WATER QUALITY BRANCH
ENVIRONMENTAL PROTECTION DIVISION
MINISTRY OF ENVIRONMENT, LANDS AND PARKS

ASSESSMENT OF A TEN YEAR RECORD OF PHYTOPLANKTON AND ZOOPLANKTON IN SIX SMALL COASTAL LAKES IN SOUTHERN BRITISH COLUMBIA

1984-1994

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August 1995

ACKNOWLEDGEMENTS

I wish to thank Dr. Rick Nordin for his guidance in the preparation of this report. Additional assistance was gratefully accepted from Dr. Malcolm Clark of Commonwealth Scientific Limited (Victoria) and Cori Barraclough, MSc.

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1.0 INTRODUCTION

During 1984, the B.C. Ministry of Environment, Lands and Parks, in response to concerns about acidic deposition in British Columbia and its effects on the aquatic environment, began a study of highly sensitive lakes. Since it was known that coastal British Columbia (in particular, the Lower Mainland and lower Vancouver Island areas) received the most acidic precipitation in British Columbia (Swain 1987), six lakes were selected on which to carry out long-term studies.

The six lakes studied were Lizard, Spectacle, Old Wolf, and Stocking lakes, on Vancouver Island; Maxwell Lake on Saltspring Island; and Jacobs Lake in the U.B.C Research Forest near Haney in the Lower Mainland area of British Columbia. These lakes have a low dissolved mineral concentration, and thus are poorly buffered to pH changes and particularly sensitive indicators of acidic inputs. Other criteria included ease of access and what was assumed to be relatively low levels of disturbance.

The data reported herein are generally for the period from May 1984 to October 1994. Data for 1984 are incomplete because sampling on each lake began at different times in 1984. Sampling was discontinued in Jacobs and Spectacle lakes in 1992 for reasons of economy, and several of the lakes are missing data from various periods. Despite these inconsistencies a continuous ten year data set exists for four of the lakes, and eight year data sets for the other two.

The biological data reported in this document have been collected as a part of a larger study which accounts for water chemistry as well. An initial assessment of biological and chemical data for the 1984 to 1989 period was conducted in 1994 by Swain *et al.* That first stage report concludes that these lakes are apparently unaffected by acidic inputs, but assessment of the second five year data set would be required to confirm this. The current assessment of the biological data is a component of the second stage evaluation, with the analysis of chemical data to follow at a later date.

1.1 Goals

Very little work has been directed towards characterising the plankton communities of small coastal B.C. lakes. The plankton communities of these lakes appear to be significantly different than the larger well studied lakes and reservoirs of the area such as

Buttle, Great Central, Cowichan, or Sooke. The bigger lakes are typically diatom dominated, and exhibit predictable seasonal dynamics. In contrast to this the lakes outlined in this study are more variable with respect to numeric dominance, periodicity, and community structure. In particular both phytoplankton and zooplankton communities tend to be much more diverse than the larger lakes (LeBresseur, 1978).

In addition to addressing the original question of acidification, the phytoplankton, zooplankton, and chlorophyll data collected over the course of this study offer a valuable opportunity to further characterise the poorly understood dynamics of small, temperate coastal lakes. The coastal zone occupied by these lakes is in many areas subject to high intensity resource extraction, forestry operations in particular. An immediate benefit of an understanding of the aquatic ecology of these lakes would be the development of water quality criteria based on biological parameters. Such criteria could then be applied to protect the water quality and ecological integrity of similar lakes. Biological indicators can be more sensitive to change than conventional water chemistry indicators, and offer economies of time and cost given that plankton data are often less complex to sample and analyse. The high degree of diversity and variability displayed by the plankton of the study lakes presents a number of challenges in interpretation. In order to interpret these data the variability in populations must first be quantified, so that it be predicted on a year to year basis. In this context populations with many genera must be characterised over time. If the plankton communities of these lakes are comparable, then aspects of both similarity and difference must be determined. In partial response to these questions this study attempts to achieve the following:

- to identify any trends or patterns within these lakes, in particular those which can be interpreted as indicative of acidification
- to characterise the phytoplankton and zooplankton with respect to dominant genera, overall diversity, and biomass
- to identify seasonal and yearly successional patterns and periodicity
- to compare the phytoplankton, zooplankton, chlorophyll and biomass of the study lakes
- to provide an analysis of water quality indicated by the phytoplankton and zooplankton communities over the ten year study period

1.2. Sampling Methods

All the lakes were sampled monthly between May and October at the normal sampling locations cited Swain (1994) with few exceptions. During the course of the program, the Regional Ministry of Environment in Nanaimo sampled Lizard Lake (and Old Wolf Lake through a University of Victoria student until 1986), the Regional Ministry of Environment in Surrey sampled Marion (Jacobs) Lake, and the Water Quality Branch in Victoria sampled the remaining lakes, including Old Wolf Lake starting in 1986. Phytoplankton were collected as a surface one litre grab sample (except Marion Lake which is discussed below) and preserved with Lugol's iodine. Identifications and counts were done using the settling method (Utermohl) at the Ministry of Environment Laboratory (before December 1989), Zenon Environmental Inc. (January 1990-December 1993), and Fraser Environmental Services (January-December 1994), all located in Vancouver. All of these labs made use of the same core group of taxonomists over this period. Organisms representing greater than 10% of the total numbers were intermittently identified to species level, while less numerous organisms were identified to the genus level. Zooplankton were sampled using a vertical haul through the water column with a 25 mesh (64 micron) conical net of 707 cm2 mouth area (except Marion Lake which is discussed below). The samples were preserved with buffered formalin and identified using standard keys at MoE Environmental Lab or subsequently at Zenon or Fraser Environmental Services.

1.3 Data Analysis

Phytoplankton taxa have been arbitrarily divided into four groups based on their frequency of occurrence over the duration of the study. These are termed dominant (present >75% samples), sub dominant (present 50-74% samples), common (25%-49% samples) and rare (present < 24% samples). The taxa have then been further broken down by mean concentration. Certain opportunistic genera, particularly the blue greens *Aphanothece* sp. and *Merismopedia* sp. show very high peak numbers but occur in most cases only infrequently. These are often several orders of magnitude above the other genera. Although these events provide other information, peak number alone cannot be used as a measure of dominance as this would provide a distorted picture of community structure over time. Few genera occur consistently and in high numbers throughout the study period in any of the six lakes, with most exhibiting a high degree of variability.

Phytoplankton biomass has been estimated using two methods. These were Chlorophyll a measurements (µg/L), and total cells/mL. Unfortunately chlorophyll data is incomplete for most of the lakes, with one or several years of data routinely missing.

Zooplankton taxa have been broken down by occurrence and mean number per square metre of lake surface. In all six lakes the zooplankton community is much less diverse than the phytoplankton, so division into categories is not necessary. Biomass has been estimated using length to weight ratios as outlined in the literature (Wetzel and Likens, 1991, Dumont *et. al.*, 1975, Nauwerck, 1963). Length data has not been recorded in this study, and as such the length values have been taken as the mean of those presented in the literature. Assigned dry weight values are recorded in Table 1.3.1. These estimates should be interpreted with caution, as much disagreement as to weights of specific genera exists in the literature, and the values used here are a synthesis of the weights presented in several papers, none of which gathered data from this area. Dry weight estimates were not available for all genera, and as such values for certain animals were estimated from the weights of similar organisms, and others that occurred at low concentrations were omitted from calculations

Analysis of both phytoplankton and zooplankton has been done as far as the general level only. Stoermer (1984) states that the although the potential of analysis schemes intermediate between the Divisional and species level is low given the wide range of ecological attributes organisms display at the genus level, they can be successful if such an analysis is applied to regions with similar physiogeography. Such criteria applies to this study. In addition to this only the numerically dominant organisms were identified to the species level in each sample, and evidence exists that calls into question the accuracy of these detailed identifications. The zooplankter *Diaptomus* sp. is the most prominent example. *Diaptomus* is the dominant copepod in most lakes, and a number of species are identified. This identification is inconsistent however, with this organism identified as *franciscanus, novomexicanus, tyrrelli, orogonensis*, or *bakeri*, or lacking species designation depending on the lake in question. There are seldom two of any of the above taxa reported at the same time which would provide some evidence that only one species is present. Over the period of sampling, at least four taxonomists have done the identifications and the counts, and there seems to be a good correlation between those who did the identification and the name of the species. As a result these have been included in one category, Total *Diaptomus* spp. Similar situations are found in the Cladocera as well. Another difficulty that arises results from the fact that the taxonomy of both the algal and animal components of the plankton is in flux, with new species or genera being designated and others absorbed. The new copepod genera *Diacyclops* and *Hesperodiaptomus* are examples of this. Notations of "sp." and "spp." will be discontinued for the remainder of this text.

A number of significant perturbations have occurred over the period of study, affecting all of the lakes to varying degrees. These disturbances include logging operations within study lake watersheds, operation of several of the lakes as reservoirs, recreational uses, and occasional large scale introductions of planktivirous fish. These fish are planktivorous during early life stages, and thus would presumably impact the zooplankton population until they reached a size where other prey would be feasible. This is perhaps as much as three or four years, with additional effects on the phytoplankton as a result of decreased zooplankton predation. As a result of these and other disturbances is very difficult to determine if any of the lakes sampled are at an equilibrium. Changes observed within the six study lakes have to be evaluated in the context of these disturbances. The perturbations experienced by each lake are described in the following sections.

Unless otherwise indicated, phytoplankton numbers are reported in numbers of cells per millilitre, Chlorophyll a in micrograms per litre, zooplankton in numbers of animals per square meter, and zooplankton biomass in micrograms per square meter.

Taxa	volume (um/3)	length (mm)	weight (ug)
Copepoda:			
Diaptomus	10^7	1.10	6.00
Cyclops	10^7	1.41	12.36
Diacyclops	10^7	1.02	8.76
Epischura	-	1.00	6.00
copepodites	-	-	3.60
Cladocera:			
Bosmina	$4.0x10^7$	0.37	2.10
Holopedium	$1.5x10^7$	1.76	23.00
Diphanosoma	$6.0x10^7$	0.80	2.30
Daphnia	10^7	1.75	23.63
Ceriodaphnia	$5.0x10^7$	0.80	4.68
Leptodera	-	3.50	50.00
Polyphemus	-	0.75	3.94
Eubosmina	-	0.60	5.50
Graptolebris	-	0.40	1.40
Sida	-	1.00	7.60
Alonella	-	-	2.50
Rotifera:			
Conochilus	$4.0x10^5$	-	0.08
Kellicottia	10^5	-	0.08
Keratella	$0.5x10^5$	-	0.11
Polyarthra	$5.0x10^5$	-	0.74
Trichocera	10^5	-	0.40
Branchionus	6.0x10	-	0.25
Testudinella	5.5x10	-	1.20
Gastropus	5.5x10	-	0.20
Asplancha	-	-	0.80
Ploesomatidae	-	-	0.45
Filinia	-	-	0.48
Synchaeta	-	-	0.27
Hexarthra	-	-	0.64

Table 1.3.1. Dry weight estimates for zooplankton taxa (After Wetzel and Likens, 1991, Dumont *et. al.*, 1975, and Nauwerck, 1963).

2.0 LIZARD LAKE

Lizard Lake is located on Vancouver Island west of Victoria (48° 36' 20", 124° 13' 20", map sheet 92C) at an elevation of about 90 m. It has a surface area of 8.7 ha, a maximum depth of 15.5 m, a shoreline perimeter of 1240 m, a mean depth of 7.5 m, and a volume of 655 dam^3. The lake has an inlet and outlet which are poorly defined, bushy, and plugged with logs.

The entire lake perimeter has been extensively logged, and the entire shoreline is covered in log debris. There is a small beach, campsite and public access to the lake, but the remainder of the shoreline is thick second-growth forest and is not accessible. A small island is located near the south-east end of the lake, and the bottom of the lake near the island is shallow and gravelly. The main shoreline is generally quite steep and muddy.

In addition to the forestry operations noted above, Lizard has been regularly stocked with rainbow trout over the last several decades, including several stocking events over the duration of the study (Appendix 1). Both the logging and the fish introductions can be considered major perturbations, and thus it is unlikely that the plankton communities of Lizard Lake are at an equilibrium. Barraclough (1995) has postulated that recreational fishing can have a measurable impact on both zooplankton and phytoplankton communities in lakes, and thus fishing in Lizard may represent a significant disturbance as well.

2.1. Phytoplankton

The phytoplankton community is very diverse, with 82 genera reported in the ten years of sampling (Appendix 2). There are many genera which are reported once or at most, a few times. The dominant and sub dominant taxa are displayed in Table 2.1.1. The composition of these two groups reflects the overall diversity of the lake, being composed of 4 divisions. *Oocystis* is the most consistent member of the phytoplankton, present in 90% of all samples. *Dinobryon* (87%), *Chroomonas* (85%), *Crucigenia* (82%), *Merismopedia* (80%) and *Cryptomonas* (79%) complete the dominant group. *Merismopedia* exhibits the highest mean concentration of 602.69 cell/mL, as is consistent with most of the other lakes. Other means for the dominant and sub dominant groups range from 16.73 cells/mL for *Quadrigula* to 440.86 cells/mL for *Cryptomonas*. This value for *Cryptomonas* is significantly higher than the usual upper mean for non cyanophyte genera.

As indicated graphically in figures 2.1.1 to 2.1.7, the year to year variation in numbers for most of the individuals in the dominant and sub-dominant groups is very high. Three of the dominant chlorophytes (*Crucigenia, Oocystis,* and *Botryococcus*) show a general trend to higher numbers before 1990, then reduced numbers through 1994. *Elakothrix,* as well as the sub dominant chlorophytes, show no clear trends. *Merismopedia* trends toward higher peak numbers after 1990. *Chroococcus* does not show a clear trend

Several notable events occur over the study period. Chlorophyll a (Figure 2.1.8) shows a definite peak in 1989, with values ranging from 1.5 to 6 ug/L. Coincident with this peak is a drop in the total numbers of cells (1500/mL, the lowest yearly peak), as well as the appearance and highest concentration of zoospores (Figure 2.1.9). The highest peak observed over the ten year period was for the blue green *Aphanothece*, with 7956 cells/mL recorded in July 1986. *Aphanothece* (Figure 2.1.10) shows an interesting trend, being present in 75% of the samples and showing high numbers between 1985 and 1988, then disappearing from the lake over the remaining six years of the study. *Microcystis* (Figure 2.1.11) exhibits a similar trend.

Biomass as measured by total cells per millilitre is relatively low, with peak concentrations generally below 7500 cells/mL (Figure 2.1.12). An overall decline in total numbers is evident. Chlorophyll a values reflect the low biomass, with a mean chlorophyll concentration of 1.21 ug/mL, and a range of 0.5 to 6.0 ug/L. Chlorophyll data show an opposite trend to the other biomass estimates, increasing slightly over the study period (Figure 2.1.8). It is difficult to determine whether the chlorophyll and total numbers data correlate well given that chlorophyll data are incomplete, extending only to 1990. It would appear that they do not, given that 1989 recorded the lowest concentration of cells coupled with the highest chlorophyll peaks recorded over the sampling period. Table 2.1.2 contains a yearly summary of chlorophyll a data.

In summary, Lizard Lake phytoplankton can be characterised as a diverse community with a relatively low standing crop. There is a wide variation in the total numbers of phytoplankton from year-to-year, and a number of species appear and disappear over this period, indicating that the phytoplankton community is not at equilibrium. Table 2.1.3 provides a yearly summary of the total number of phytoplankton observed, mean number of phytoplankton, range, and number of samples collected. A high degree of variability is evident in total number, mean and maximum values. No clear evidence exists for any consistent changes in individual taxa or major taxonomic groups which may be symptomatic of changes in the lake.

2.2. Zooplankton

The zooplankton community of Lizard Lake (composed of only eighteen genera) is much less diverse than its phytoplankton. This number of zooplankton genera is consistent with the other lakes in this study. As with the phytoplankton there is much variation in the numbers of individuals from month to month and year to year, and several taxa appear and disappear over the duration of the study. Lizard Lake zooplankton data is contained in Appendix 3.

Lizard Lake contains three genera of copepods. Of these *Diaptomus* is the dominant, present in 95% of the samples taken over ten years at relatively high numbers (Figure 2.2.1). *Diaptomus* does not seem to follow any regular seasonal pattern and persists through the sampling period from May to October throughout the study, excepting September of 1991 and October of 1994. The standing crop of *Diaptomus* generally peaks at about 15000-25000/m^2. Two exceptions to this occur: 1987 shows very low numbers, with a peak of only 3800/m^2, and 1994 shows elevated numbers with a peak of over 50000/m^2.

Two other copepods appear over the period of sampling. *Cyclops* is present sporadically in 1985-1987 and 1989 with small numbers (1,750 - 5,350 animal/m^2), while *Diacyclops* is reported once each fall during 1992 through 1994, again with relatively low numbers (Figure 2.2.2). Nauplii and copepodite stages were observed throughout the study and appear to be fairly stable over time with no long-term trend evident (Figure 2.2.3).

The cladocera are a more diverse group with five genera present: *Holopedium* , *Bosmina*, *Diaphanosoma*, *Daphnia*, *Ceriodaphnia*. An unidentified chydorid species ~~in~~ appeared in one 1989 sample and the unusual, large predatory genus *Leptodora* was also reported once in fairly high numbers in 1989. The cladocera form the dominant zooplankton numerically, and of these *Daphnia* and *Diaphanosoma* show the highest numbers and consistent presence (Figure 2.2.4). The five common cladocerans listed above all show a similar trend, with declining numbers and occurrence from 1989 through to 1991 or 1992. *Ceriodaphnia* (Figure 2.2.5) is absent from the lake during the periods 1985 to 1986 and 1989 to 1992, and *Holopedium* (Figure 2.2.6) appears only once in 1989 and is absent in 1990. All five genera then show a general increase in numbers through to 1994.

This pattern is reflected in the total number of zooplankton (Figure 2.2.7) and is an indication of the numeric dominance of the cladoceran portion of the population.

Eight rotifer genera are present in the lake during the study period, none of which show consistent monthly or yearly presence. Of these *Kellicottia* , *Keratella* , and *Conochilus* are the most prominent. *Kellicottia* shows an increase in presence and number from 1991 to 1994. It is notable that rotifers were absent from all 1990 samples. The population dynamics of the rotifer community are displayed in figures 2.2.8 to 2.2.11.

Analysis of biomass by dry weight demonstrates the relative contributions made by the cladoceran, copepod, and rotifer communities (Figure 2.2.12). This confirms that the cladocerans are the dominant group of zooplankters, with the copepods and rotifers accounting for significantly less biomass. A slight decline in overall biomass is evident over the ten year study period. This is confirmed by a similar decline in total numbers (Figure 2.2.13).

	Dominant	Sub-dominant	% presence	mean conc. cells/mL
Chlorophyte	*Oocystis*		90	92
	Crucigenia		82	193
		Botryococcus	73	144
		Elakothrix	73	17
		Quadrigula	69	16
Chrysophyte	*Dinobryon*		87	74
Cryptophyte	*Chroomonas*		85	24
	Cryptomonas		79	440
Cyanophyte	*Merismopoedia*		80	602
		Chroococcus	50	98.2

Table 2.1.1:Lizard Lake Phytoplankton: Dominant and Sub-dominant taxa.

Year	n	mean	maximum	minimum	# of samples
1984	2987	47.41	1987	.001	2
1985	10541	110.96	1752	.001	6
1986	27887	281.69	7956	.001	6
1987	8337	99.26	1741	.001	5
1988	19529	203.42	2760	.001	6
1989	4587	48.29	587	.001	5
1990	6143	55.85	2447	.001	6
1991	11668	88.40	3860	.001	6
1992	5393	37.71	2365	.001	7
1993	10609	114.07	4585	.001	6
1994	13582	70.37	3768	.001	7

Table 2.1.2. Lizard Lake Phytoplankton: Summary of total numbers of phytoplankton /mL by year.

year	mean	maximum	minimum
1984	0.61	0.8	0.5
1985	0.58	0.7	0.5
1986	0.68	1.1	0.5
1987	0.58	0.9	0.5
1988	3.21	0.6	1.6
1990	1.44	2.5	0.7

Table 2.1.3. Lizard Lake Phytoplankton. Mean and range of Chlorophyll a measurements by year in µg/L.

Figure 2.1.1. Lizard Lake Phytoplankton: *Oocystis*

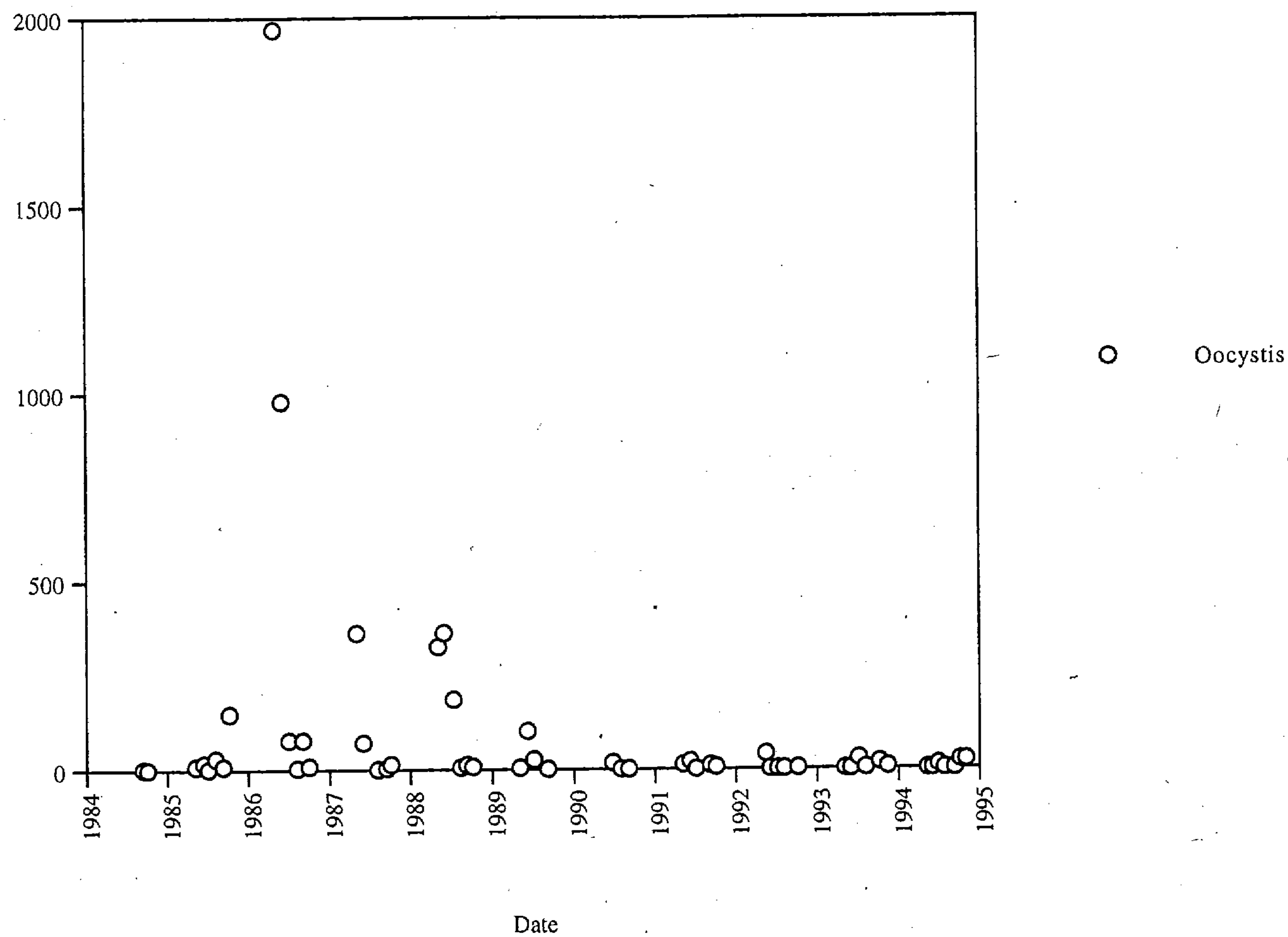


Figure 2.1.2. Lizard Lake Phytoplankton: *Crucigenia/Dinobryon*

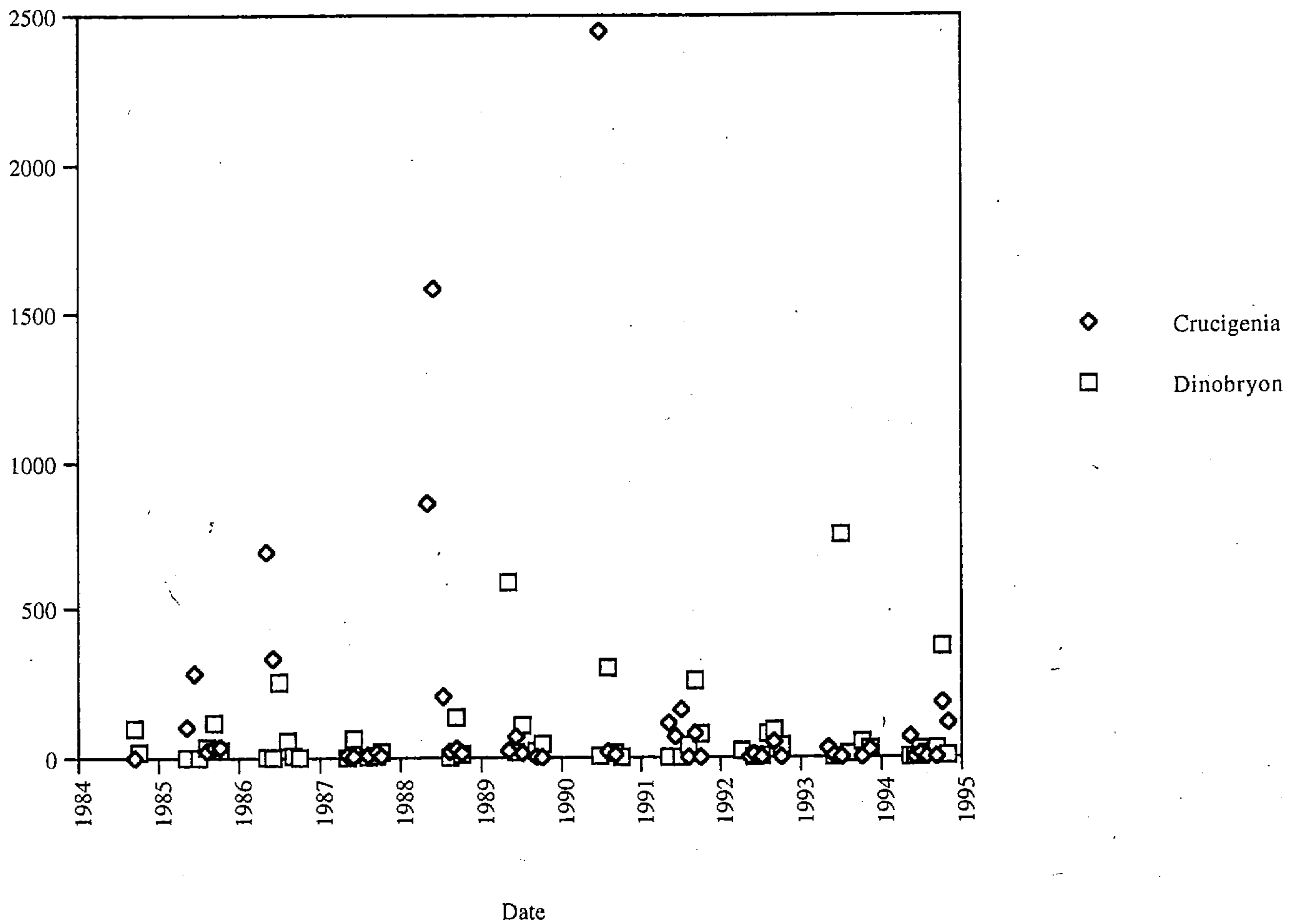


Figure 2.1.3. Lizard Lake Phytoplankton: *Chroomonas*.

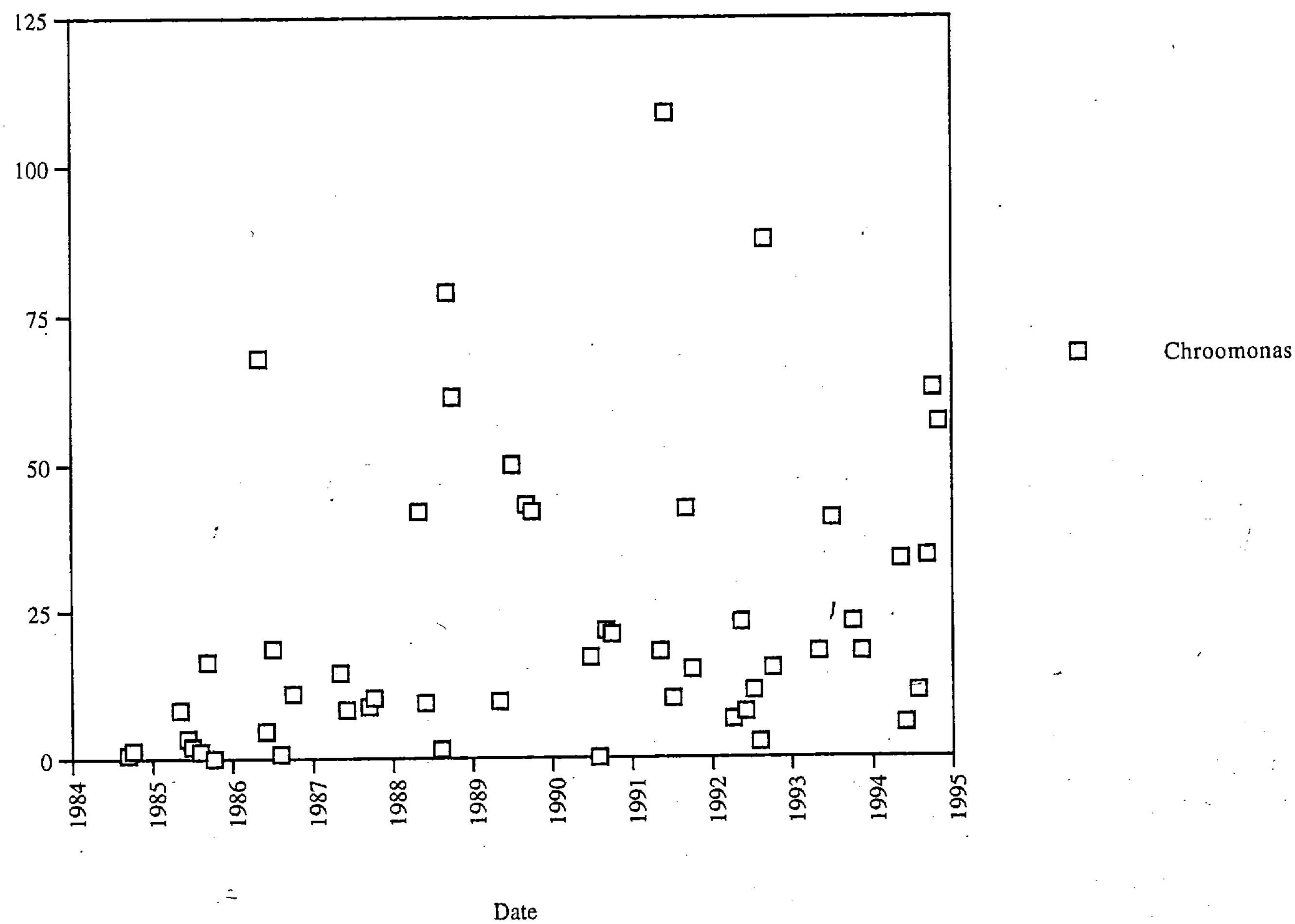


Figure 2.1.4. Lizard Lake Phytoplankton: *Merismopedia/Botryococcus*.

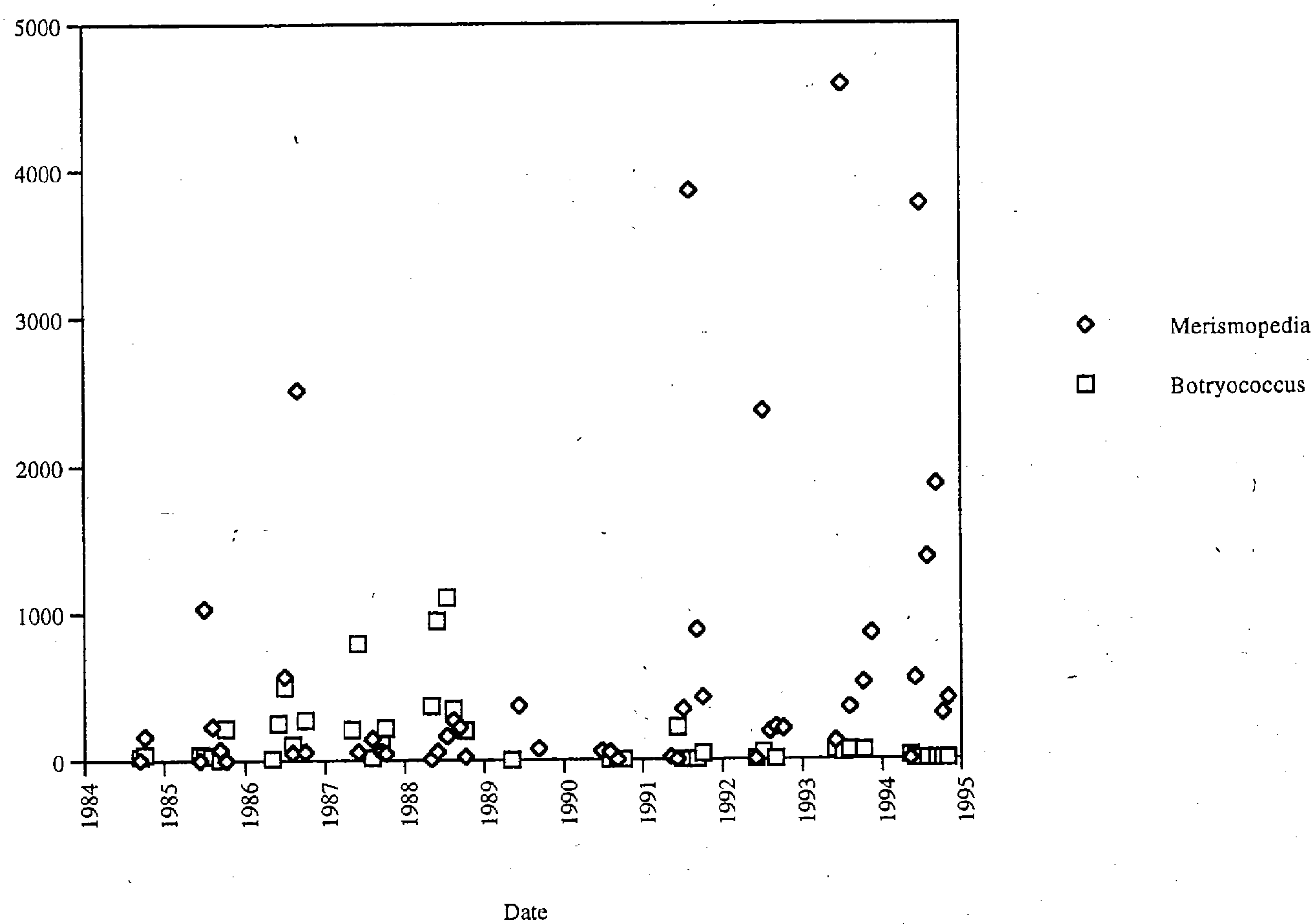


Figure 2.1.5. Lizard Lake Phytoplankton: *Chroococcus*.

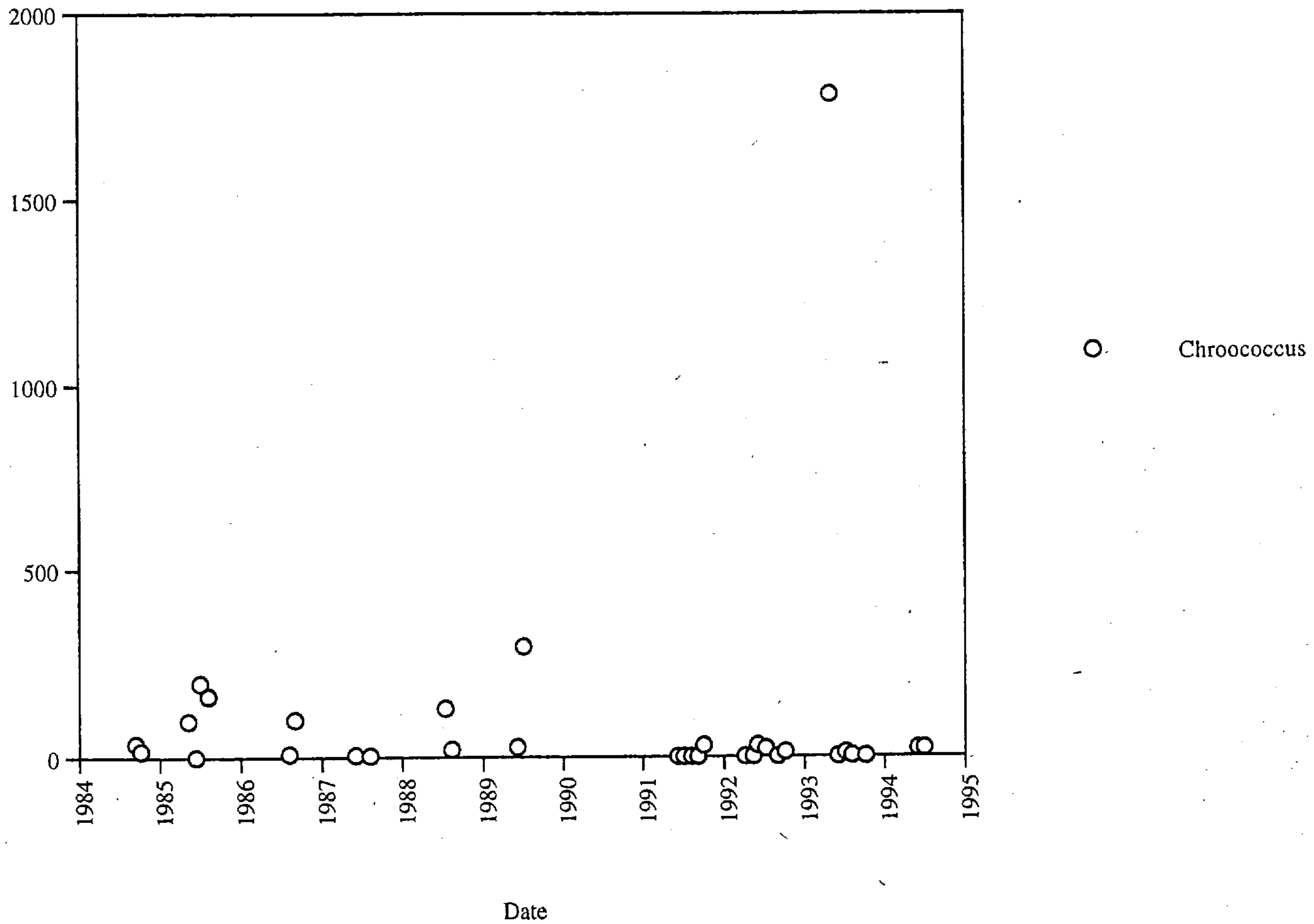


Figure 2.1.6. Lizard Lake Phytoplankton: *Quadrigula/Elakothrix*.

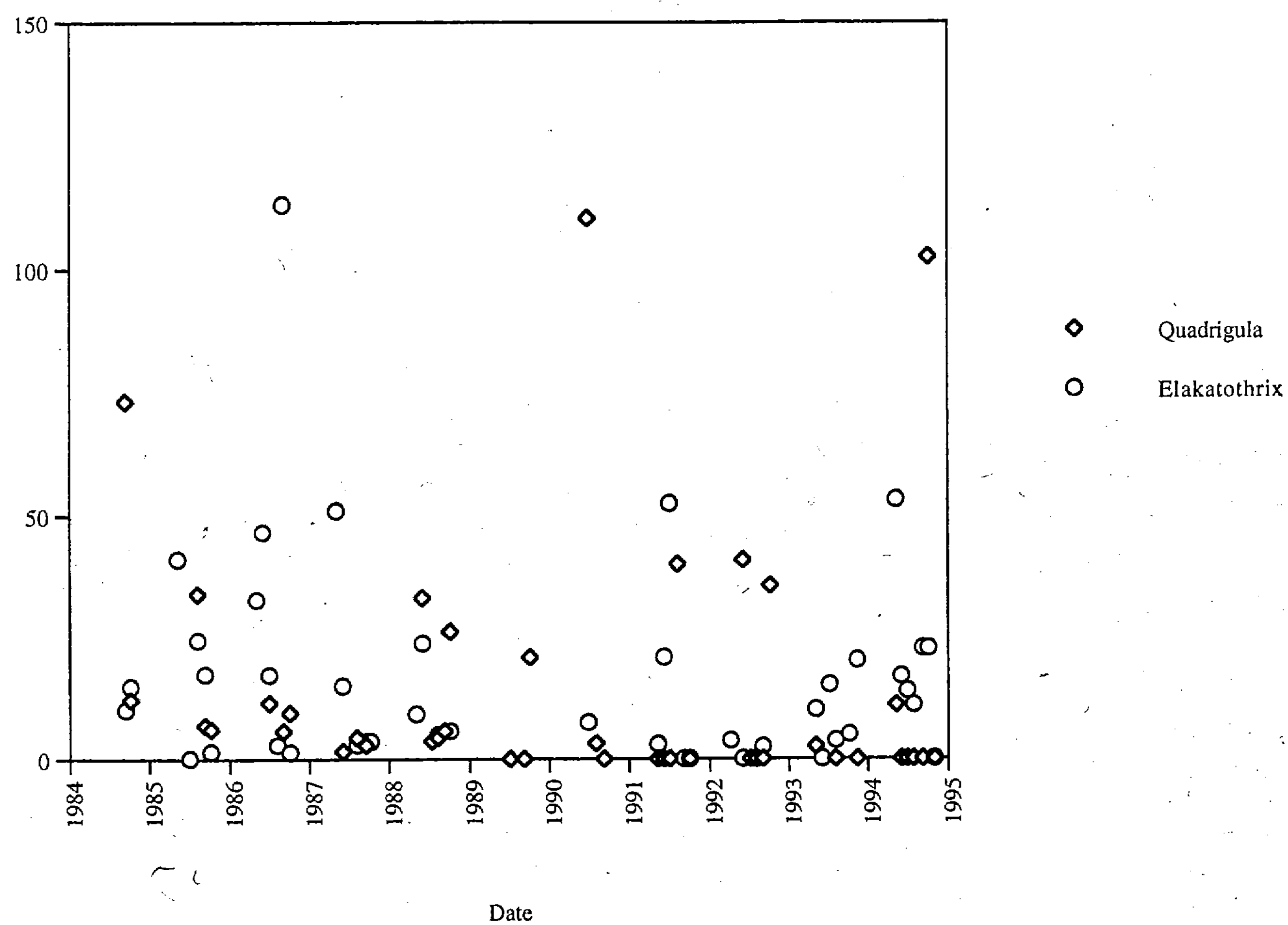


Figure 2.1.7. Lizard Lake Phytoplankton: *Cryptomonas*.

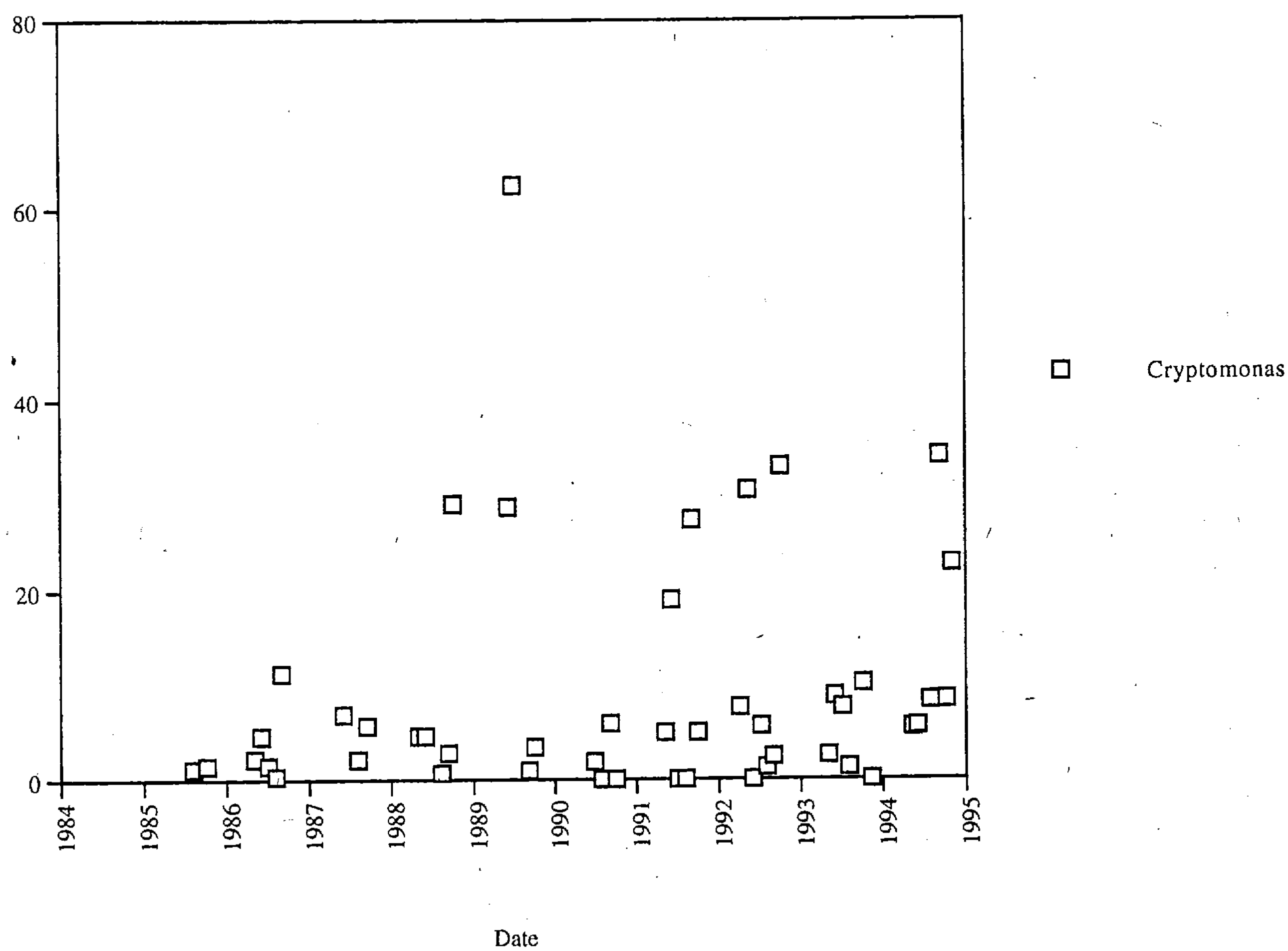


Figure 2.1.8. Lizard Lake Phytoplankton: Chlorophyll a

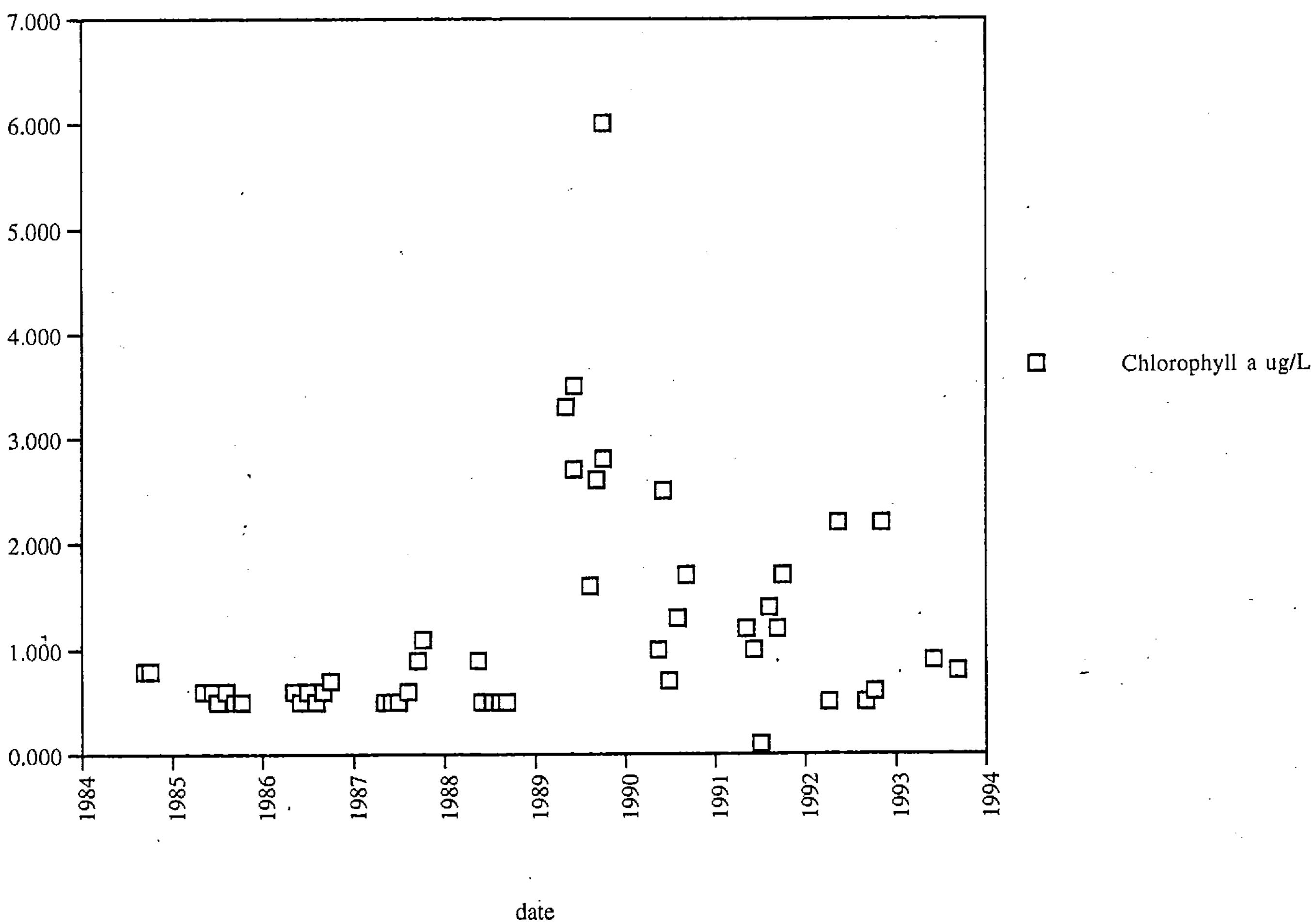


Figure 2.1.9. Lizard Lake Phytoplankton: Zoospores.

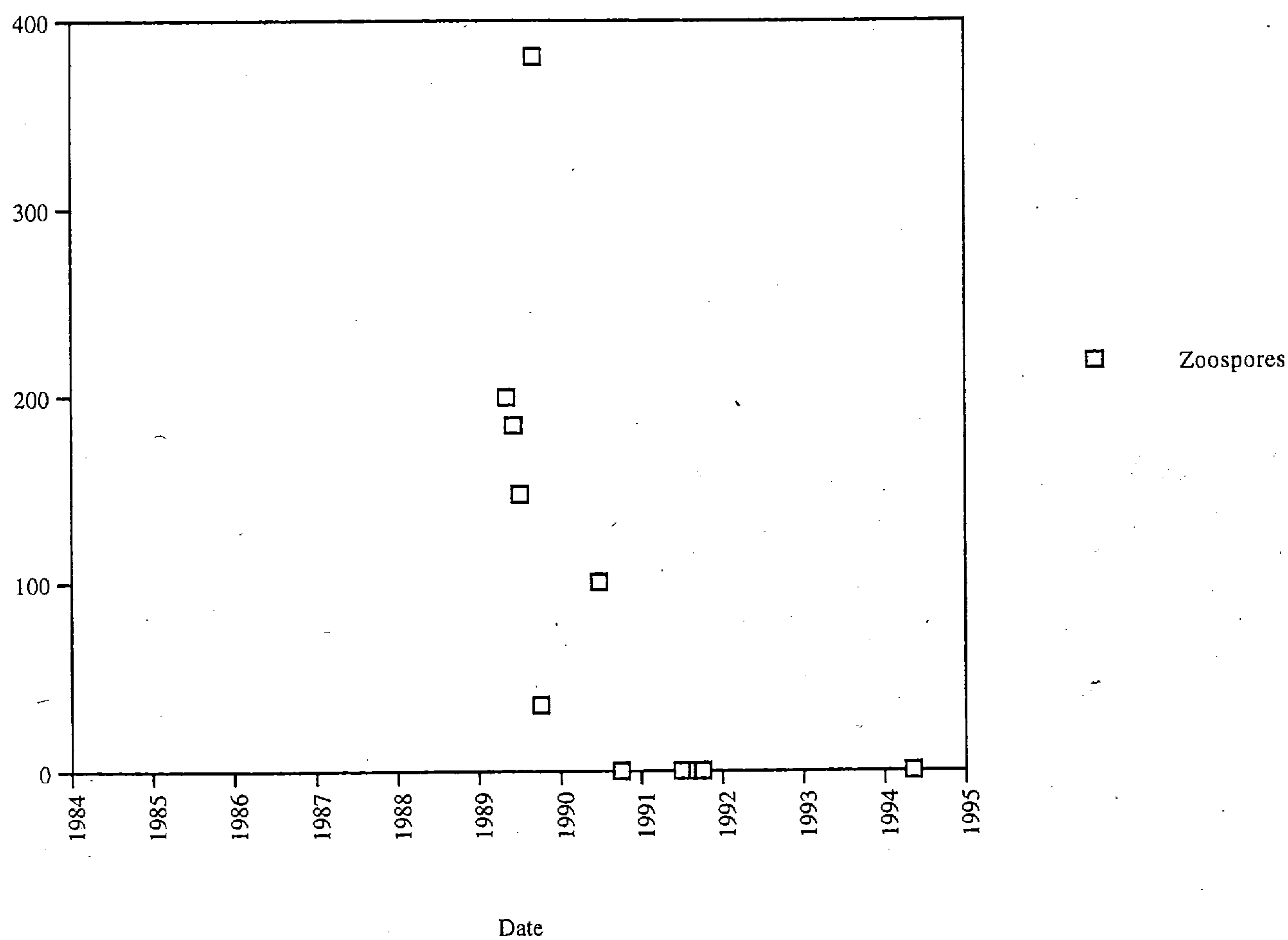


Figure 2.1.10. Lizard Lake Phytoplankton: *Aphanothece*.

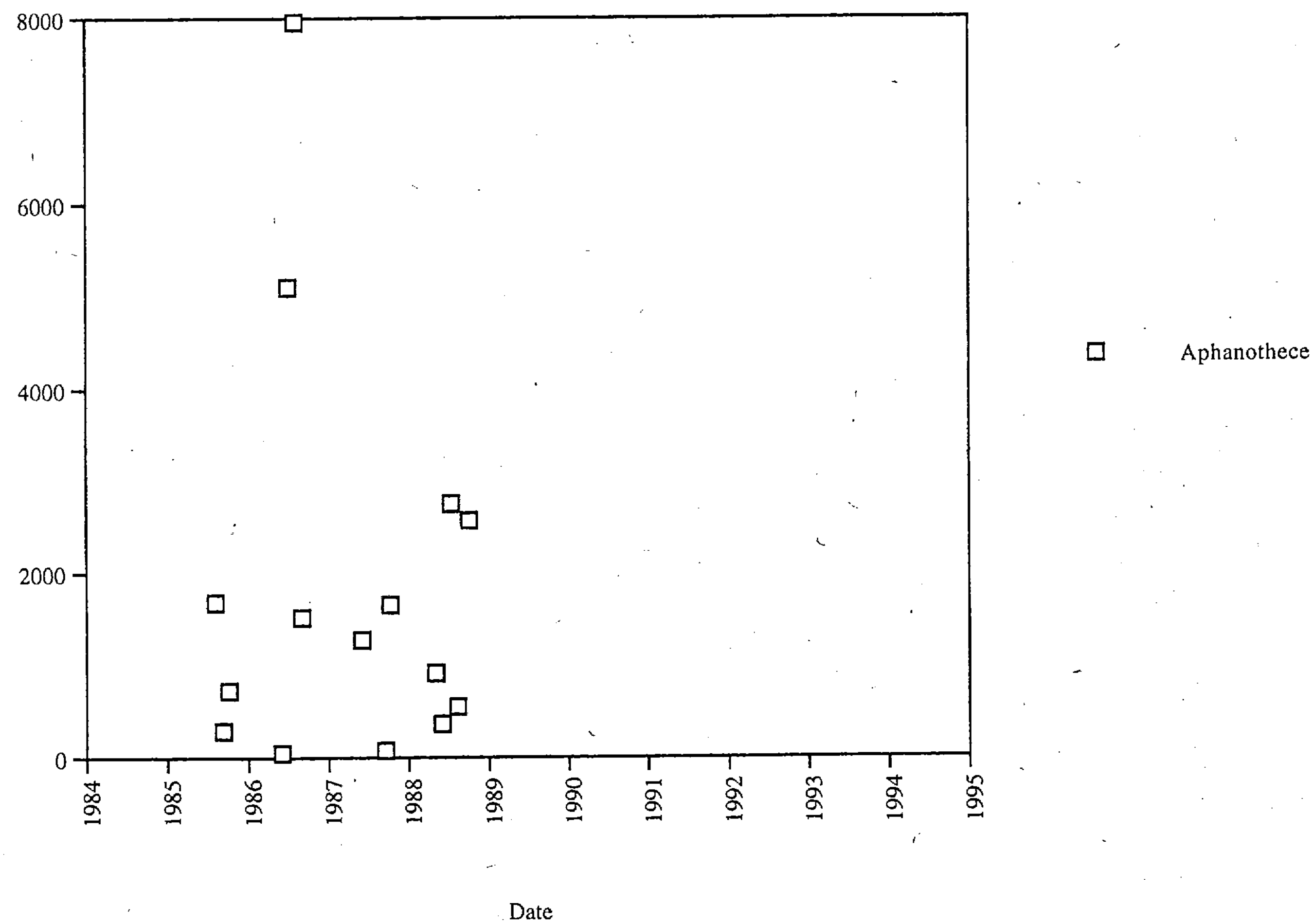


Figure 2.1.11. Lizard Lake Phytoplankton: *Microcystis*.

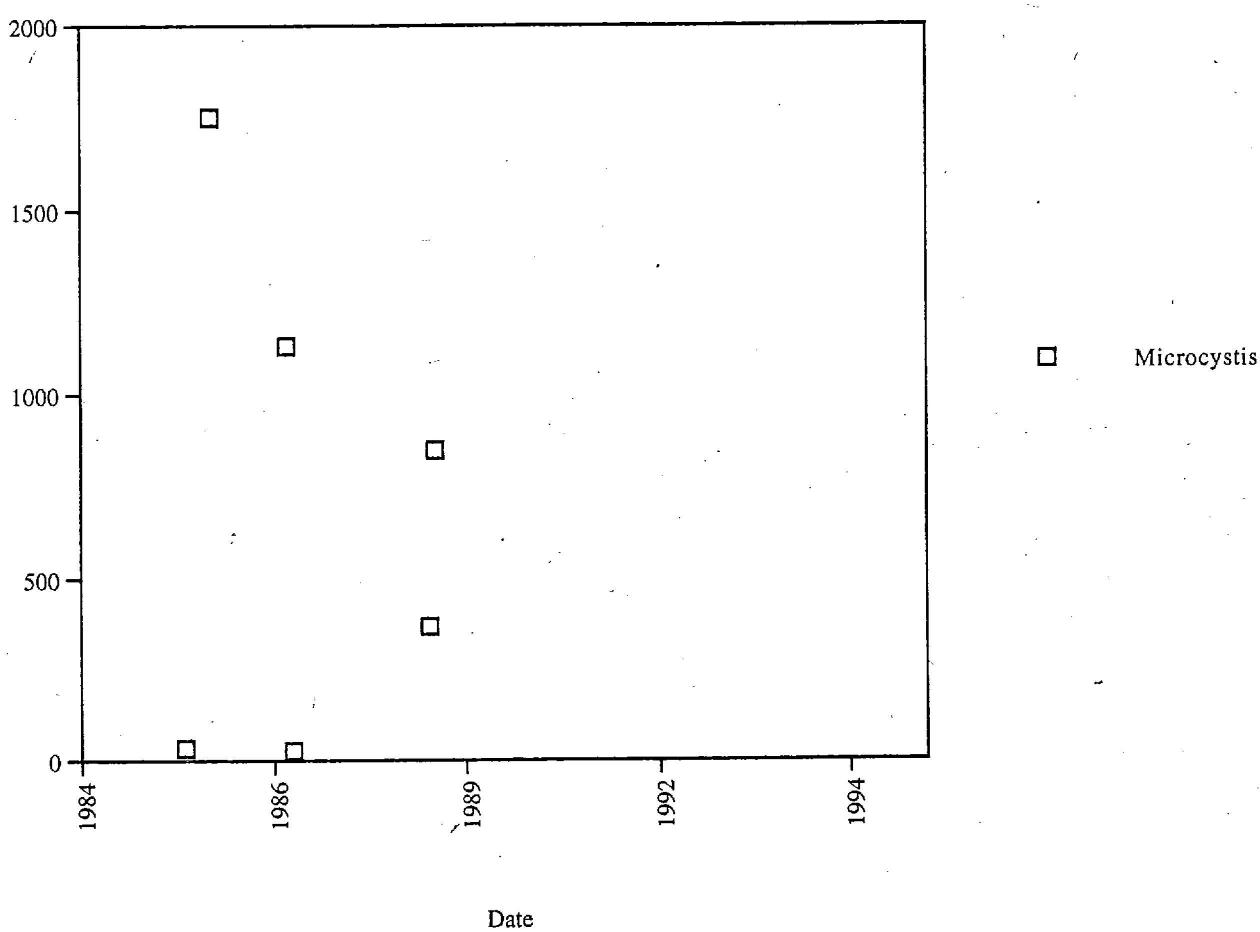


Figure 2.1.12. Lizard Lake Phytoplankton: Total Cells/mL

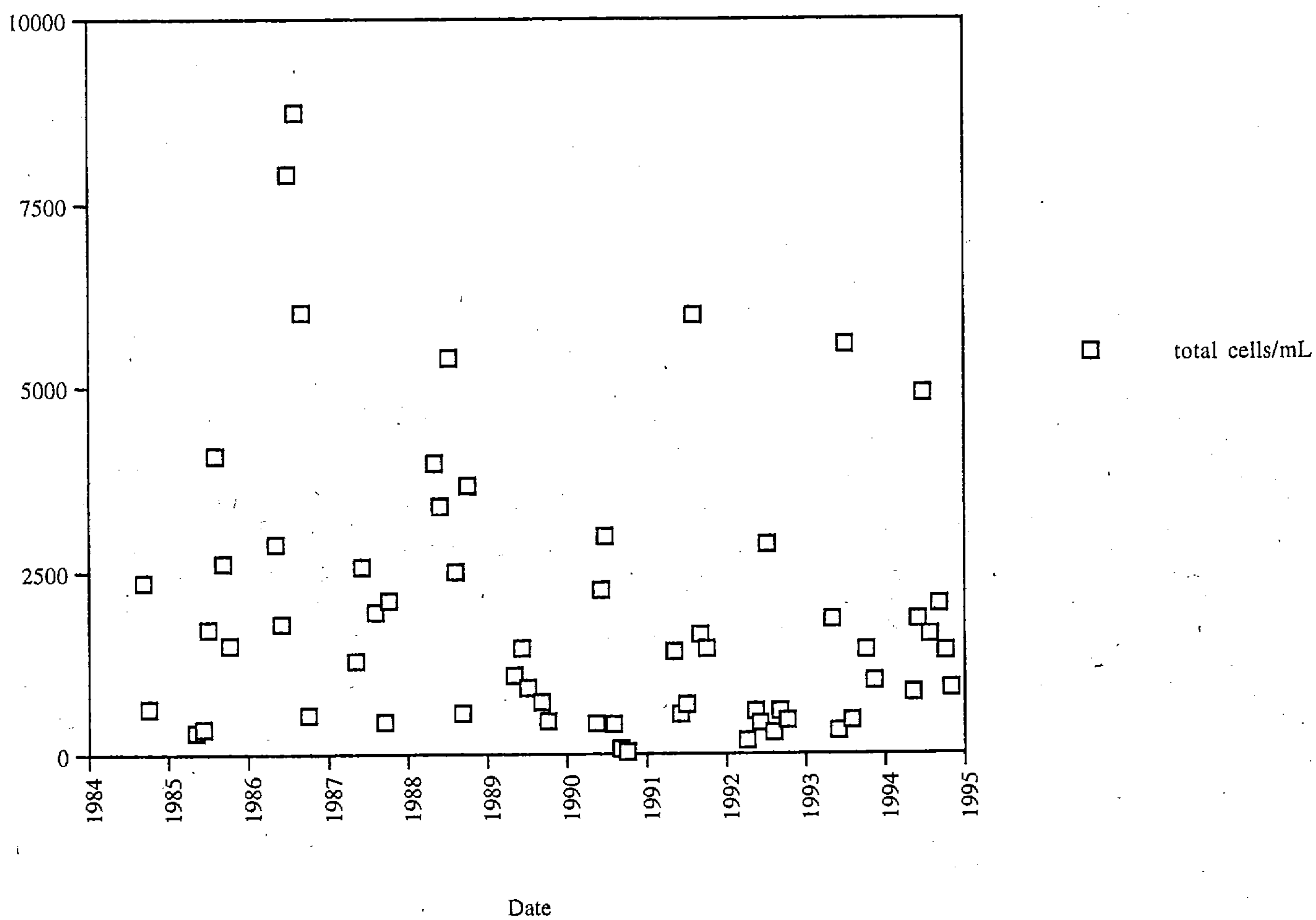


Figure 2.2.1. Lizard Lake Zooplankton: *Diaptomus*.

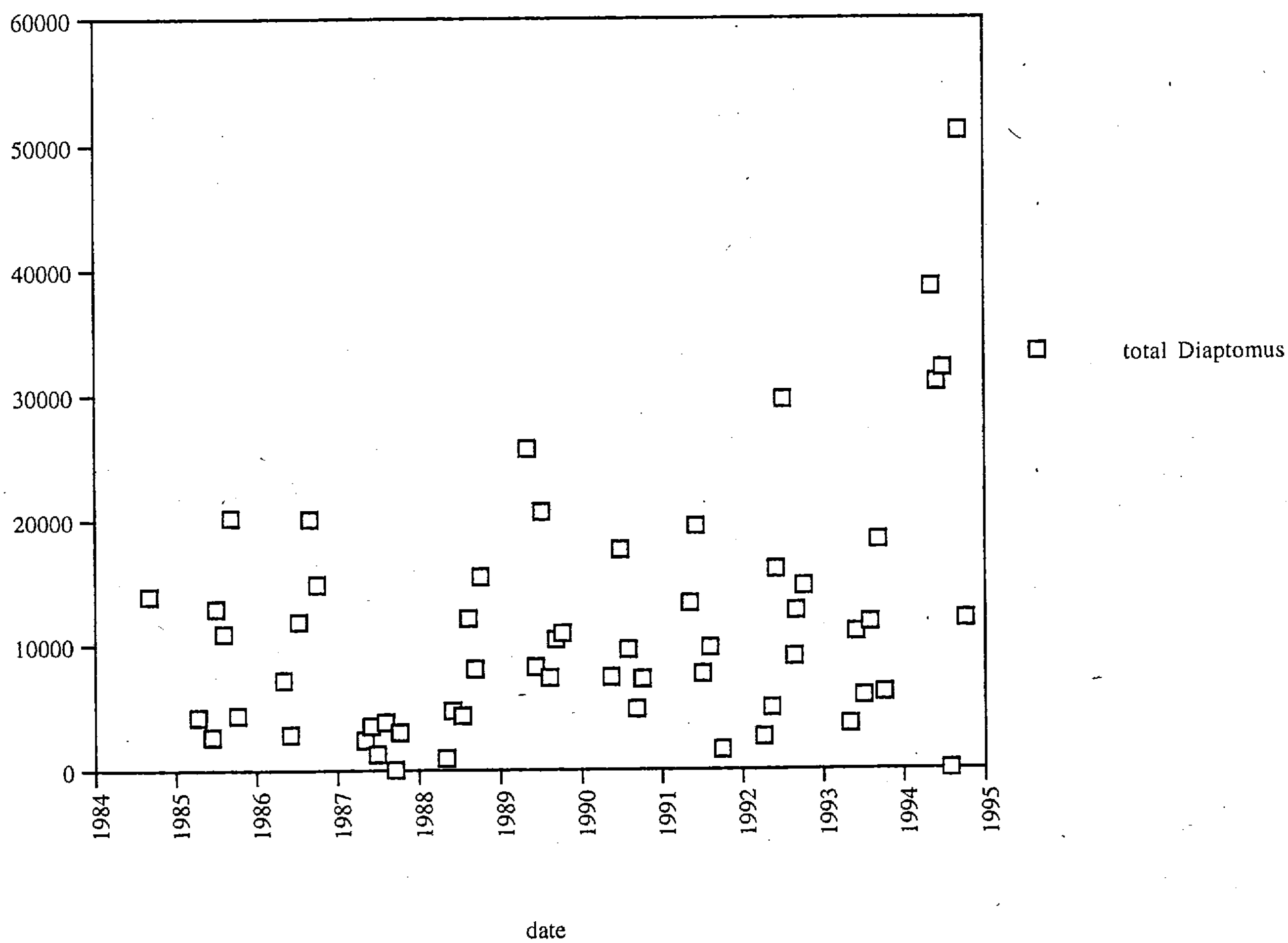


Figure 2.2.2. Lizard Lake Zooplankton: *Cyclops/Diacyclops.*

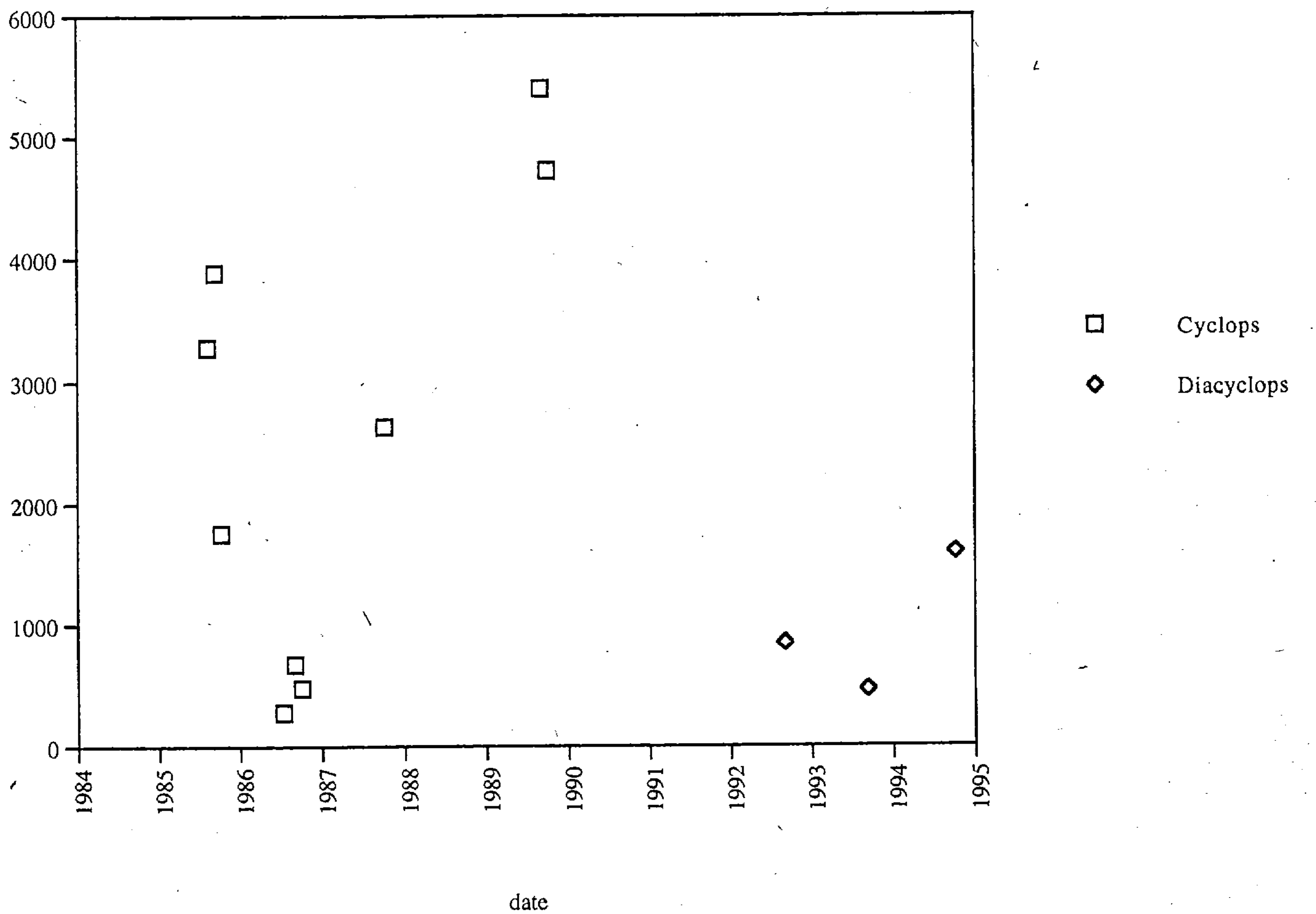


Figure 2.2.3. Lizard Lake Zooplankton: Copepodites/Nauplii

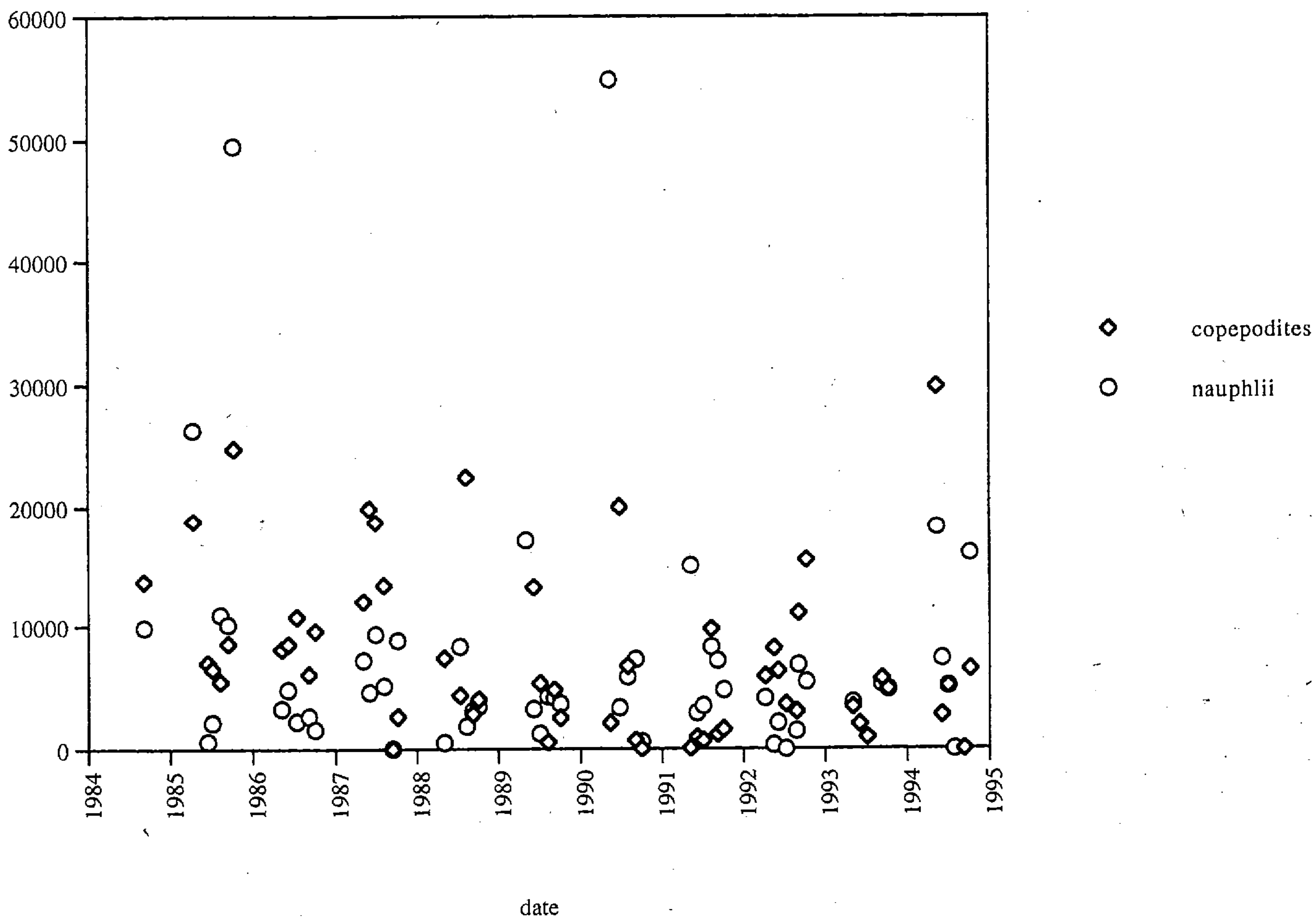


Figure 2.2.4. Lizard Lake Zooplankton: *Diphanosoma/Daphnia*.

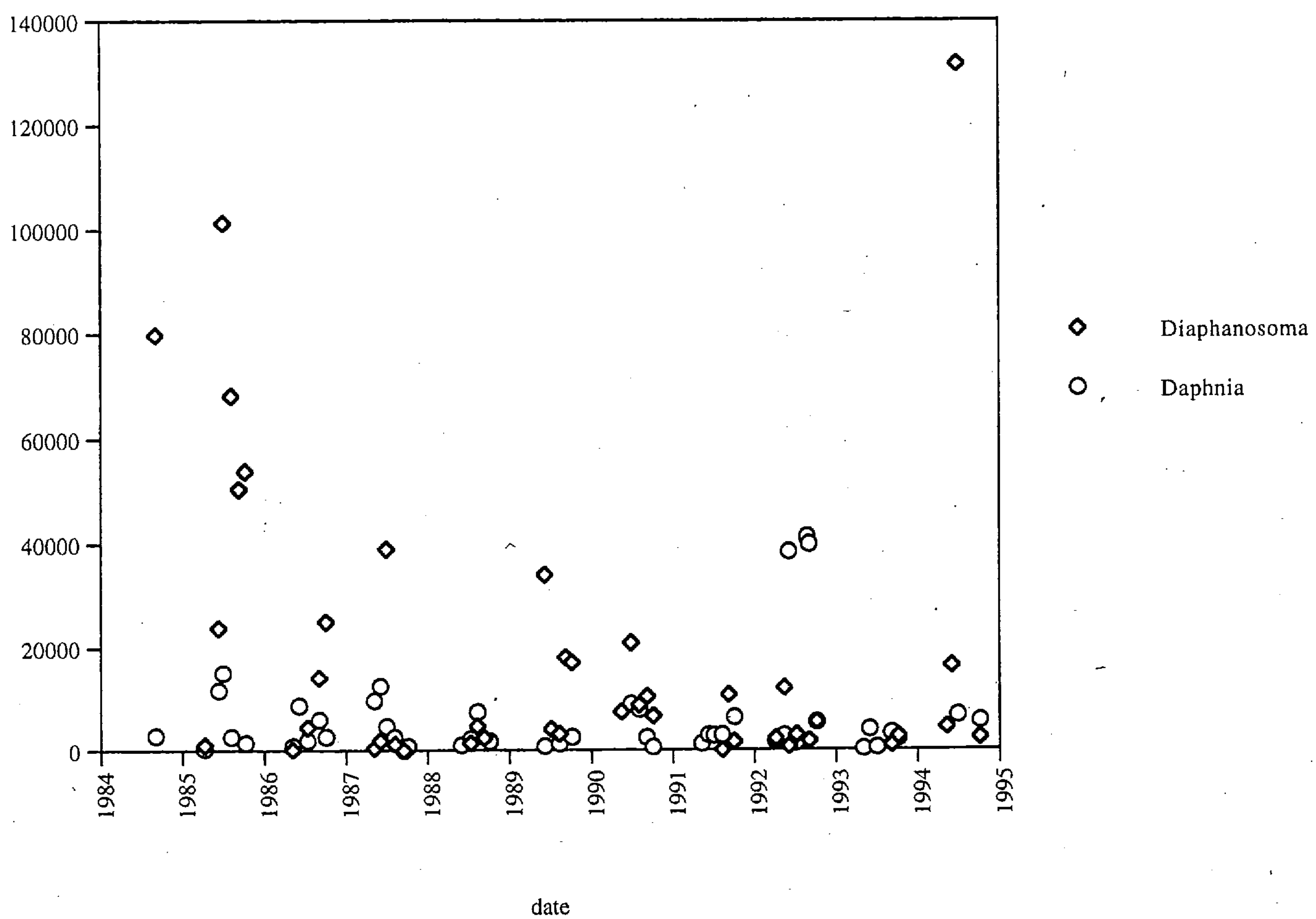


Figure 2.2.5. Lizard Lake Zooplankton: *Ceriodaphnia*.

