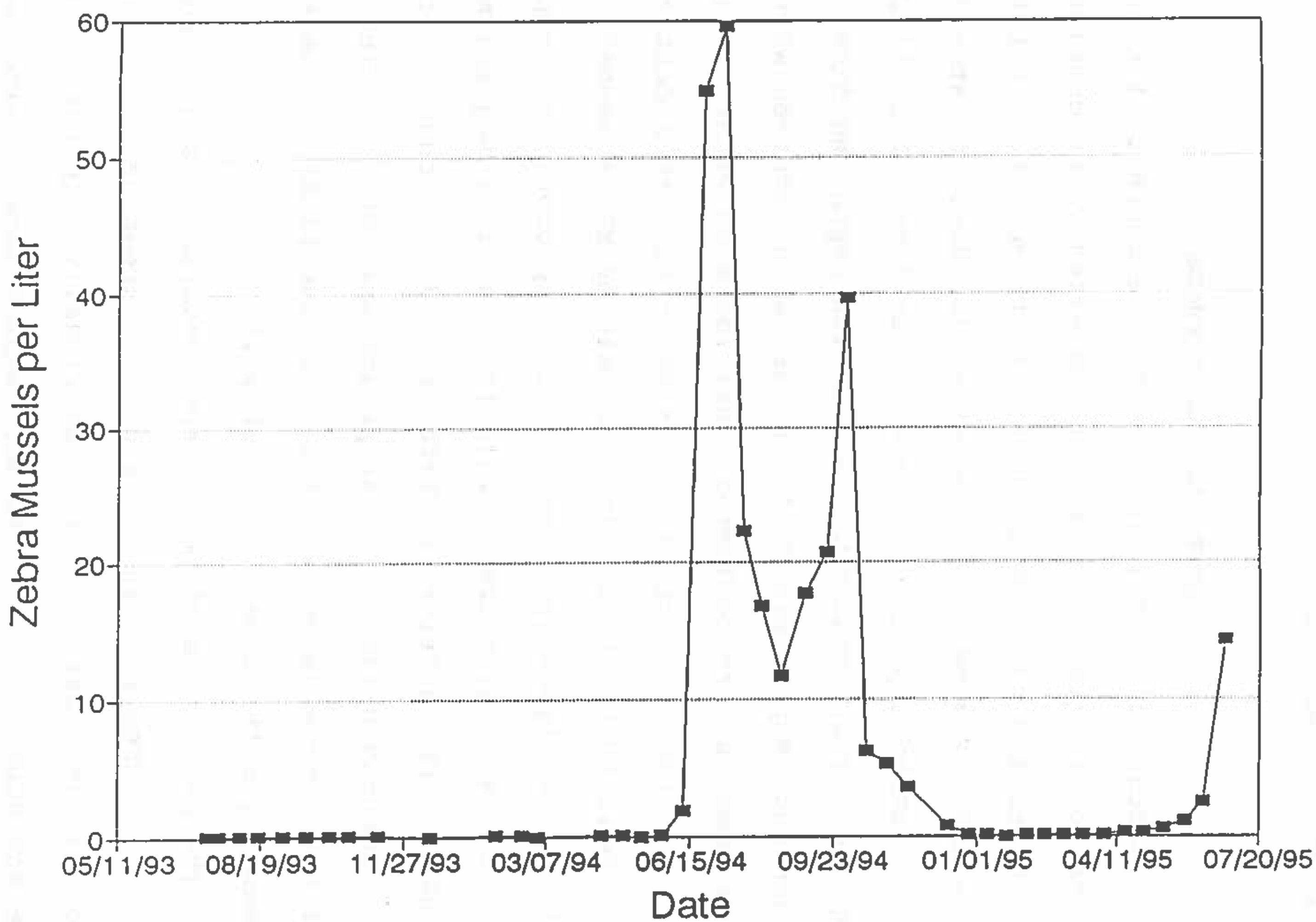

Figure 3. Changes in density of zebra mussels in the plankton of Lake Dardanelle, AR, since July 8, 1993. The value for each date is the mean density of zebra mussels collected in pump and vertical tow samples (unless only one type was taken) averaged across four sample areas.

Table 1. Water chemistry parameters tested and sampling dates. An X denotes the that parameters were sampled on the corresponding date.

Date of Sample	Ca, Cl, NH_4-N, NO_3-N, Total P, Chlorophylls a, b, and c	Mg, NO_2-N, pH, PO_4-P, SO_4, TSS, Turbidity, Conductivity
9/3/94	X	X
9/18/94	X	
10/2/94	X	X
10/16/94	X	
10/30/94	X	X
11/13/93	X	
11/27/94	X	X
12/11/94	X	
12/26/94	X	X
1/9/95	X	
1/22/95	X	X
2/6/95	X	
2/19/95	X	X
3/5/95	X	
3/19/95	X	X
4/4/95	X	
4/16/95	X	X
4/30/95	X	
5/14/95	X	X
5/29/95	X	
6/11/95	X	X
6/27/95	X	

Zooplankton was collected at 4 sites along with the larval zebra mussel samples by vertical tows and by pumping water through a 64 micron mesh Nitex net. These samples were preserved in Lugol's solution, and analyzed at ATU laboratories following the methodology of Wetzel and Likens (1991). For each zooplankton sample, the density of individuals in each major group, Copepoda, Cladocera, Ostracoda, nauplii, Rotifera, and other, was determined.

RESULTS

Turbidity in Lake Dardanelle was high during this study, averaging 22.5 NTU and Secchi disk depths were typically less than 0.8 m (Figures 4 and 5). The site in the main lake had the highest average turbidity and the Illinois Bayou bay of the lake had the lowest (29.0 and 16.4 NTU respectively; Table 2). Most of the chlorophyll was chlorophyll a (mean of 15.8 ug/L) which was lowest in winter (< 3 ug/L) when water temperatures and solar infiltration were the lowest (Figure 6). Turbidity was high during this period due to above average flows and higher loading of sediments. Total suspended solids were also high with an overall average of 16.7 mg/L and followed the same pattern as turbidity (Figure 7). Average soluble reactive phosphorus concentration was higher in the main lake than in the large bay areas (60 versus 31 ug P/L) and concentrations above 100 ug P/L were associated with the highest levels

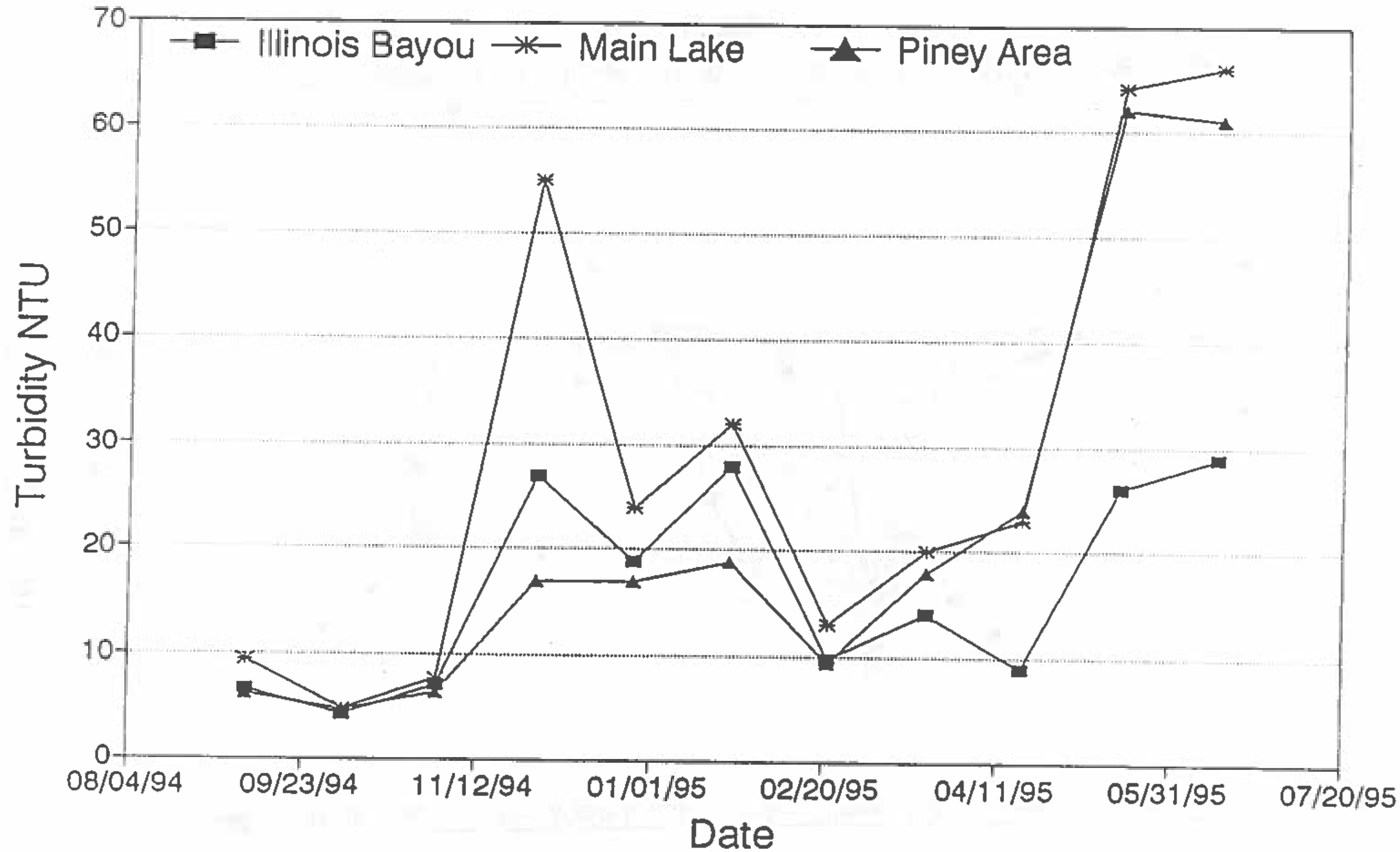

Figure 4. Comparison of turbidity among sample areas and dates.

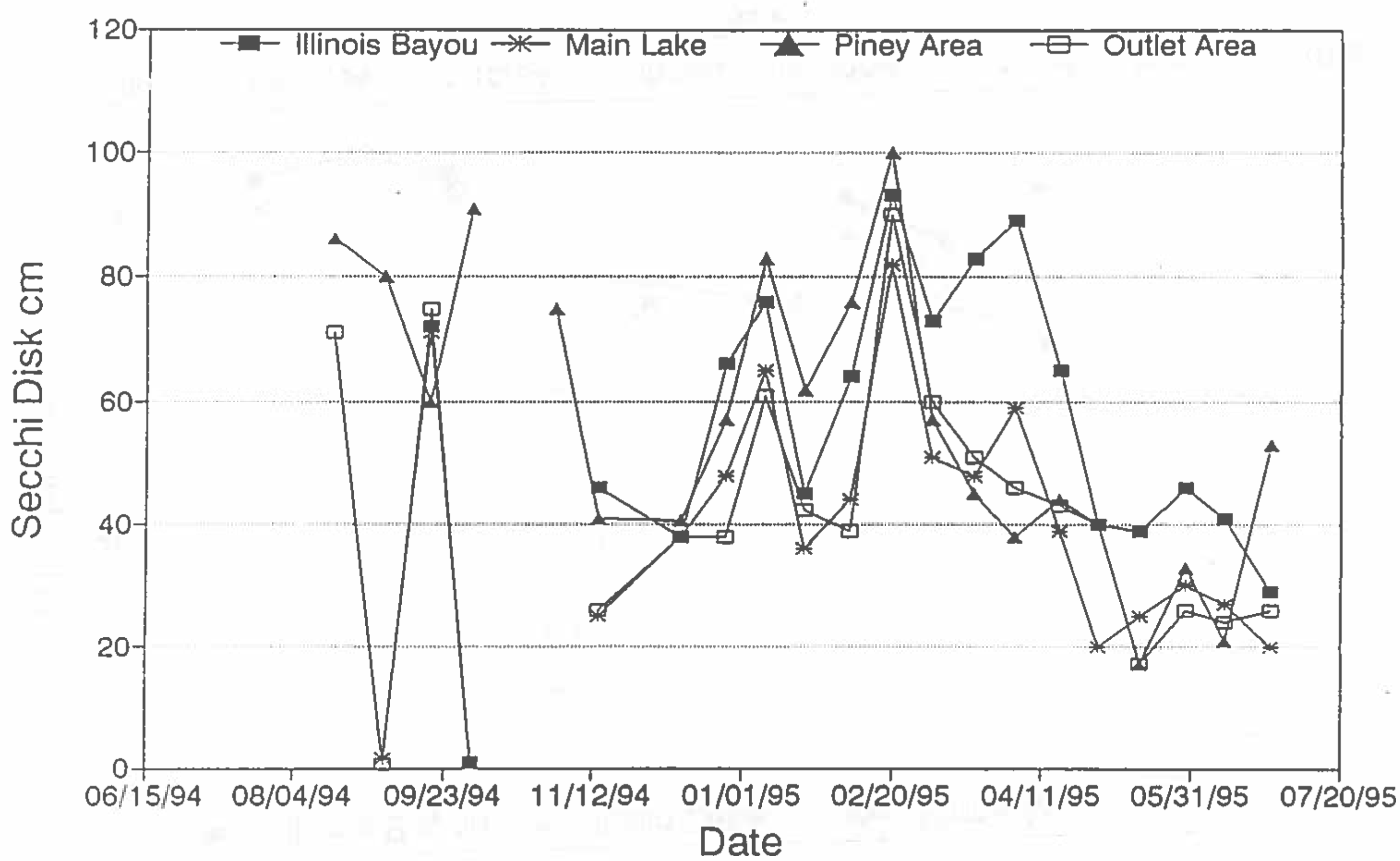

Figure 5. Comparison of Secchi disk visibility among sample areas and dates.

Table 2. Lake Dardanelle water chemistry from September 1994 through June 1995. Data are presented as means in mg/L (unless noted) ± one standard error for the farthest upstream site to the farthest downstream site.

Parameter measured	Samples per site	Piney Bay	Main Lake	Illinois Bayou
Ca	22	19.6 ± 2.7	27.9 ± 1.4	21.3 ± 2.2
Cl	22	47.0 ± 9.0	60.9 ± 6.63	51.5 ± 7.1
Mg	11	5.1 ± 1.0	7.0 ± 0.6	5.1 ± 0.9
NH4-N	22	0.030 ± 0.003	0.031 ± 0.003	0.056 ± 0.024
NO3-N	22	0.26 ± 0.05	0.30 ± 0.04	0.29 ± 0.06
NO2-N	11	0.008 ± 002	0.007 ± 001	0.008 ± 003
pH	11	7.60 ± 0.20	7.92 ± 0.13	7.86 ± 0.18
PO4-P	11	0.034 ± 0.010	0.060 ± 0.014	0.028 ± 0.005
SO4	11	25.43 ± 5.35	32.43 ± 3.61	27.24 ± 4.52
Total P	21[1]	0.08 ± 0.01	0.10 ± 0.01	0.08 ± 0.01
TSS	11	17.31 ± 6.24	23.44 ± 6.79	9.25 ± 1.31
Turbidity (NTU)	11	22.25 ± 6.14	29.00 ± 6.81	16.35 ± 2.92
Conductivity (uS/cm)	11	326 ± 68	420 ± 48	310 ± 60
Chlorophyll A (ug/L)	22	15.2 ± 2.7	15.3 ± 2.4	16.8 ± 2.6
Chlorophyll B (ug/L)	22	0.51 ± 0.12	0.37 ± 0.11	0.38 ± 0.10
Chlorophyll C (ug/L)	22	1.84 ± 0.39	1.74 ± 0.25	1.93 ± 0.37

[1]Only 21 samples for total phosphorous in Piney Area; the 5/16/95 sample failed QC

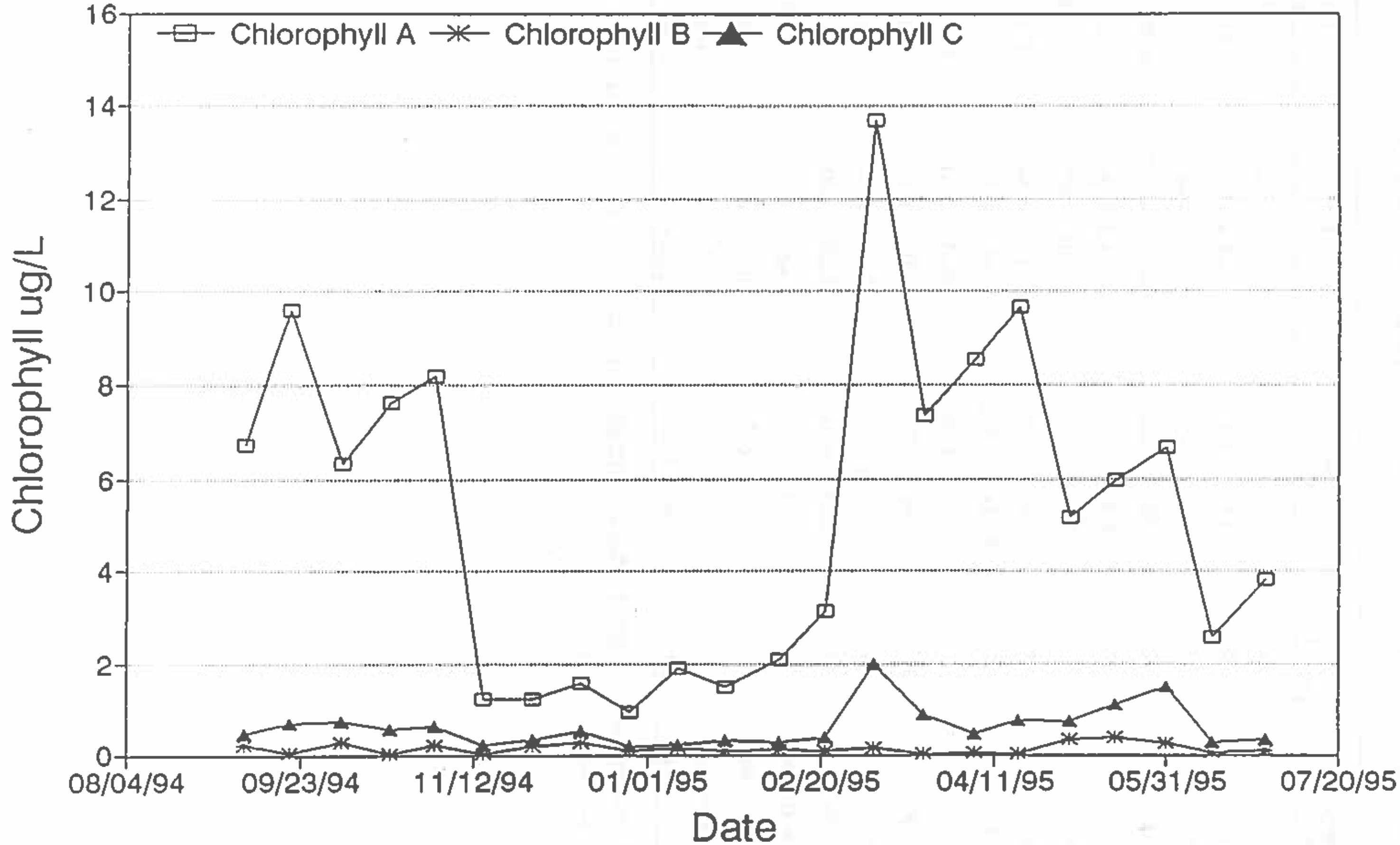

Figure 6. Comparison of chlorophylls a, b, and c among dates. Values are averaged across four sample areas.

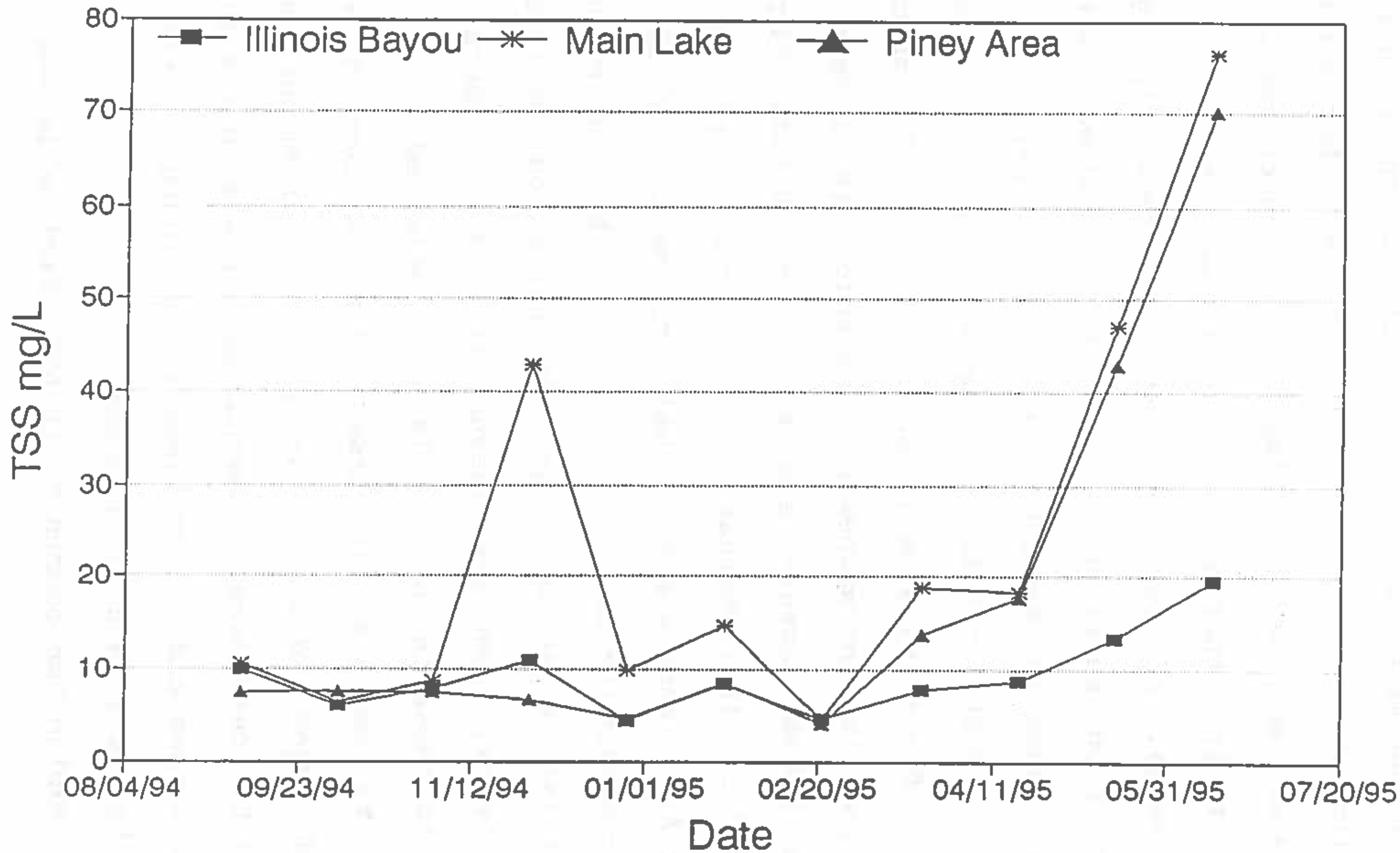

Figure 7. Comparison of total suspended solids among sample areas and dates.

suspended solids. Lake pH was highest in fall and lowest in winter, ranging from over 8.5 to near 6.5, and it was most stable in the main lake. The stability in the main lake can be attributed to dilution effects and the higher buffering capacity as reflected in higher calcium concentration relative to the other sites (27.9 versus 20.5 mg/L, respectively). Nitrogen levels were not generally high for a reservoir on the Arkansas River, but we did document a 560 ug N/L peak in ammonium in the Illinois Bayou and two > 1000 ug N/L peaks in nitrate. One was in the Illinois Bayou and one in the Piney area (Figures 8 and 9). The major cations (calcium and magnesium) and anions (sulfate and chloride) showed patterns similar to conductivity (Figure 10 shows conductivity; whereas the major ions are plotted in Appendix A). There was a gradual increase during fall and a precipitous decline in early winter which has not returned near fall levels yet this year. Concentrations of these ions in the bay areas are somewhat diluted by tributary flow compared to those in the main lake as reflected in conductivity (means of 318 verses 420 uS/cm, respectively). Dissolved oxygen and temperature were similar among sample areas and followed normal seasonal patterns with the highest dissolved oxygen and lowest temperatures in the winter months (Figures 11 and 12, respectively).

The zooplankton community in Lake Dardanelle was

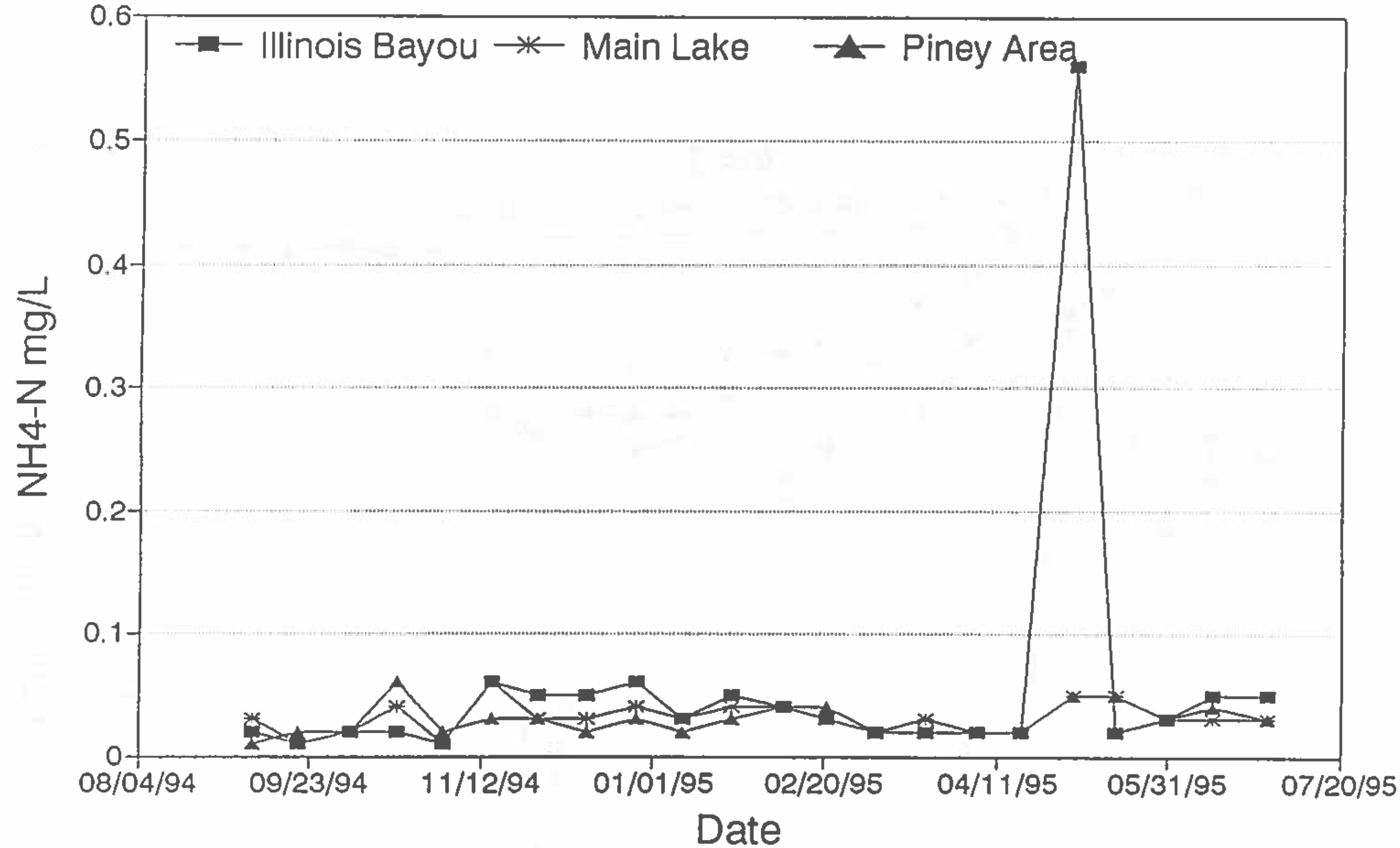

Figure 8. Comparison of ammonia-N among sample areas and dates.