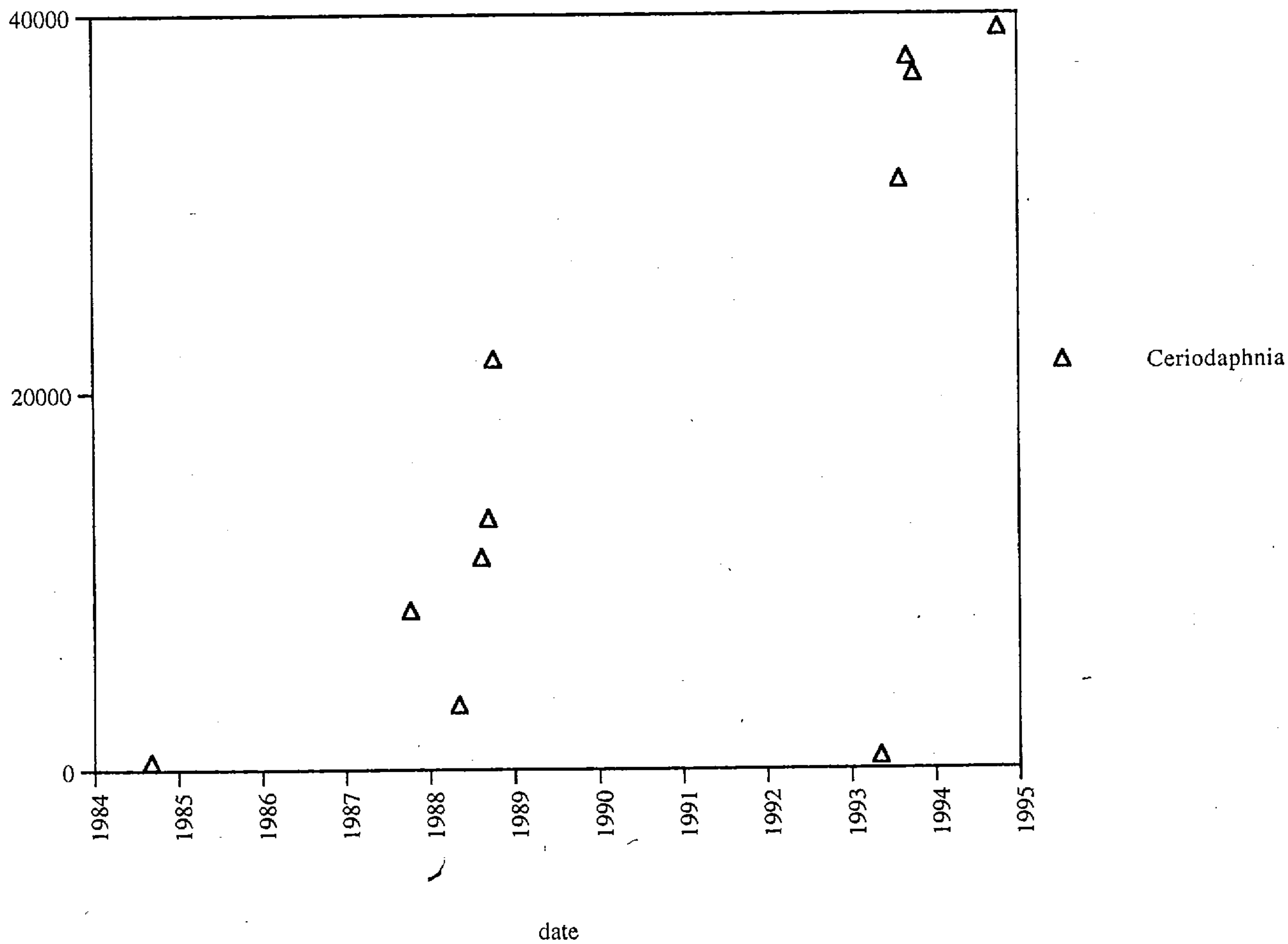


Figure 2.2.6. Lizard Lake Zooplankton: *Holopedium/Bosmina.*

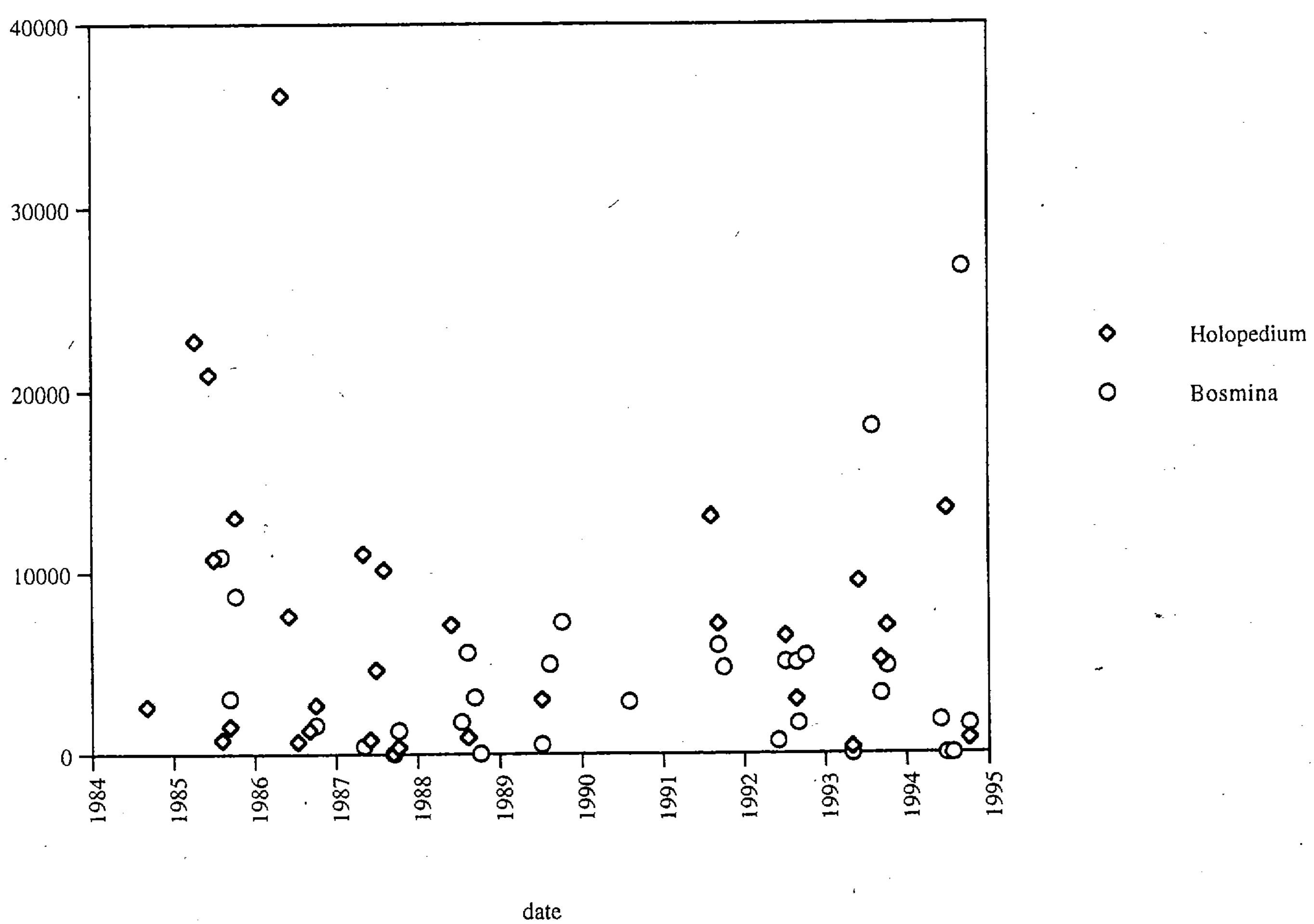


Figure 2.2.7. Lizard Lake Zooplankton: Total/m2

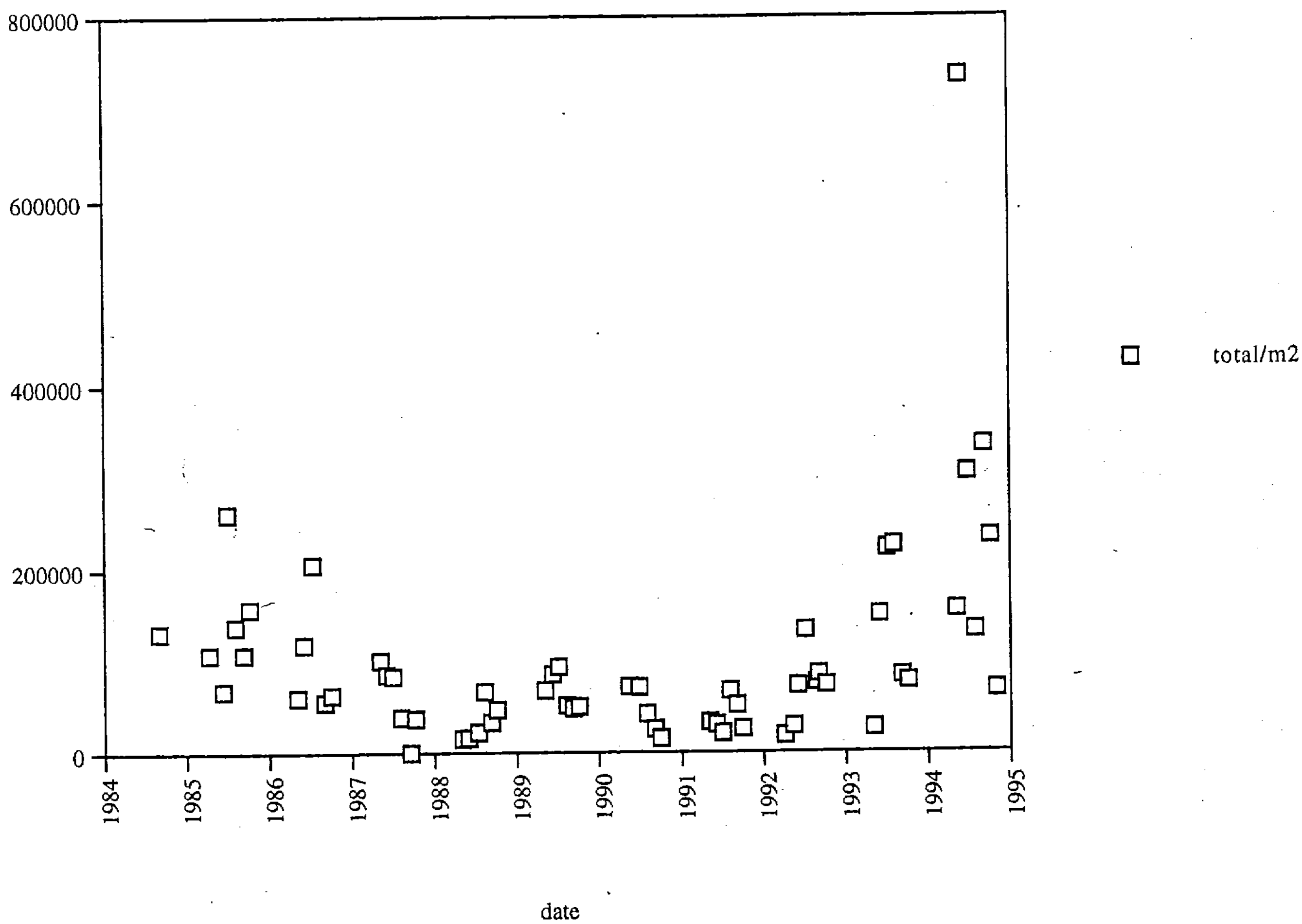


Figure 2.2.8. Lizard Lake Zooplankton: *Kellicottia.*

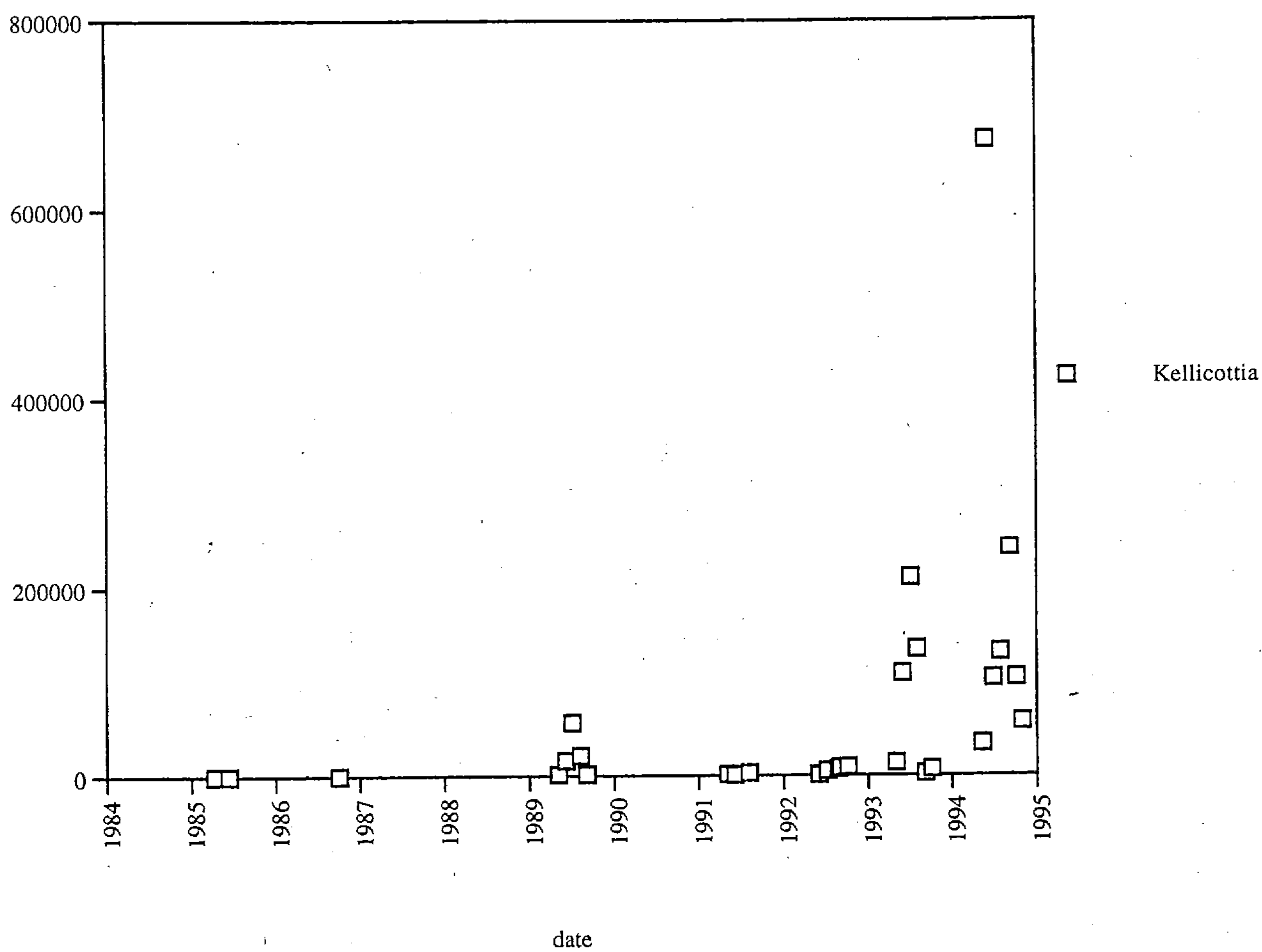


Figure 2.2.9. Lizard Lake Zooplankton: *Conochilus/Keratella*.

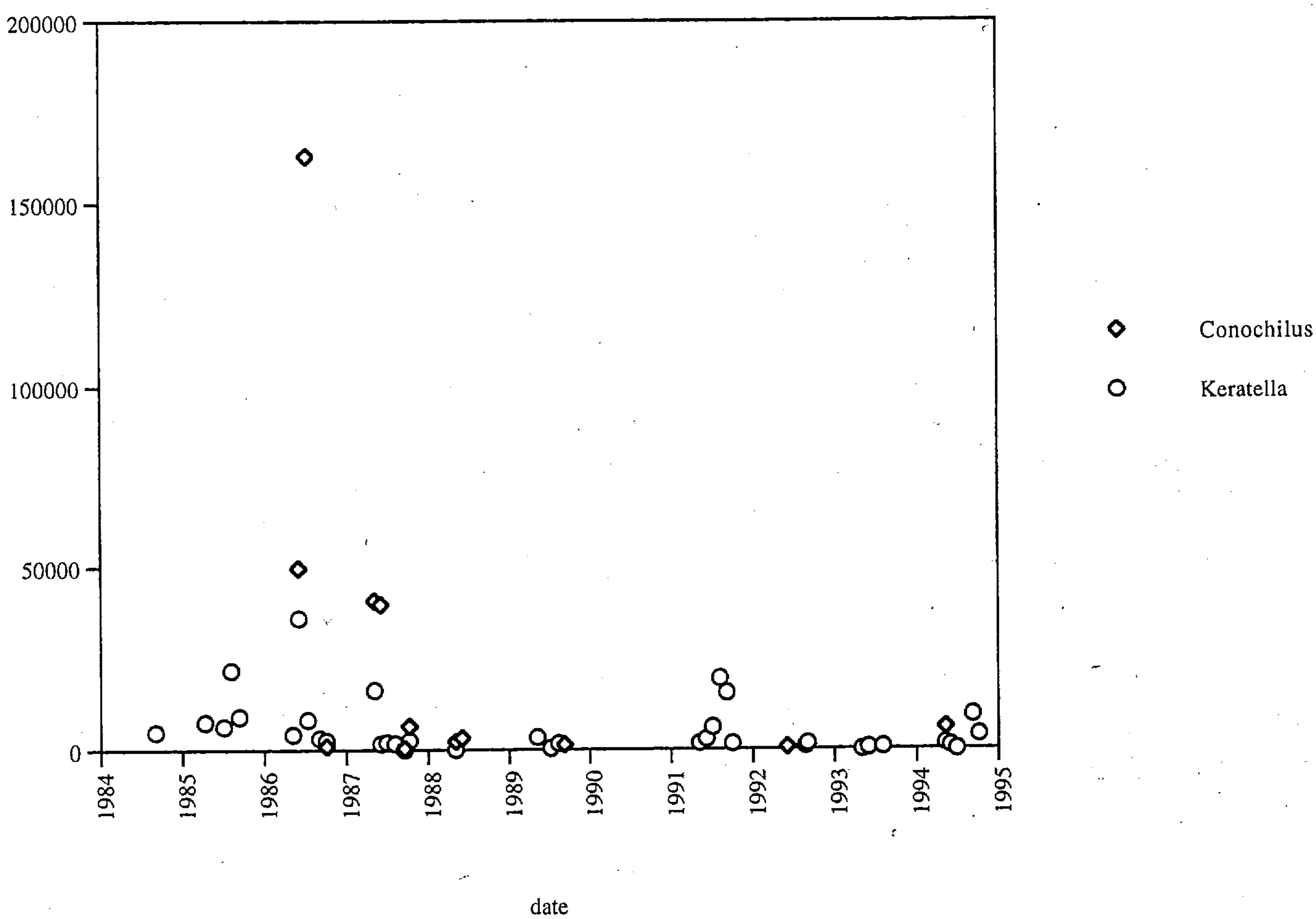


Figure 2.2.10. Lizard Lake Zooplankton: *Polyarthra*.

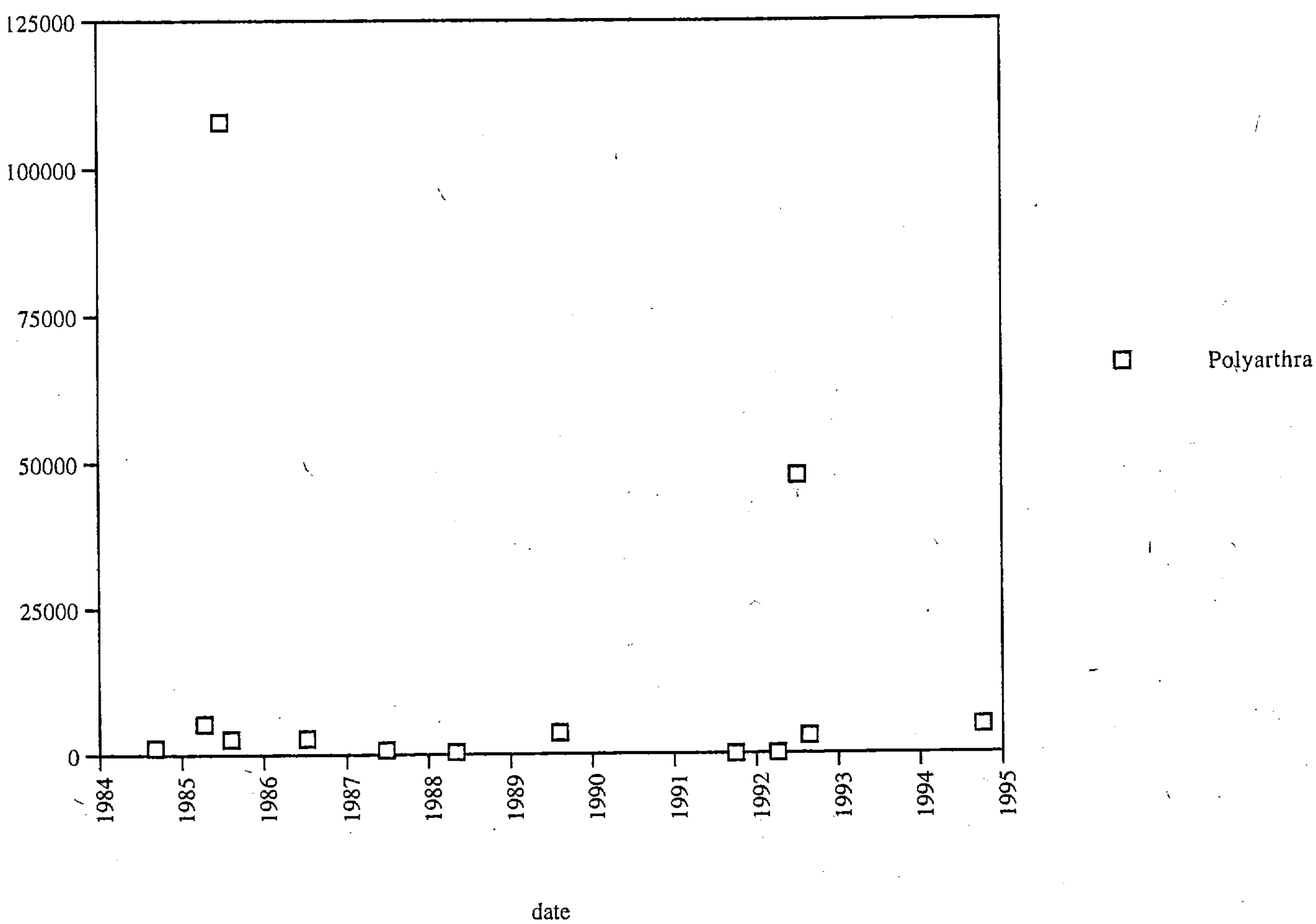


Figure 2.2.11. Lizard Lake Zooplankton: Rare Rotifers.

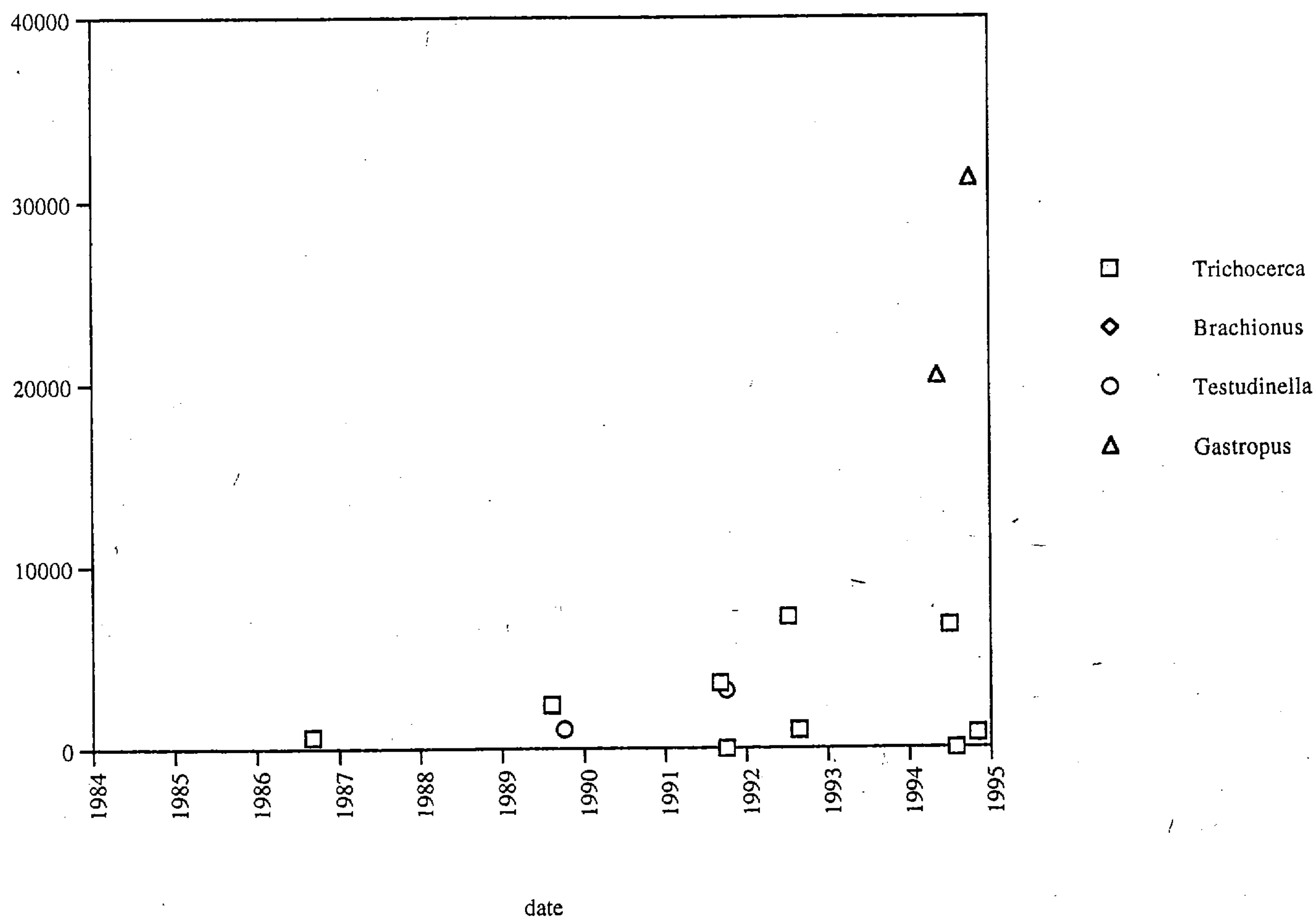


Figure 2.2.12. Lizard Lake Zooplankton; Biomass Comparisons.

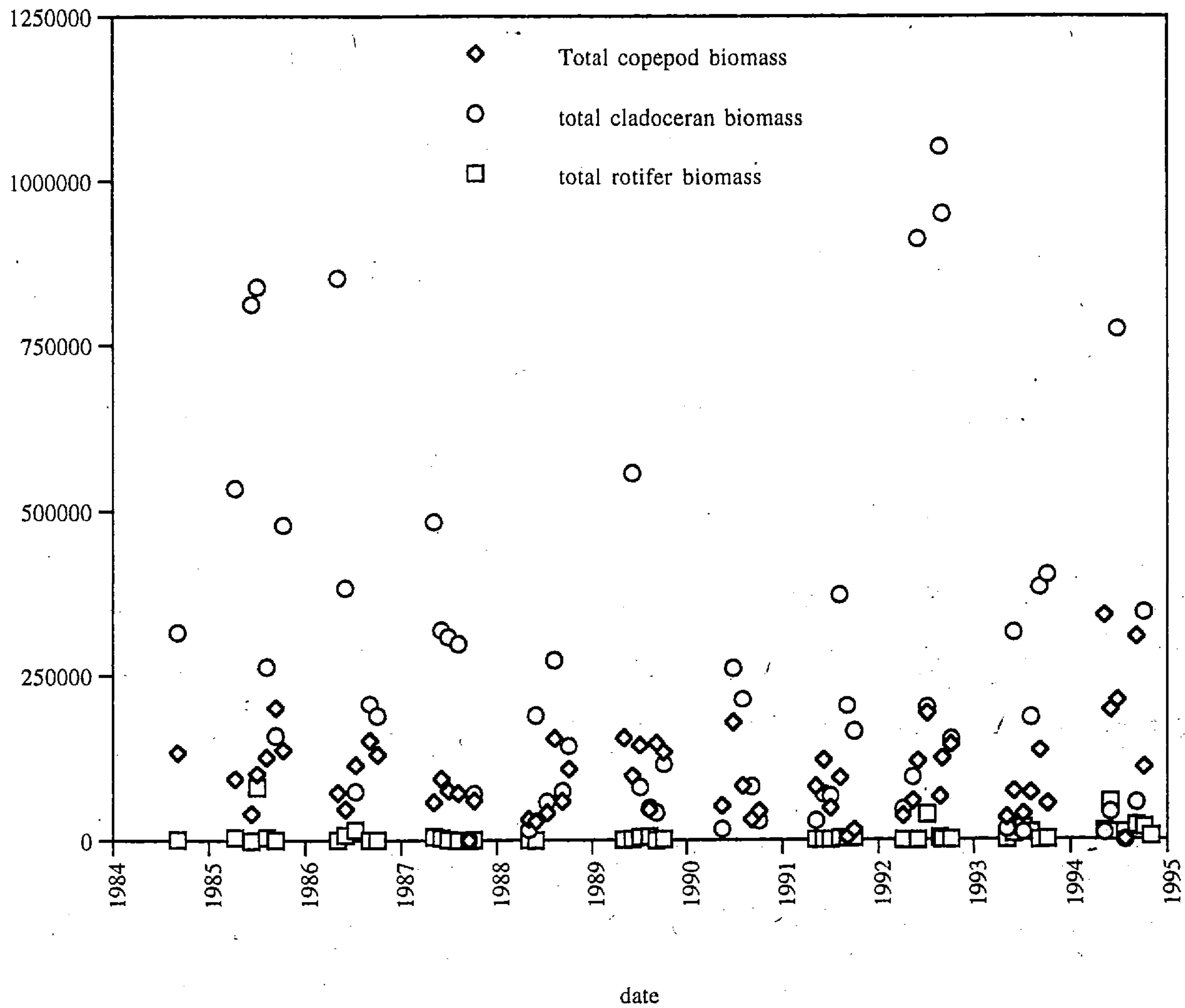
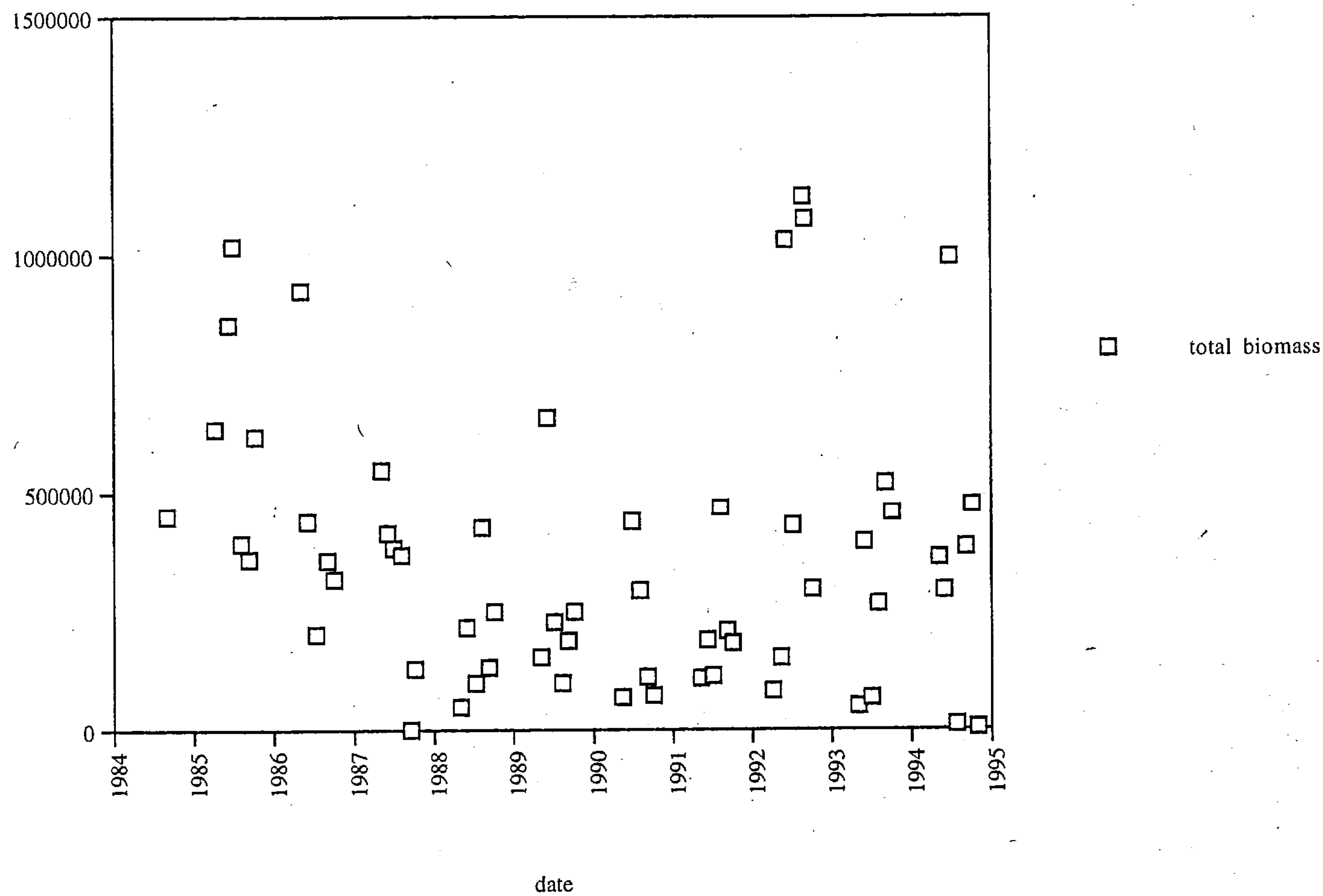


Figure 2.2.13. Lizard Lake Zooplankton: Total Biomass µg/m2



3.0. JACOBS LAKE

Jacobs Lake is located on the lower Mainland 10 km north-north-east from Haney approximately 50 km east from Vancouver, B.C (49° 18' 40", 122° 32' 46", map sheet 92G). This location is in the University of British Columbia Research Forest, at an elevation of 300 m on the south slope of the coastal mountains in a U-shaped 500 m wide valley. Jacobs Lake is also known locally as Marion Lake, and previous studies (Dickman,1968) have used this local name. Jacobs has an area of 13 ha, a maximum depth of 7m and a mean depth of about 2.4m.. The lake has a drainage area of about 6.5 km^2 and a volume of 312 dam^3. The valley floor is covered with glacial drift, with shallow soils and recent regenerative tree growth following logging and fire.

The climate is wet with an annual precipitation of 240 cm/year. This high rainfall coupled with the impermeable substrata of the watershed and the morphometry of the basin result in rapid flushing of the lake. Efford (1967) reports that during times of peak precipitation the water residence time in Jacobs Lake is as low as 2.3 days, and that water levels may rise as much as 1m in 24 hours.

Unlike the other lakes there has been a considerable amount of work done on Jacobs Lake as part of the Marion Lake International Biological Program (IBP) project (Dickman 1968, Dickman and Efford 1972, McQueen 1970). As a result background data exists for both phytoplankton and zooplankton populations with which data from this study can be compared. In addition, physical and some limited chemical data from this late 1960's/early 1970's period has been collected as well. Both the phytoplankton and zooplankton communities were characterised by very low total numbers and biomass. Dickman (1968) correlates this low productivity with the high flushing rate noted above. This has a direct effect on both the type and quantity of the plankton. Larger organisms are washed out of the lake and selection pressure favours the nannoplankton, which have a reproduction rate that compensates for losses due to flushing (Findenegg, 1965). Enclosure studies completed by Dickman confirmed that when this pressure was removed the structure of the community shifted to larger organisms. Given these conditions the term "dominant" must be used with caution when used to describe the plankton community of Jacobs Lake as sampled in this study..

3.1 Phytoplankton

The phytoplankton sampling and analysis methods used over the course of this study of Jacobs Lake have been inconsistent, and thus interpretation of the data is a challenge. From May 1984 to June 1990 phytoplankton were collected using vertical net tows. The data records cite these tows as 3m, 4m or 13m vertical tows. Marion has Lake has a maximum depth of 7m at high water and a mean depth of only 2.3m, thus a 13m vertical tow seems implausible. This raises the question of whether some or all of these tows being horizontal. From July 1990 through October 1993 samples were collected with an unconcentrated surface grab, consistent with the other study lakes. Plankton data were apparently not collected in 1994. Curiously chlorophyll a data are available for this year. The net tows do not provide quantitative measurements of phytoplankton population, and the 264 µm mesh size used on some samples is too large to provide accurate qualitative information. Finally, the count results have been reported in a number of different units (cells/mL, cells/m^3, cells/0.59m^3) and have required conversion. As a result of these uncertainties the data from May of 1985 through June 1990 cannot be relied upon to provide accurate quantitative or qualitative information and must be interpreted with caution.

Jacobs exhibits the greatest diversity among the study lakes, with 99 genera reported between 1985 and 1993. All genera exhibit a high degree of variability, and are listed in Appendix 4. The dominant and sub-dominant genera are displayed in Table 3.1.1. *Navicula* is the most consistent of the dominants, present in 90% of all samples with a low mean concentration of 2.5 cells/mL. *Dinobryon* (88%), *Ankistrodesmus* (86%), and *Cryptomonas* (80%) complete the dominant group. Of all dominant and sub-dominant taxa only *Ankistrodesmus, Dinobryon, Cryptomonas, Scenedesmus*, and *Merismopedia* occur at concentrations over 100 cells/mL. Table 3.1.1 reflects this, with low mean concentrations displayed for all but *Merismopedia.* Peaks of over 100 cells/mL are infrequent, tending to occur between 1990 and 1993. *Aphanothece* and *Merismopedia* both show notable anomalies. *Aphanothece* appears in only three samples, once in August of 1985 with 234,000 cells/mL, then once each in 1988 and 1992 at background levels only. *Merismopedia* peaks at over 2000 cells/mL, once in 1992 and twice in 1993. The trend to higher peak numbers after 1990 may be an artefact of the change in sampling method. These taxa are displayed in Figures 3.1.2 to 3.1.7.

Phytoplankton standing crop as measured by total cells/mL (Figure 3.1.8) shows very low numbers from 1986 through 1988 with the exception of the peak in *Aphanothece* noted above. Most totals for this period are below 10 cells/mL, and only two samples show total concentrations of over 100 cells/mL. Standing crop then increases significantly, showing peaks of over 2000 cells/mL during 1989 through 1992, then decreasing to between 200 and 600/mL for 1993. The majority of this peak can be accounted for by increases in *Cryptomonas*, *Merismopedia*, and *Uroglenopsis* populations, and to a lesser degree increases in *Dinobryon* and *Sphaerocystis*. Chlorophyll data (Figure 3.1.9) reflects this pattern, increasing from a mean concentration of 1.75µg/L to 3.63µg/L, then decreasing to a mean of 1.60µg/L for 1993 and 1994. A value of 22.4µg/L was recorded in September of 1989. This appears to be out of scale with the rest of the data, and thus has been excluded from the calculations of mean concentration.

The low standing crop values are consistent with the findings of the earlier studies of Marion, however the data for the 1986 to 1988 period appear to be particularly low. Chlorophyll data for this period shows values similar to those in 1993 and 1994, during which the standing crop is significantly higher. Chlorophyll is sampled in a manner analogous to the grab sample collection of phytoplankton and this method has been consistent throughout the study. This may indicate that the low standing crop values for 1986 to 1988 are in part a result of the inadequate collection technique. In addition there was a change in chlorophyll analytical technique in June 1990 which resulted in higher values being measured thereafter (M. Clark, personal communication). This may have had some effect on the Jacob's lake data, although the increase in chlorophyll concentration occurred prior to this. In general the chlorophyll values for Jacobs are similar to the other lakes in the study, despite the relatively low standing crop observed. Yearly summaries of phytoplankton and chlorophyll a values are shown in tables 3.1.2 and 3.1.3.

Dickman (1968) provides a quantified list of planktonic organisms observed in Marion Lake from 1965 through 1967. Comparison with the 1985-1993 data reveals that the community structure was significantly different during the earlier study. A higher diversity is evident in the Dickman study, with 111 phytoplankton taxa reported to the genus level over that three year period. Table 3.1.4 displays the taxa from the Dickman study that would be considered dominant and sub-dominant in this study, as well as their mean concentration over the sample period. This group reflects the higher diversity, being composed of 7 divisions encompassing 23 genera. Standing crop would appear to be significantly higher as well given the mean concentrations of this group. The less common phytoplankton show similar elevated concentrations over the later data.

Comparison of tables 3.1.1 and 3.1.4 indicates some consistency between this and the Dickman study with regard to the composition of the dominant and sub-dominant groups. *Navicula* and *Scenedesmus* occur as dominants and *Frustulia* occurs as a sub-dominant in both studies. As noted above Dickman's results show greater diversity and biomass, however these data are based on a 3 year mean, while the later data covers 9 years. This could account for some of the observed differences.

3.2. Zooplankton

The difficulties with zooplankton are less than with the phytoplankton, but there are some significant handicaps in using or interpreting the data. The net mesh size used for collection in 1984-1985 was 243 µm and after 1986, 363 µm. This is significantly larger than the mesh size used in the other lakes. As a result the composition of the samples has a number of peculiarities. The numbers of immature copepod stages are low in comparison to the number of adults, as are the occurrence and numbers of rotifers. Total numbers are substantially lower than for any of the other lakes, although the low water residence time of the lake is probably partially responsible for this (Dickman, 1968) Because of the shallowness of the lake, vertical tows were confined to between 3 and 4m. As in the phytoplankton the data were recorded in a number of different units (numbers per total sample, animals/m^3, animals/0.59m^3, animals/m^2). The data was converted to animals per m^2 to be comparable with the other lakes (Appendix 5).

Unlike the high diversity exhibited by the phytoplankton, Jacobs has the lowest zooplankton diversity of the study lakes with only fourteen genera reported. Of the three copepod genera identified in the lake, *Diaptomus* (Figure 3.2.1) is the most prominent. Two species are identified, *D. oregonensis* and *D. tyrelli*, as well as one unidentified species. There are several occasions on which both species are reported from the same sample and this provides some evidence that they are in fact two distinct species and that it is unlikely a taxonomic problem. Peaks for most years are between 10000 and 20000 individuals/m^2, with a slight decline in numbers evident over the period of sampling. *Cyclops* is reported up until 1991, generally with numbers below 10000/m^2 except for 1990 which shows a peak of over 60000. *Diacylops* is then reported in 1992 and 1993 with numbers similar to those shown by *Cyclops* (Figure 3.2.2). As noted above, the numbers of copepodites and nauplii are low in relation to the numbers of adult animals and decline over the study period, excepting two copepodite peaks of 16000 and 6500 cells/mL in 1992 (Figure 3.2.3).

Bosmina (Figure 3.2.4) and *Diaphanasoma* (Figure 3.2.5) are the two prominent cladoceran genera in Jacobs Lake. They have comparable numbers and occurrence through 1993. Both show a peak of over 30000/m^2 in 1992. *Holopedium, Eubosmina, Daphnia, Ceriodaphnia, Leptodora, Graptoleberis*, and *Sida* occur sporadically with no apparent pattern (figures 3.2.6 to 3.2.8). The latter two are typically littoral or benthic organisms and are likely accidental members of the plankton community given the shallow depth of the lake.

Three rotifer genera were reported (Figure 3.2.9). *Keratella* is reported five times, at levels between 70 and 600 cells/mL. *Polyarthra* and *Conochilus* are present once each, at 19,706 cells/mL and 1 cell(s)/mL respectively. The overall absence of rotifers is likely a reflection of the large net mesh size used.

Estimation of zooplankton dry weight biomass indicates that the copepods form the bulk of the zooplankton standing crop in Jacobs, followed by a much lesser contribution from the cladocera and very small amount from the rotifers (Figure 3.2.10). A slight decline in zooplankton biomass (Figure 3.2.11) and total numbers (Figure 3.2.12) is evident over the study period.

Comparison of the 1985-1993 data with that collected by Dickman (1968) and Efford (1972, as reported in Wissmar and Wetzel, 1978) is difficult given that the materials and methods of both authors are at present unavailable. A comparative list of the zooplankton observed in each study is provided in Table 3.2.1. The Dickman study shows the greatest diversity, with 21 taxa reported, followed by the present study with 17 taxa and the Efford study with 6 taxa reported. The data collected for this study and Dickman appear roughly similar in the presence of the major taxa (*Diaptomus, Cyclops, Bosmina* and *Diaphanosoma*). Efford reports *Diaptomus* and *Cyclops*, but *Ceriodaphnia* as the only cladoceran. All three studies report *Keratella, Polyarthra* and *Conochilus*, but Dickman displays a greater rotifer diversity with 5 other genera reported. Knowledge of both Dickman and Effords sampling methods are required before an attempt to account for these differences can be made.

	Dominant	Sub dominant	% presence	mean conc. cells/mL
Diatom	*Navicula*		90	2.56
		Tabellaria	73	1.09
		Achnanthes	65	1.04
		Cymbella	59	0.27
		Frustulia	53	0.60
Chrysophyte	*Dinobryon*		88	21.18
Chlorophyte	*Ankistrodesmus*		86	13.13
		Scendesmus	53	8.31
Cryptophyte	*Cryptomonas*		80	13.09
Cyanophyte		*Merismopoedia*	59	379.07

Table 3.1.1. Jacobs Lake Phytoplankton: Dominant and Sub-dominant taxa.

Year	n	mean	maximum	minimum	# of samples
1985	235356	2674	234000	.001	6
1986	41	0.50	4.56	.001	4
1987	29	0.29	22.62	.001	6
1988	450	4.24	236	.001	6
1989	5497	40.71	2271	.001	6
1990	11069	106.43	5343	.001	6
1991	5931	49.94	4130	.001	6
1992	7057	63.00	2593	.001	6
1993	1498	14.00	347	.001	6

Table 3.1.2. Jacobs Lake Phytoplankton: Summary of total numbers of phytoplankton cells/mL by year.

year	mean	maximum	minimum
1986	1.76	2.7	0.9
1987	1.03	3.0	0.5
1988	2.0	2.9	0.5
1989	3.72	6.0	0.5
1990	3.0	5.1	1.3
1991	4.0	5.0	2.6
1992	3.82	5.8	2.1
1993	1.8	3.2	0.7
1994	1.4	2.4	0.6

Table 3.1.3. Jacobs Lake Phytoplankton: Mean and range of Chlorophyll a measurements by year in µg/L

	Dominant	Sub-dominant	mean conc. cells/mL
Cyanophyte		*Microcystis*	30.00
		Gomphosphaeria	63.31
		Aphanocapsa	484.98
Chlorophyte	*Chlamydomonas*		65.00
	Sphaerocystis		4.00
		Schroderia	5.30
		Oocystis	109.99
		Ankistrodesmus	11.00
		Quadrigula	20.00
		Spondylosium	3.90
		Scendesmus	50.00
		Crucigenia	86.00
Chrysophyte		*Chrysapsis*	1294.00
		Chrysococcus	103.00
Diatom	*Navicula*		2.00
		Cyclotella	3.34
		Synedra	14.52
		Frustulia	4.52
		Amphora	0.80
Cryptophyte	*Cryptomonas*		96.00
Euglenophyte	*Rhabdomonas*		342.00
Pyyrophyte		*Glenodinium*	16.00
		Gymnodinium	48.00

Table 3.1.4. Jacobs Lake Phytoplankton: Dominants taxa recorded in Dickman (1968).

Taxa		Dickman	Efford	this study
Copepoda	*D. orogonensis*	P	P	P
	D. tyrelli			P
	Cyclops	P	P	P
	Eucyclops	P		P
	Diacyclops			P
Cladocera	*Bosmina*	P		P
	Alona	P		
	Chydorus	P		
	Diphanosoma	P		P
	Holopedium	P		P
	Polyphemus	P		
	Eubosmina			P
	Daphnia	P		P
	Ceriodaphnia	P	P	P
	Streblocerus	P		
	Leptodora			P
	Graptoleberis			P
	Sida	P		P
	Ostracoda			P
Rotifera	*Keratella*	P	P	P
	Polyarthra	P	P	P
	Conochilus	P	P	P
	Ploesoma	P		
	Trichocera	P		
	Monostyla	P		
	Ascomorpha	P		
	Lecane	P		

Table 3.2.1. Jacobs Lake Zooplankton: Comparison of zooplankton taxa recorded in three Jacobs Lake studies.

Figure 3.1.1. Jacobs Lake Phytoplankton: *Ankistrodesmus.*

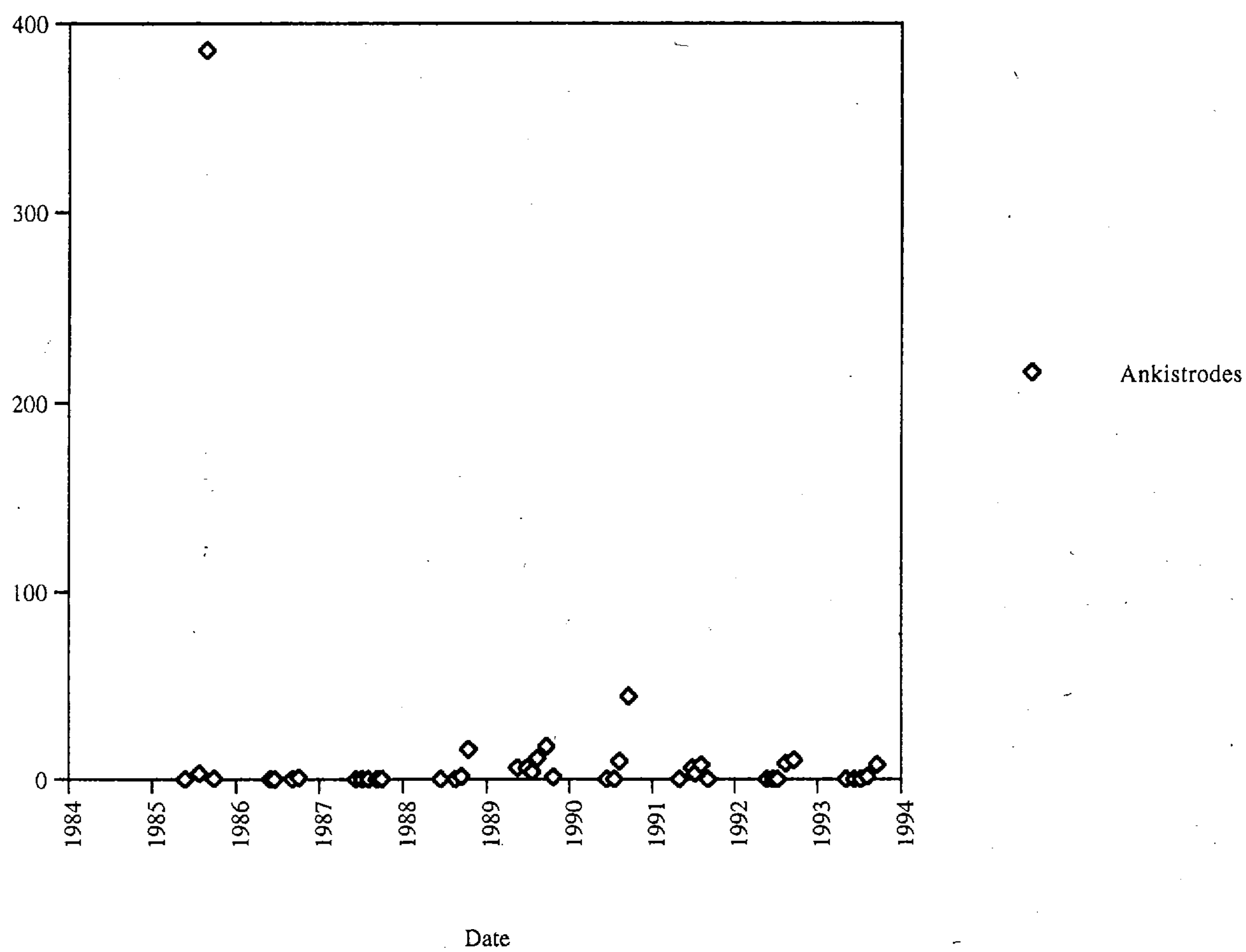


Figure 3.1.2. Jacobs Lake Phytoplankton: *Dinobryon*.

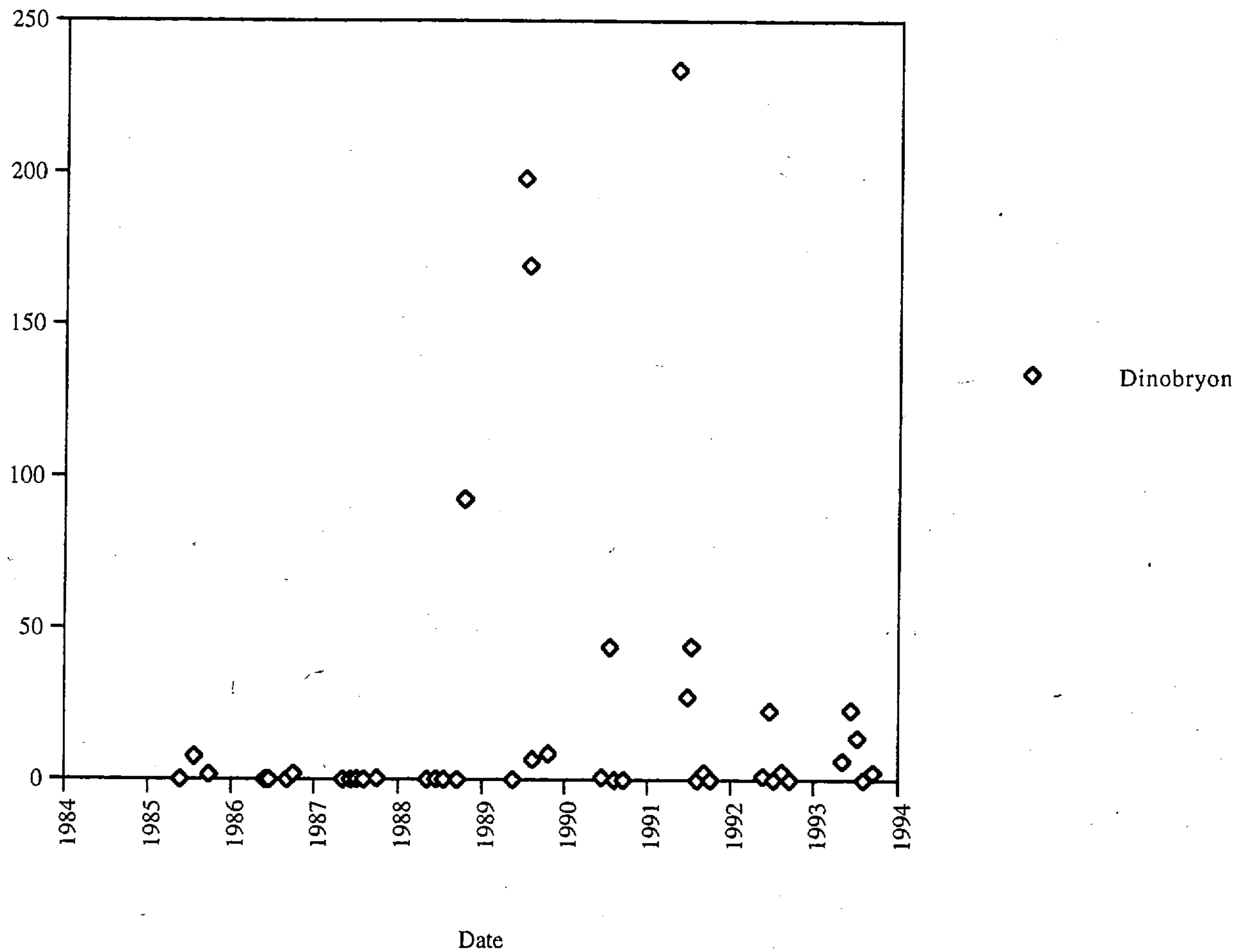


Figure 3.1.3. Jacobs Lake Phytoplankton: *Cryptomonas*.

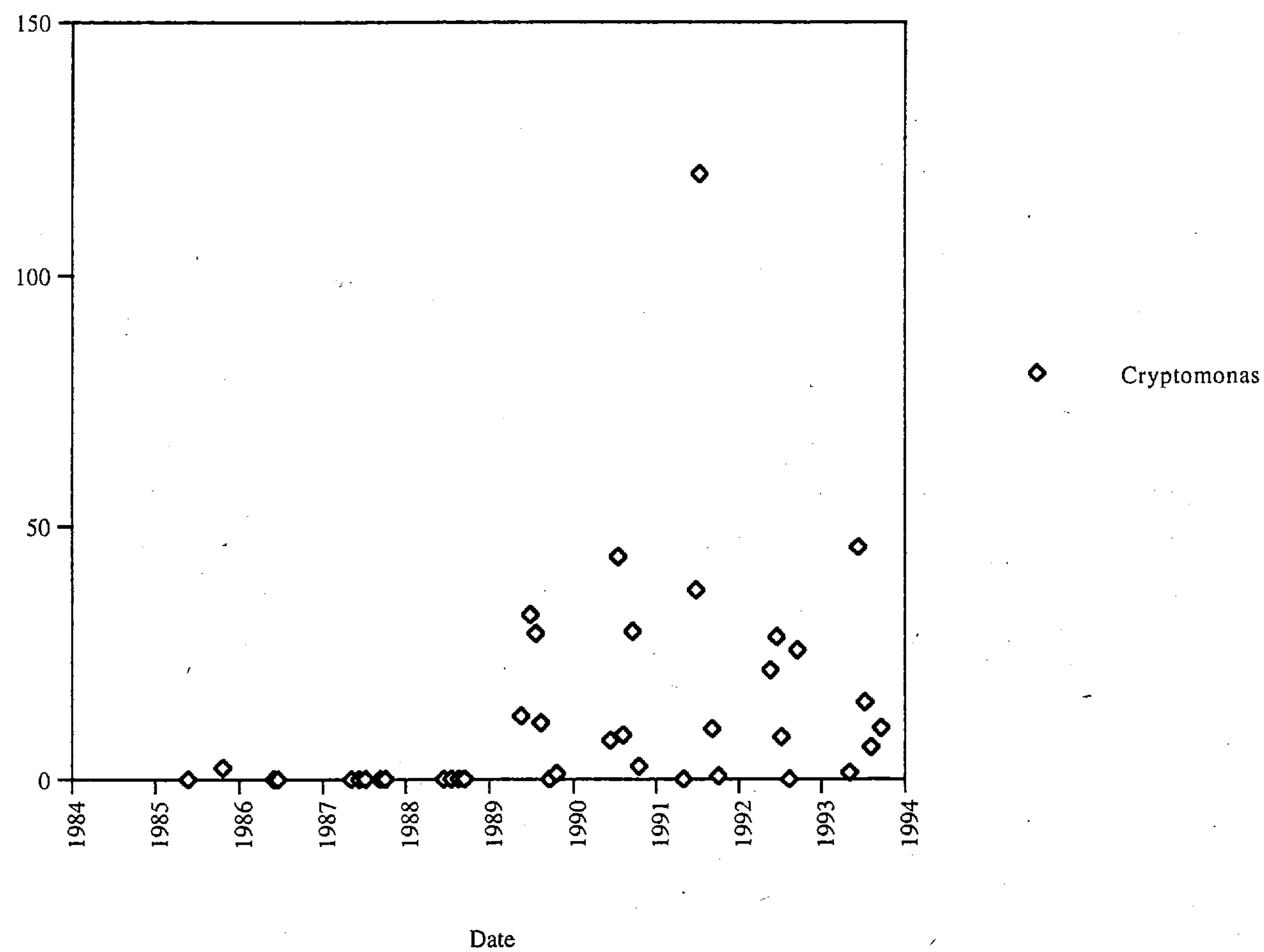


Figure 3.1.4. Jacobs Lake Phytoplankton: Oocystis/Scendesmus.

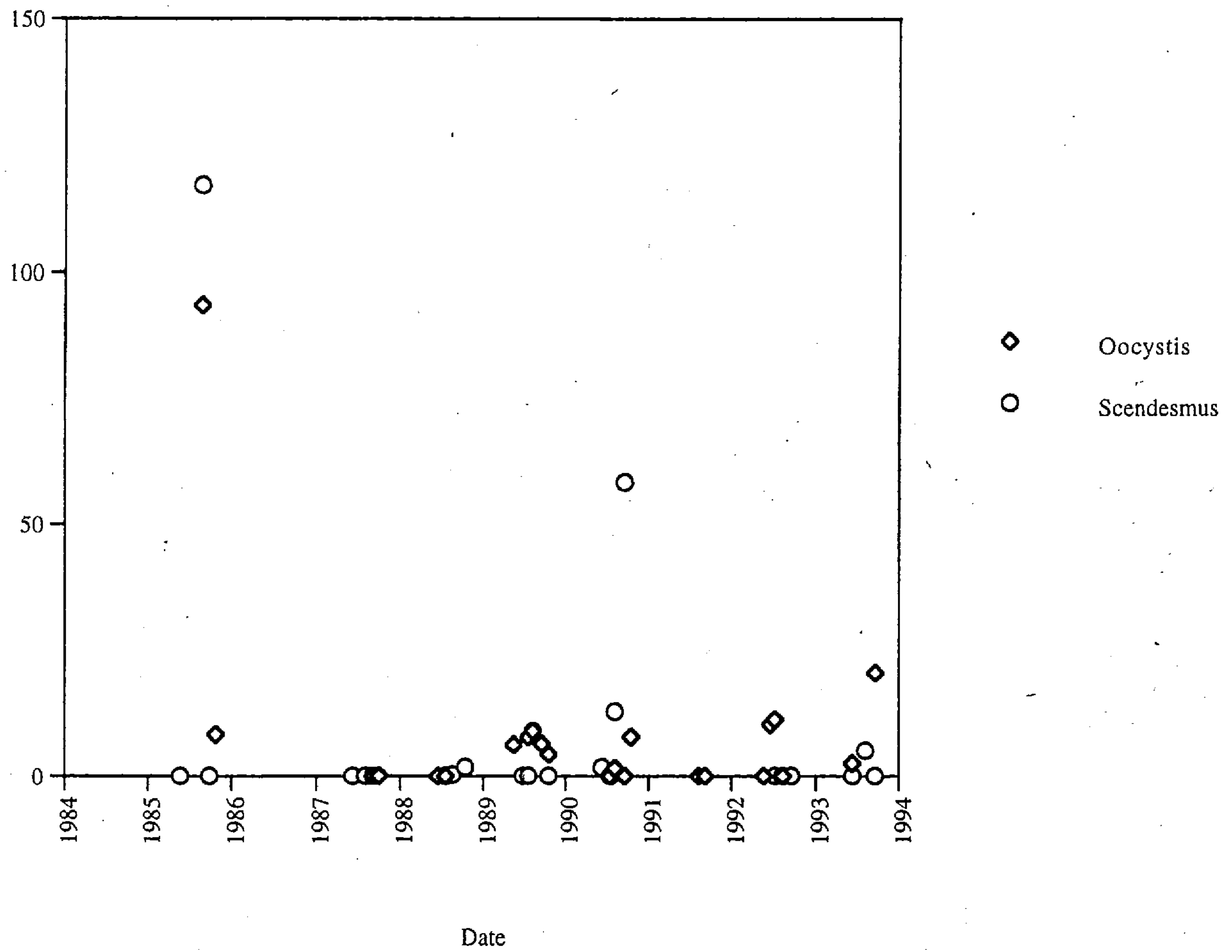


Figure 3.1.5. Jacobs Lake Phytoplankton: *Merismopedia*.

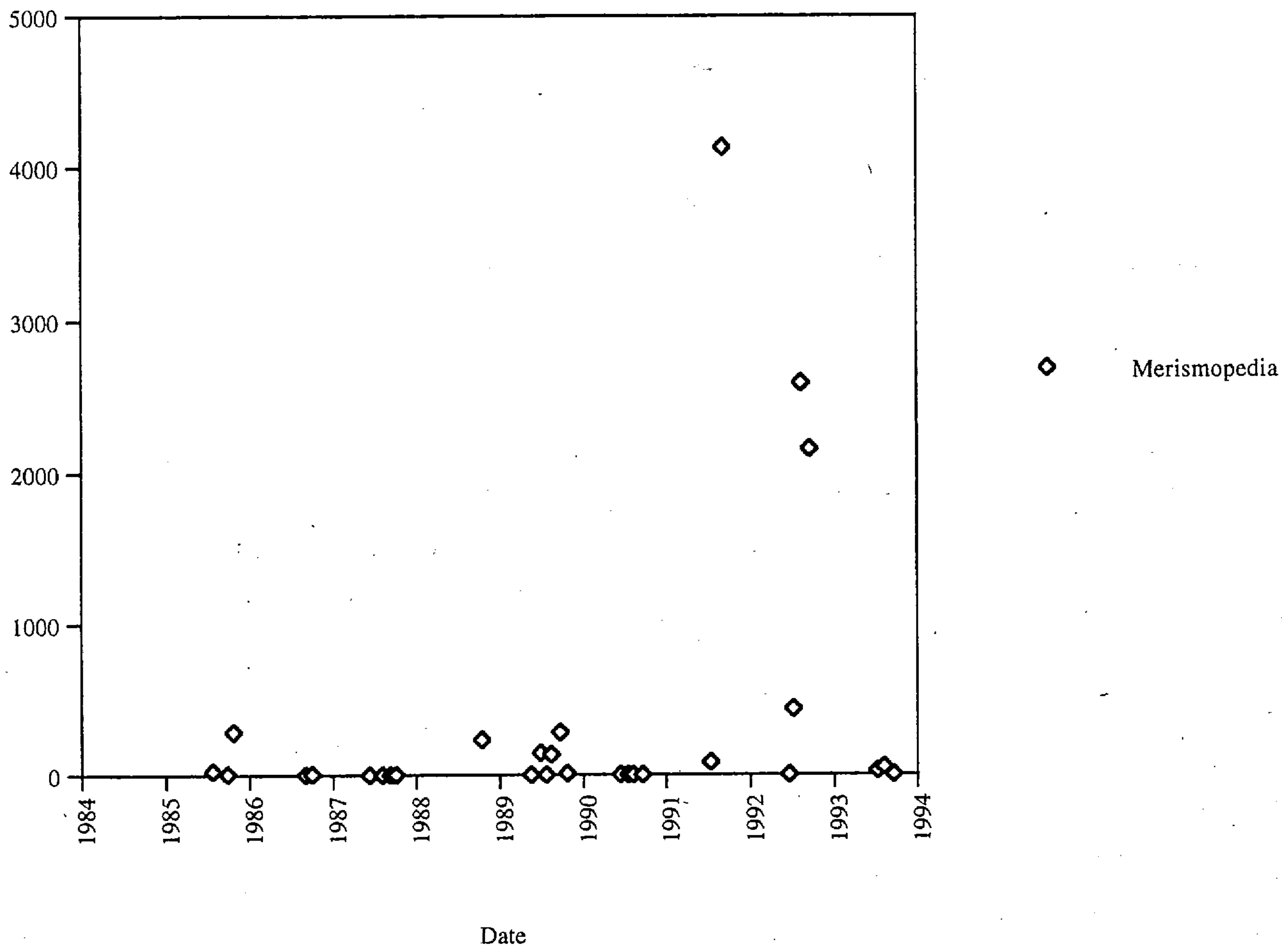


Figure 3.1.6. Jacobs Lake Phytoplankton: *Aphanothece*.

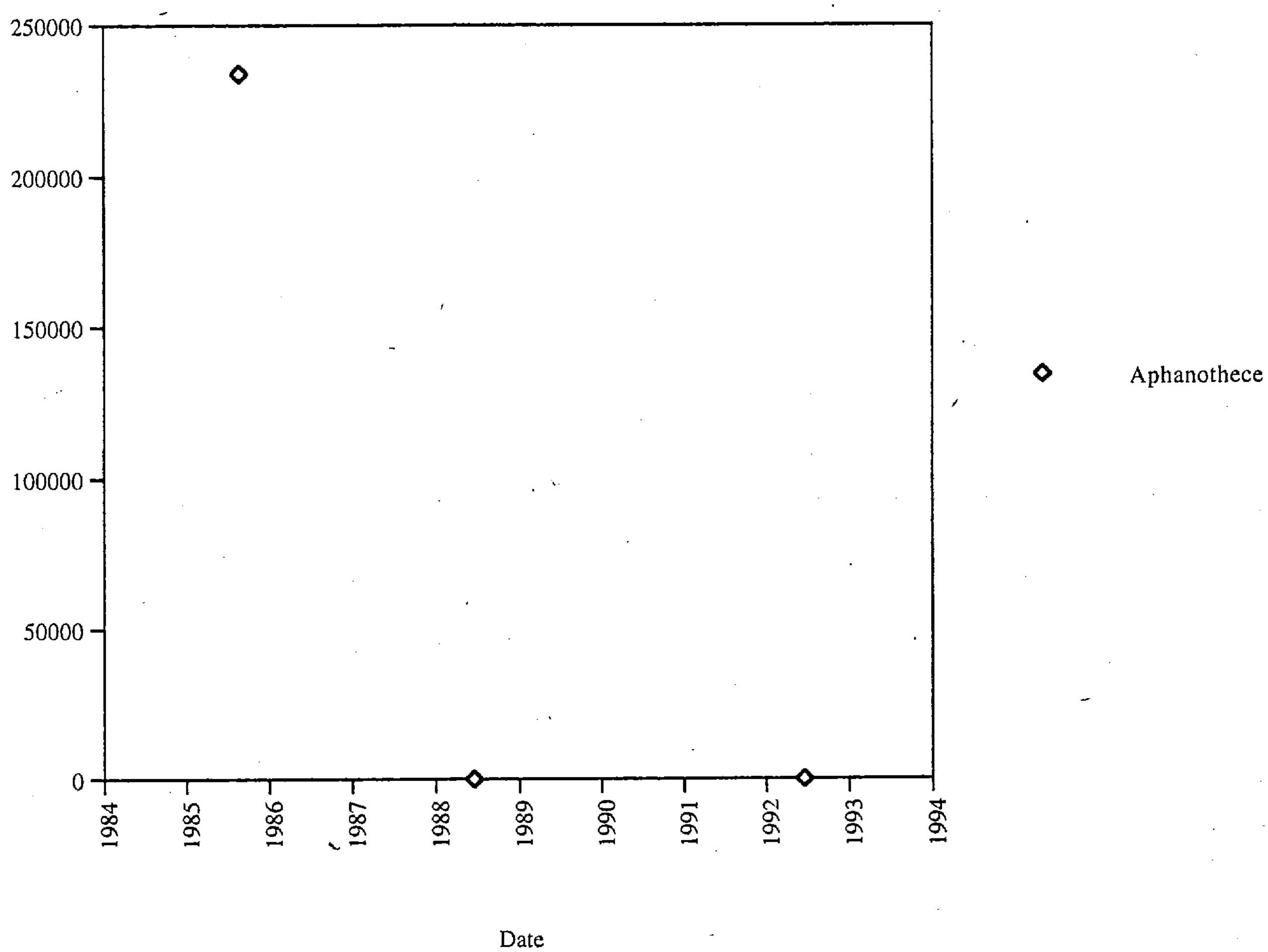


Figure 3.1.8. Jacobs Lake Phytoplankton: Chlorophyll a

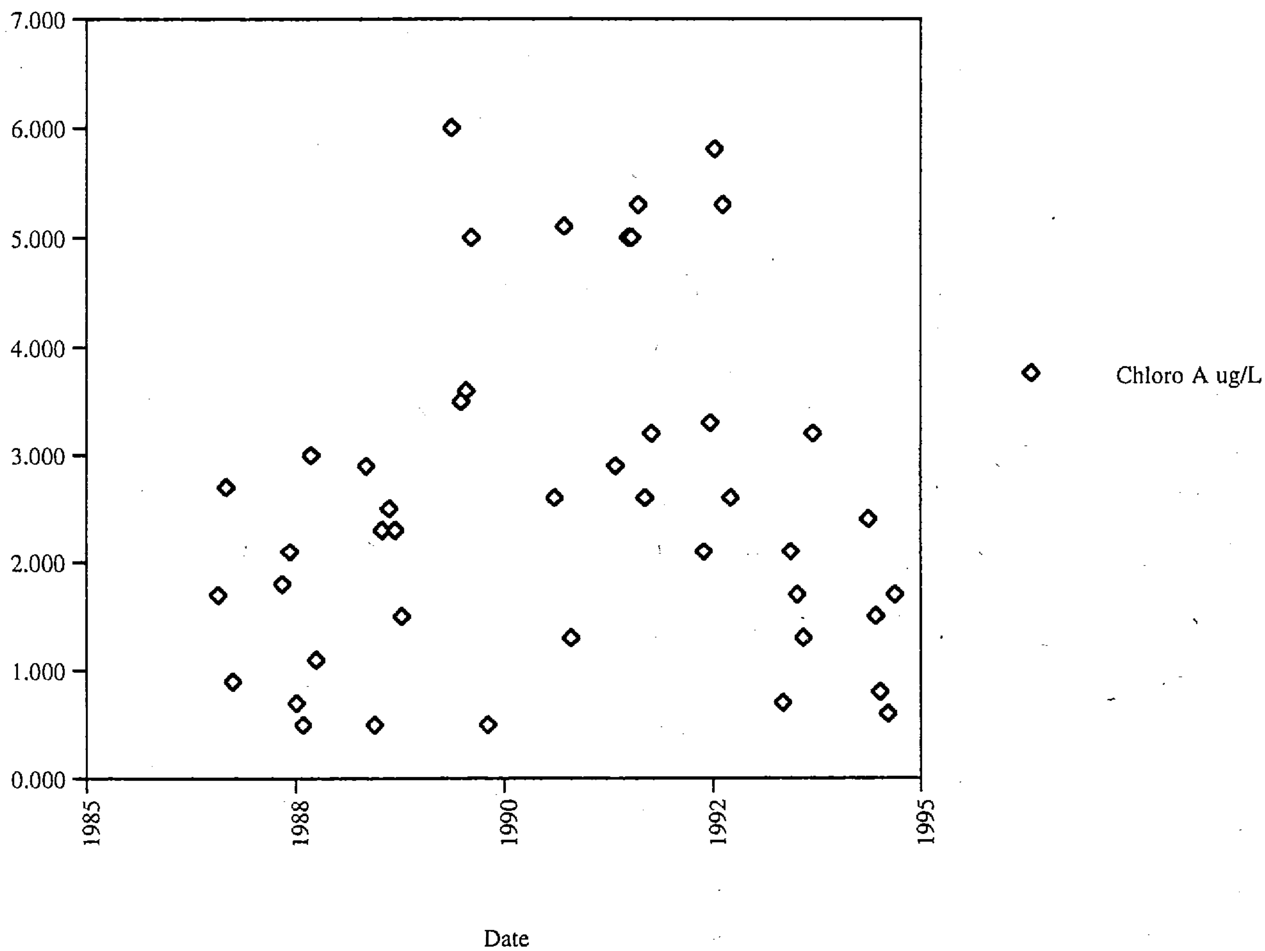


Figure 3.2.1 Jacobs Lake Zooplankton: *Diaptomus*.

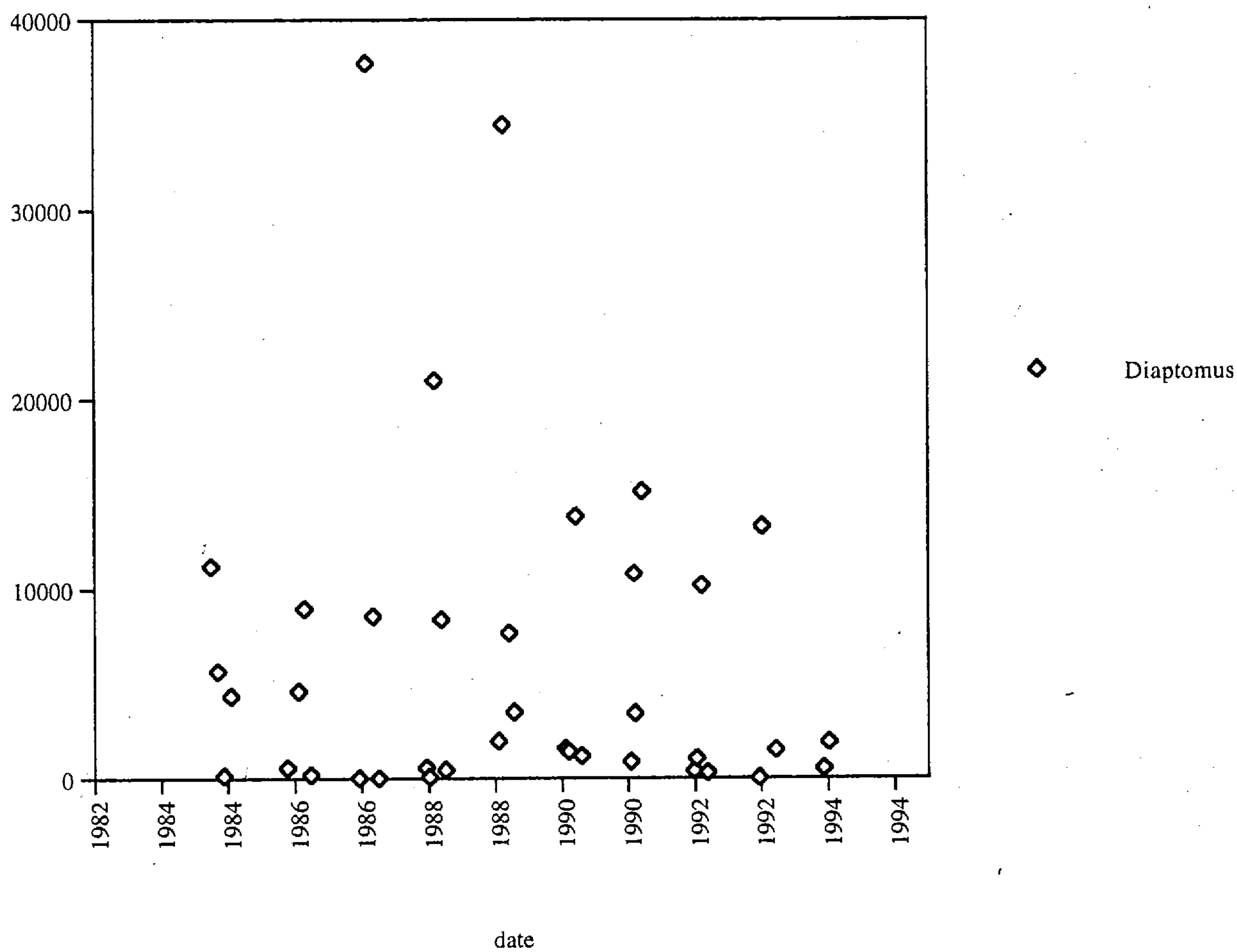


Figure 3.2.2. Jacobs Lake Zooplankton: *Cyclops/Diacyclops*

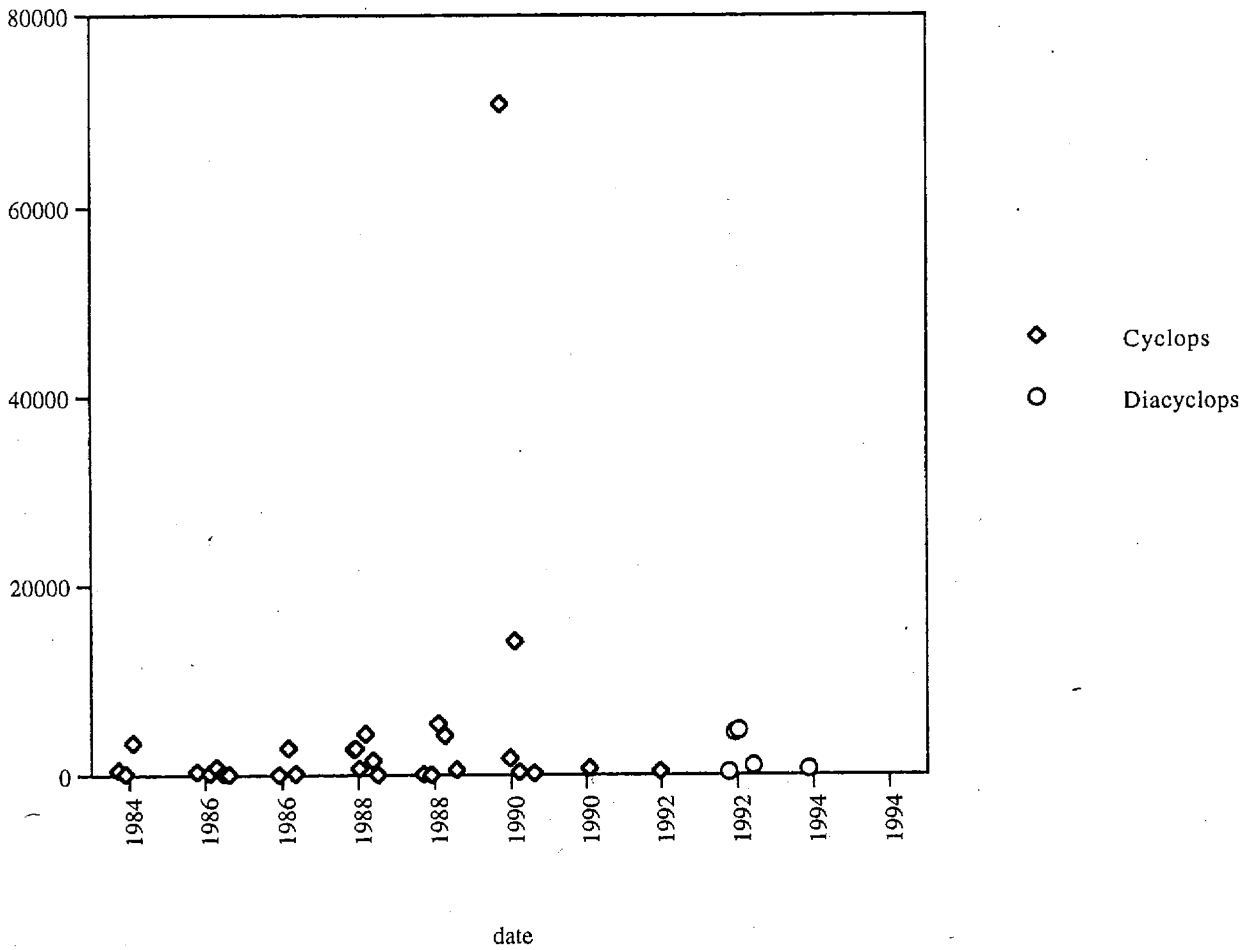


Figure 3.2.3. Jacobs Lake Zooplankton: Copepodites/Nauplii.

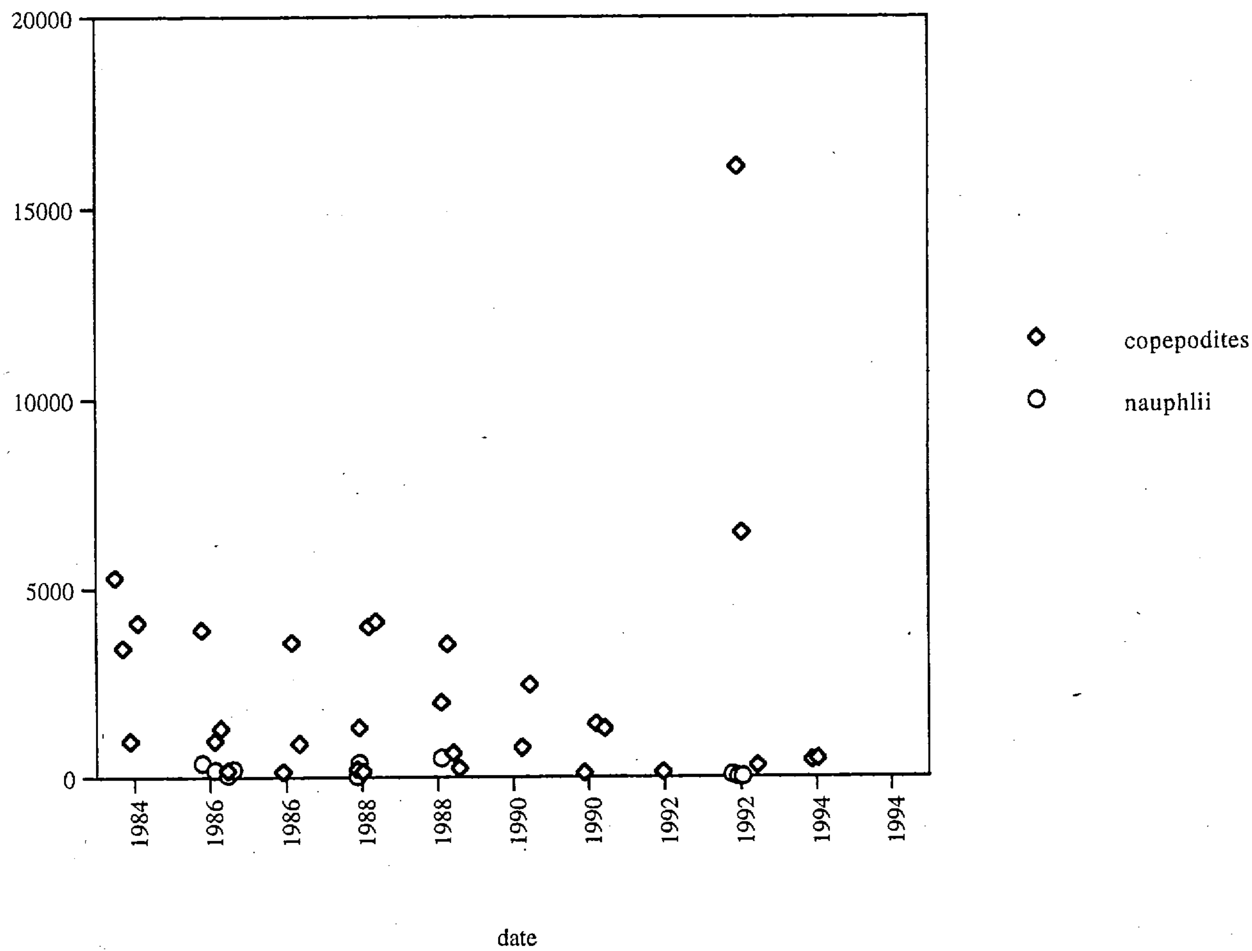


Figure 3.2.4. Jacobs Lake Zooplankton: *Bosmina.*

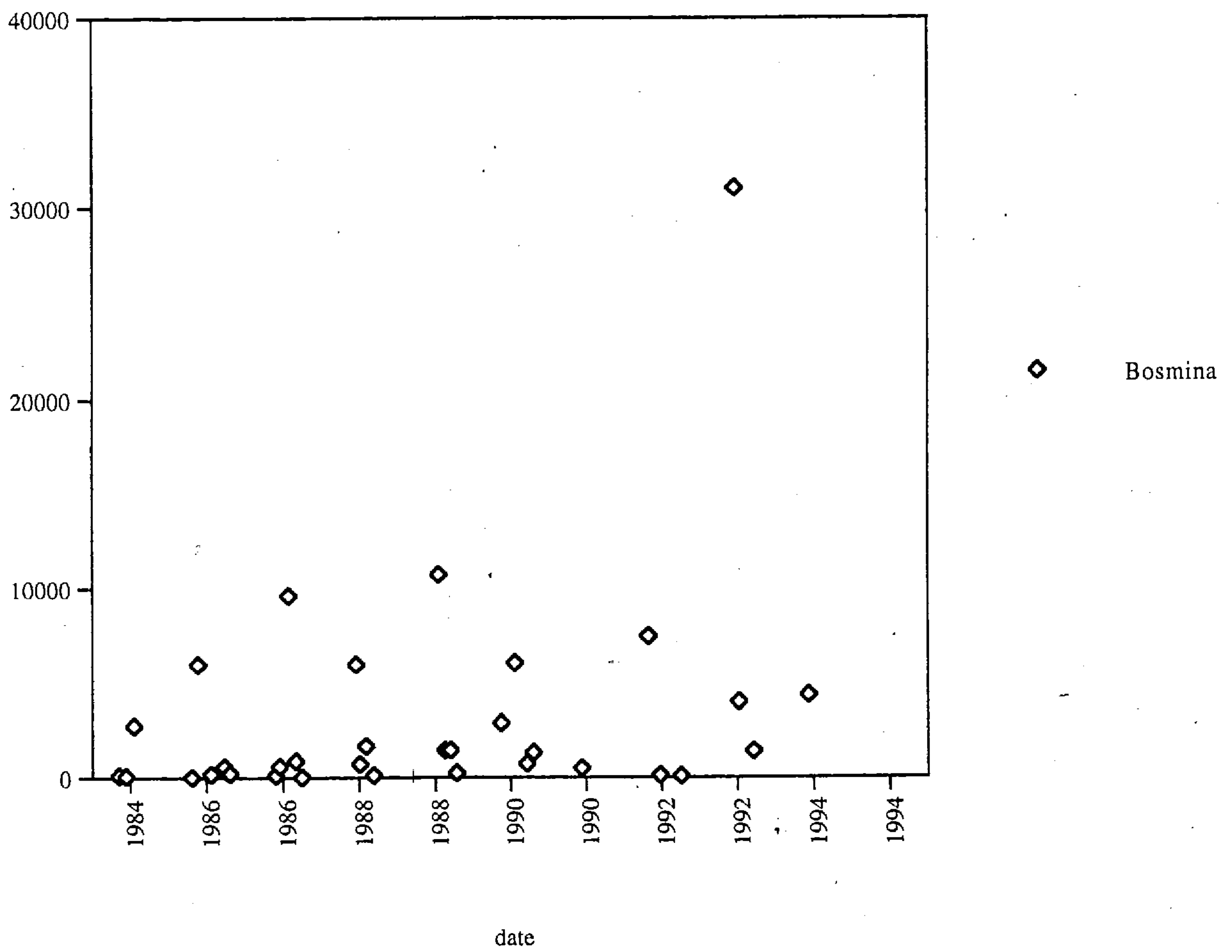


Figure 3.2.5. Jacobs Lake Zooplankton: *Diphanosoma.*

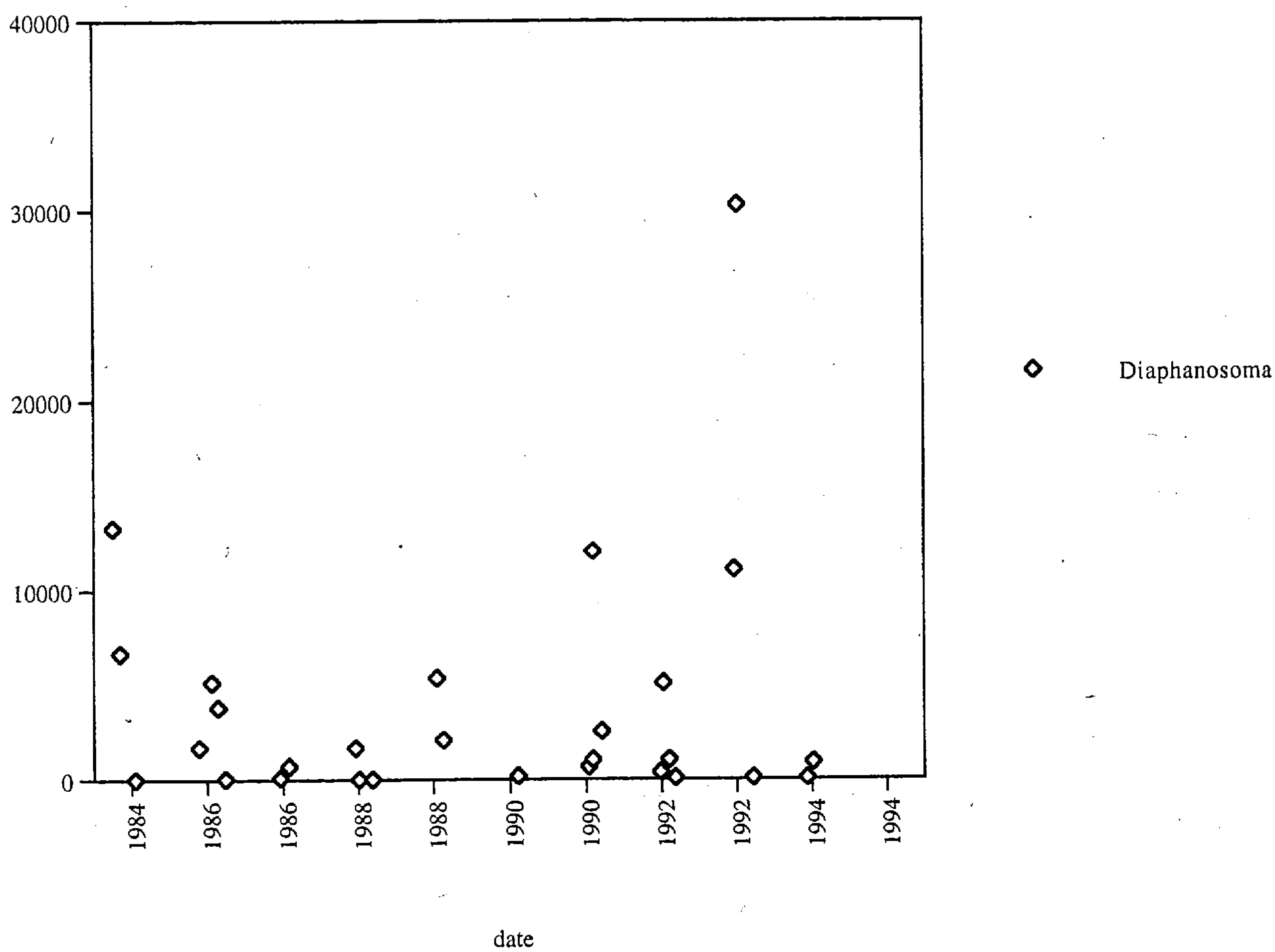


Figure 3.2.6. Jacobs Lake Zooplankton: *Holopedium/Eubosmina.*

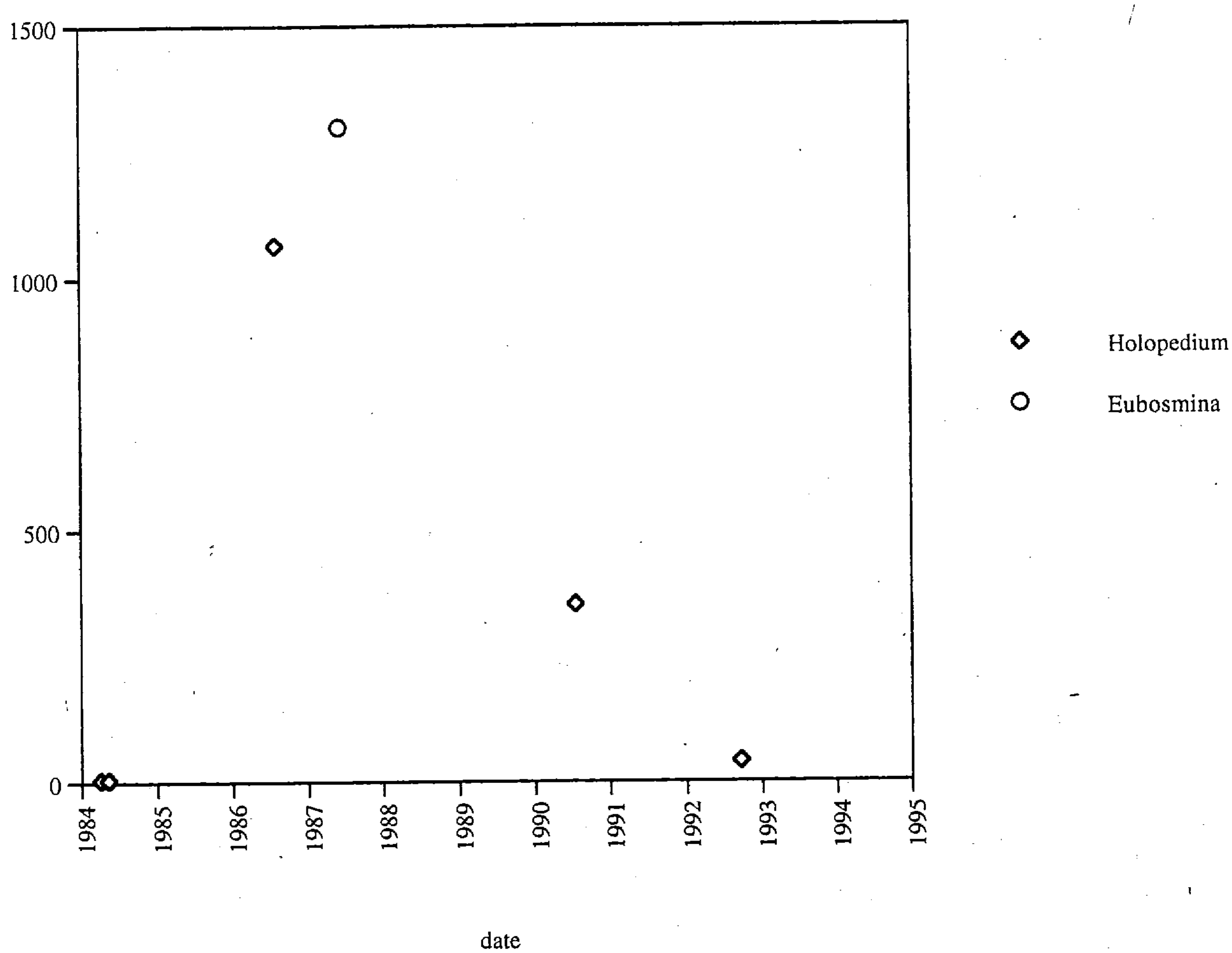


Figure 3.2.7. Jacobs Lake Zooplankton: *Ceriodaphnia/Daphnia*.

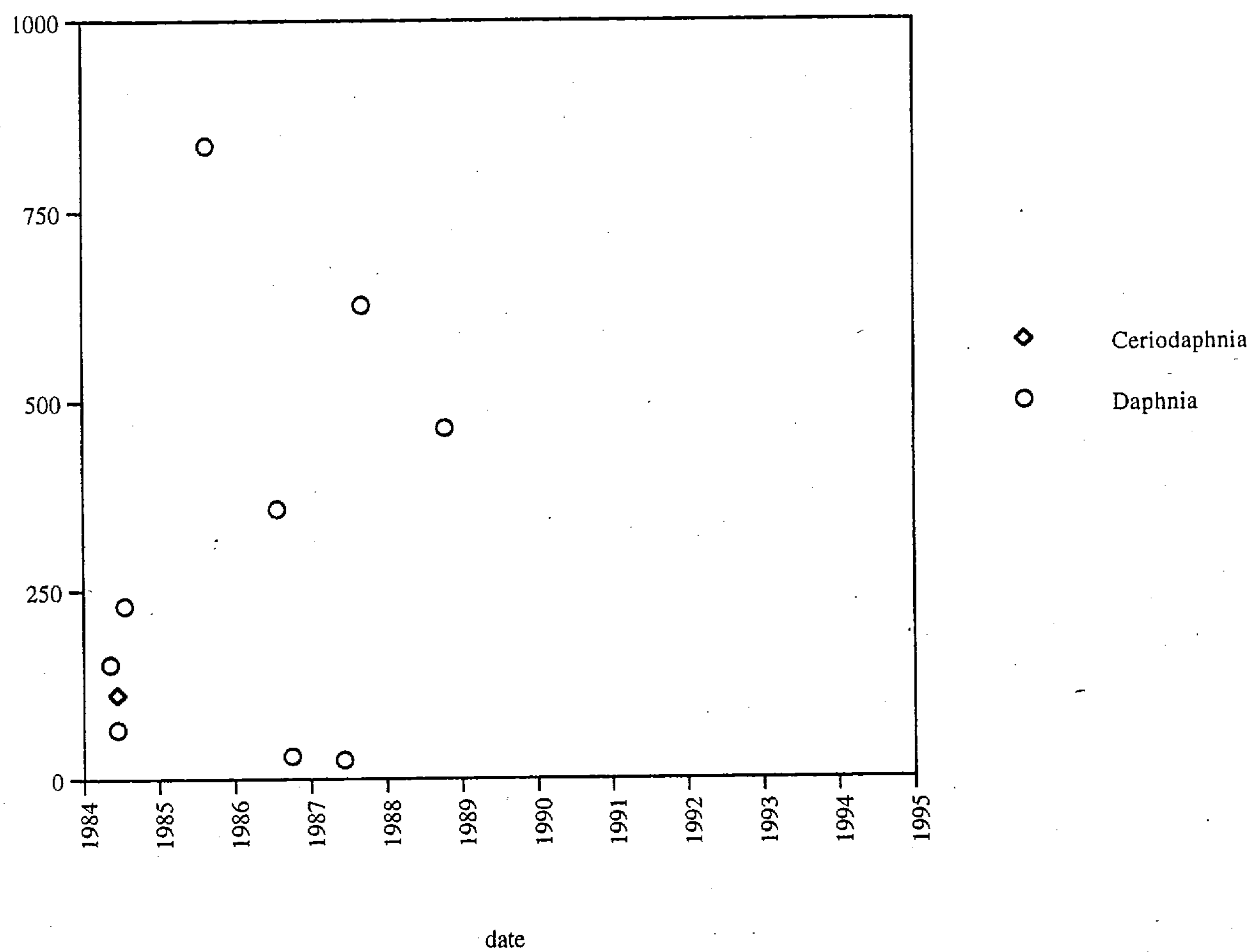


Figure 3.2.8. Jacobs Lake Zooplankton: *Leptodera/Graptolebris/Sida.*

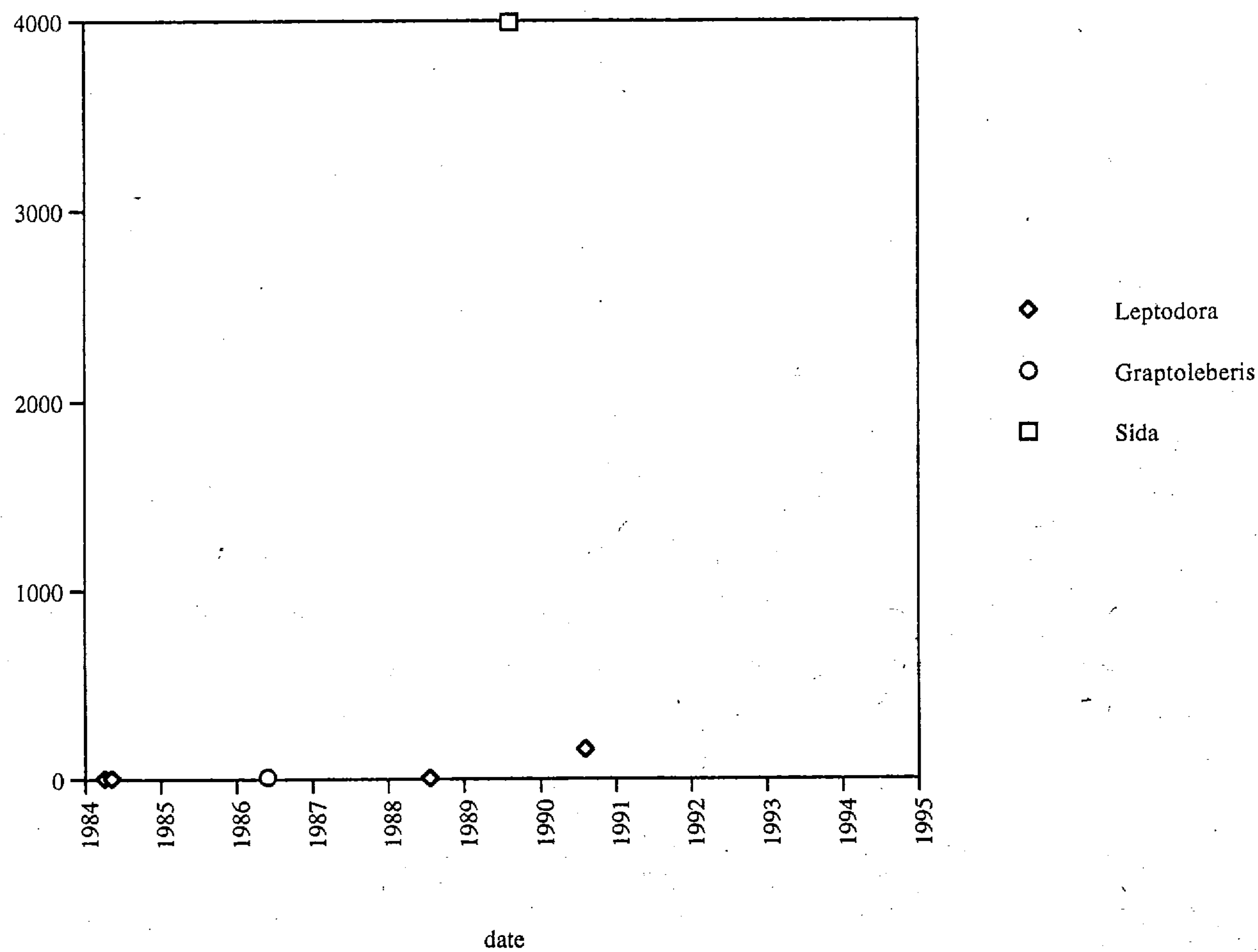


Figure 3.2.9. Jacobs Lake Zooplankton: *Keratella/Conochilus/Polyarthra*.

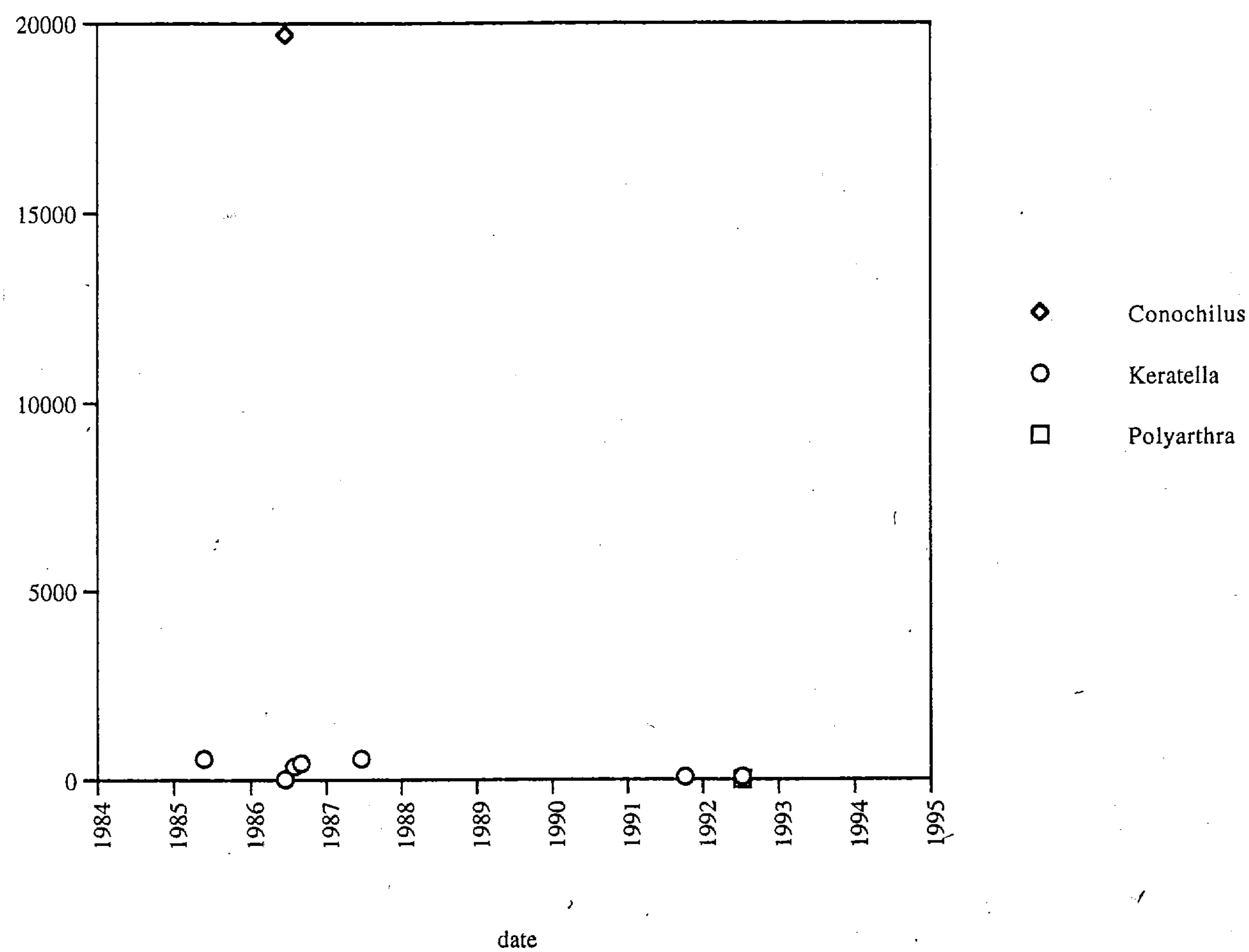


Figure 3.2.10. Jacobs Lake Zooplankton: Crustacean and Rotifer Biomass Comparison.

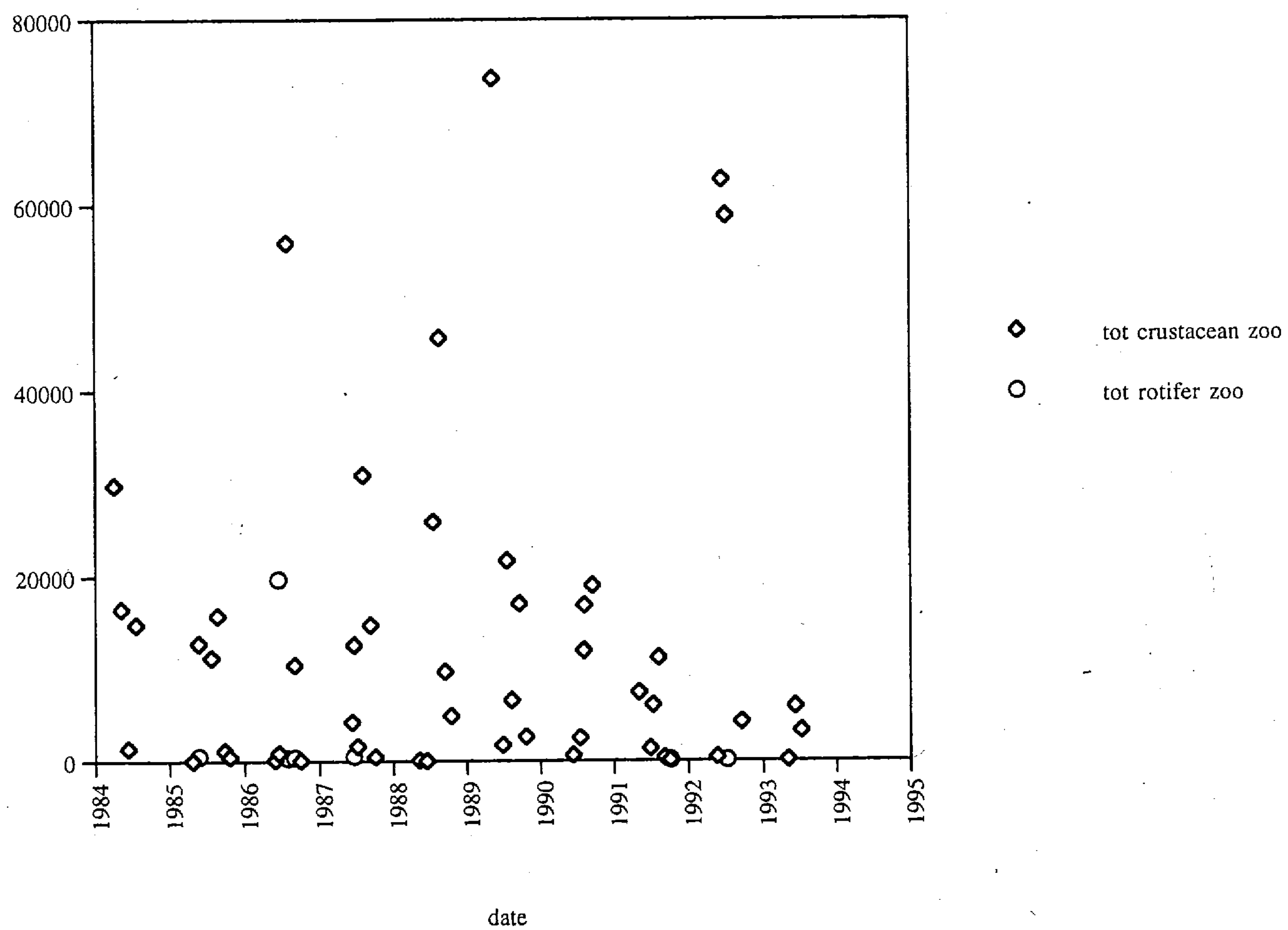


Figure 3.2.11. Jacobs Lake Zooplankton: Total Biomass µg/m2.

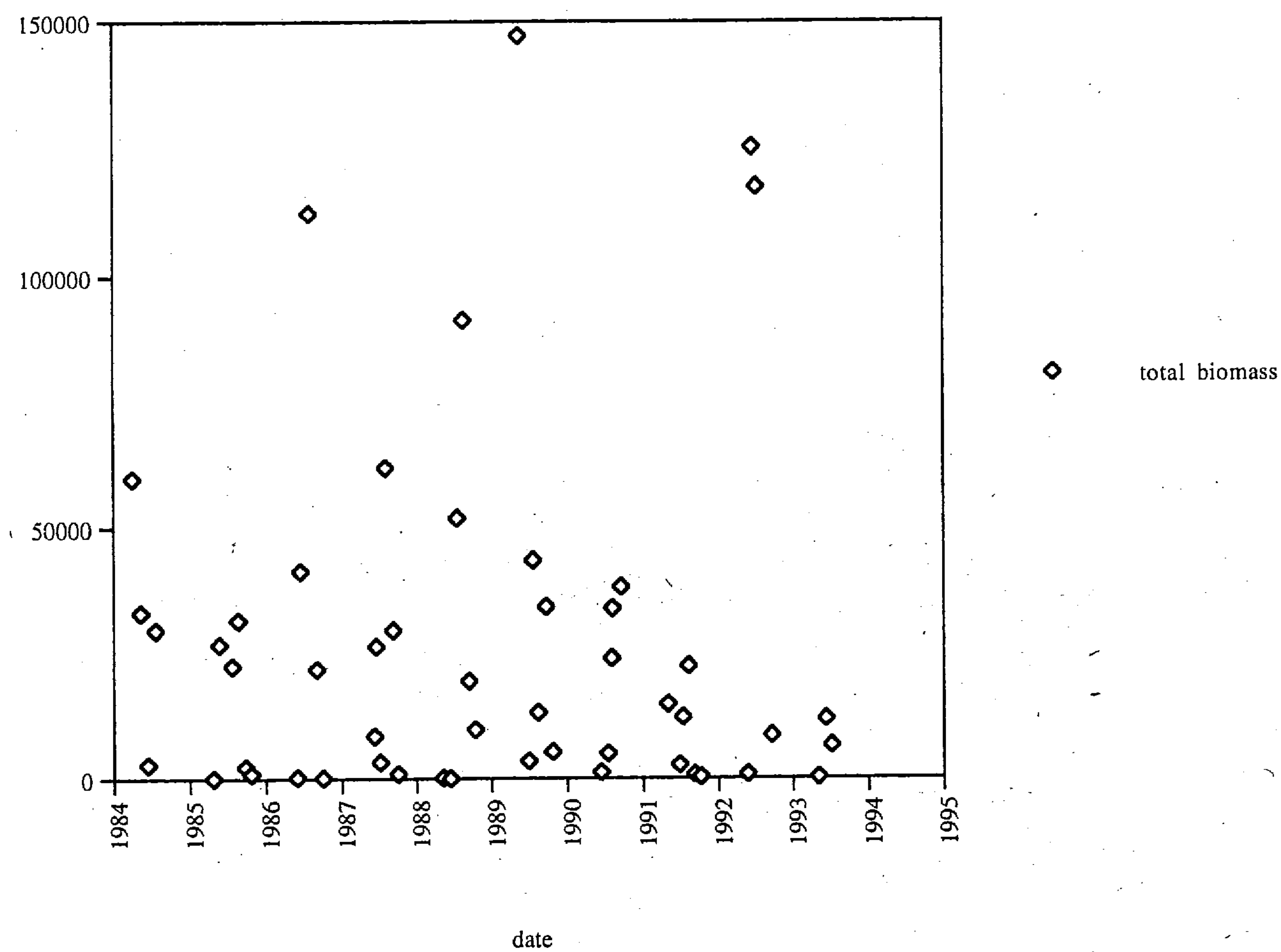
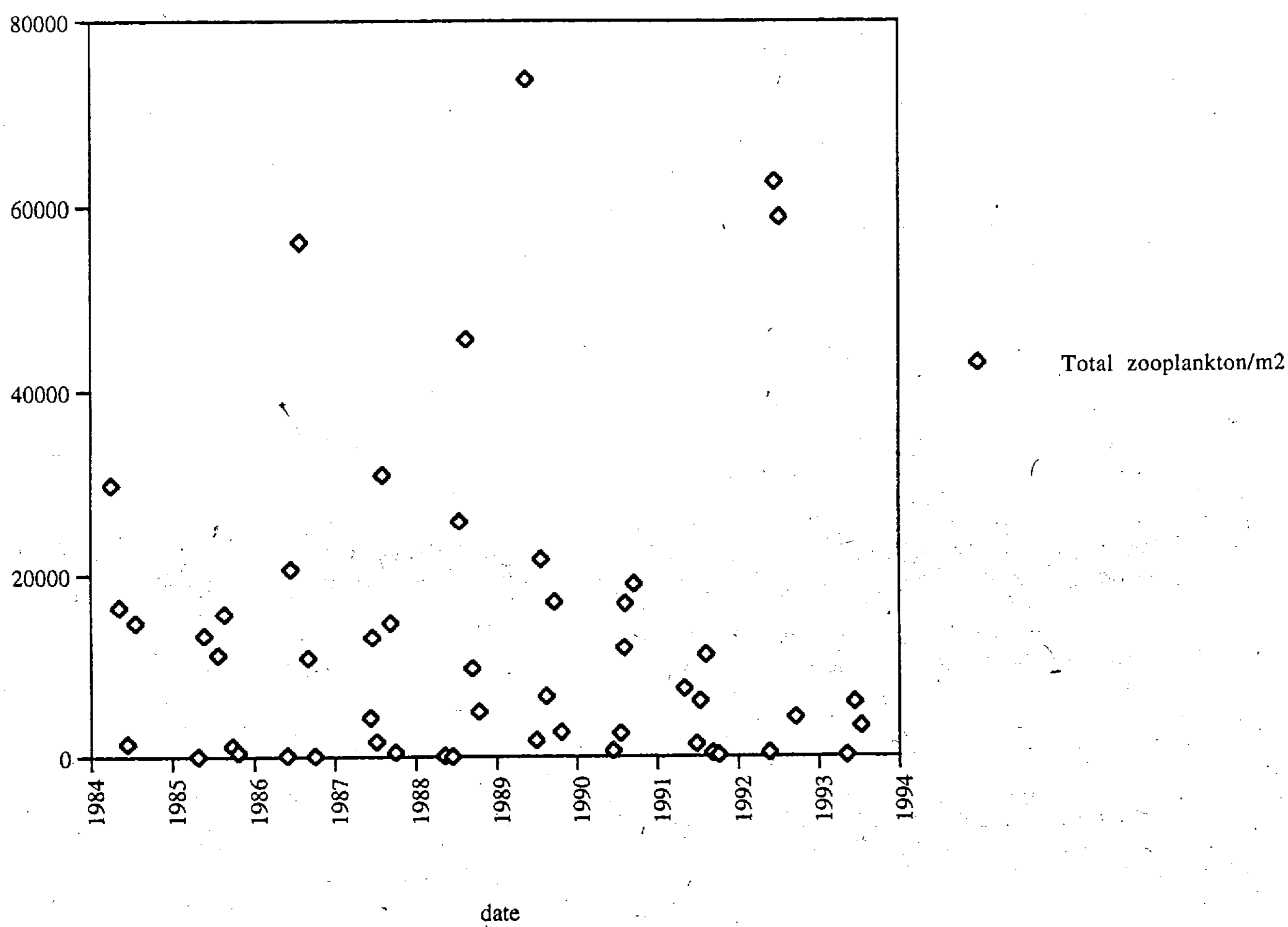


Figure 3.2.12. Jacobs Lake Zooplankton: Total Zooplankton/m2.



4.0. MAXWELL LAKE

Maxwell Lake is located on Mount Maxwell in the west central portion of Saltspring Island (48° 49' 24", 123° 32' 40", map sheet 92B) at an elevation of 335 m. Maxwell has a surface area of 27.6 ha, a mean depth of 6.5 m, a maximum depth of 17 m, and a volume of 947 dam^3. Precipitation is approximately 100 cm/year. Nordin (1982) has calculated a mean water residence time of 1.7 years. The outlet from the lake is through a creek located in a bay at the north-east corner of the lake. Maxwell has a watershed area of 1.2 km^2, with the lake encompassing about 22% of the watershed area. Maxwell serves as part of the water supply to the town of Ganges (North Saltspring Waterworks District), and is operated as a reservoir. The lake is surrounded by trees, although there is one cottage

Little development exists in the watershed, except for one permanent residence and a pump station for the waterworks located on its shores. In addition to its operation as a reservoir two other perturbations are noted that may impact the plankton communities in Maxwell. The perimeter of the lake was logged and cleared in 1992 in preparation for construction of a permanent earthen dam so that more water could be stored, and in 1994 the dam and spillway were constructed. Finally, 5000 rainbow trout were introduced to the lake in 1984. The last stocking event previous to this was in 1949. Maxwell Lake benefits from controlled access, and thus impacts on the fish population from angling are probably light.

4.1 Phytoplankton

As with the previous lakes, the diversity of the Maxwell Lake phytoplankton community is very high with 84 taxa reported (Appendix 6). The dominant and sub-dominant taxa and mean concentration are displayed in Table 4.1.1. *Dinobryon* is the most conspicuous of the dominants, present in 95% of all samples with the highest mean concentration of this group, 110.35 cells/mL. This is followed by *Crucigenia* (89%) *Anabaena* and *Cryptomonas*, each at 85%, *Peredinium* (81%), *Asterionella* (77%), and *Arthrodesmus* (76%). Mean concentrations range from 0.6 to 21.18 cells/mL for the non cyanophyte genera. These are the lowest mean concentrations and the smallest range of the study. The dynamics of the dominant and sub dominant groups are displayed in Figures 4.1.1 to 4.1.10. Most dominant and sub dominant genera exhibit high monthly and yearly variation. Exceptions to this are *Arthrodesmus, Asterionella*, and *Navicula* which tend to show more consistency. *Dinobryon, Peredinium, Crucigenia,* *Cryptomonas, Scenedesmus*, and *Elakothrix* all show a trend to increased numbers over the study period. *Dinobryon, Peredinium, Crucigenia*, and *Cryptomonas* were not found in 1989 samples, and *Asterionella* was absent in 1990. *Cryptomonas* shows a strong trend to increased numbers over the ten year sampling period.

Several notable events occur within the common and rare groups. *Aphanothece* (Figure 4.1.11) occurs once at low concentration in 1984 and three times in 1987, peaking at over 15,000 cells/mL. This is the highest algal concentration observed in Maxwell. *Selanastrum* and *Sphaerocystis* first appear in the spring of 1989, and then are present in 78% and 70% of samples respectively, with high mean concentrations of 55.500 and 56.790 cells/mL (Figure 4.1.12). Other notable events include a *Chrysosphaerella* bloom of over 1000/mL in 1990 and the appearance of Haematococcoid cyst-like cells at high concentrations in 1990 and 1991 (Figure 4.1.13).

A zooplankton sample taken in May 1988 records a bloom concentration of *Gloeotrichia*. Unfortunately no phytoplankton sample was taken that day to check this occurrence. *Gloeotrichia* was not reported from any other sample from Maxwell or the other study lakes.. *Gloeotrichia* is a genus which typically becomes present in large numbers in the autumn in larger lakes and reservoirs such as Shawnigan or Sooke on southern Vancouver Island.

Despite a slight increase in total cells/mL over the period of sampling, Maxwell lake exhibits the lowest standing crop of any of the study lakes (Figure 4.1.14). Total numbers peak in 1990 at concentrations under 2500/mL, significantly less than Marion Lake, the next lowest. Maxwell does not suffer from a short water residence time like Marion. The cause of this low productivity is not readily apparent. The overall increase in total concentration can be accounted for by increases in the dominant and sub dominant taxa. Unfortunately chlorophyll a data is incomplete, with the samples from 1989 and 1992 through 1994 either not collected or missing. The available data (Figure 4.1.15) show no clear trends and do not correlate with the dynamics of the total/mL data. The chlorophyll values for 1985, 1986 and 1990 seem high given the low standing crop. Phytoplankton total numbers and chlorophyll a values are summarised by year in tables 4.1.2 and 4.1.3.

4.2. Zooplankton

The zooplankton community of Maxwell Lake exhibits a similar diversity to the other study lakes, with 23 genera reported over the duration of the study (Appendix 7). However, the composition of the population shows some distinctive characteristics. The only copepod genera consistently present is *Cyclops*. It occurs from 1984 through 1989 and then is absent in all subsequent samples through 1994. *Diaptomus, Epishura* and *Diacyclops* have been identified from Maxwell, but are very rare and present only at low concentrations (Figure 4.2.1). With the exception of three observations of *Diacyclops* in 1992 and one in 1993, adult copepods are absent from Maxwell after 1990. In contrast to the adult organisms, immature copepods are present in all but one sample. Nauplii are routinely present, while copepodites display a conspicuous four year absence, from September of 1984 through May of 1988 (Figure 4.2.2).

The cladocera are more diverse and numerous than the copepoda. *Bosmina* is consistently the most numerous genera. Elevated peaks occur in 1987 through 1989, with a slight decrease in total number evident over the entire sampling period (Figure 4.2.3). *Daphnia, Holopedium*, and *Diaphanosoma* commonly occur at significant concentrations as well, although year to year variation is high. *Ceriodaphnia* peaks of over 60,000 animals/m^2 are reported in 1984 and 1992, as well as a low level occurrence in 1985. *Eubosmina* is reported in 1989 only, present in 4 of that years samples with a peak of over 70, 000 animals/m^2. These taxa are graphed together in figures 4.2.4 and 4.2.5.

The rotifer component the community is the most abundant and diverse of the Maxwell zooplankton, with 12 genera reported. Of these *Keratella* (Figure 4.2.6) and *Kellicottia* (Figure 4.2.7) are routinely the most numerous. *Polyarthra, Asplancha, Testudinella* and *Filinia* are occasionally present at concentrations of over 100,000 animals/m^2 as well. *Kellicottia* and *Keratella* show a slight decrease overall, while *Polyarthra* and *Asplancha* (Figure 4.2.8) show slight increases. *Testudinella* (Figure 4.2.9) appears in 1989, is present through 1992, then is absent for the remainder of the study. *Gastropus* appears in 1993 and is present in significant concentrations through 1994 (Figure 4.2.10)

Estimates show that the contribution of the three components of the zooplankton community to total biomass varies from year to year (Figure 4.2.11). Cladocerans make up the majority of the biomass for 6 of the ten years. Copepods dominate during 1994, and rotifers contribute the majority of biomass in 1985 and 1987. This high relative contribution to biomass from the rotifers is unusual given their small size. Contributions from all three communities were roughly equal for 1993. Figure 4.2.12 reveals a general increase in biomass up to 1988, followed by a decline through 1994. This same pattern is observed in the total animals/m^2 (Figure 4.2.13).

Chaoborus was found in one sample in the summer of 1985, three times in 1988 and once in 1989.

	Dominant	Sub-dominant	% presence	mean conc.
Chrysophyte	*Dinobryon*		95	110.35
Chlorophyte	*Crucigenia*		89	41.43
	Arthrodesmus		76	5.38
		Elakothrix	66	5.98
		Scendesmus	60	4.91
		Tetraedron	55	10.94
Cyanophyte	*Anabaena*		85	20.19
Cryptophyte	*Cryptomonas*		85	13.63
		Chroomonas	60	25.26
Pyrrhophyte	*Peredinium*		81	67.28
Diatom	*Asterionella*		77	46.99
		Navicula	64	1.73
		Synedra	55	8.03
		Tabellaria	53	1.50
		Rhisosolenia	51	33.85

Table 4.1.1. Maxwell Lake Phytoplankton: Dominant and Sub-dominant taxa.

Year	n	mean	maximum	minimum	# of samples
1984	695	11.98	182	.001	3
1985	655	6.96	224	.001	5
1986	306	5.46	84	.001	5
1987	31309	267.59	18688	.001	6
1988	1752	22.75	234	.001	6
1989	1440	11.25	184	.001	6
1990	7325	54.81	1139	.001	6
1991	3819	19.89	533	.001	6
1992	6165	31.94	1377	.001	7
1993	4559	42.60	638	.001	6
1994	3964	17.93	455	.001	6

Table 4.1.2. Maxwell Lake Phytoplankton: Summary of total numbers of phytoplankton/mL by year.

year	mean	maximum	minimum
1985	4.48	6.1	1.8
1986	3.56	5.4	1.0
1987	1.15	1.6	0.8
1988	0.94	1.4	0.8
1990	2.34	4.9	1.6
1991	1.8	2.8	1.3

Table 4.1.3. Maxwell Lake Phytoplankton: Mean and range of Chlorophyll a measurements by year in µg/L.

Figure 4.1.1. Maxwell Lake Phytoplankton: *Dinobryon*.

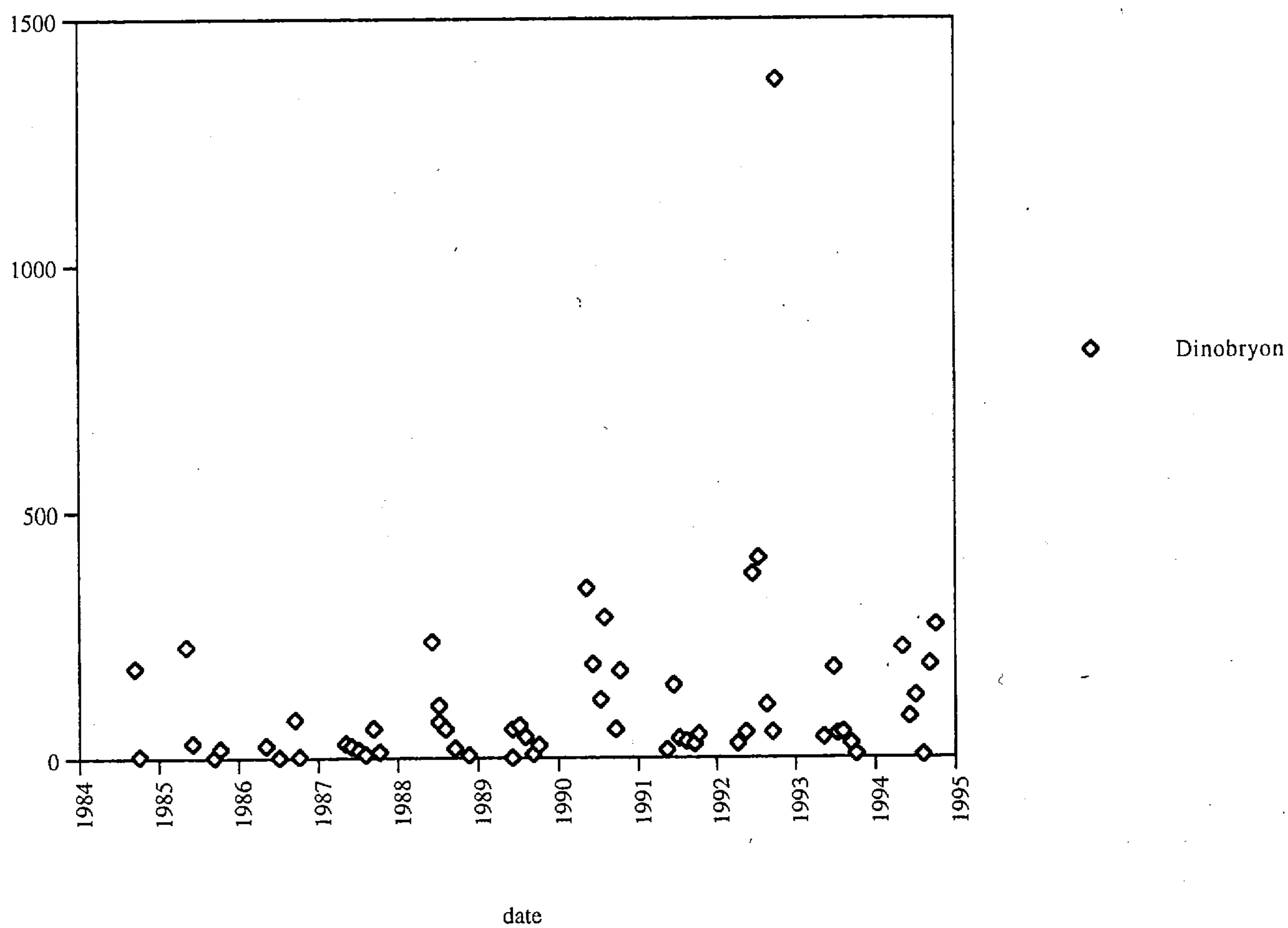


Figure 4.1.2. Maxwell Lake Phytoplankton: *Arthrodesmus/Crucigenia.*

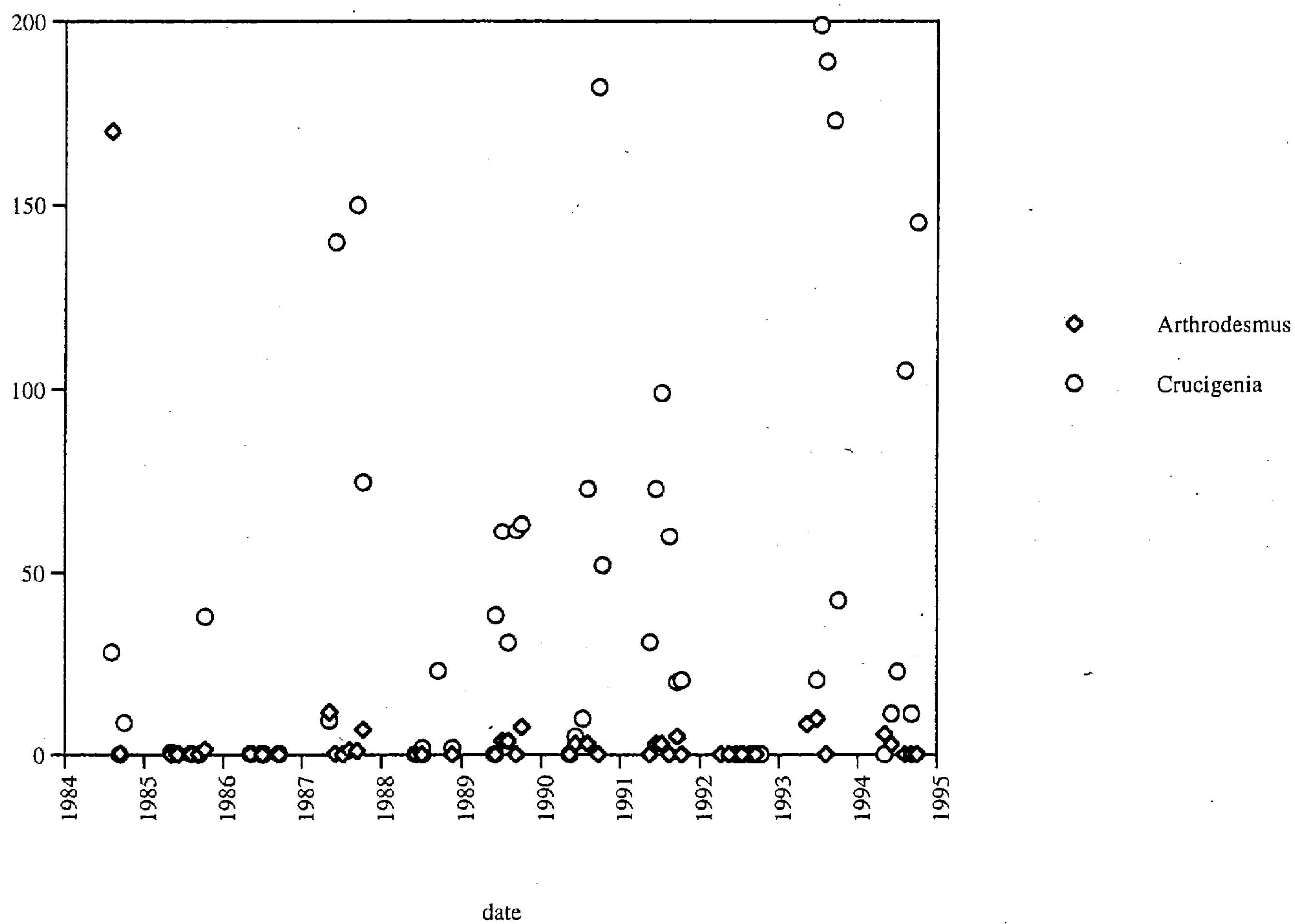


Figure 4.1.3. Maxwell Lake Phytoplankton: *Anabaena/Peredinium.*

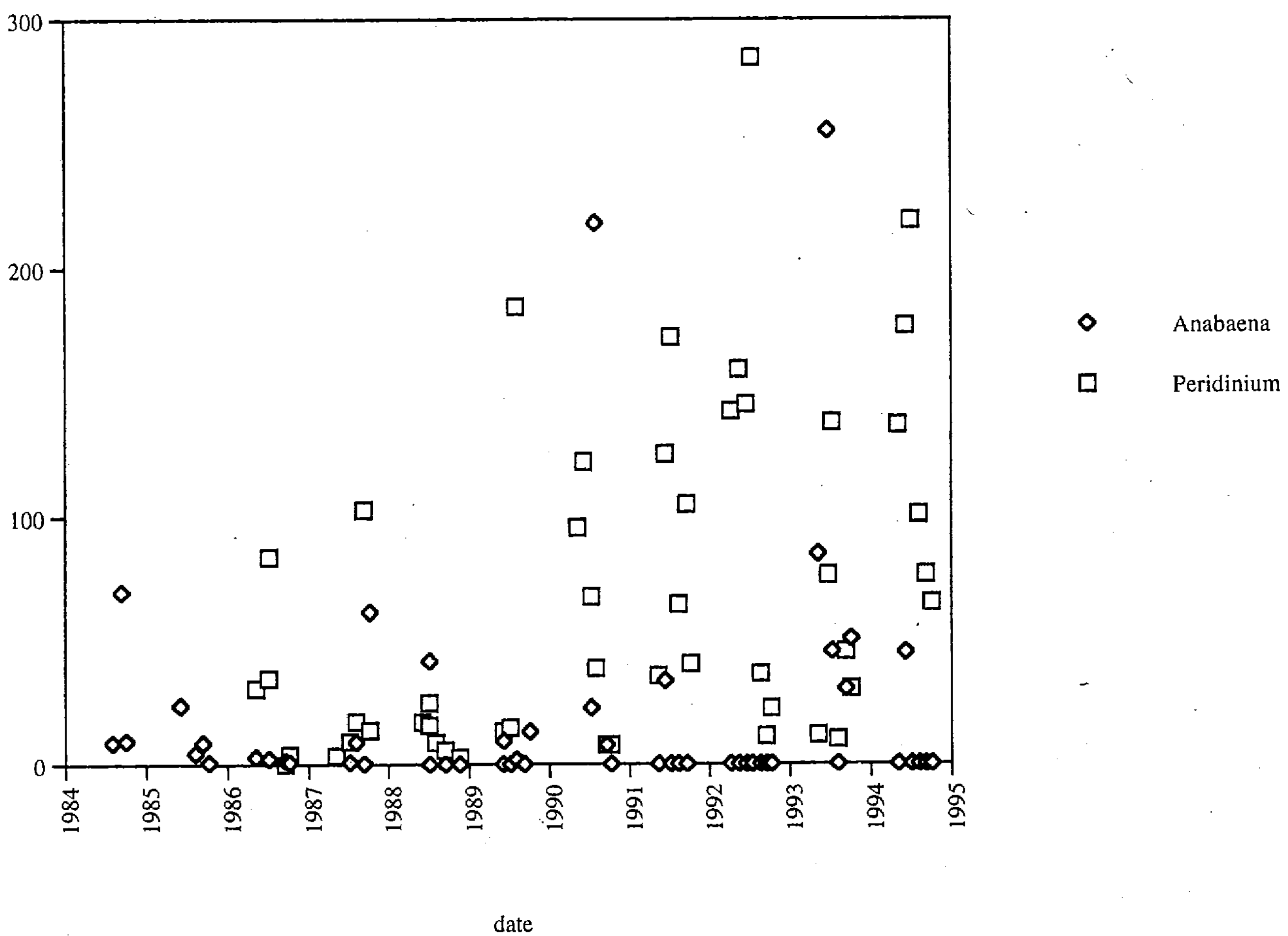


Figure 4.1.4. Maxwell Lake Phytoplankton: *Cryptomonas.*

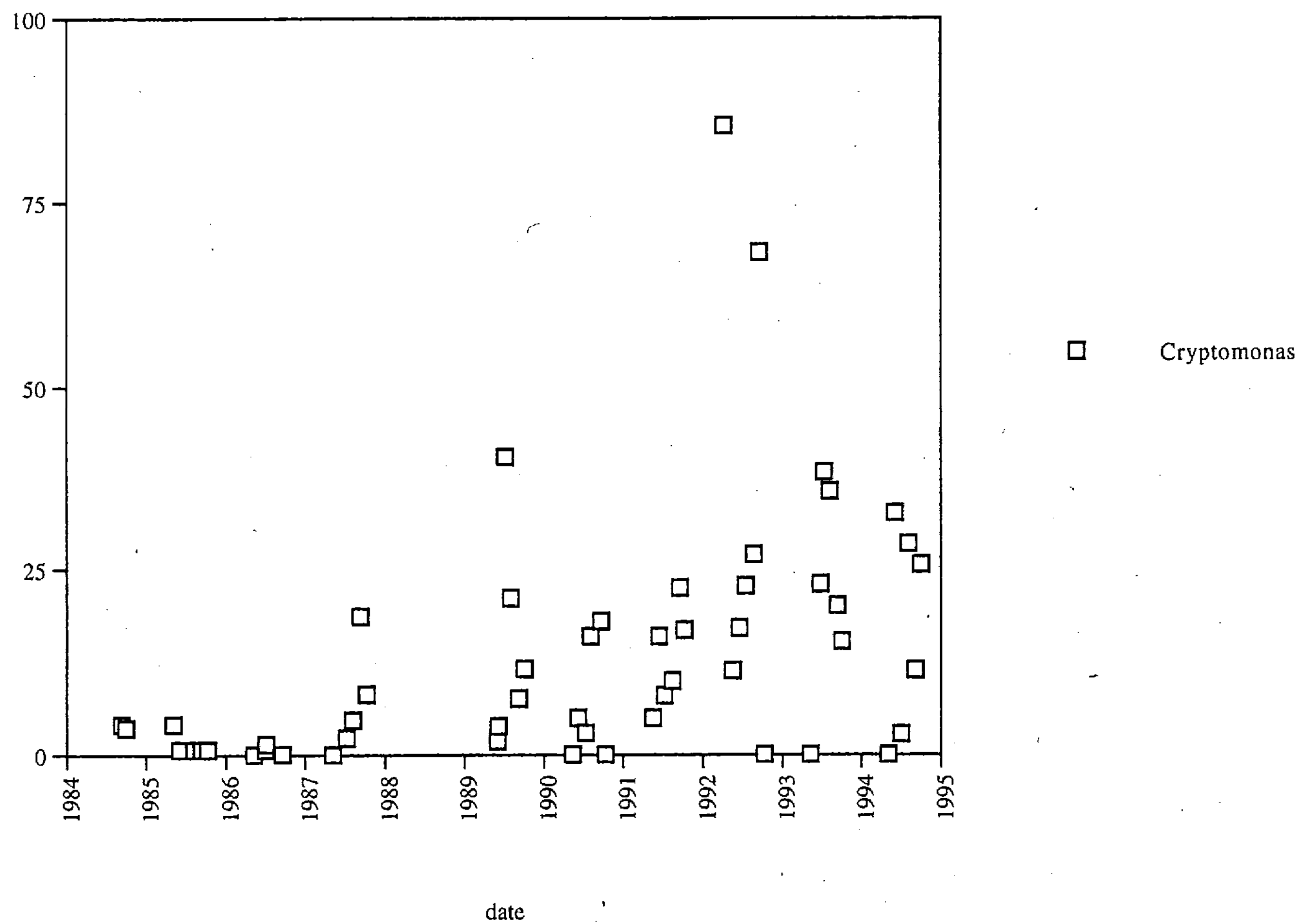


Figure 4.1.5. Maxwell Lake Phytoplankton: *Asterionella.*

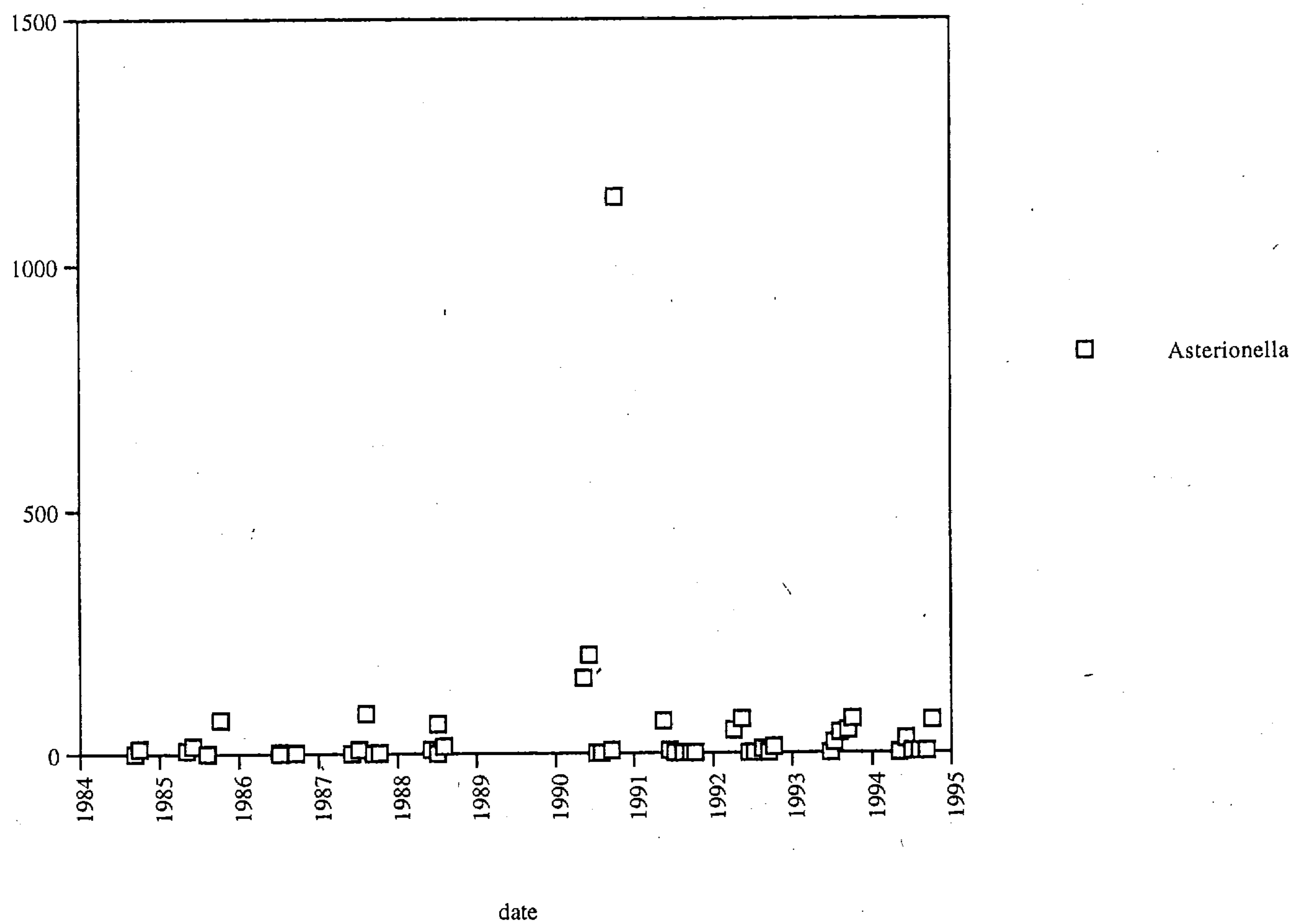


Figure 4.1.6. Maxwell Lake Phytoplankton: *Synedra/Tetraedron.*

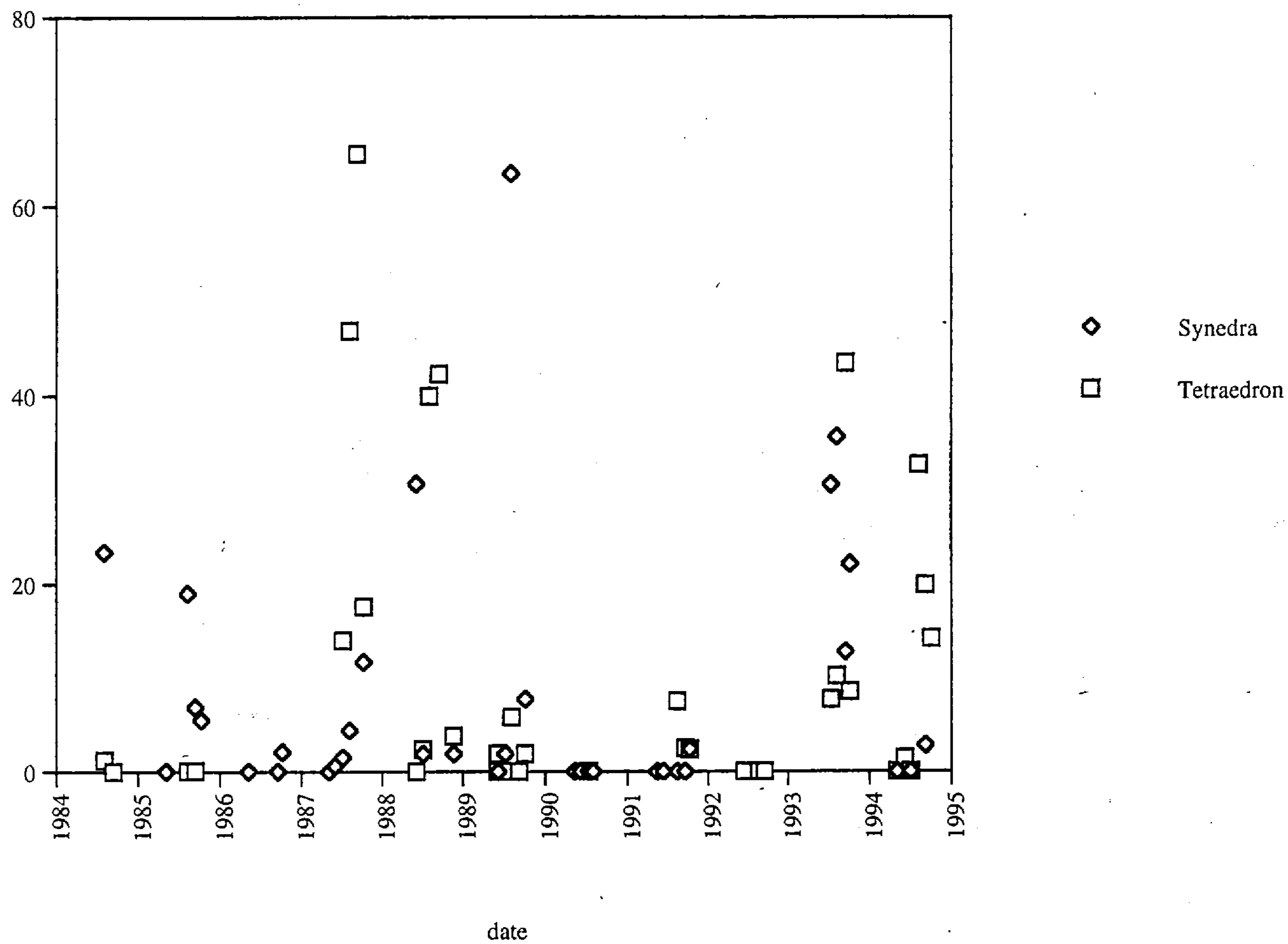


Figure 4.1.7. Maxwell Lake Phytoplankton: *Scendesmus/Elakothrix.*

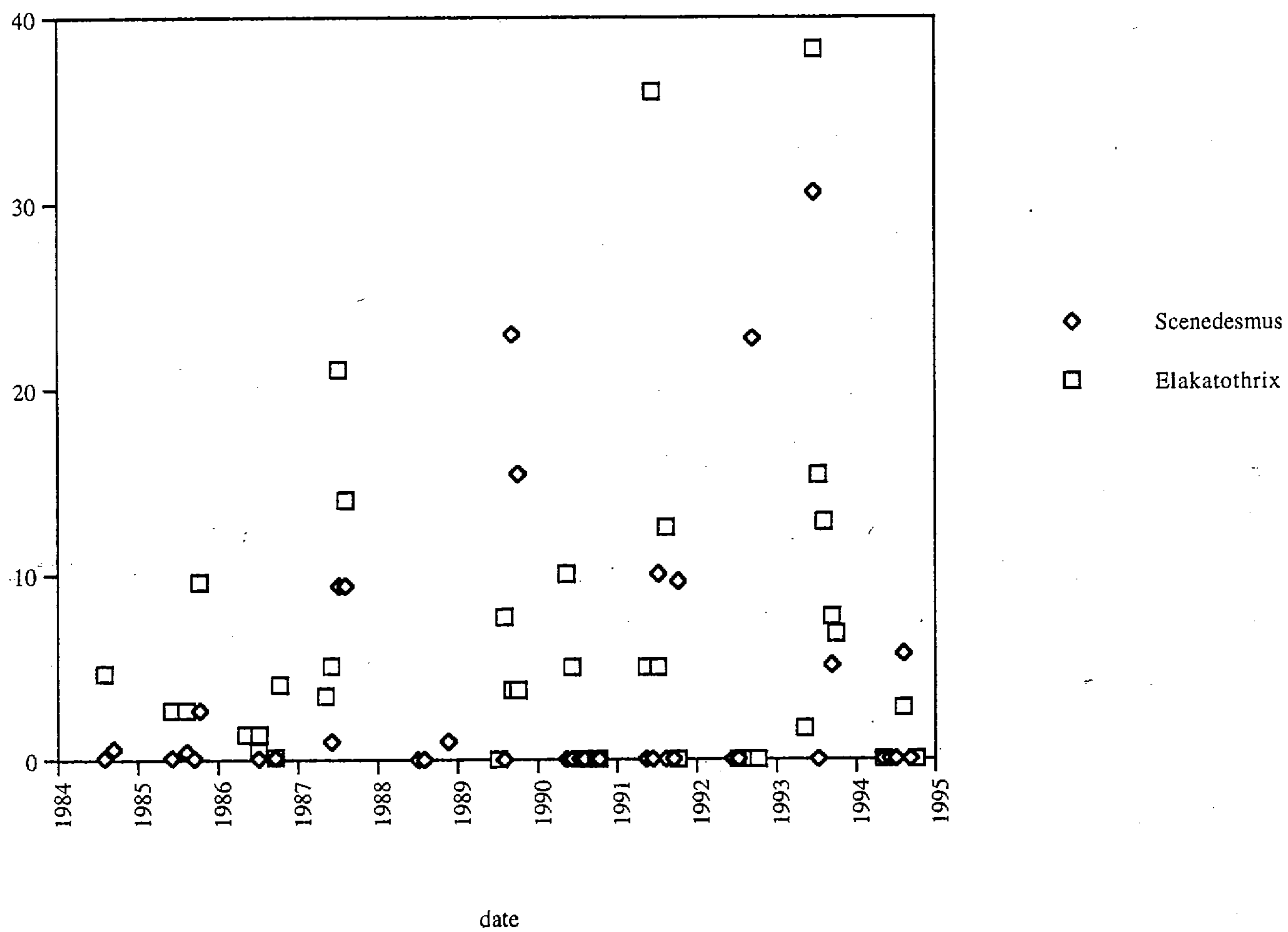


Figure 4.1.8. Maxwell Lake Phytoplankton: *Navicula.*

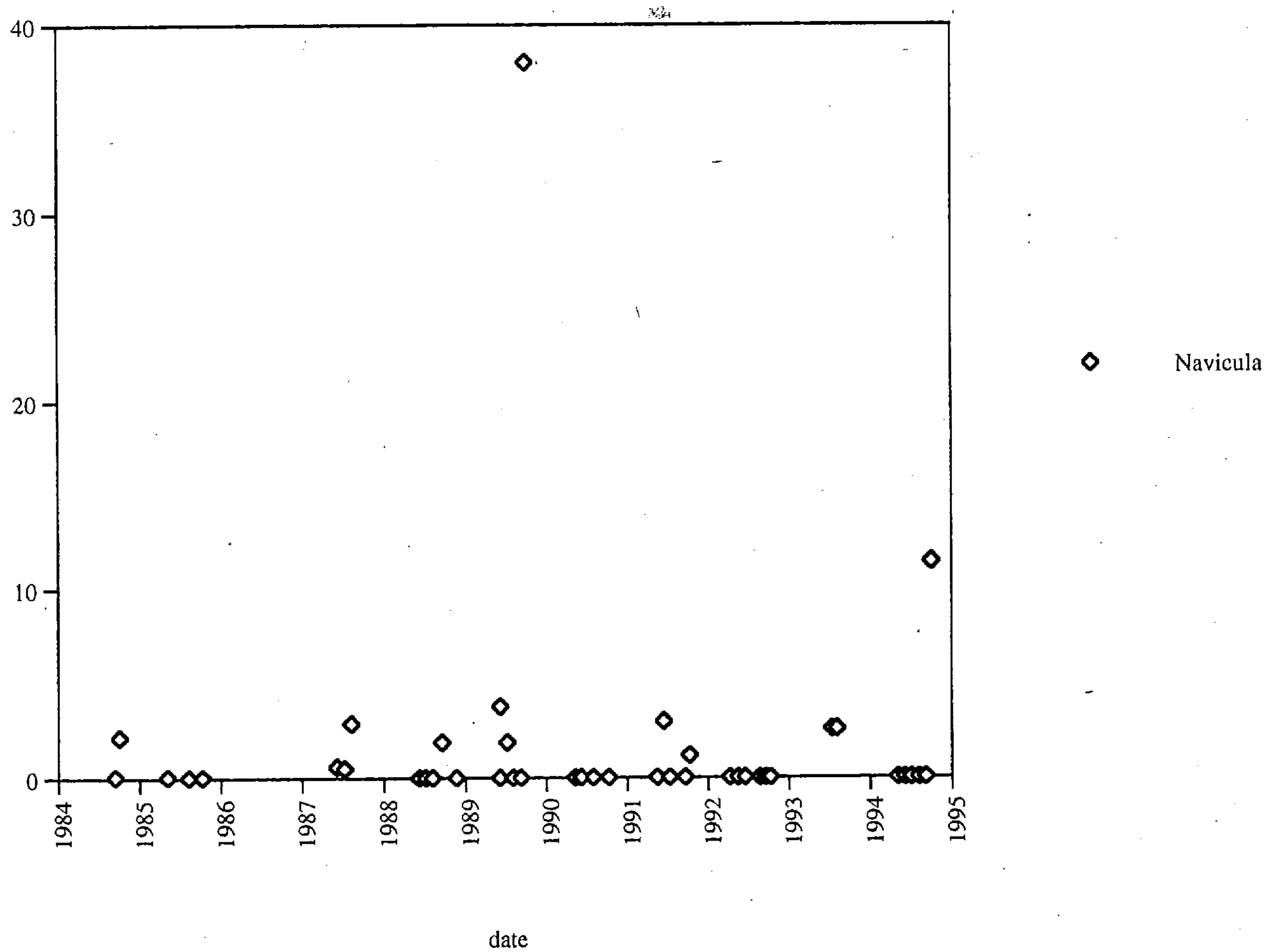


Figure 4.1.9. Maxwell Lake Phytoplankton: *Tabellaria.*

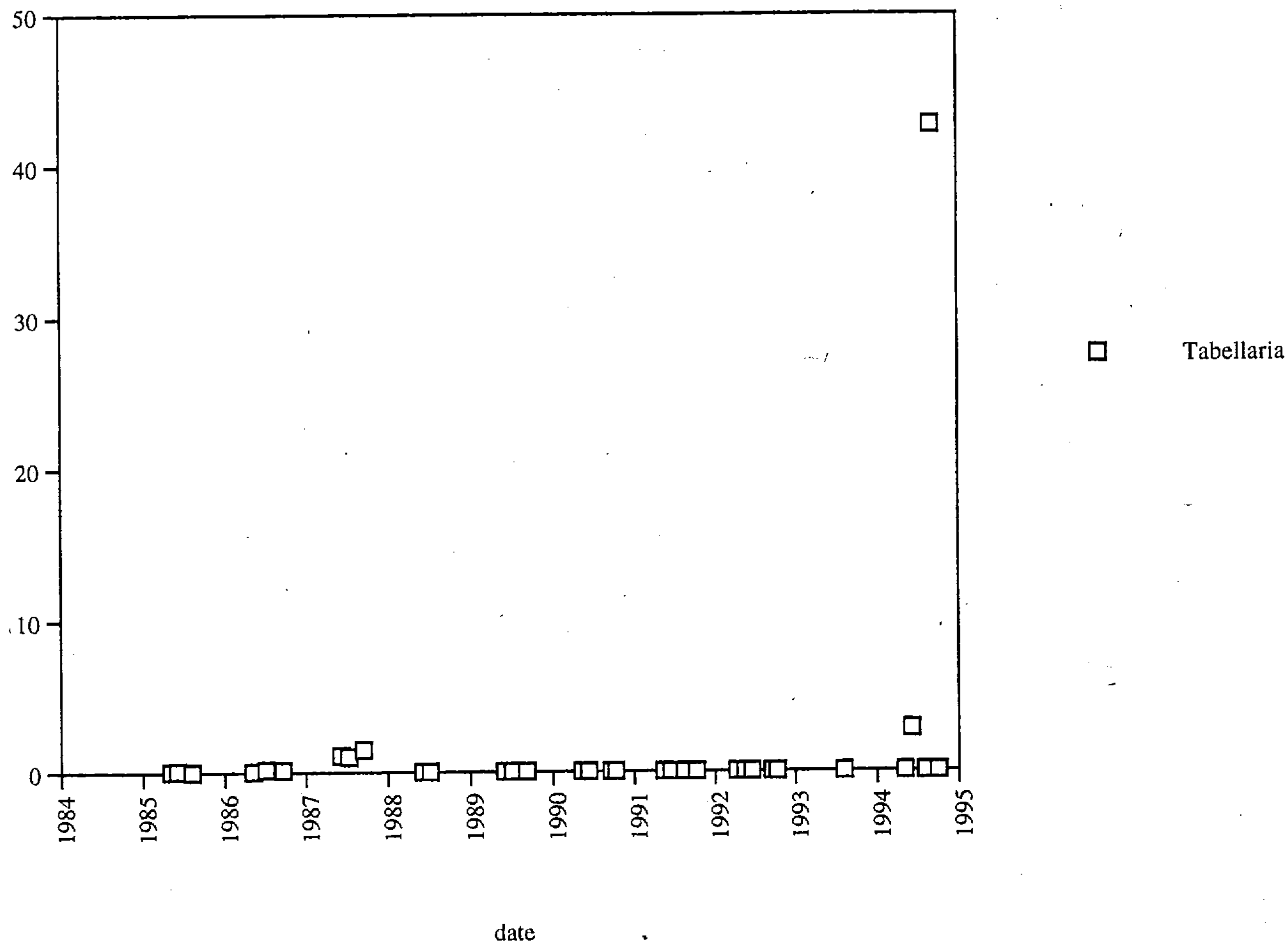


Figure 4.1.10. Maxwell Lake Phytoplankton: *Chroomonas/Rhisosolenia.*

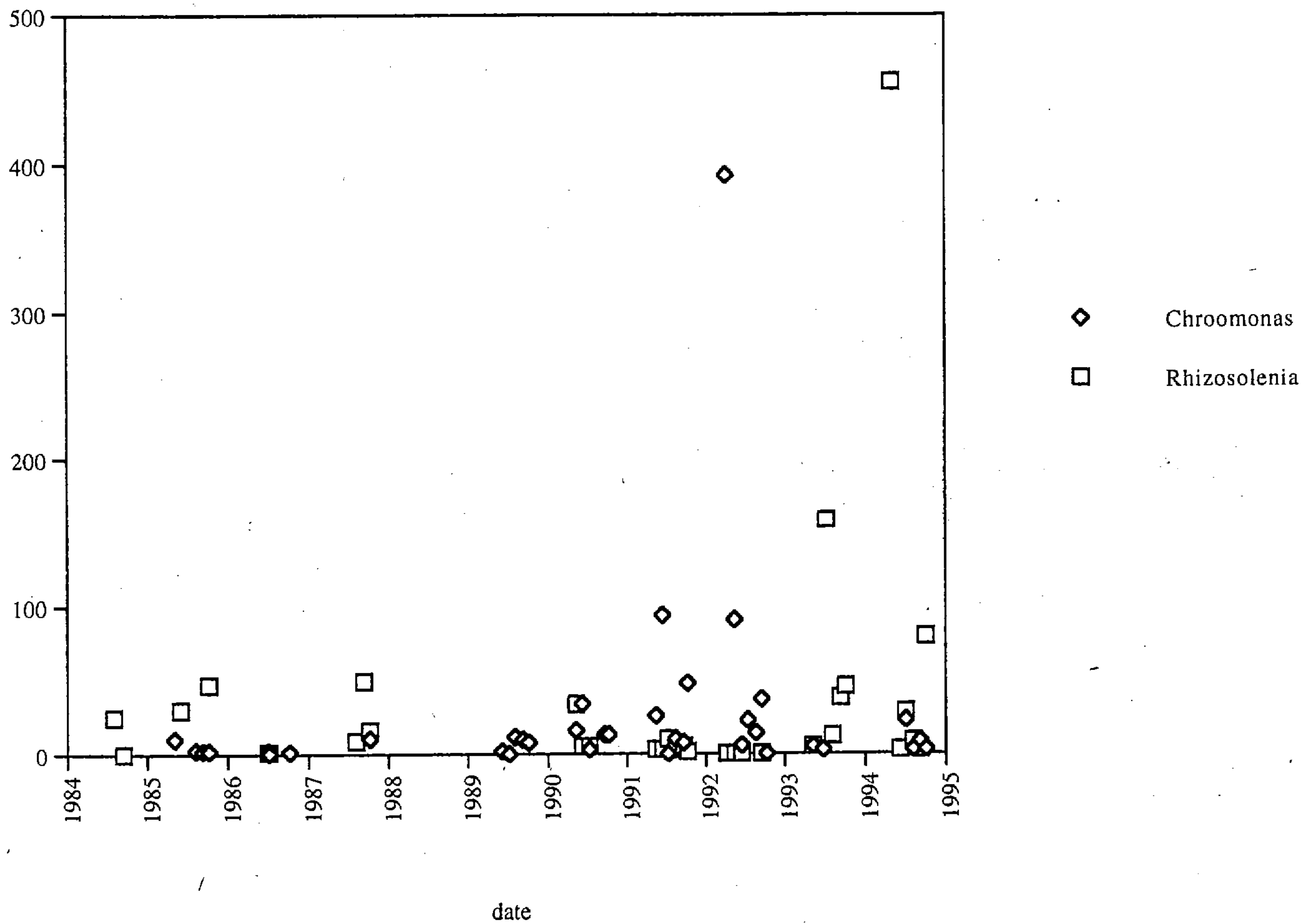


Figure 4.1.11. Maxwell Lake Phytoplankton: *Aphanothece*.

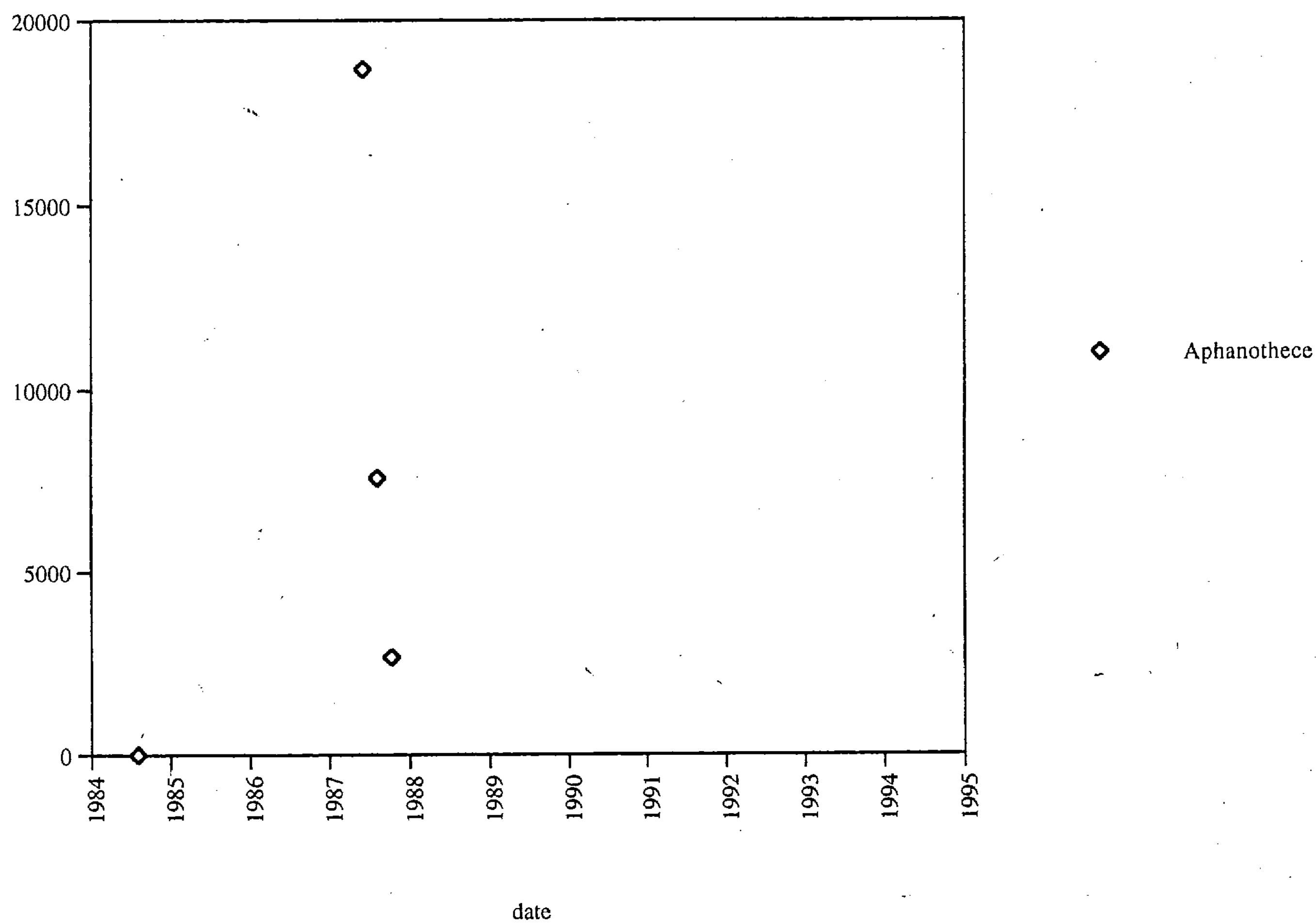


Figure 4.1.12. Maxwell Lake Phytoplankton: *Selenastrum/Sphaerocystis.*

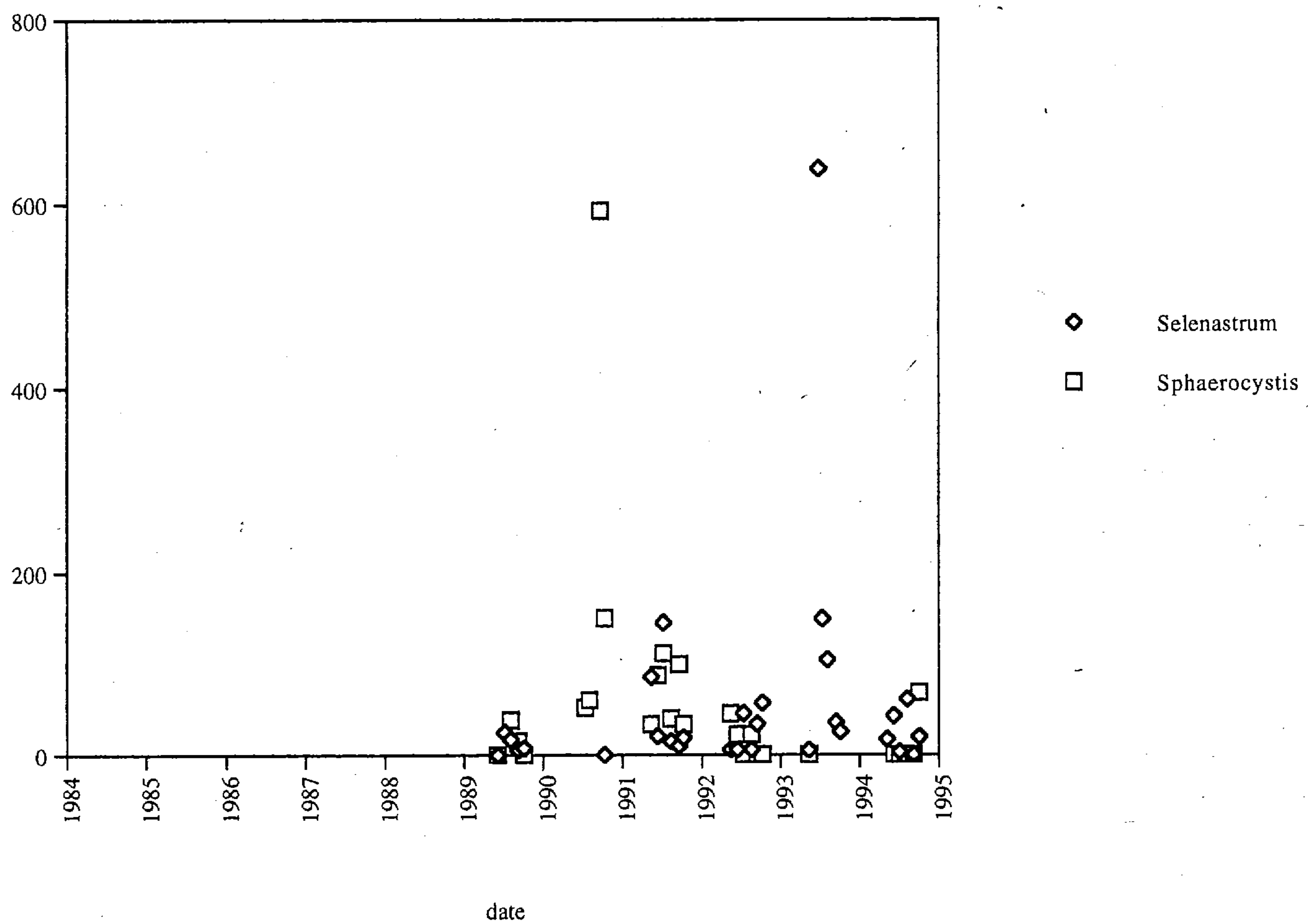


Figure 4.1.13. Maxwell Lake Phytoplankton: Haematococcoid Cyst-Like Cells.

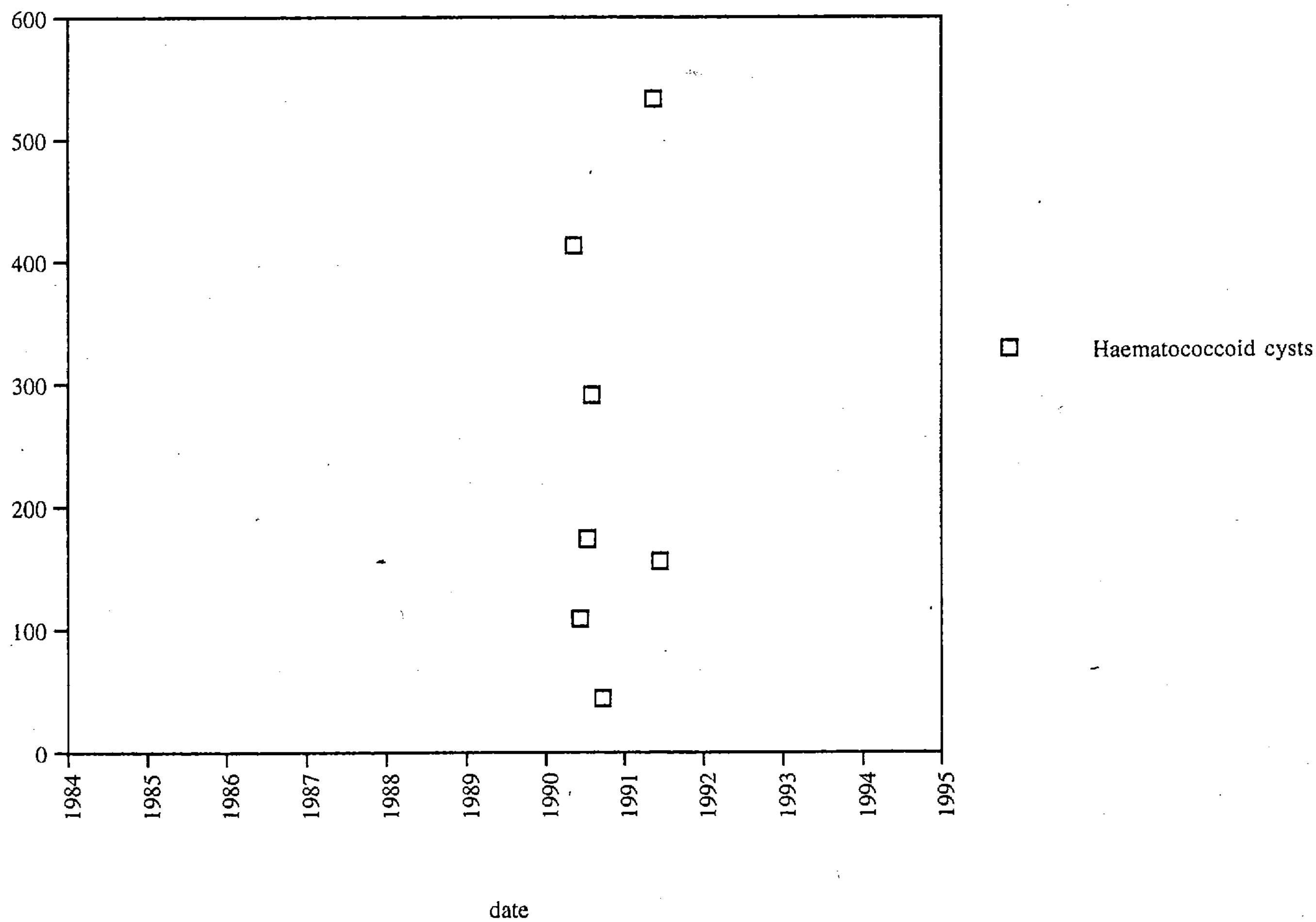


Figure 4.1.14. Maxwell Lake Phytoplankton: Total Cells/mL.