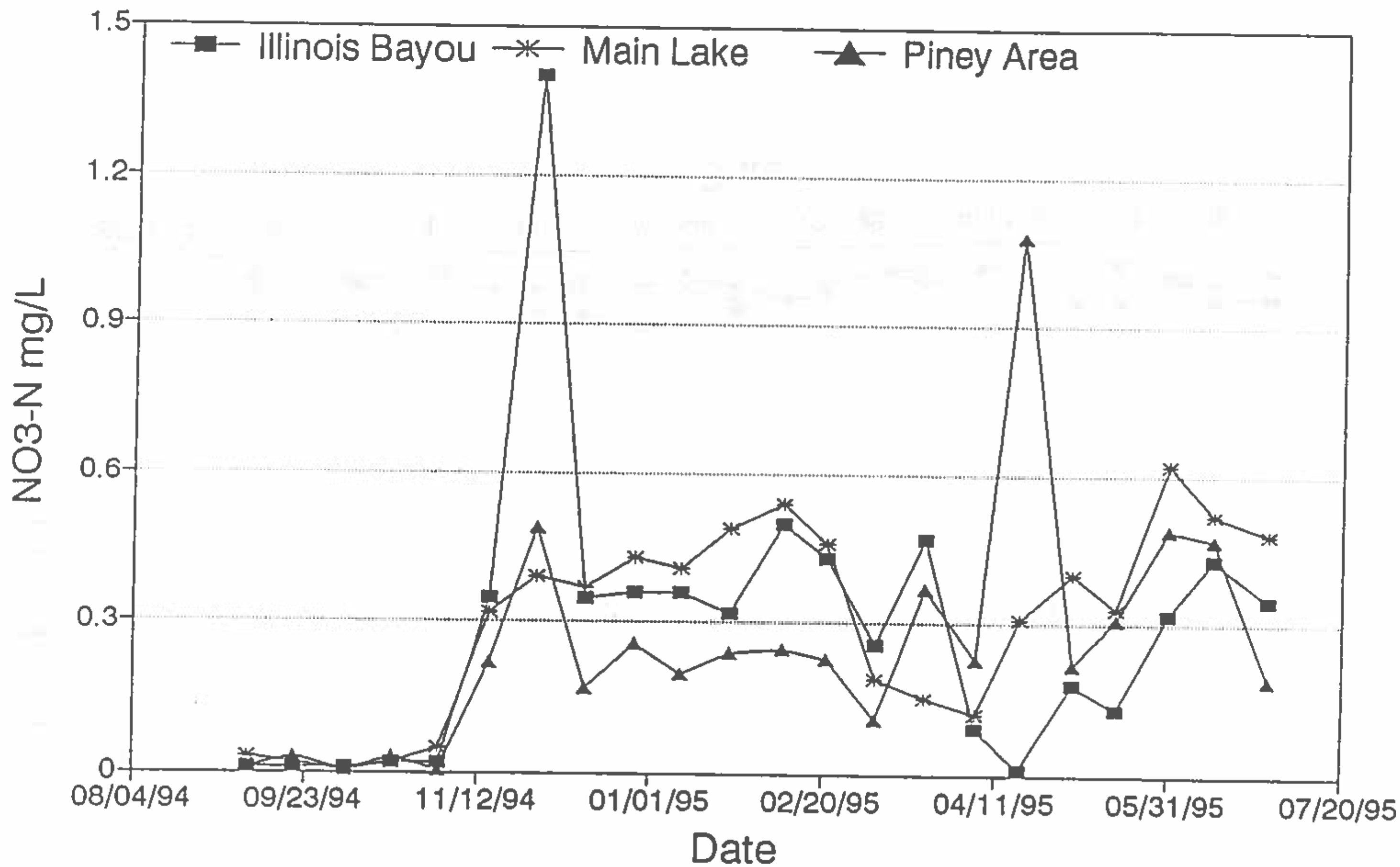

Figure 9. Comparison of nitrate-N among sample areas and dates.

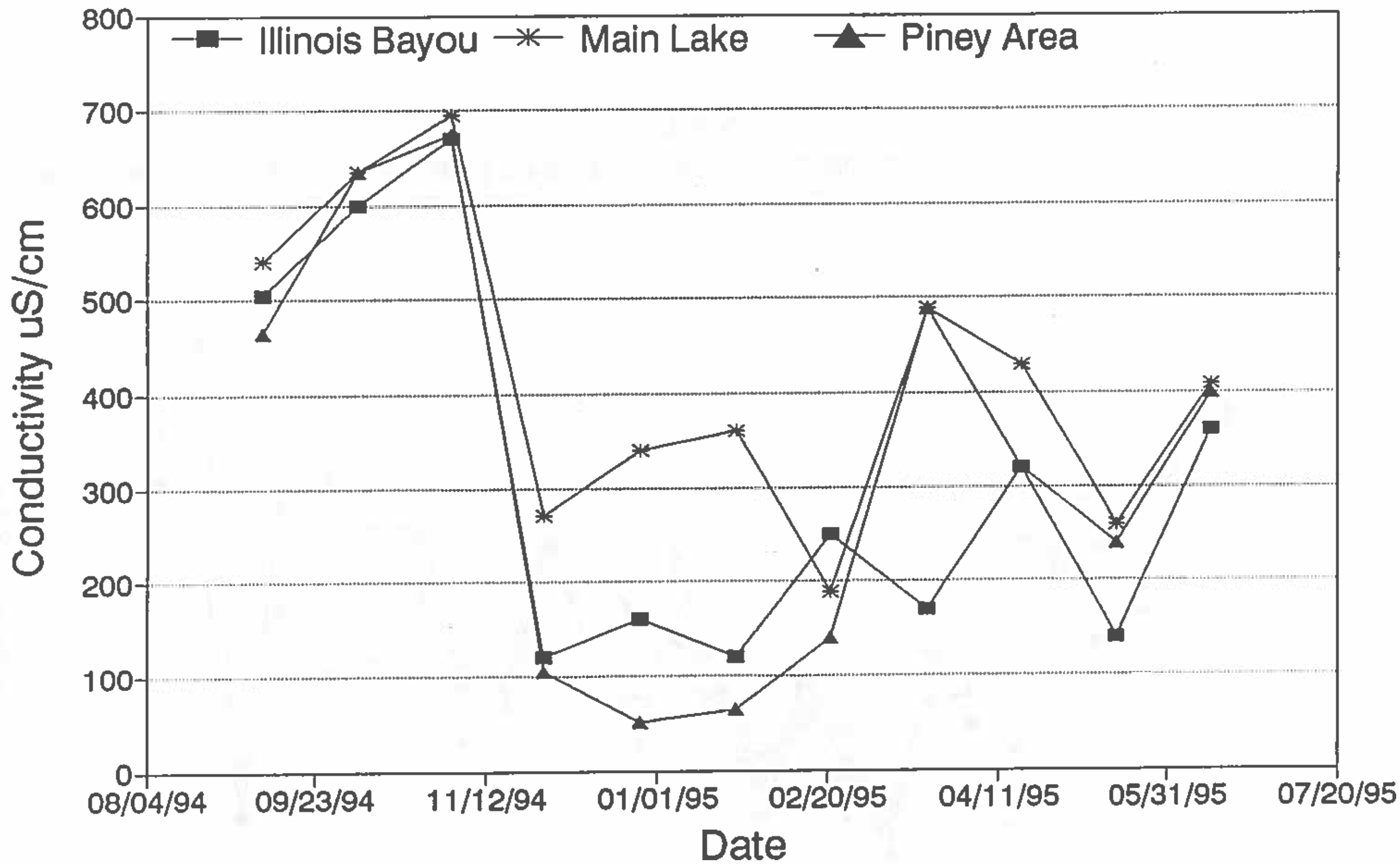

Figure 10. Comparison of conductivity among sample areas and dates.

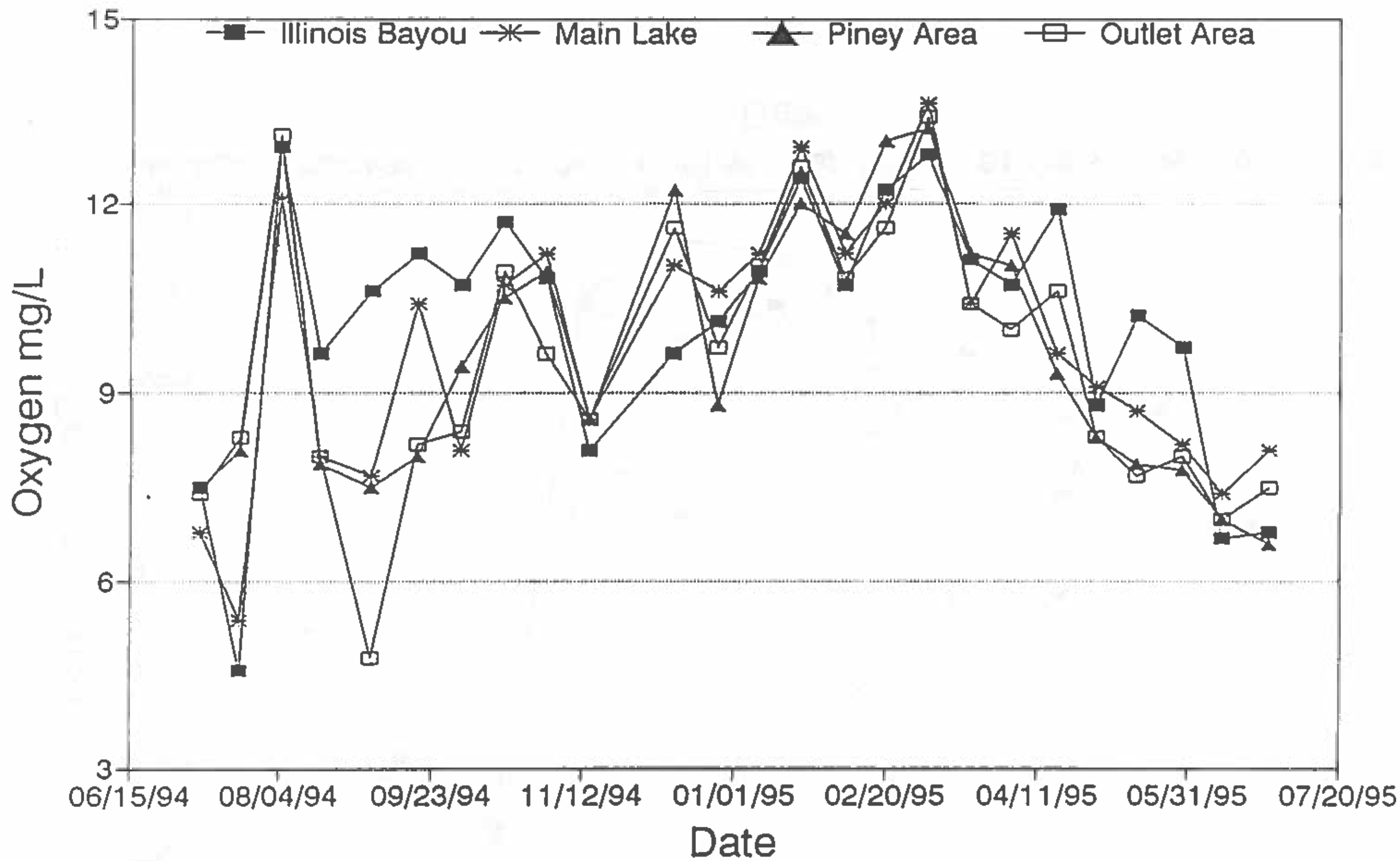

Figure 11. Comparison of dissolved oxygen among sample areas and dates.

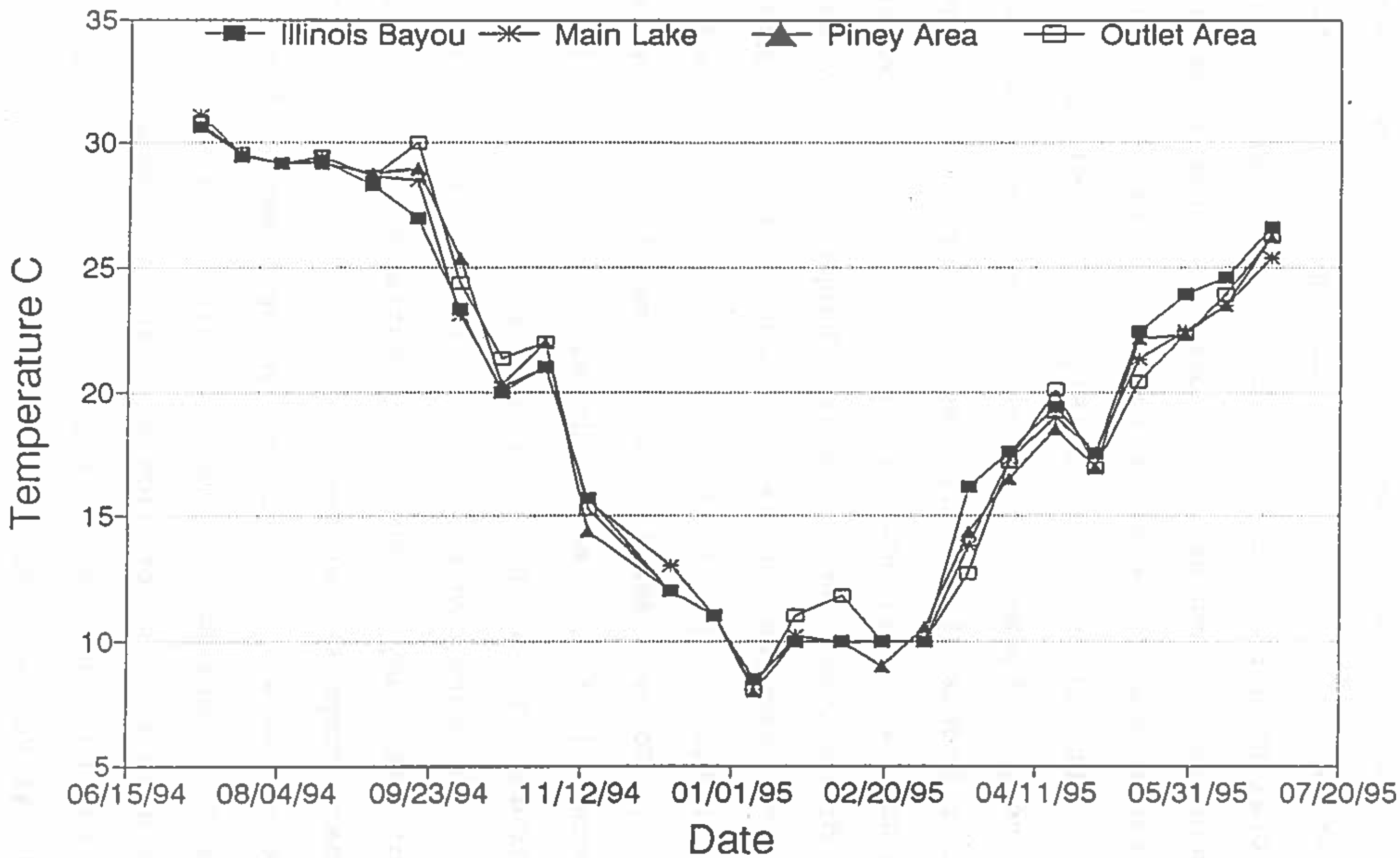

Figure 12. Comparison of temperature at a depth of 1 m among sample areas and dates.

numerically dominated by rotifers (Figure 13). Their density was similar among sites and often exceeded 40/L in vertical tow samples (Figure 14). Rotifer density was lower in winter as expected. Larval zebra mussels constituted a substantial proportion of the zooplankton community during peak abundance. Pump samples showed a higher proportion of larval zebra mussels relative to the zooplankton community than did vertical tow samples (Figures 15 and 16, respectively). Higher densities of copepods, cladocerans, and "other zooplankton" were found in vertical tow samples than in pump samples; however, no such bias was evident for nauplii or rotifers (Appendix B). Nauplii density in vertical tow samples has been increasing from a winter low of < 4/L (Figure 17). Fall, 1994 densities exceeded 20/L at each site. Copepod density in vertical tow samples remained < 4/L except in fall when densities exceeded 10/L in the bays (Figure 18). Cladocerans have been < 4/L since February, but were typically twice that in the earlier months of the study (Figure 19). Ostracods were never a significant component of the community (< 1/L) and "other zooplankton" were < 10/L except in September at Piney Area (13/L) and in February at the Illinois Bayou site (7/L). Separate area graphs for each site showing community composition for each taxa are presented in Appendix B for the vertical tow samples.

We found only 2.5 to 37.5 % coverage of emergent

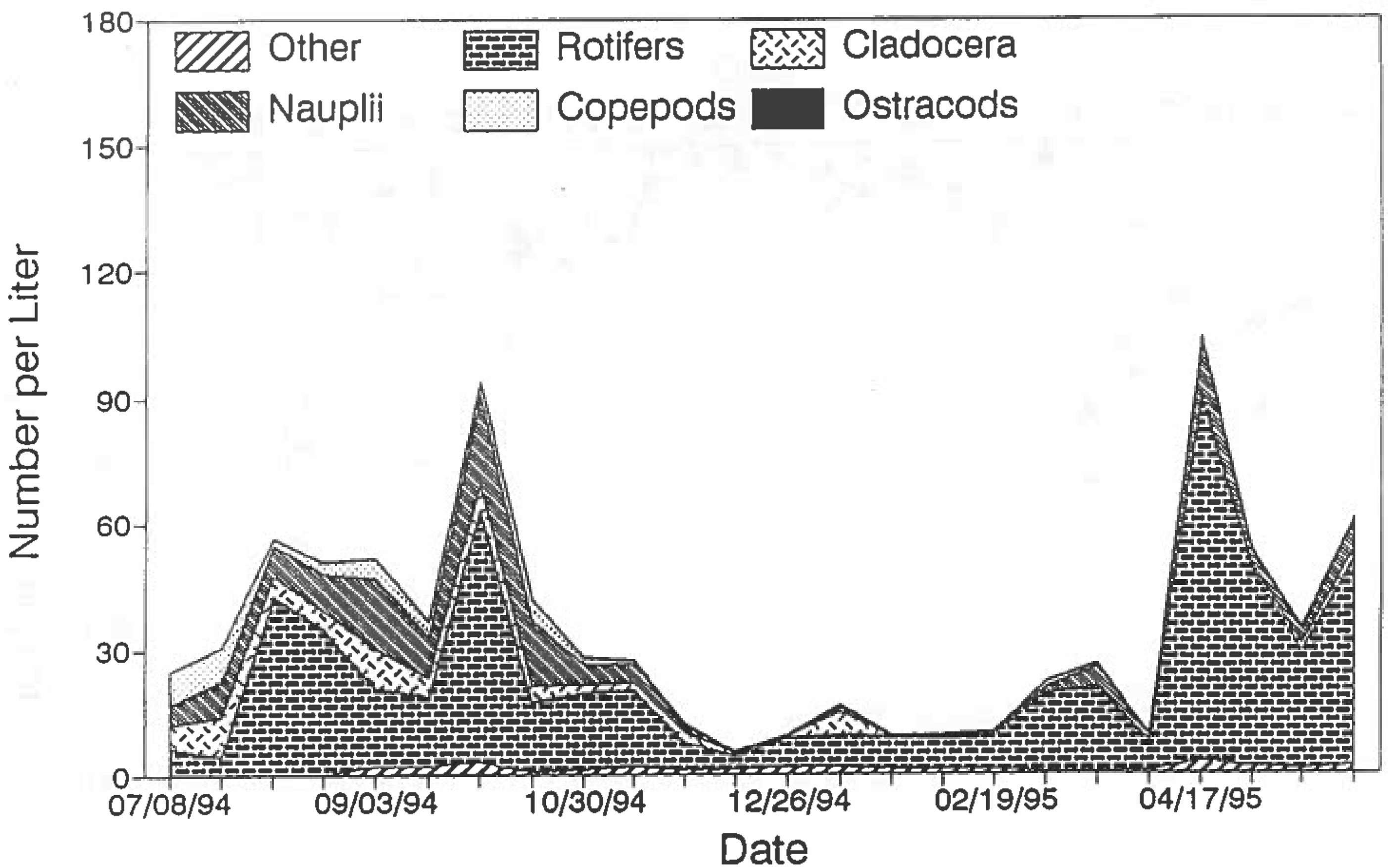

Figure 13. Changes in density of zooplankton (exclusive of zebra mussels) in the plankton of Lake Dardanelle, AR, since July 8, 1994. The value for each date is the mean density of zooplankton collected in pump and vertical tow samples (unless only one type was taken) averaged across four sample areas.

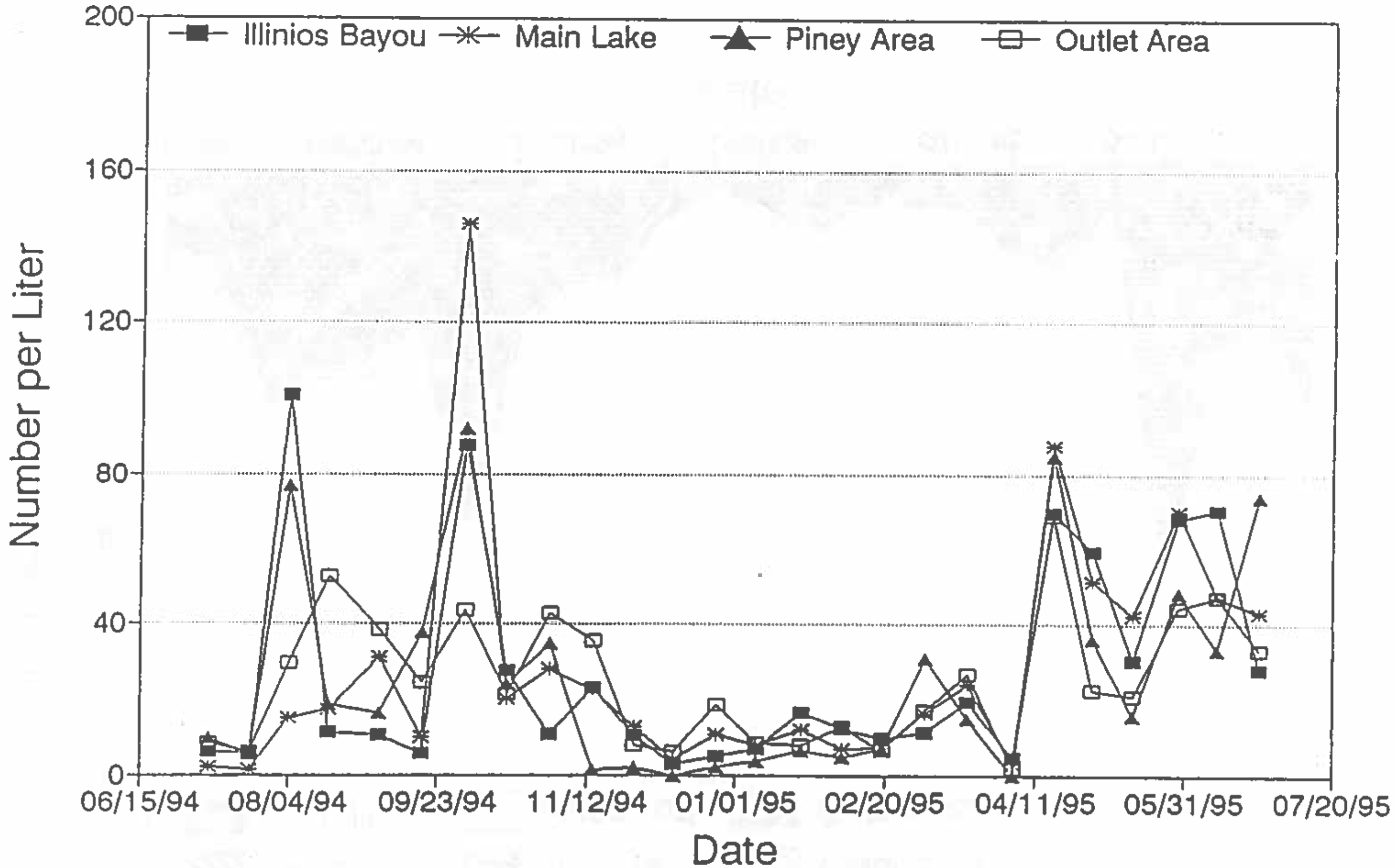

Figure 14. Changes in densities of rotifers collected in vertical tow samples among sample areas and dates.

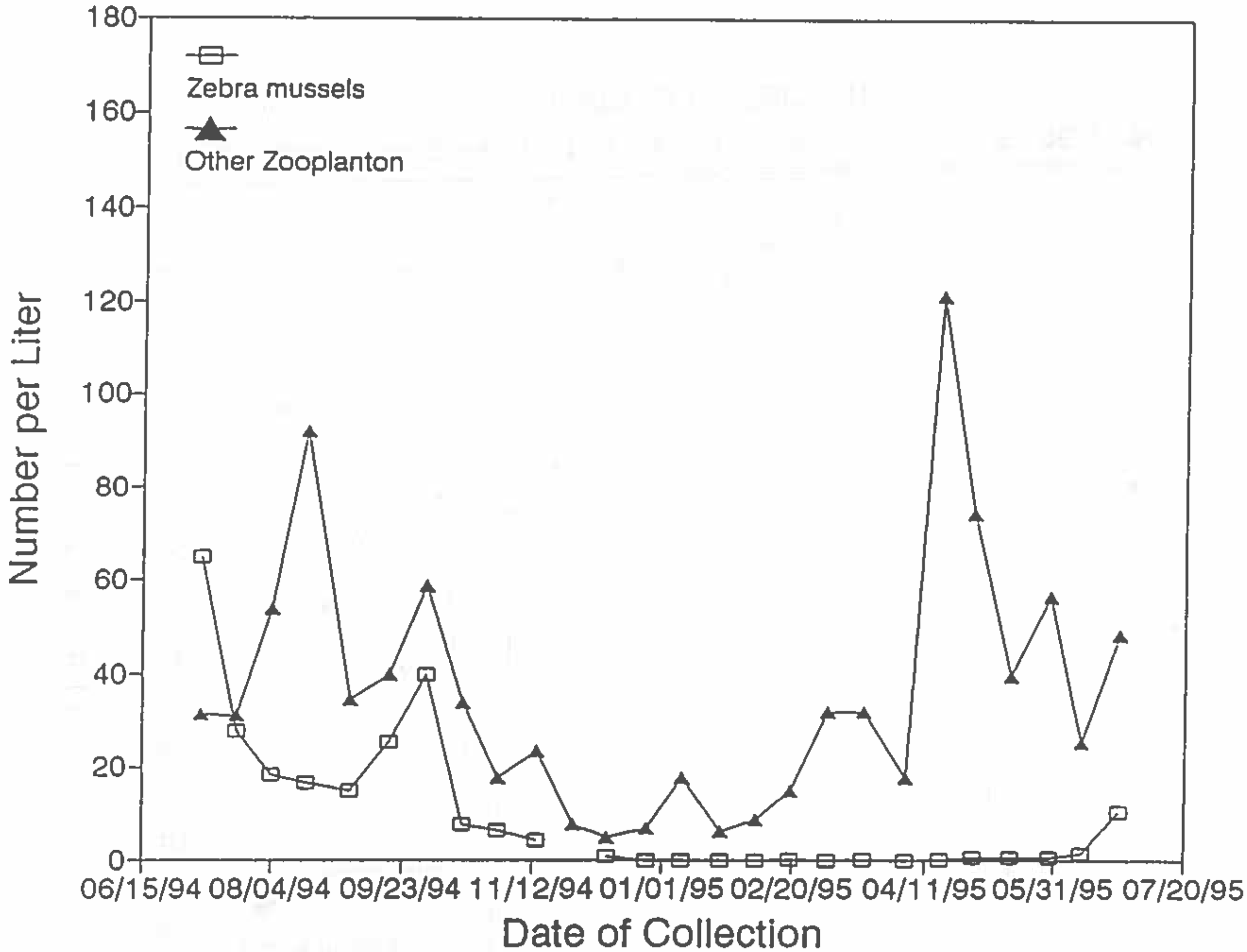

Figure 15. Changes in densities of zebra mussels and total zooplankton, exclusive of zebra mussels, collected in pump samples among dates. The value for each date is averaged across four sample areas.