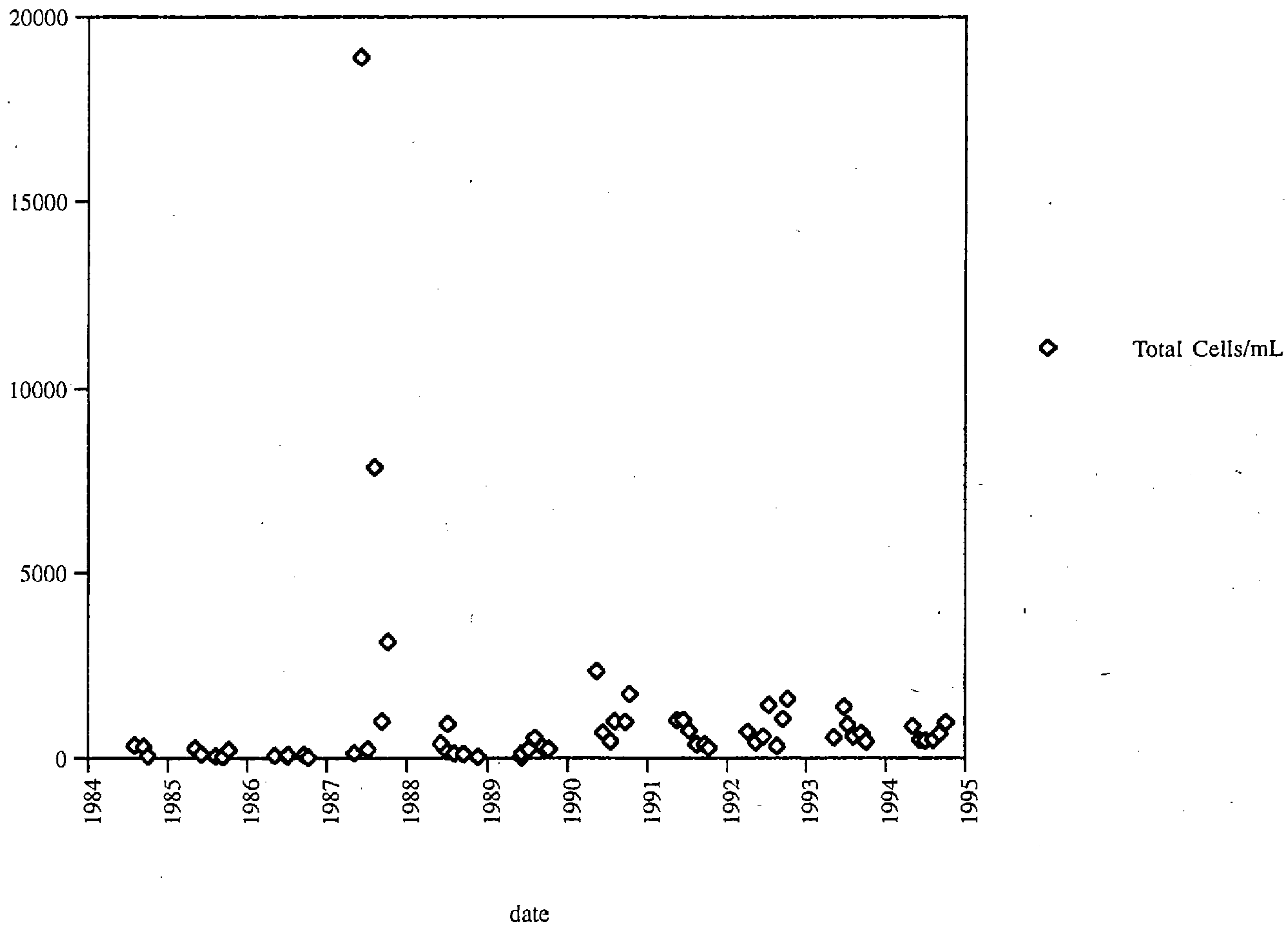


Figure 4.1.15. Maxwell Lake Phytoplankton: Chlorophyll a.

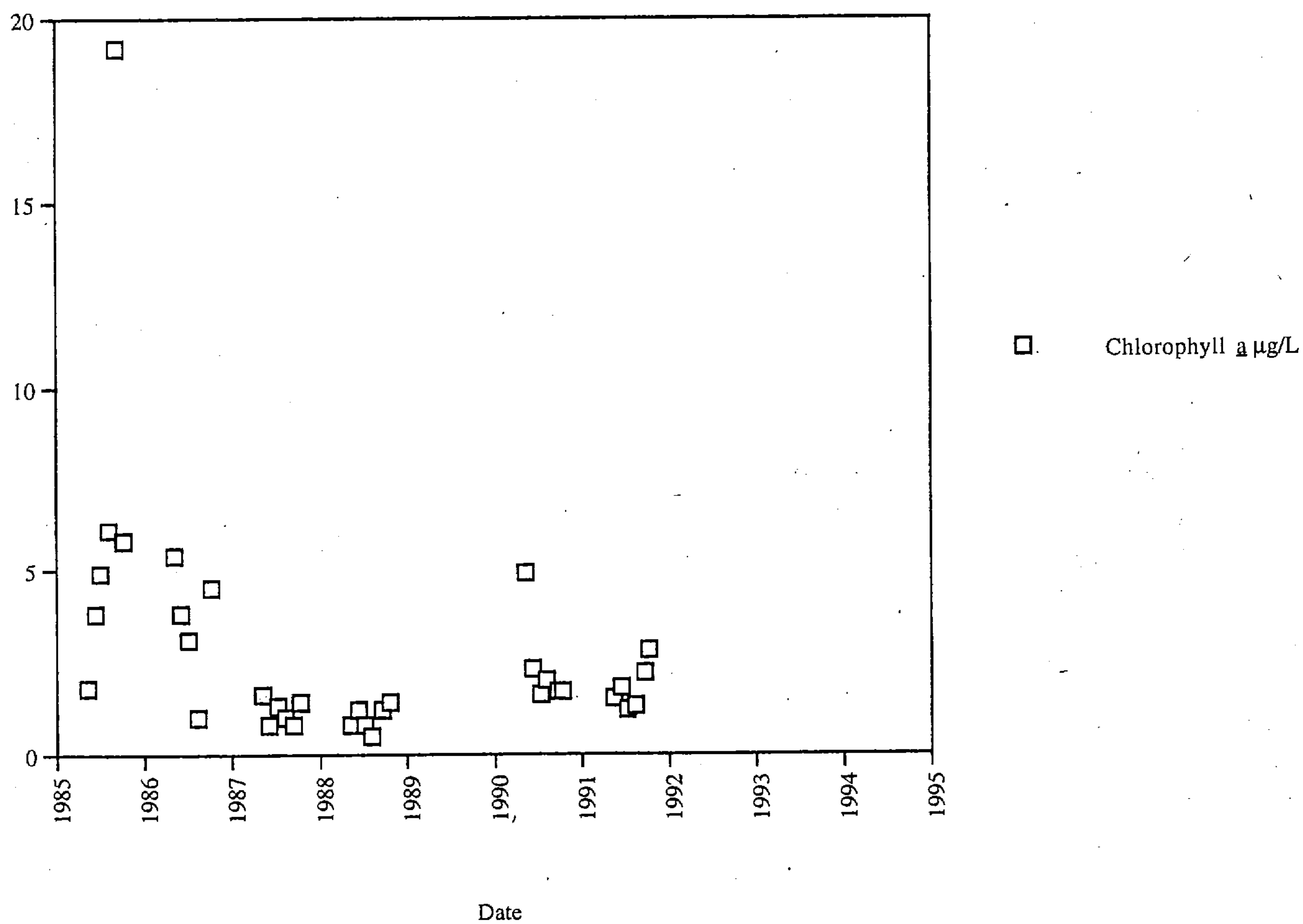


Figure 4.2.1. Maxwell Lake Zooplankton: Copepods.

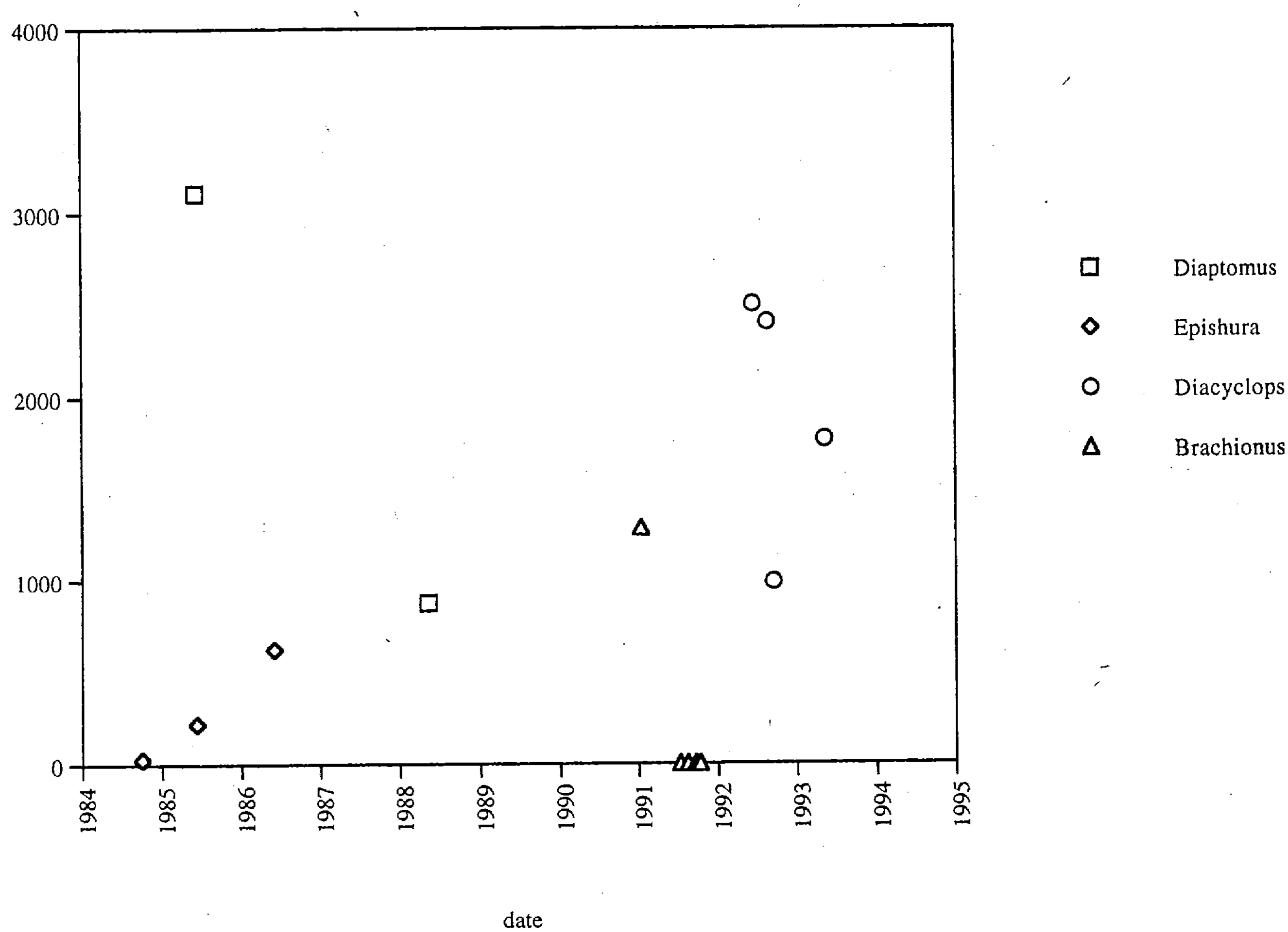


Figure 4.2.2. Maxwell Lake Zooplankton: Copepodites/Nauplii.

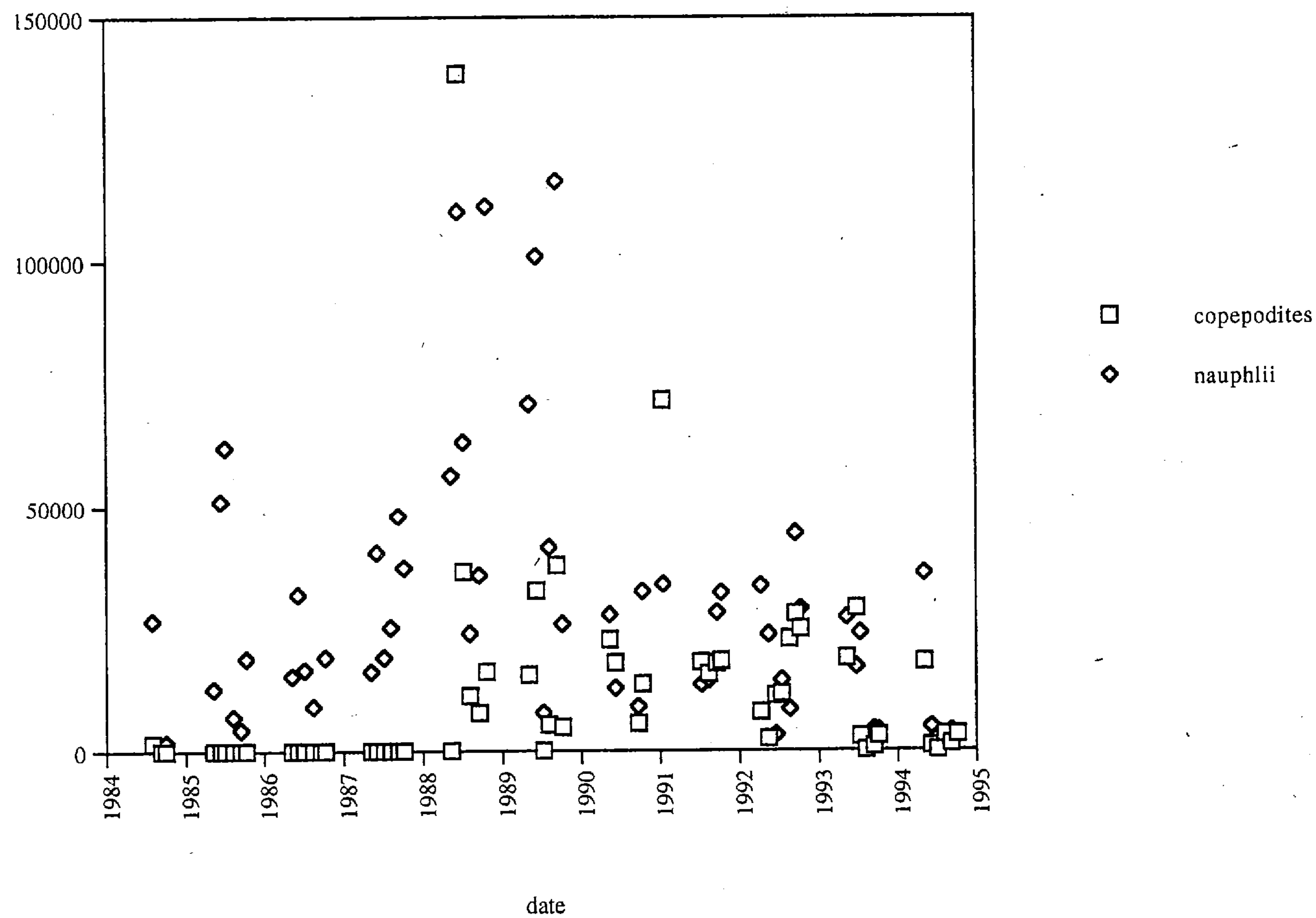


Figure 4.2.3. Maxwell Lake Zooplankton: *Bosmina.*

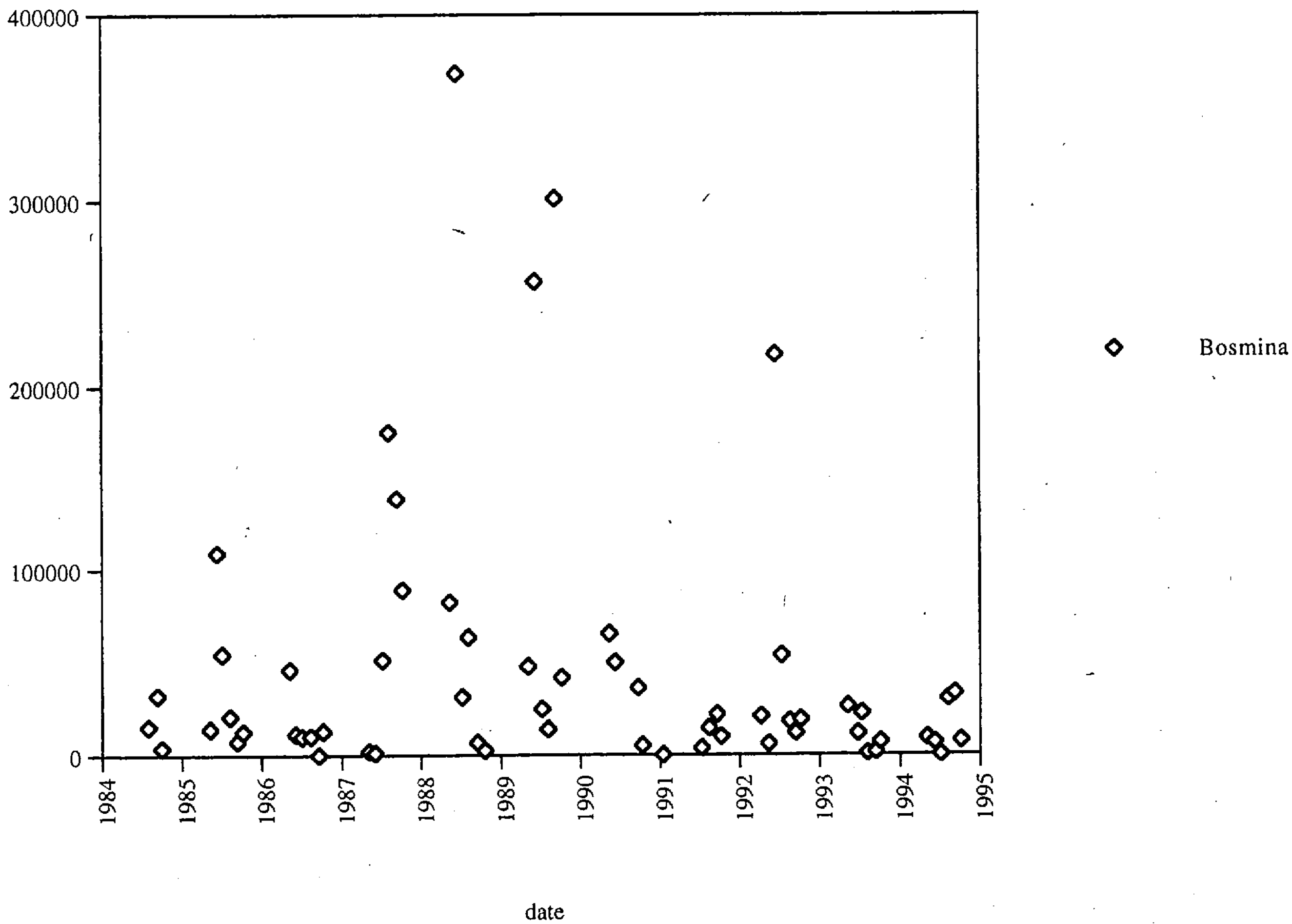


Figure 4.2.4. Maxwell Lake Zooplankton: *Holopedium/Eubosmina/Diaphanosoma.*

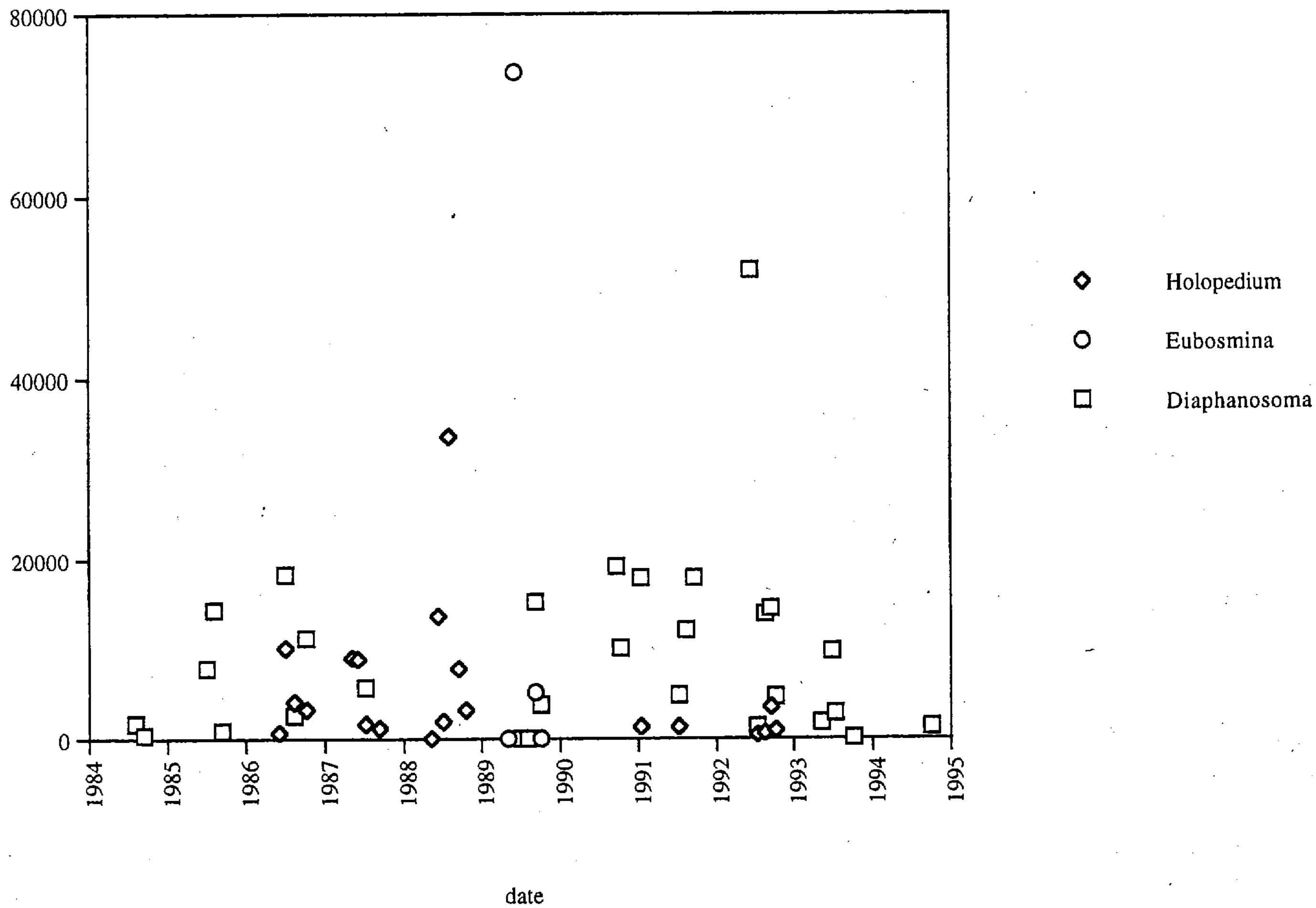


Figure 4.2.5. Maxwell Lake Zooplankton: *Daphnia/Ceriodaphnia.*

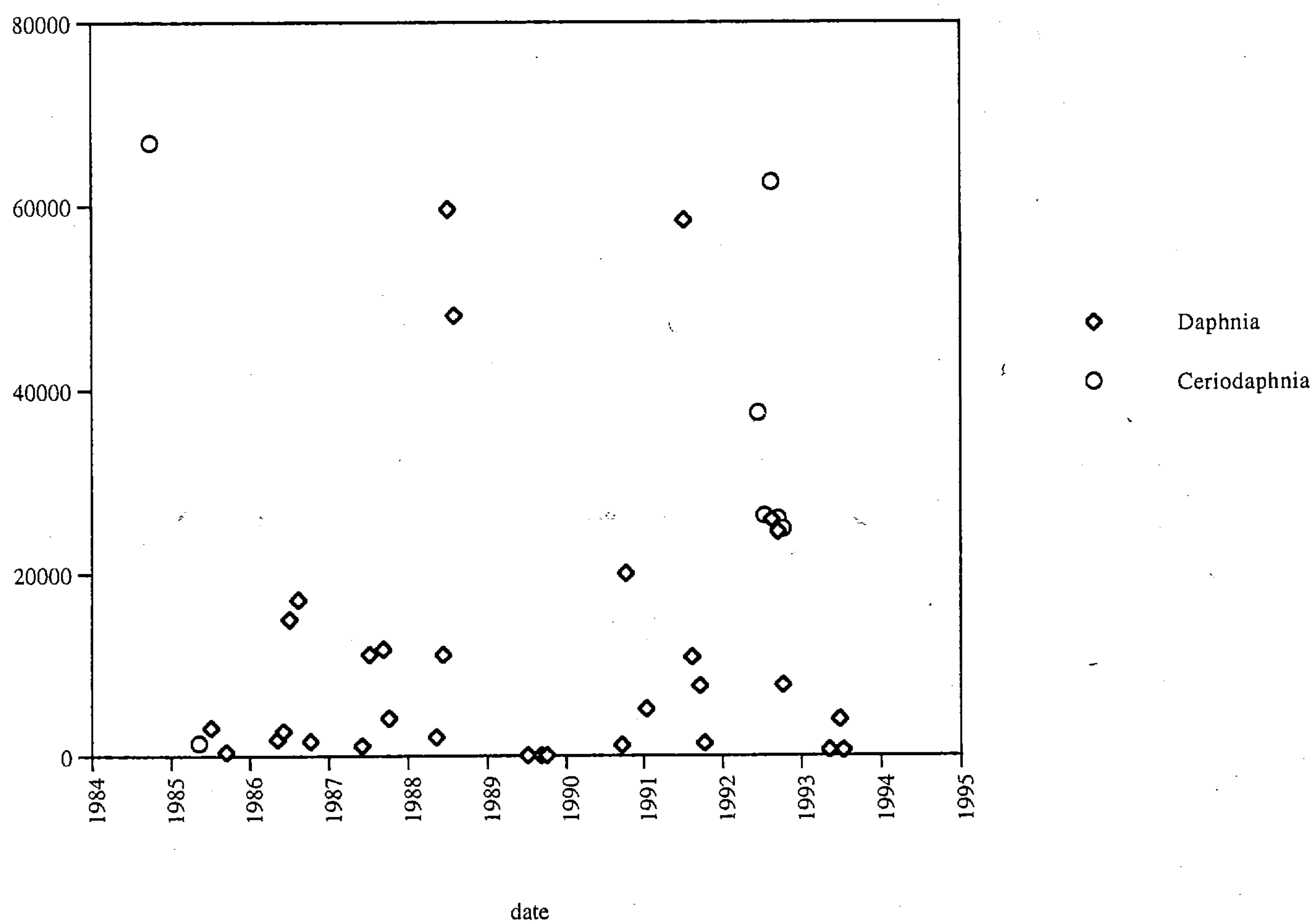


Figure 4.2.6. Maxwell Lake Zooplankton: *Keratella.*

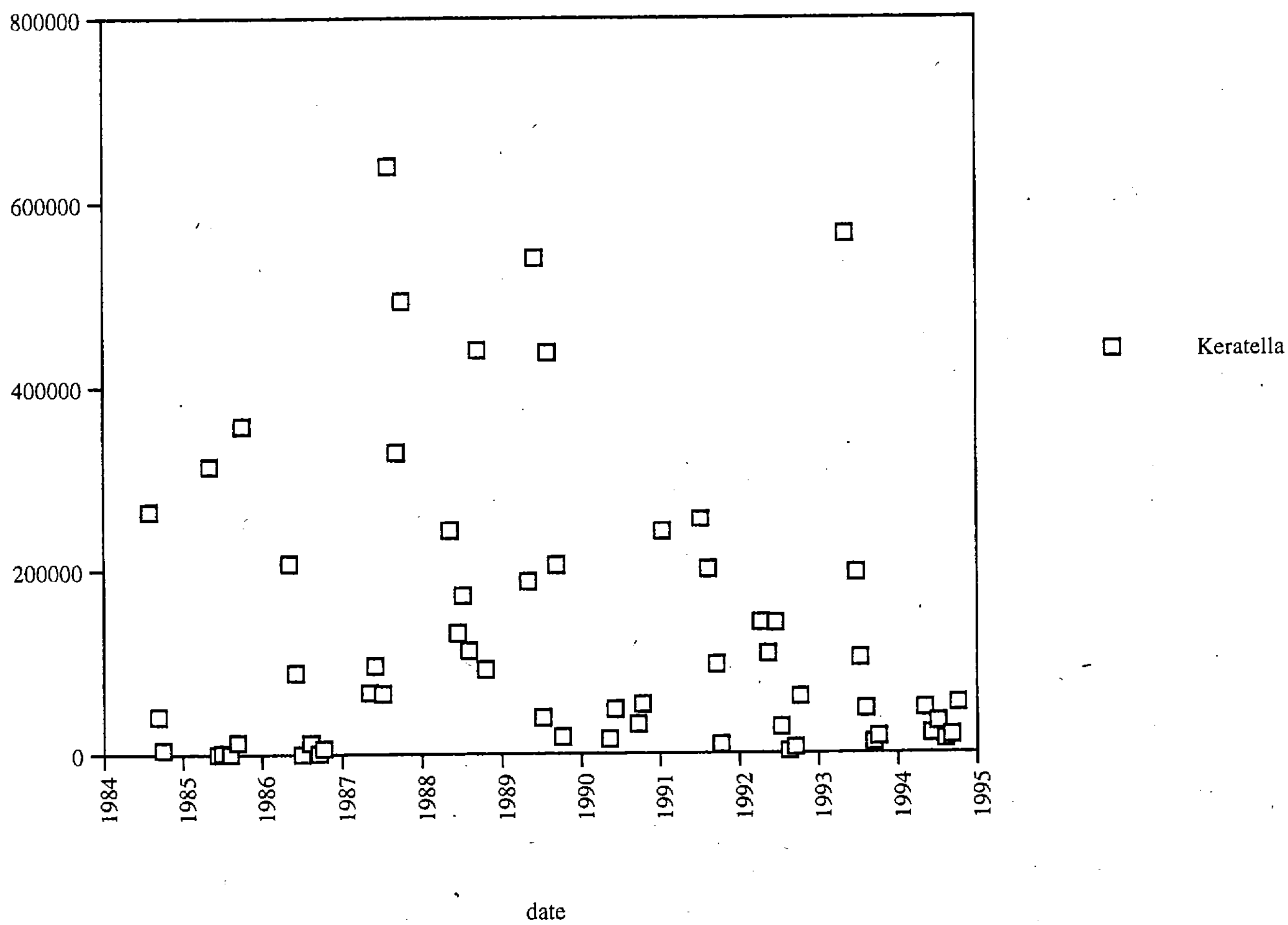


Figure 4.2.7. Maxwell Lake Zooplankton: *Kellicottia*.

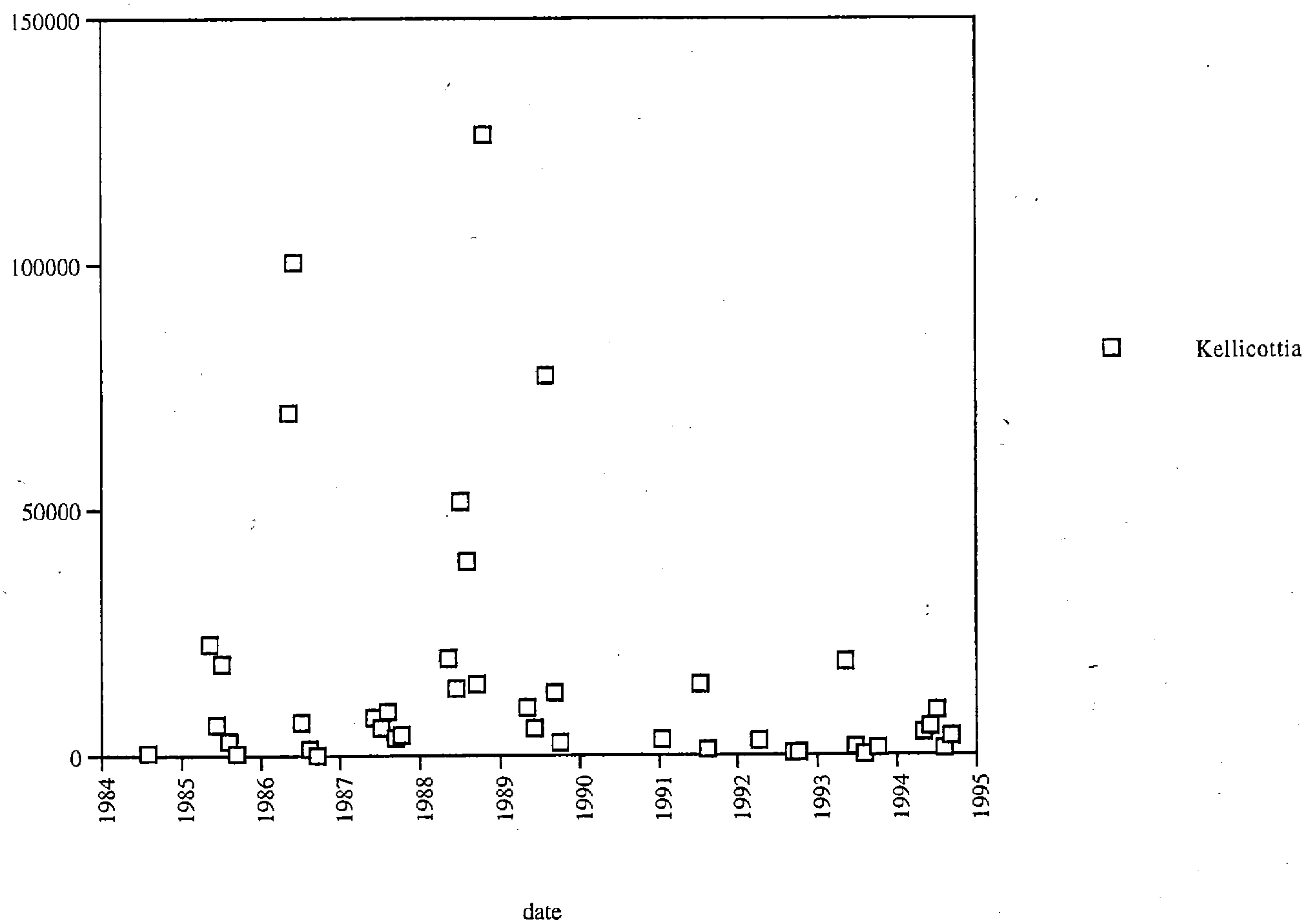


Figure 4.2.8. Maxwell Lake Zooplankton: *Polyarthra/Asplancha.*

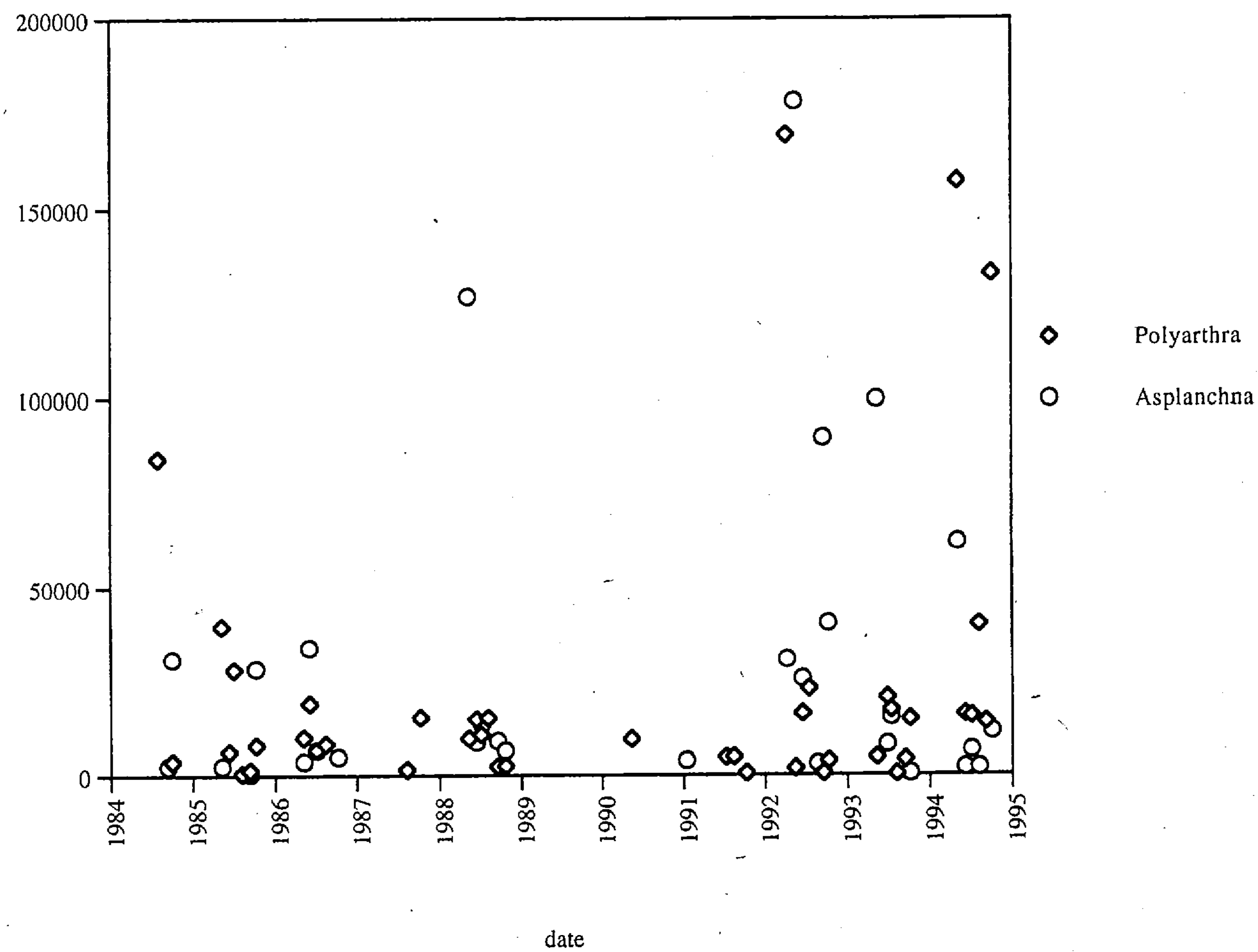


Figure 4.2.9. Maxwell Lake Zooplankton: Rotifers #1

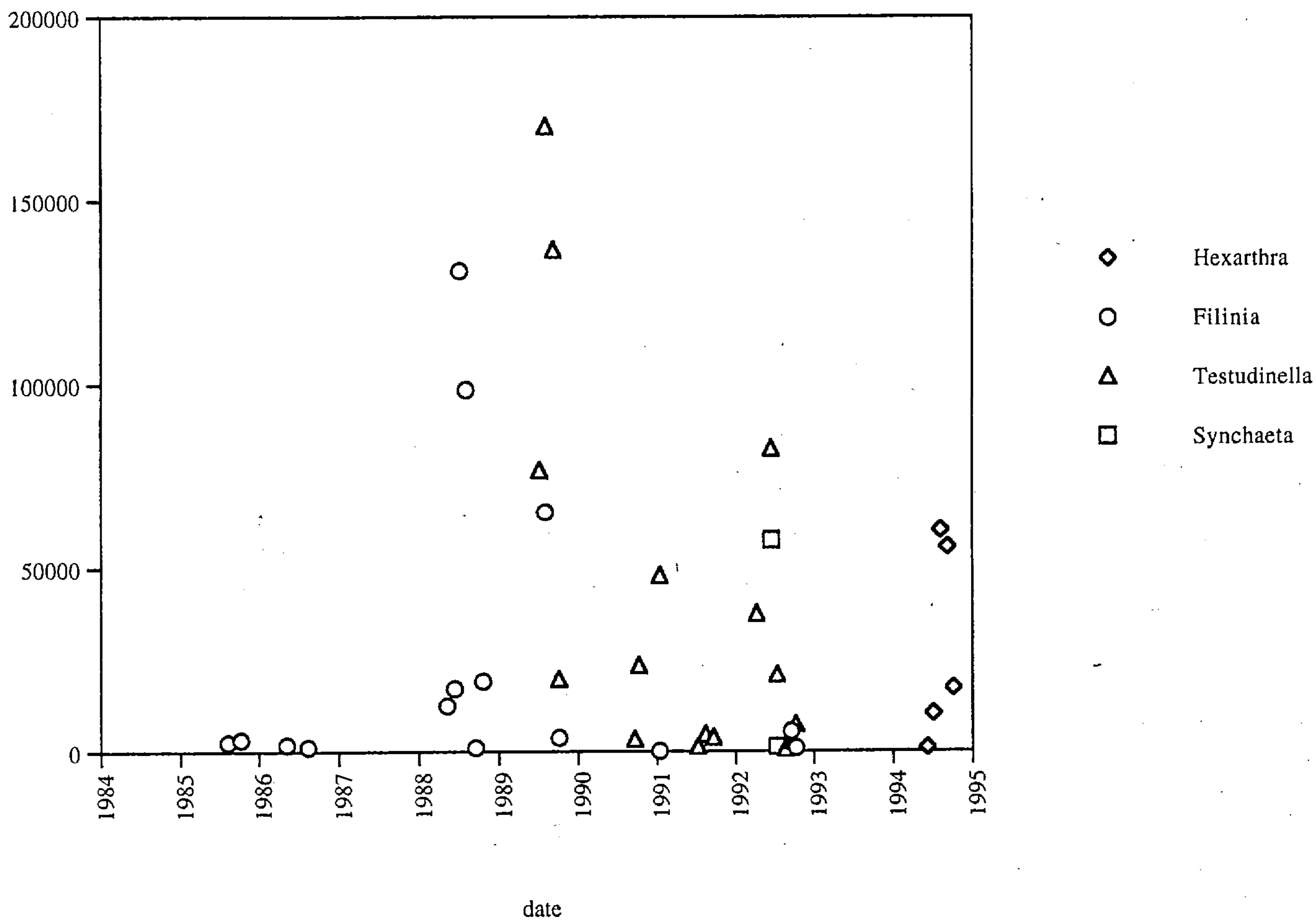


Figure 4.2.10. Maxwell Lake Zooplankton: Rotifers #2.

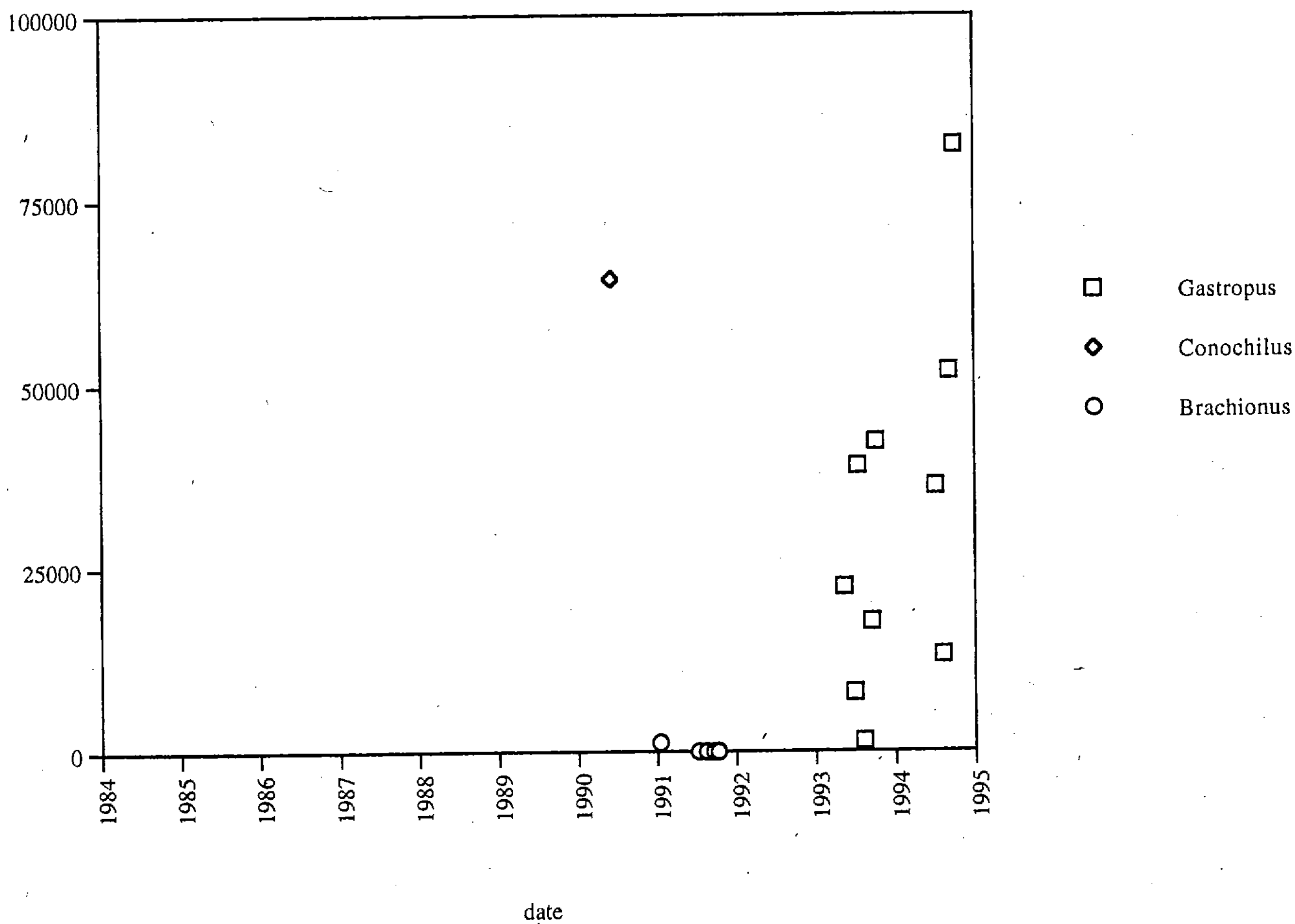


Figure 4.2.11. Maxwell Lake Zooplankton: Zooplankton Biomass Comparisons.

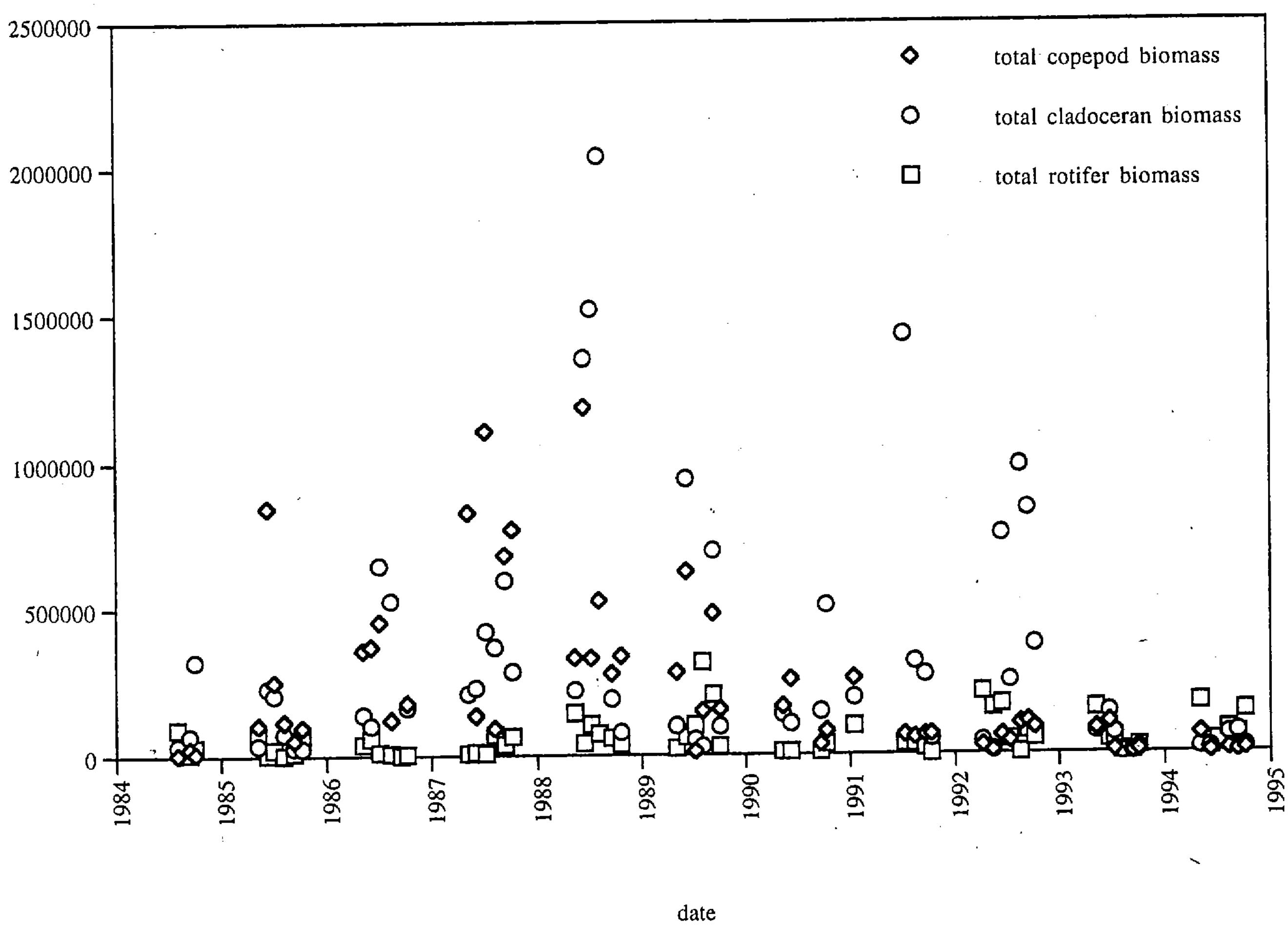


Figure 4.2.12. Maxwell Lake Zooplankton: Biomass mg/m2

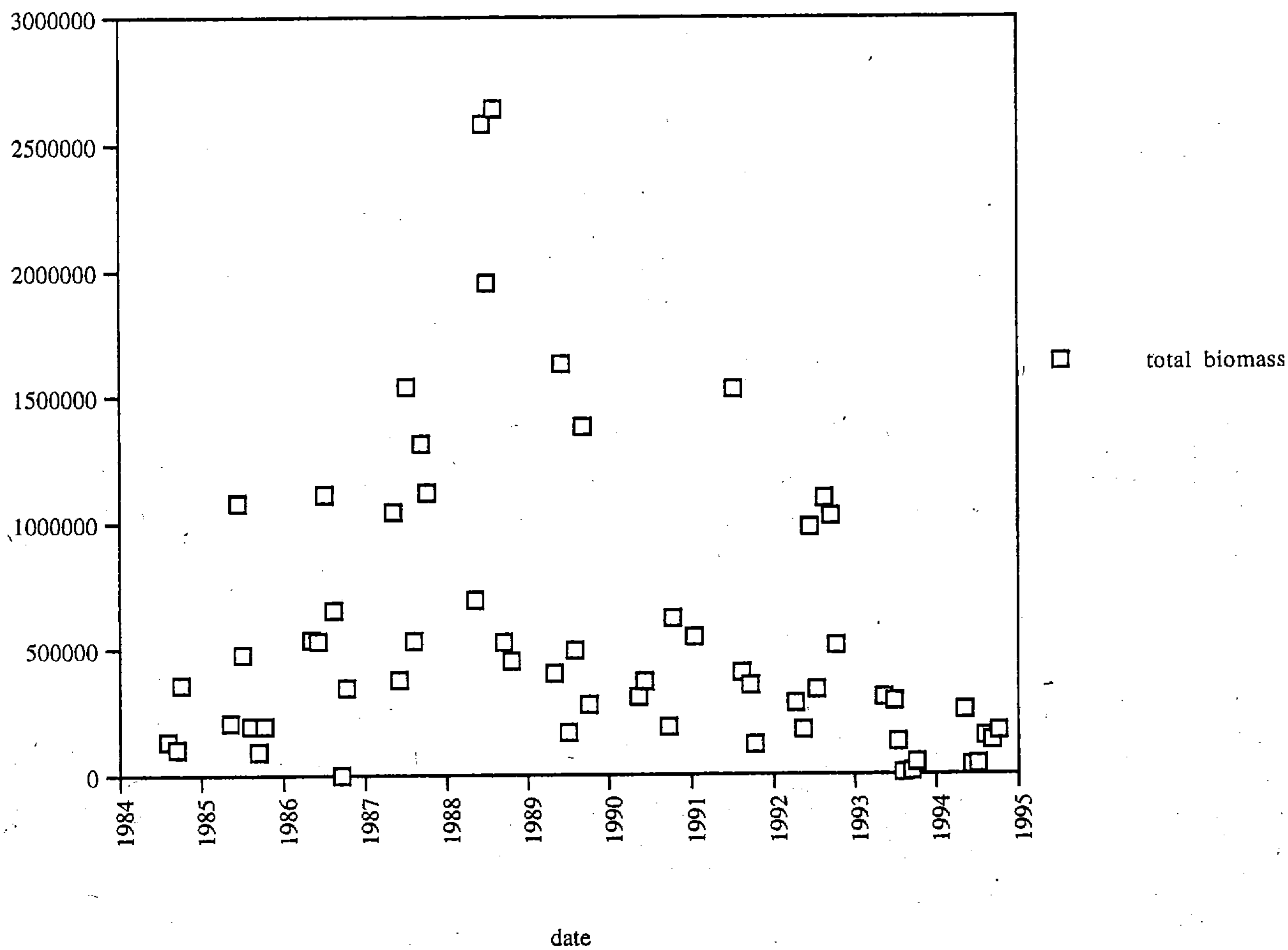
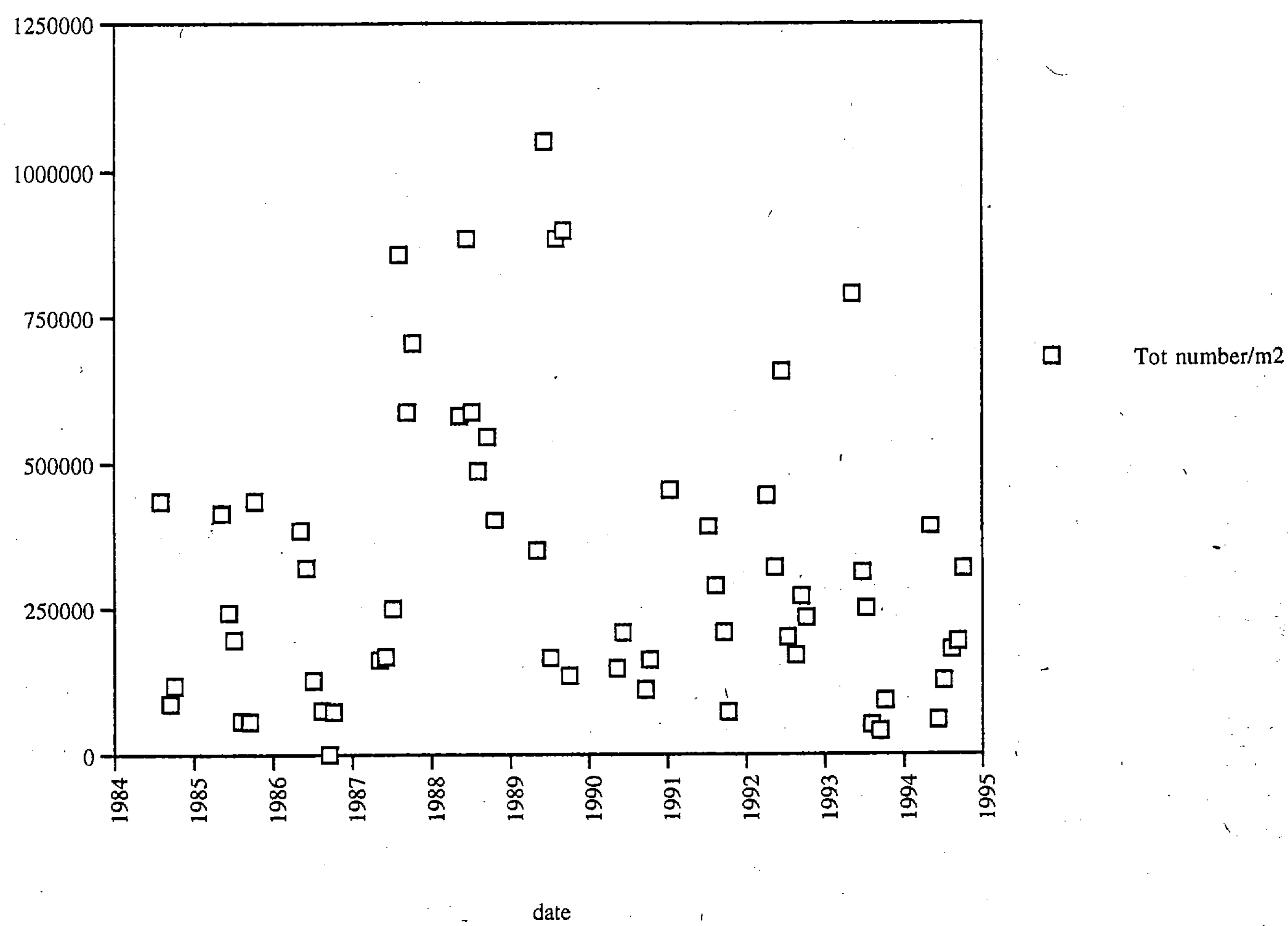


Figure 4.2.13. Maxwell Lake Zooplankton: Total Zoopankton/m2



5.0. OLD WOLF LAKE

Old Wolf Lake is located on Vancouver Island, to the north and west from Victoria (48^{o} 30' 00", 123^{o} 40' 10", map sheet 92B) , in the protected watershed of the Greater Victoria Water District, although the lake itself is not used as a water supply. It is located at an elevation of 335 m and was totally surrounded by second-growth forest (Douglas fir and other coniferous trees) until September 1986, when logging commenced on its eastern shore. All trees were removed from that shore. Old Wolf Lake has an area of 23.6 ha, a mean depth of 4.4 m, a maximum depth of 13 m, and a volume of 1050 dam^3. It has a watershed area of 1.75 km^2 and a lake residence time of 0.625 years (rate 1.6 times/year).

With the exception of the north and south ends of the lake, most of the shoreline drops steeply into the water. Most of the shoreline is difficult to access due to deadfall and debris related to root rot and high water. Old Wolf Creek is the outflow from the lake, eventually discharging to the Sooke River, and there is no visible inflow.

Two perturbations complicate the analysis of the Old Wolf Lake data. As noted above part of the lake's watershed (most of the eastern drainage) was logged in the autumn of 1986. The result was an increase in nutrient export to the lake, as outlined in Nordin (1995, in preparation). In addition to this 1000 juvenile Rainbow Trout in May of 1984.. This event is anecdotal, and is not recorded in the Ministry of Environment Fisheries Branch stocking data base. It is possible that this unrecorded introduction is not an isolated event in this or any other of the study lakes.

5.1 Phytoplankton

The phytoplankton community exhibits a similar diversity to the lakes described previously, with 88 genera reported over the period of study (Appendix 8). The dominant and sub-dominant taxa are listed in Table 5.1.1. Of the dominants, *Dinobryon* and *Cryptomonas* are the most consistent genera, present in 92% and 90% of all samples respectively. These are followed by *Merismopedia* (83%), and three chlorophytes: *Crucigenia* (81%), *Elakothrix* (80%), and *Oocystis* (77%). The dominant and sub dominant taxa are displayed graphically in figures 5.1.1 to 5.1.16.

Mean concentrations for dominant and sub-dominant taxa range between 0.5 and 206 cells/mL, as is consistent with the other lakes. The two exceptions to this are

Merismopedia (Figure 5.1.3) and *Aphanothece* (Figure 5.1.4), which have mean concentrations of 4227.08 and 13,529.70 cells/mL. In the case of *Merismopedia* the mean is elevated by a single event bloom concentration of 132,000 cells/mL in June of 1987. With this corrected for *Merismopedia* still displays a high mean of 1665.53/mL. The lowest mean concentrations displayed are for the two diatom genera and *Arthrodesmus*, the only desmid represented in this group.

Monthly and/or yearly variation in numbers and occurrence is high for most genera, and successional patterns are not readily apparent. *Dinobryon, Crucigenia*, and *Cryptomonas* appear to be the least variable on a yearly basis. Few trends are evident for individual taxa. A number of genera either appear at or increase to significant concentrations in 1986 and 1987, then decrease in number or disappear subsequently. These include *Aphanothece, Merismopedia, Chroococcus, Gomphosphaeria, Botryococcus, Gloeocystis, Scenedesmus*, and *Rhabdoderma*.. The increase in numbers may be related to release of nutrients from the logging of the eastern part of the watershed in the fall of 1986, although in some cases an increase is observed prior to the onset of logging operations.

Three taxa appear in 1989, then increase to high concentrations and are present for the remainder of the study. *Lyngbya* (Figure 5.1.16), which makes two appearances at low concentrations late in 1984 and early in 1985, appears in 1989, then is present in 90% of the remaining samples at a high mean concentration of 1309.07 cells/mL. *Aphanocapsa* appears in 1989 at 7400 cells/mL, then steadily decreases in number through 1994 with an occurrence of 77% and a mean concentration of 1045.40 cells/mL for that period (Figure 5.1.18). In addition to these blue-greens, one chlorophyte genera also exhibits this trend. *Sphaerocystis* is present in 77% of the 1989 to 1994 samples at a mean concentration of 280 cells/mL, yet absent prior to this. Sphaerocystis exhibits an almost identical trend in Maxwell and Stocking Lakes.

Standing crop as measured by the total number of phytoplankton (Figure 5.1.20) reflects the patterns noted above, with both the 1986/1987 and 1992/1993 peaks clearly evident. Total numbers show a definite decrease over the period of sampling. It is possible that this observed decrease is a result of the nutrient pulse received in 1986/1987 and represents the system rebounding from this event. The cells/mL levels recorded in the fall of 1984 and throughout 1985 indicate that this may be the case. Chlorophyll data (Fig. 5.1.19) is incomplete for Old Wolf, but unlike (the other lakes) a strong correlation exists between the total cell/mL figures and the measured chlorophyll a. Total numbers of phytoplankton and chlorophyll a are summarised by year in tables 5.1.2 and 5.1.3.

5.2. Zooplankton

The zooplankton community of Old Wolf exhibits a similar diversity to the previously described lakes, with 22 genera reported over the period of study. Four copepod genera have been observed, with *Diaptomus* the only conspicuous member. It is present in all samples at significant concentrations, excepting a five month absence in 1986 and early 1987, and one absence in 1994 (Figure 5.2.1). *Cyclops* is reported eight times at relatively low concentrations between 1984 and 1987, and *Epishura* is reported once in 1986 (Figure 5.2.2). *Diacyclops* was reported twice at very low numbers in 1993. *Diaptomus* exhibits a pattern that can be observed in Figure 5.2.1 as do, to varying degrees, most of the major zooplankton taxa in Old Wolf. Low numbers are observed in 1984 and steadily increase through 1987 and 1988. Numbers decline through 1992, and then increase again. Copepodite and nauplii stages (Figure 5.2.3) occur consistently throughout the study, and mirror the trend shown by *Diaptomus*.

Five cladoceran genera are observed. Of these, *Holopedium, Diaphanosoma*, *Bosmina*, and *Daphnia* all show roughly similar numbers, as well as a general pattern to increased concentration in 1987 and 1988, followed by a decline (figures 5.2.4 and 5.2.5). *Holopedium* and *Diaphanosoma* show a second peak analogous to the pattern displayed by *Diaptomus* during the last three years. *Ceriodaphnia* is reported twice in 1984 and 1985 at low concentrations, and once in 1994 at an elevated peak of 25,000/m2 (Figure 5.2.6).

The rotifer component of the zooplankton is the most diverse component of the Old Wolf zooplankton, with ten genera reported. Of these *Kellicottia* and *Keratella* are the most consistent (Figure 5.2.7), showing roughly equal concentrations some years and one or the other dominant at different times throughout the study. Both of these rotifers show a slight overall increase in numbers. *Testudinella* (Figure 5.2.8) appears in 1990, is present at mid concentrations in 1991-1993, then shows one peak in 1994 of over 1,000,000 individuals/m^2. *Conochilus* (Figure 5.2.9) appears in 1988 at high numbers, declines, and then peaks again in 1994 in a manner similar to *Diaptomus* and the two cladocerans. Several other rotifers appear or increase in concentration towards the end of the sampling period. These are displayed in figures 5.2.10 and 5.2.11.

Old Wolf shows the highest incidence of *Chaoborus* (Figure 5.2.12) found in any of the study lakes.

Total numbers of zooplankton (Figure 5.2.13) to show a definite increase over the study period. In addition, the pattern noted above is readily evident. The increase in total numbers would appear to be a result of increases in the rotifer component of the zooplankton, given that a general decrease is evident in the crustaceans. Biomass estimates (Figure 5.2.14) reveal that the cladocerans are the majority contributor, followed by the copepods and rotifers. For one date in 1994 the rotifers contributed the majority of biomass in the lake. It appears that the total zooplankton biomass in Old Wolf has remained relatively constant over time (Figure 5.2.15).

	Dominant	Sub-dominant	% presence	mean conc. cells/mL
Chrysophyte	*Dinobryon*		92	90.75
Cryptophyte	*Cryptomonas*		90	20.66
		Chroomonas	70	30.16
Cyanophyte	*Merismopoedia*		83	4227.08
		Anabaena	68	207.60
		Chroococcus	67	194.85
		Aphanothece	55	13,529.70
Chlorophyte	*Crucigenia*		81	107.88
	Elakothrix		80	11.56
	Oocystis		77	41.25
		Scendesmus	72	20.99
		Botryococcus	70	205.98
		Quadrigula	62	15.04
		Gloeocystis	59	127.17
		Arthrodesmus	52	0.83
		Pediastrum	51	5.60
Diatom		*Tabelaria*	59	1.14
		Navicula	50	0.50

Table 5.1.1. Old Wolf Lake Phytoplankton: Dominant and Sub-dominant taxa.

Year	n	mean	maximum	minimum	# of samples
1984	401	25.58	80.3	.001	1
1985	21830	263.01	16000	.001	6
1986	236997	2633.3	86112	.001	6
1987	293708	2622.3	132000	.001	6
1988	99622	1071.2	58500	.001	5
1989	28964	202.54	4872	.001	6
1990	14450	131.36	3006	.001	5
1991	24723	148.93	3921	.001	5
1992	53977	321.2	10492	.001	6
1993	67164	490.24	9945	.001	6
1994	23617	111.4	4380	.001	6

Table 5.1.2. Old Wolf Lake Phytoplankton: Summary of total numbers of phytoplankton/mL by year.

year	mean	maximum	minimum
1985	1.5	3.0	0.5
1986	5.8	8.2	4.1
1987	1.3	4.3	0.5
1988	1.5	2.8	0.8
1991	0.9	2.3	0.5

Table 5.1.3. Old Wolf Lake Phytoplankton: Mean and range of Chlorophyll a measurements by year in µg/L.

Figure 5.1.1. Old Wolf Lake Phytoplankton: *Dinobryon/Crucigenia.*

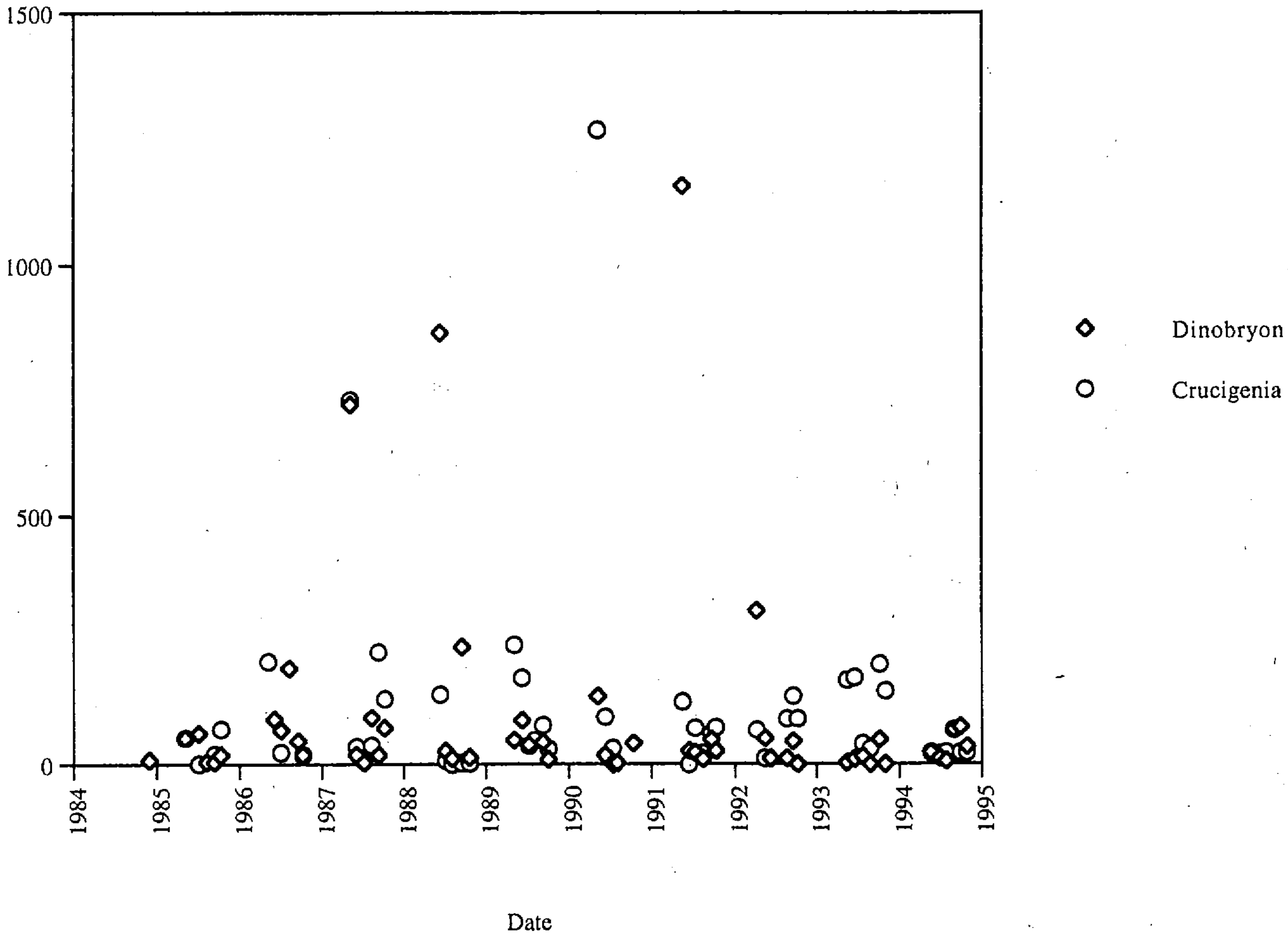


Figure 5.1.2. Old Wolf Lake Phytoplankton: *Cryptomonas.*

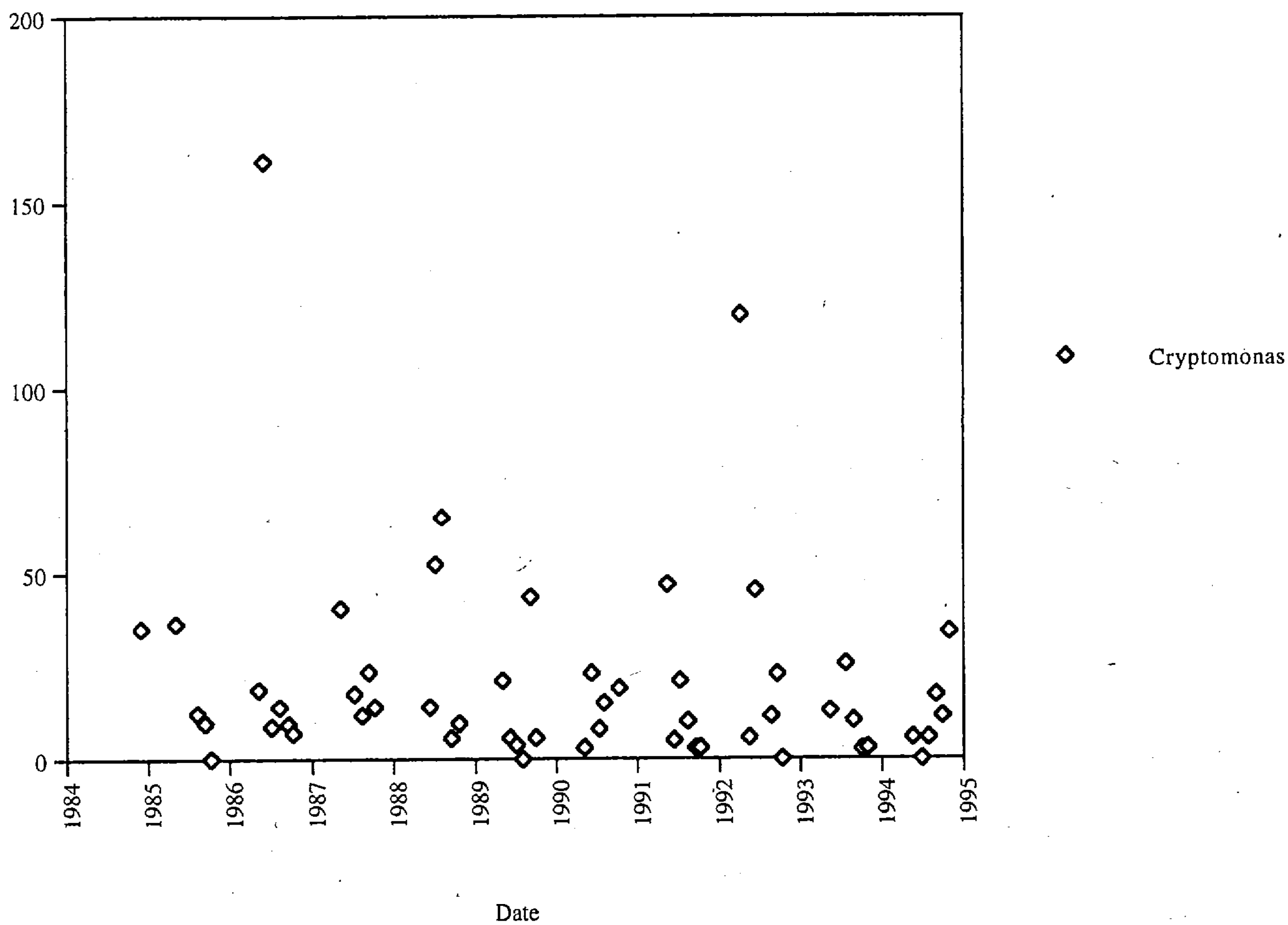


Figure 5.1.3. Old Wolf Lake Phytoplankton: Merismopedia..

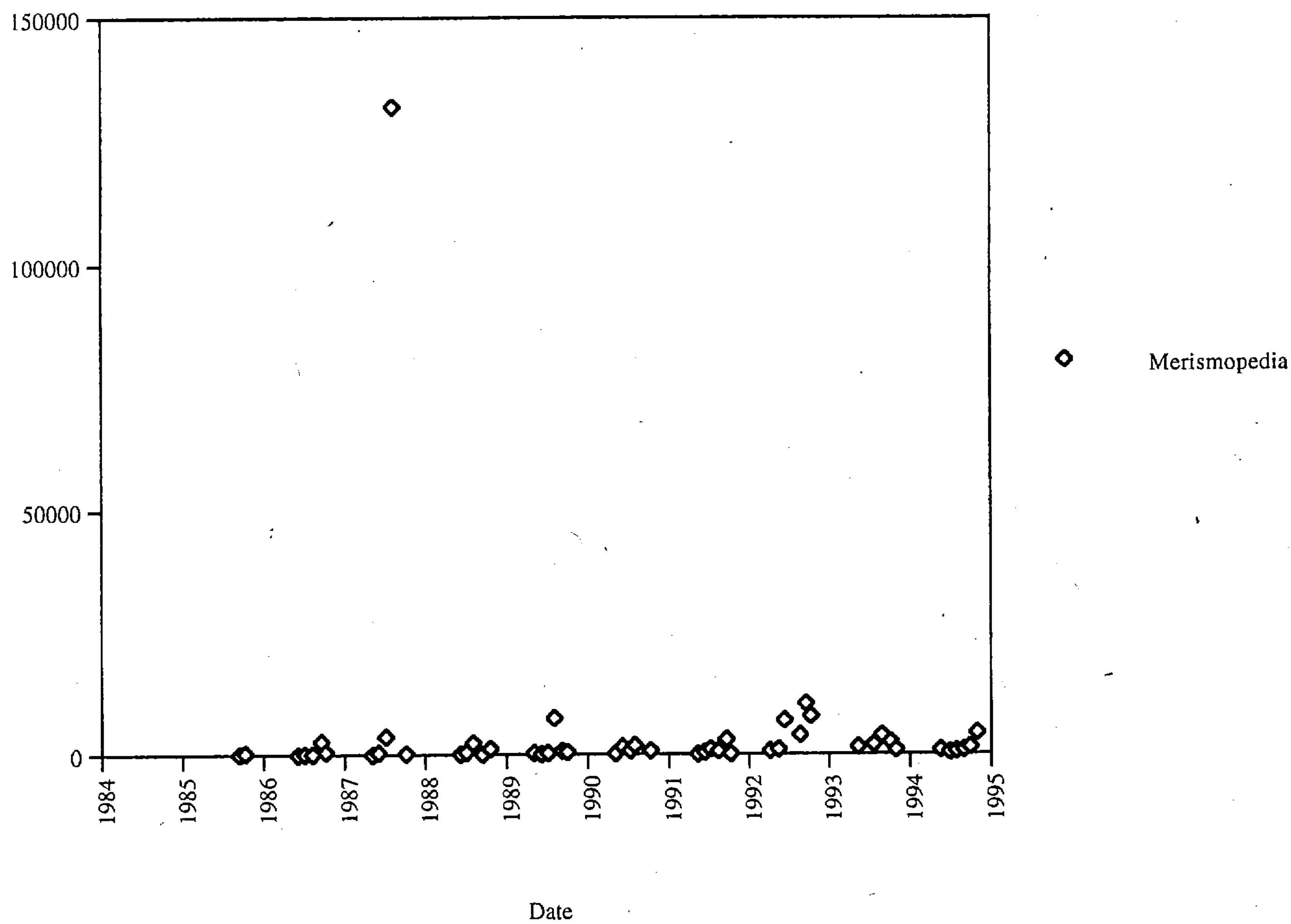


Figure 5.1.4. Old Wolf Lake Phytoplankton: *Aphanothece.*

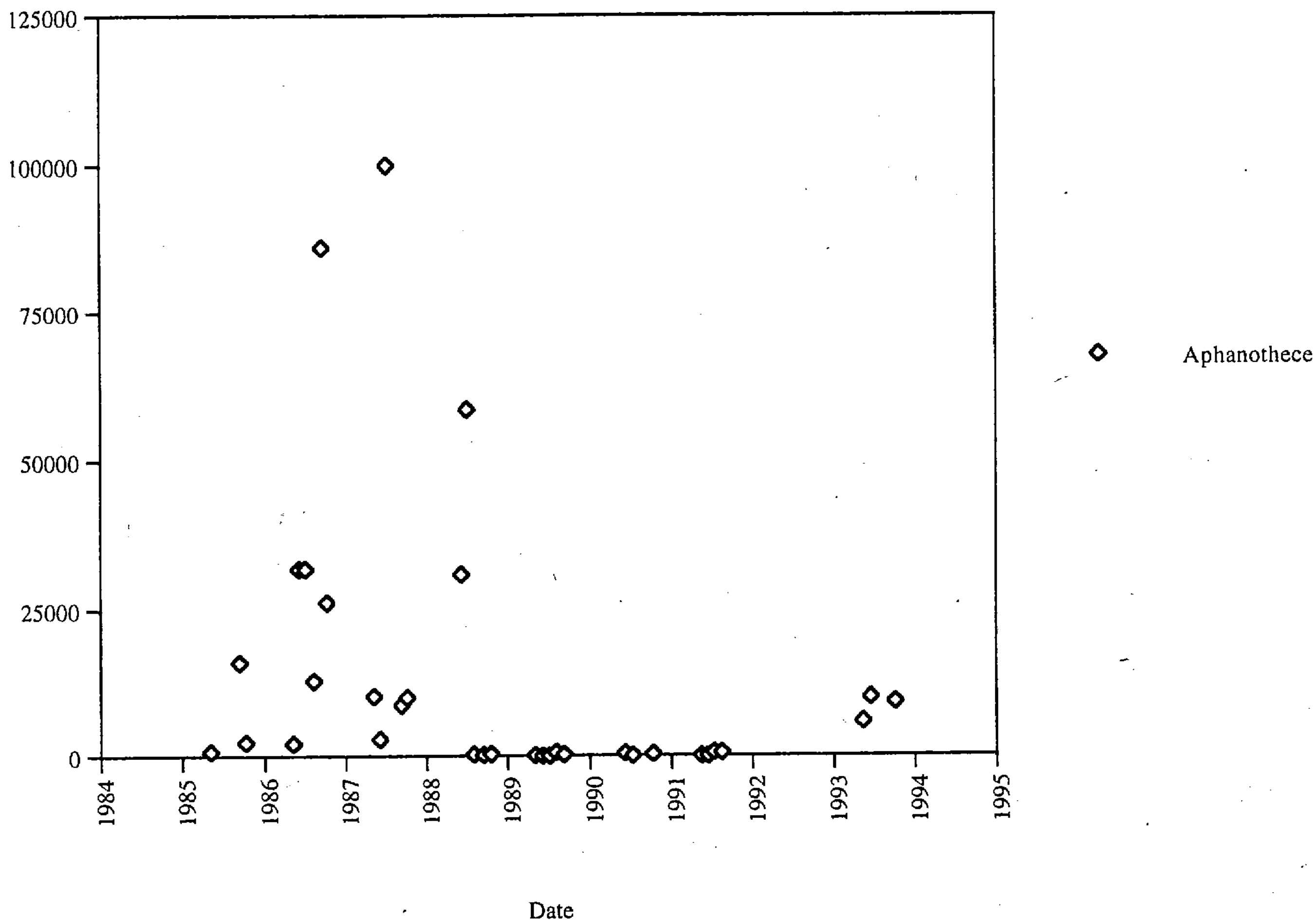


Figure 5.1.5. Old Wolf Lake Phytoplankton: Tabellaria/Navicula.

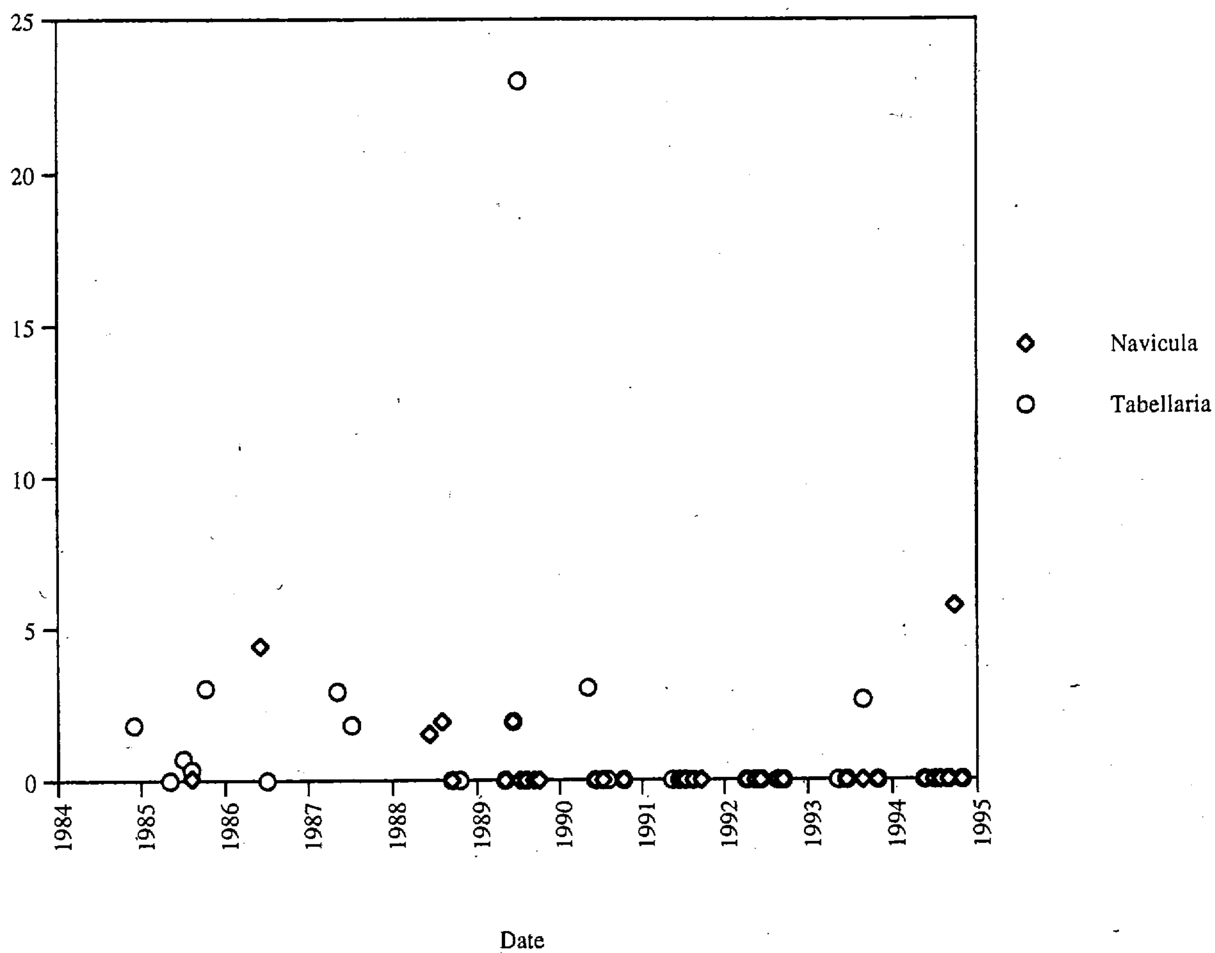


Figure 5.1.6. Old Wolf Lake Phytoplankton: *Scenedesmus/Elakothrix*.

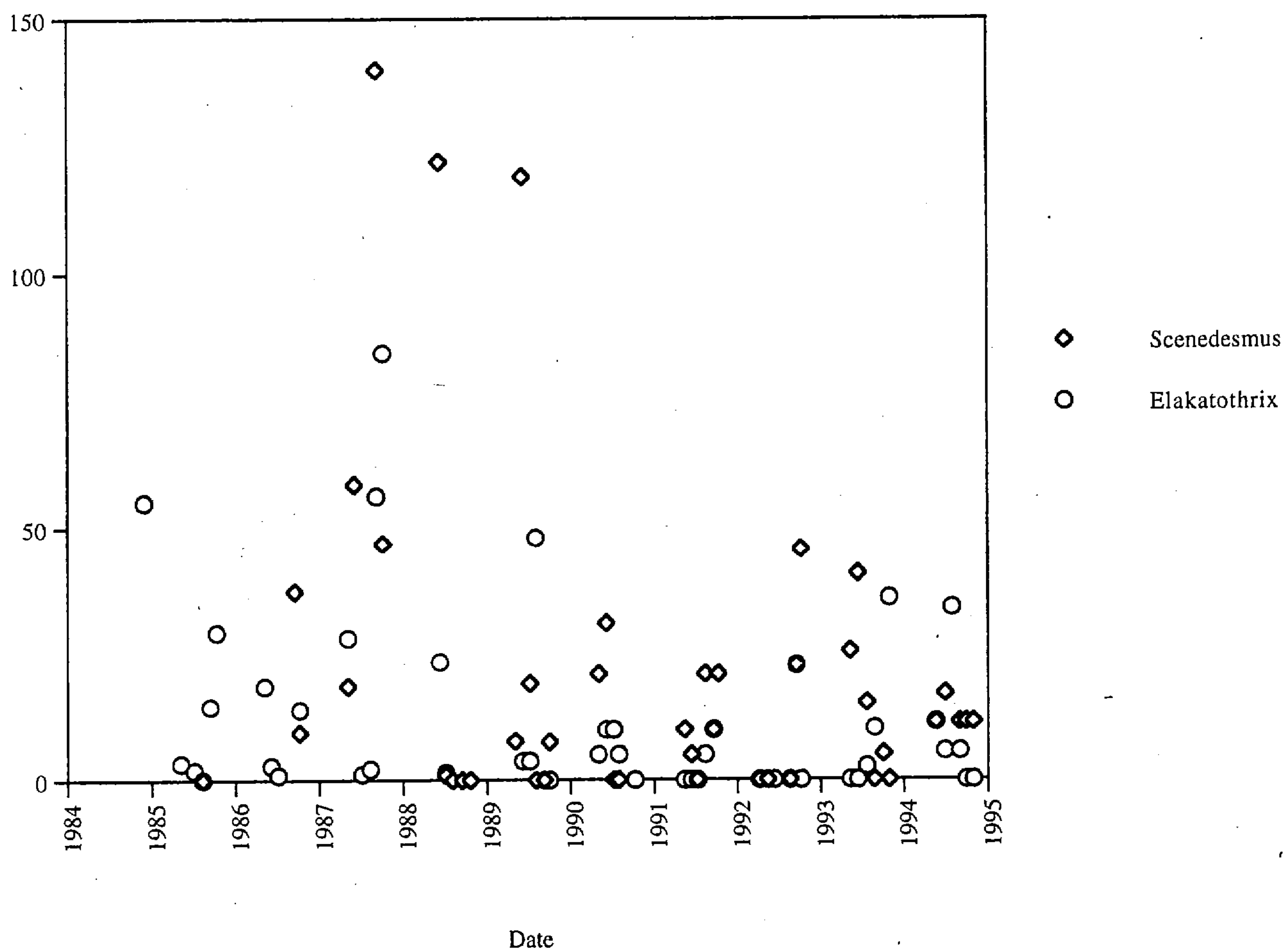


Figure 5.1.7. Old Wolf Lake Phytoplankton: *Chroococcus.*

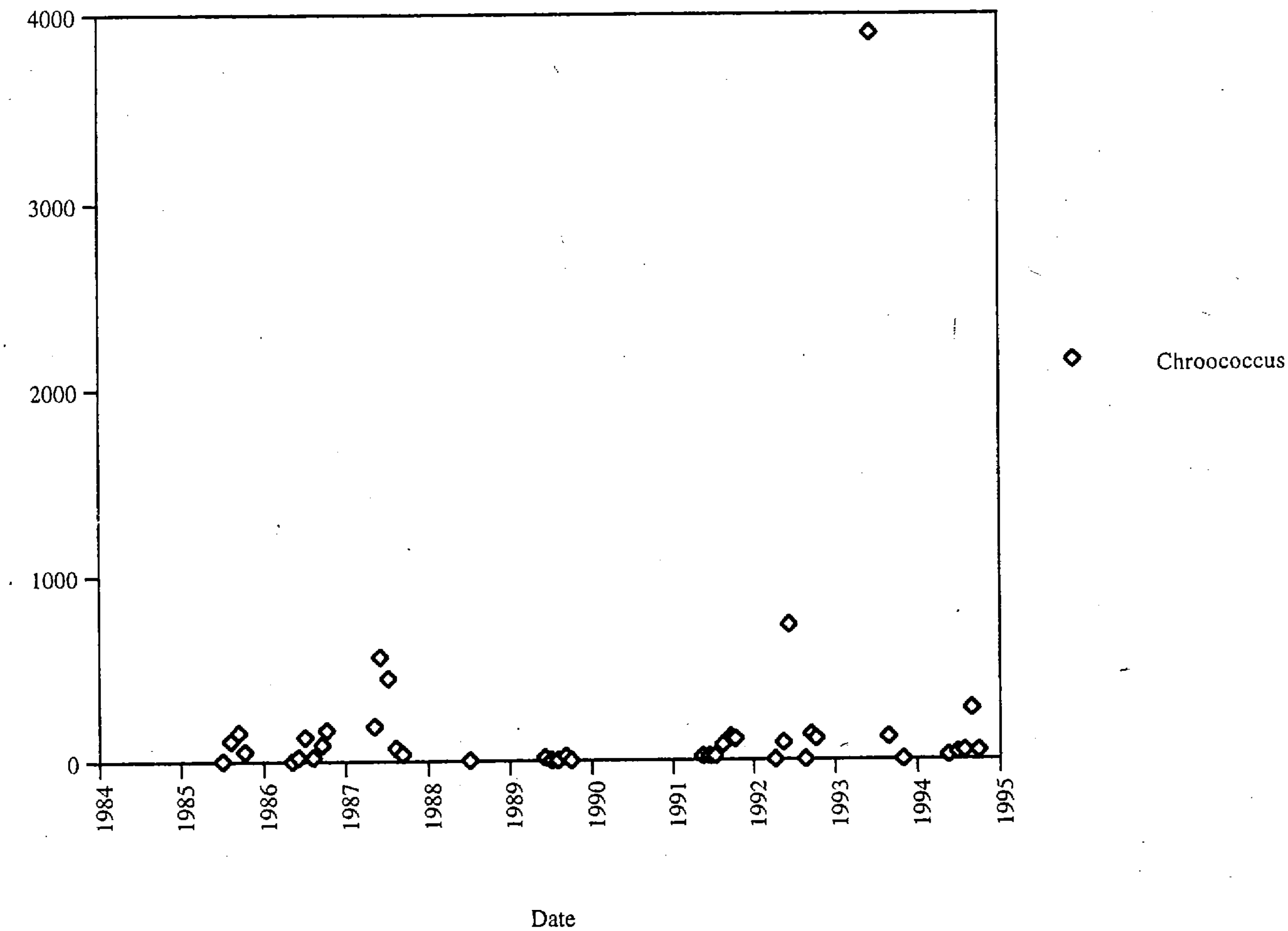


Figure 5.1.8. Old Wolf Lake Phytoplankton: *Gloeocystis*.

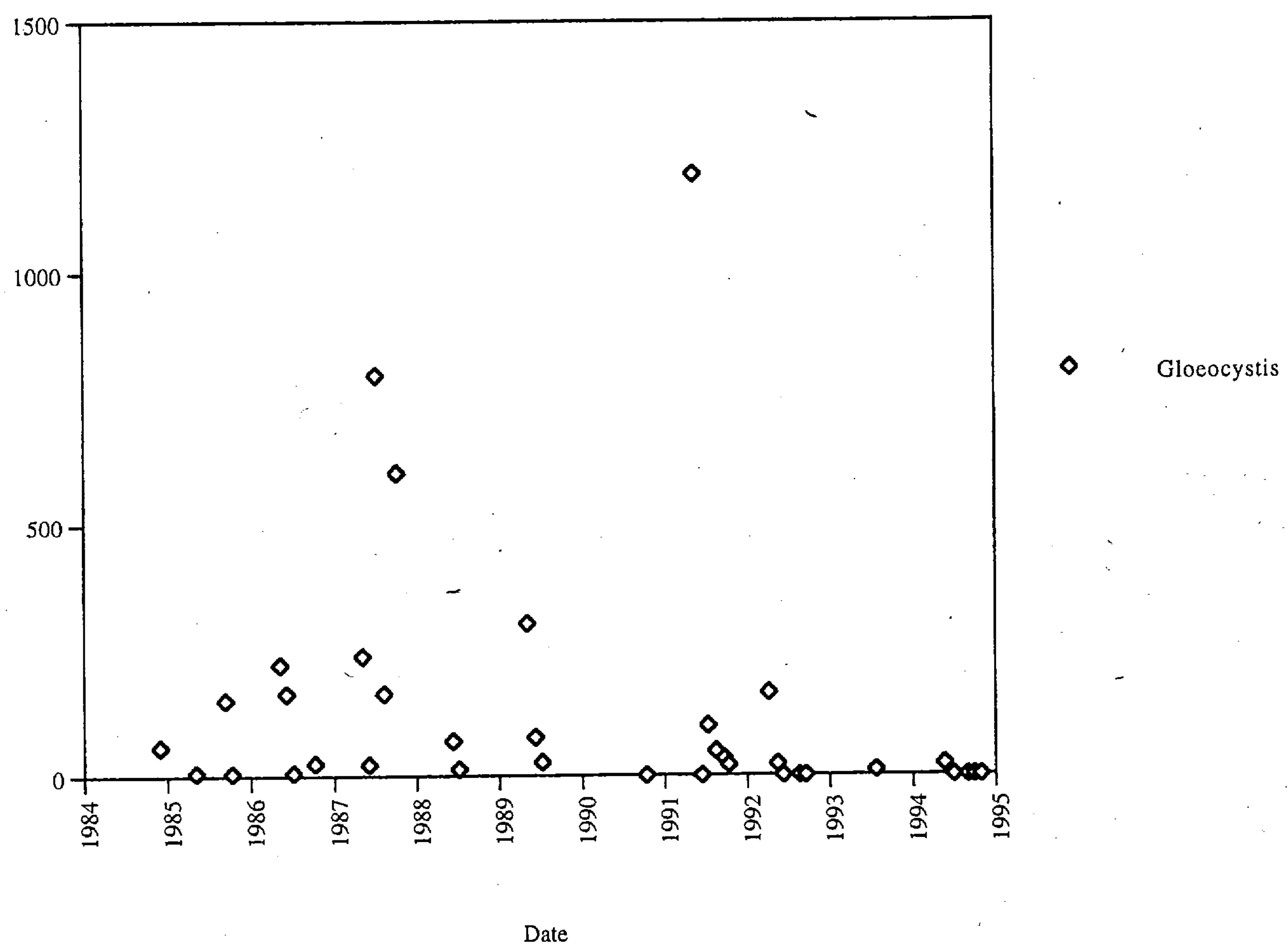


Figure 5.1.9. Old Wolf Lake Phytoplankton: *Botryococcus/Chroomonas.*

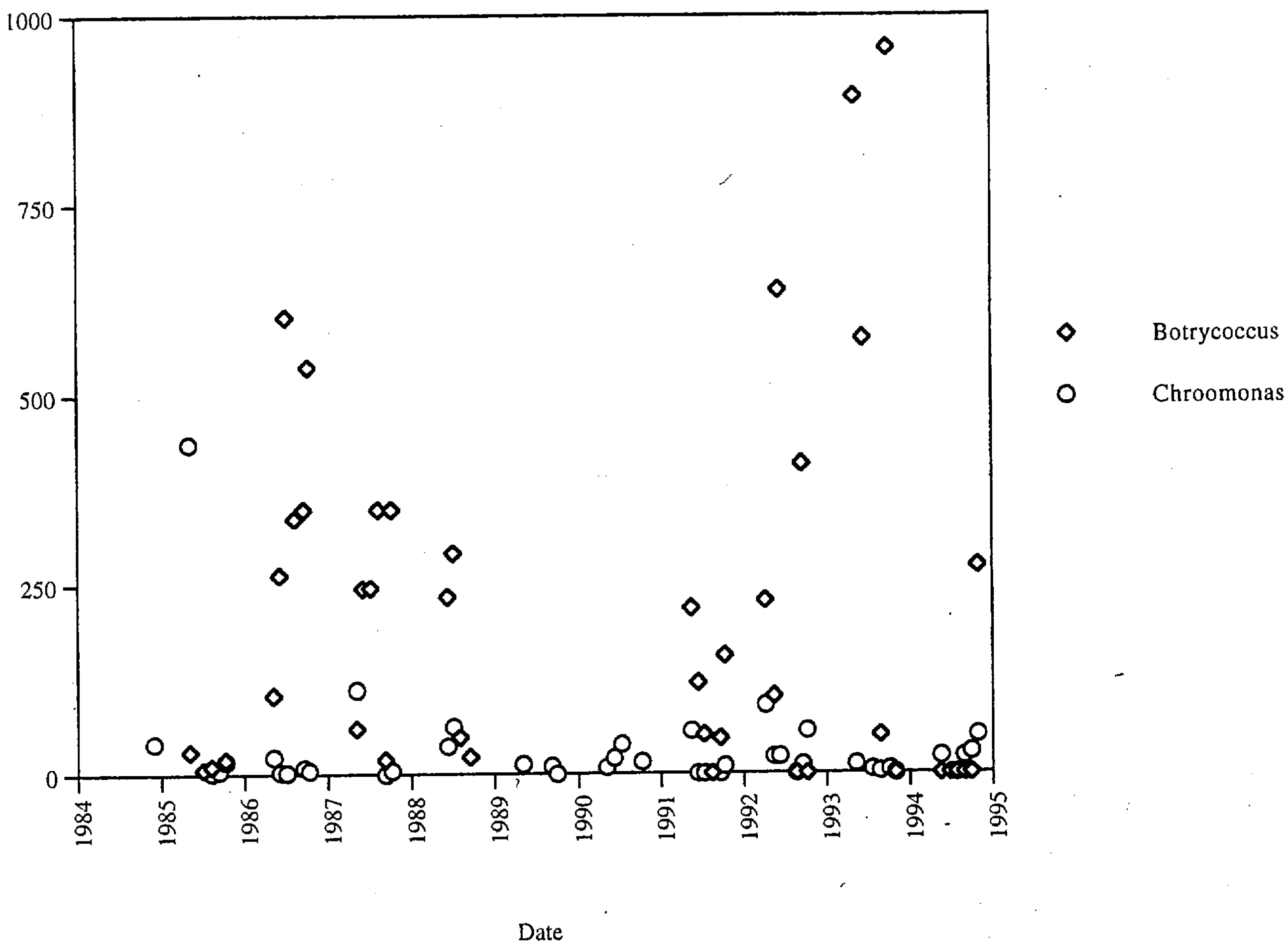


Figure 5.1.10. Old Wolf Lake Phytoplankton: *Chroococcus.*

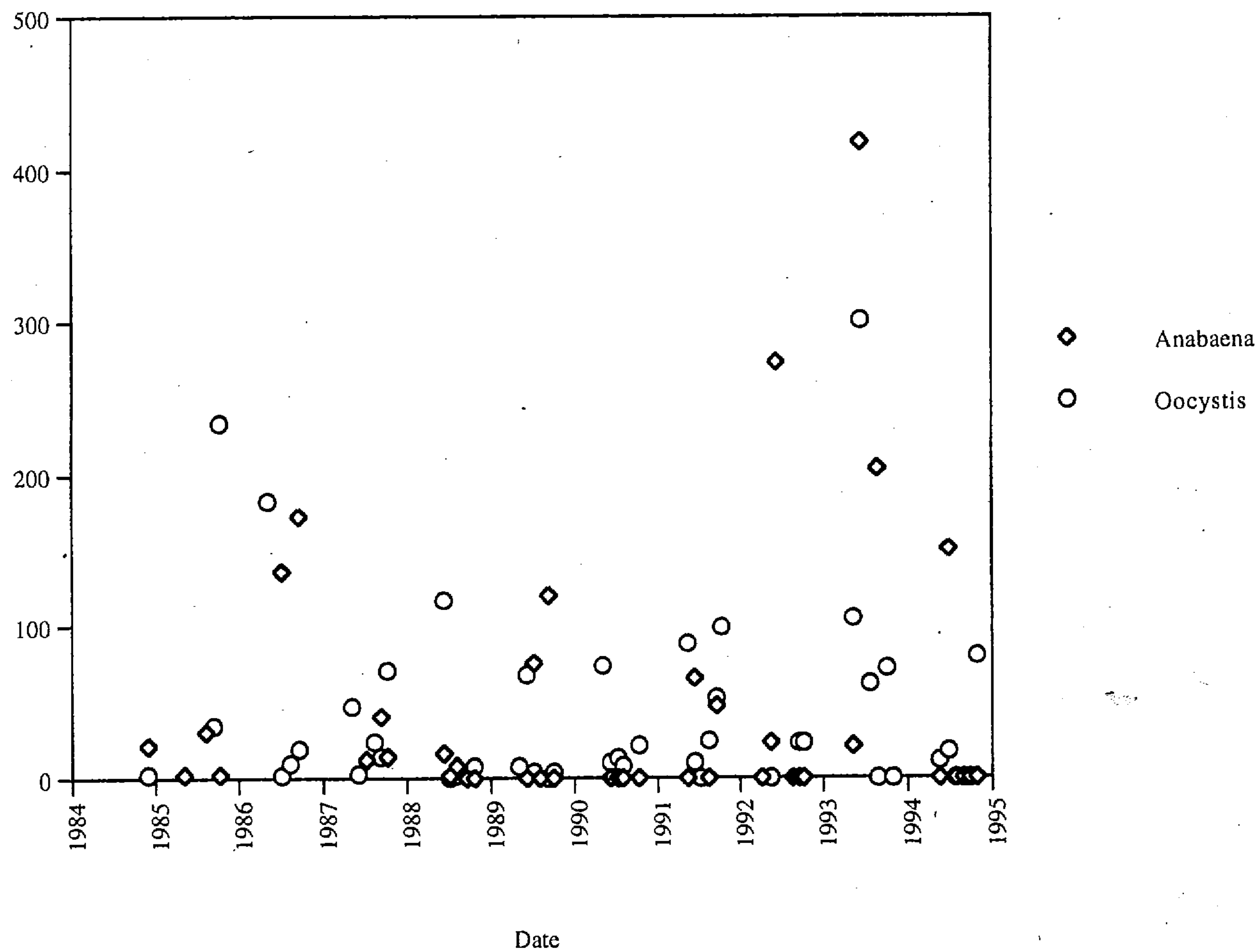


Figure 5.1.11. Old Wolf Lake Phytoplankton: *Pediastrum*.

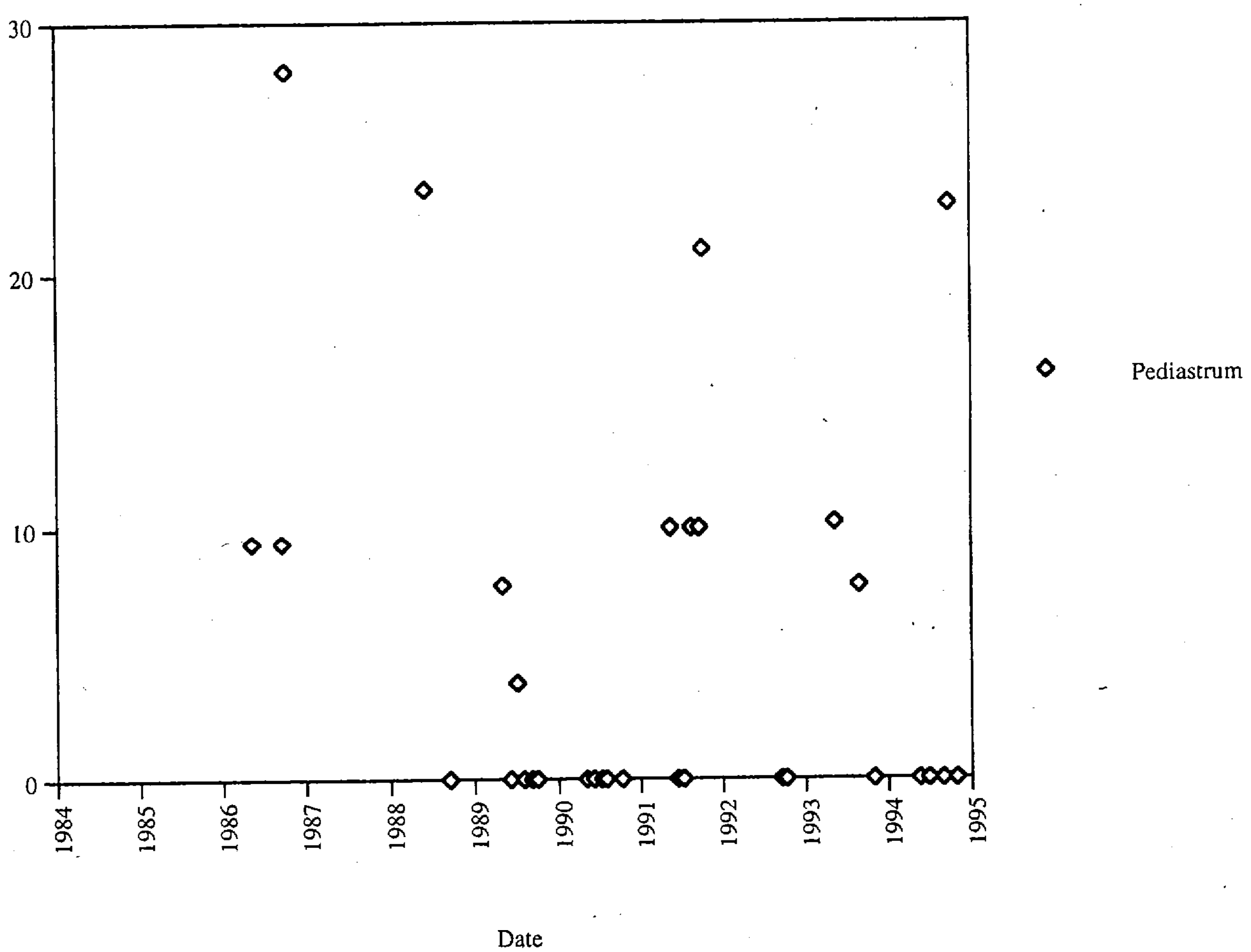


Figure 5.1.12. Old Wolf Lake Phytoplankton: *Quadrigula*.

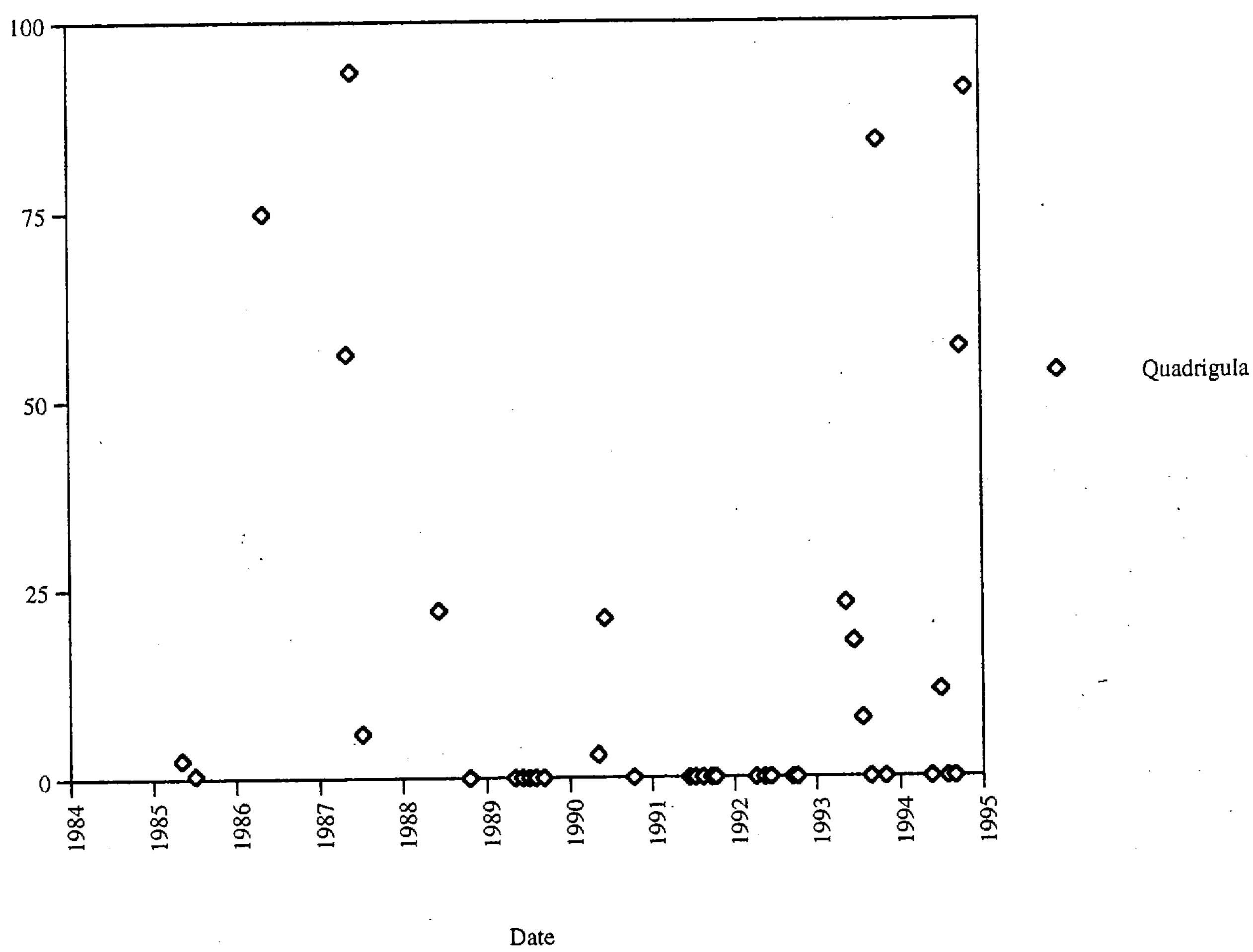


Figure 5.1.13. Old Wolf Phytoplankton: Arthrodesmus.

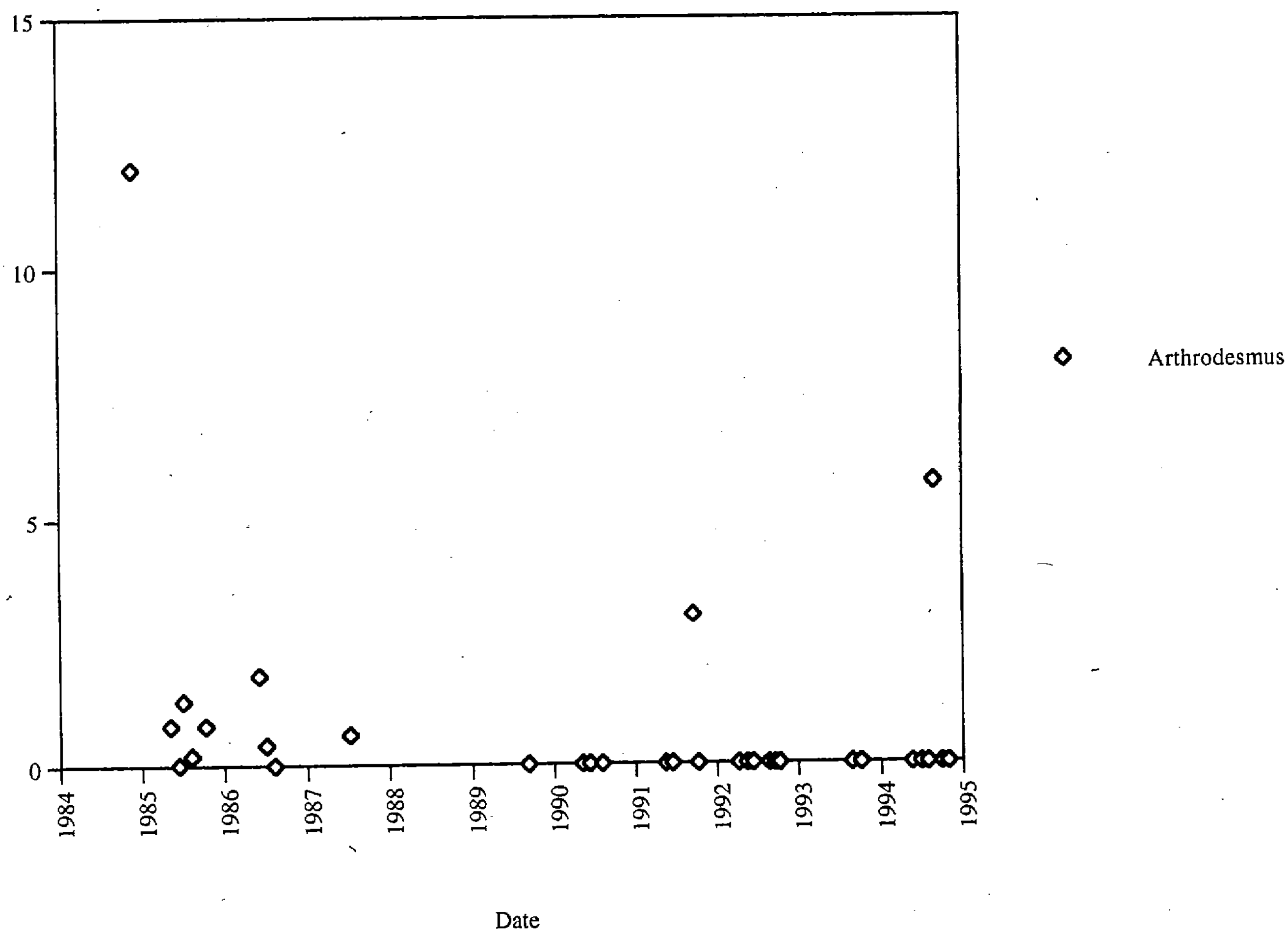


Figure 5.1.14. Old Wolf Lake Phytoplankton: *Lyngbya.*

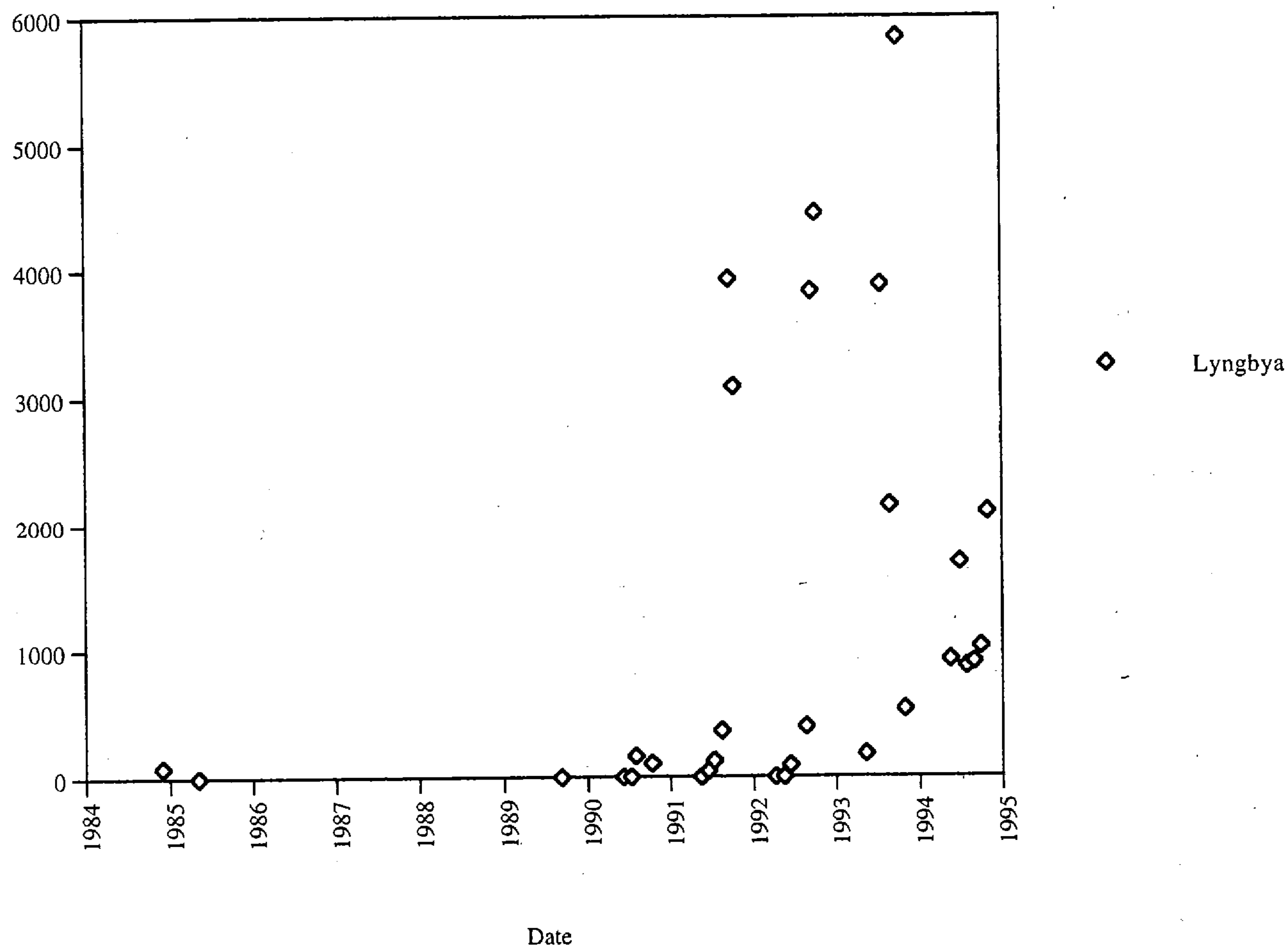


Figure 5.1.15. Old Wolf Lake Phytoplankton: *Rhabdoderma*. .

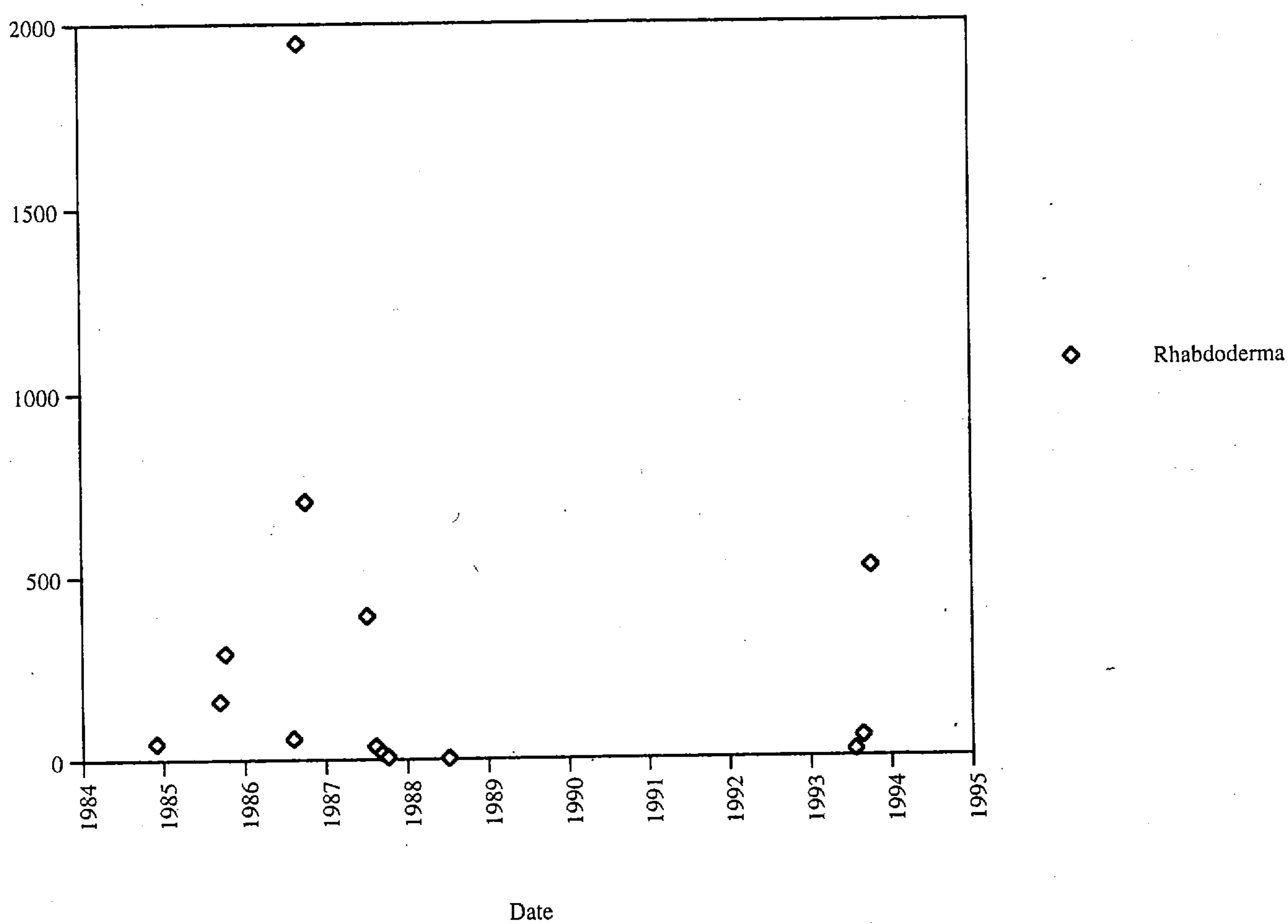


Figure 5.1.16. Old Wolf Lake Phytoplankton: *Aphanocapsa.*

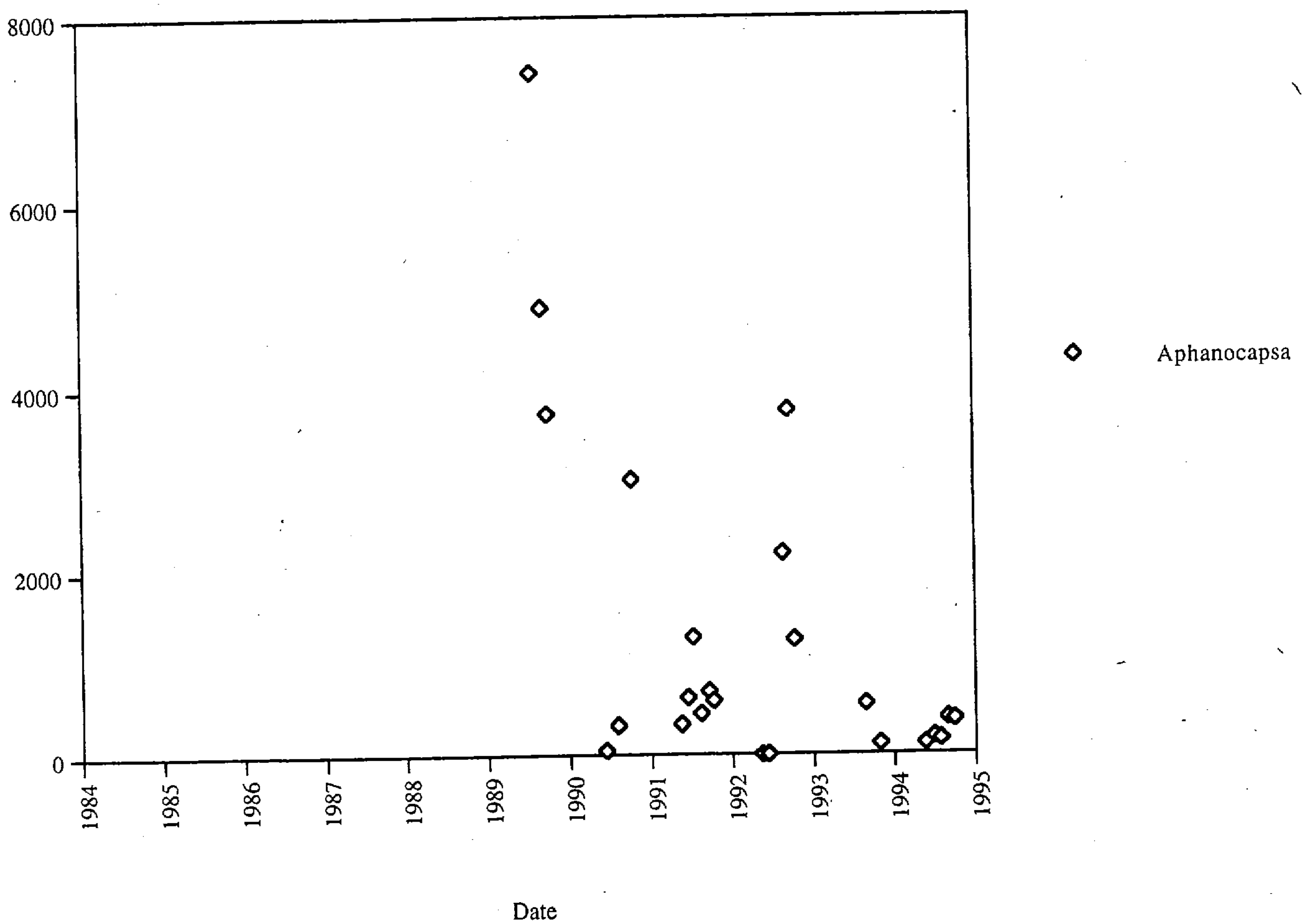


Figure 5.1.17. Old Wolf Lake Phytoplankton: *Sphaerocystis.*

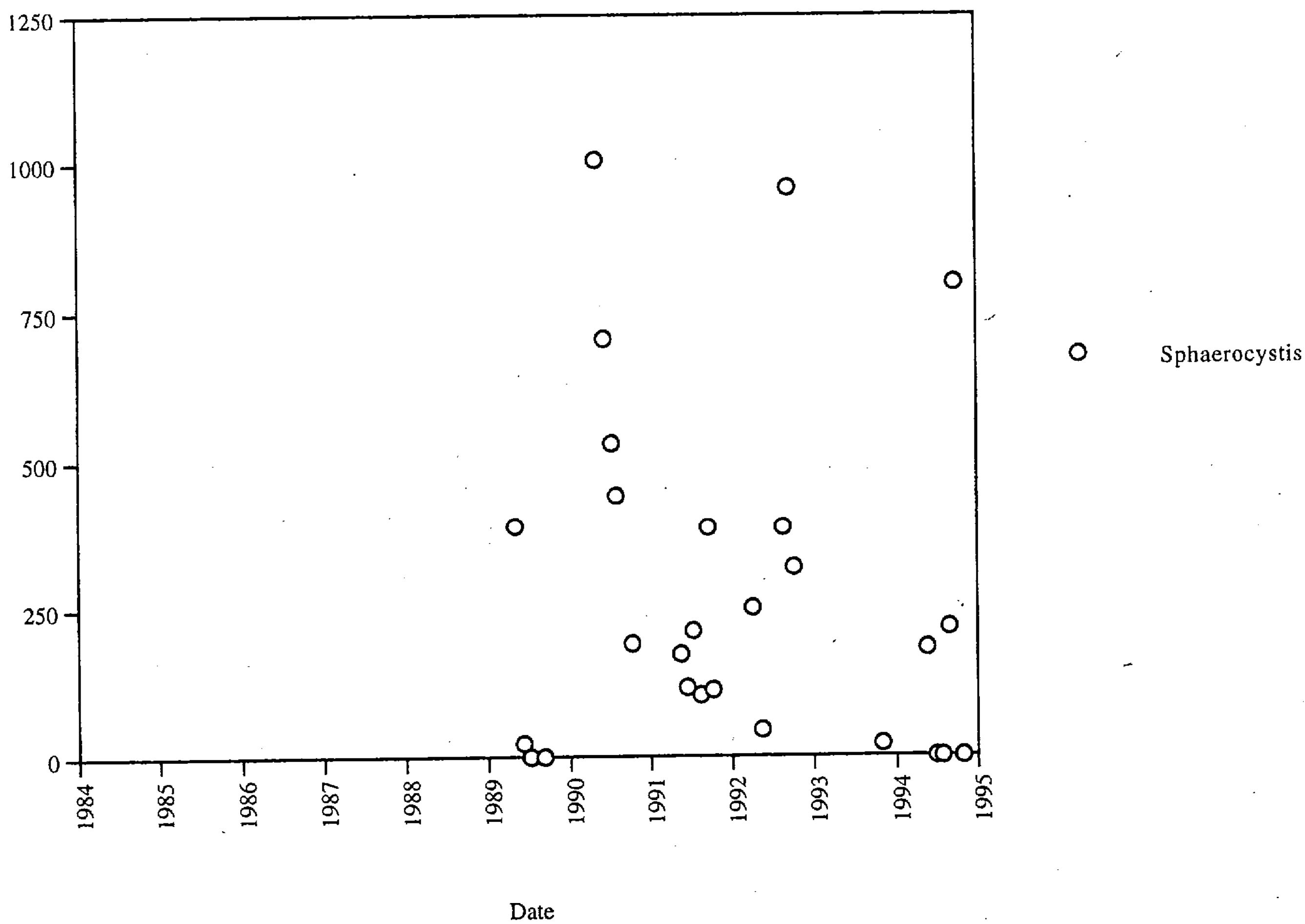


Figure 5.1.18. Old Wolf Lake Phytoplankton: Total Cells/mL

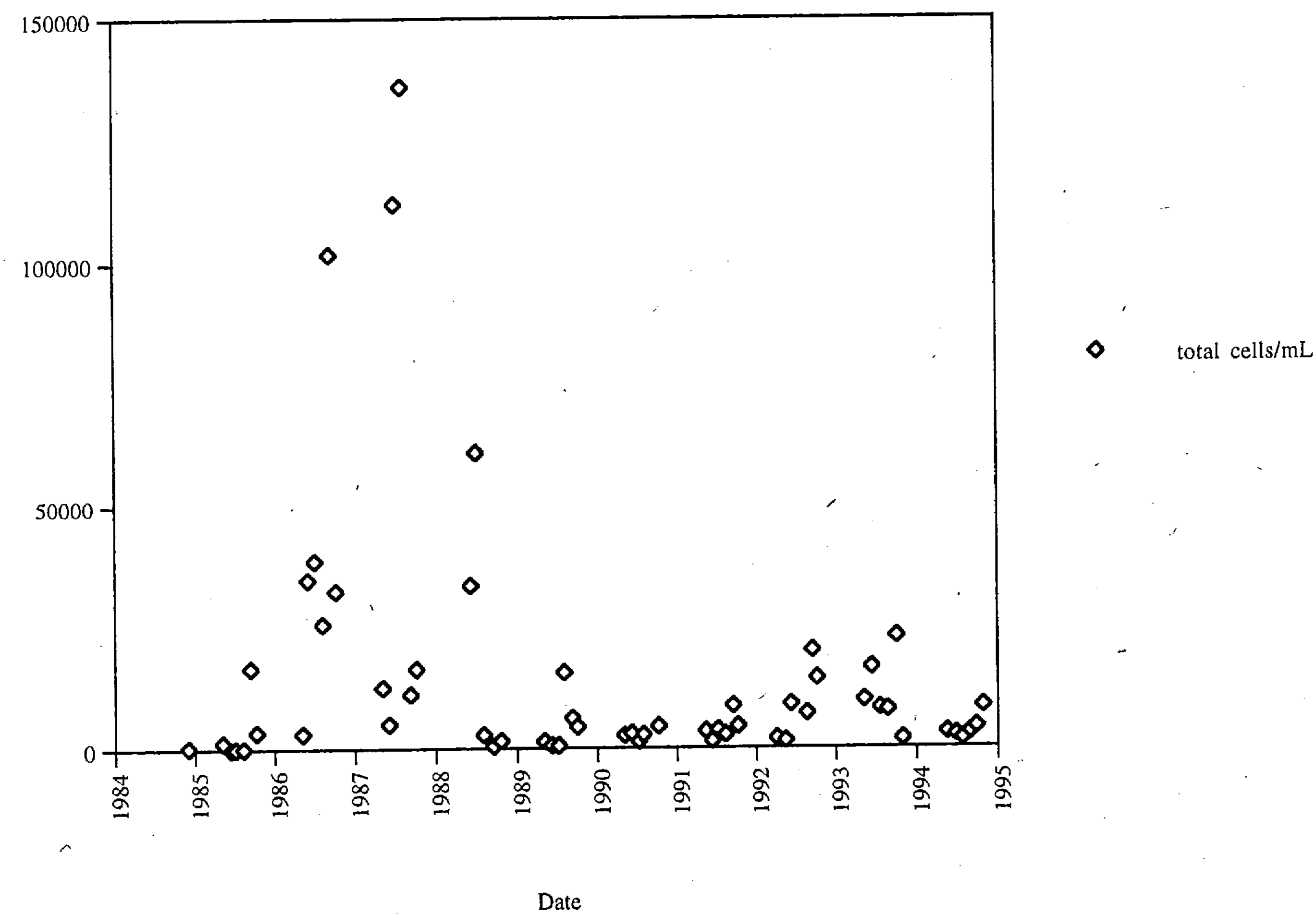


Figure 5.1.19. Old Wolf Lake Phytoplankton: Chlorophyll a, µg/L

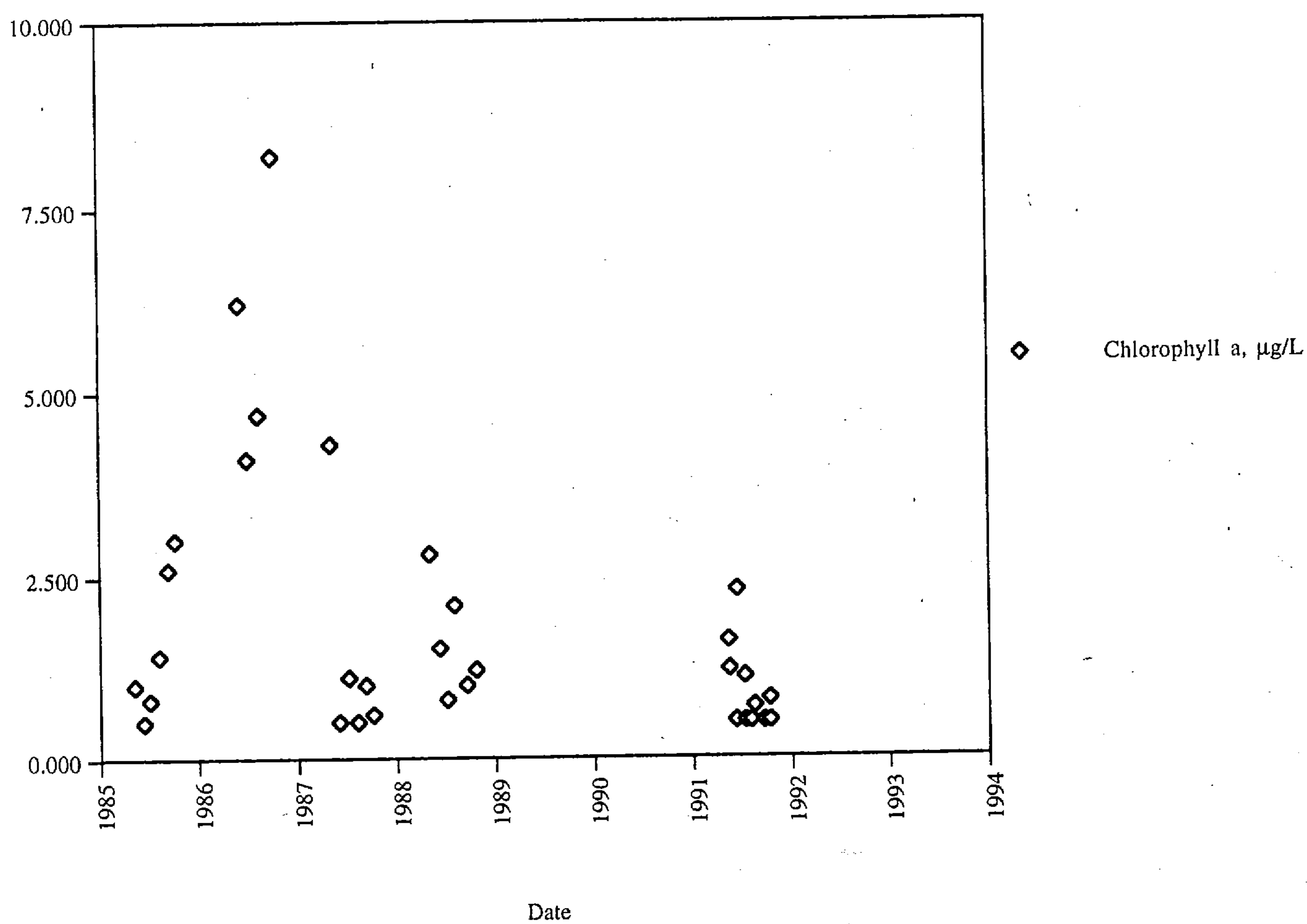


Figure 5.2.1. Old Wolf Lake Zooplankton: Diaptomus.

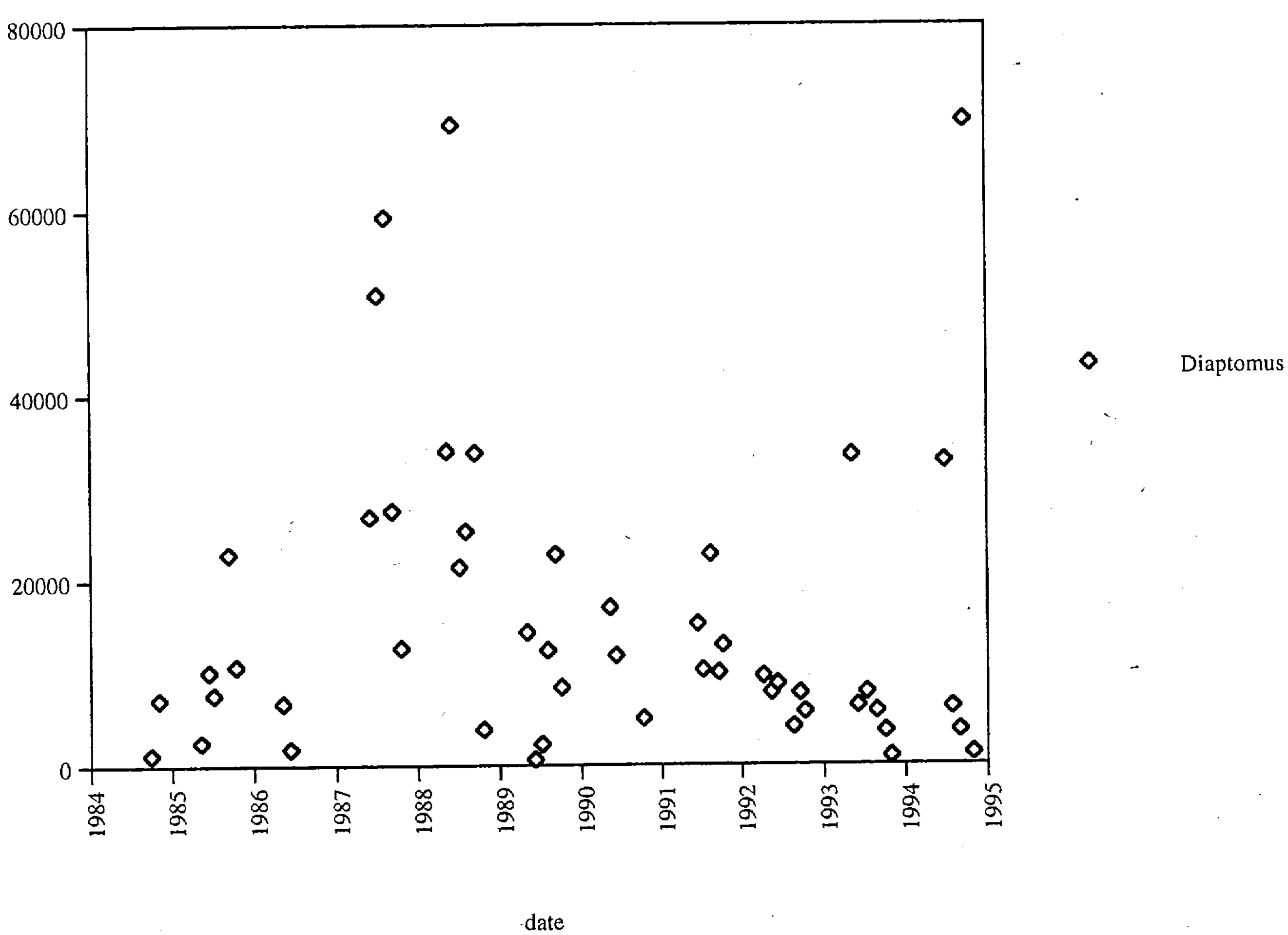


Figure 5.2.2. Old Wolf Lake Zooplankton: *Epishura/Cyclops/Diacyclops.*

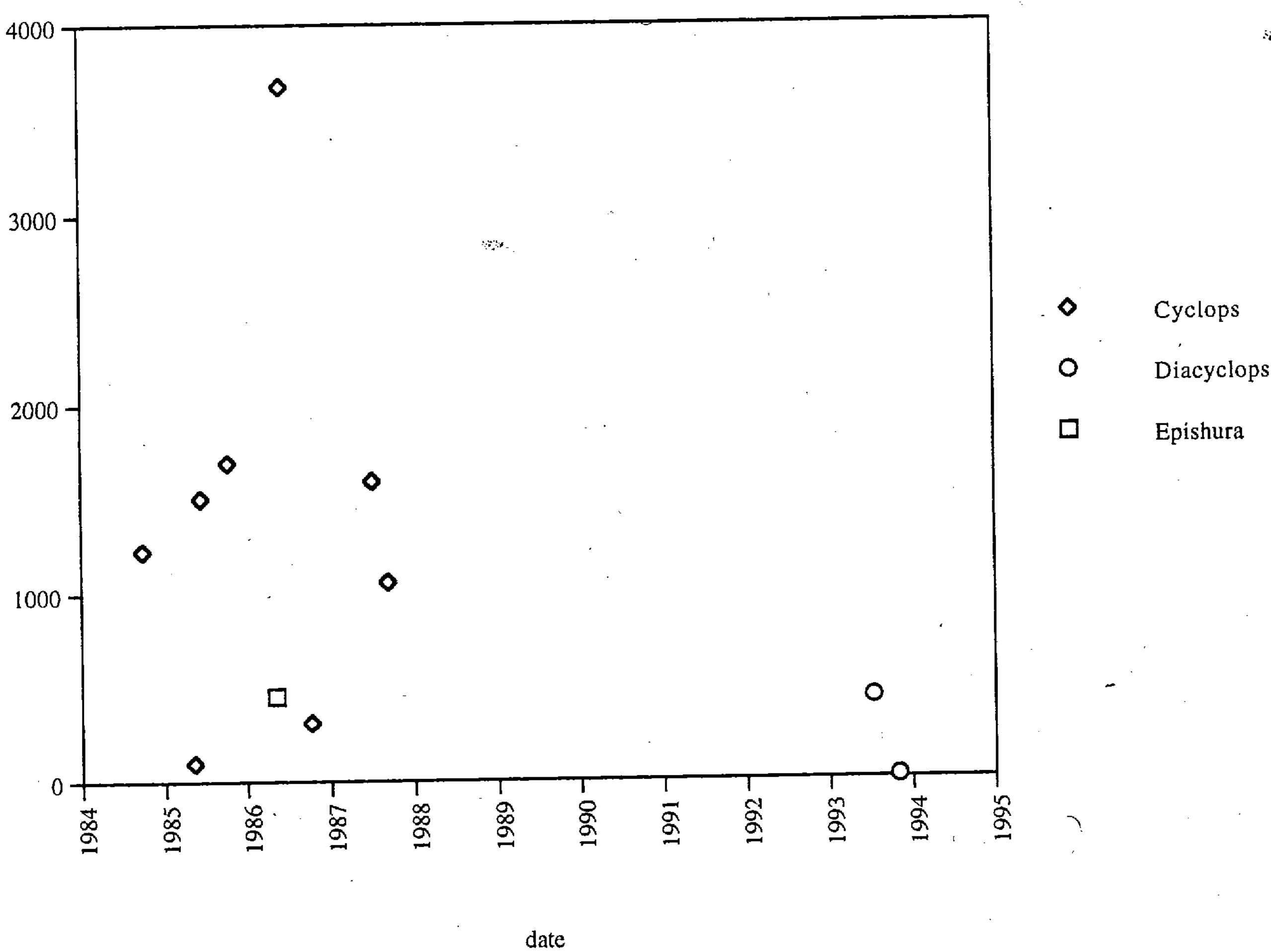


Figure 5.2.3. Old Wolf Lake Zooplankton: Copepodites/Nauplii.

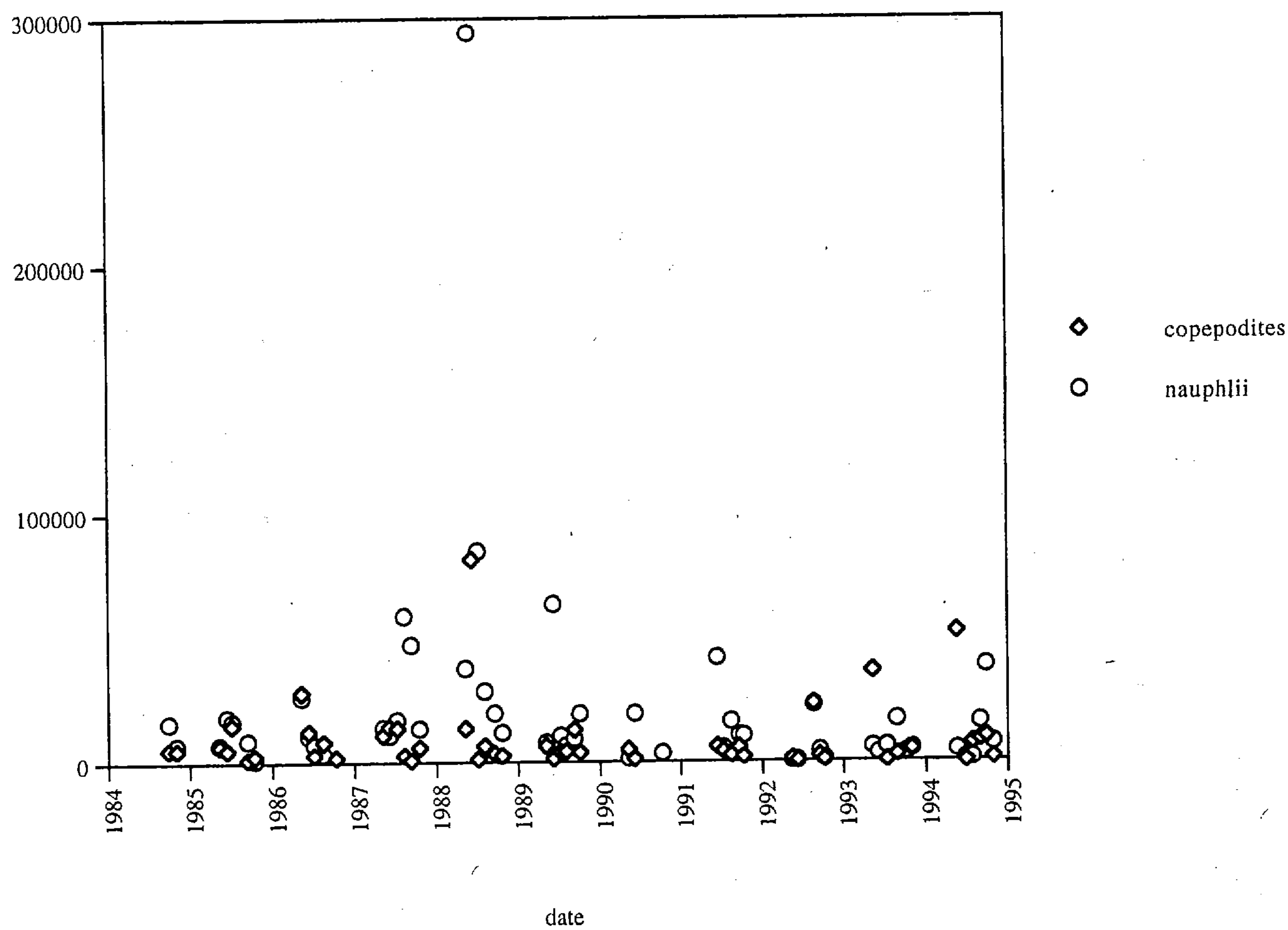


Figure 5.2.4. Old Wolf Lake Zooplankton: *Bosmina/Daphnia.*

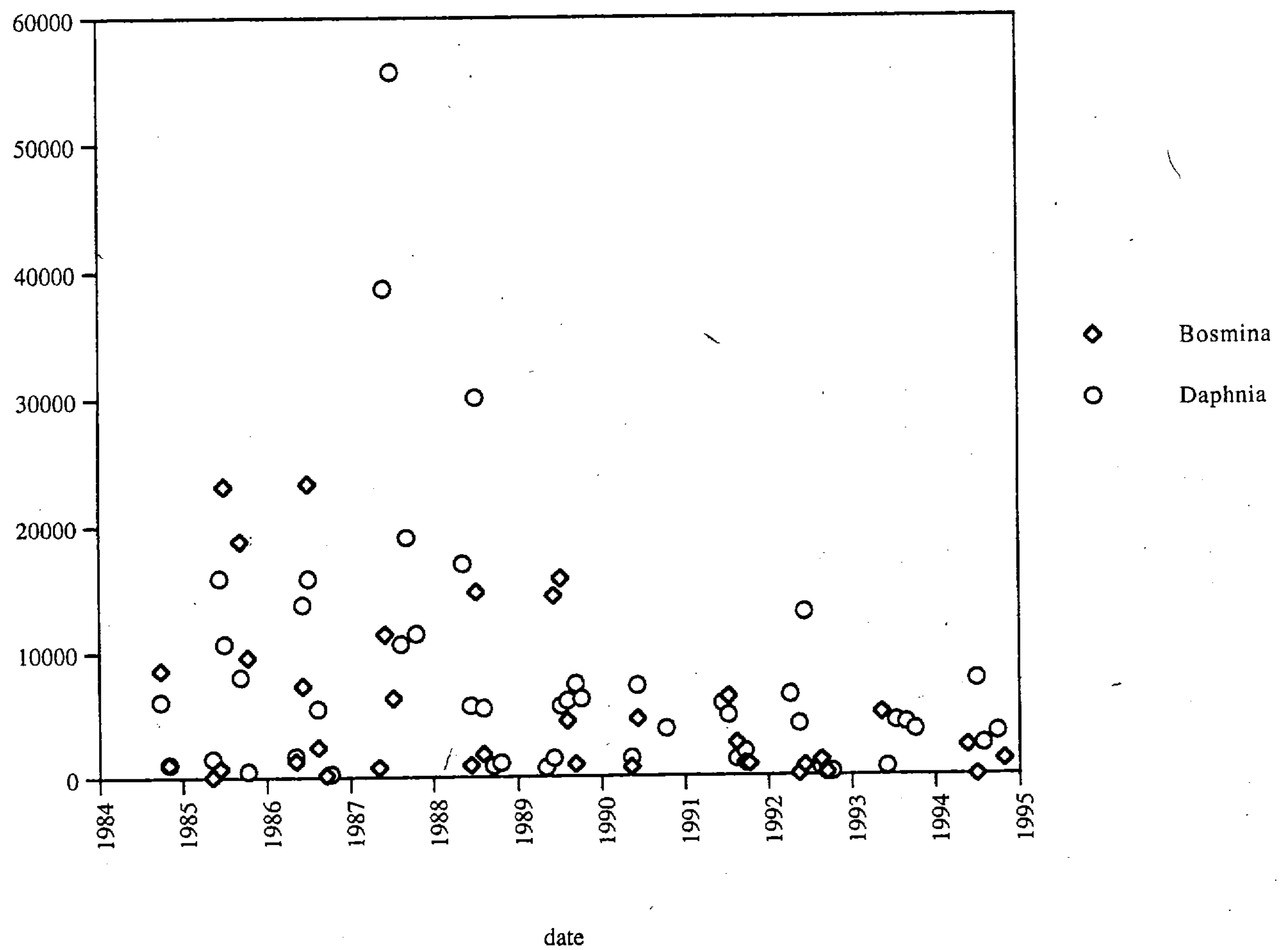


Figure 5.2.5. Old Wolf Lake Zooplankton: *Holopedium/Diaphanosoma.*

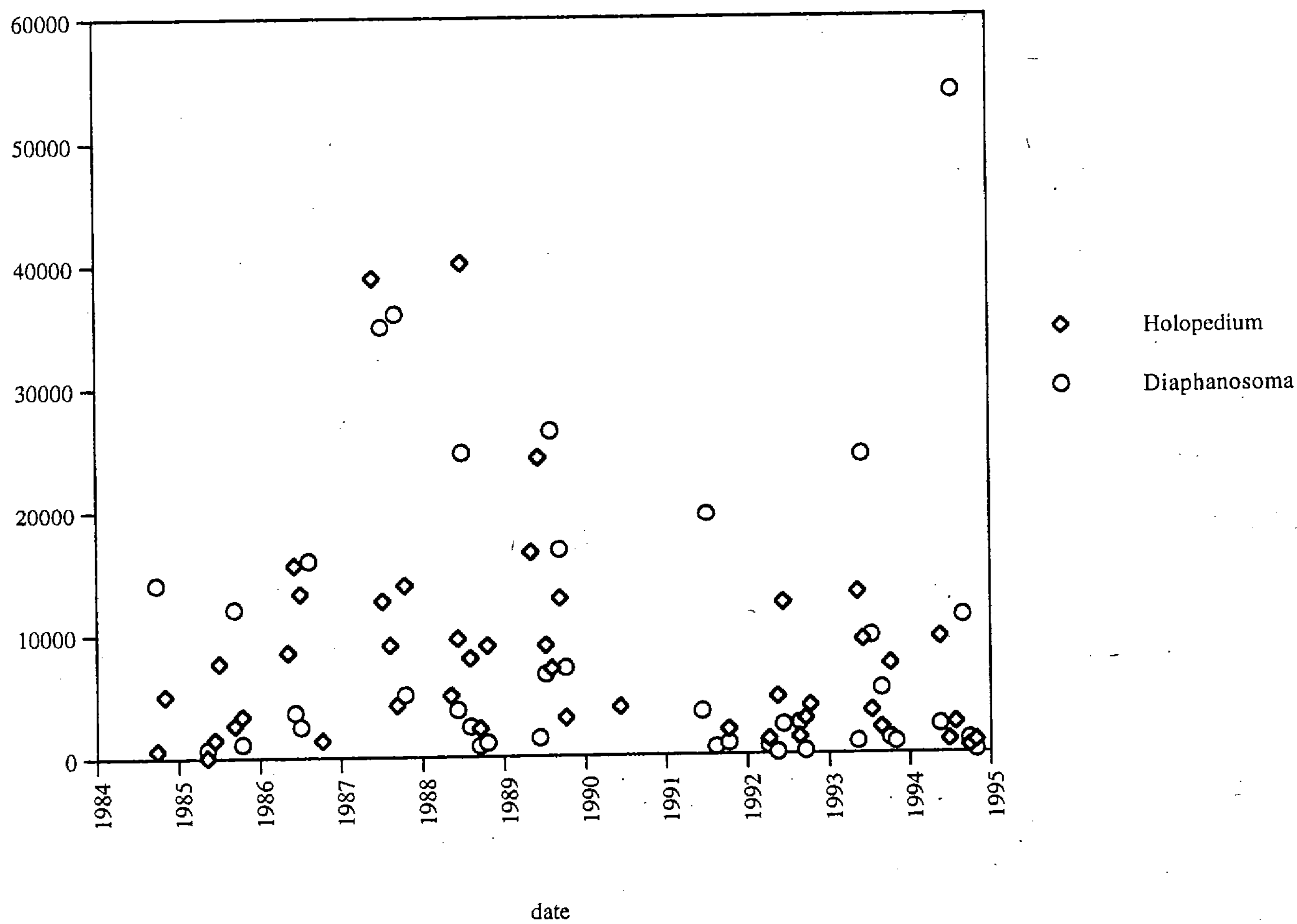


Figure 5.2.6. Old Wolf Lake Zooplankton: *Ceriodaphnia*.

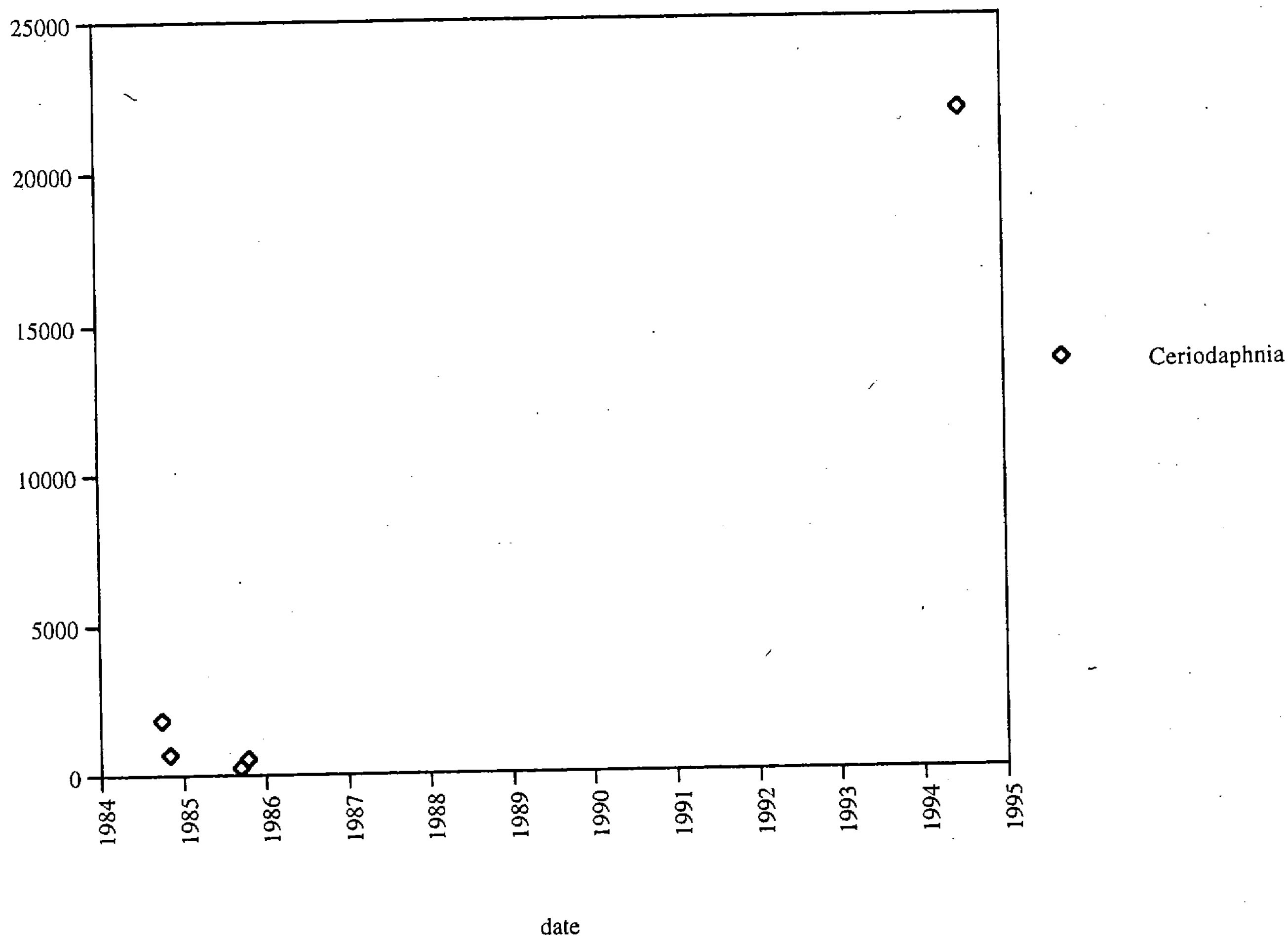


Figure 5.2.7. Old Wolf Lake Zooplankton: Kellicottia/Keratella.

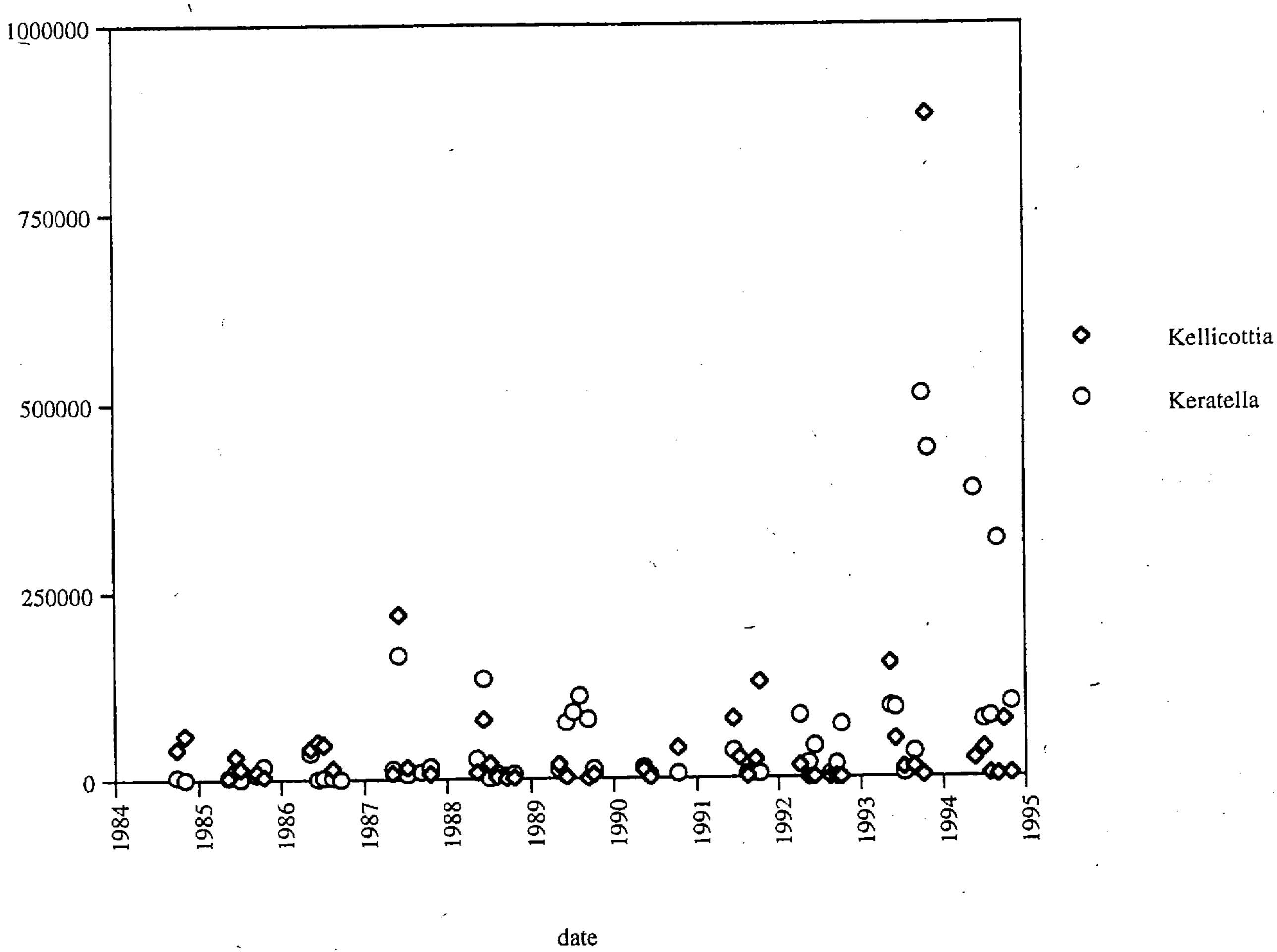


Figure 5.2.8. Old Wolf Lake Zooplankton: *Testudinella.*

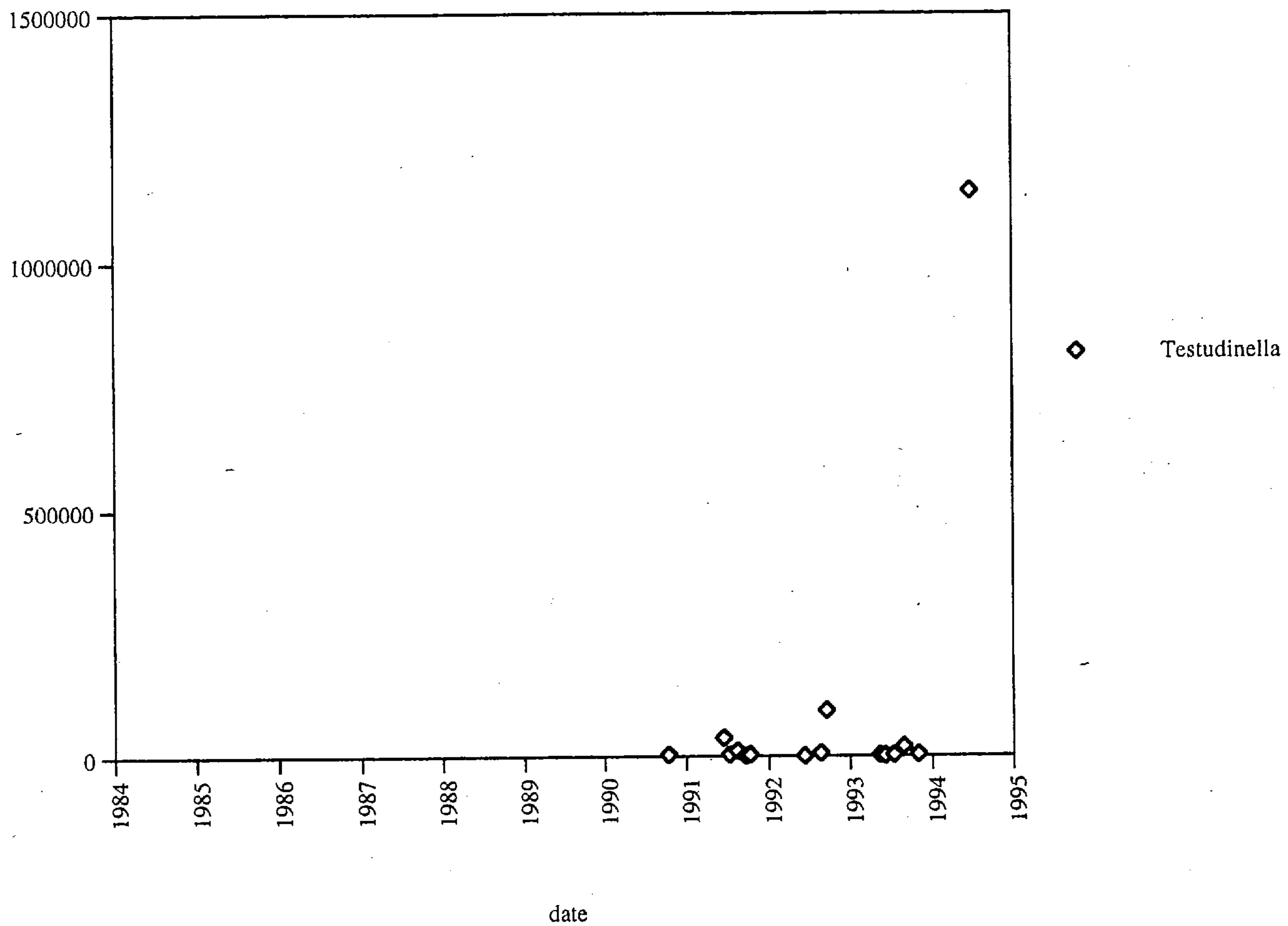


Figure 5.2.9. Old Wolf Lake Zooplankton: *Conochilus.*

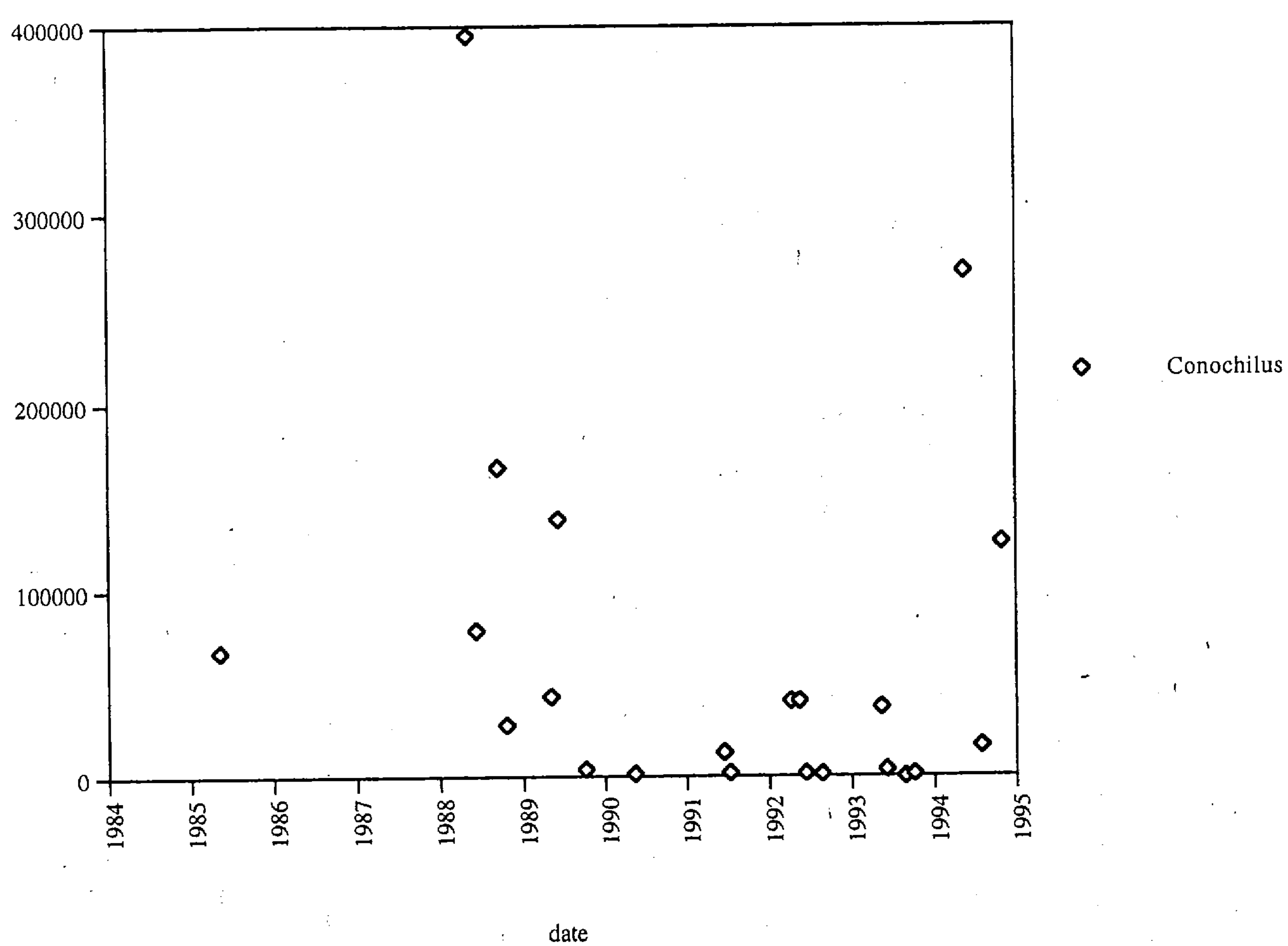


Figure 5.2.10. Old Wolf Lake Zooplankton: *Trichocera/Filinia.*

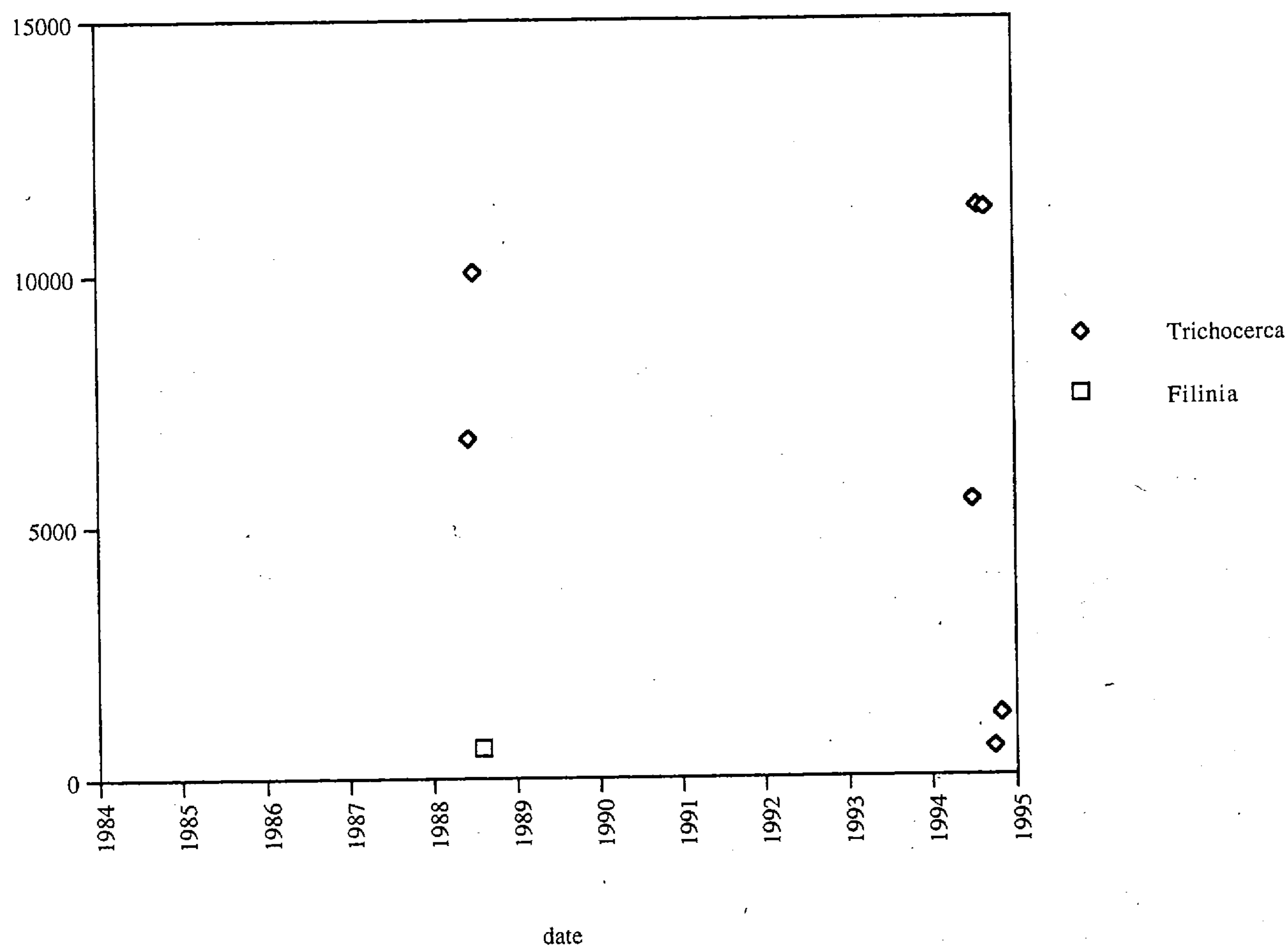


Figure 5.2.11. Old Wolf Lake Zooplankton: Rare Rotifers.