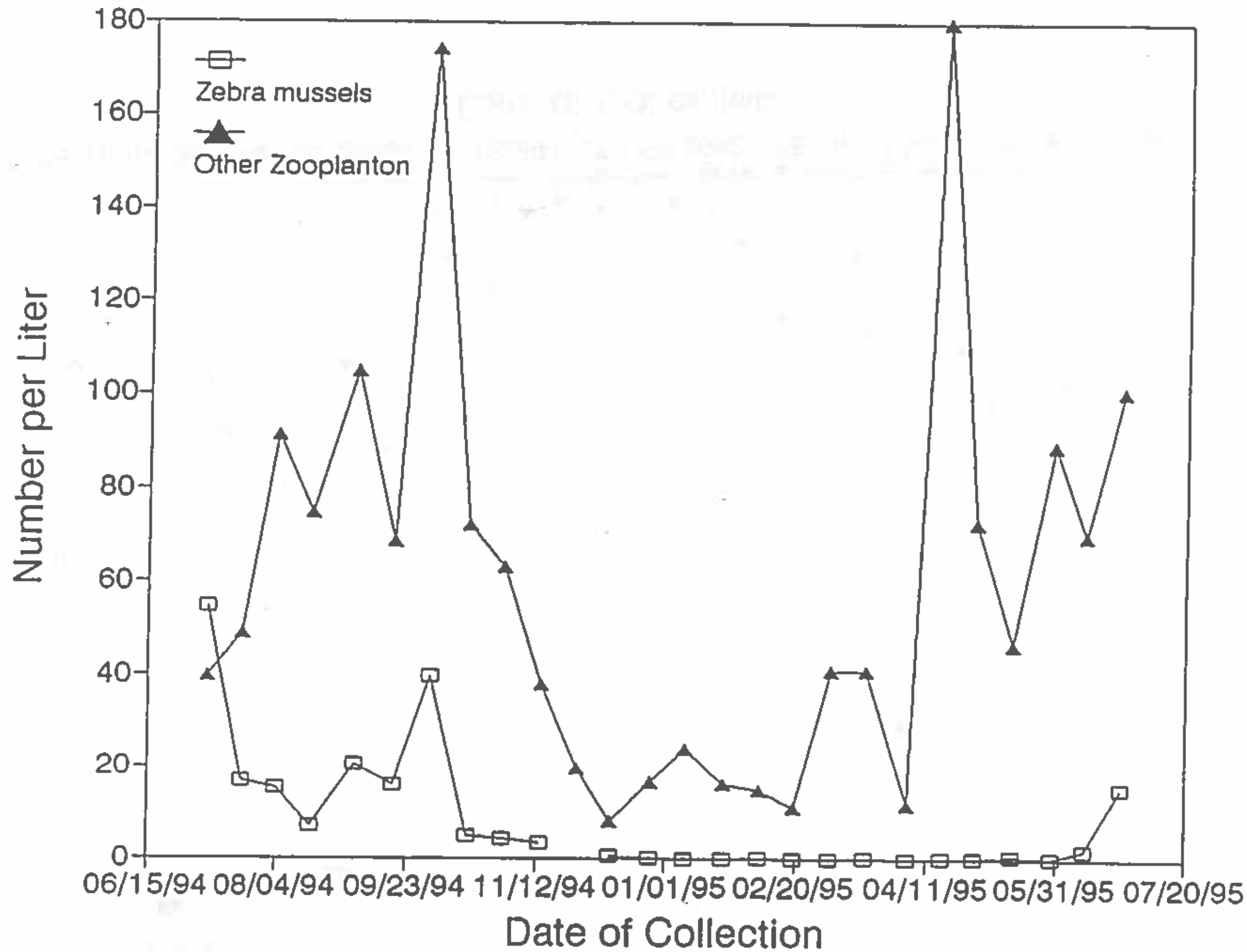

Figure 16. Changes in densities of zebra mussels and total zooplankton, exclusive of zebra mussels, collected in vertical tow samples among dates. The value for each date is averaged across four sample areas.

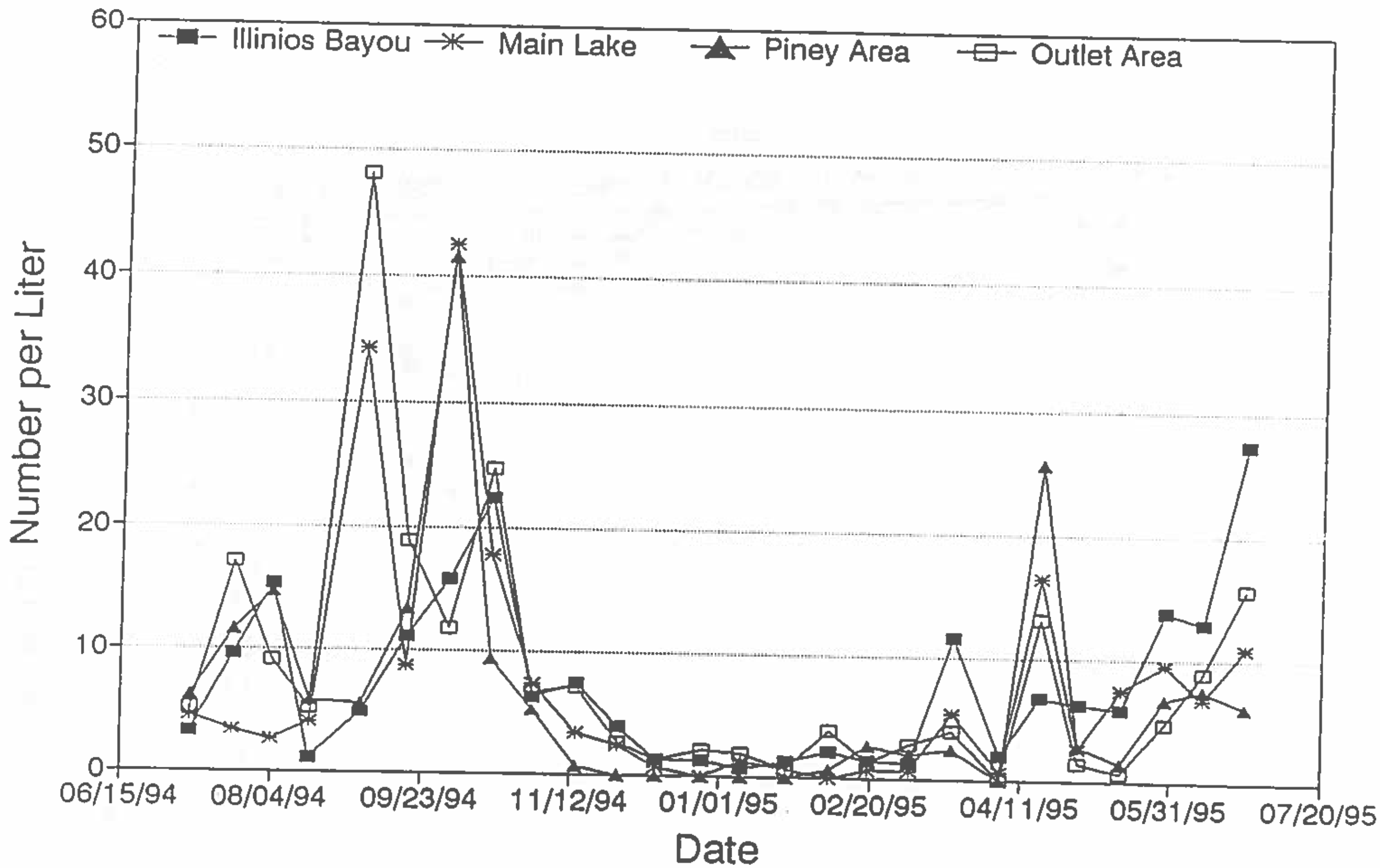

Figure 17. Changes in densities of nauplii collected in vertical tow samples among sample areas and dates.

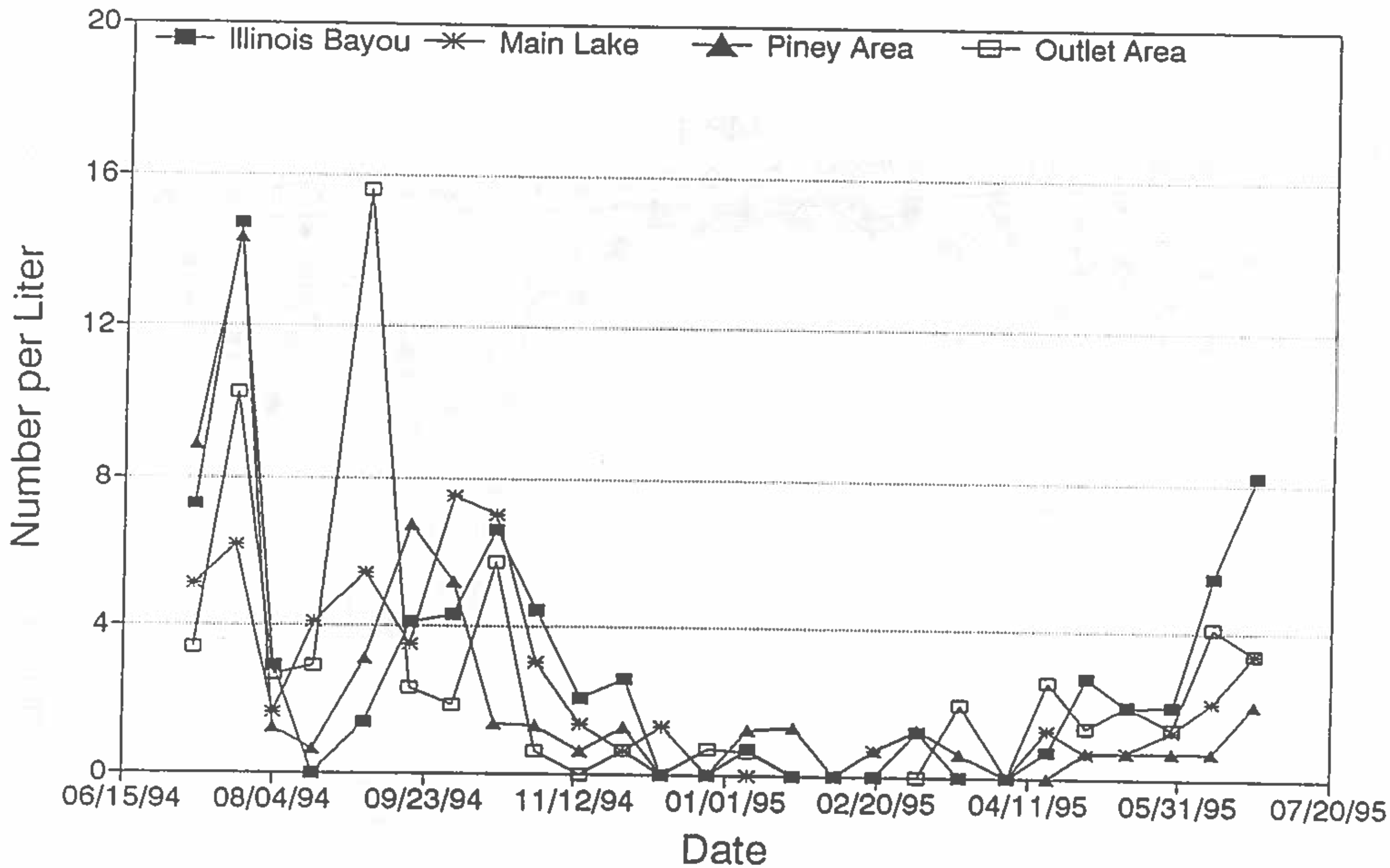

Figure 18. Changes in densities of copepods collected in vertical tow samples among sample areas and dates.

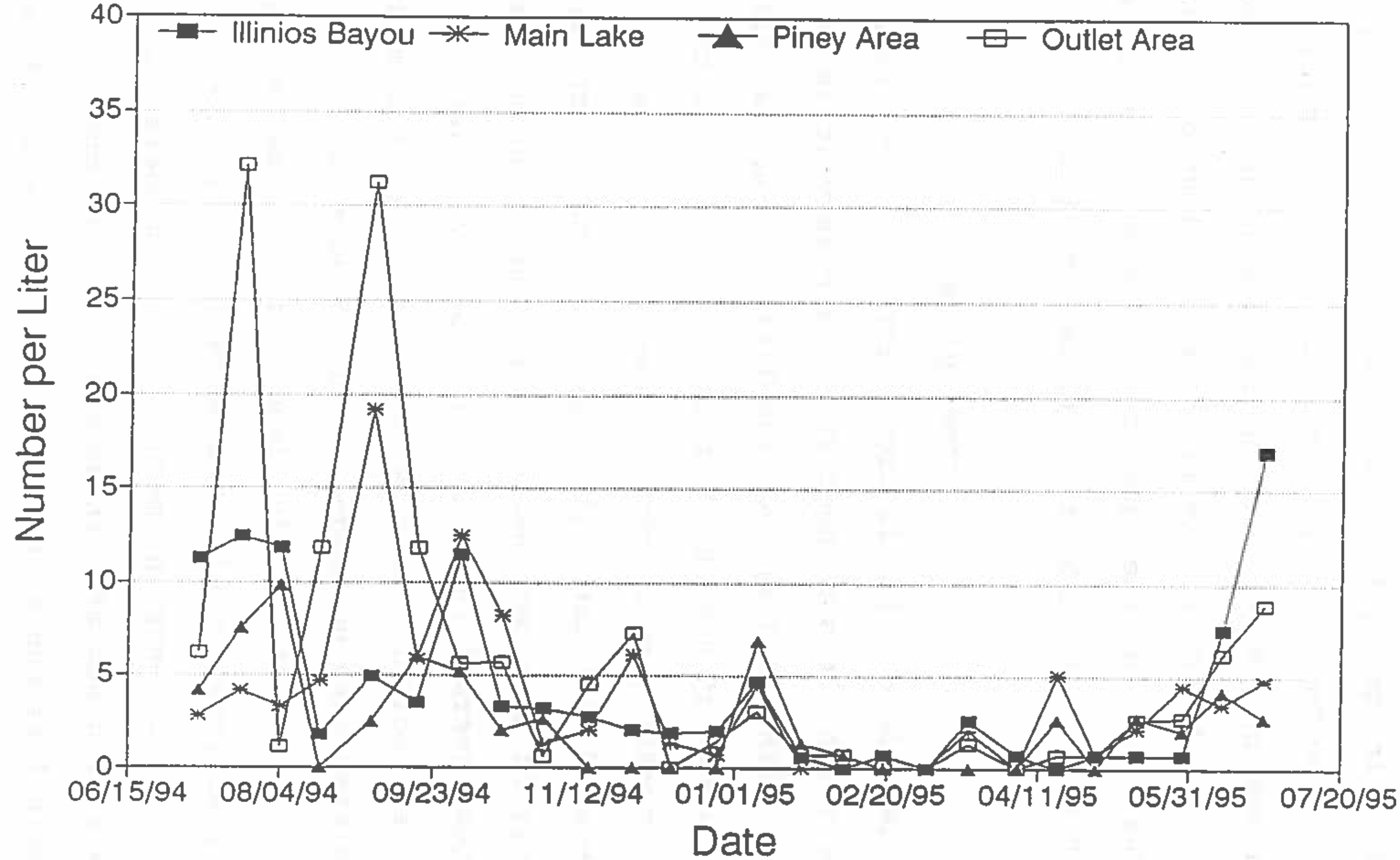

Figure 19. Changes in densities of cladocerans collected in vertical tow samples among sample areas and dates.

vegetation in sample areas and no submergent vegetation (Figure 20). Average coverage was lowest in the winter and highest in spring for Piney Area and for Illinois Bayou Area. The Main Lake Area has had lower vegetative cover each season. Higher than normal discharge and suspended solids in the main lake may have contributed to this trend. Virtually all of the aquatic vegetation in sample areas was water willow, Dianthera (Justicia) americana.

CONCLUSIONS

Lake Dardanelle is highly influenced by the Arkansas River which flows through it. The reservoir is very shallow (mean depth ≈ 4.3 m), yet the littoral zone is narrow due to high levels of suspended solids during most of the year. The concentration of total suspended solids was positively correlated with turbidity suggesting that in the current ecology of Lake Dardanelle, suspended solids have the greatest overall influence on turbidity (Figure 21). As we expected, soluble reactive phosphorus was also positively correlated with suspended solids (Figure 22). It is conceivable that the high levels of suspended solids may slow proliferation of zebra mussels in the lake by reducing feeding efficiency and perhaps covering these sessile filter feeders with sediment in some areas. The observation that the main lake had higher turbidity and suspended solids is consistent with our hypothesis that large bays are more

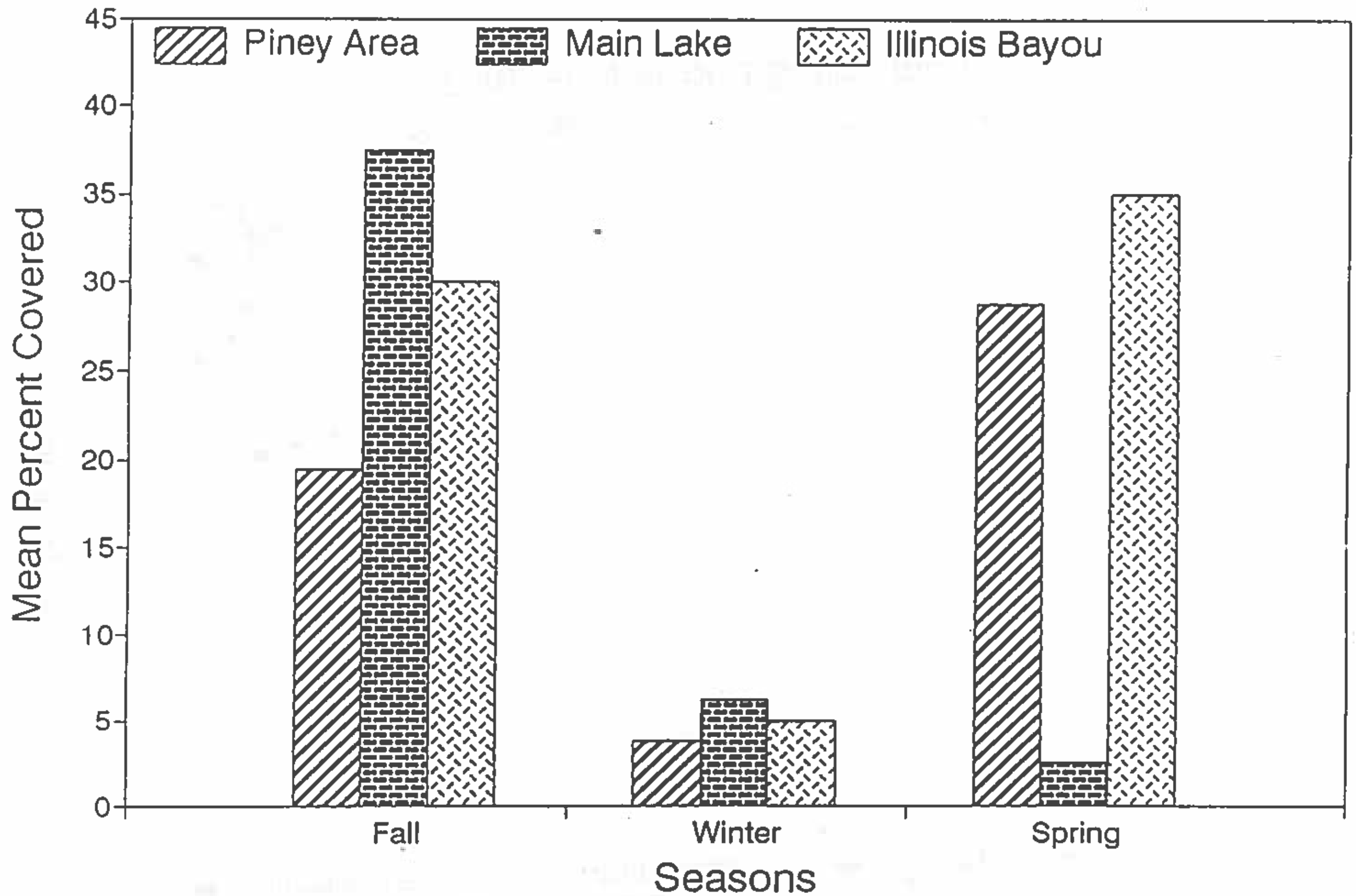

Figure 20. Seasonal changes in percent surface area coverage of submergent and emergent vegetation among sample areas.

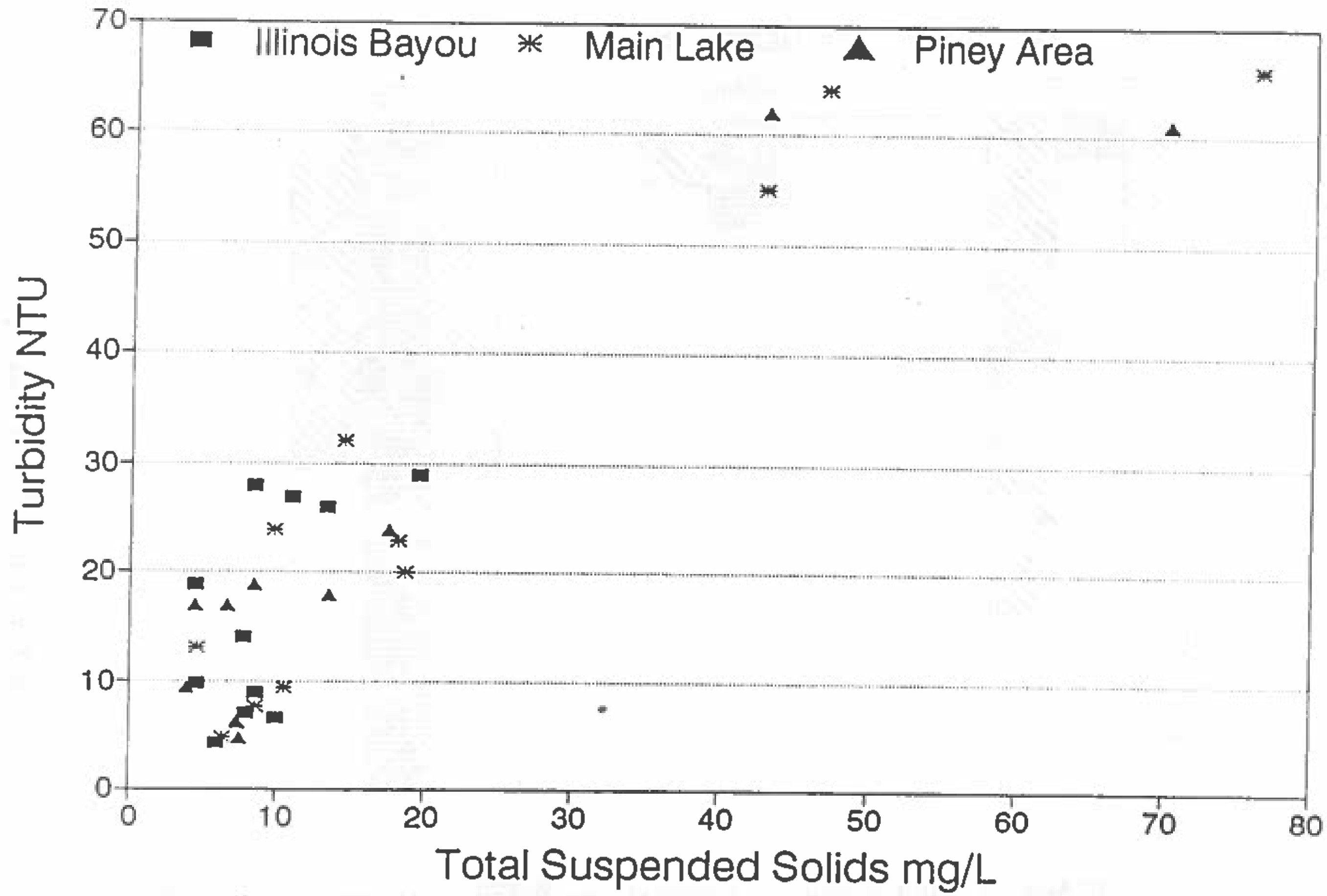

Figure 21. Scatter plot of turbidity versus total suspended solids for all sample areas and dates combined.

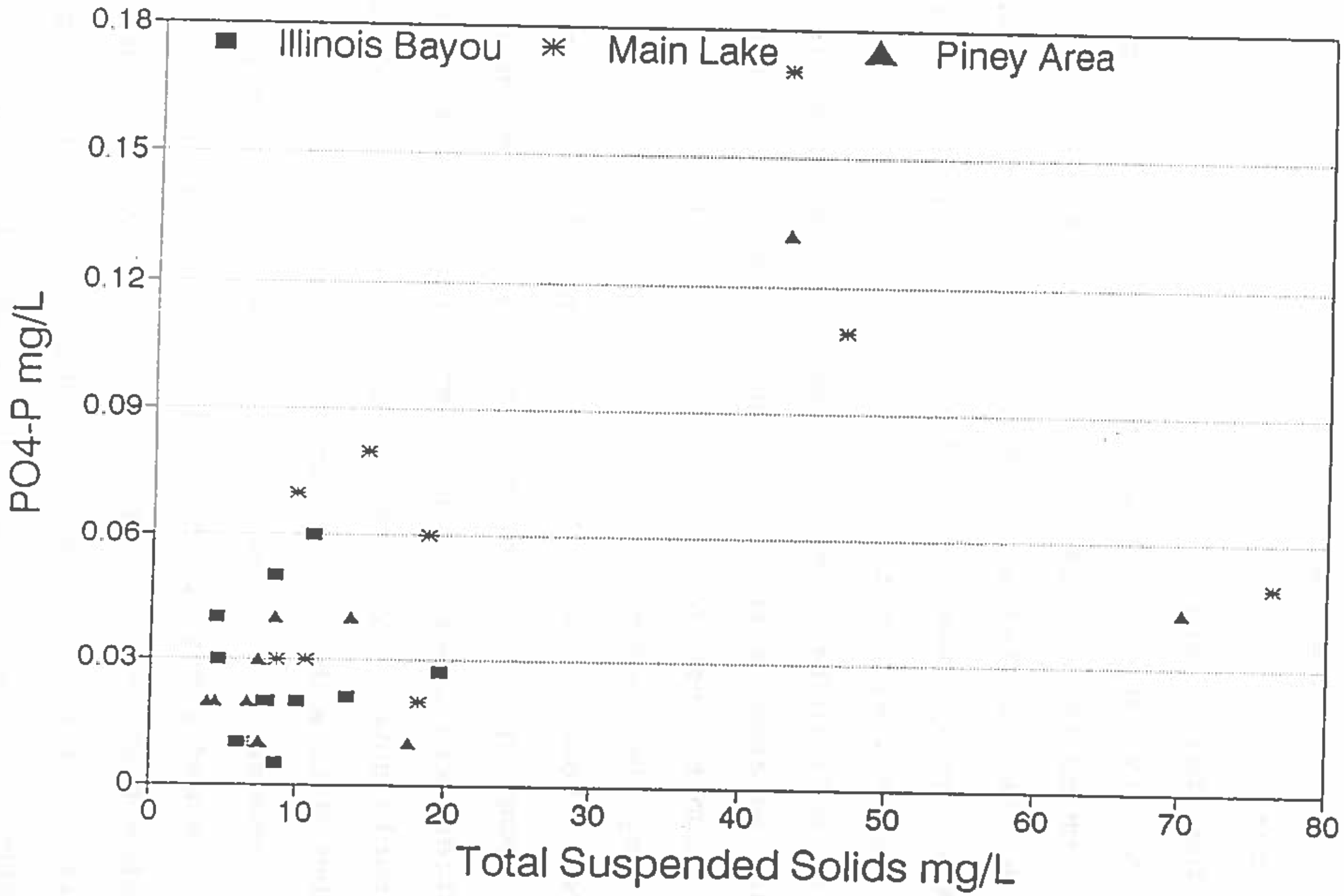

Figure 22. Scatter plot of phosphate-P versus total suspended solids for all sample areas and dates combined.

vulnerable to high filtration rates of dense mussel communities. The ecology of the lake would be totally different if clarity were increased significantly as a result of high zebra mussel density, and consequent high filtration.

The spatial and temporal variation in major ions and conductivity was no greater than that normally expected in a lake such as Lake Dardanelle; however, it was critical to examine these patterns in anticipation of changes that may accompany zebra mussel proliferation. Levels of the major ions are well within tolerance zones of zebra mussels.

As anticipated, the zebra mussel population in Lake Dardanelle appears to be increasing rapidly in size. The population has not yet reached a size that appears to be impacting the reservoir significantly. Zebra mussel veligers showed a ten-fold to one-hundred-fold increase, from summer of 1993 to summer of 1994, but the veliger densities were lower in the first part of summer 1995 for comparable dates. The lower veliger densities can not be attributed to a declining population of adults, because our random shoreline surveys indicate that the adult population has increased significantly. A preliminary analysis indicates that the rate of settling of juvenile zebra mussels has also increased. In addition to the possibility of random fluctuations in larval production, it is possible that the higher summer flow levels in the Arkansas River in

1995 diluted densities and washed more out of the reservoir. Figure 3 shows that the summer peak in larval zebra mussel density may still be in progress and our most recent samples analyzed (July 9) document a mean density exceeding 32/L.