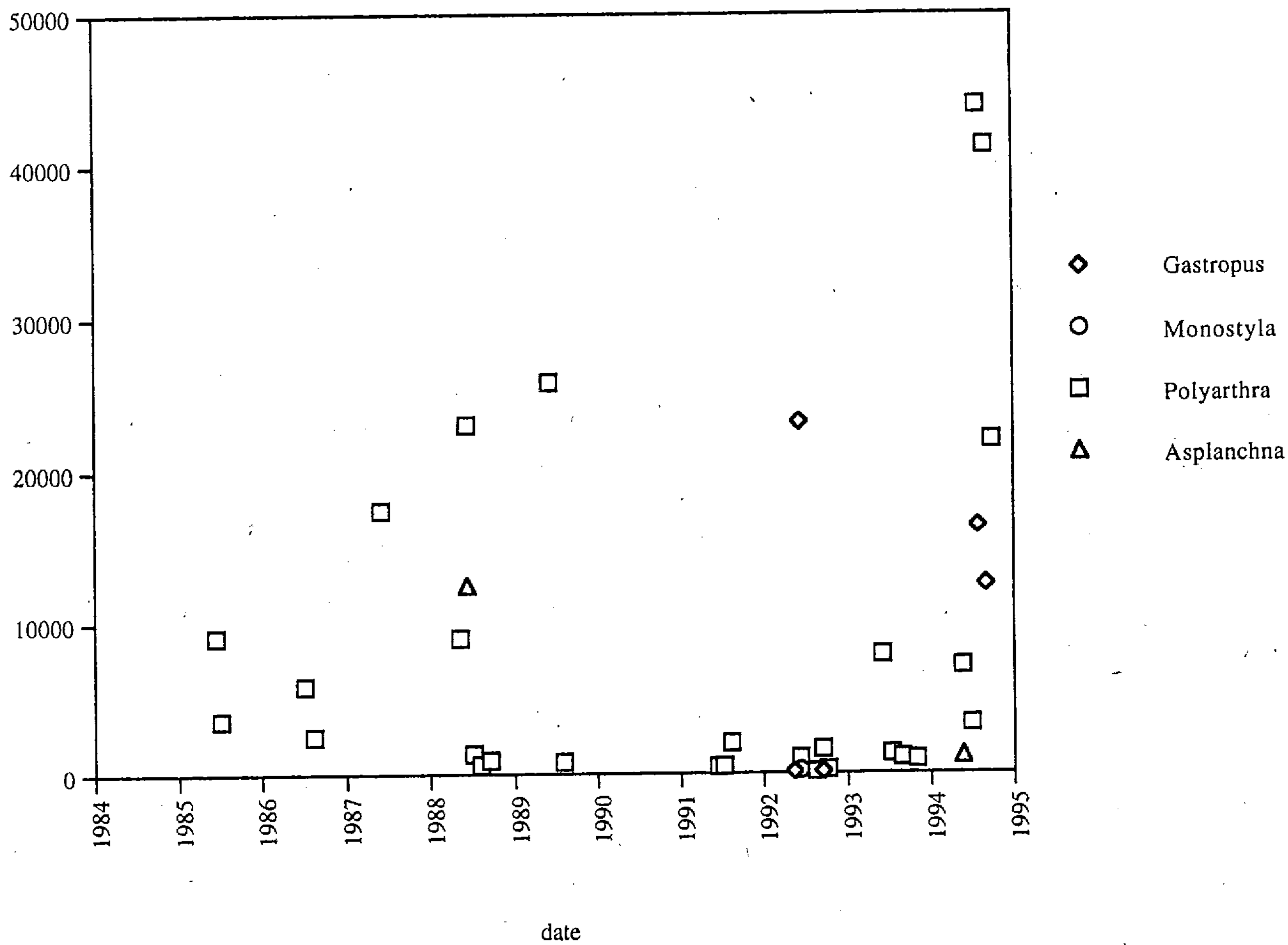


Figure 5.2.12. Old Wolf Lake Zooplankton: *Chaoborus*.

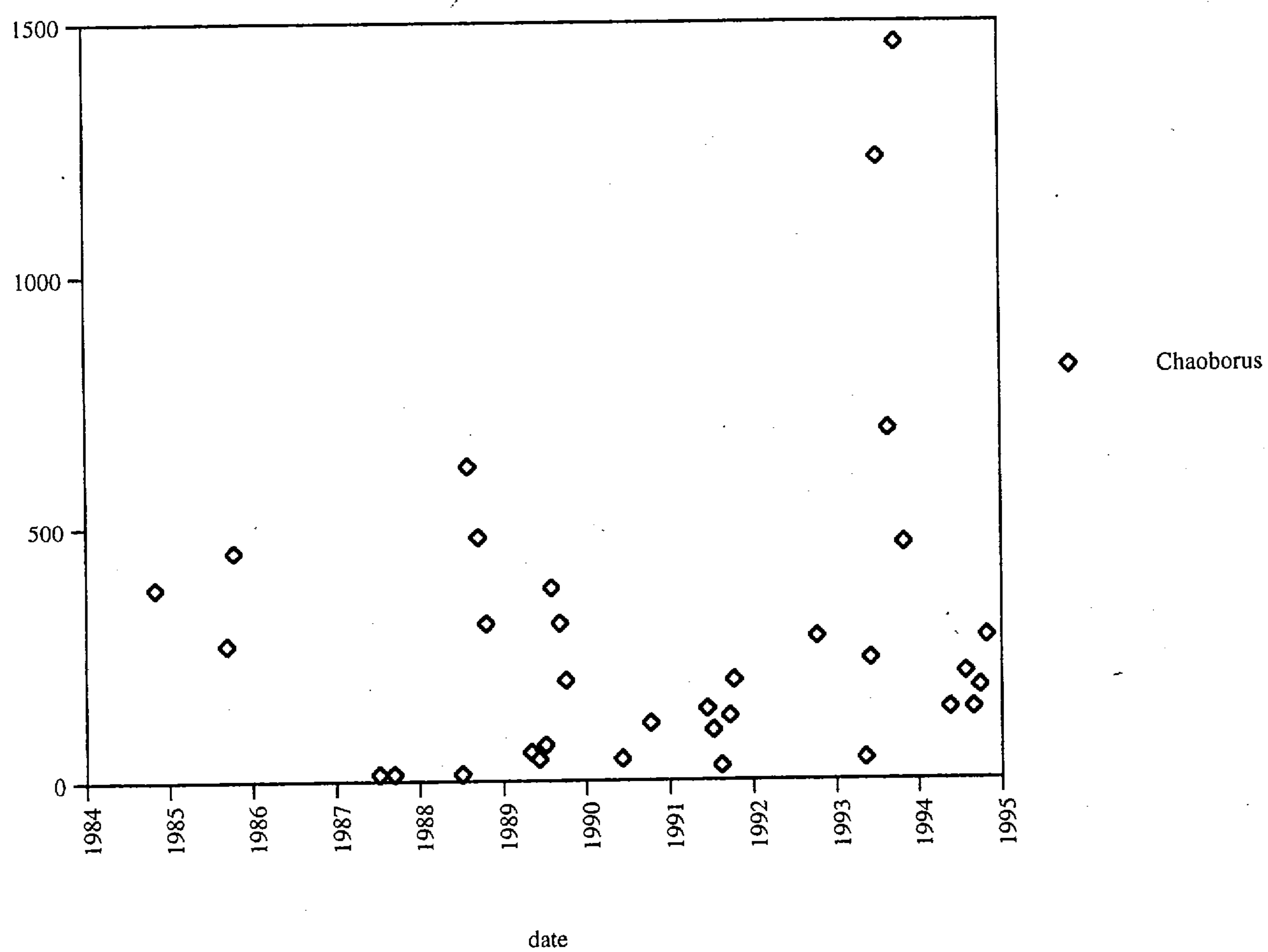


Figure 5.2.13. Old Wolf Lake Zooplankton: Total Animals/m2.

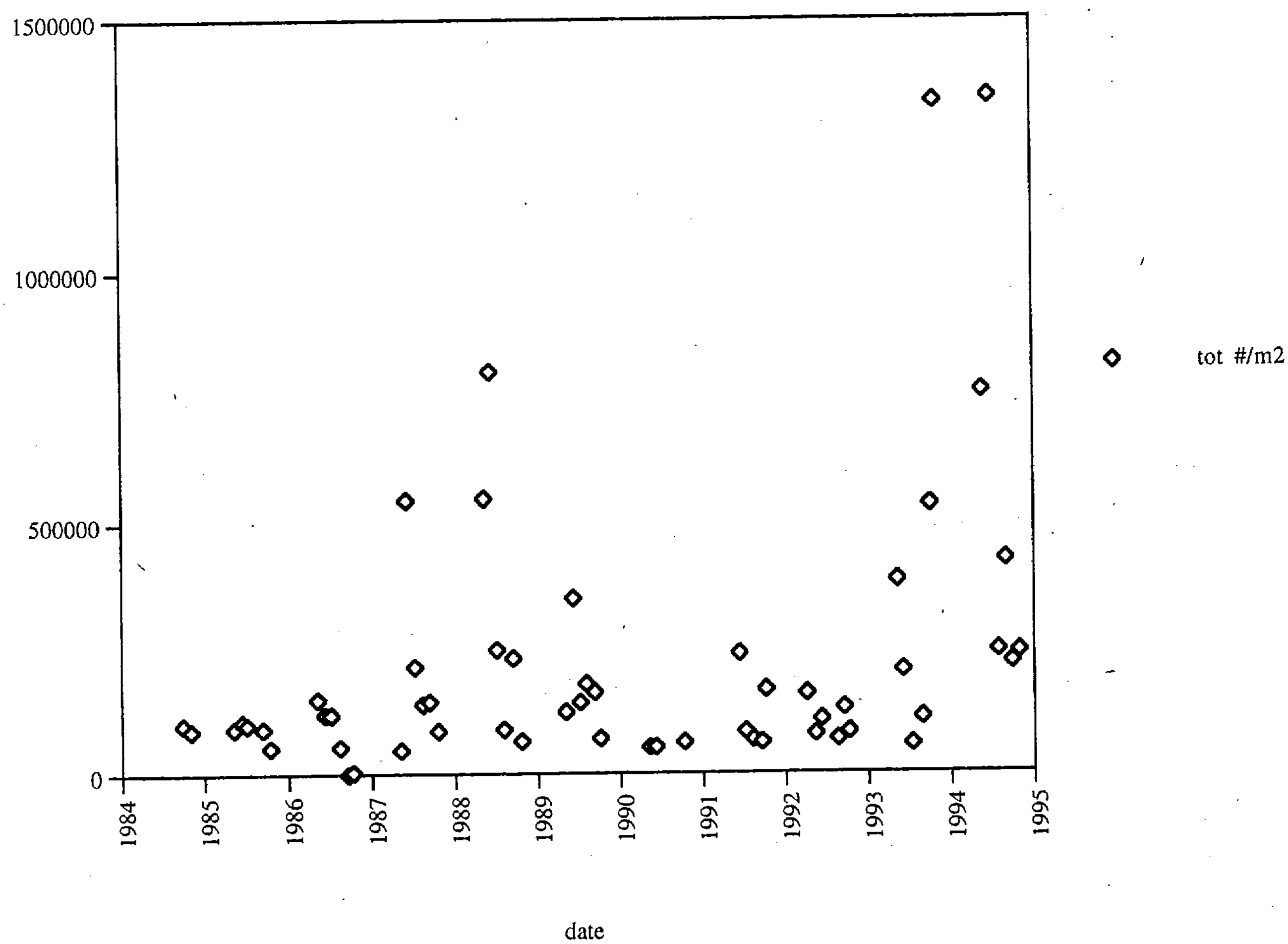


Figure 5.2.14. Old Wolf Lake Zooplankton: Biomass Comparisons.

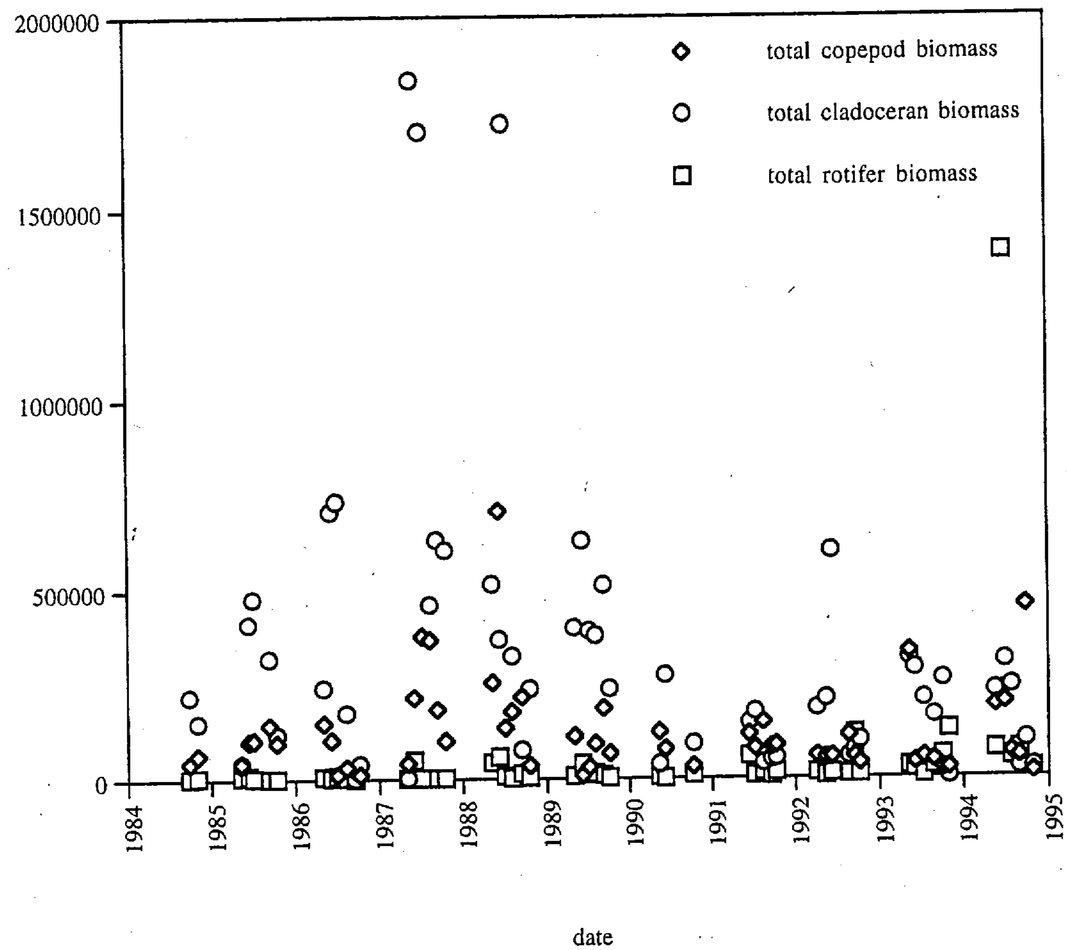
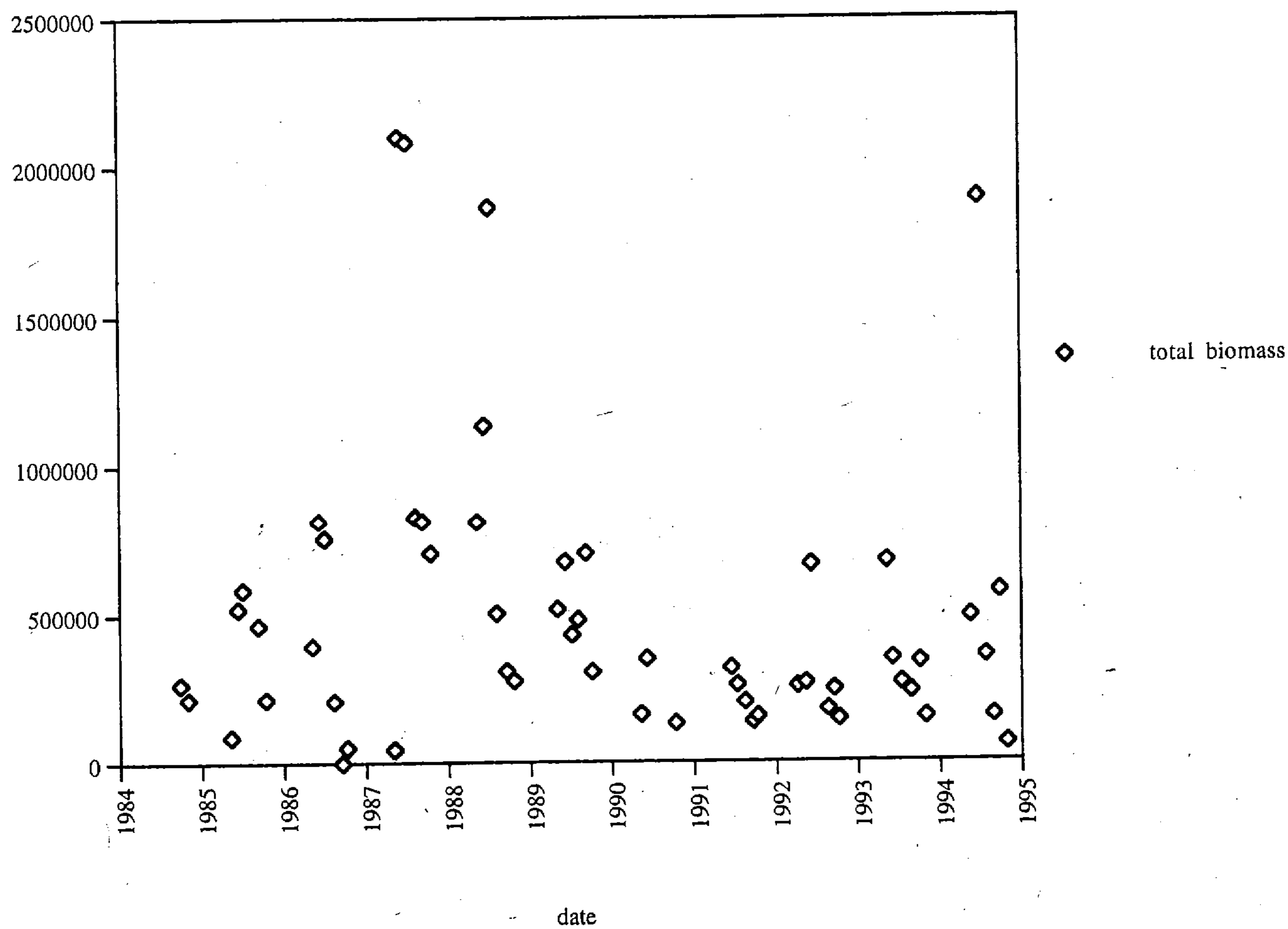


Figure 5.2.15. Old Wolf Lake Zooplankton: Total Zooplankton Biomass mg/m2



trend to increased concentrations.. *Mallomonas* shows no clear trend. *Oocystis* is present at low numbers from 1984 to 1986, then at elevated concentrations through 1990, then falling to previous levels. Three chrysophyte and one blue-green taxa show a similar pattern. These are *Elakothrix, Botryococcus, Quadrigula,* and *Chroococcus.* Other taxa that show bloom concentrations in this period are *Microcystis, Chrysosphaerella, Gomphosphaeria, Gloeocystis,* and *Aphanothece.* These taxa are graphed in figures 6.1.1 to 6.1.14. *Sphaerocystis* (Figure 6.1.6) appears at low concentrations in 1988, then increases in number and is present in 94% of the 1989-1992 samples at a mean concentration of 138.5 cells/mL. This is the same pattern *Sphaerocystis* exhibits in Old Wolf, Maxwell, and Stocking lakes.

One interesting correlation observed involves the appearance of *Euglena* (Figure 6.1.15) in every sample taken in 1990, coincident with a sharp decline in total cells/mL concentration for that year (Figure 6.1.16). *Euglena* was not recorded from any other sample taken from Spectacle. *Euglena* is generally regarded as very tolerant of reduced water quality, in particular high organic carbon and low dissolved oxygen (Schubert, 1984). Given this relationship a possible explanation for both the drop in numbers of other algae and its appearance may be the occurrence of an event that reduced the quality of water in Spectacle. More evidence would be provided by increases in other tolerant genera, but none are notable. *Anabaena* does show a small increase during this period, but this is inconclusive.

The chlorophyll data for Spectacle is incomplete, with no values available for 1984, 1989, or 1992 (Figure 6.1.17). The values that are available do not correlate well with the total cells/mL data, and some years they seem to be inversely proportional. Overall chlorophyll appears to decrease, while the total cells/mL data show an increase. Total numbers of phytoplankton and chlorophyll a values are summarised in tables 6.1.2 and 6.1.3.

6.2. Zooplankton

Twenty one zooplankton genera are identified in Spectacle Lake between 1984 and 1992 (Appendix 9). Four copepod genera are reported, of which only *Diaptomus* occurs consistently (Figure 6.2.1) throughout the period of sampling. *Diaptomus* occurs at low concentrations in 1986 and 1989, a pattern exhibited to varying degrees by other taxa. *Cyclops* appears at low concentrations in 1985 and 1986, Higher concentrations in 1988, then declines again in 1990 and 1991. *Epishura* and *Diacyclops* are also reported

(Figure 6.2.2). Copepodite and nauplii stages are consistently present, with copepodites occurring at higher numbers in 1988 and 1989 (Figure 6.2.3).

The cladoceran community is dominated by *Daphnia*, which is present in concentrations above 10,000/m^2 most years. A decline in numbers of *Daphnia* is evident during 1986 and 1990 to 1992 (Figure 6.2.4). *Holopedium* and *Bosmina* are present in significant concentrations as well. No clear trends are evident, although *Holopedium* is absent during 1991 and 1992, *Bosmina* shows a reduced occurrence in 1986, and both trend towards higher numbers in 1987 (Figure 6.2.5). *Diaphanosoma* is reported several times, and shows high concentrations in 1989, a year that most taxa exhibit a decline in numbers (Figure 6.2.6). *Alonella* is reported twice in 1988 at very low concentrations.

Kellicottia and *Keratella* are the most consistent of the nine rotifer genera reported, *Keratella* showing higher concentrations most years (Figure 6.2.7). Both of these seem to show reduced concentrations and occurrence in 1986 and 1990, similar to the pattern noted above, and both seem to decline in numbers over the eight year period. This is opposite to the trend shown by the other rotifer genera, most of which first appear in 1988 and then show increases in occurrence and/or concentration. The dynamics of this group are displayed in figures 6.2.8 and 6.2.9

Spectacle Lake has the highest occurrence of *Chaoborus* next to Old Wolf. It is present in at least one sample each year except 1984 and 1987, and was recorded in every sample taken in 1991 (Figure 6.2.10).

The zooplankton biomass as measured by total number of individuals/m^2 seems to decline slightly over the study period (Figure 6.2.11). A marked decline in total numbers is observed in 1986 and 1990, which is consistent with the pattern noted above. Biomass estimates show a similar decline and, to a lesser degree, the two noted reductions (Figure 6.2.12). Analysis of biomass by class reveals that the cladoceran community is the majority contributor, with the copepods and rotifers accounting for much less of the estimated dry weight. The increase in total numbers of rotifers is evident as well, with the rotifers contributing more biomass than the copepods in one sample collected in 1991 and another in 1992 (Figure 6.2.13).

	Dominant	Sub-dominant	% presence	mean conc. cells/mL
Chrysophyte	*Dinobryon*		96	220.60
	Mallomonas		83	32.04
Cryptophyte	*Cryptomonas*		87	36.62
	Chroomonas		85	66.69
Chlorophyte	*Oocystis*		83	19.81
		Elakothrix	72	10.63
		Sphaerocystis	63	138.89
		Crucigenia	63	32.86
		Quadrigula	63	20.25
		Botryococcus	52	116.75
		Gloeocystis	50	44.59
Cyanophyte	*Merimopoedia*		83	3524.94
		Anabaena	56	16.57
		Chroococcus	52	49.31
Diatom		*Navicula*	67	4.95
		Achnanthes	67	3.50
		Tabellaria	56	1.14
		Cymbella	54	0.83

Table 6.1.1. Spectacle Lake Phytoplankton: Dominant and Sub-dominant taxa.

Year	n	mean	maximum	minimum	# of samples
1985	235356	2674	234000	.001	6
1986	41	0.50	4.56	.001	4
1987	29	0.29	22.62	.001	6
1988	450	4.24	236	.001	6
1989	5497	40.71	2271	.001	6
1990	11069	106.43	5343	.001	6
1991	5931	49.94	4130	.001	6
1992	7057	63.00	2593	.001	6
1993	1498	14.00	347	.001	6

Table 6.1.2. Spectacle Lake Phytoplankton: Summary of total numbers of phytoplankton/mL by year.

year	mean	maximum	minimum
1985	3.43	7.7	0.6
1986	3.98	4.9	2.3
1987	0.91	1.5	0.5
1988	1.41	3.1	0.5
1990	2.21	5.9	0.5
1991	1.26	2.9	0.9

Table 6.1.3. Spectacle Lake Phytoplankton: Mean and range of Chlorophyll a measurements by year in µg/L.

Figure 6.1.1. Spectacla Lake Phytoplankton: *Dinobryon.*

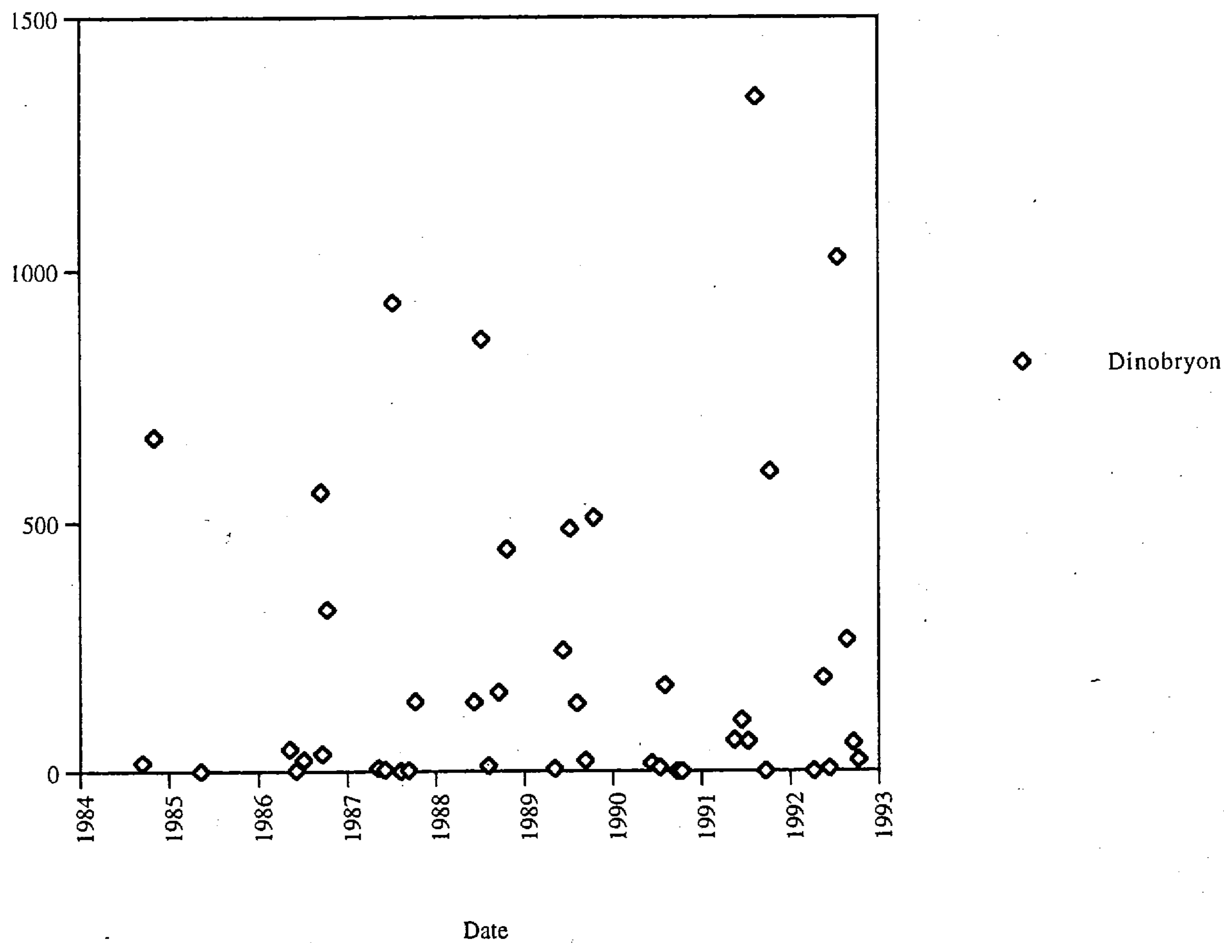


Figure 6.1.2. Spectacla Lake Phytoplankton: *Merismopedia.*

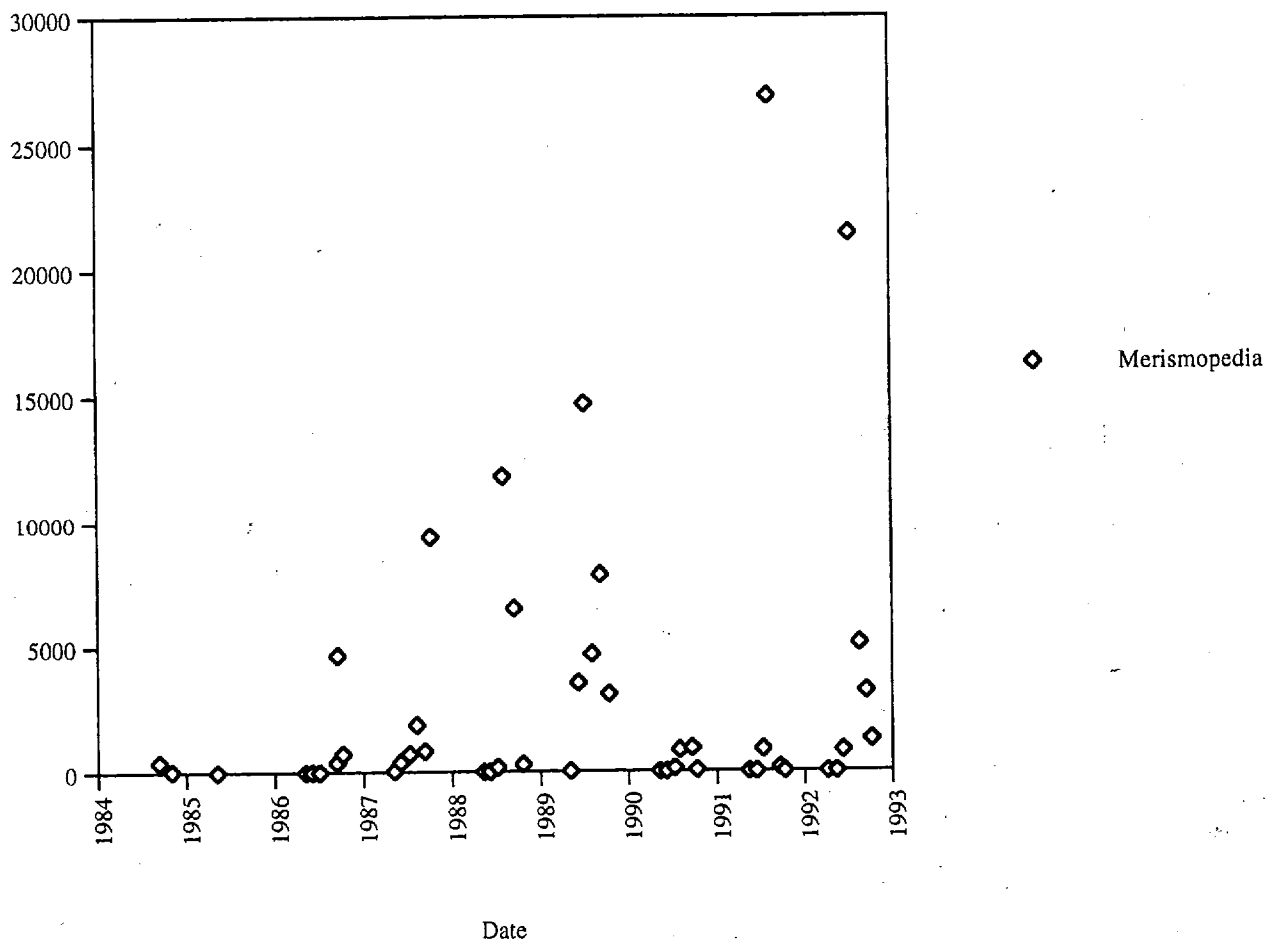


Figure 6.1.3. Spectacla Lake Phytoplankton: *Cryptomonas/Oocystis.*

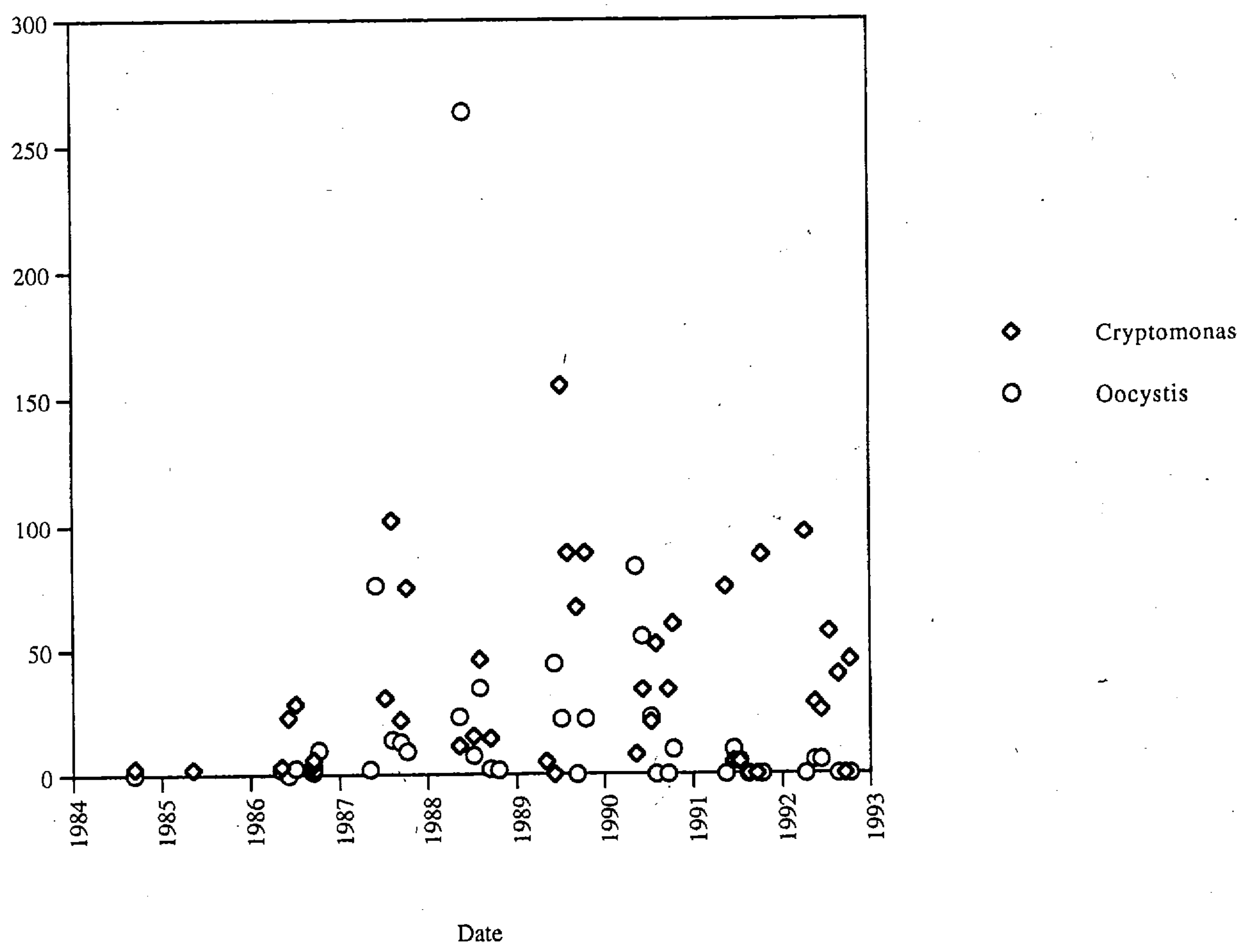


Figure 6.1.4. Spectacla Lake Phytoplankton: *Mallomonas/Chroomonas.*

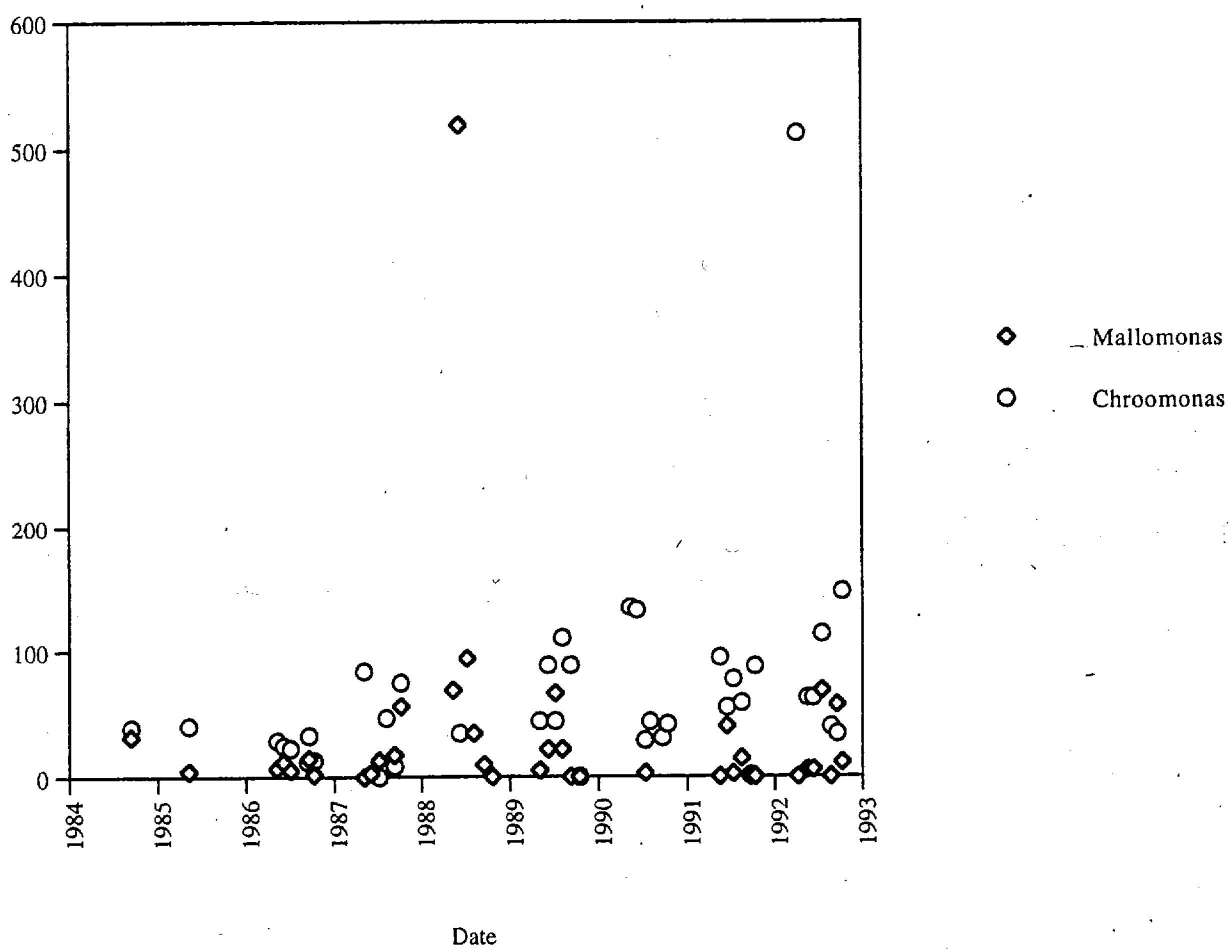


Figure 6.1.5. Spectacla Lake Phytoplankton: *Elakothrix.*

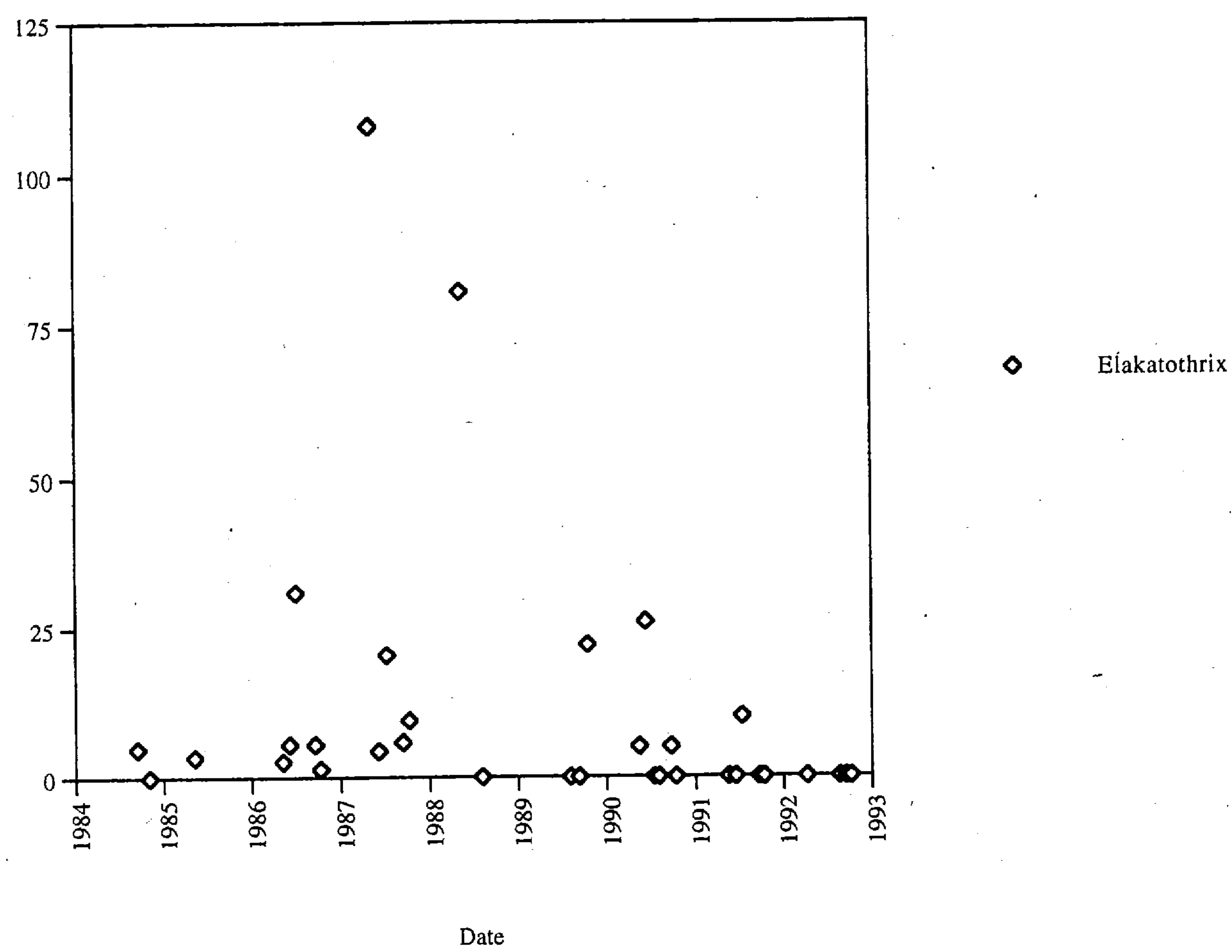


Figure 6.1.6. Spectacla Lake Phytoplankton: *Sphaerocystis/Gloeocystis/Botryococcus.*

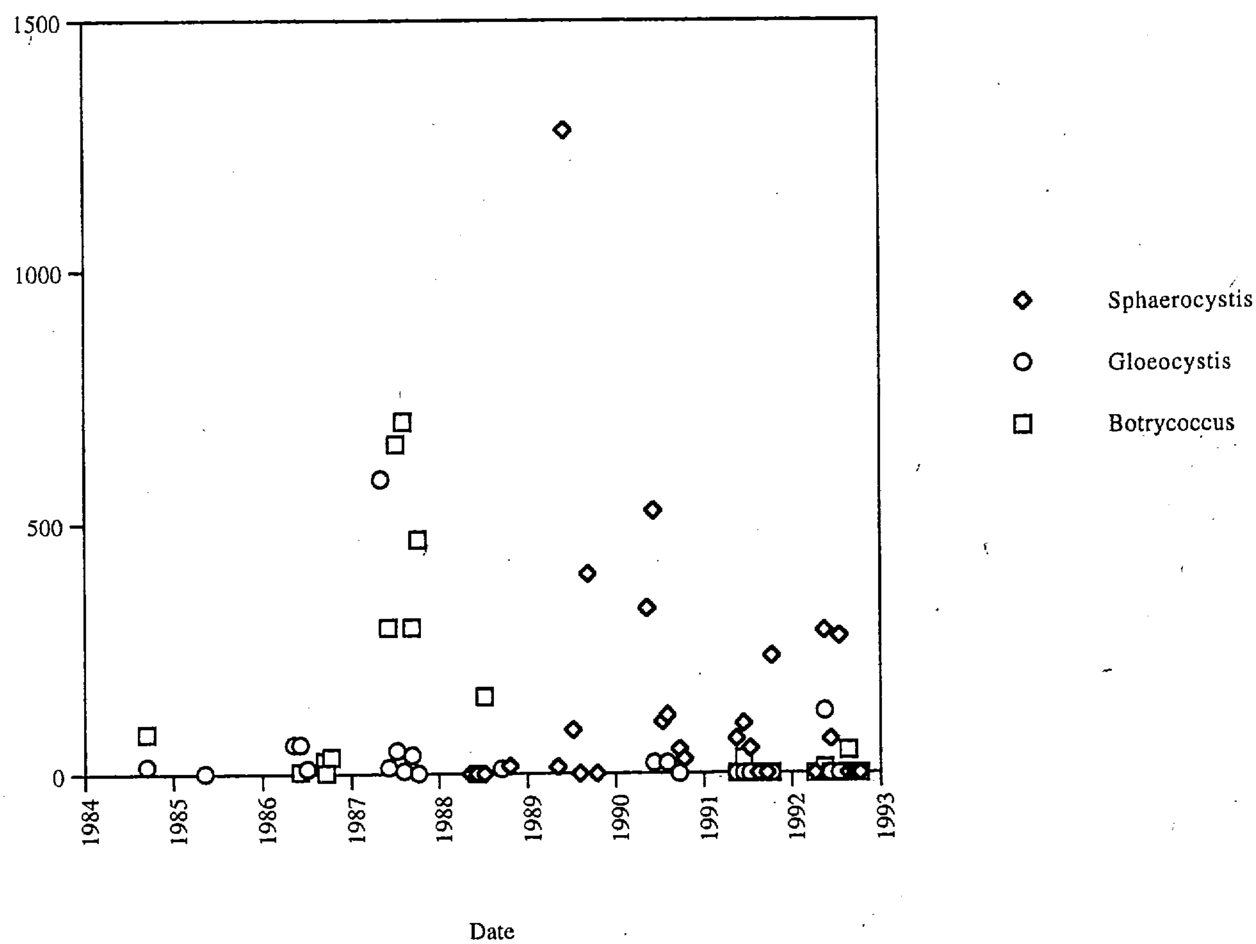


Figure 6.1.7. Spectacla Lake Phytoplankton: *Crucigenia/Quadrigula.*

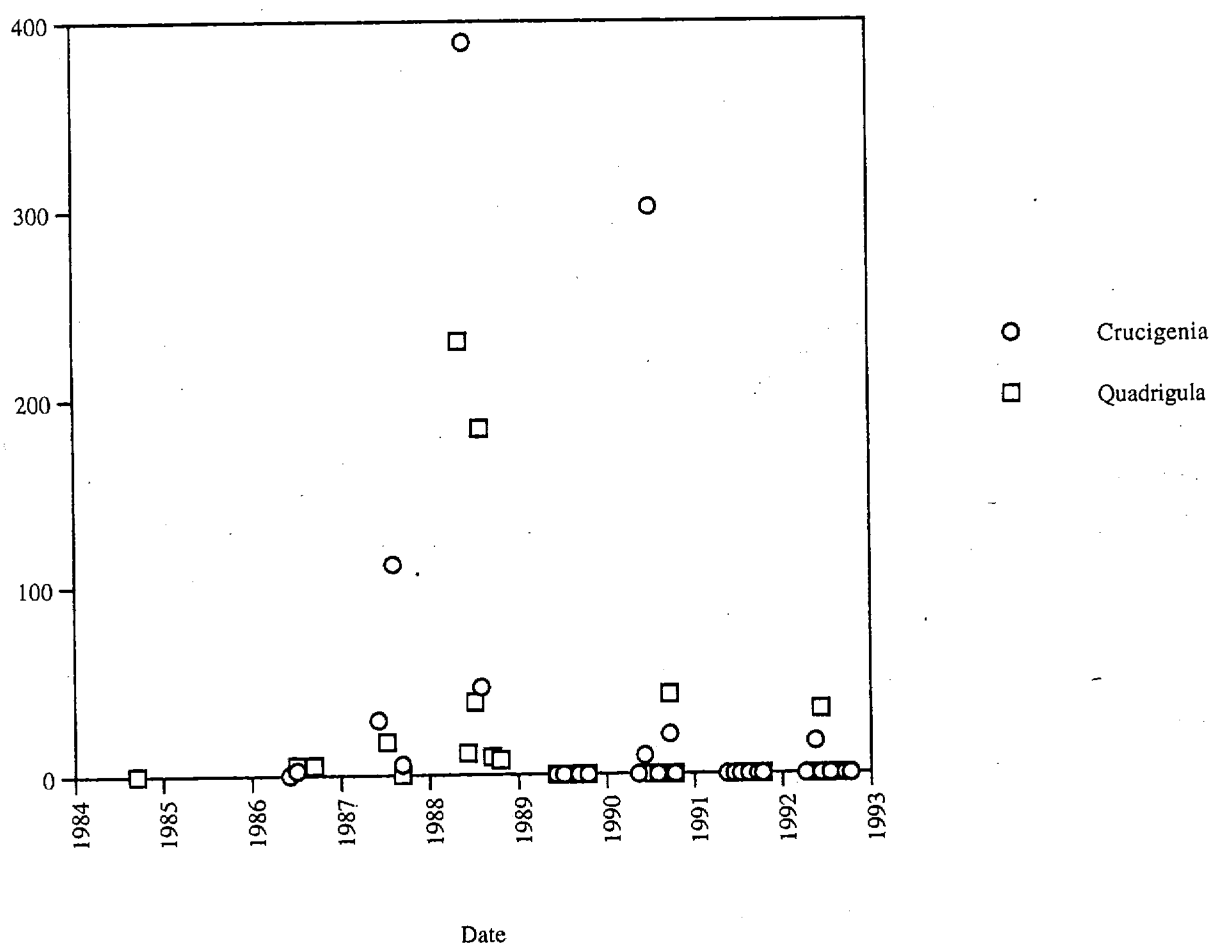


Figure 6.1.8. Spectacle Lake Phytoplankton: *Chroococcus.*

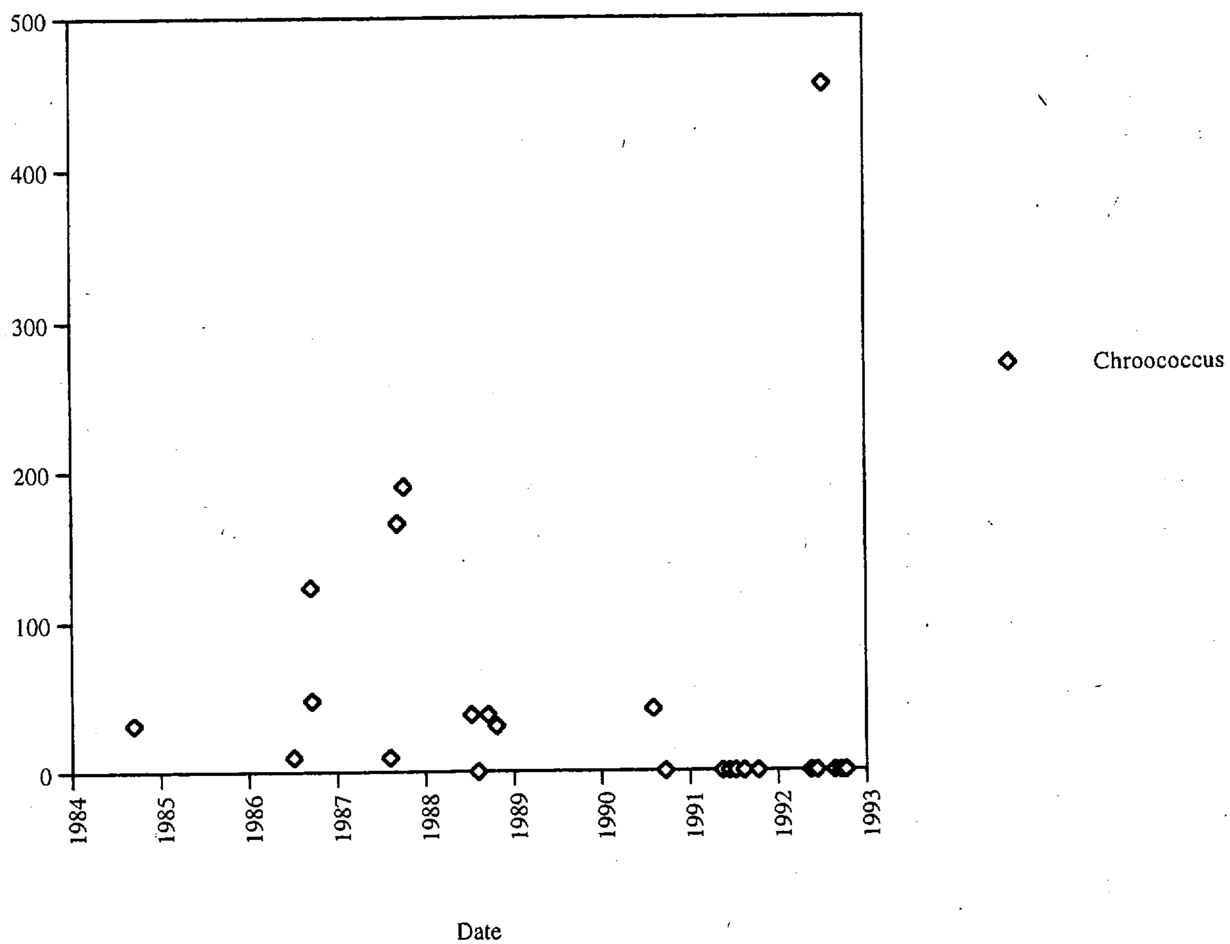


Figure 6.1.8. Spectacle Lake Phytoplankton: *Gomphosphaeria.*

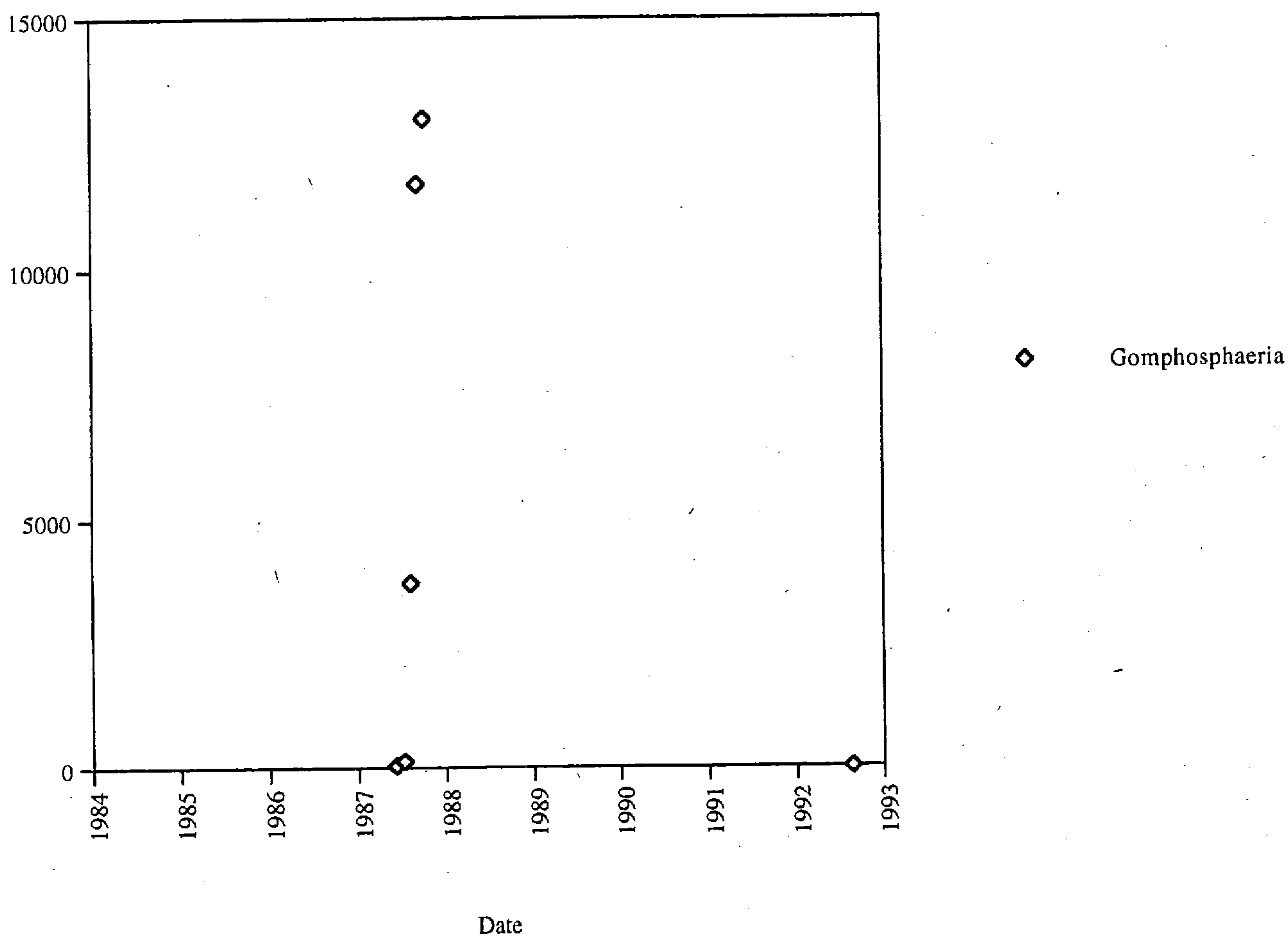


Figure 6.1.10. Spectacle Lake Phytoplankton: *Achnanthes/Navicula*..

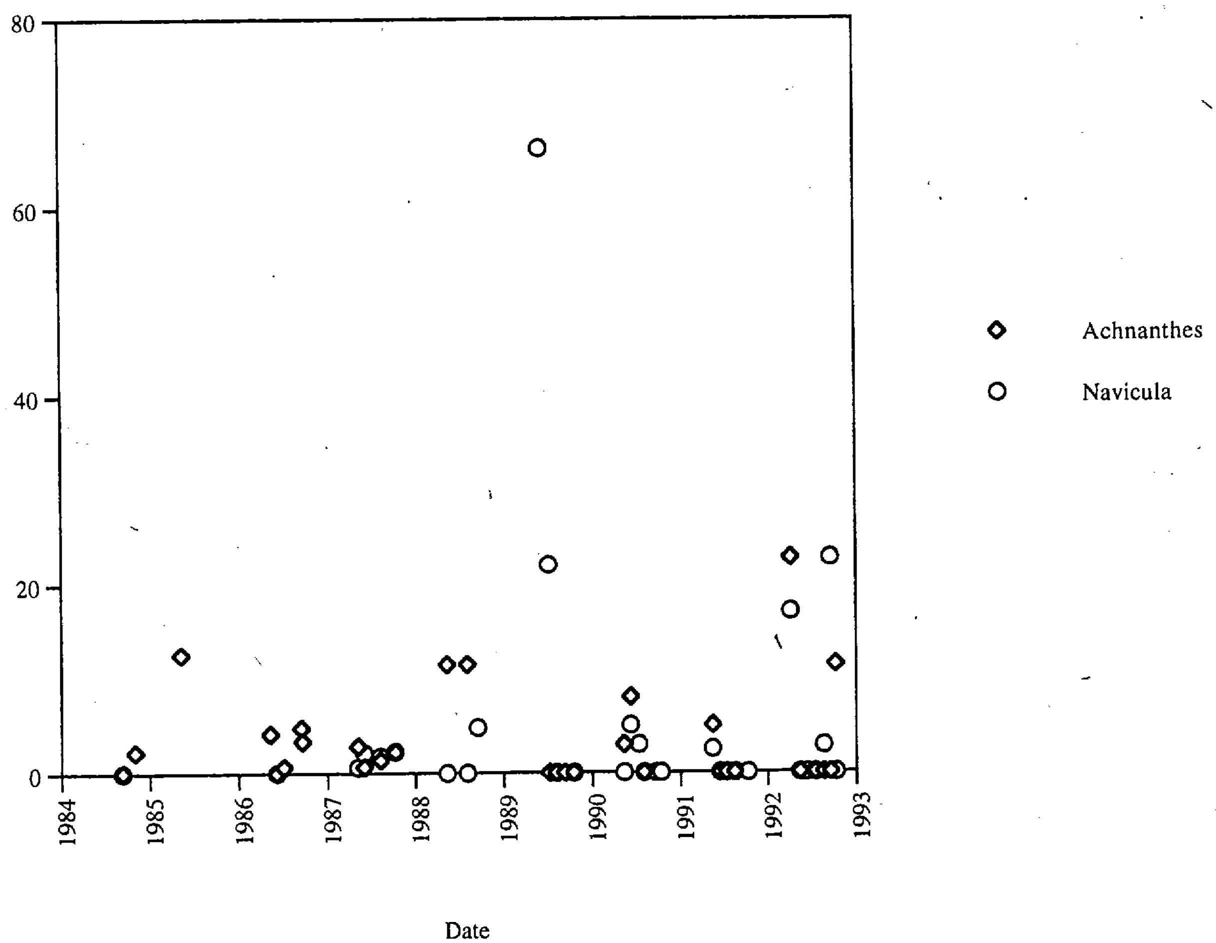


Figure 6.1.11. Spectacle Lake Phytoplankton: *Cymbella/Tabellaria.*

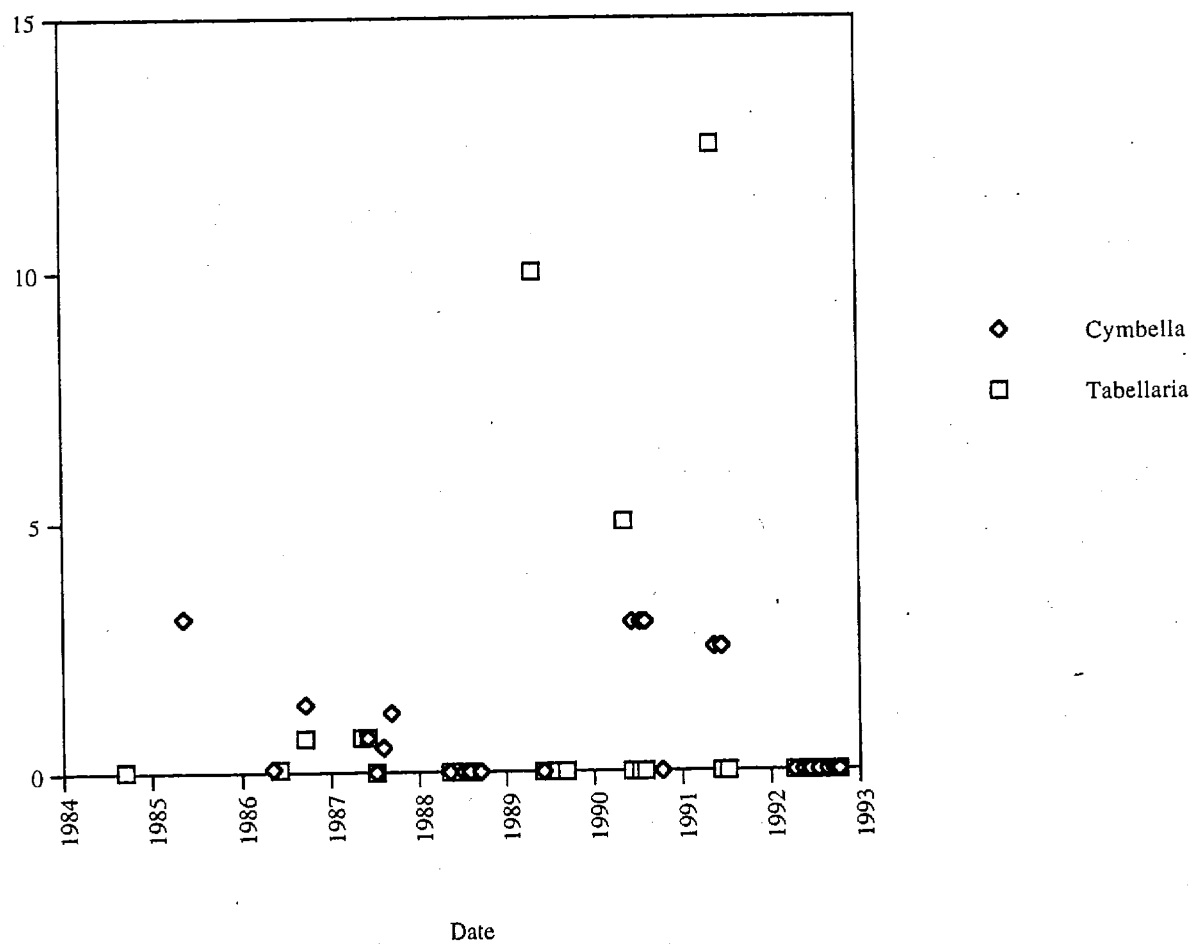


Figure 6.1.12. Spectacle Lake Phytoplankton: *Chrysosphaerella*.

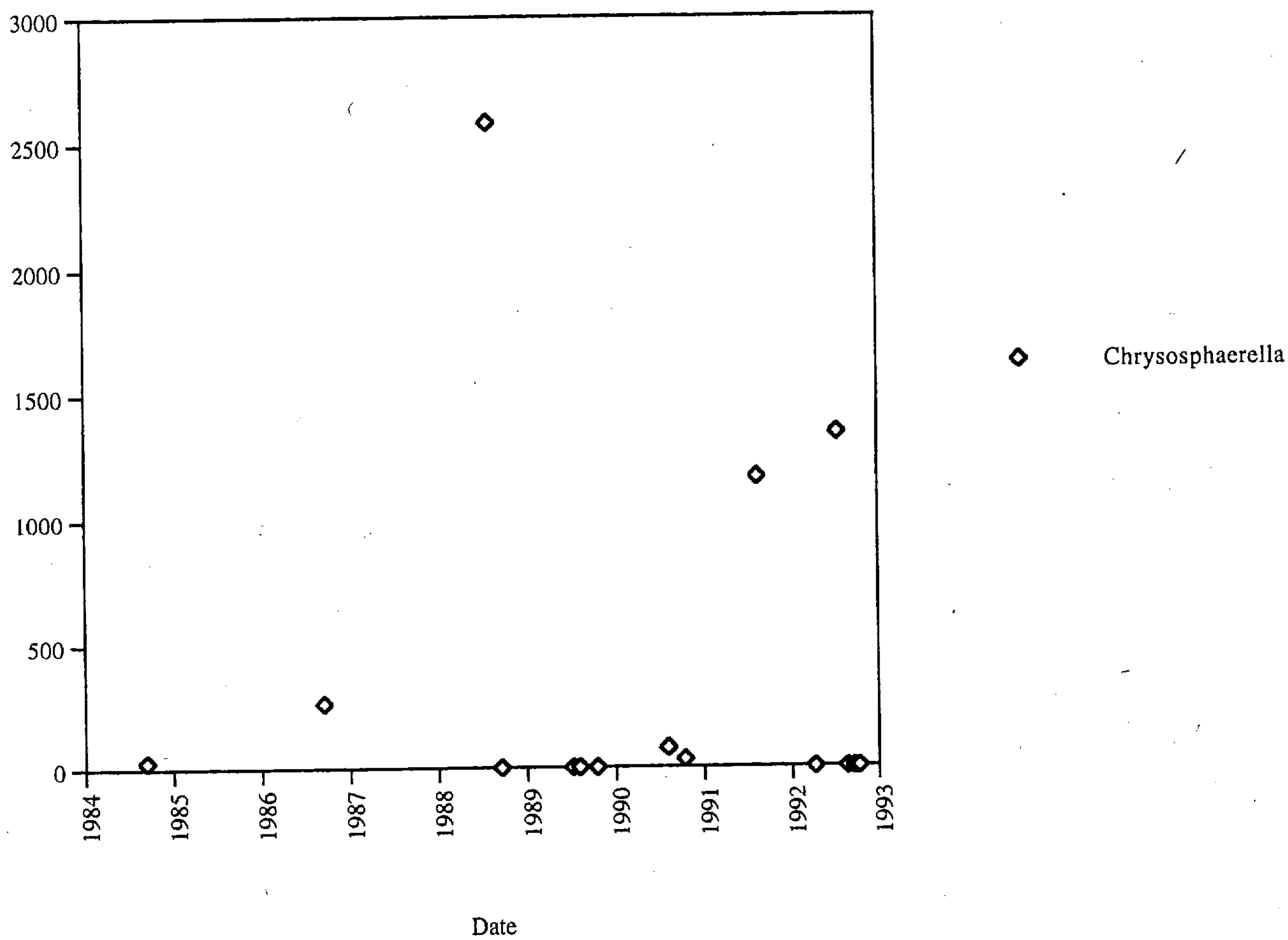


Figure 6.1.13. Spectacle Lake Phytoplankton: *Synura/Microcystis/Cyclotella.*

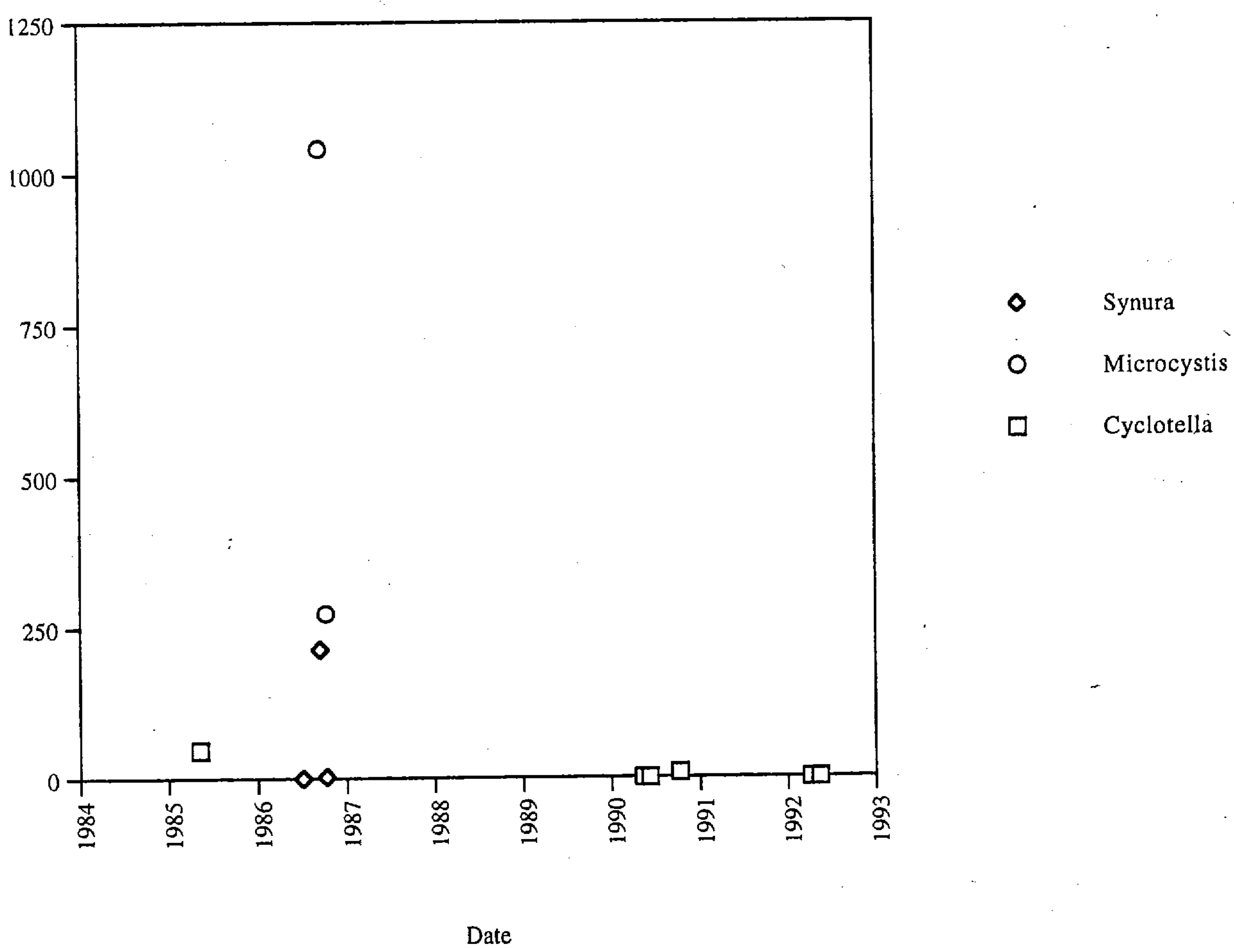


Figure 6.1.14. Spectacle Lake Phytoplankton: *Aphanothece/Aphanocapsa.*

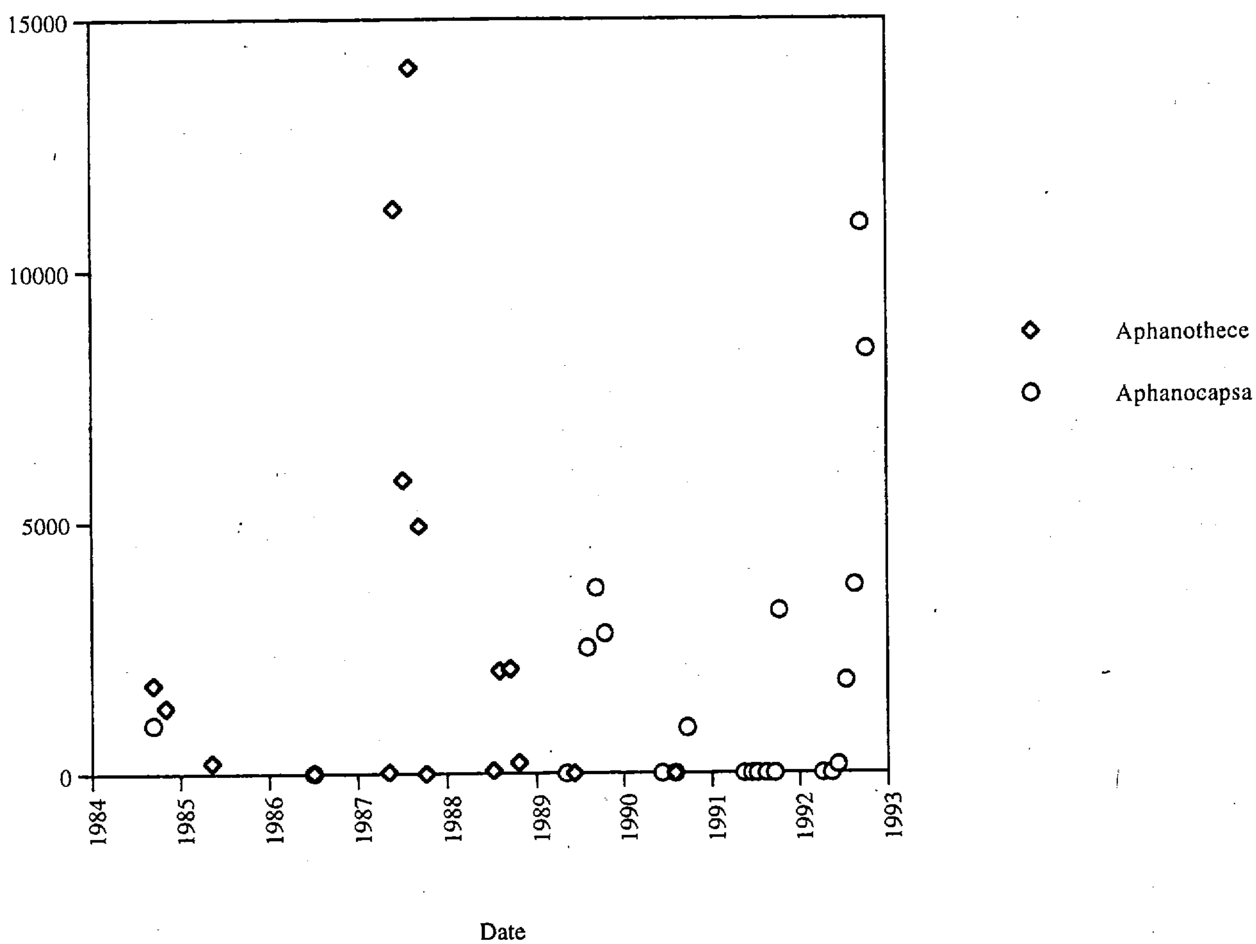


Figure 6.1.15. Spectacle Lake Phytoplankton: *Euglena*.

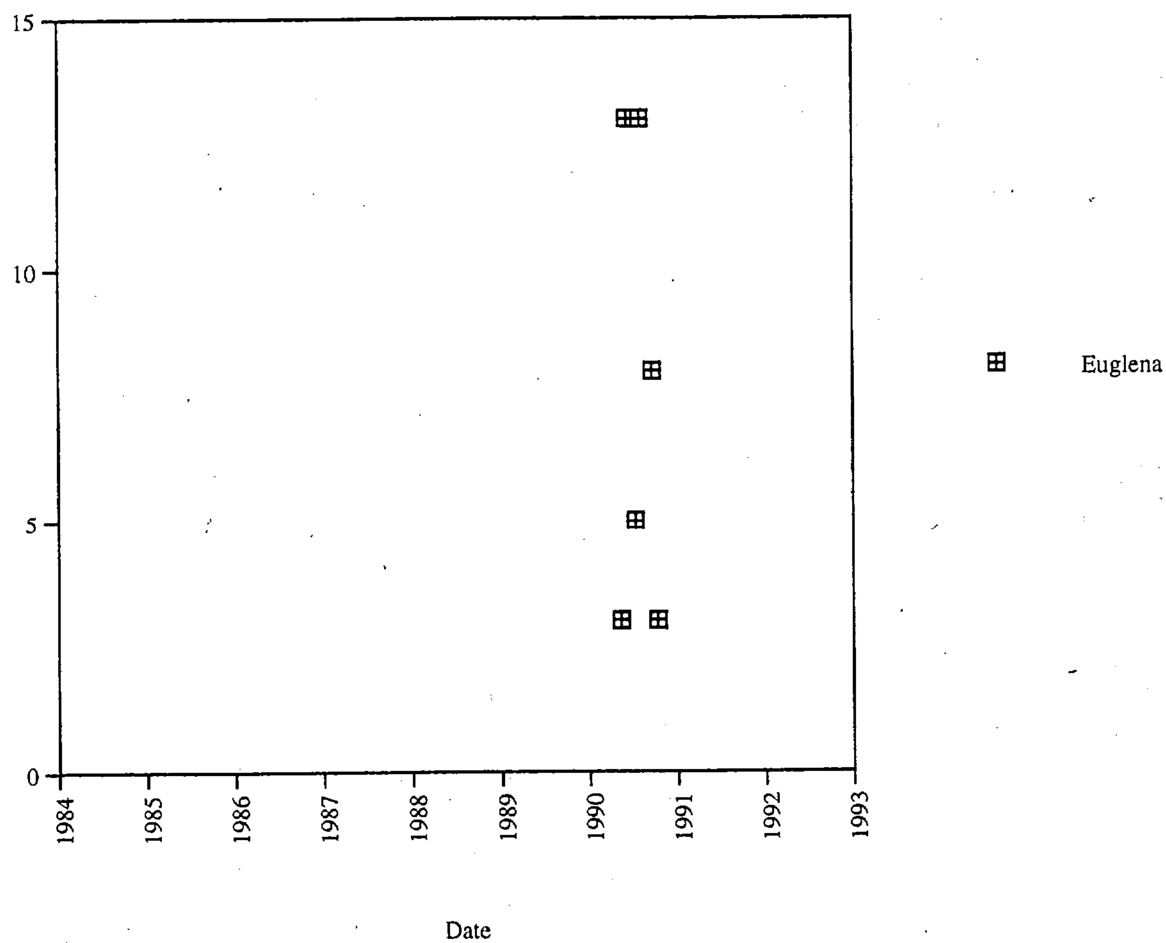


Figure 6.1.16. Spectacle Lake Phytoplankton: Total Cells/mL.

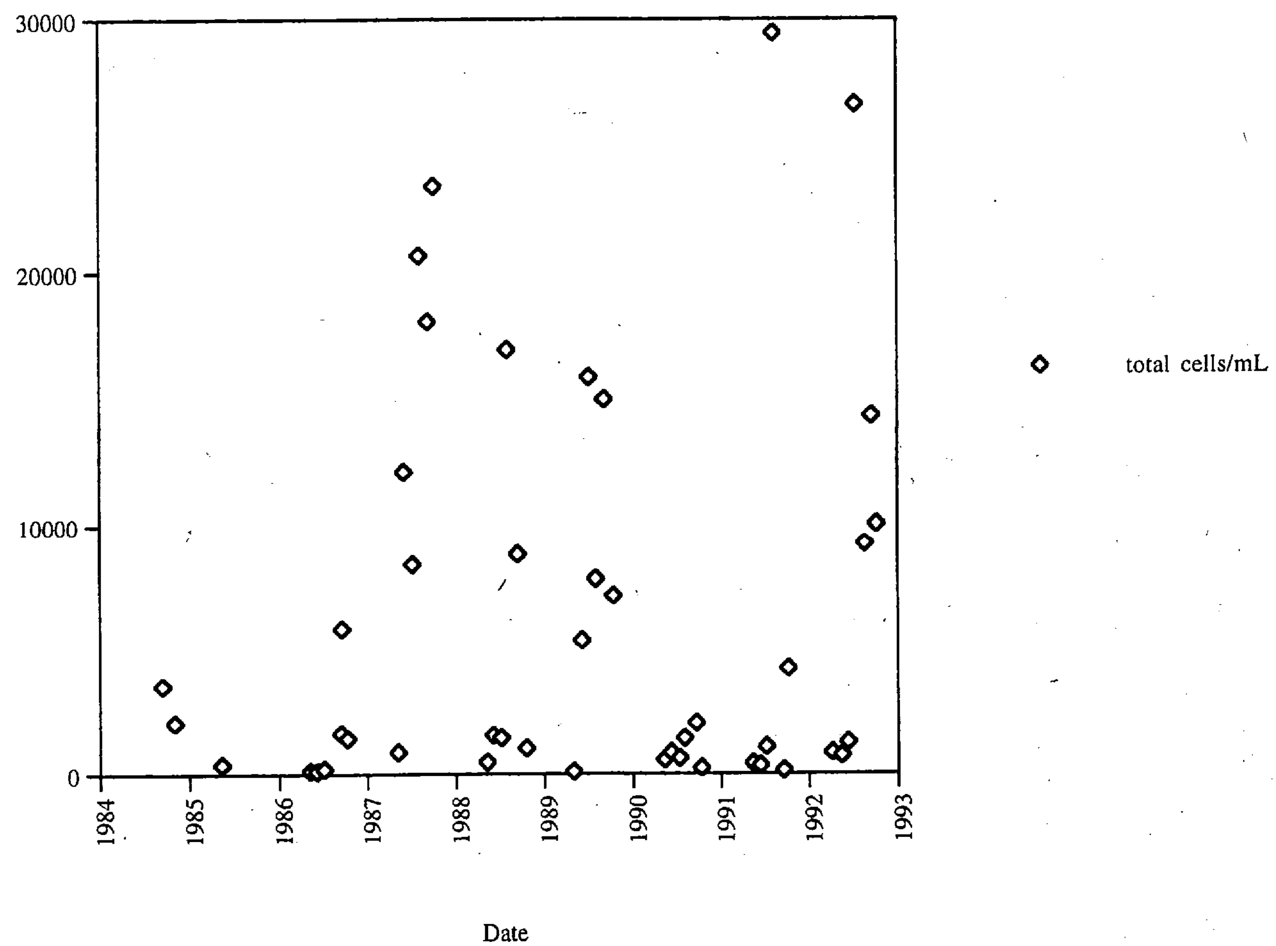


Figure 6.1.17. Spectacle Lake Phytoplankton: Chlorophyll a, µg/L.

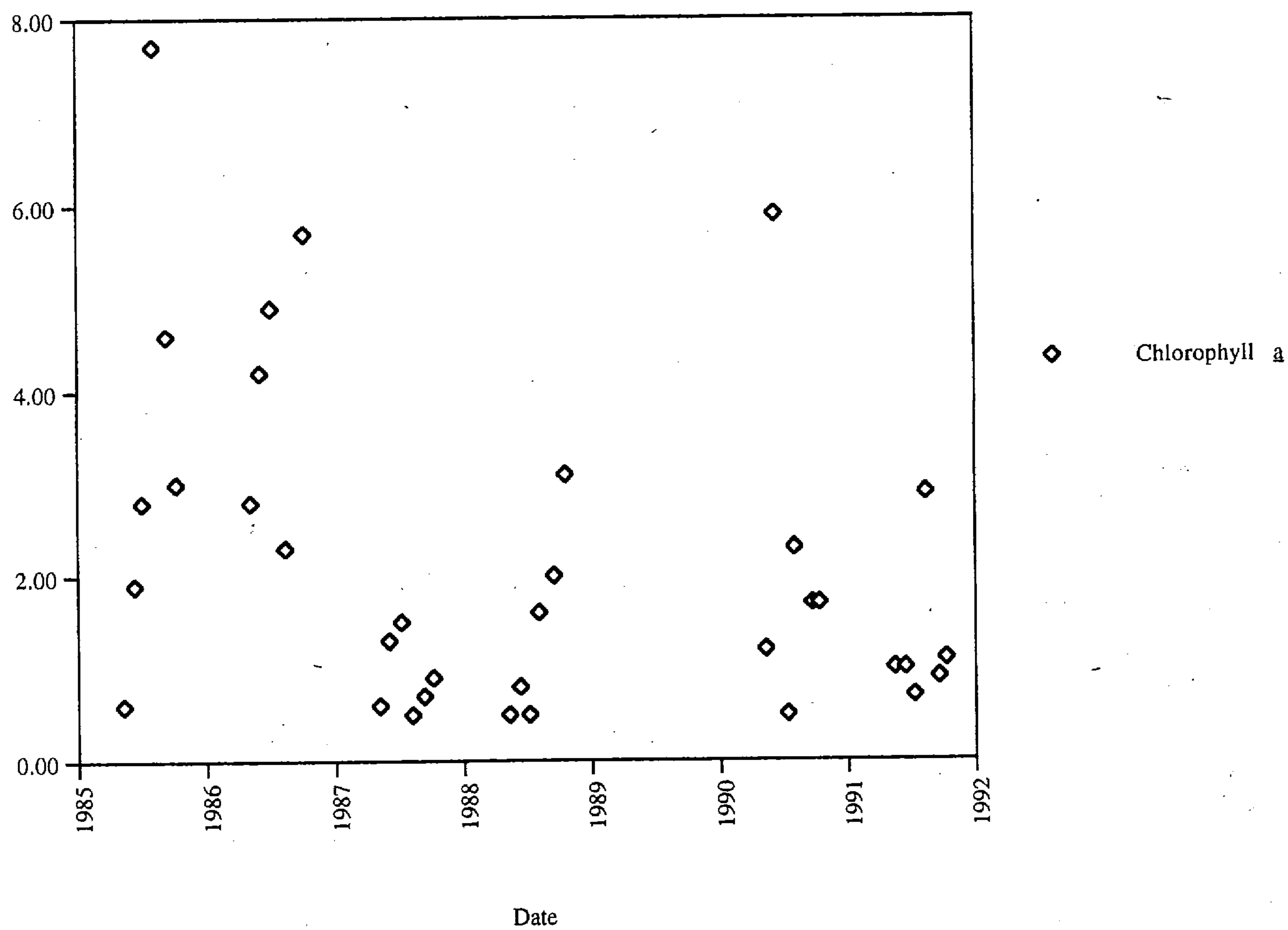


Figure 6.2.1. Spectacle Lake Zooplankton: *Diaptomus.*

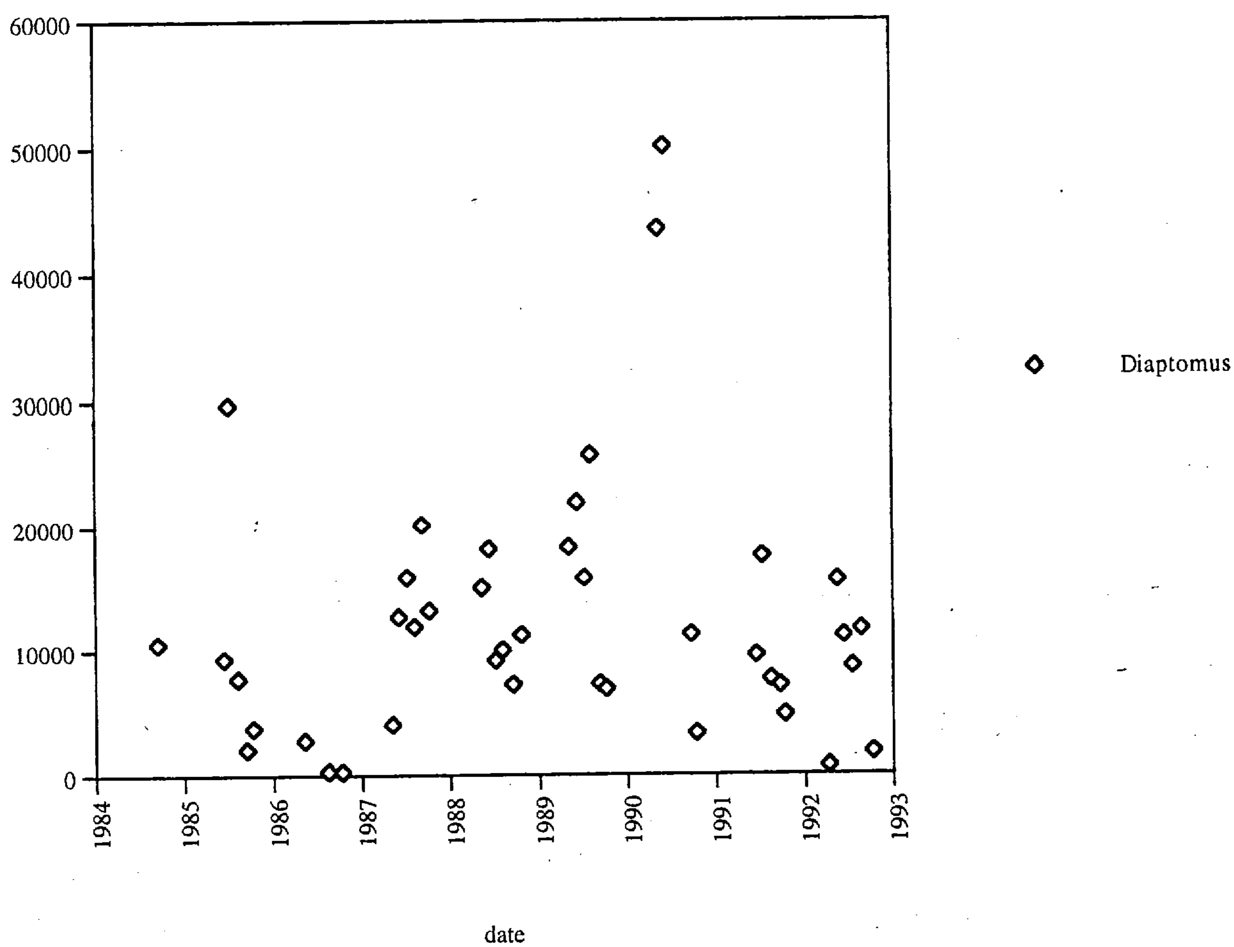


Figure 6.2.2. Spectacle Lake Zooplankton: *Cyclops/Diacyclops/Epishura.*

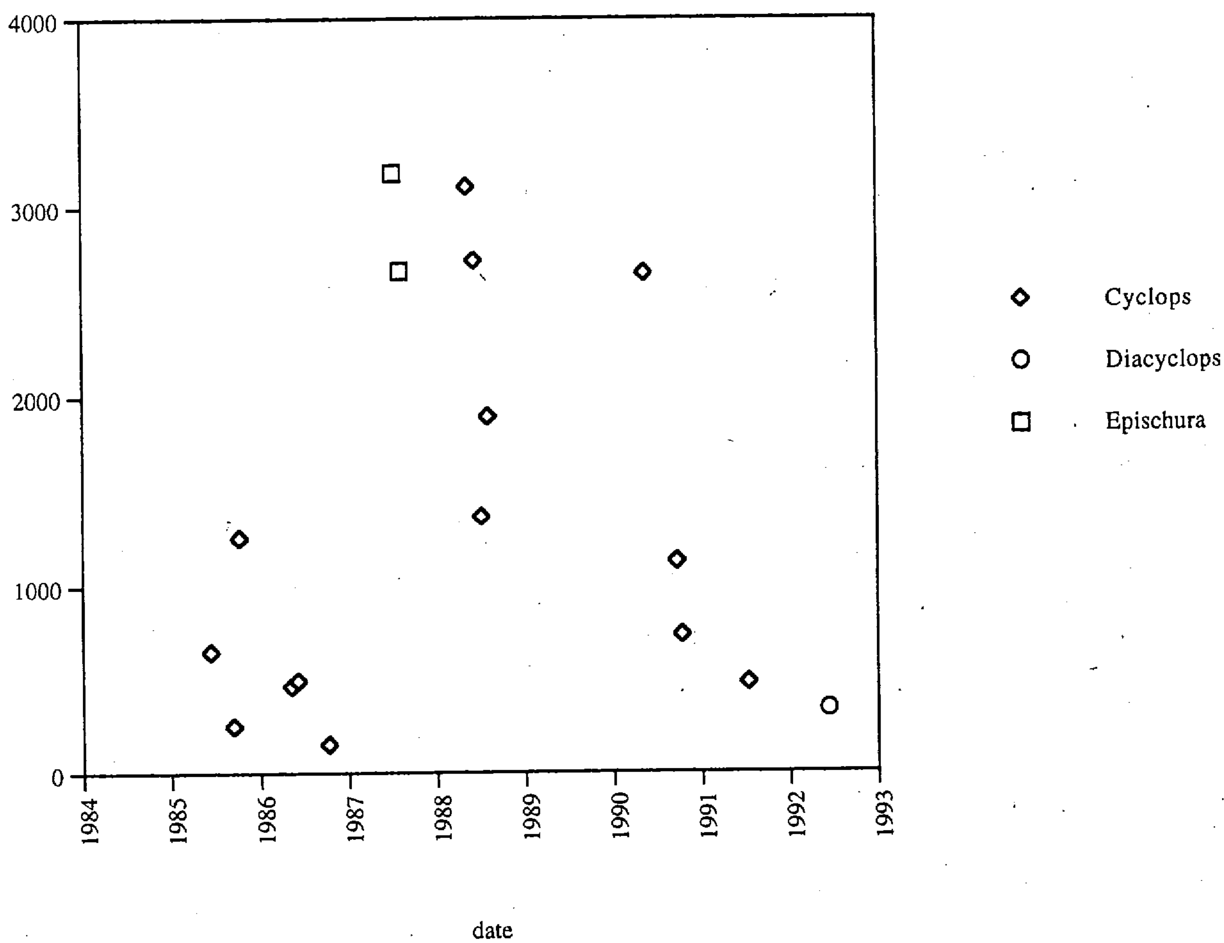


Figure 6.2.3. Spectacle Lake/Zooplankton: Copepodites/Nauplii.

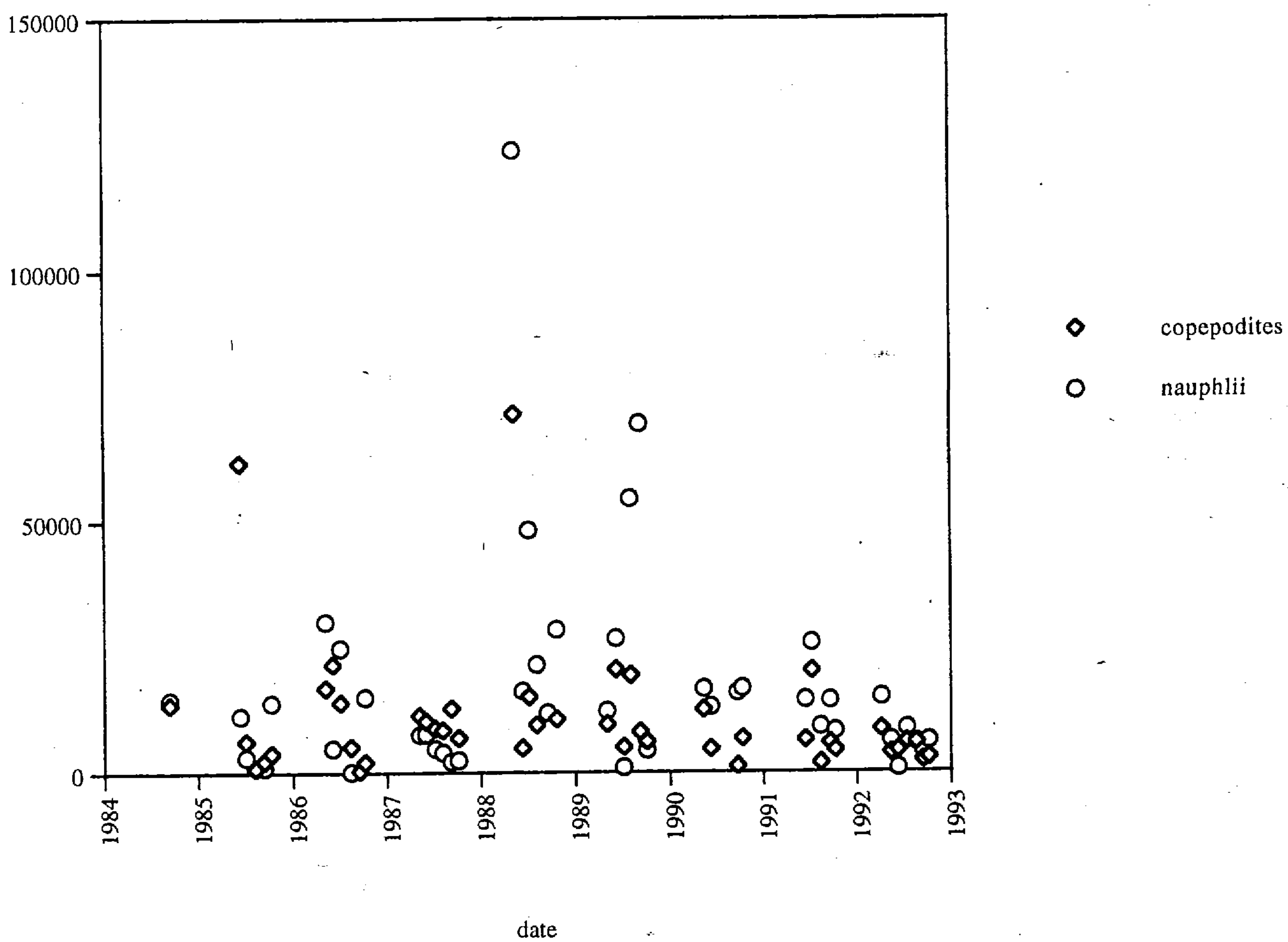


Figure 6.2.4. Spectacle Lake Zooplankton: *Daphnia*.

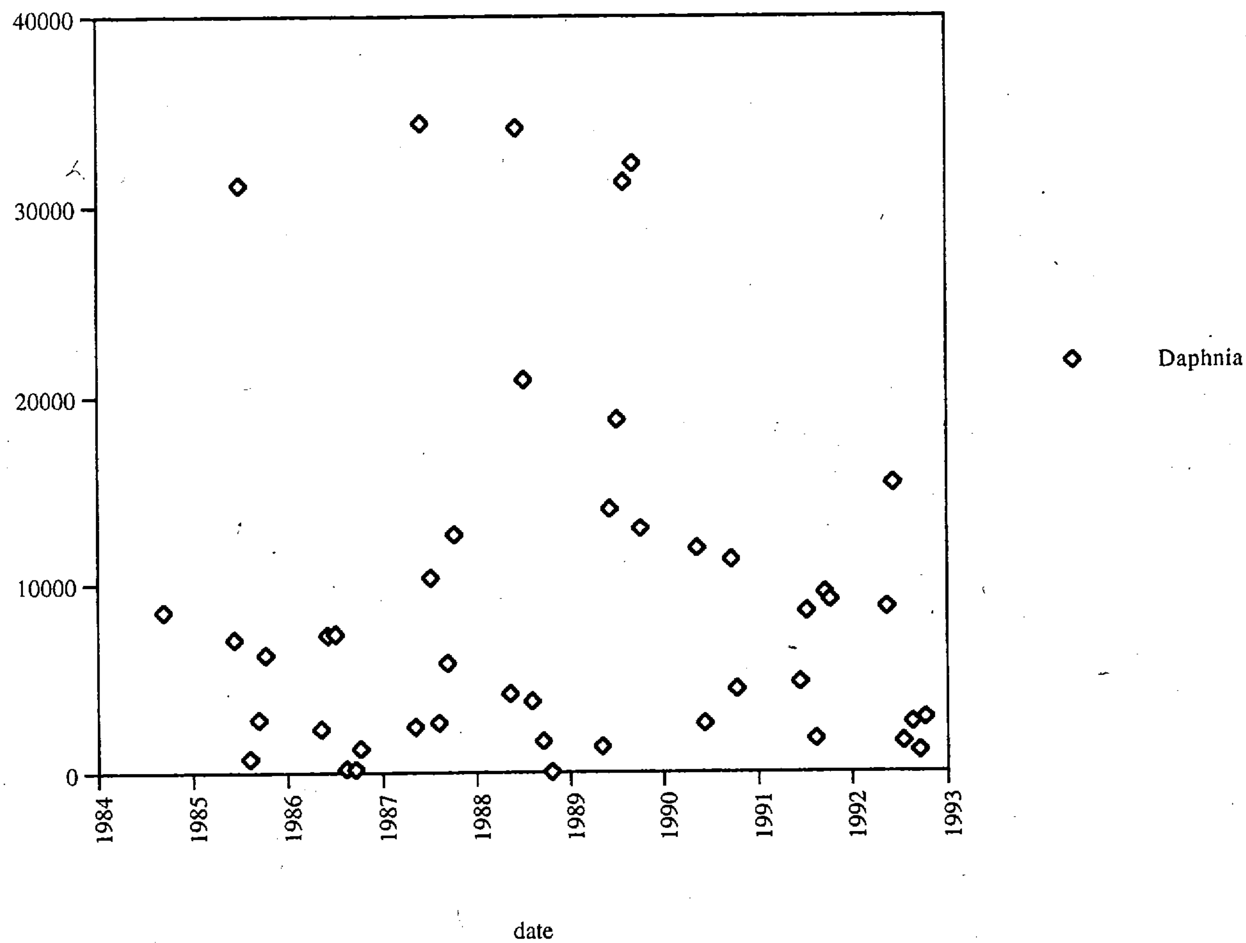


Figure 6.2.5. Spectacle Lake Zooplankton: *Holopedium/Bosmina.*

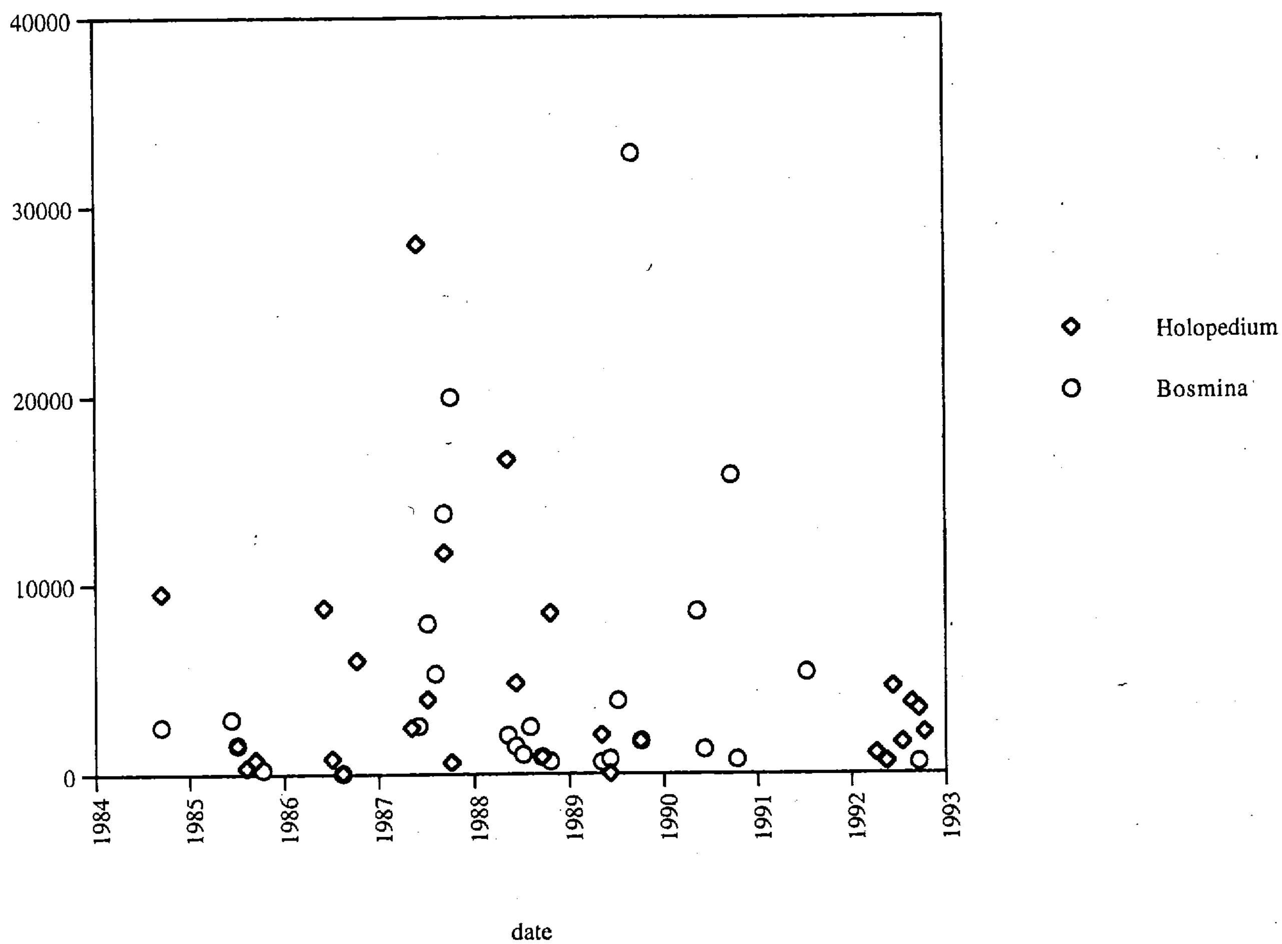


Figure 6.2.6. Spectacle Lake Zooplankton: *Diaphanosoma/Alonella.*

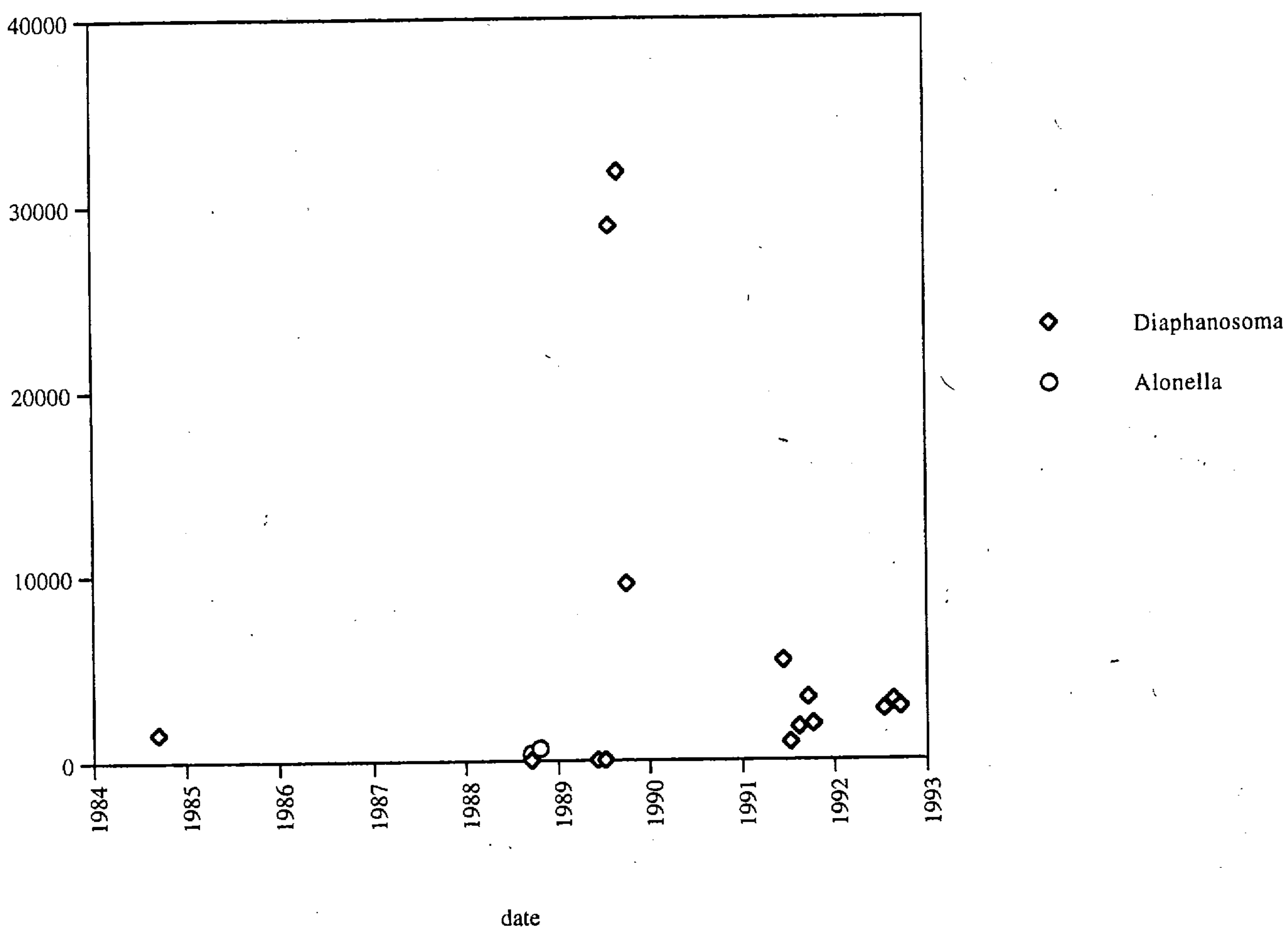


Figure 6.2.7. Spectacle Lake Zooplankton: *Kellicottia/Keratella.*

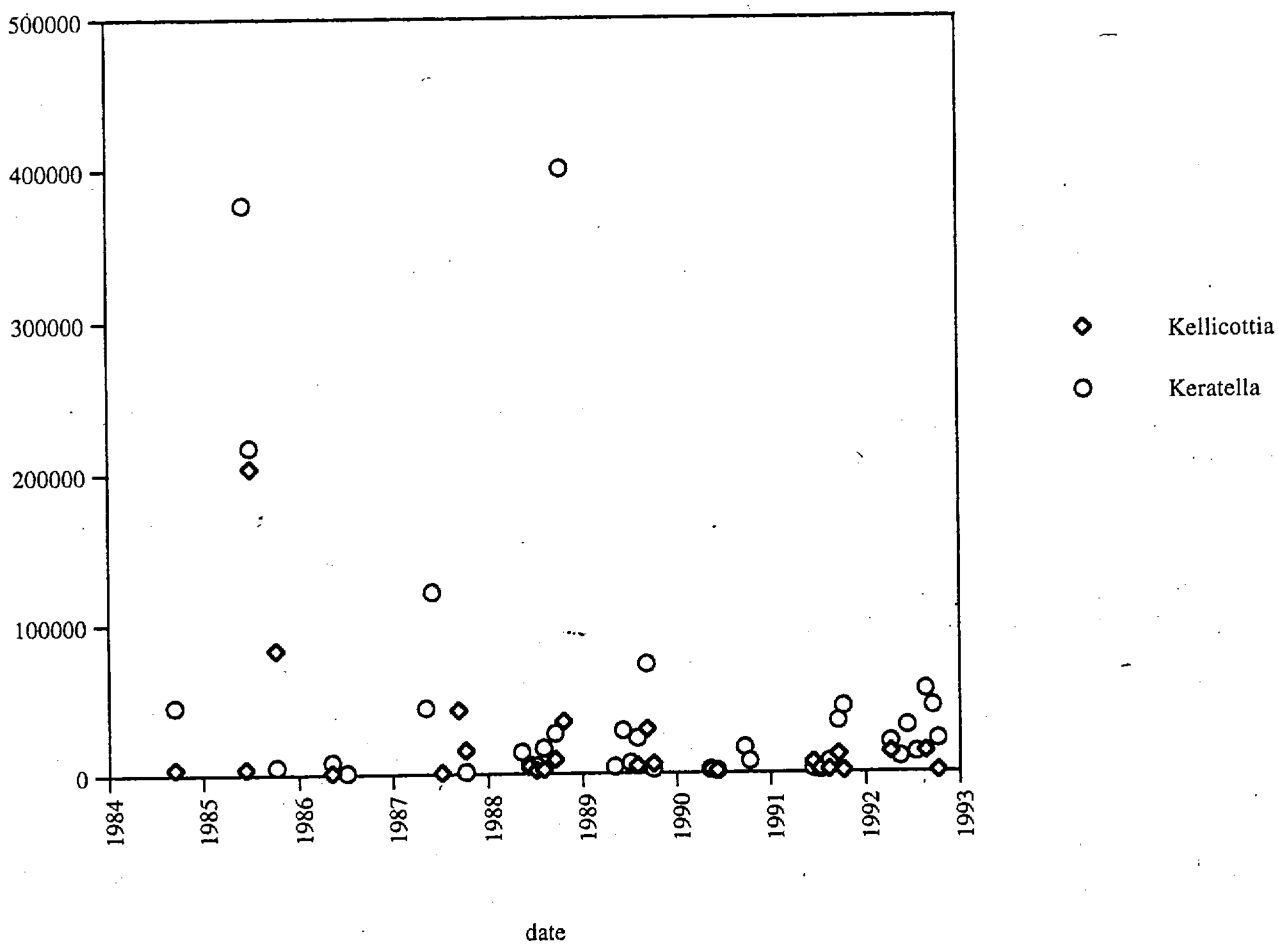


Figure 6.2.8. Spectacle Lake Zooplankton: Rare Rotifers.

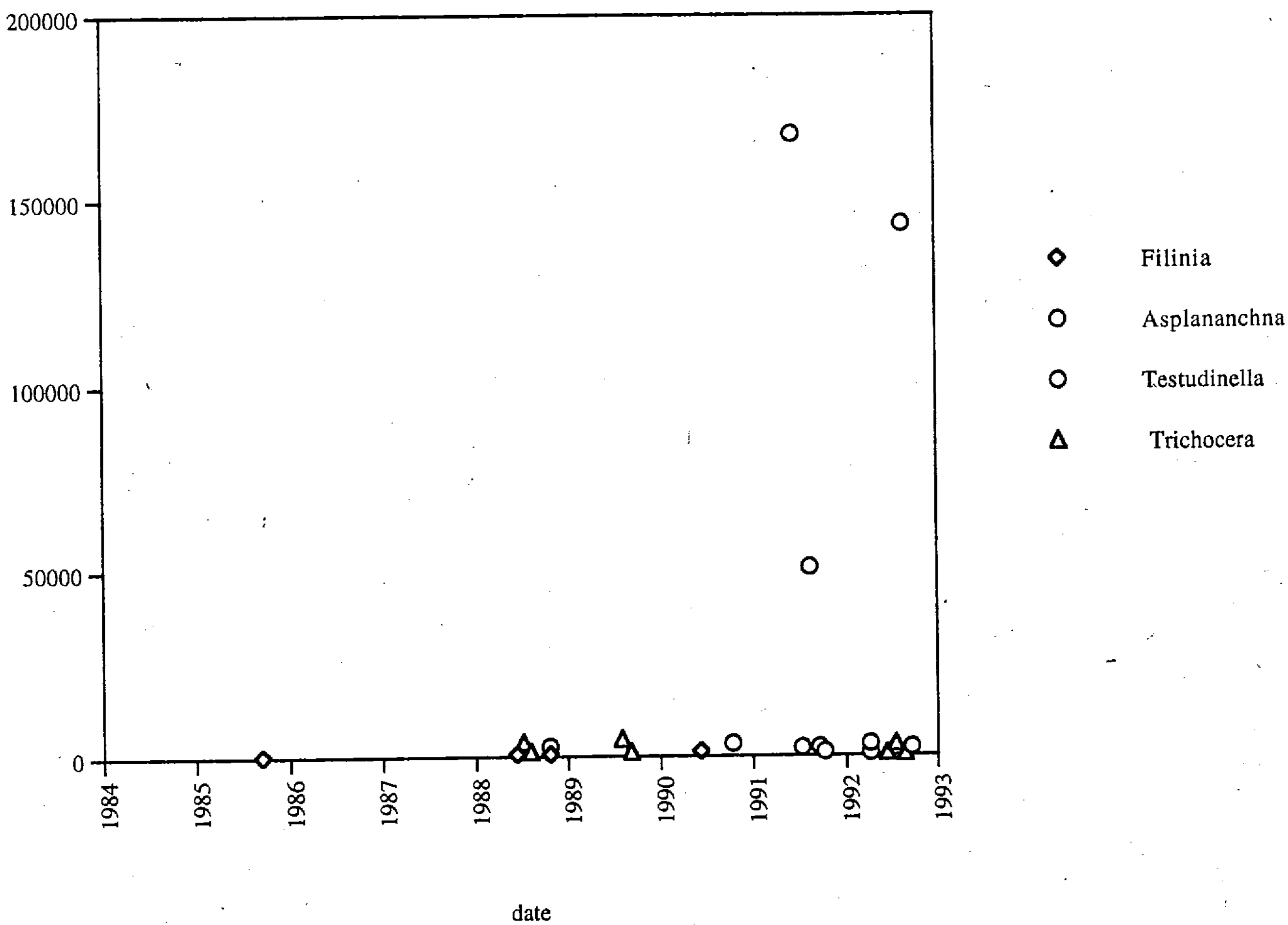


Figure 6.2.9. Spectacle Lake Zooplankton: Rare Rotifers 2

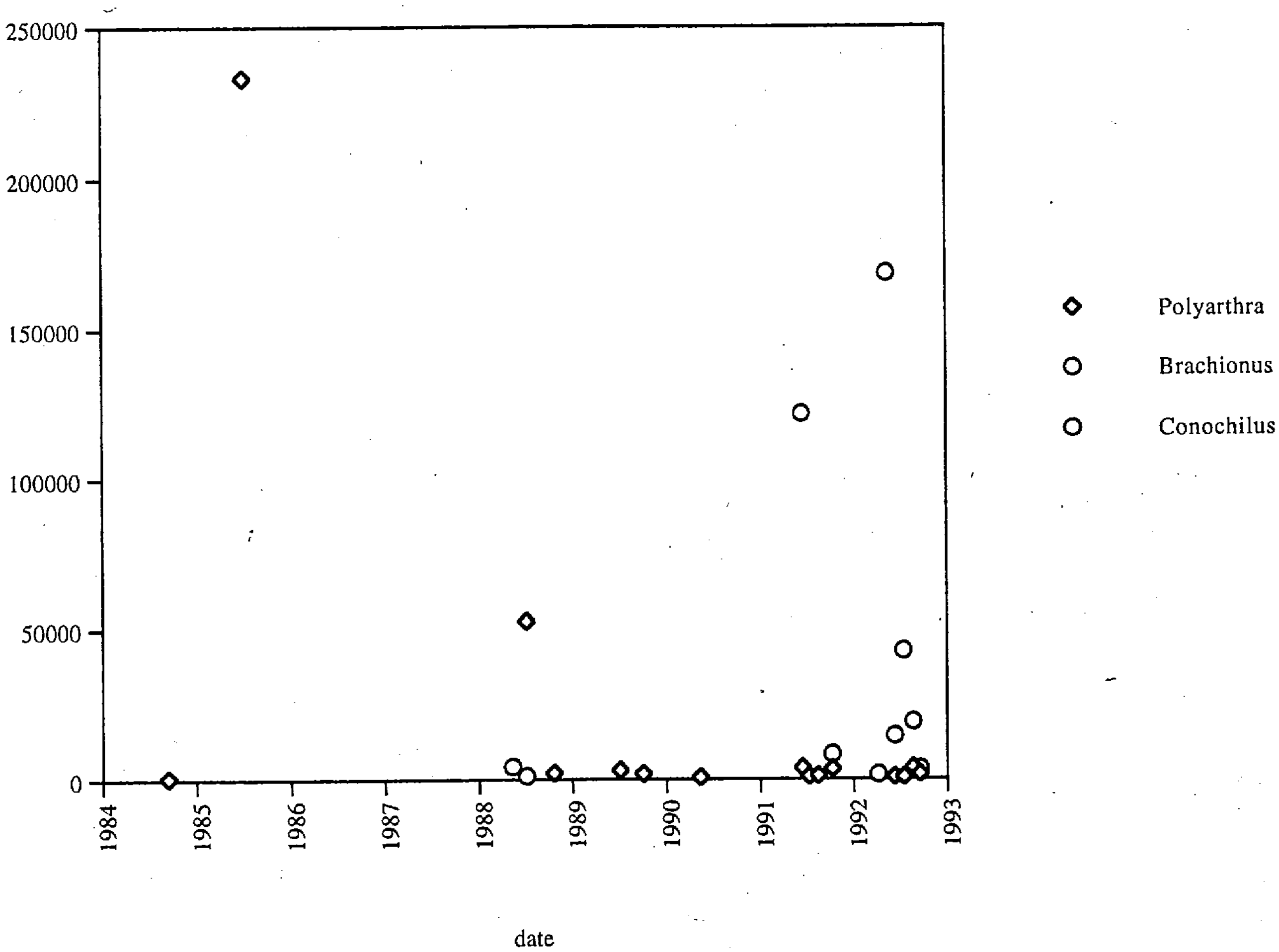


Figure 6.2.10. Spectacle Lake Zooplankton: *Chaoborus*.

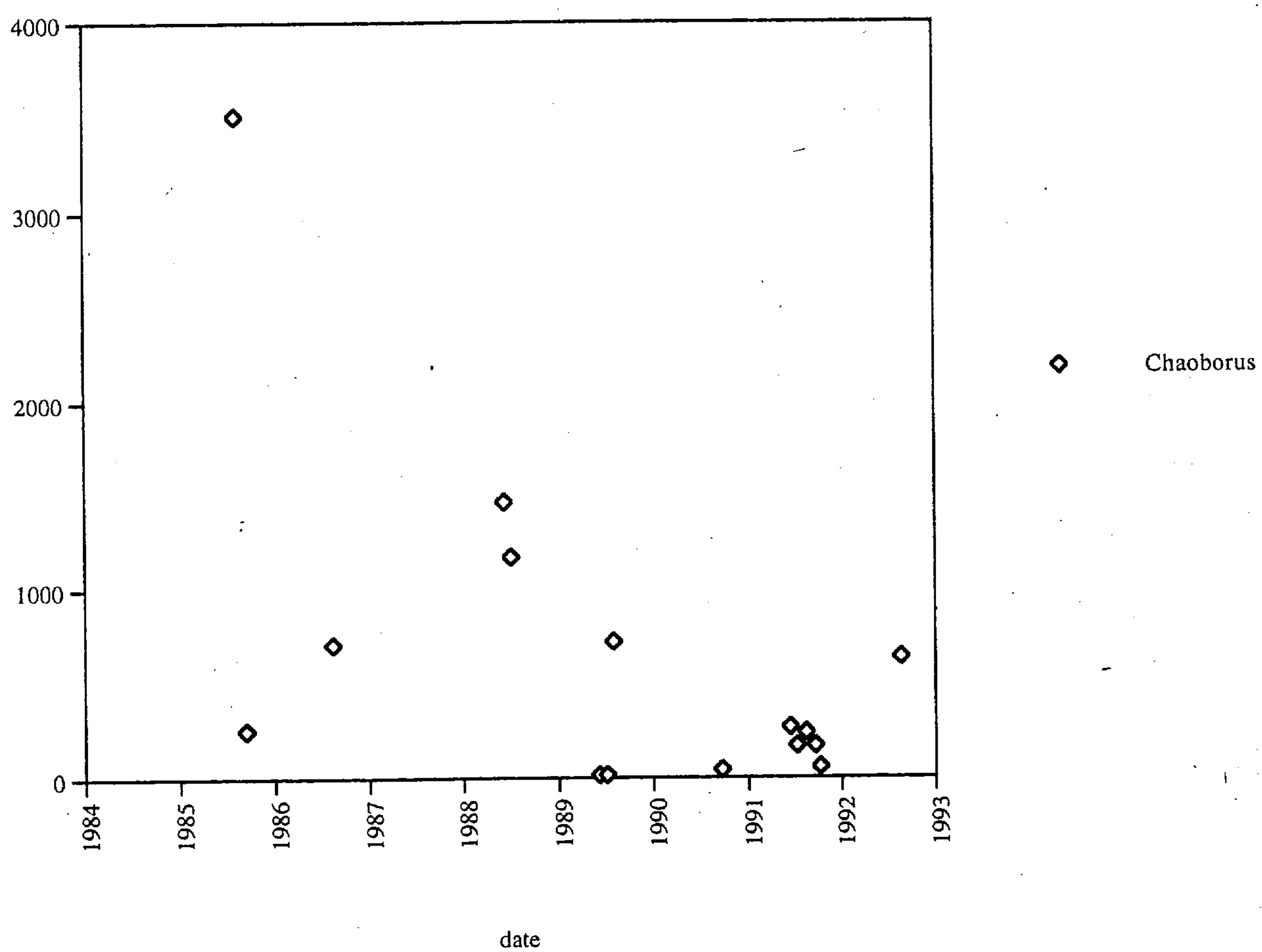


Figure 6.2.12. Spectacle Lake Zooplankton: Total Biomass µg/m2.

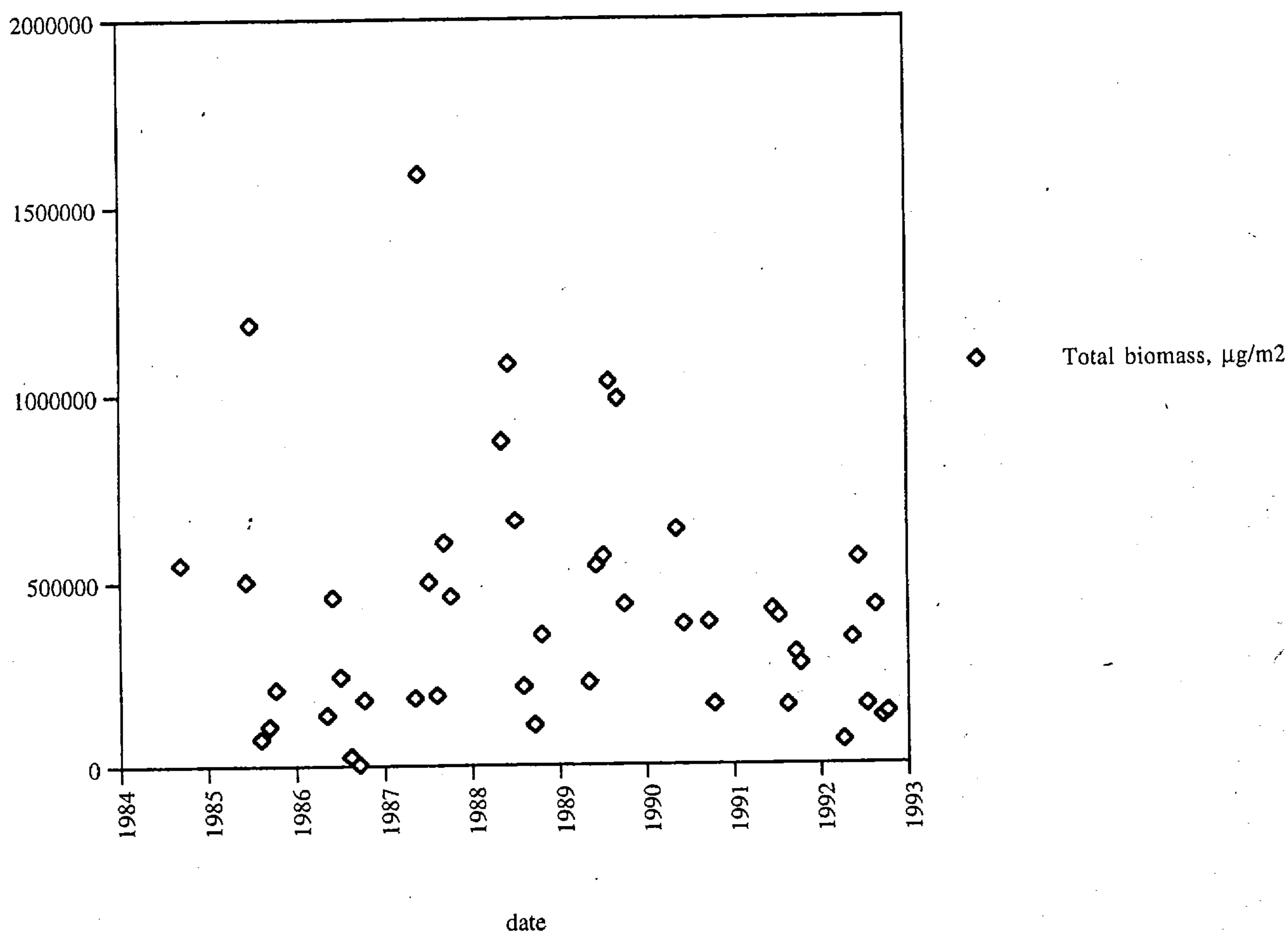
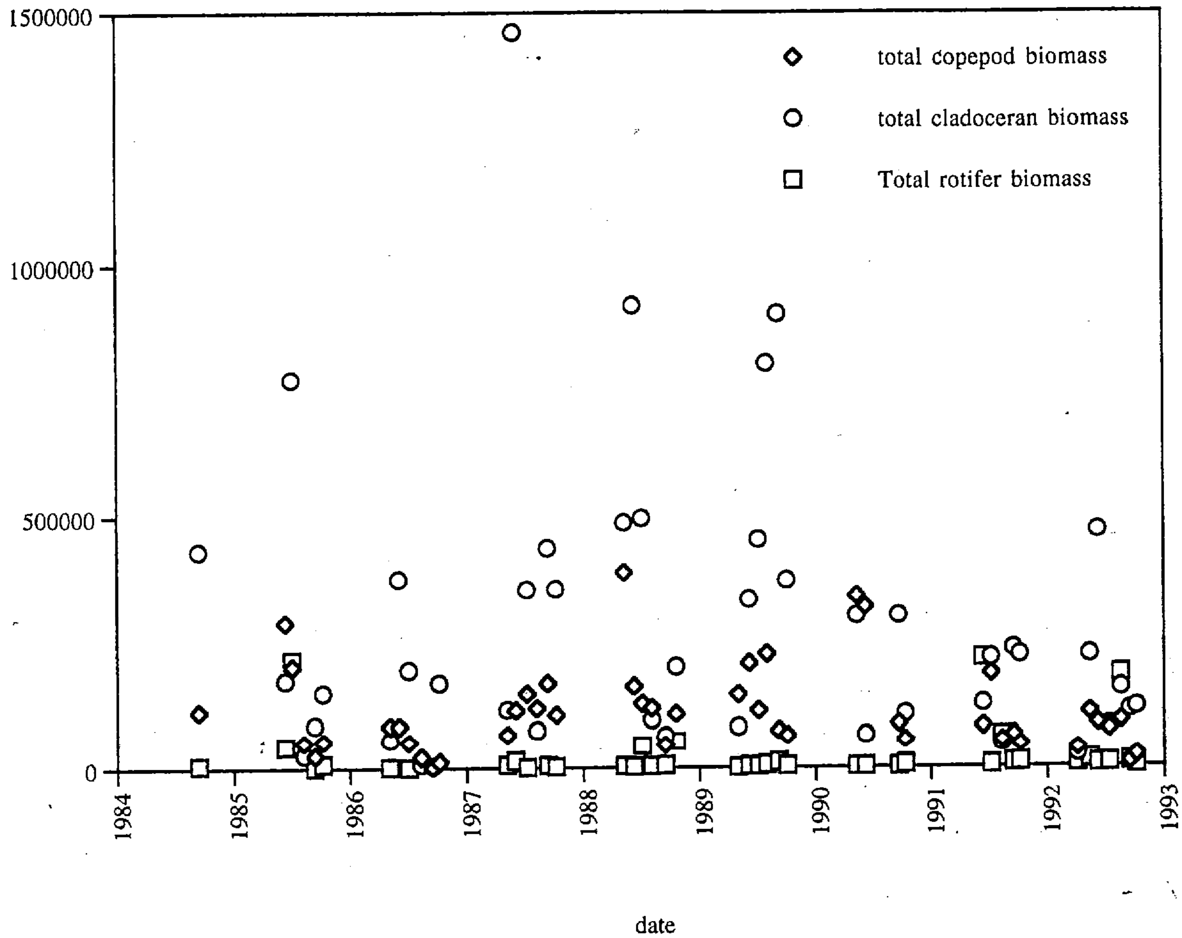


Figure 6.2.13. Spectacle Lake Zooplankton: Biomass Comparisons.



7.0. STOCKING LAKE

Stocking Lake is located on Vancouver Island, just to the south and west from Ladysmith, and north from Duncan (48° 57' 29", 123° 49' 25", map sheet 92B). Stocking Lake has a volume of 1018 dam^3, a maximum depth of 27 m, a mean depth of 8.4 m, and an area of 23.3 ha. It has a drainage area of 1.65 km^2 and a mean annual inflow of 2140 dam^3. The mean residence time of the water in the lake is about one year. Stocking Creek is the outlet stream from the dam, eventually discharging to the south end of Ladysmith Harbour.

Stocking Lake has been converted to a reservoir to provide water to the Town of Ladysmith. The lake is surrounded by forest, and the only permanent structure is a low earthen dam at the spillway. Four recent stocking events are recorded, each time introducing 15,000 Rainbow Trout to the lake. Two of these occurred within the sampling period, once in 1984 and again in 1986.

7.1 Phytoplankton

The diversity of the phytoplankton community in Stocking Lake is consistent with the other lakes, with 84 genera reported (Appendix 10). The dominant and sub dominant taxa are listed in Table 7.1.1. *Cryptomonas* and *Dinobryon* are again the two most consistent genera, present in 93% and 89% of all samples respectively. *Oocystis* and *Crucigenia* are also present in 89% of samples, but at lower mean concentrations. *Chroomonas* (86%) and *Elakothrix* (84%) complete the dominant group. Mean concentrations range from 6.04 to 261.23 cells/mL, which is consistent with the other lakes. Stocking differs from the other lakes in lacking any members of the cyanophyte genera in either the dominant or sub-dominant groups. In addition, *Melosira* (Figure 7.1.11) and *Asterionella* (Figure 7.1.12) exhibit the highest mean concentration observed for diatoms within the dominant or sub-dominant categories of the study lakes. The numbers for *Melosira* are influenced by a peak in 1986 of 5000 cells/mL, but otherwise occurs in similar numbers to diatoms in other lakes. The mean concentration of *Asterionella* is similarly elevated by peak concentrations in 1991 and 1992.

As with the other study lakes seasonal and yearly variability within most taxa is high, and clear trends are not readily apparent. In general, *Dinobryon* (Figure 7.1.1) appears to decrease in concentration, while *Cryptomonas* (Figure 7.1.2) appears to increase. A number of the sub-dominant chlorophytes exhibit a similar characteristic. *Crucigenia, Quadrigula, Gloeocystis, Nephrocytium,* and *Botryococcus* all show very high peaks in 1987, relative to their background concentrations. The prominent blue green genera in Stocking are *Merismopedia, Chroococcus, Aphanothece, Lyngbya, Anabaena,* and *Aphanocapsa.* All these taxa show higher numbers and occurrence in the 1987-1992 period. Dominant and sub dominant taxa are displayed in figures 7.1.1 to 7.1.12. *Sphaerocystis* exhibits the same trend noted in Maxwell, Old Wolf and Spectacle lakes, being absent prior to 1989, then present at significant concentrations and occurrence thereafter (Figure 6.1.6).

Standing crop as measured by total cells/mL is roughly similar to the other lakes, excepting the low numbers in Jacobs, and shows an apparent decline over the ten year sampling period (Figure 7.1.13). Higher concentrations are observed in 1986 to 1991, attributable in part to the increased cyanophyte concentrations found in these years. The chlorophyll a data is incomplete, with no values available for 1989 and 1992 through 1994. The available chlorophyll data does correlate with the total cells/mL values on a yearly basis, but shows an overall increase in concentration as opposed to the decrease shown in the total/mL concentrations. In general the chlorophyll a values are lower than those observed in the other lakes, ranging from 0.5 to 2.2 µg/mL with a mean of 0.97 µg/mL (Figure 7.1.14). Total numbers of phytoplankton and chlorophyll a values are summarised by year in tables 7.1.2 and 7.1.3.

7.2. Zooplankton

The zooplankton community of Stocking Lake is shown to support 22 different genera over the study period, as is consistent with the other study lakes (Appendix 11). *Diaptomus* (Figure 7.2.1) is dominant copepod for the majority of the study, generally present in concentrations of 10,000-45,000/m^2 up until 1988. Numbers then decline sharply to under 10,000/m^2 through 1994. *Epishura* appears in 1992, occurring more frequently and at higher concentrations than *Diaptomus* for the remainder of the study (Figure 7.2.2). *Cyclops* is present until 1991 at concentrations below 5000/m^2, and then *Diacyclops*, is reported thereafter (Figure 7.2.3). *Hesperodiaptomus* and *Leptodiaptomus* are reported once each at concentrations below 5000/m^2. Copepodite stages are present throughout the study at consistent concentrations, but a sharp decline is observed in the number of nauplii recorded (Figure 7.2.4).

There are six cladoceran genera reported. *Bosmina* is the most numerous, with *Holopedium, Diaphanosoma, Daphnia, Ceriodaphnia*, and *Polyphemus* present in successively lower occurrence and concentrations. Excepting *Bosmina* all of these taxa exhibit decline in numbers and/or occurrence over the duration of the study. This is particularly evident for *Holopedium*. *Bosmina* does decline through 1991, but then increases in concentration over 1992 and 1993. A very high peak concentration of 285,787/m^2 is observed for *Bosmina* in October of 1984. Cladoceran population dynamics are exhibited in figures 7.2.5 to 7.2.8.

The rotifers are the most diverse component of the Stocking zooplankton with 9 genera reported. *Keratella* (Figure 7.2.9) is the most numerous, with one recorded sample of over 1.5 million individuals in 1986. *Kellicottia* shows elevated numbers in 1987 and 1988 (Figure 7.2.10). *Trichocera, Filinia* and *Testudinella* show increased concentrations or occurrence during this period as well (Figure 7.2.11). The dynamics of the less numerous rotifers are displayed in Figure 7.2.12.

There are five recorded observations of Chaoborus in Stocking (Figure 7.2.13).

Biomass estimates, both using total individuals/m^2 (7.2.14) and dry weight estimates for the individual taxa (Figure 7.2.15) clearly reflect the declines noted above. Total biomass (Figure 7.2.16) shows a decline from a mean 971,644 mg/m^2 for 1984/1985 to 112,141 mg/m^2 for 1994. The majority of this decline can be accounted for by the decline in the cladoceran component of the community.

	Dominant	Sub-dominant	% presence	mean conc. cells/mL
Cryptophyte	*Cryptomonas*		93	12.49
	Chroomonas		86	41.52
Chrysophyte	*Dinobryon*		91	261.23
Chlorophyte	*Oocystis*		89	69.94
	Crucigenia		89	44.44
	Elakothrix		84	12.91
		Quadrigula	67	35.18
		Nephrocytium	67	6.04
		Botryococcus	65	154.21
		Gloeocystis	54	93.39
		Sphaerocystis	53	74.77
		Selanastrum	51	38.27
Diatom		*Melosira*	61	168.77
		Asterionella	60	62.92

Table 7.1.1: Stocking Lake Phytoplankton: Dominant and Sub-dominant taxa.

Year	n	mean	maximum	minimum	# of samples
1985	711	26.33	225	.001	2
1986	9168	77.04	4974	.001	6
1987	1069	113.08	1524	.001	6
1988	10911	109.11	2365	.001	6
1989	16573	136.96	3801	.001	6
1990	4523	35.33	998	.001	6
1991	13407	87.62	5872	.001	6
1992	5439	25.77	603	.001	7
1993	2818	35.55	523	.001	6
1994	3153	16.50	383	.001	6

Table 7.1.2. Stocking Lake Phytoplankton: Summary of total numbers of phytoplankton/mL by year.

year	mean	maximum	minimum
1984	1.25	1.7	0.8
1985	0.76	1.8	0.5
1986	0.96	2.1	0.5
1987	0.68	1.1	0.5
1988	1.31	1.8	0.7
1990	0.78	1.2	0.5
1991	1.25	2.2	0.5

Table 7.1.3. Stocking Lake Phytoplankton: Mean and range of Chlorophyll a measurements by year in µg/L.

Figure 7.1.1. Stocking Lake Phytoplankton: *Dinobryon.*

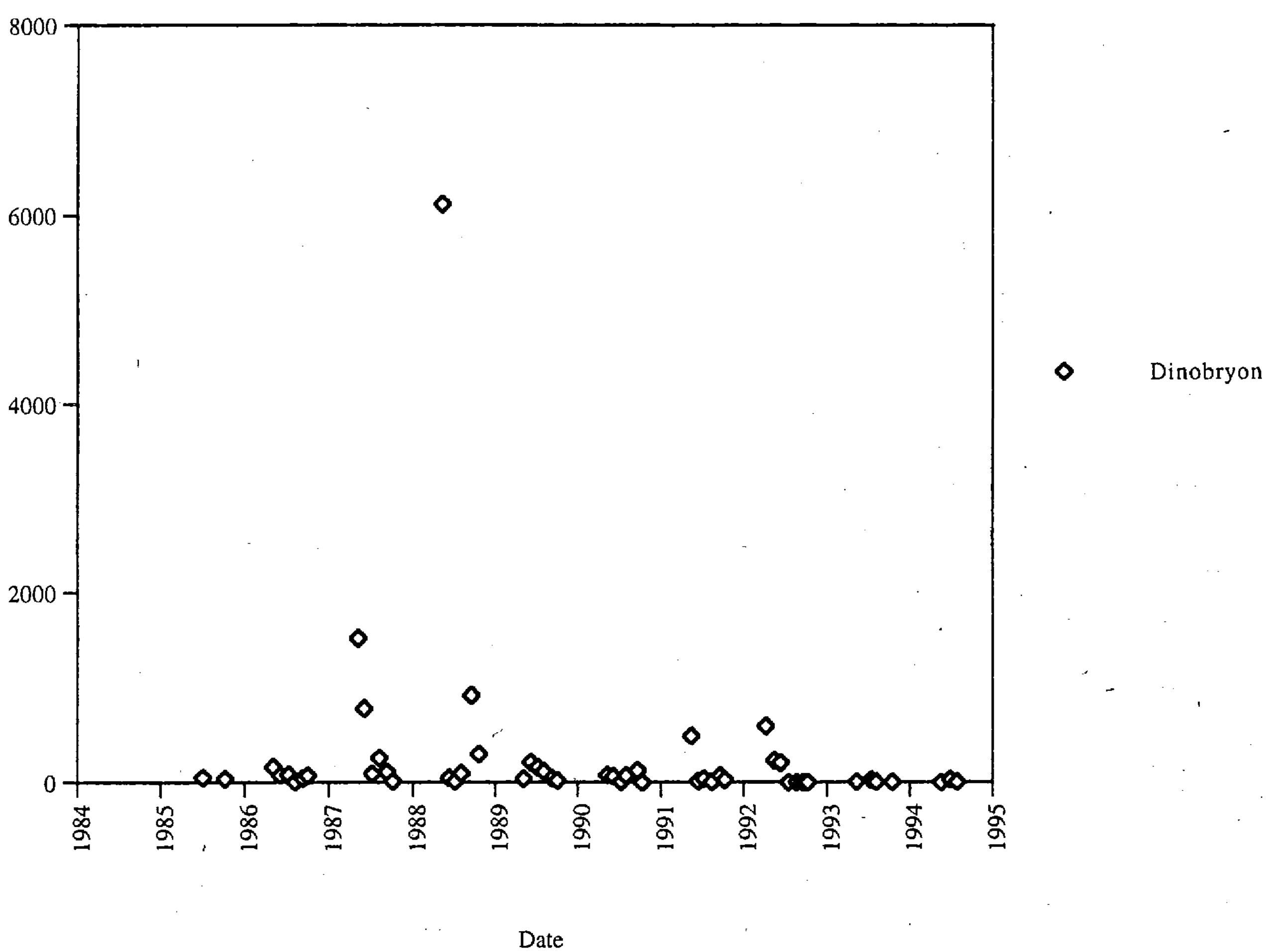


Figure 7.1.2. Stocking Lake Phytoplankton: *Cryptomonas*.

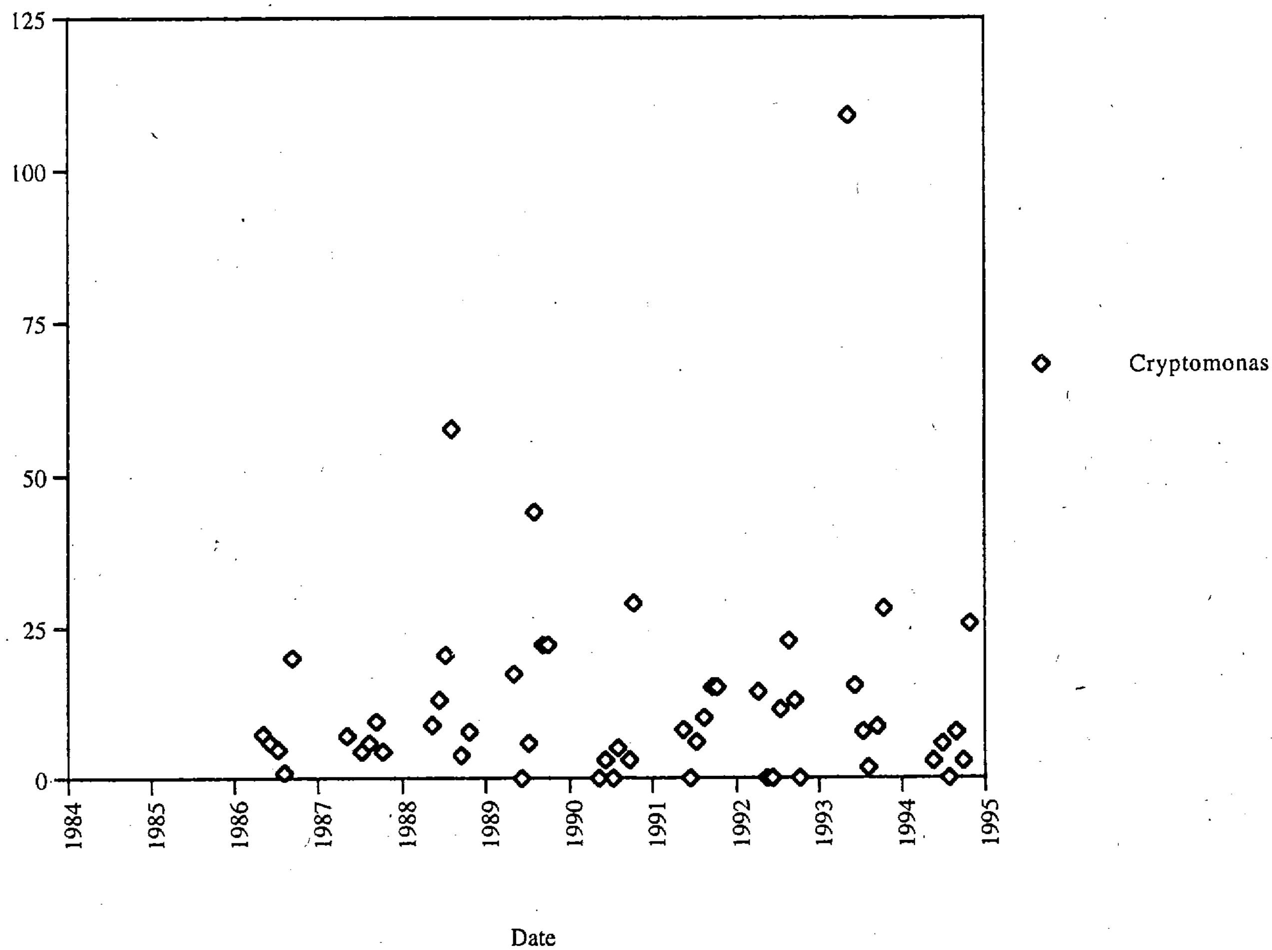


Figure 7.1.3. Stocking Lake Phytoplankton: *Crucigenia/Oocystis.*

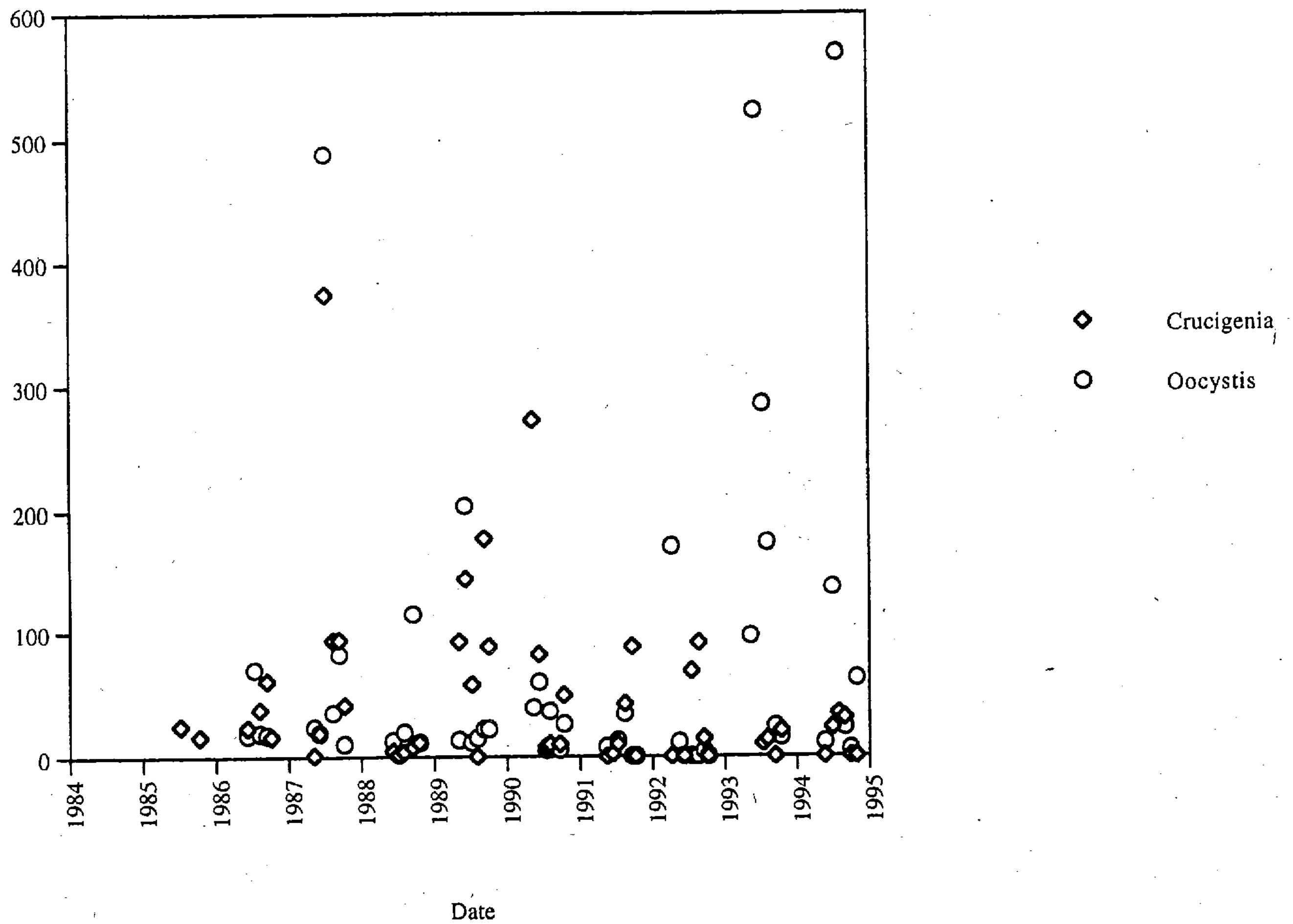


Figure 7.1.4. Stocking Lake Phytoplankton: *Chroomonas/Elakothrix*.

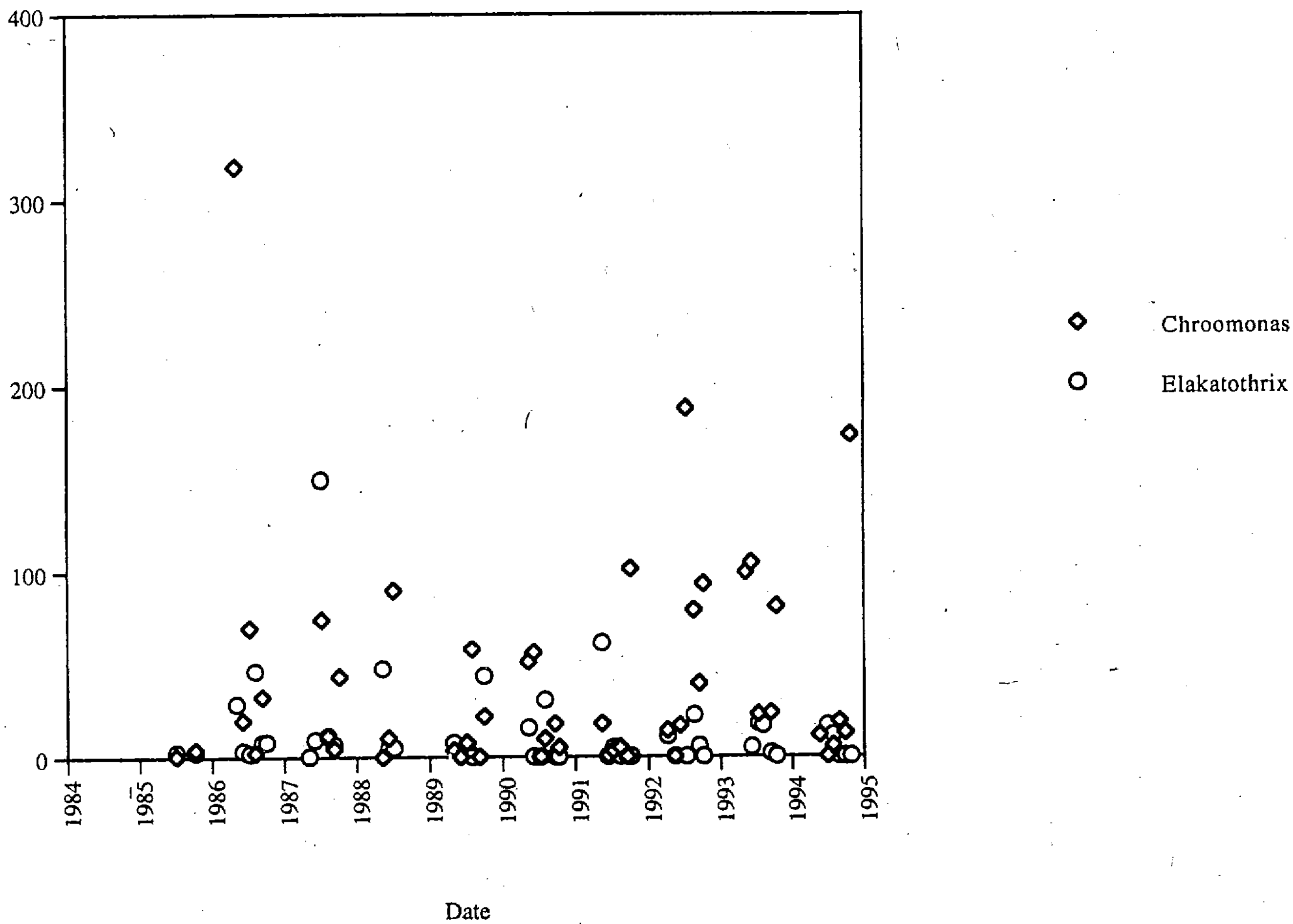


Figure 7.1.5. Stocking Lake Phytoplankton: *Sphaerocystis.*

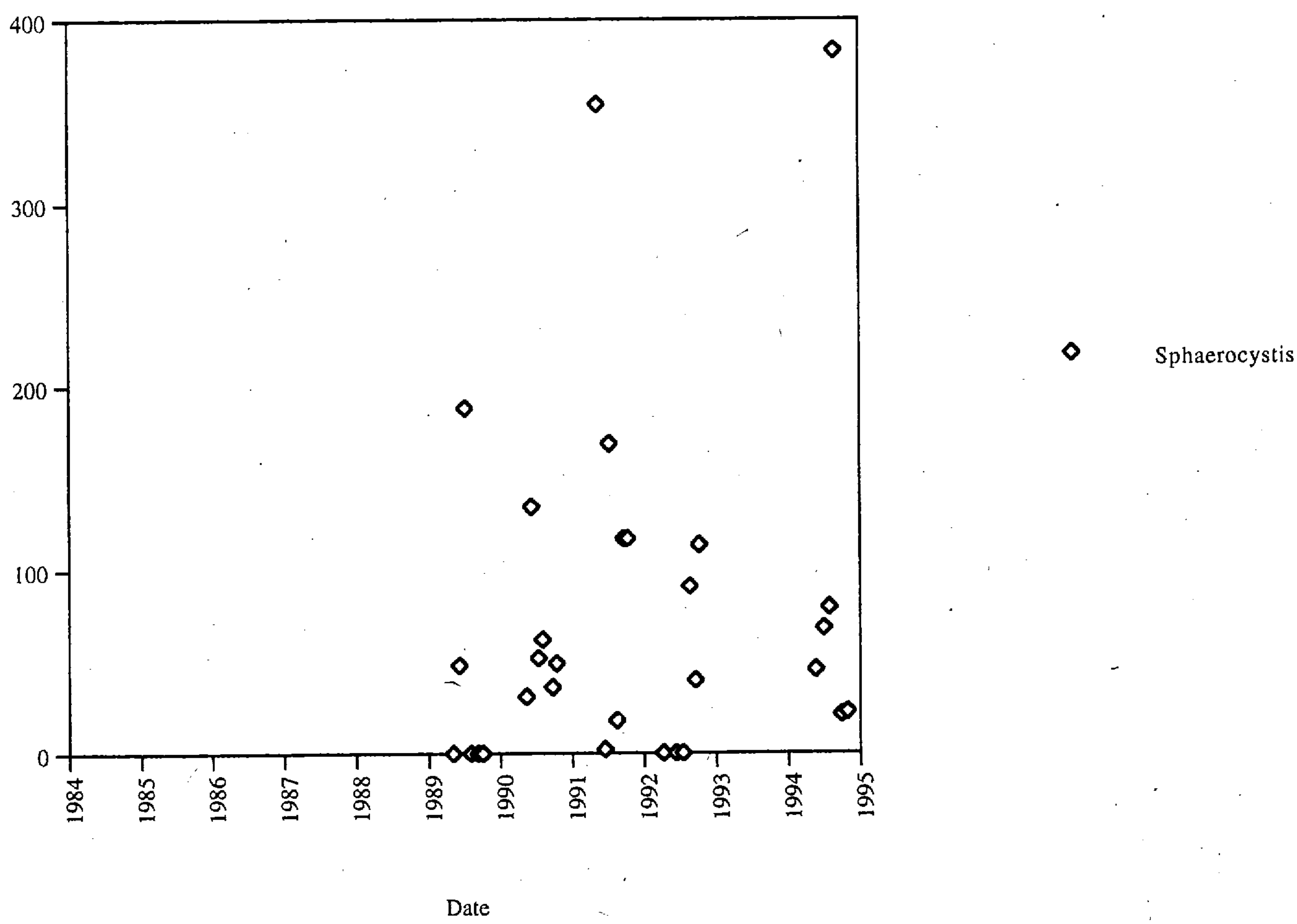


Figure 7.1.6. Stocking Lake Phytoplankton: *Quadrigula*.

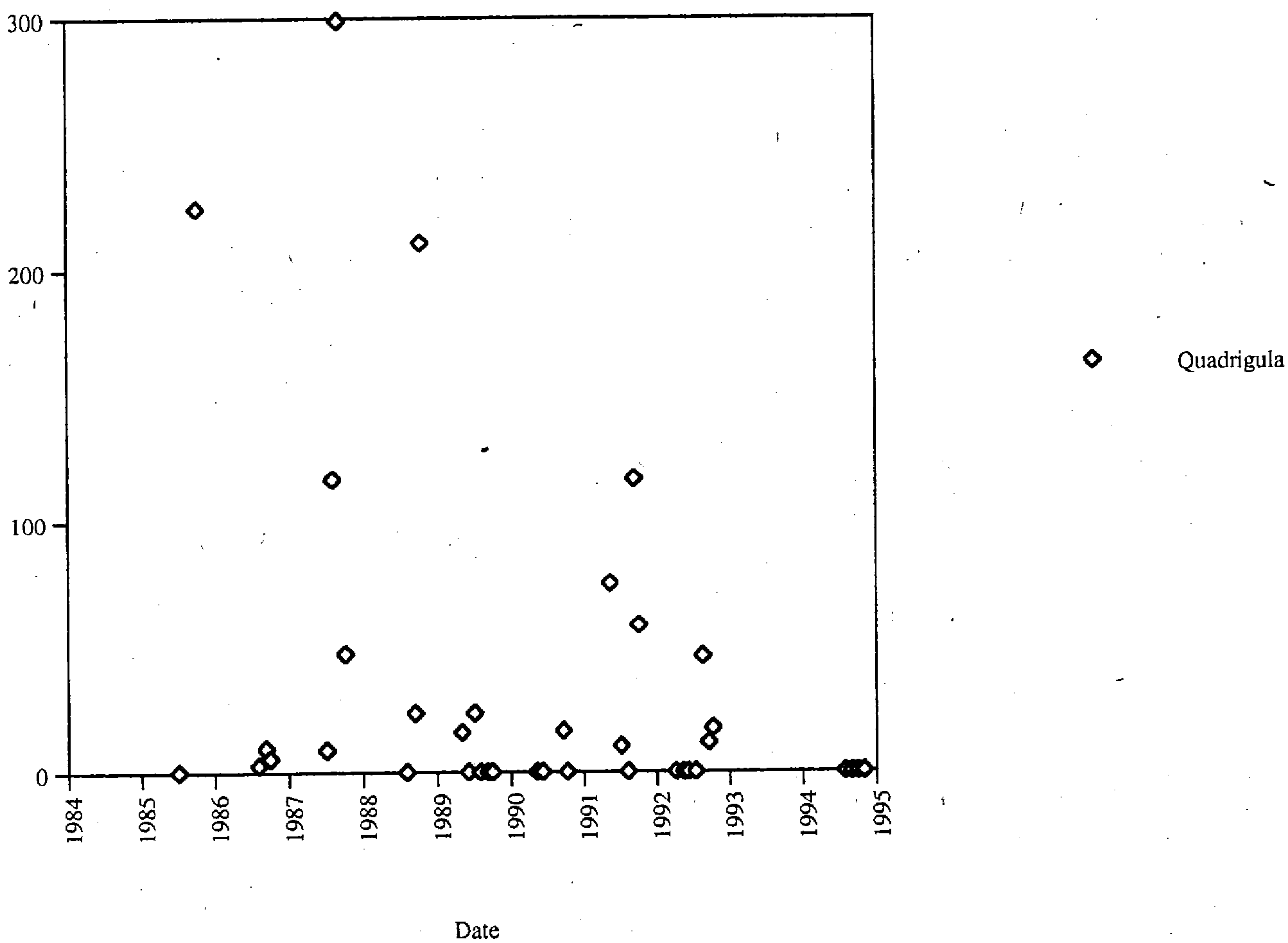


Figure 7.1.7. Stocking Lake Phytoplankton: *Nephrocytium*.