The higher density of several zooplankton taxa in vertical tows (to the surface during daylight) than in samples pumped from a depth of 3 m, indicated that light intensity (and associated predation) is not high enough in the upper water levels to cause avoidance of these areas in daylight. Should water clarity increase as a result of zebra mussel filtration, we expect zooplankton communities to avoid sight feeding predators by moving deeper into the water column during daylight hours. If zebra mussels establish a substantial population and selectively remove larger zooplankton, then copepods and cladoderans would comprise smaller proportions of future samples. Furthermore, it is possible that larval fish productivity could decline due to competition for the larger zooplankton.

High nutrient availability and suitable substrate in Lake Dardanelle could support dense stands of aquatic macrophytes; however, light penetration is limiting as is typical of other reservoirs on the Arkansas River. Increased light penetration could result in establishment of dense beds of emergent and submergent vegetation, which could drastically influence fish population dynamics and negatively impact boating. We have made substantial progress toward characterizing key water quality and biotic parameters of Lake Dardanelle, and upon completion of this study we should be able to test critical hypotheses relative to zebra mussel invasion of shallow southern reservoirs.

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Appendix A

Physical and Chemical Parameters of Lake Dardanelle, AR

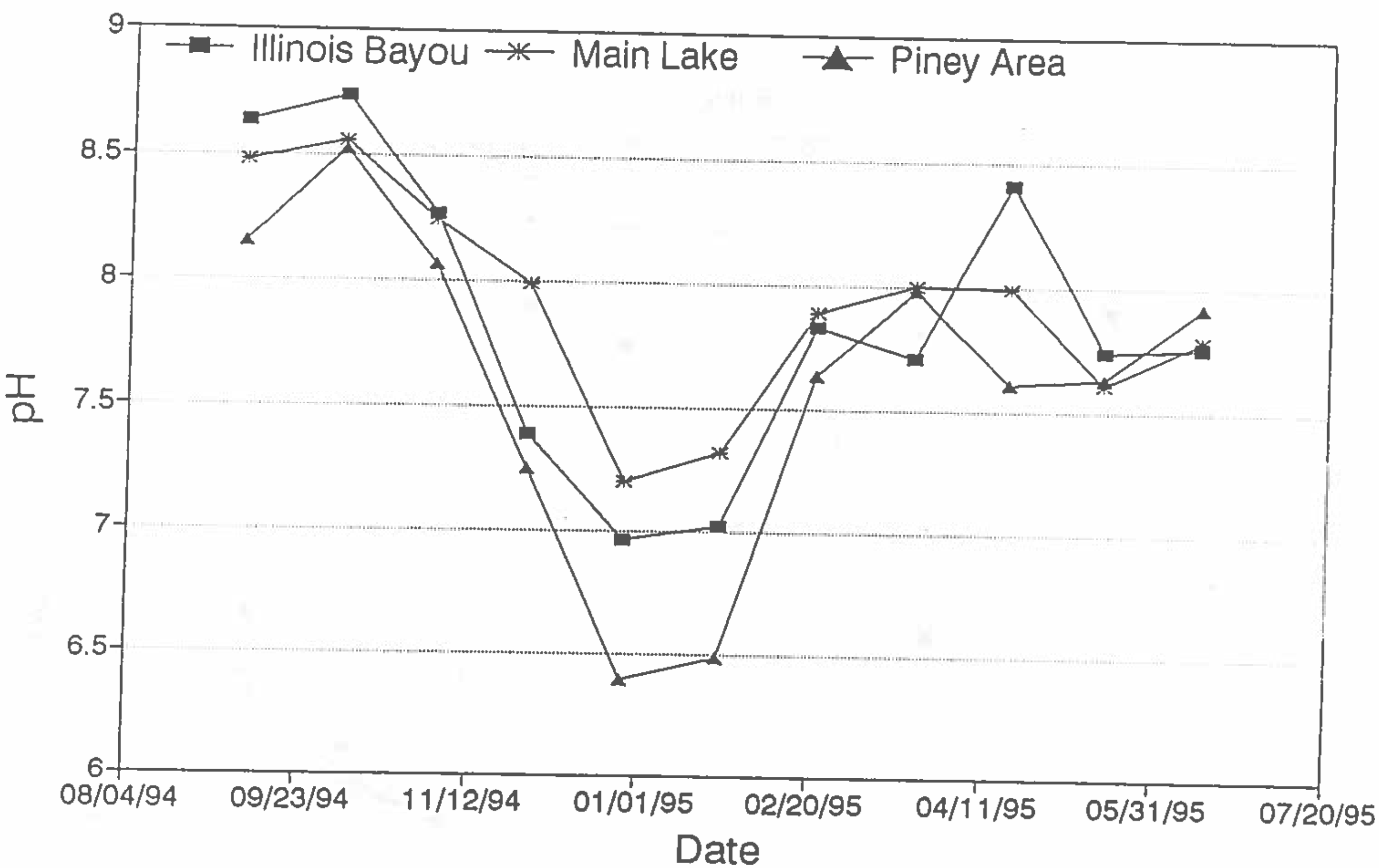

Figure 23. Comparison of pH values among sample areas and dates.

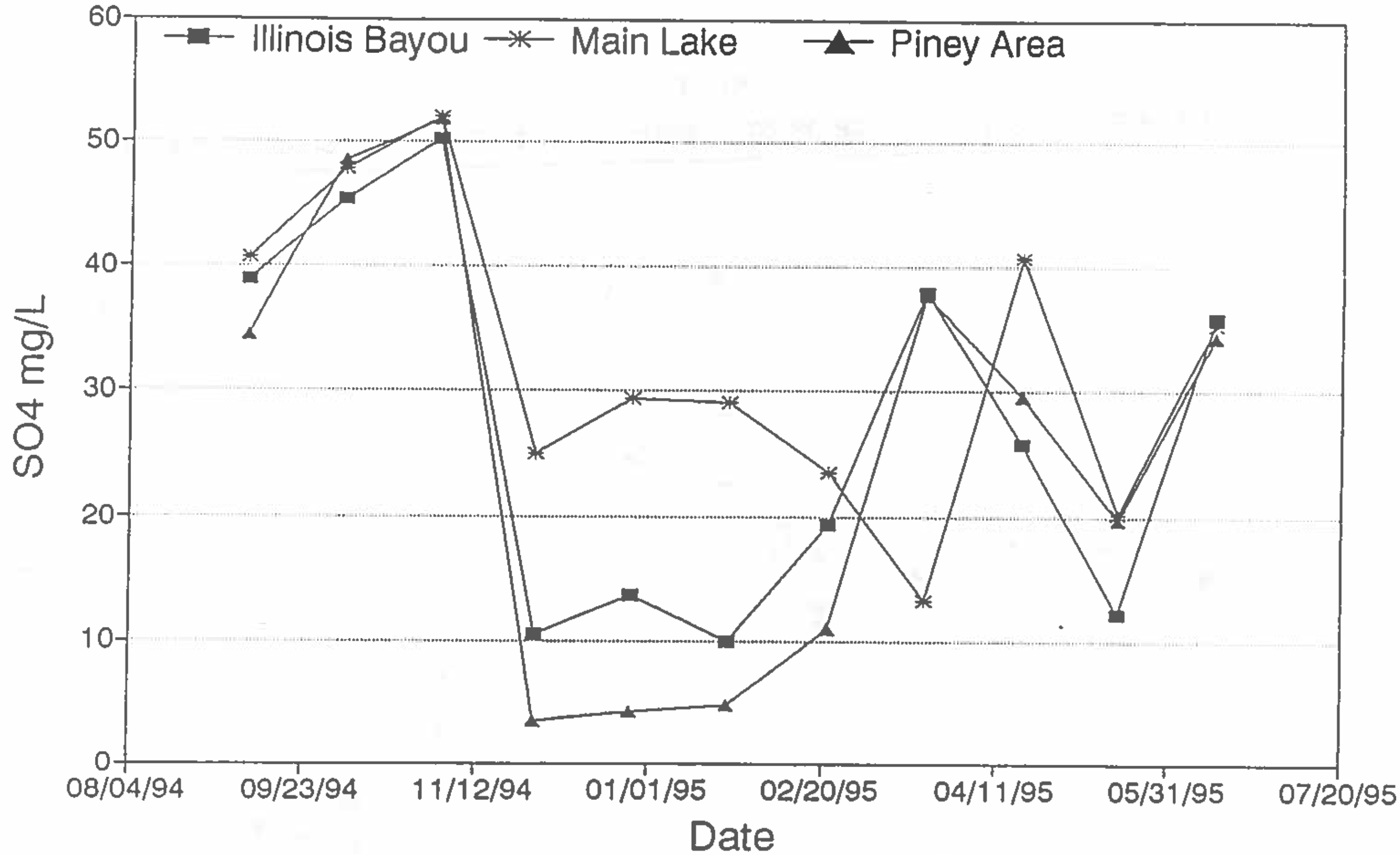

Figure 24. Comparison of sulfate concentrations among sample areas and dates.

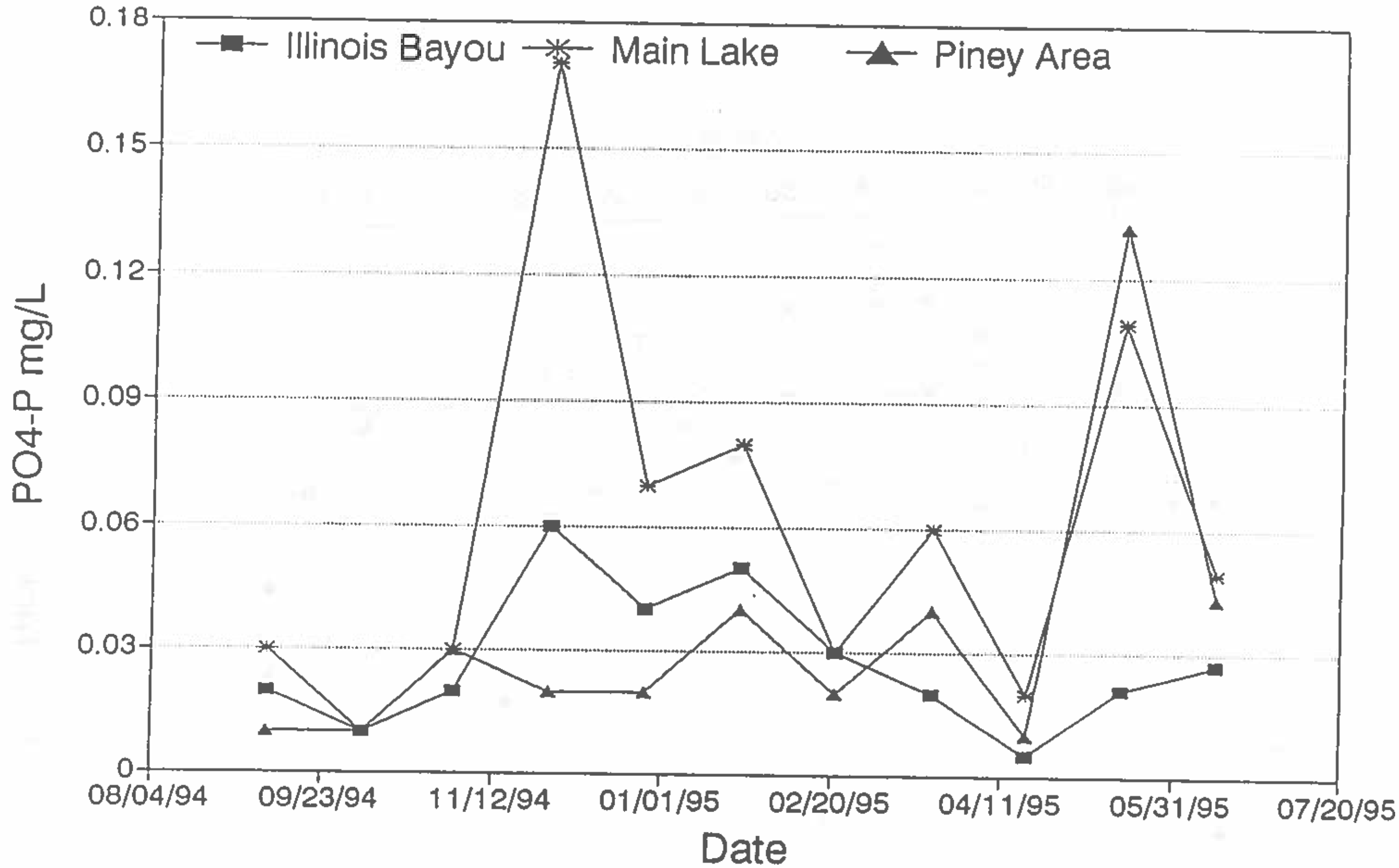

Figure 25. Comparison of phosphate-P concentrations among sample areas and dates.

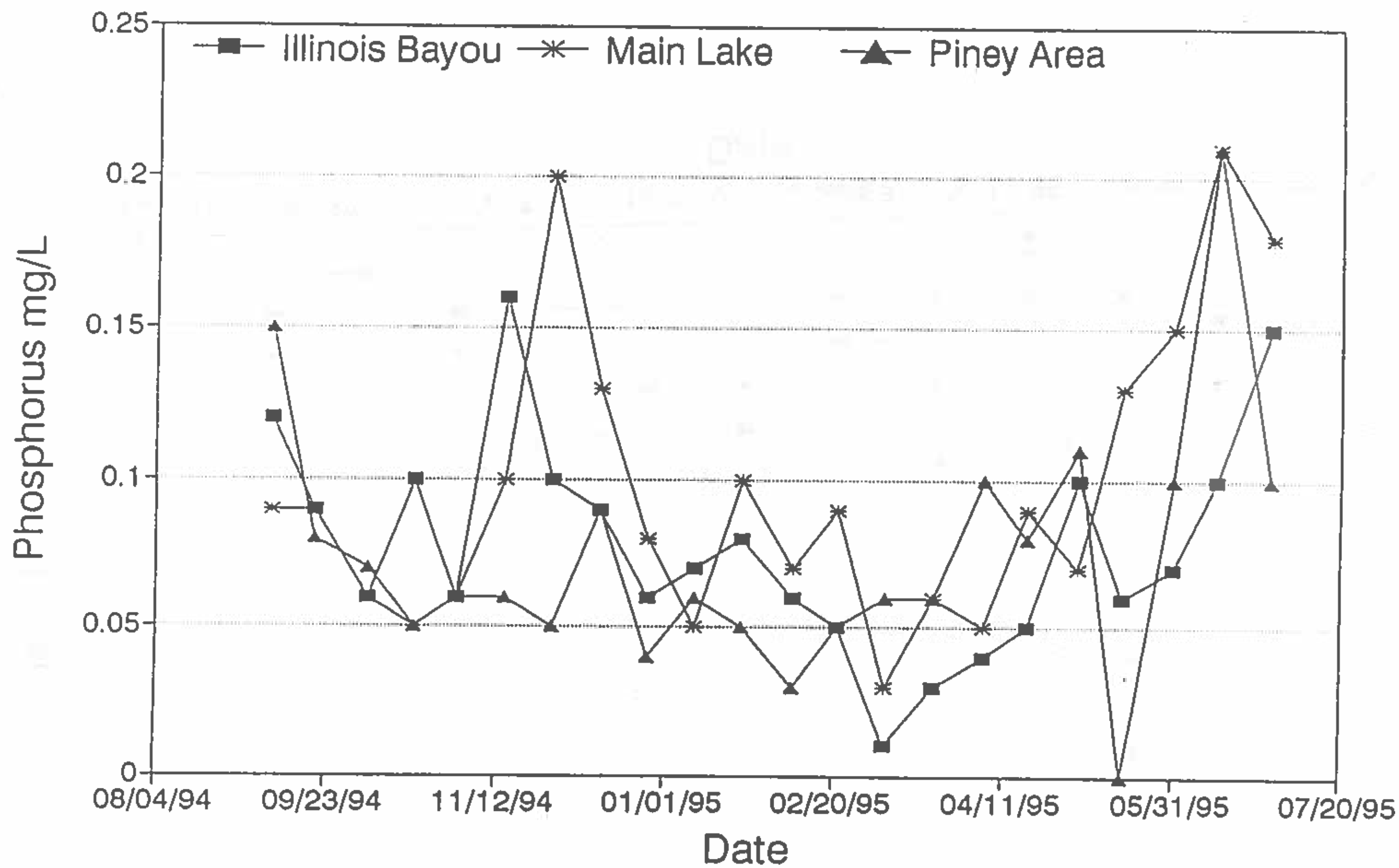

Figure 26. Comparison of total phosphorous concentrations among sample areas and dates.

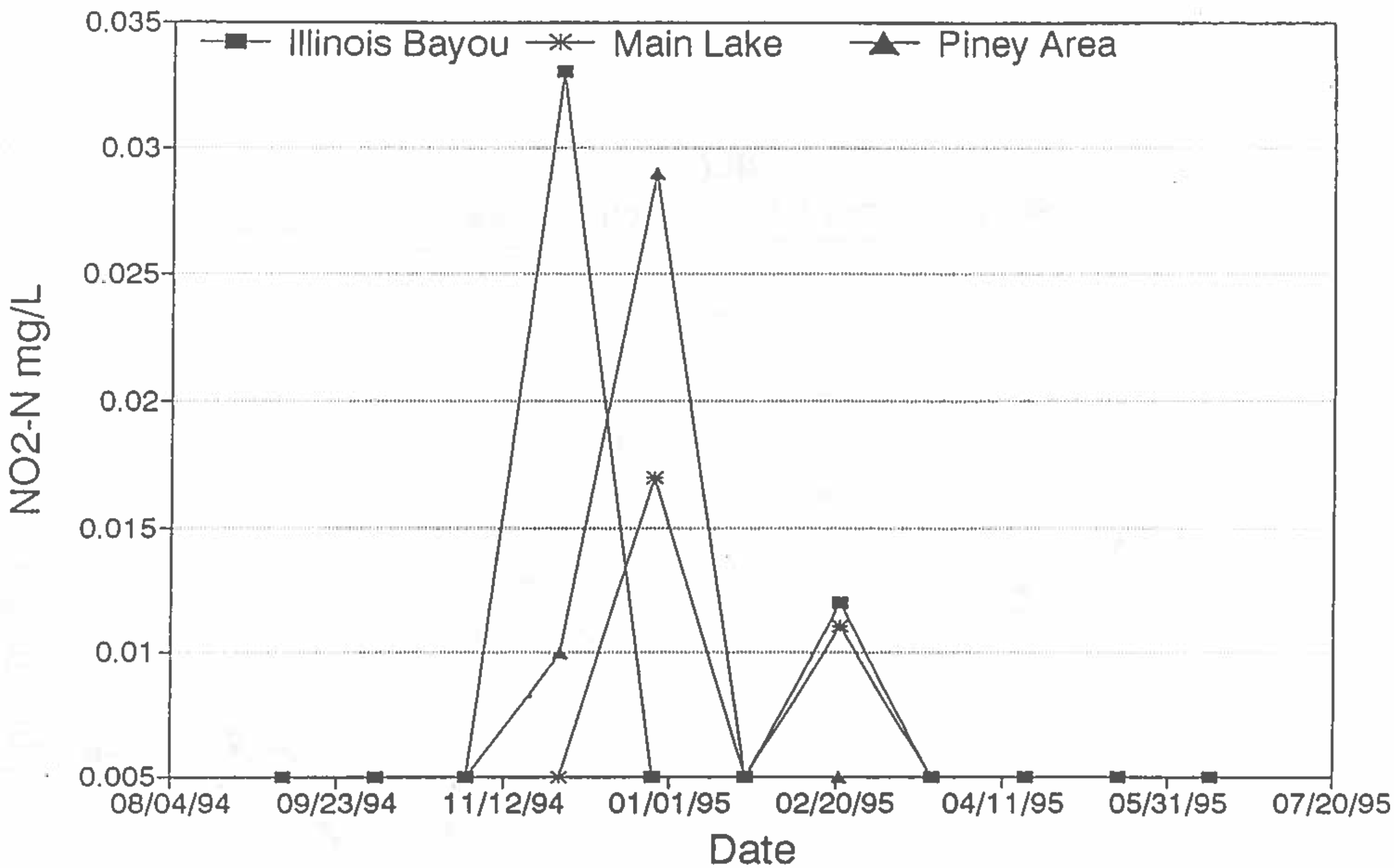

Figure 27. Comparison of nitrite-N concentrations among sample areas and dates.

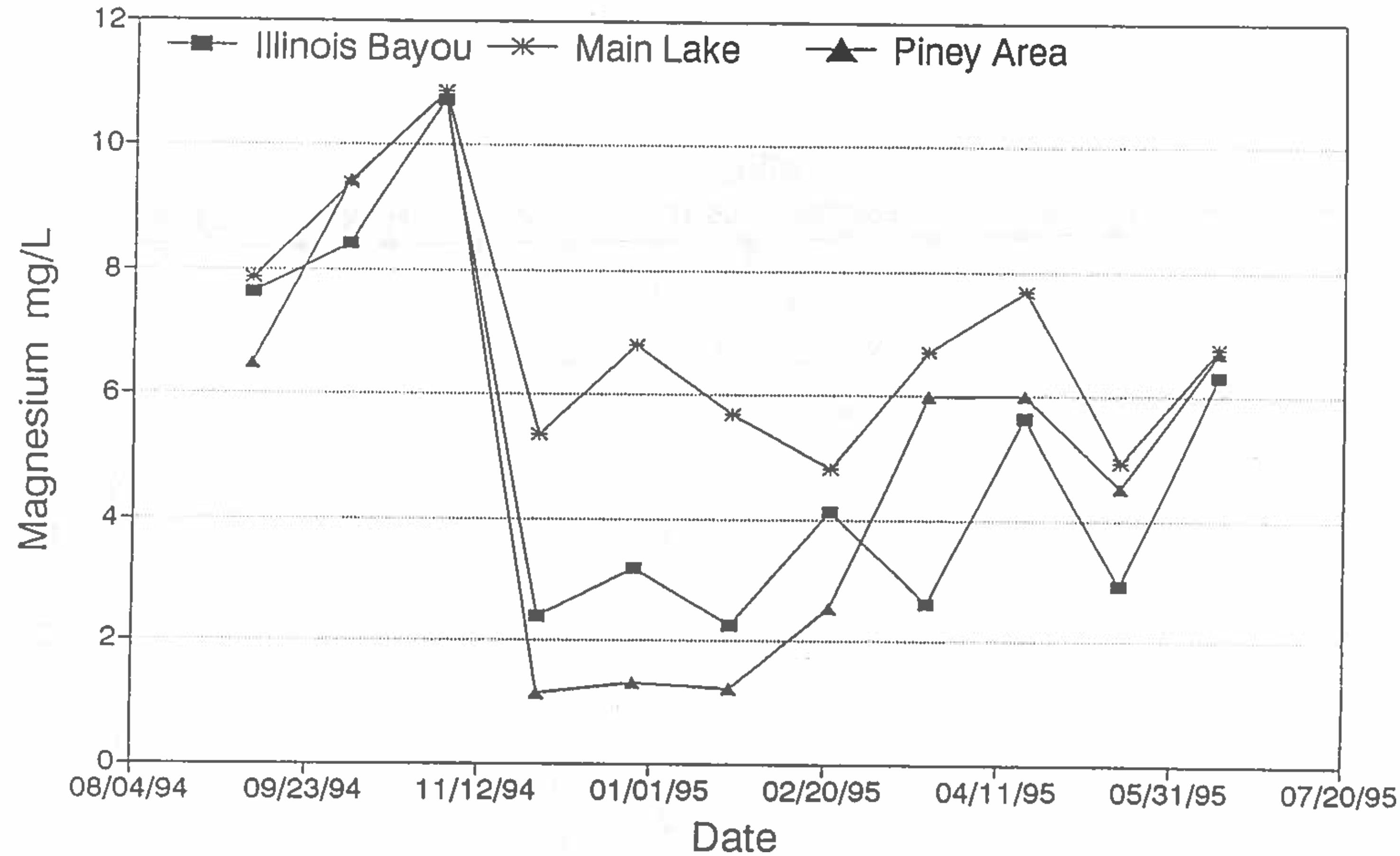

Figure 28. Comparison of magnesium concentrations among sample areas and dates.

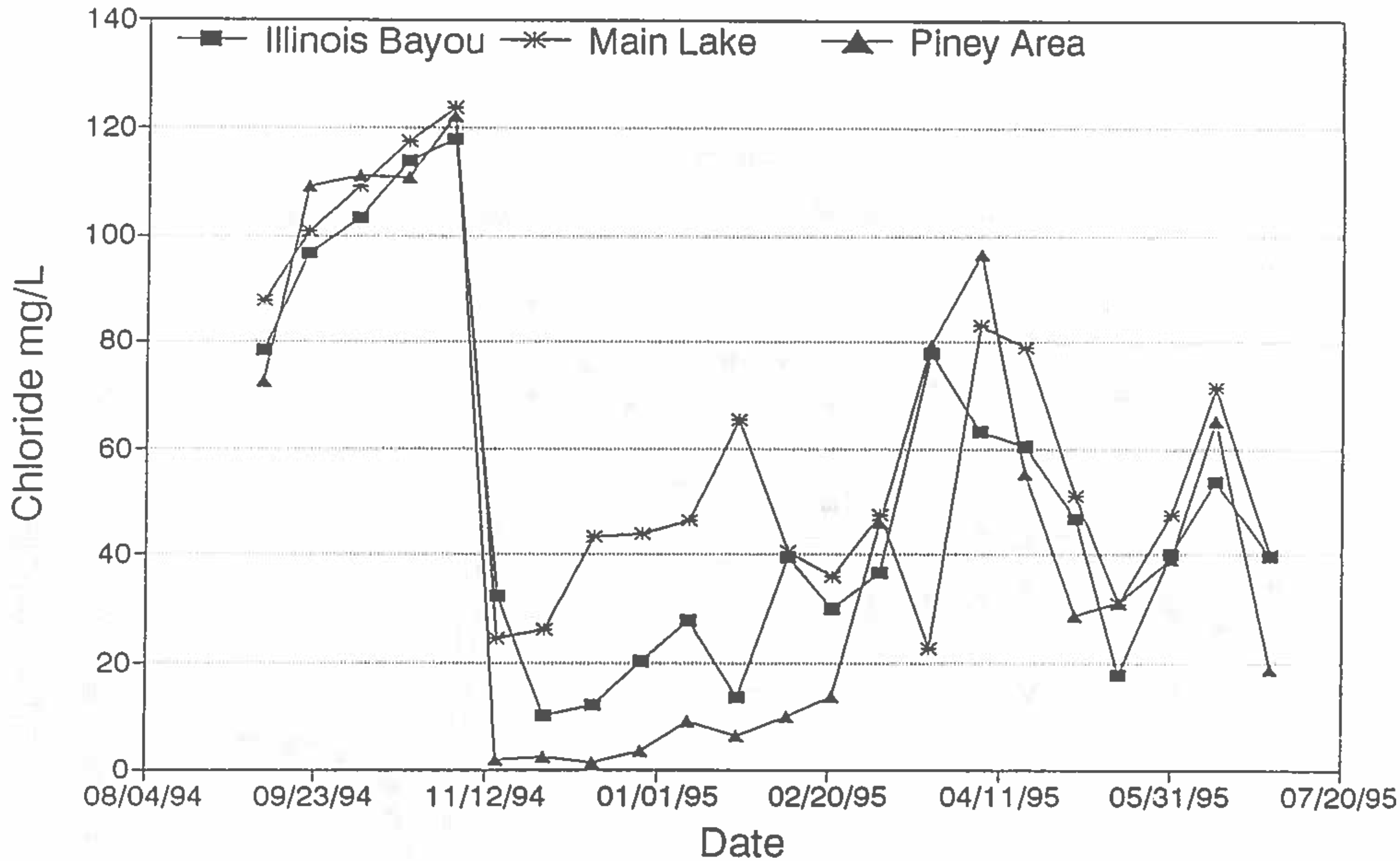

Figure 29. Comparison of chloride concentrations among sample areas and dates.

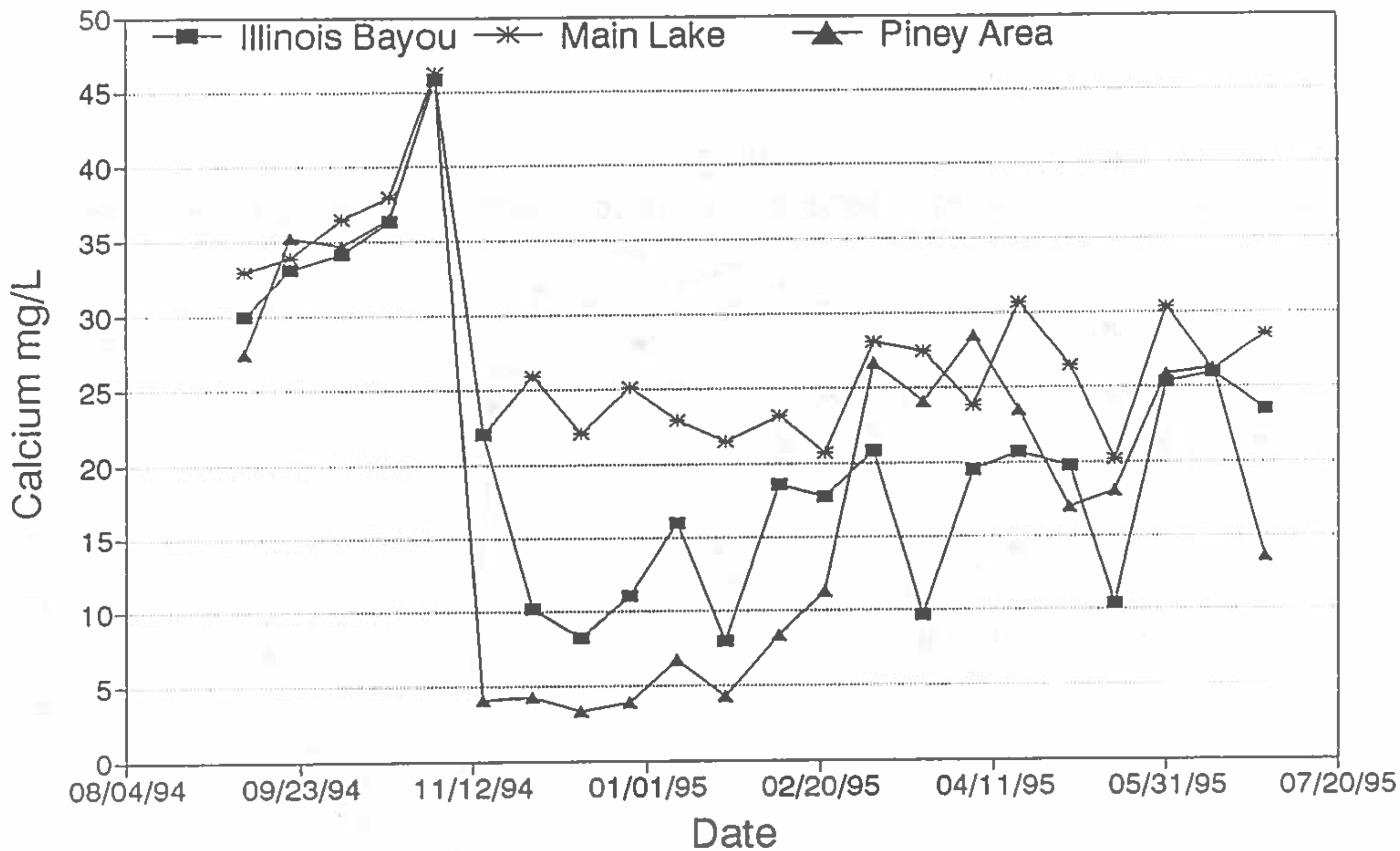

Figure 30. Comparison of calcium concentrations among sample areas and dates.

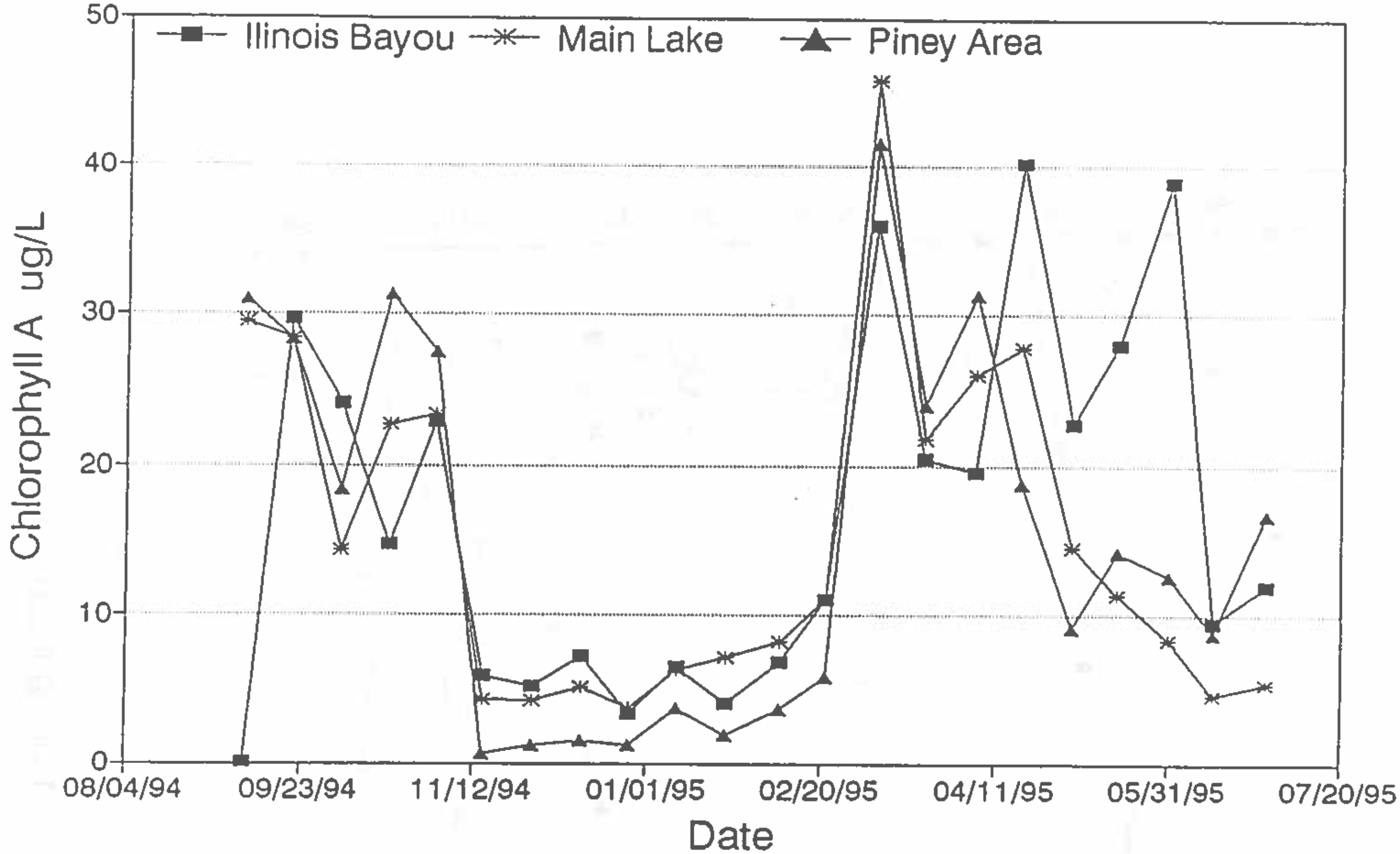

Figure 31. Comparison of chlorophyll a concentrations among sample areas and dates.

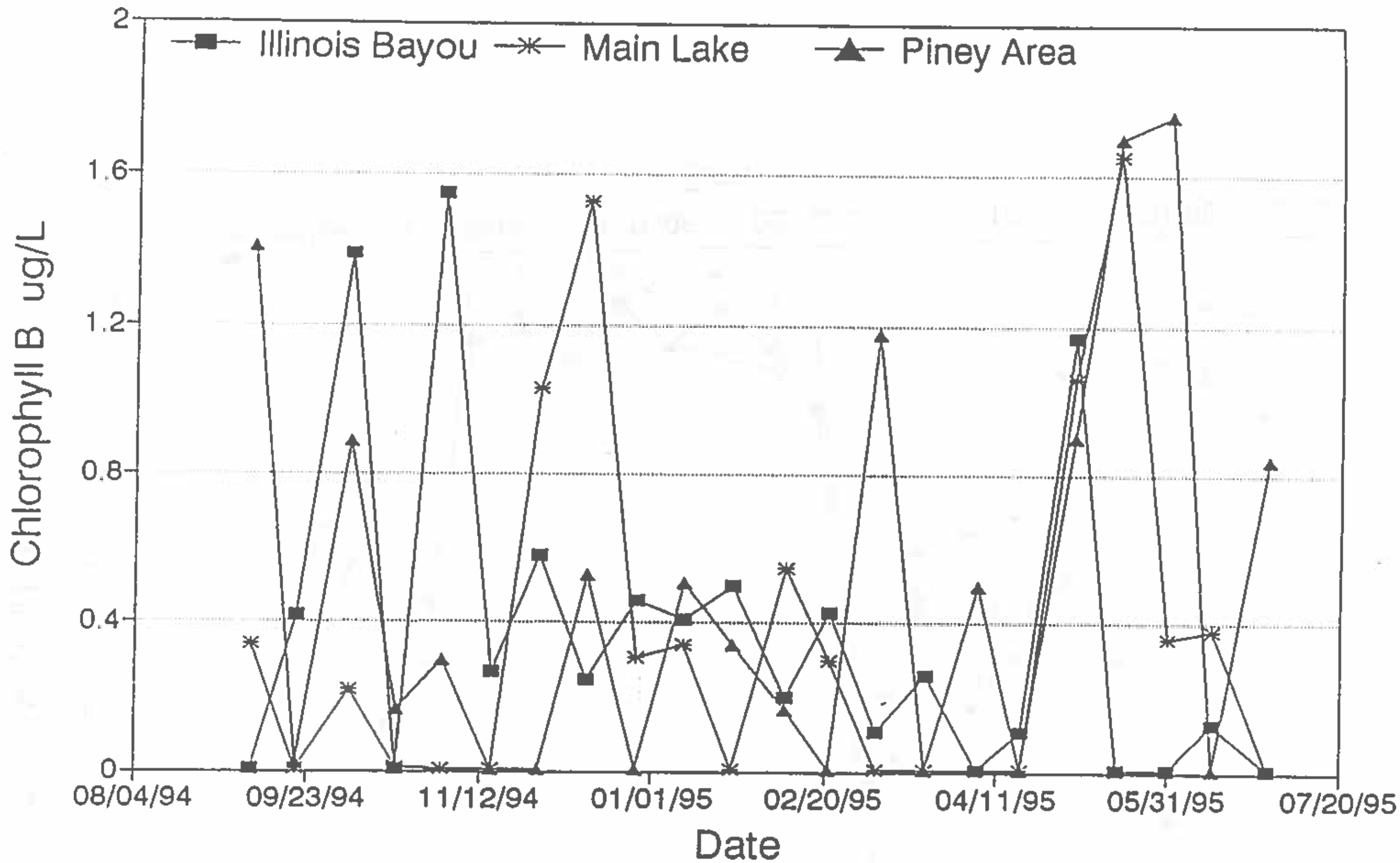

Figure 32. Comparison of chlorophyll b concentrations among sample areas and dates.

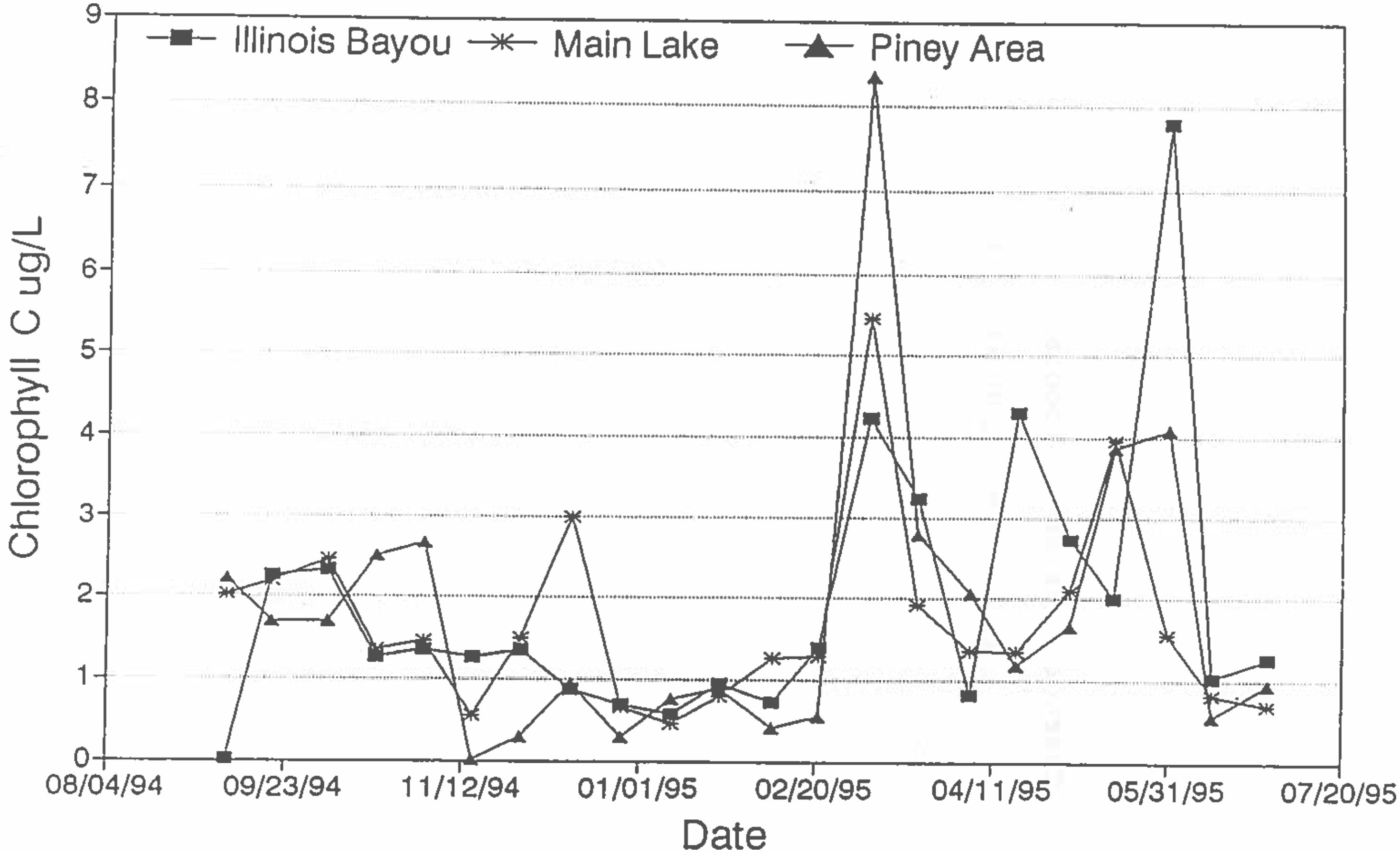

Figure 33. Comparison of chlorophyll c concentrations among sample areas and dates.

Appendix B

Characteristics of Zooplankton Samples

from Lake Dardanelle, AR

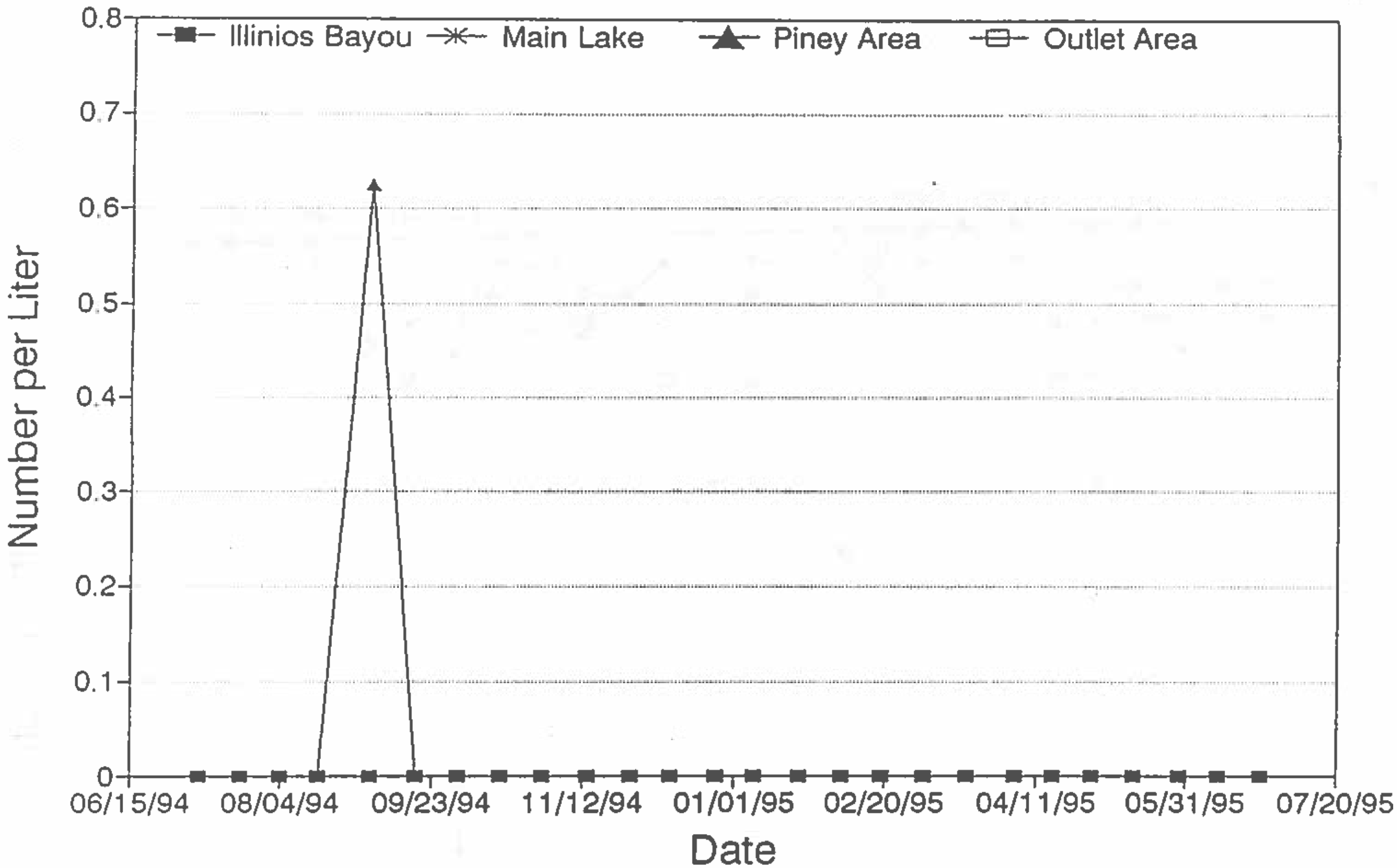

Figure 34. Changes in densities of ostracods collected in vertical tow samples among sample areas and dates.

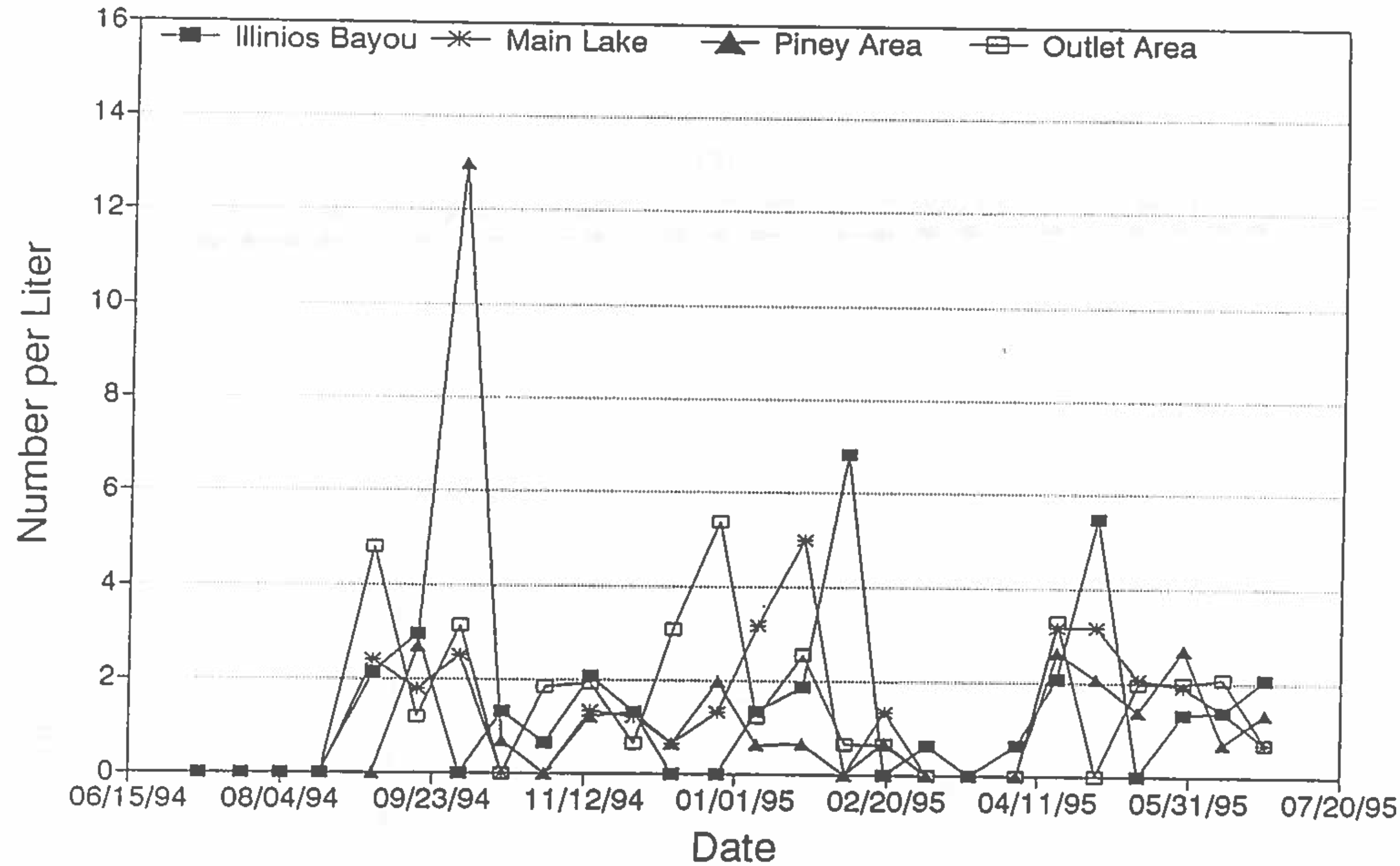

Figure 35. Changes in densities of other zooplankton collected in vertical tow samples among sample areas and dates.

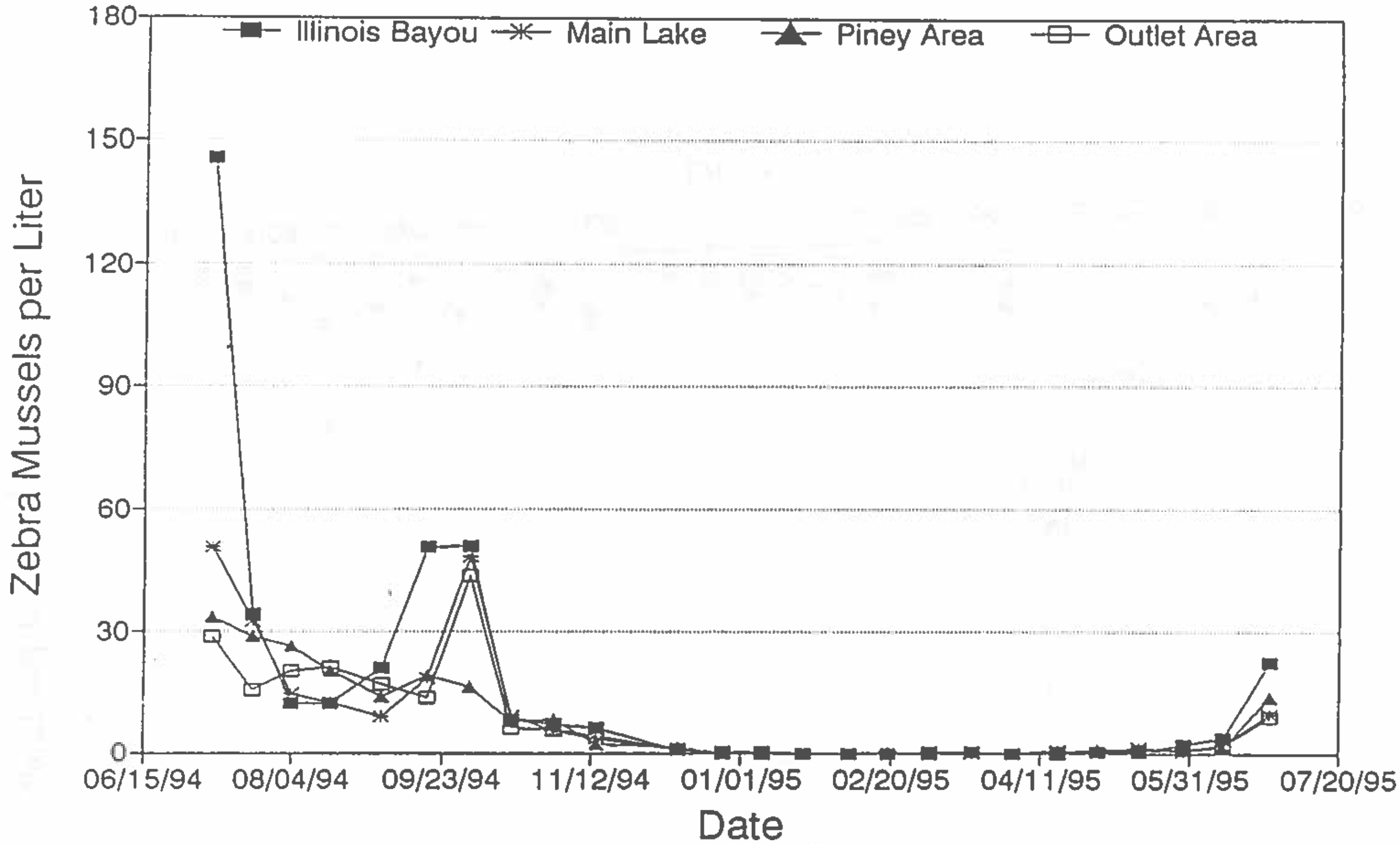

Figure 36. Changes in densities of zebra mussels collected in vertical tow samples among sample areas and dates.

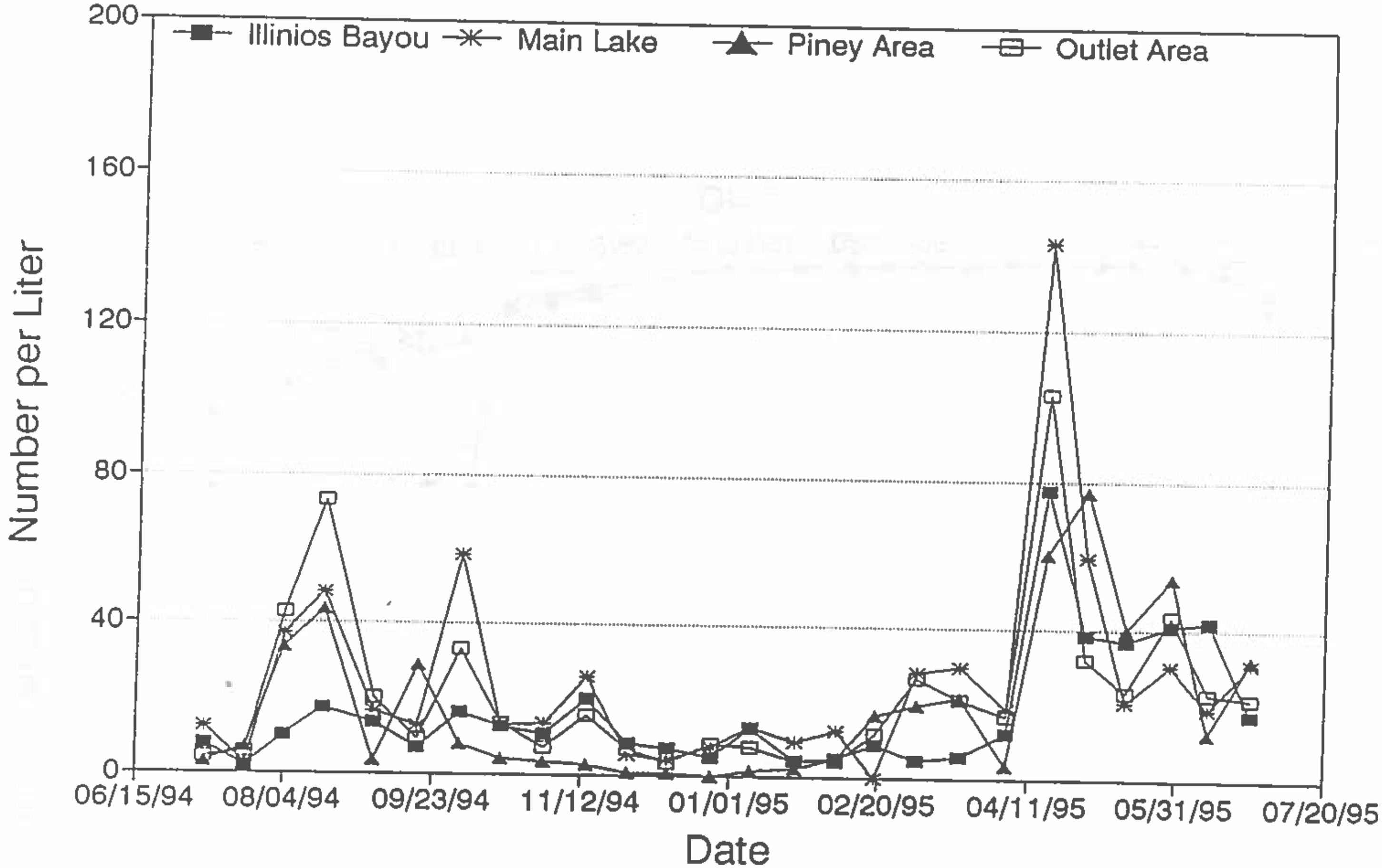

Figure 37. Changes in densities of rotifers collected in pump samples among sample areas and dates.

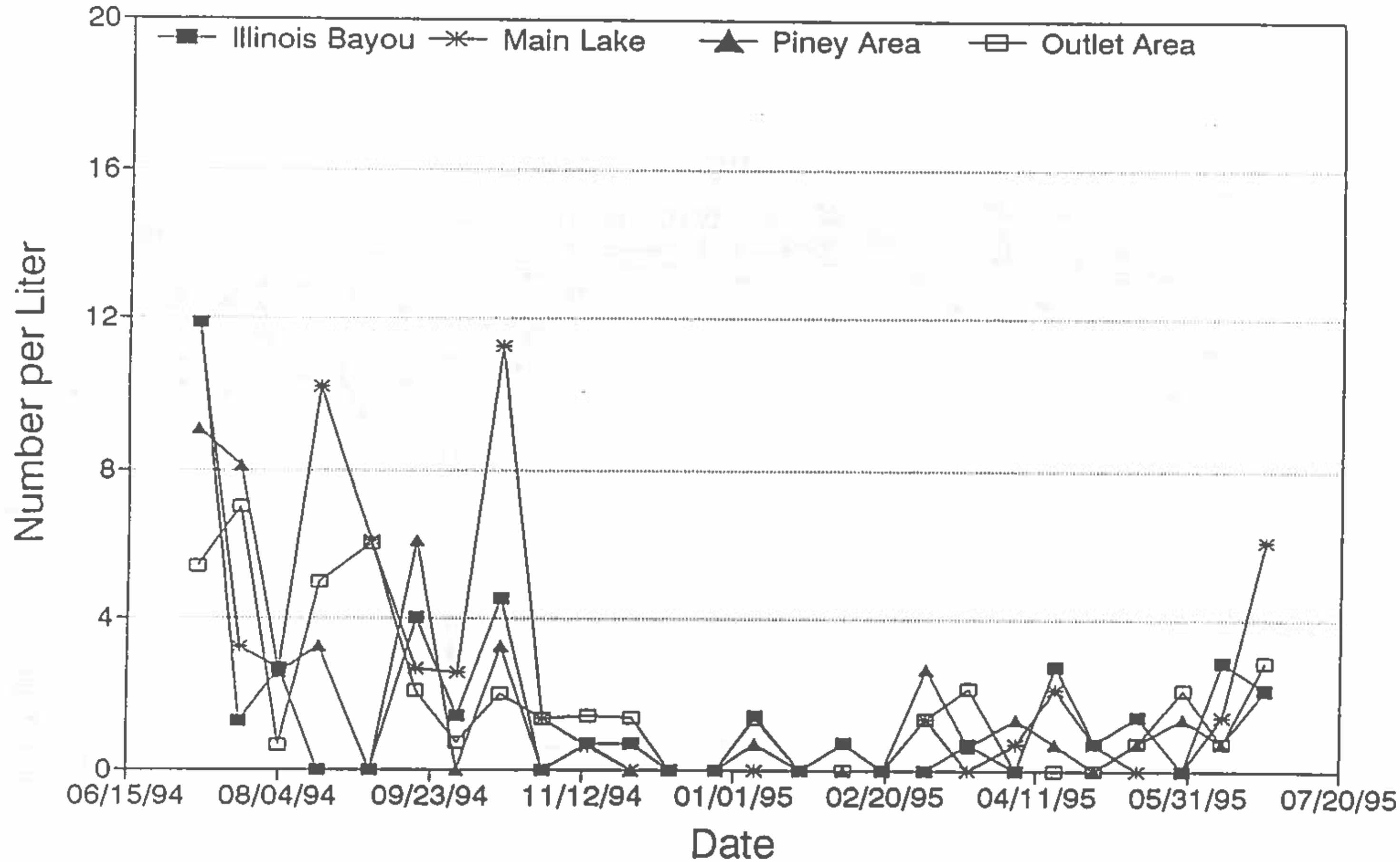

Figure 38. Changes in densities of nauplii collected in pump samples among sample areas and dates.

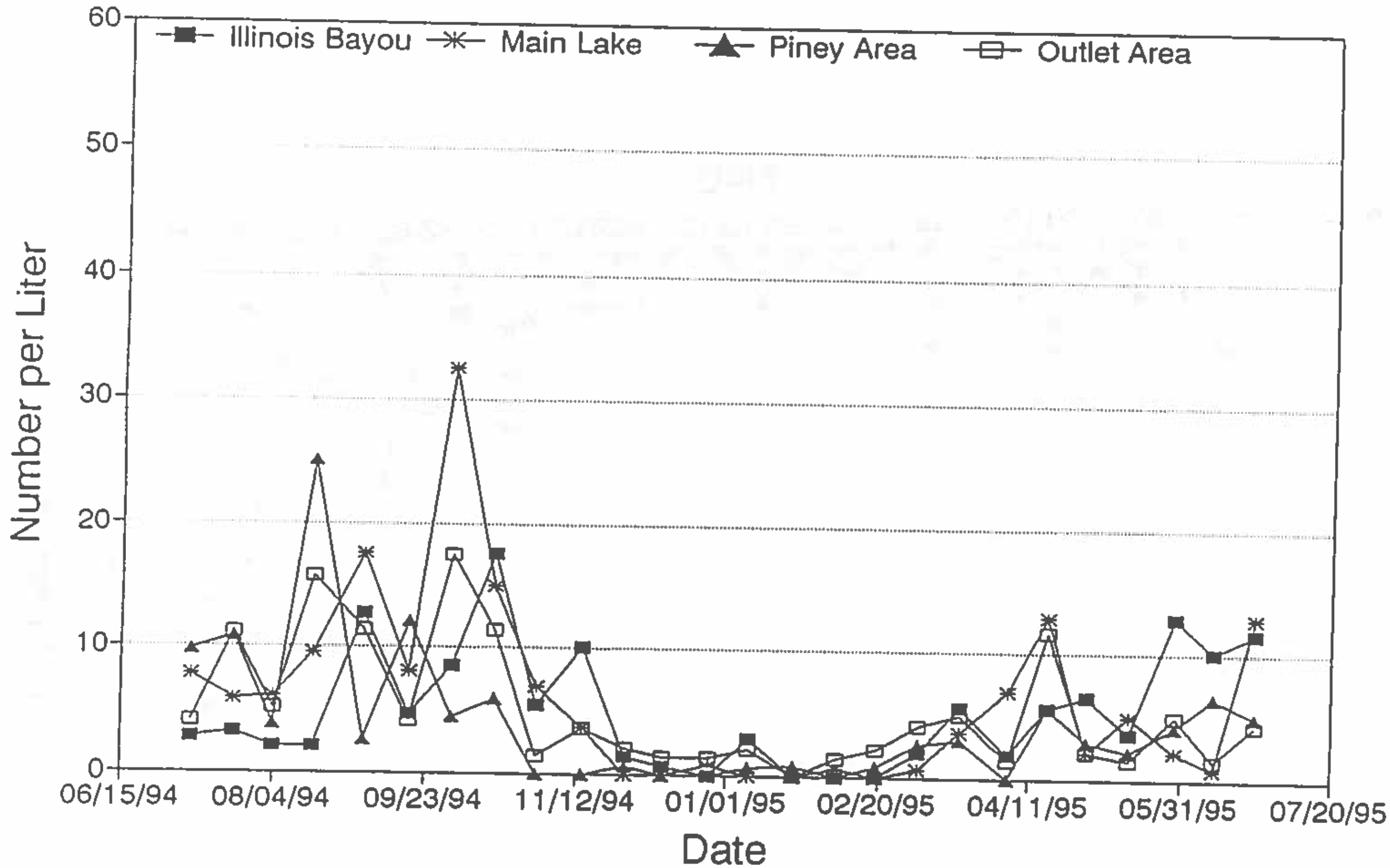

Figure 39. Changes in densities of copepods collected in pump samples among sample areas and dates.

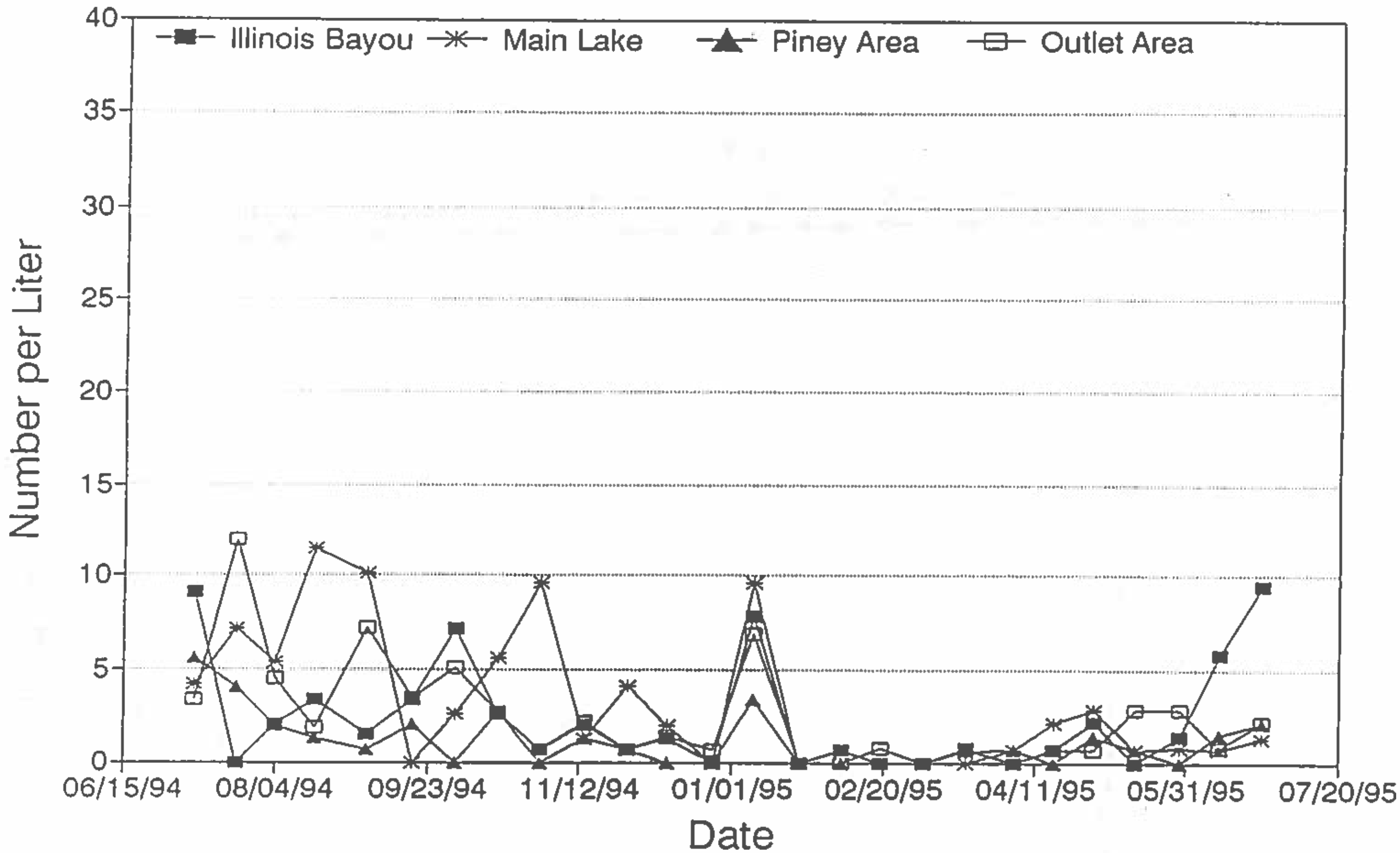

Figure 40. Changes in densities of cladocerans collected in pump samples among sample areas and dates.

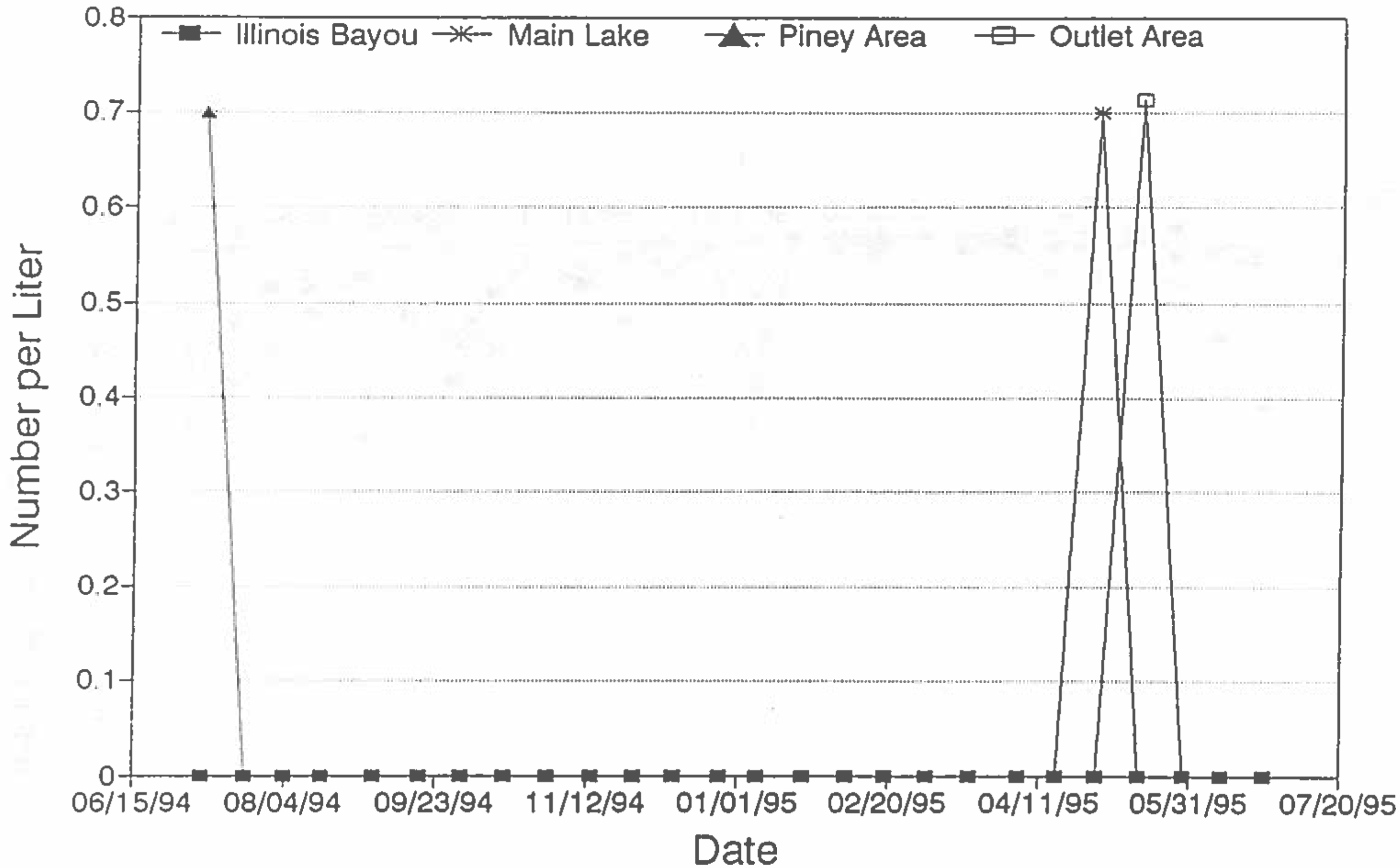

Figure 41. Changes in densities of ostracods collected in pump samples among sample areas and dates.

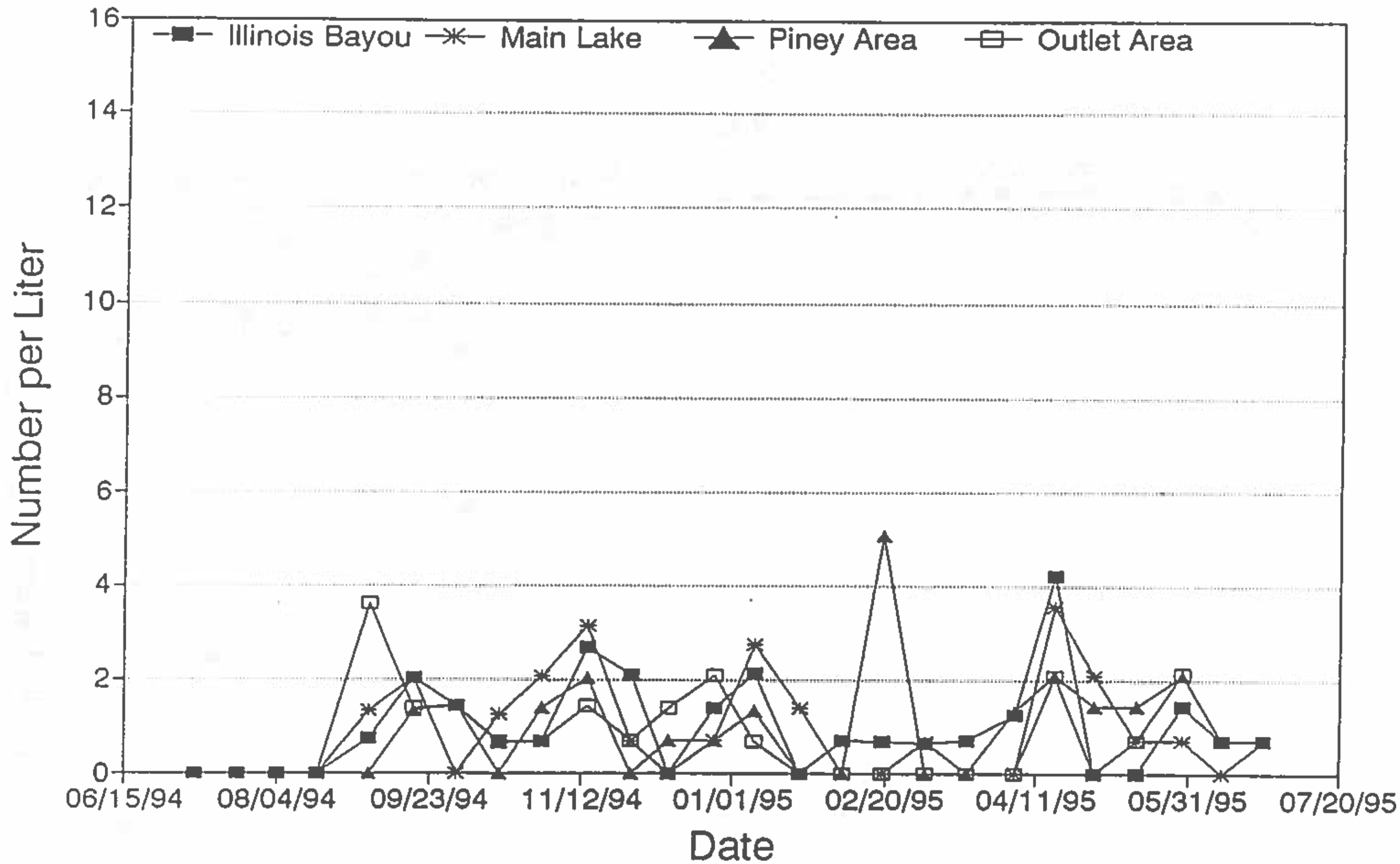

Figure 42. Changes in densities of other zooplankton collected in pump samples among sample areas and dates.

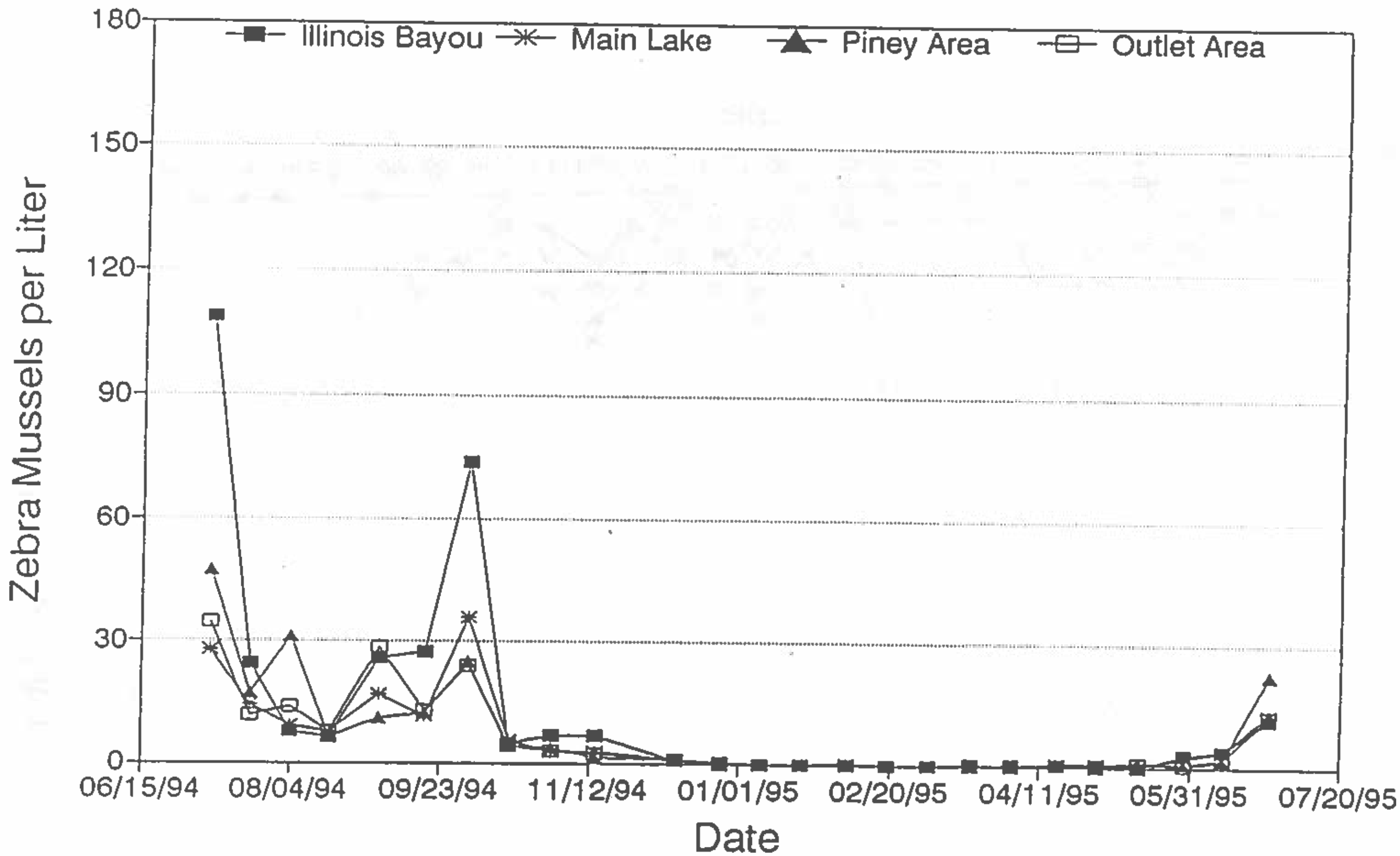

Figure 43. Changes in densities of zebra mussels collected in pump samples among sample areas and dates.

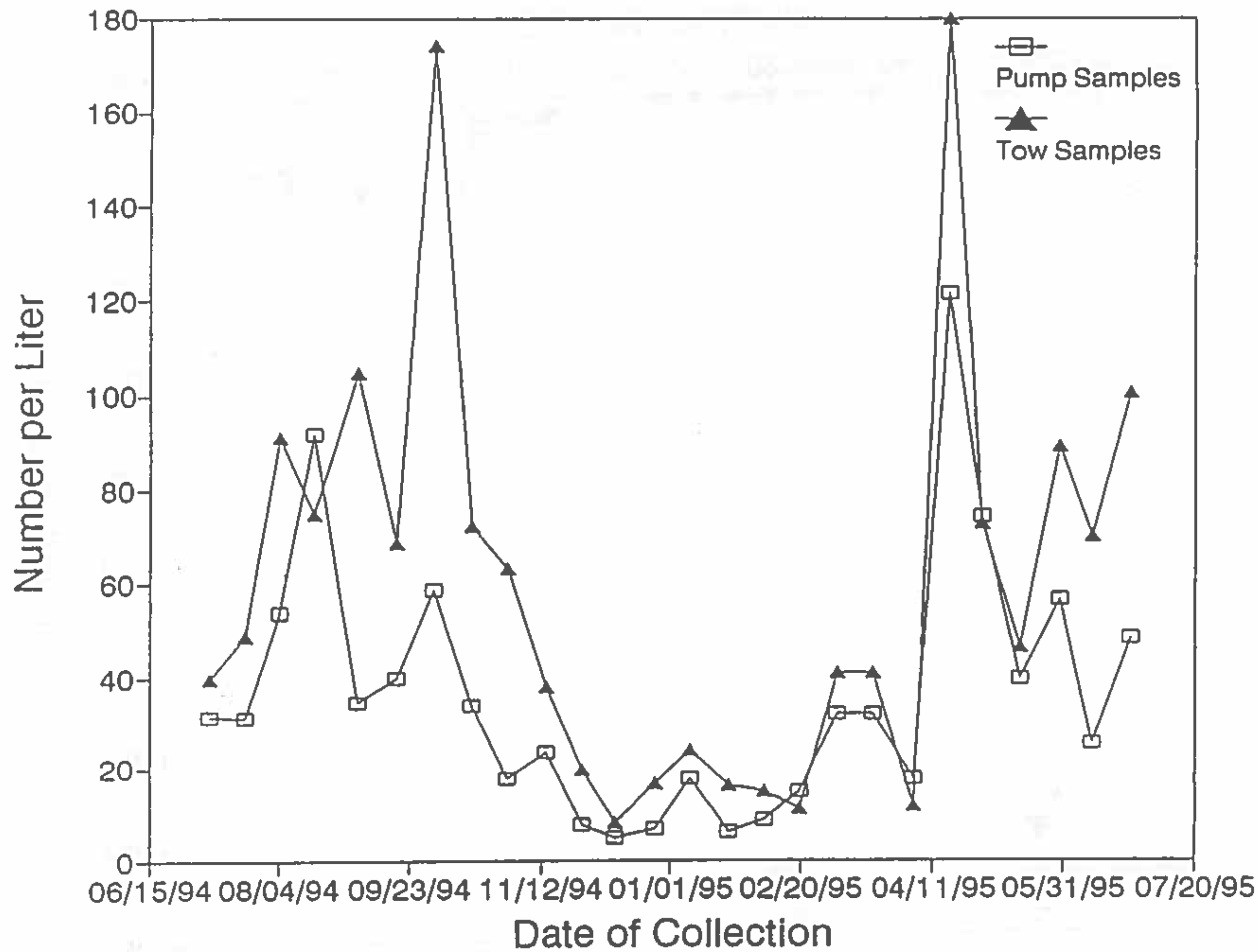

Figure 44. Comparison of densities of zooplankton collected in pump samples and densities of zooplankton collected in pull samples among dates. Values for each date are averaged across four sample areas.

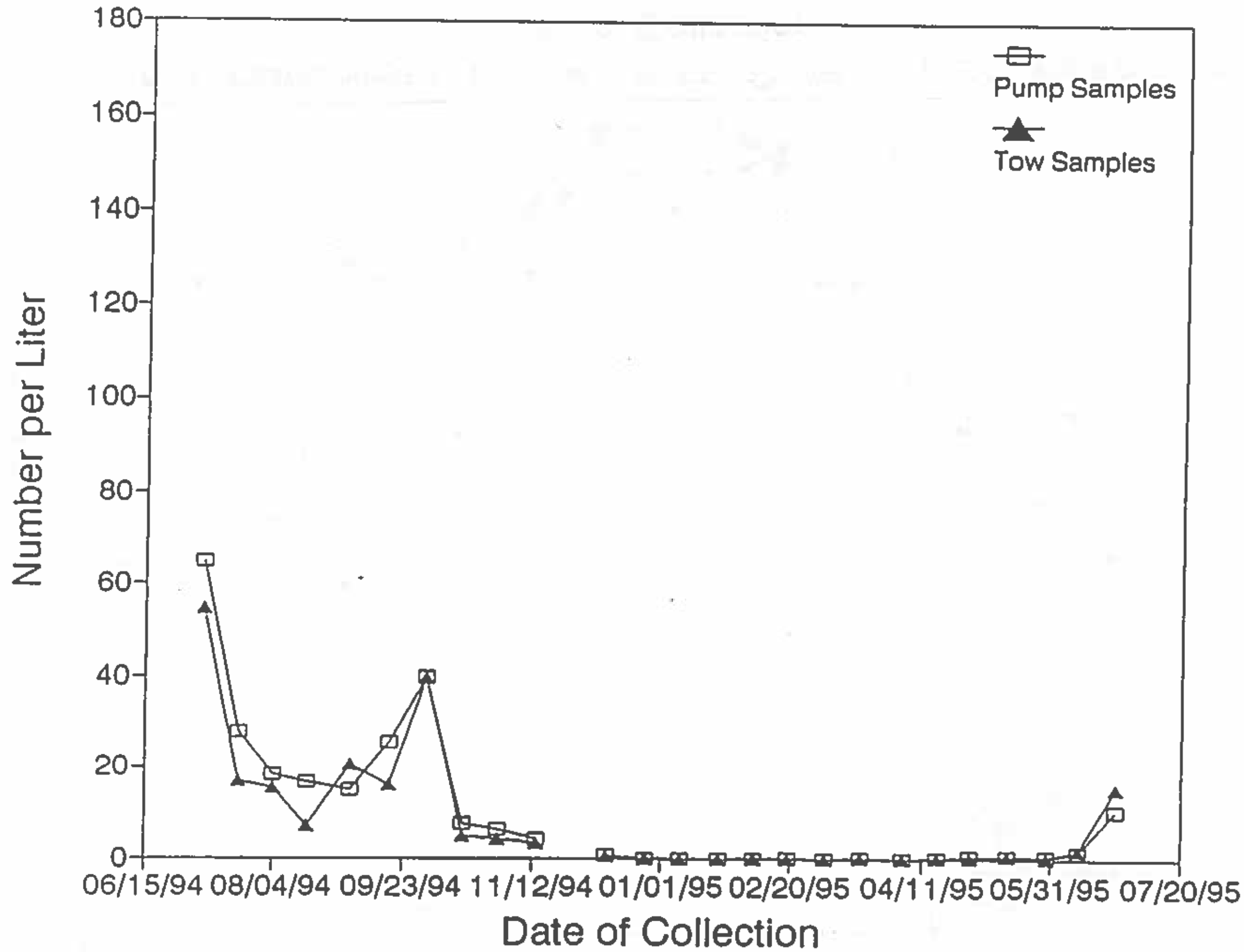

Figure 45. Comparison of densities of zebra mussels collected in pump samples and densities of zebra mussels collected in pull samples among dates. Values for each date are averaged across four sample areas.

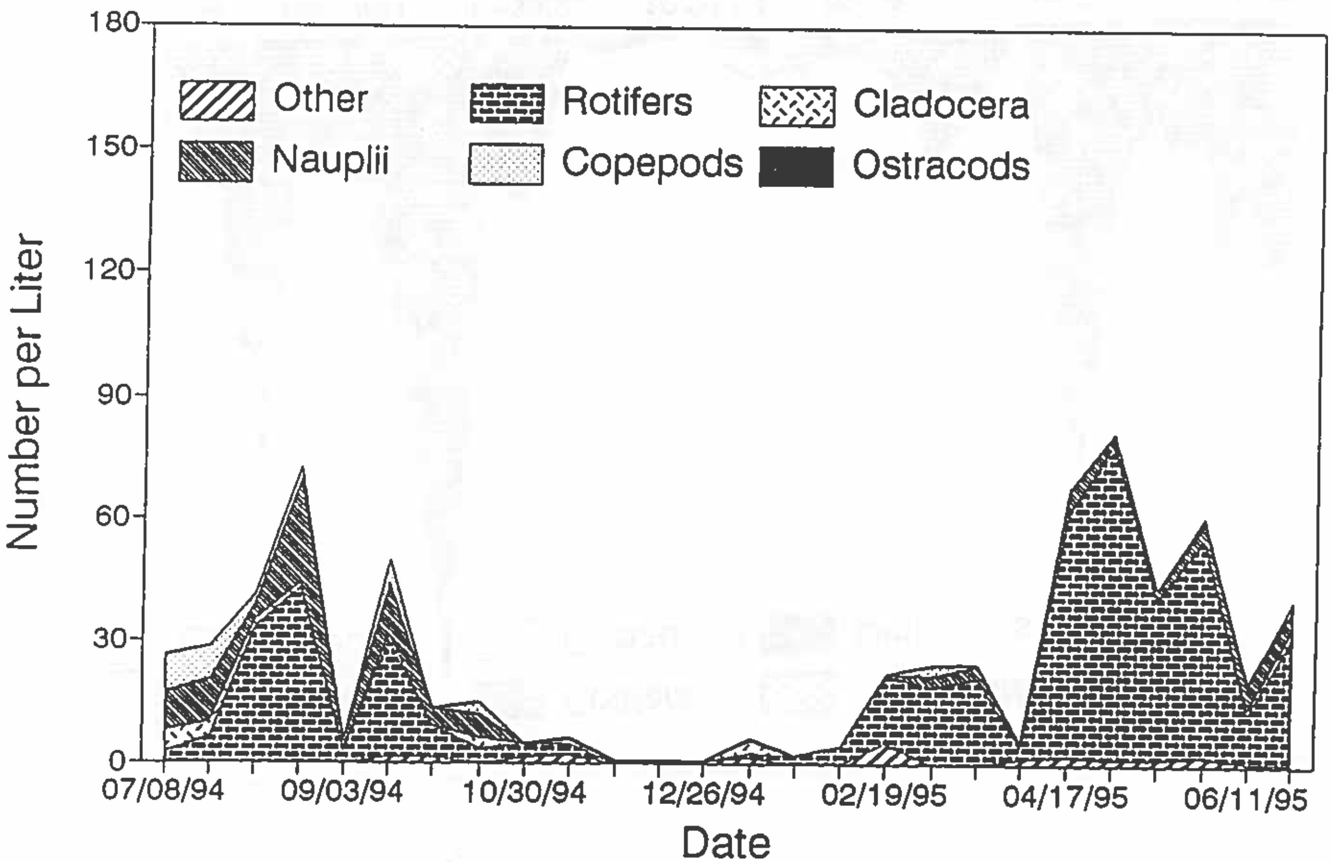

Figure 46. Comparison of densities of zooplankton (exclusive of zebra mussels) collected in pump samples at the Piney Area of Lake Dardanelle, AR, since July 8, 1994.

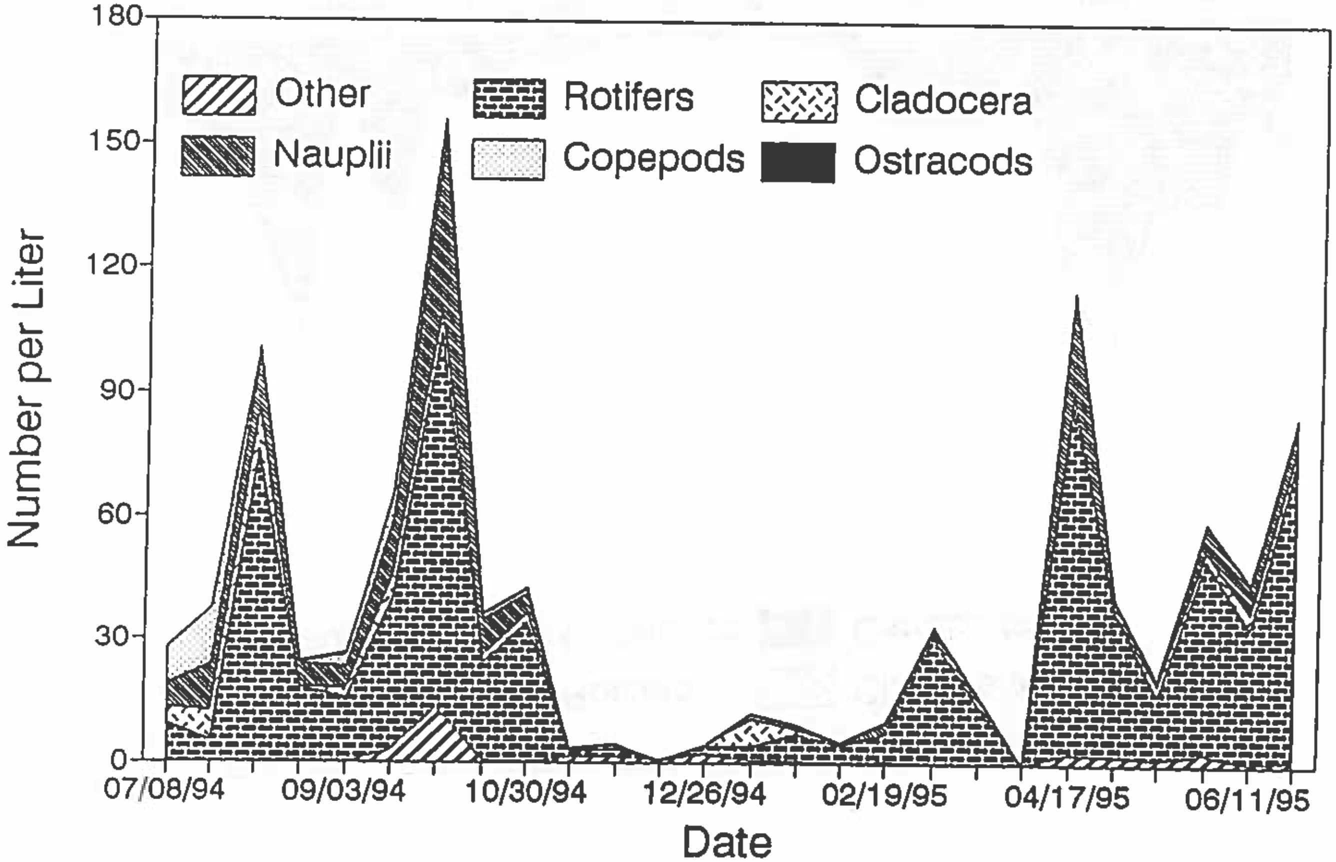

Figure 47. Comparison of densities of zooplankton (exclusive of zebra mussels) collected in vertical tow samples at the Piney Area of Lake Dardanelle, AR, since July 8, 1994.

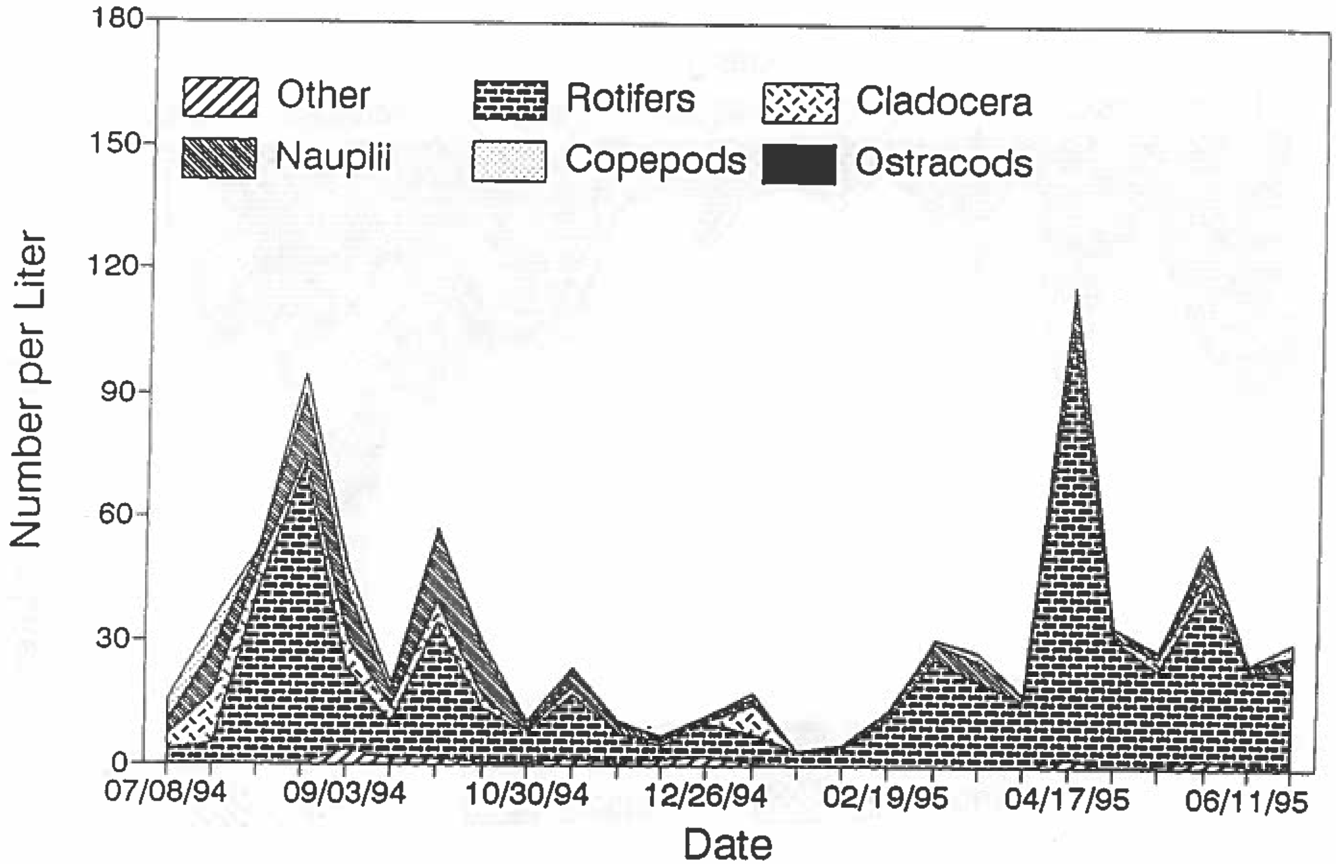

Figure 48. Comparison of densities of zooplankton (exclusive of zebra mussels) collected in pump samples at the Outlet Area of Lake Dardanelle, AR, since July 8, 1994.

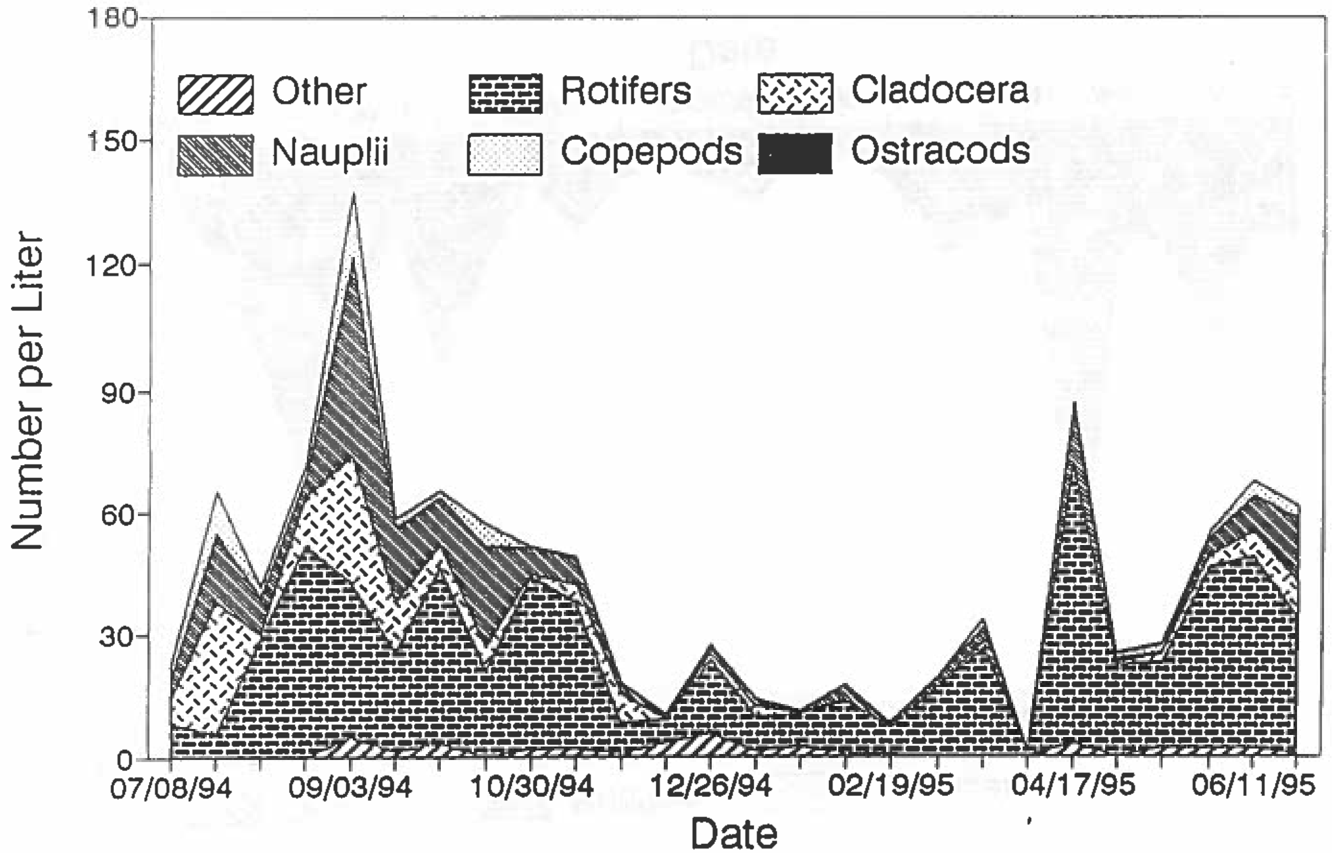

Figure 49. Comparison of densities of zooplankton (exclusive of zebra mussels) collected in vertical tow samples at the Outlet Lake Area of Lake Dardanelle, AR, since July 8, 1994.

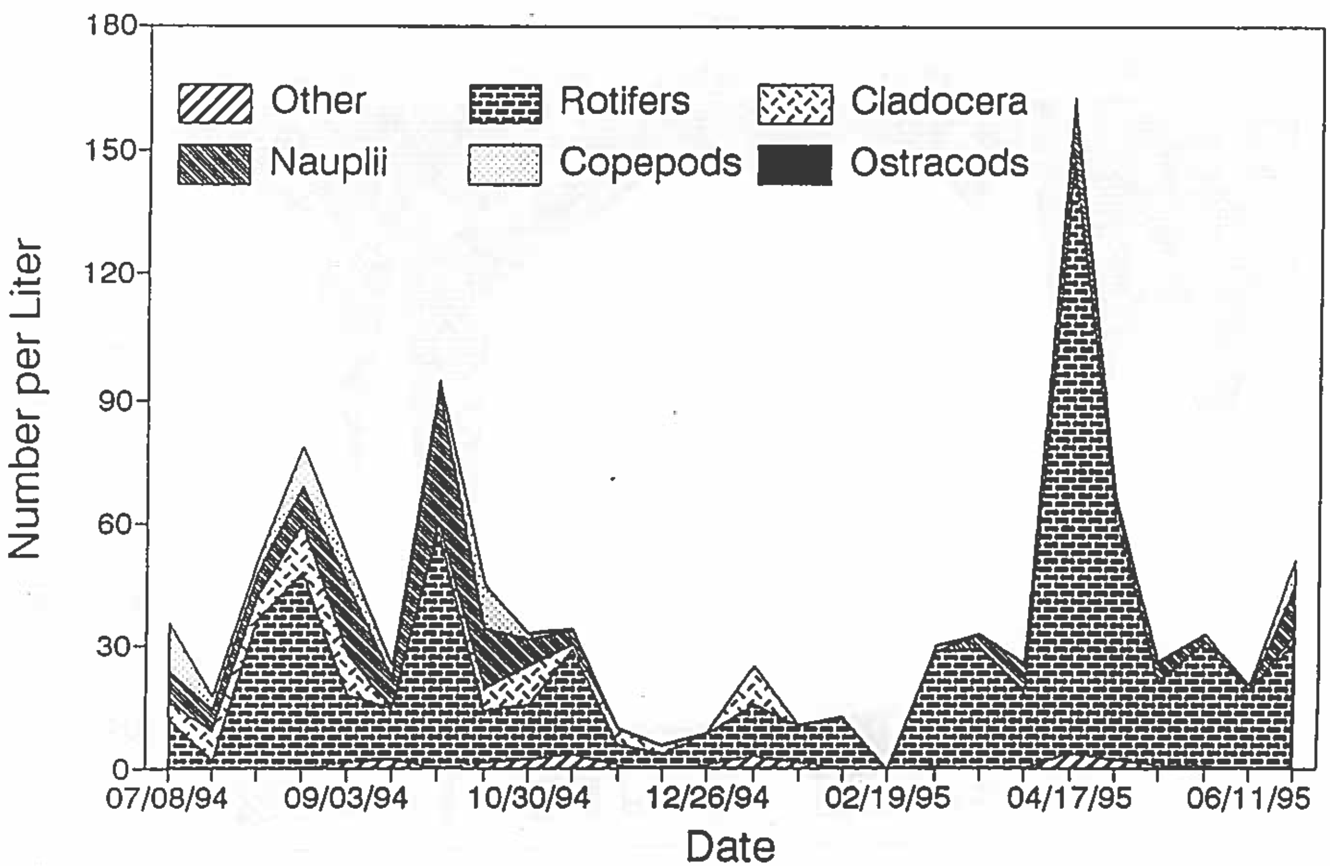

Figure 50. Comparison of densities of zooplankton (exclusive of zebra mussels) collected in pump samples at the Main Lake Area of Lake Dardanelle, AR, since July 8, 1994.

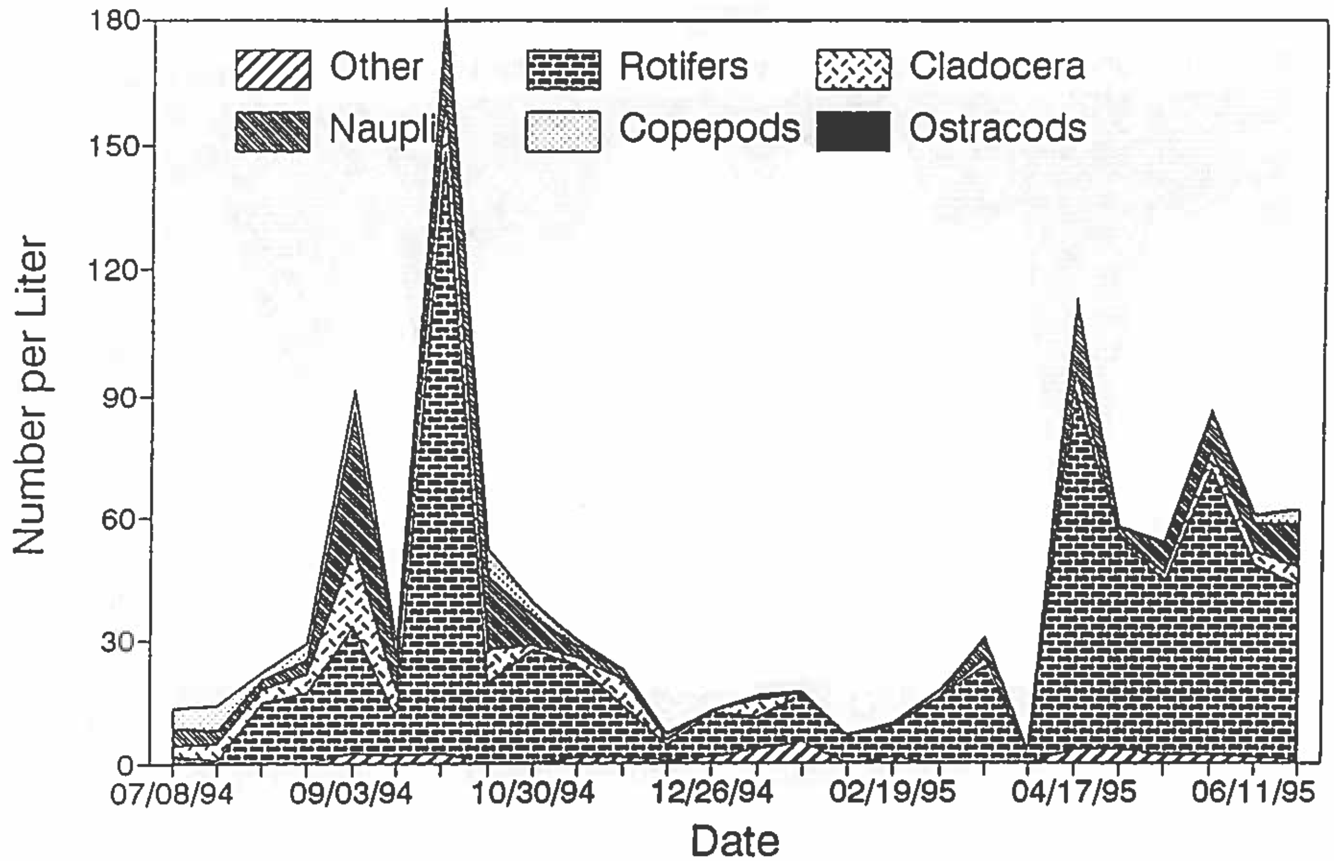

Figure 51. Comparison of densities of zooplankton (exclusive of zebra mussels) collected in vertical tow samples at the Main Lake Area of Lake Dardanelle, AR, since July 8, 1994.

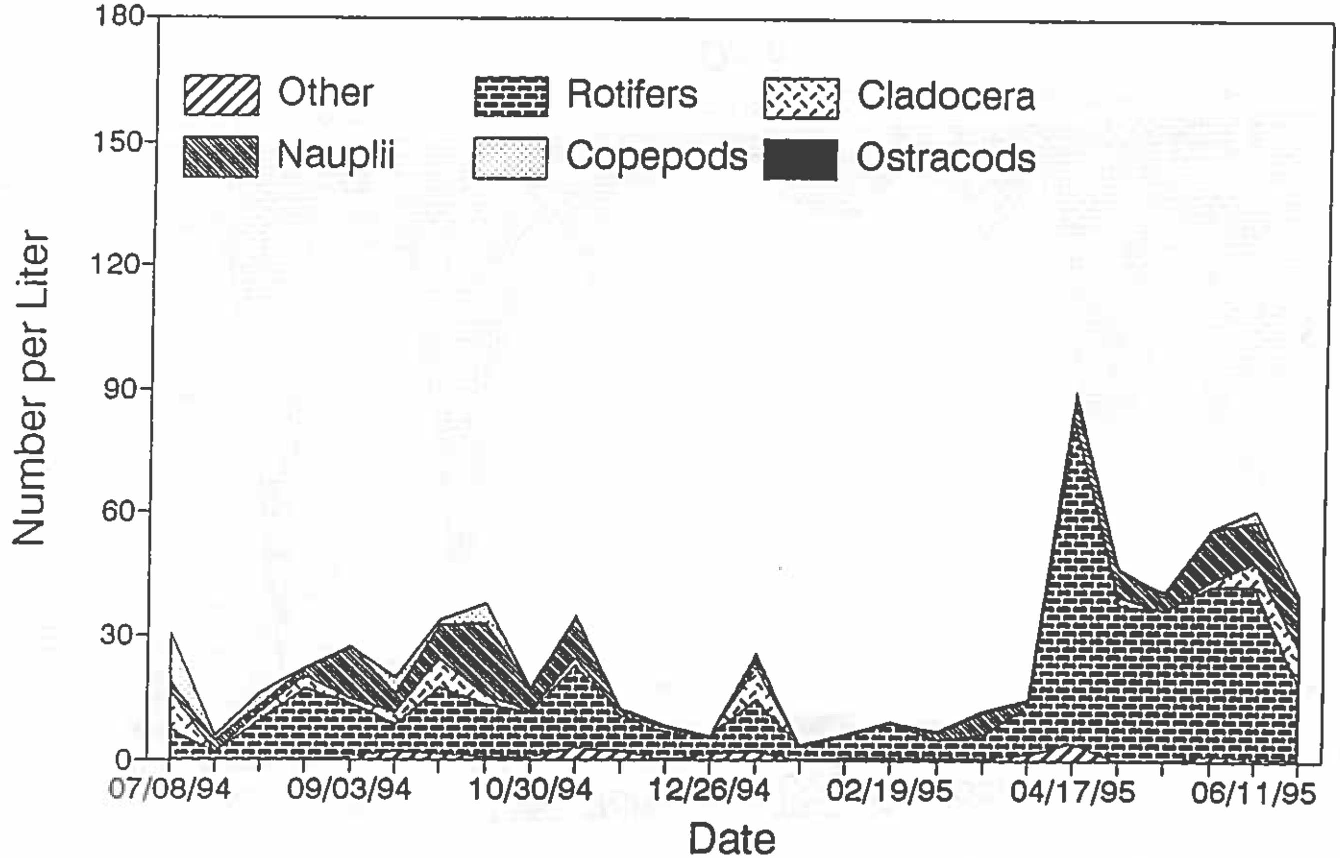

Figure 52. Comparison of densities of zooplankton (exclusive of zebra mussels) collected in pump samples at the Illinois Bayou Area of Lake Dardanelle, AR, since July 8, 1994.

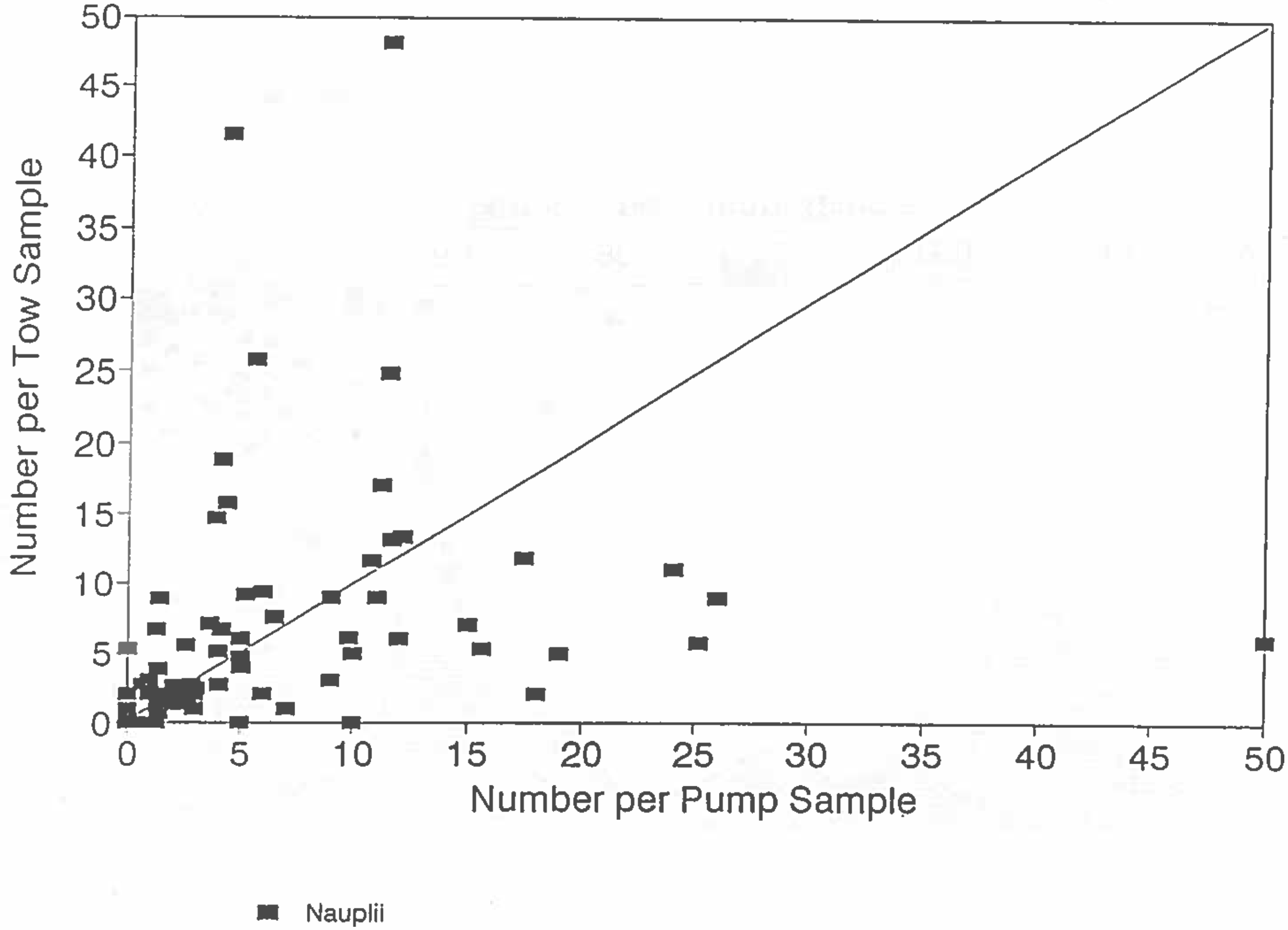

Figure 55. Scatter plot of number of nauplii per liter collected in pump samples versus number of nauplii collected per liter in vertical tow samples.

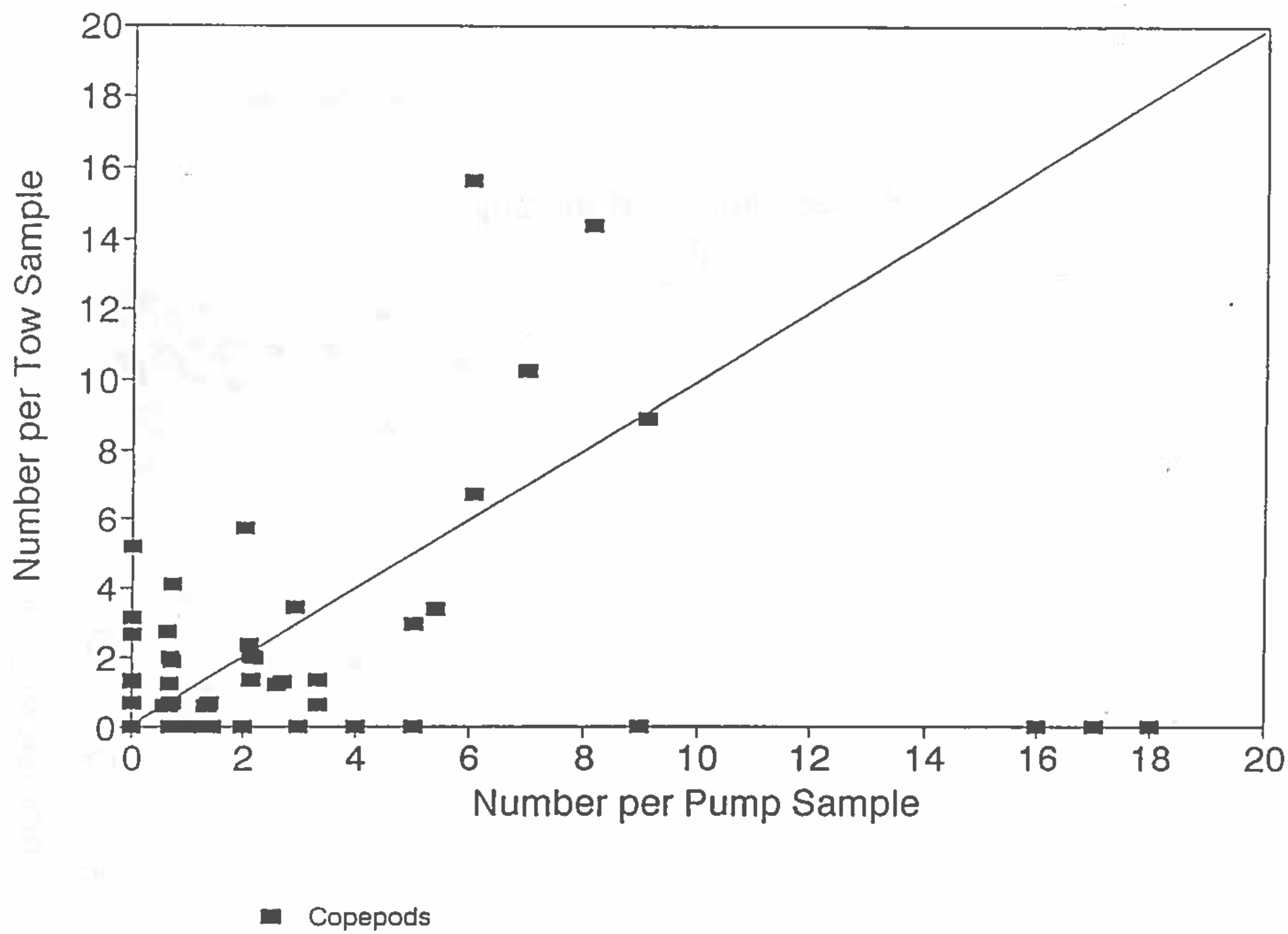

Figure 56. Scatter plot of number of copepods per liter collected in pump samples versus number of copepods collected per liter in vertical tow samples.

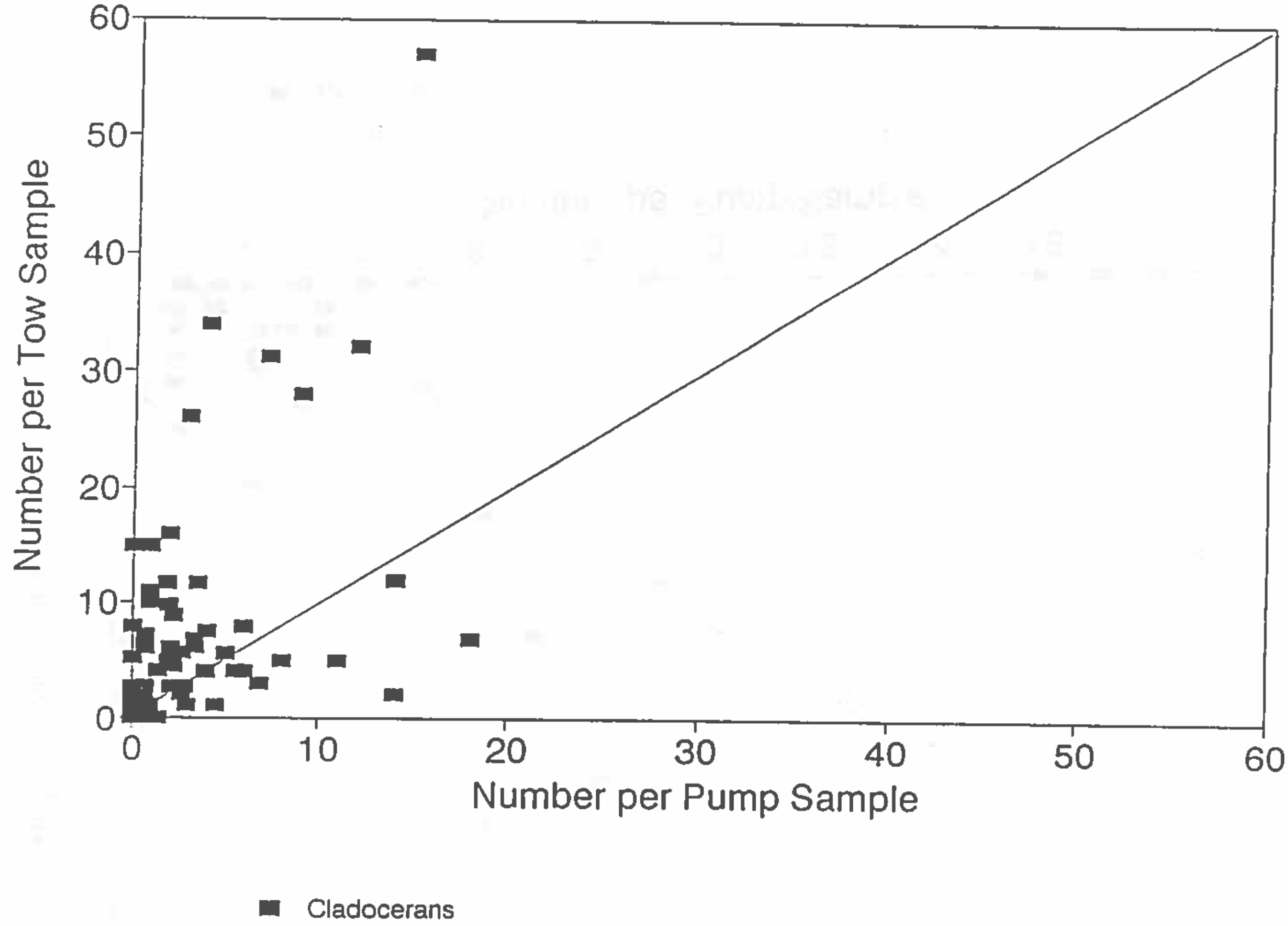

Figure 57. Scatter plot of number of cladocerans per liter collected in pump samples versus number of cladocerans collected per liter in vertical tow samples.

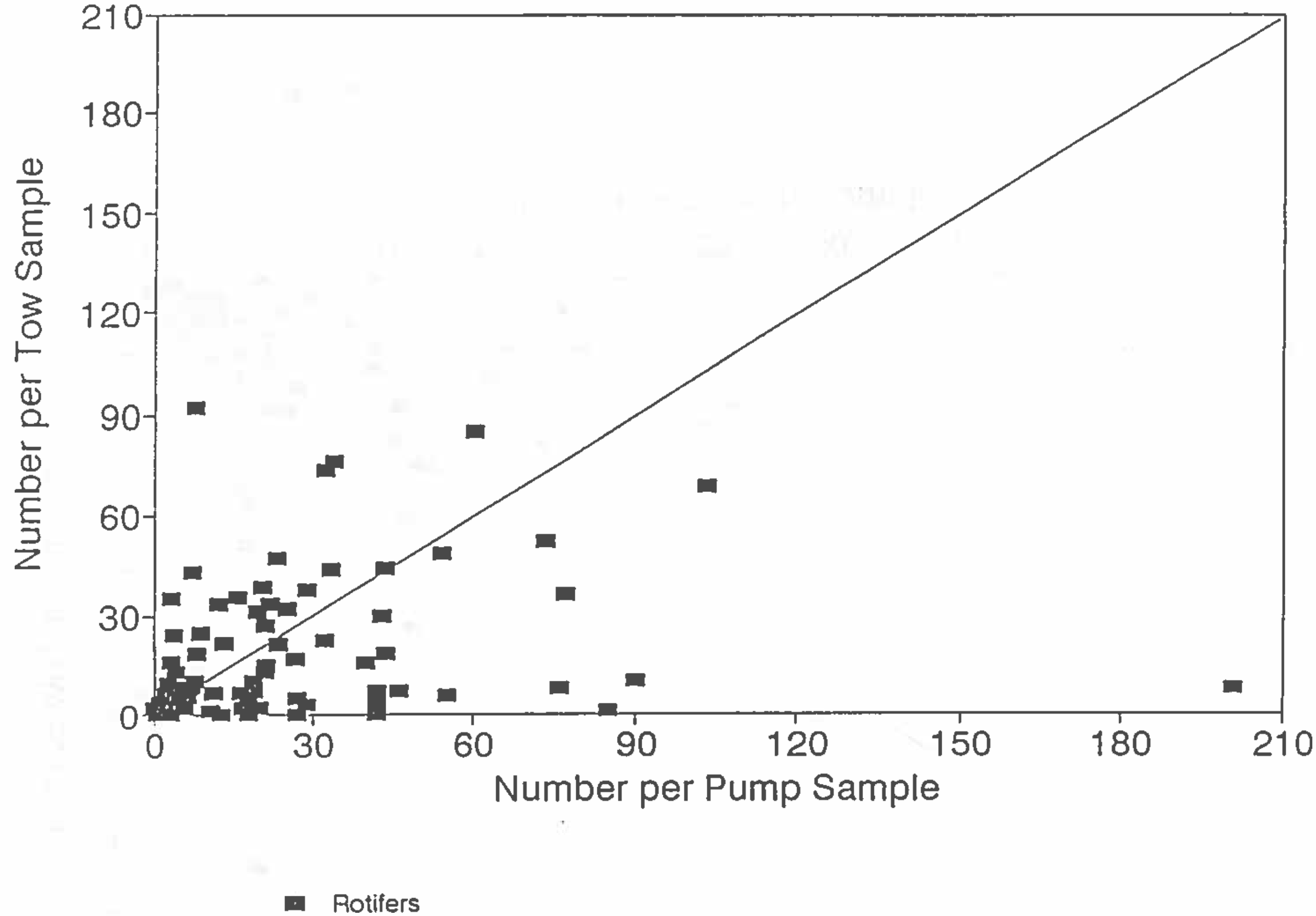

Figure 54. Scatter plot of number of rotifers per liter collected in pump samples versus number of rotifers collected per liter in vertical tow samples.

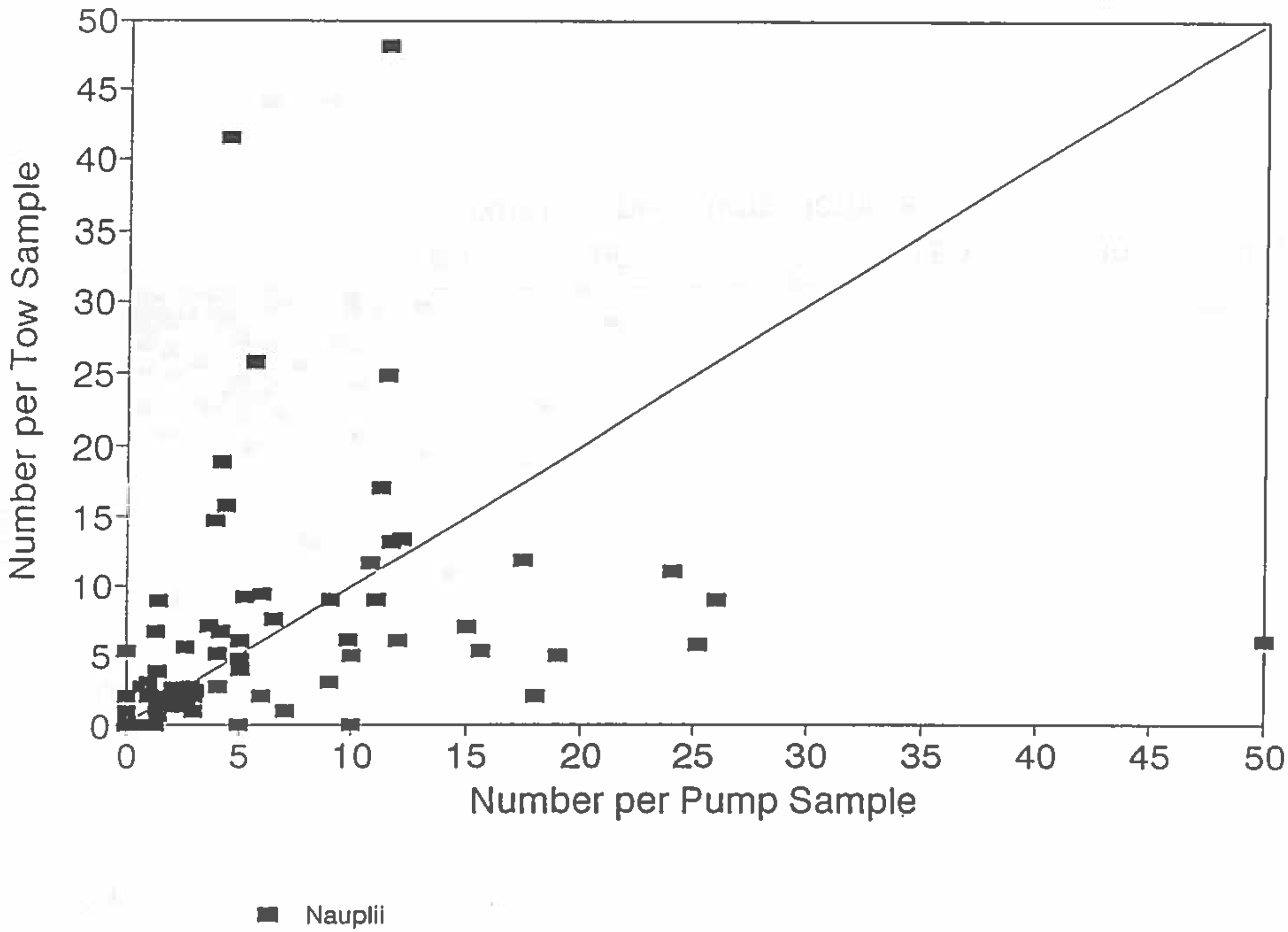

Figure 55. Scatter plot of number of nauplii per liter collected in pump samples versus number of nauplii collected per liter in vertical tow samples.

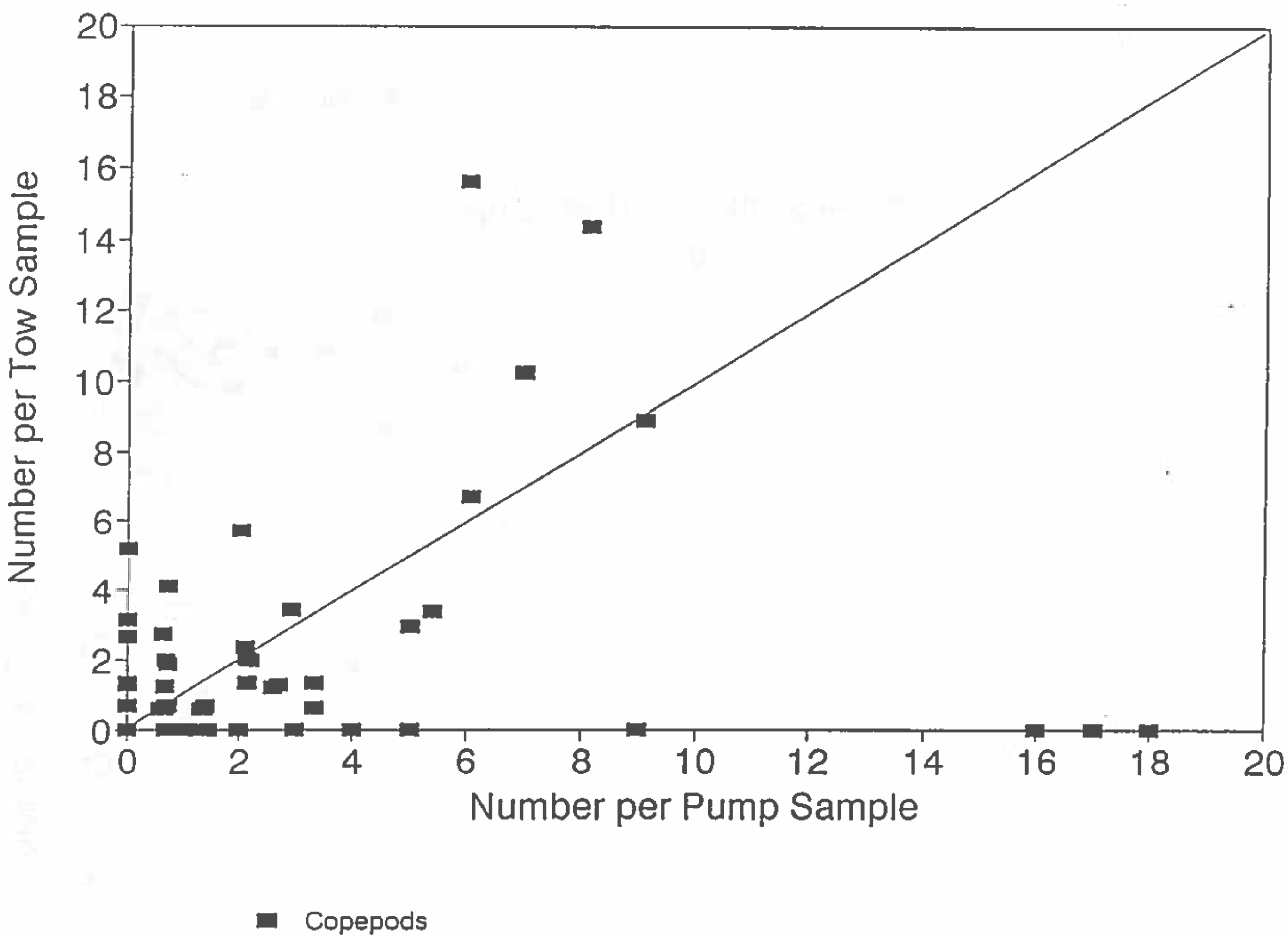

Figure 56. Scatter plot of number of copepods per liter collected in pump samples versus number of copepods collected per liter in vertical tow samples.

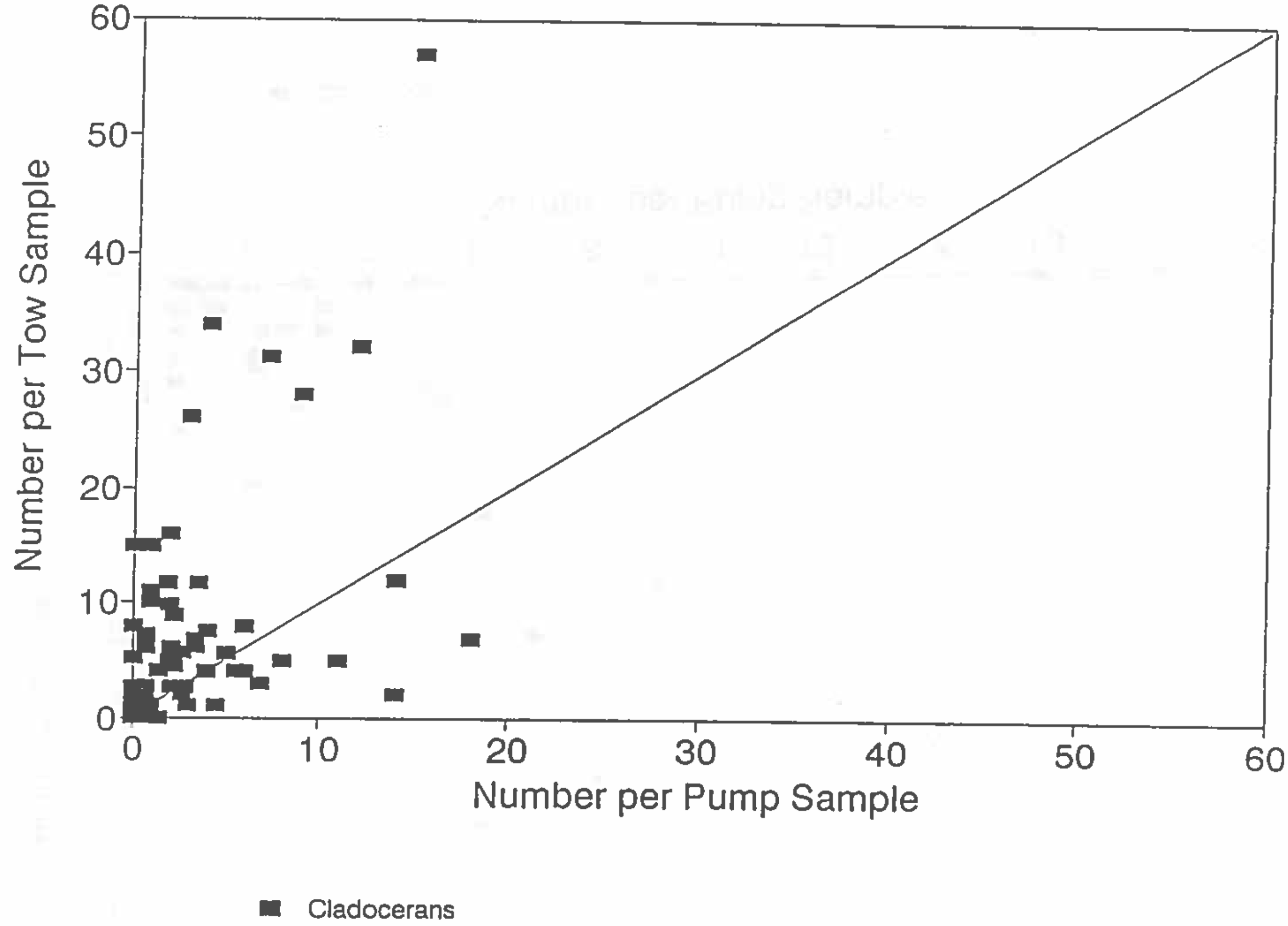

Figure 57. Scatter plot of number of cladocerans per liter collected in pump samples versus number of cladocerans collected per liter in vertical tow samples.