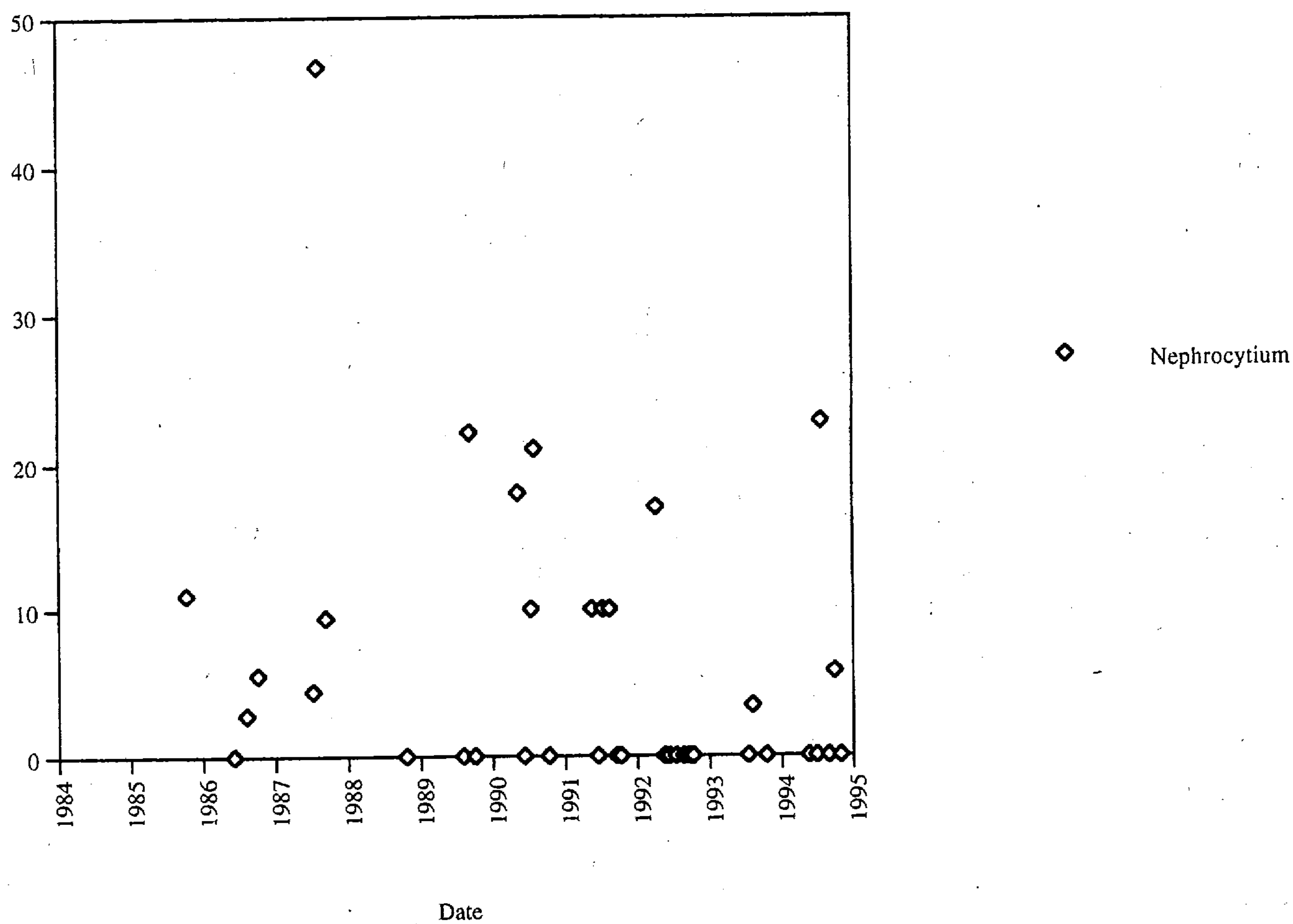


Figure 7.1.8. Stocking Lake Phytoplankton: *Botryococcus.*

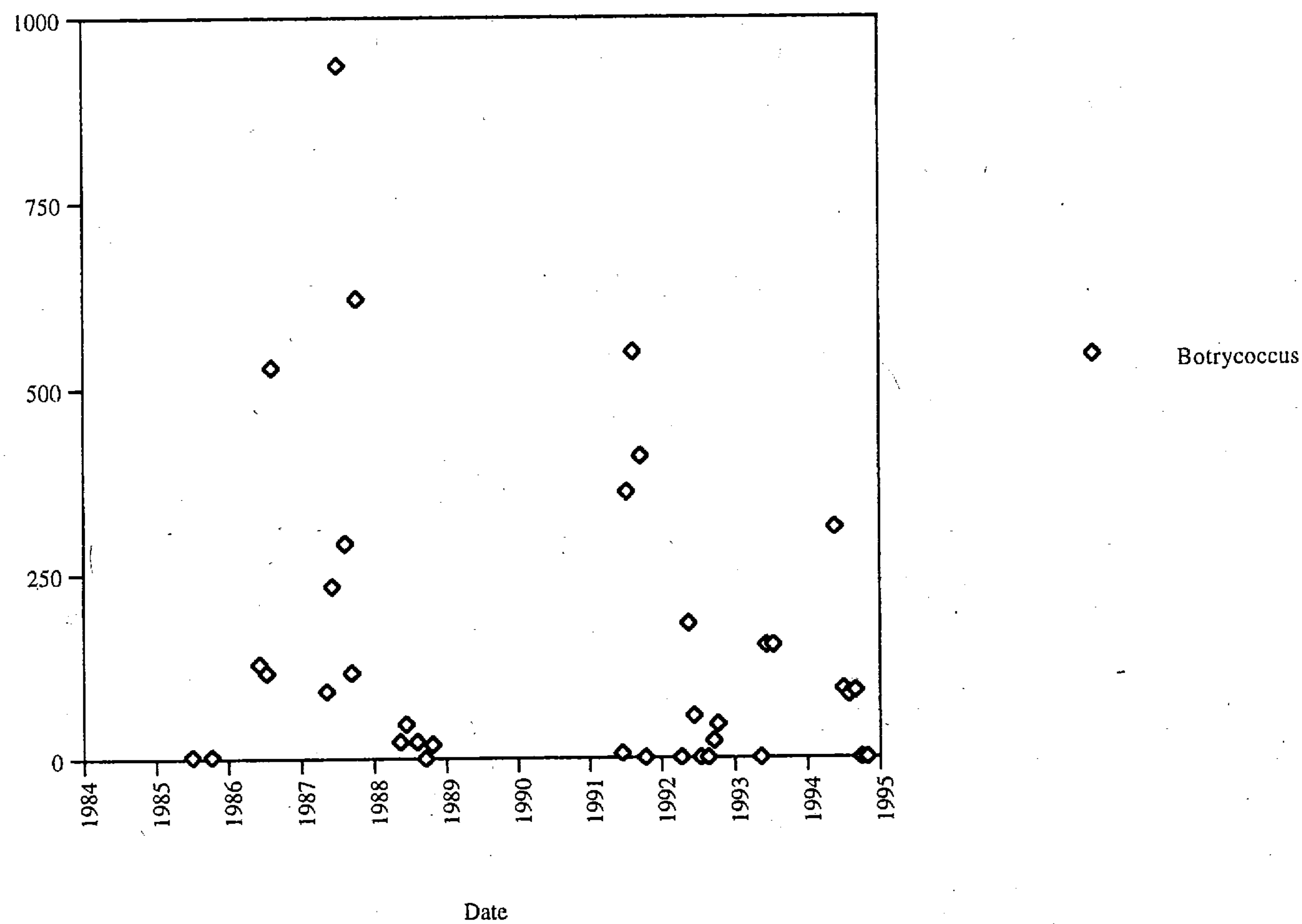


Figure 7.1.9. Stocking Lake Phytoplankton: *Gloeocystis*.

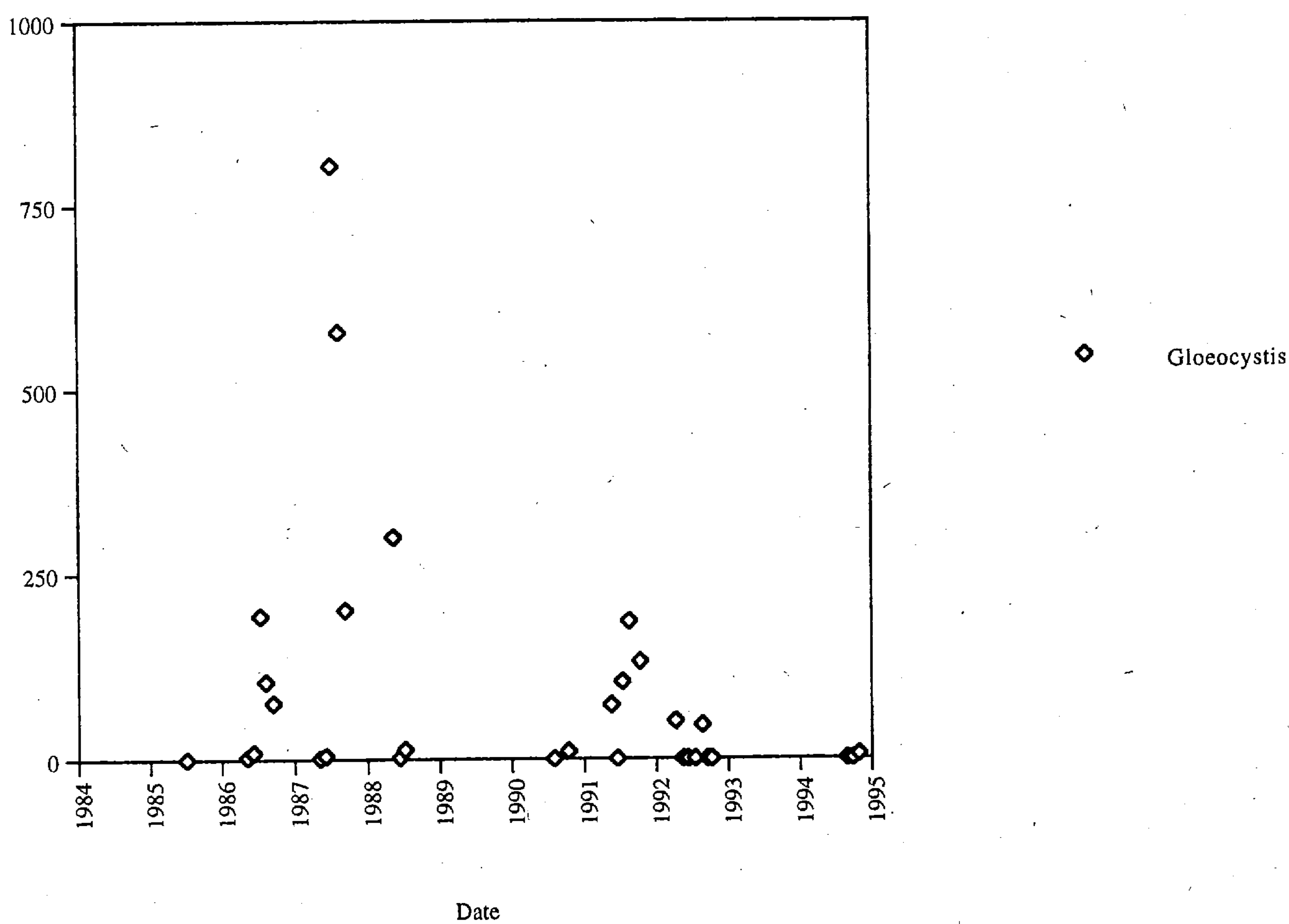


Figure 7.1.10. Stocking Lake Phytoplankton: *Selenastrum.*

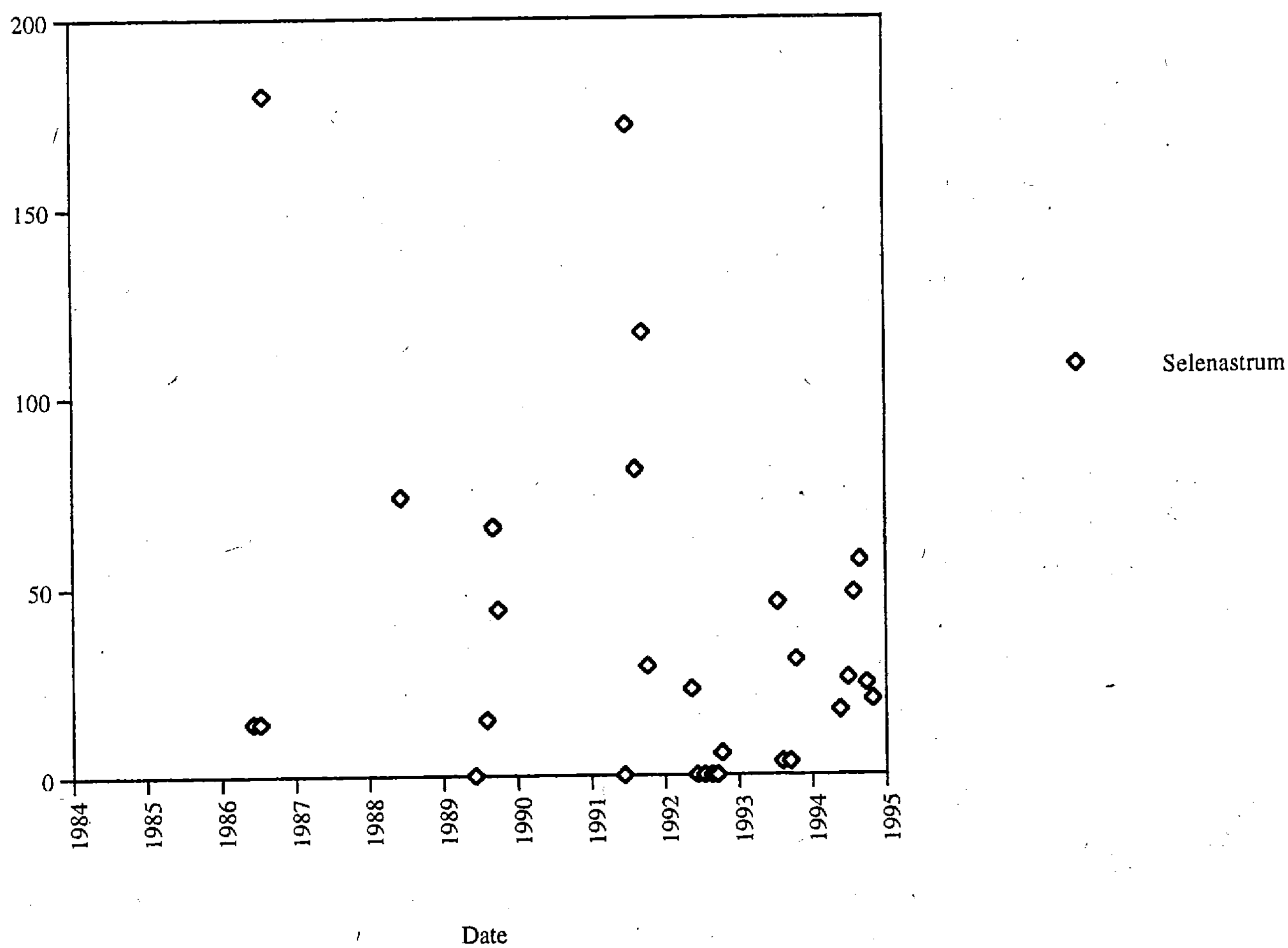


Figure 7.1.11. Stocking Lake Phytoplankton: *Melosira*.

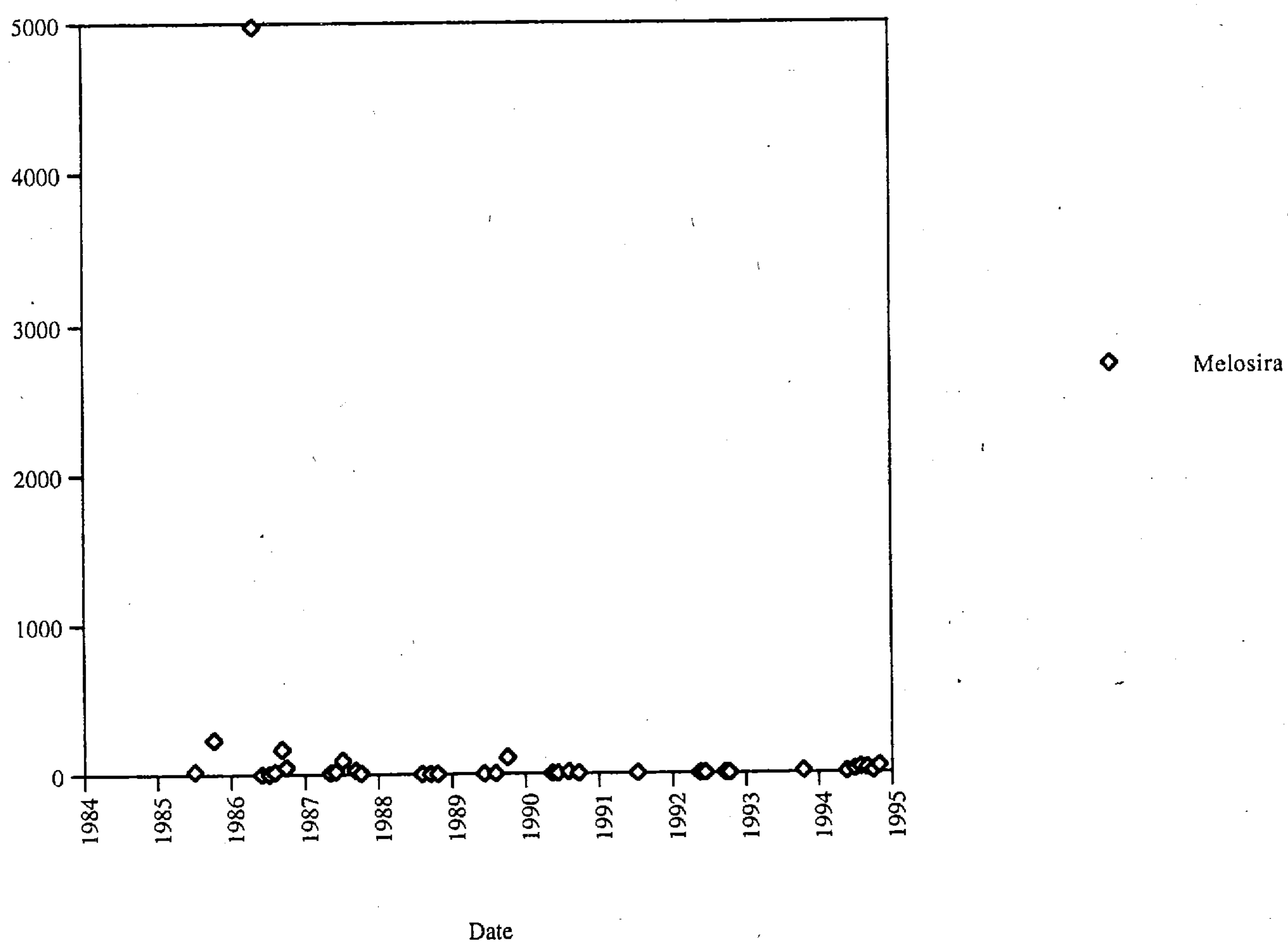


Figure 7.1.12. Stocking Lake Phytoplankton: *Asterionella.*

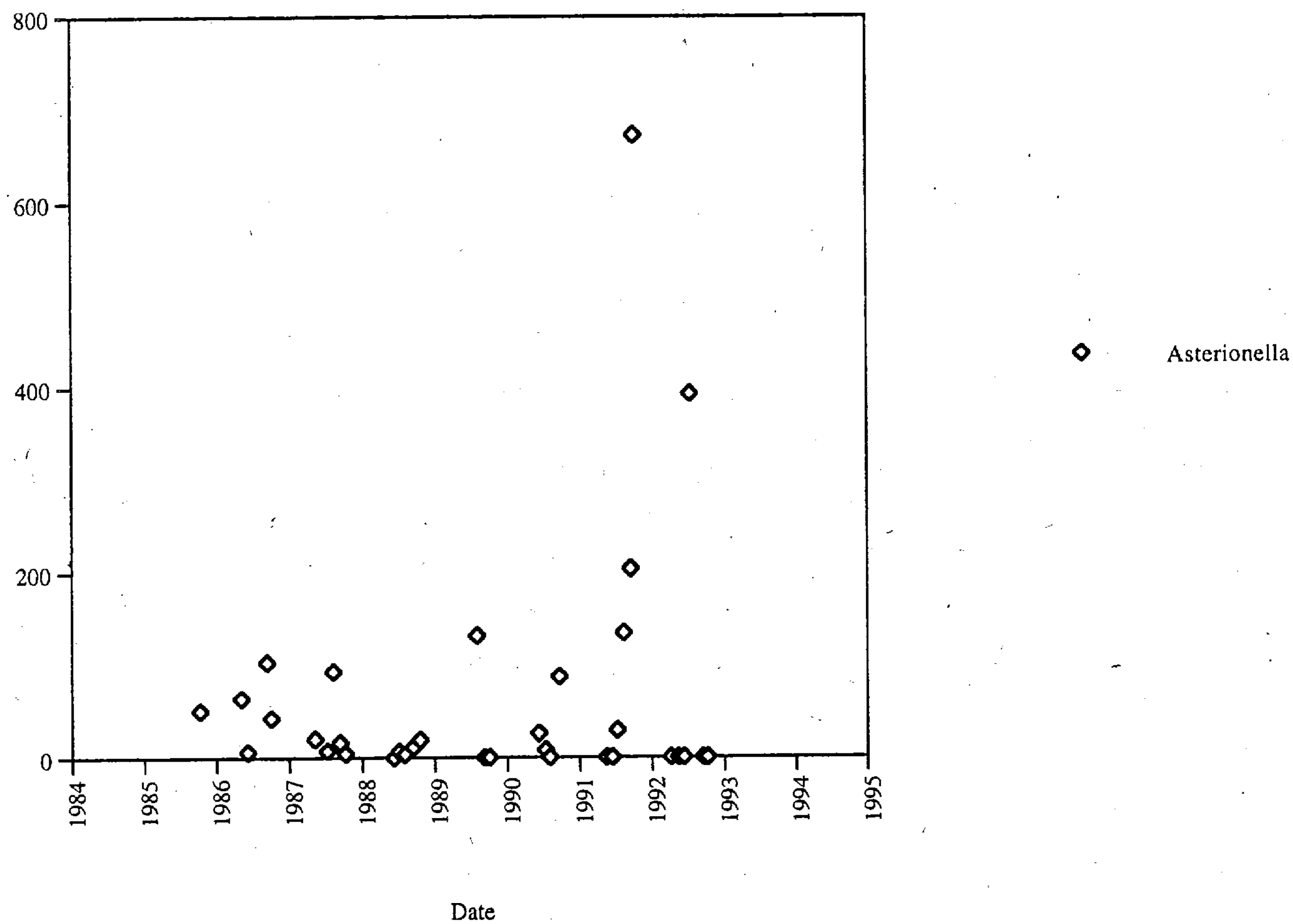


Figure 7.1.13. Stocking Lake Phytoplankton: Total Cells/mL

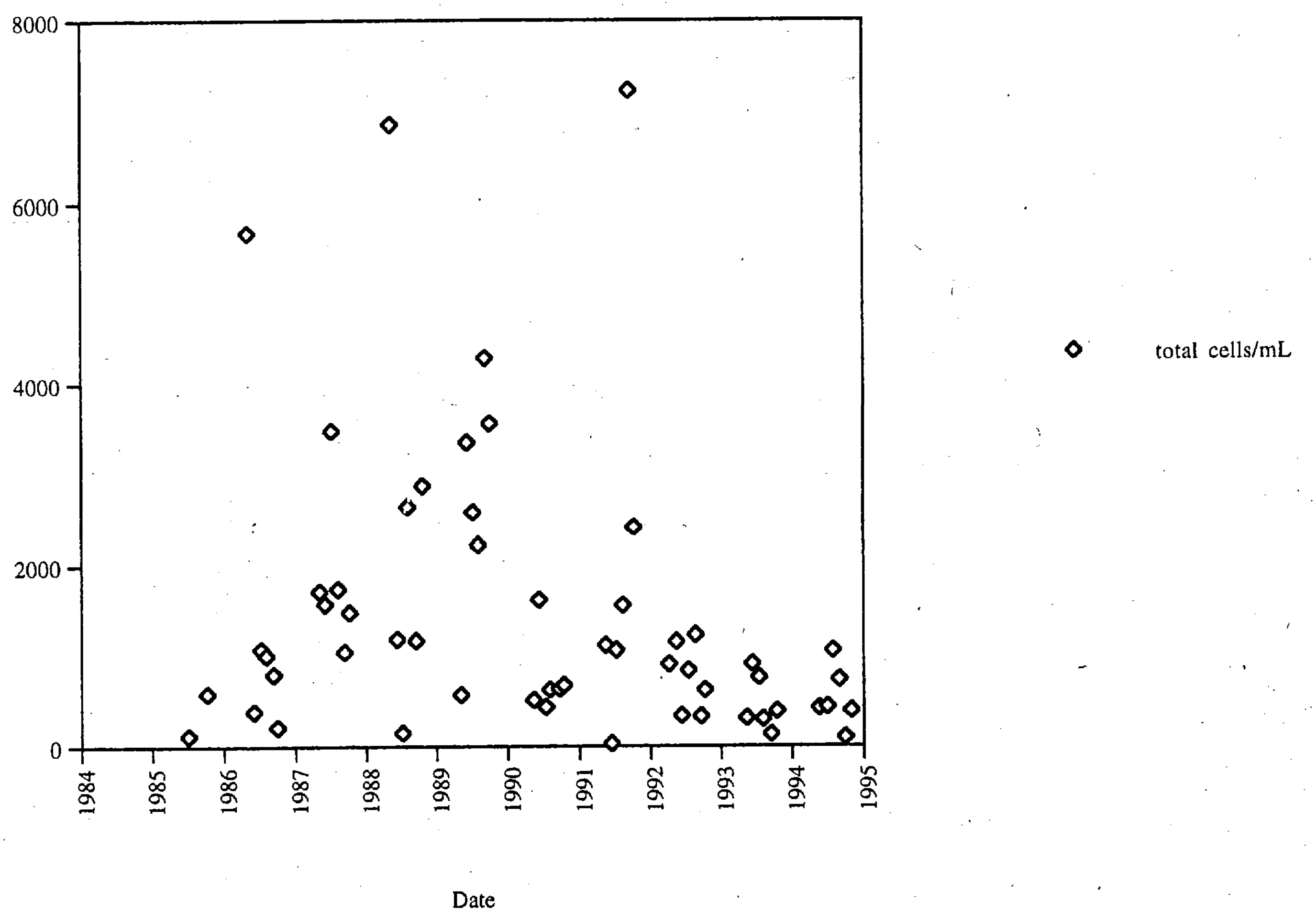


Figure 7.1.14. Stocking Lake Phytoplankton: Chlorophyll a, μg/L.

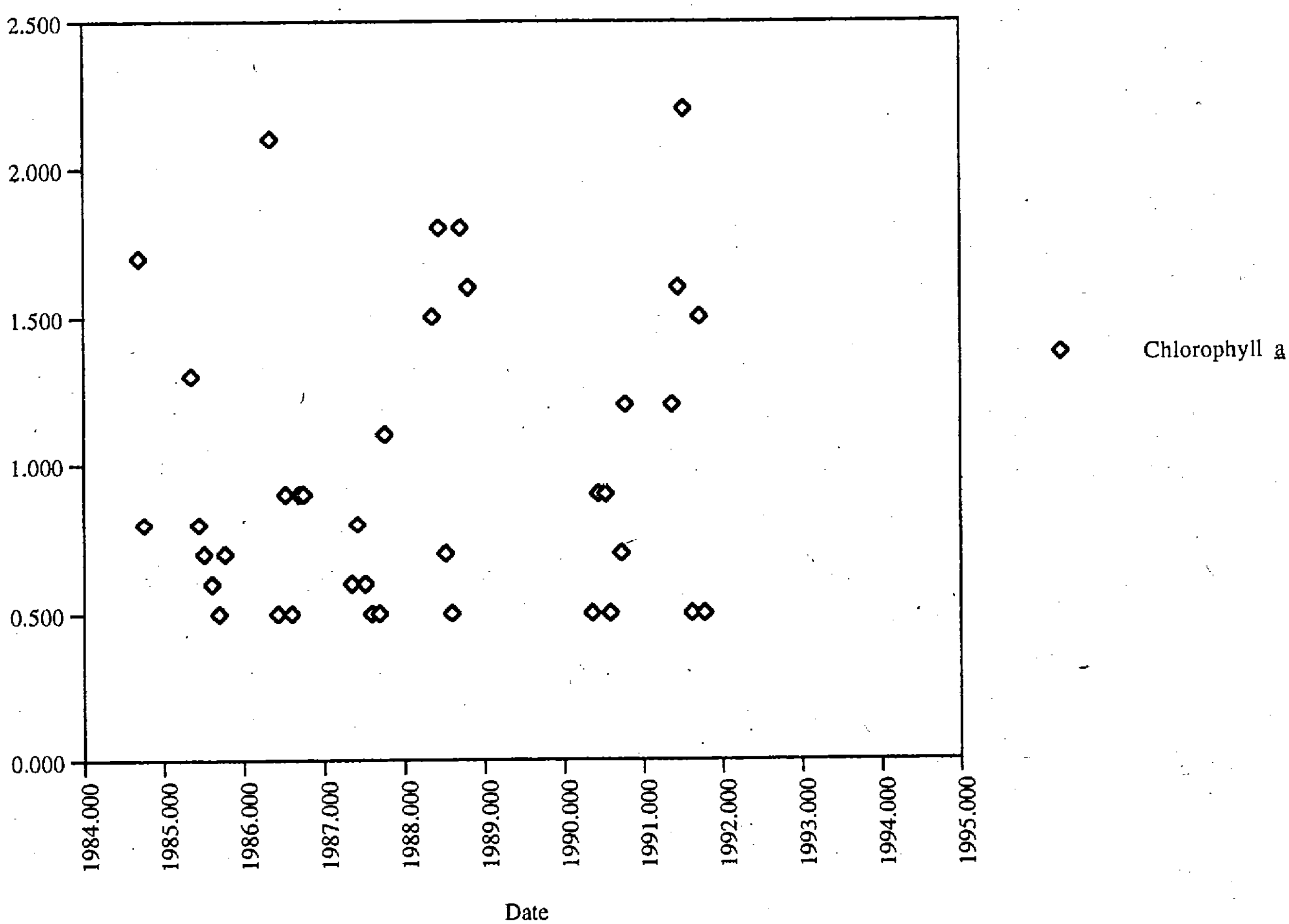


Figure 7.2.1. Stocking Lake Zooplankton. *Diaptomus*.

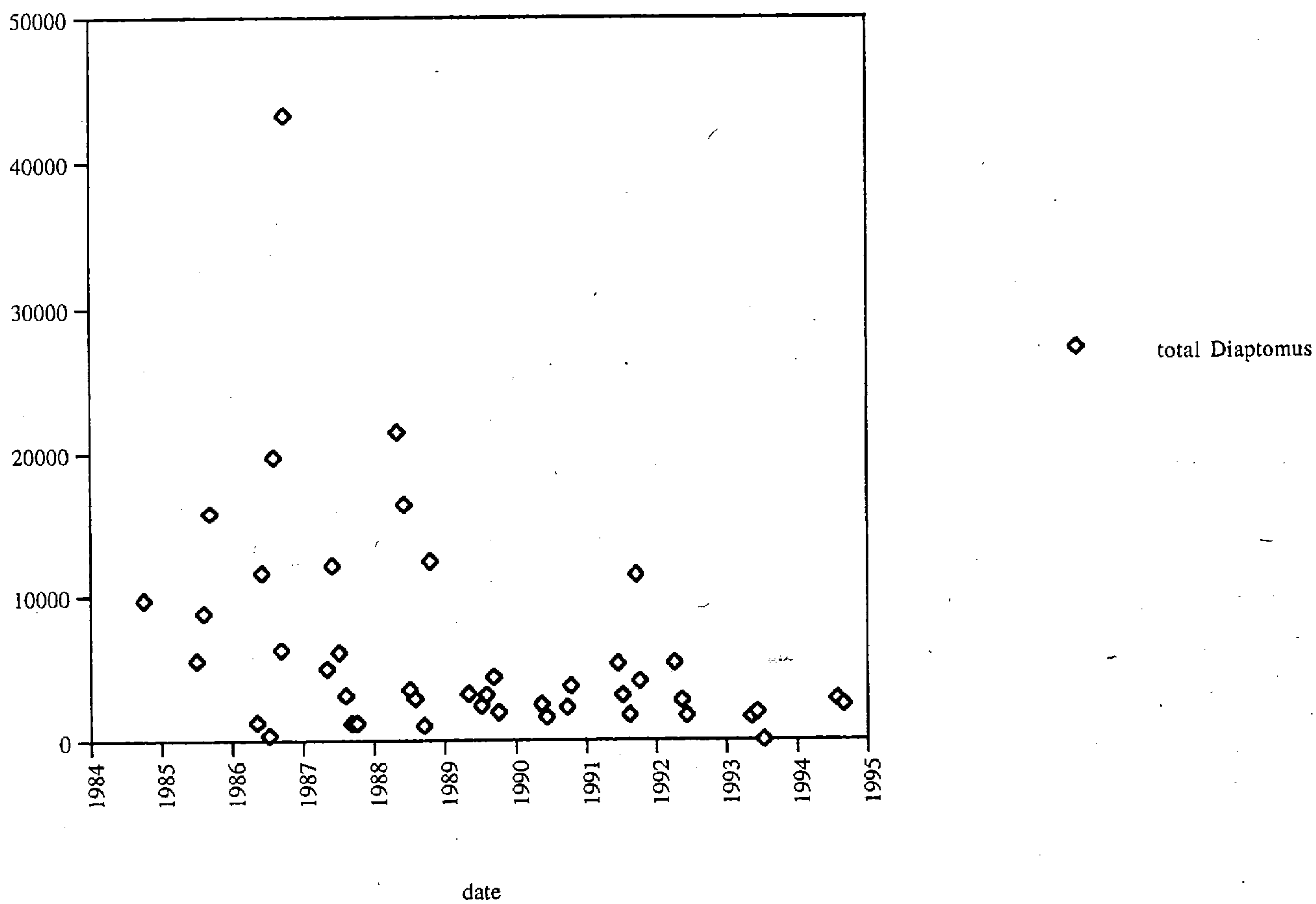


Figure 7.2.2. Stocking Lake Zooplankton. *Epishura*.

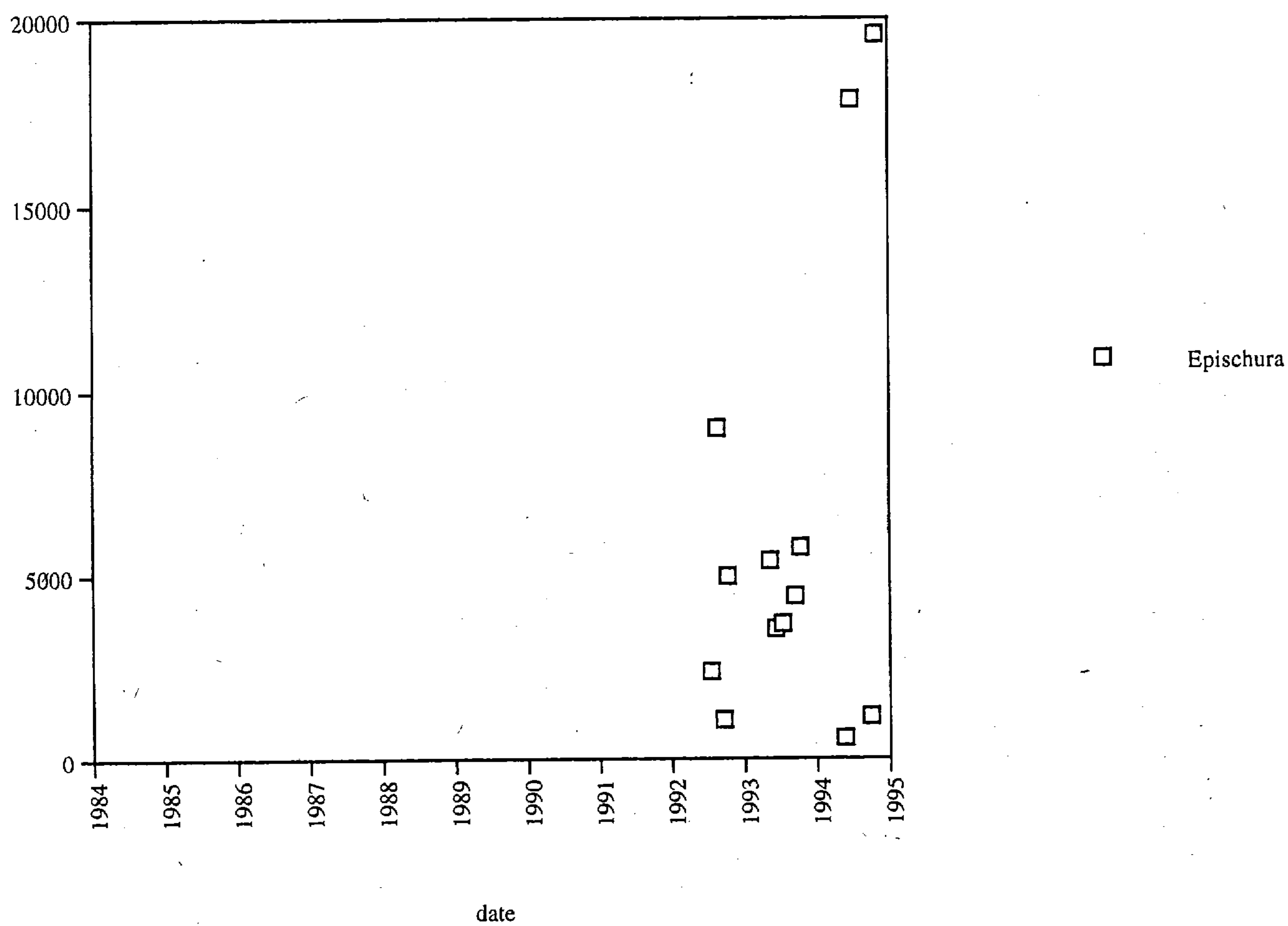


Figure 7.2.3. Stocking Lake Zooplankton. *Cyclops/Diacyclops*.

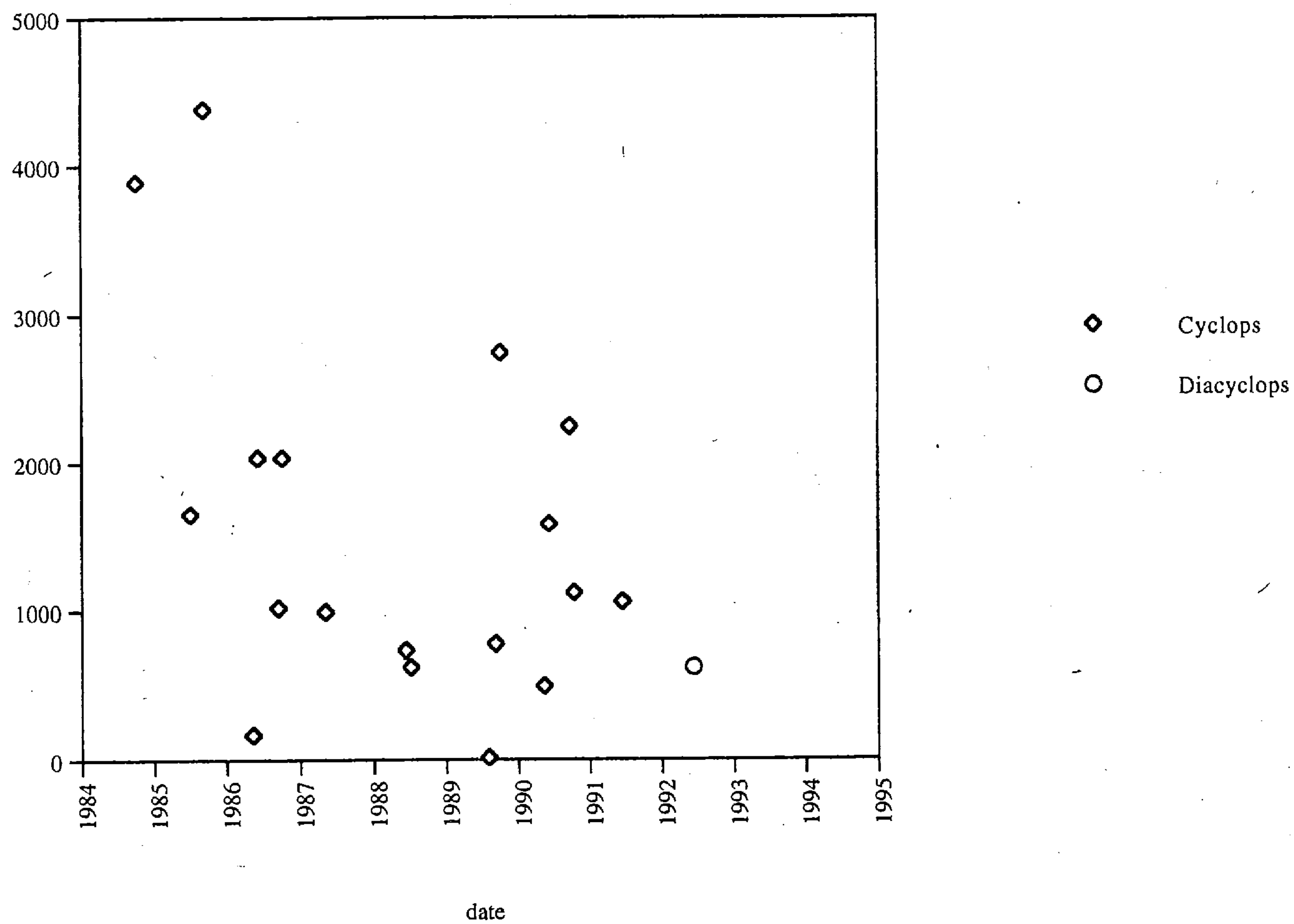


Figure 7.2.4. Stocking Lake Zooplankton. Copepodites/Nauplii.

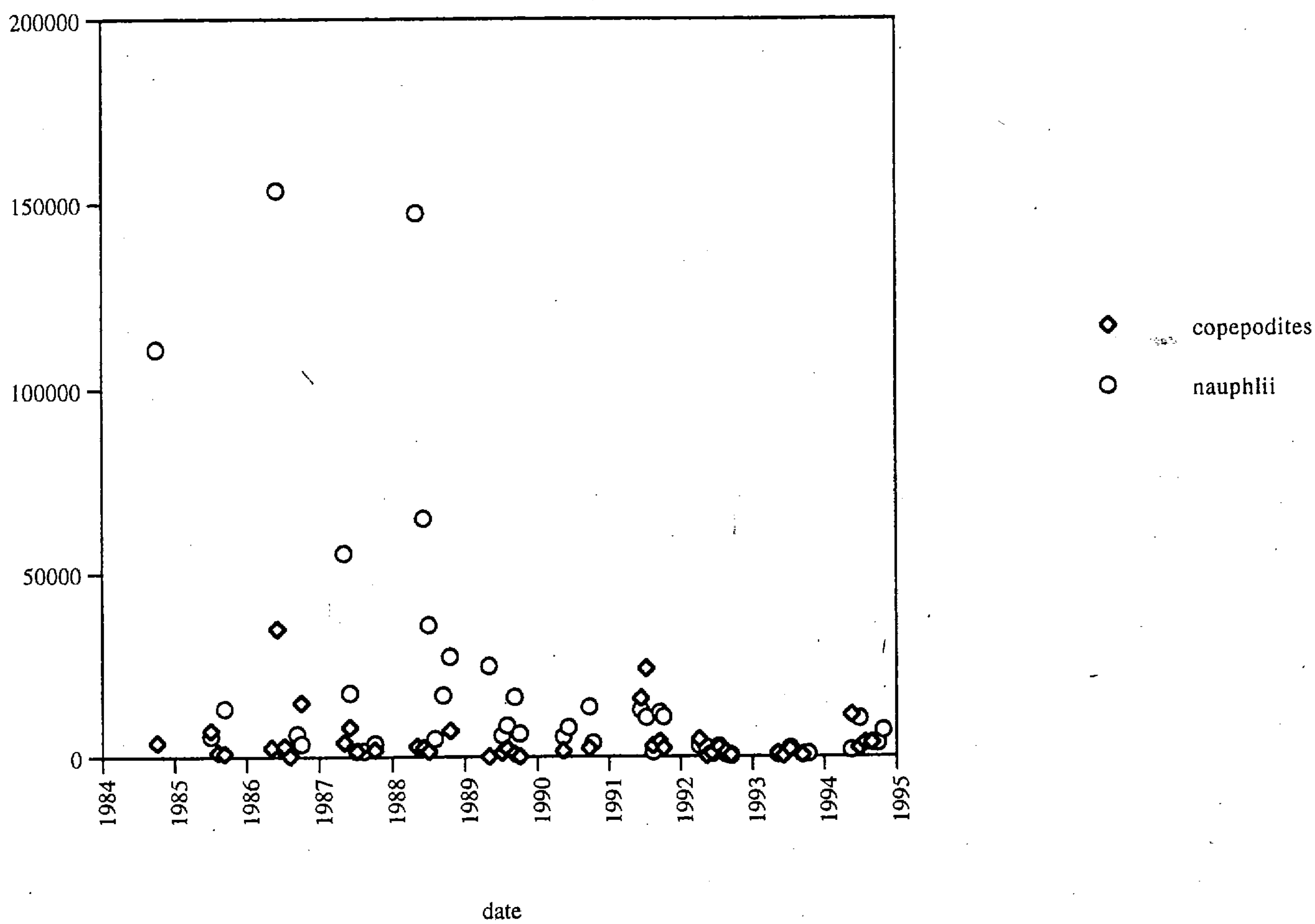


Figure 7.2.5. Stocking Lake Zooplankton: *Bosmina.*

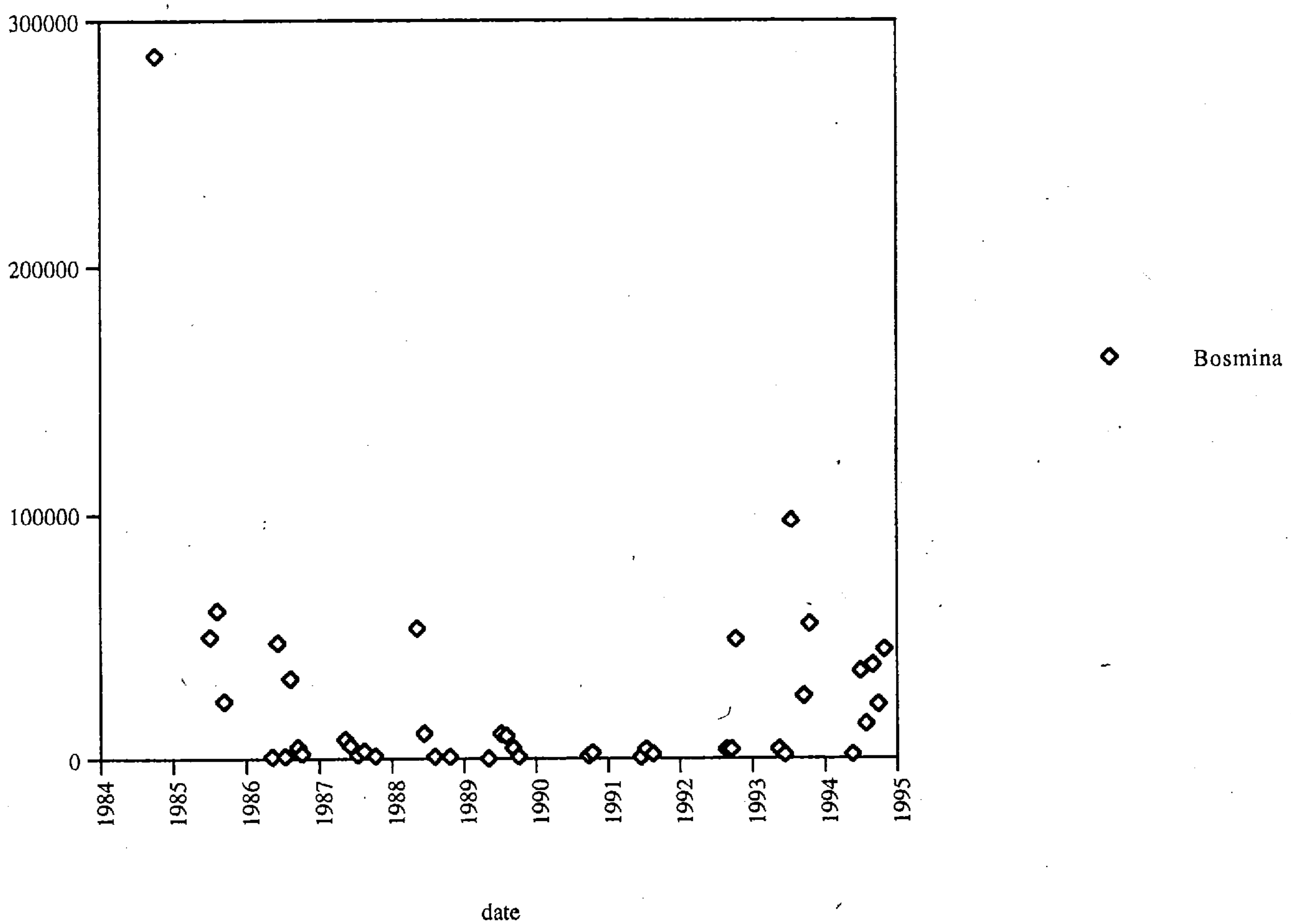


Figure 7.2.6. Stocking Lake Zooplankton: *Holopedium.*

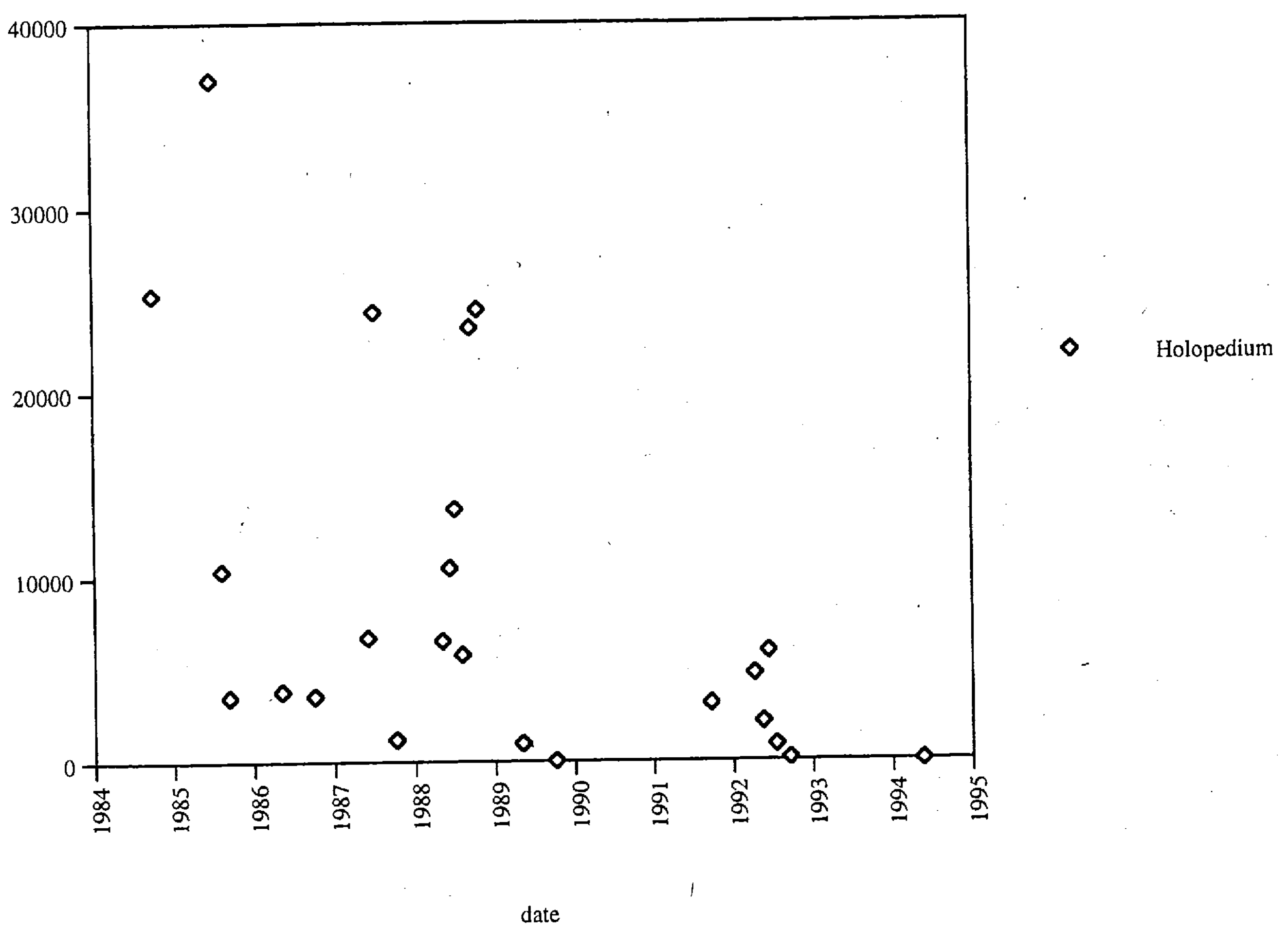


Figure 7.2.7. Stocking Lake Zooplankton: *Diaphanosoma/Daphnia.*

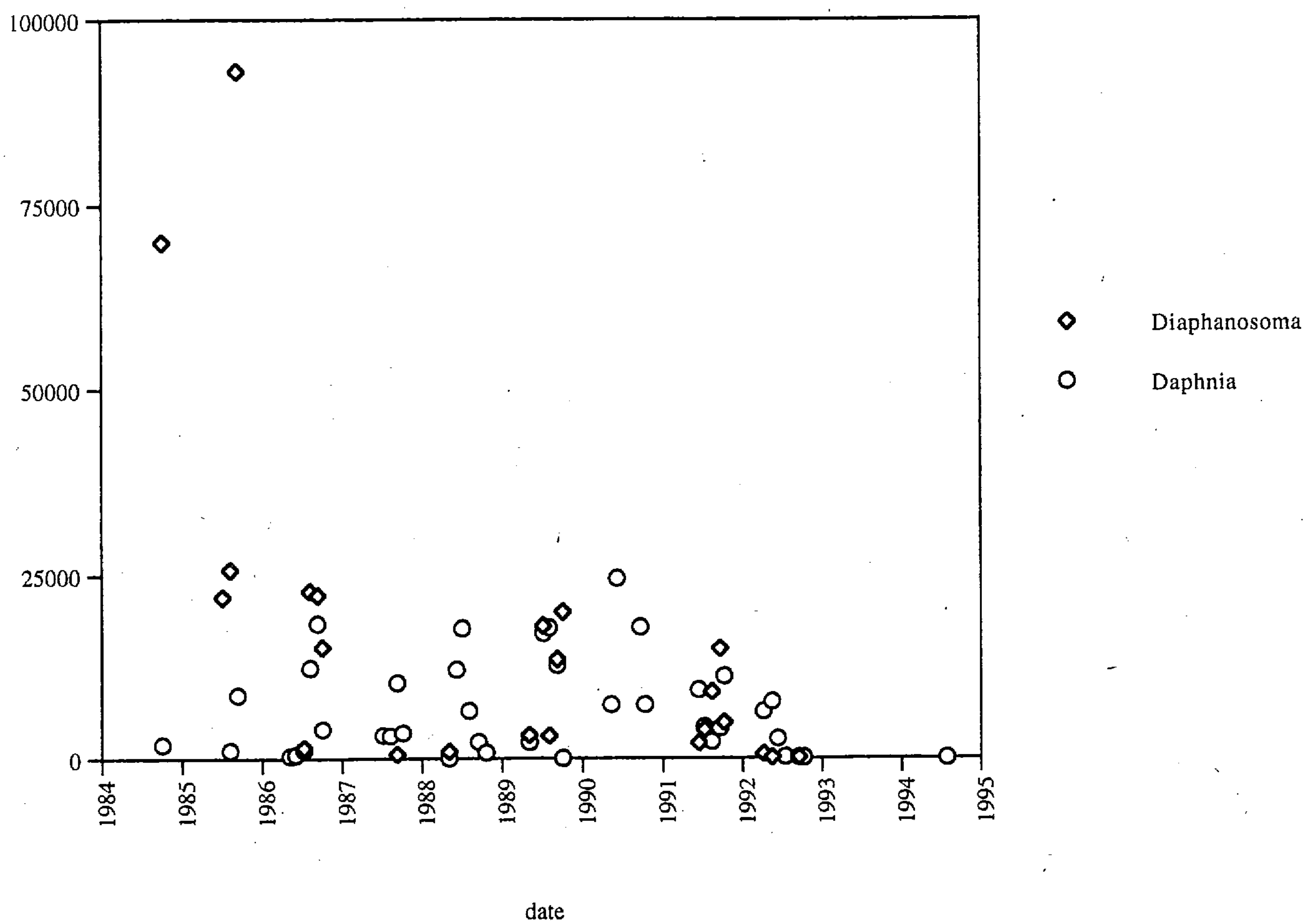


Figure 7.2.8. Stocking Lake Zooplankton: *Polyphemus/Ceriodaphnia.*

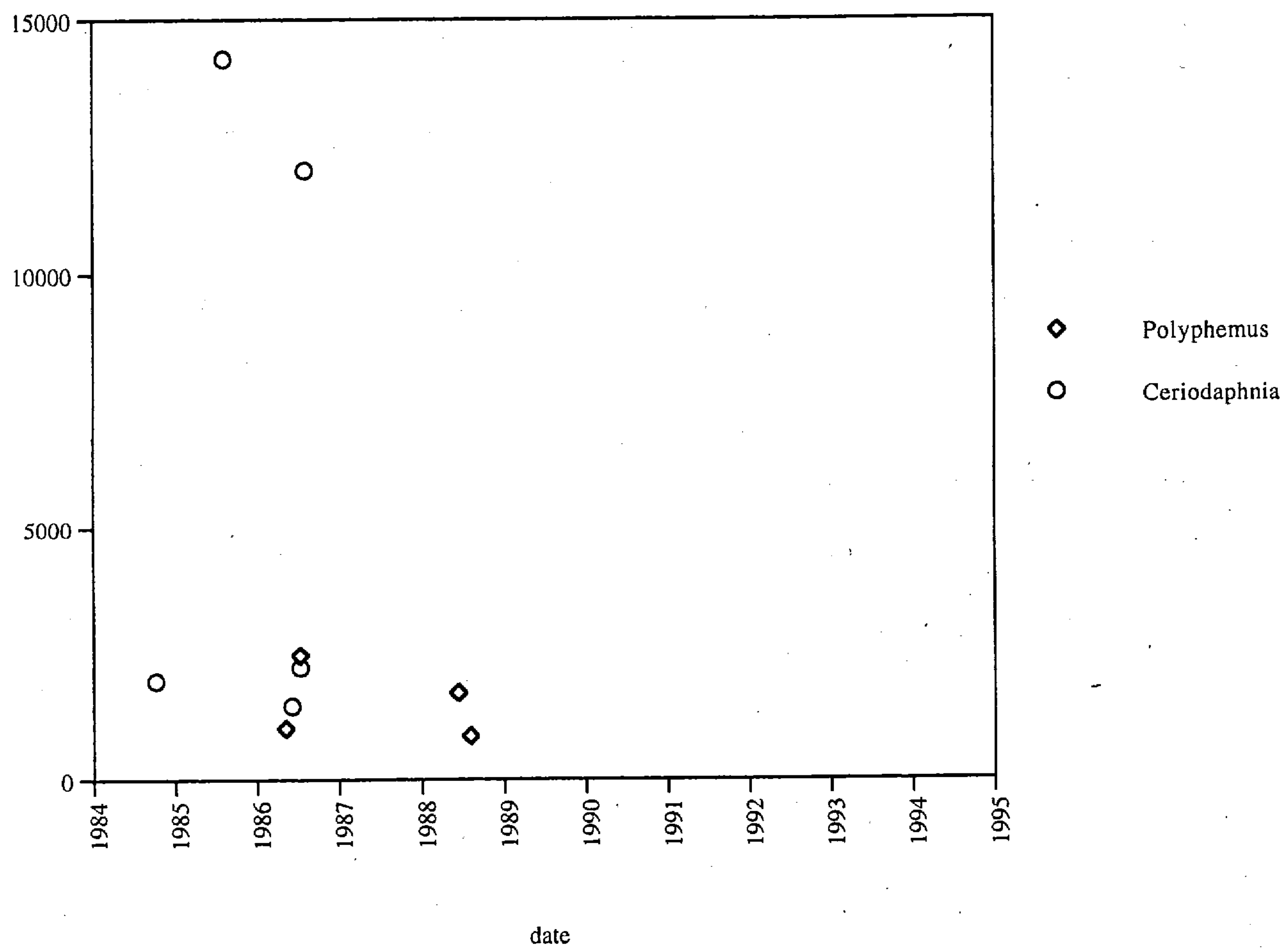


Figure 7.2.9. Stocking Lake Zooplankton: *Keratella.*

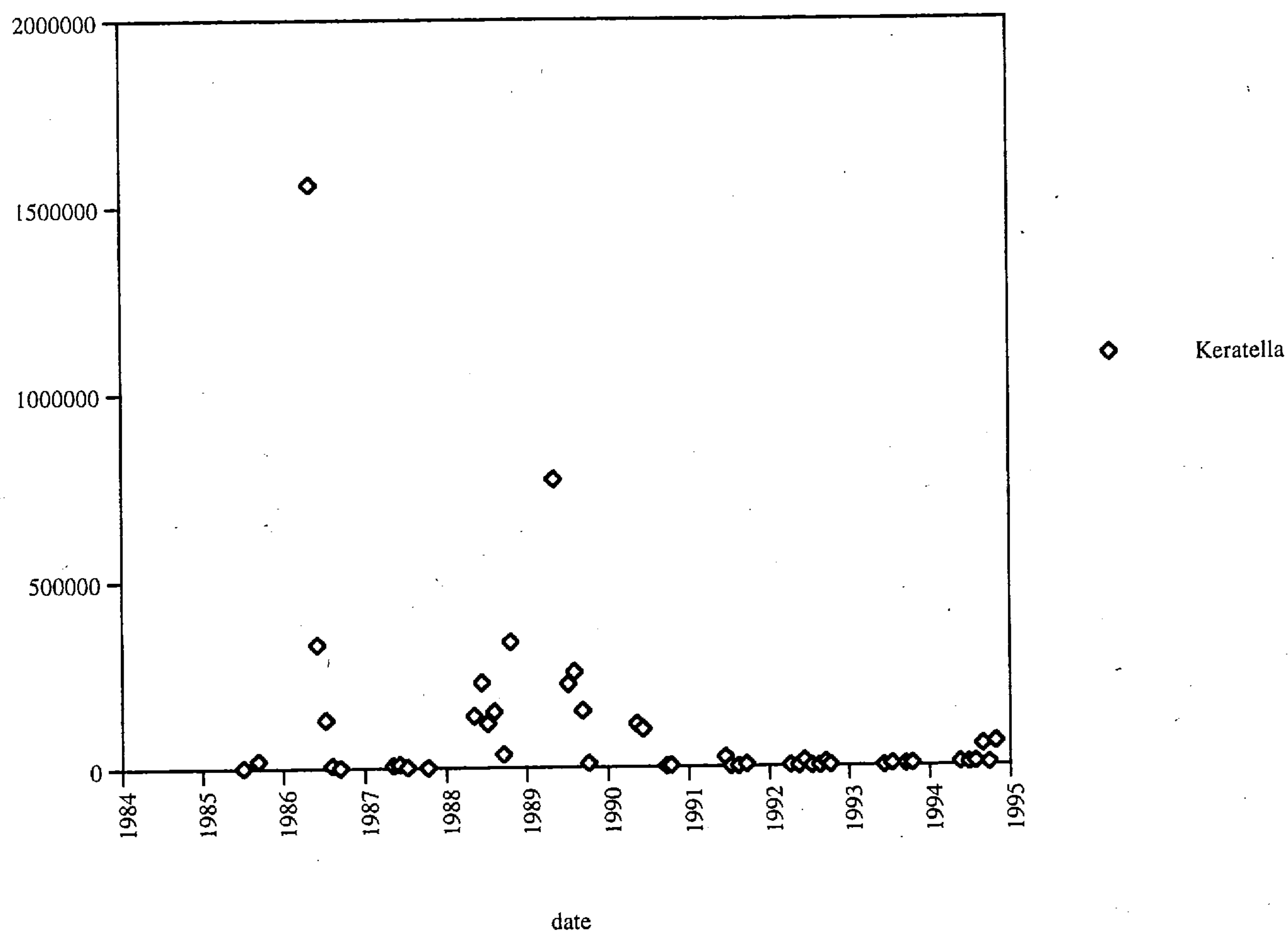


Figure 7.2.10. Stocking Lake Zooplankton: *Kellicottia.*

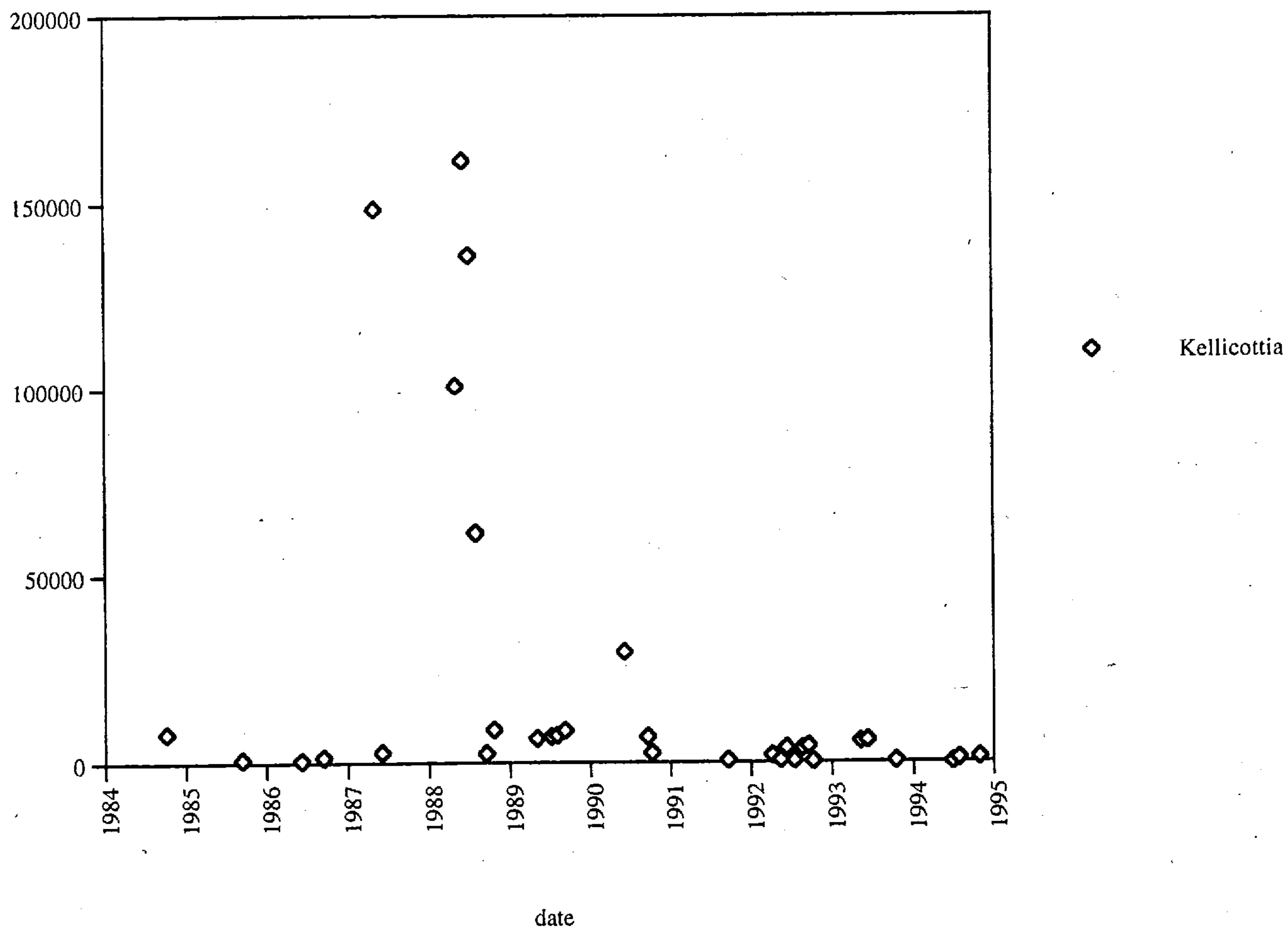


Figure 7.2.11. Stocking Lake Zooplankton: *Trichocera/Filinia/Testudinella.*

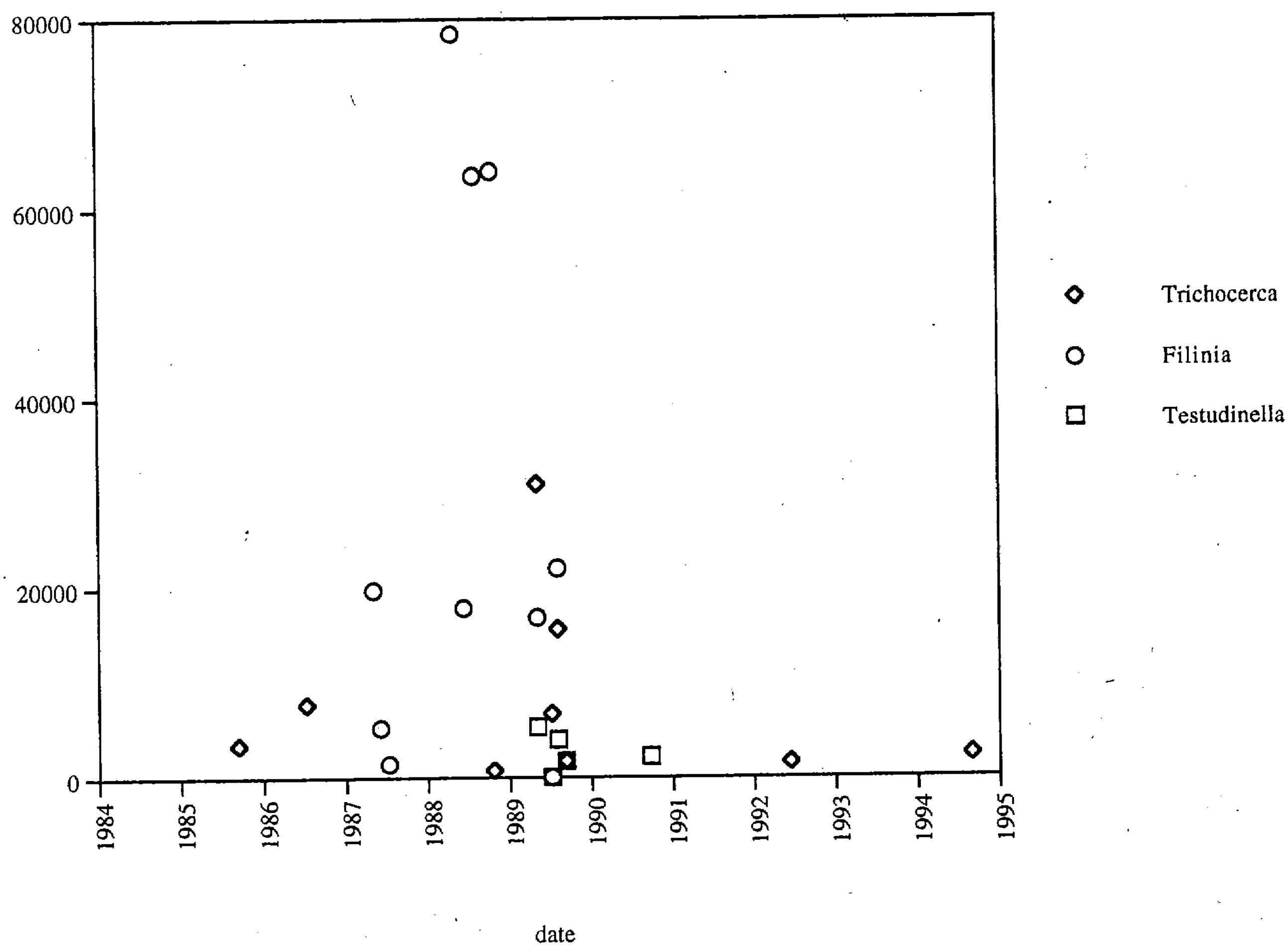


Figure 7.2.12. Stocking Lake Zooplankton: Rare Rotifers.

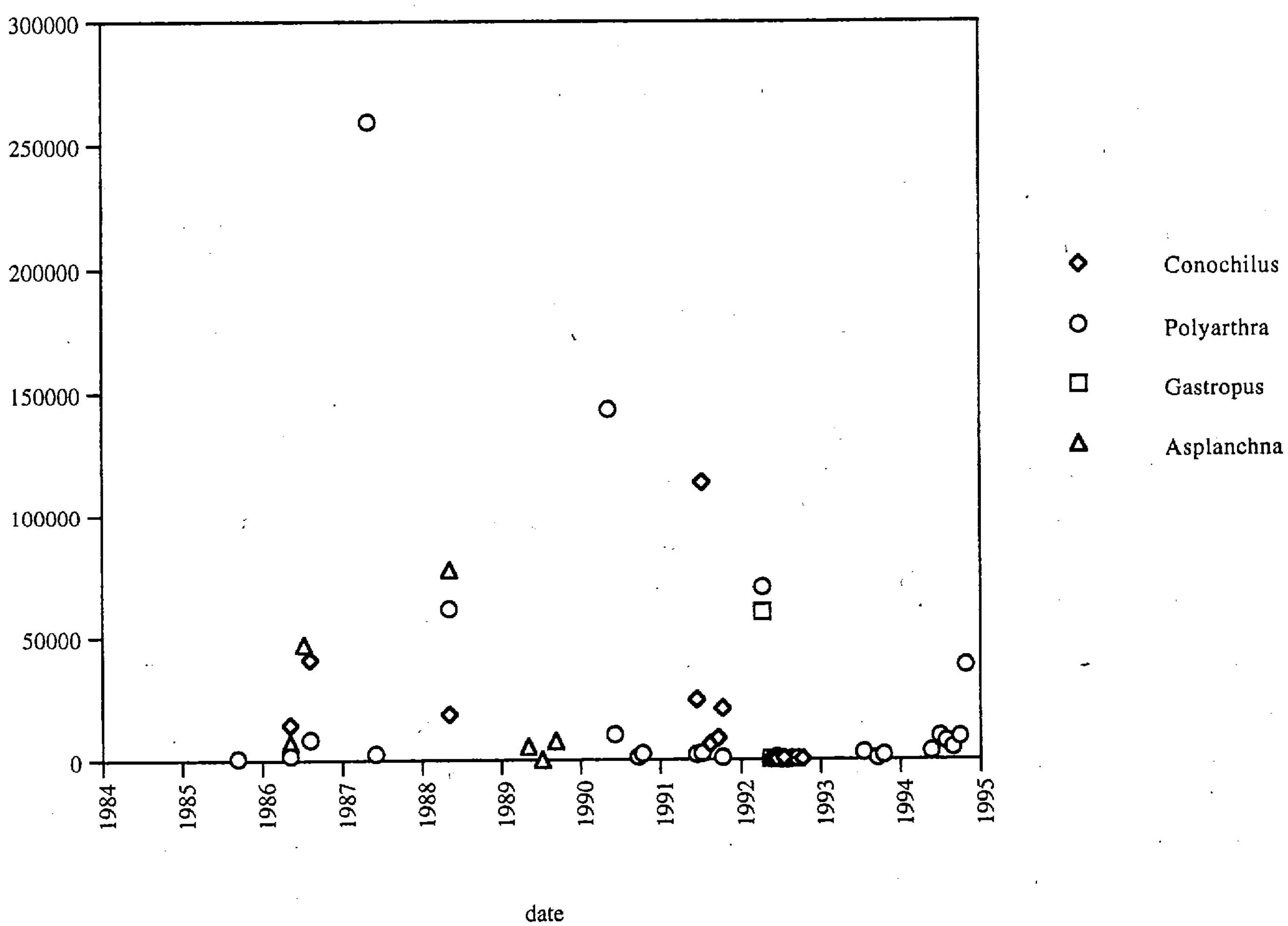


Figure 7.2.13. Stocking Lake Zooplankton: Total Animals/m2.

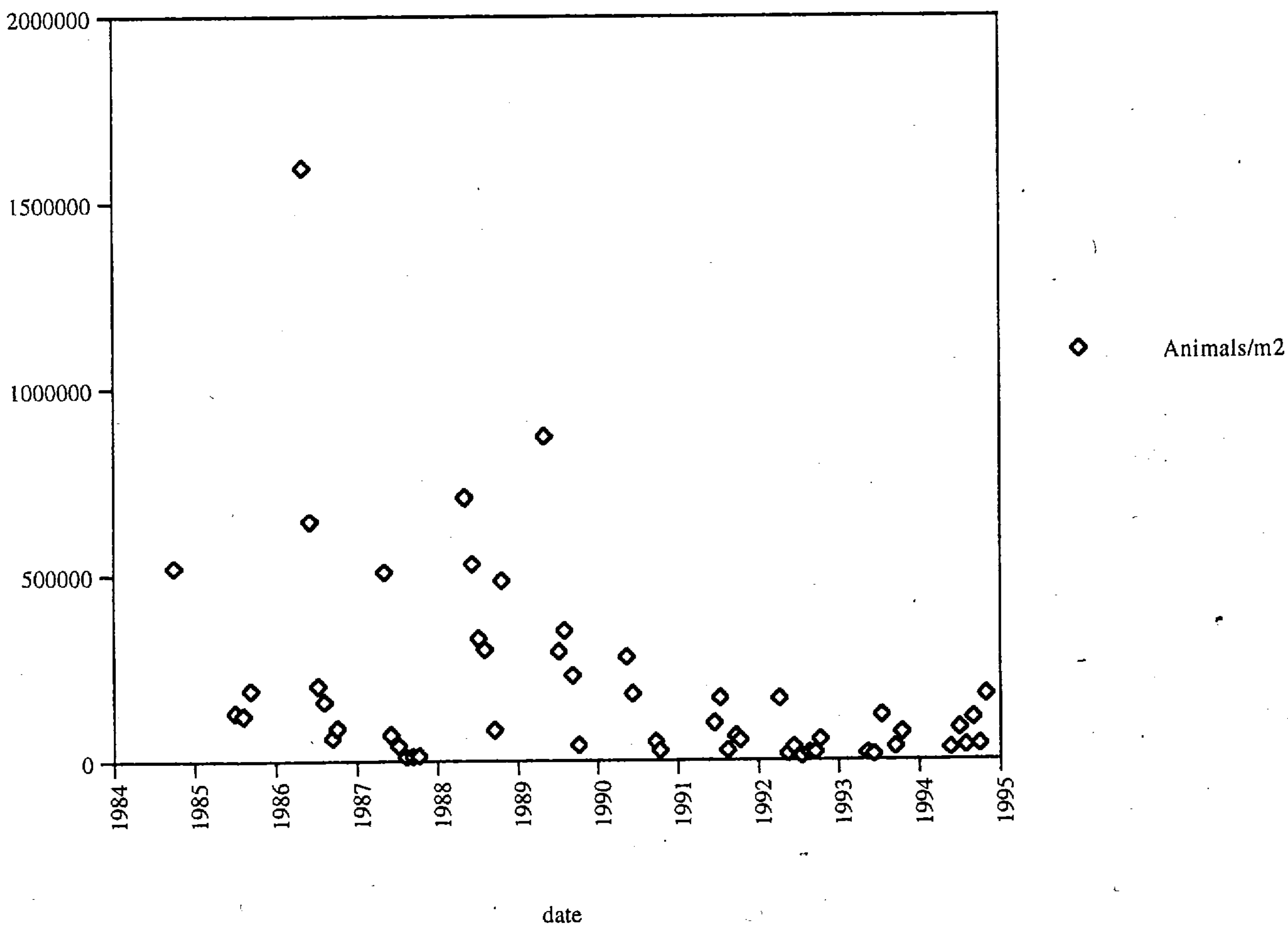


Figure 7.2.14. Stocking Lake Zooplankton: Biomass Comparisons.

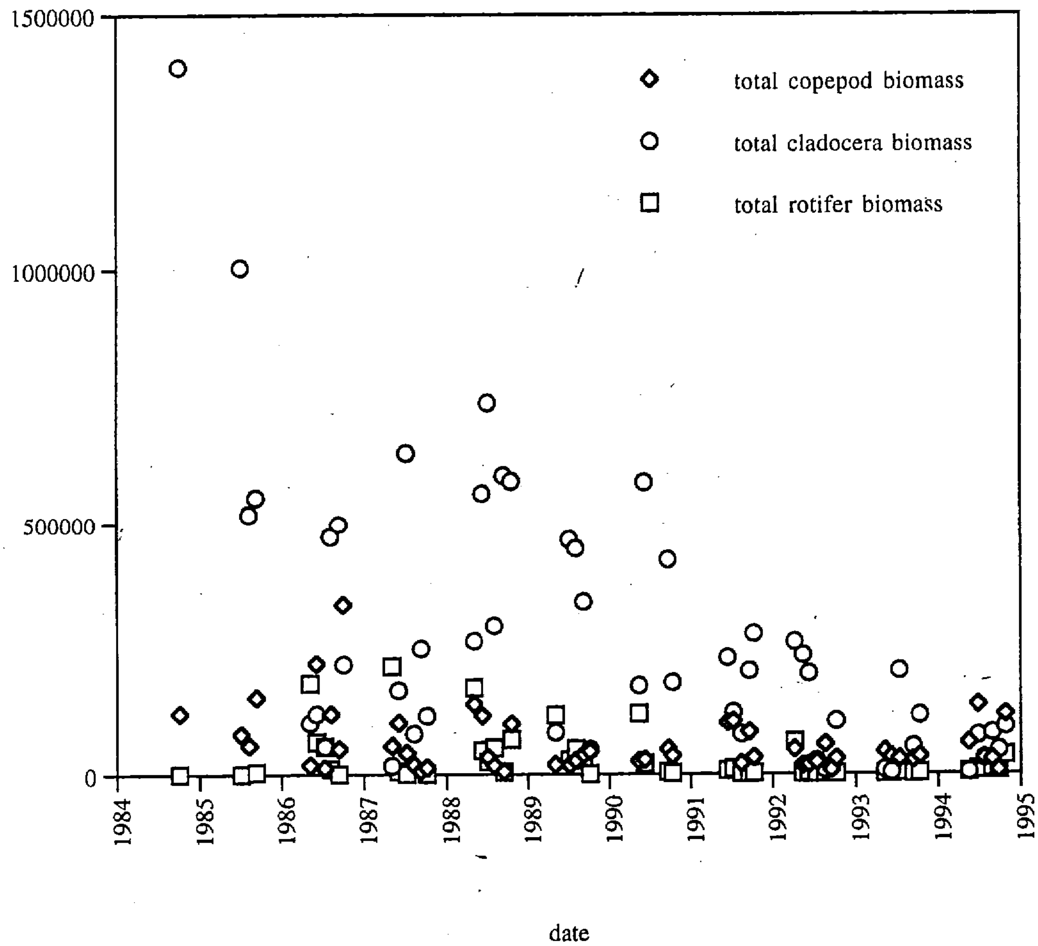
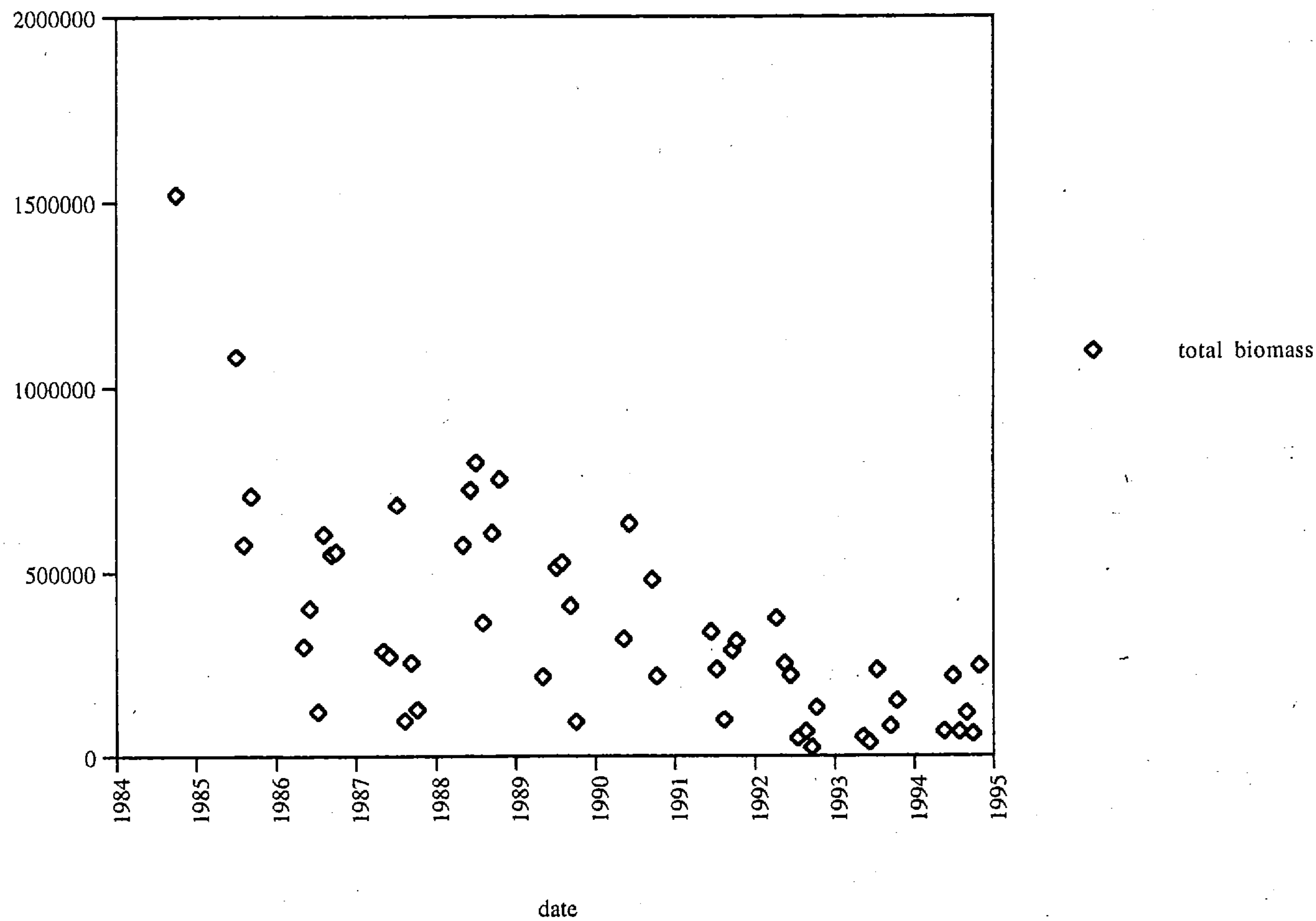


Figure 7.2.15. Stocking Lake Zooplankton: Total Biomass, μg/m2.



8. DISCUSSION

The primary purpose for the trend lakes study was to determine if the study lakes experienced changes that would indicate acidification. In response to an increasing level of acidification in many eastern North American lakes considerable effort has been directed towards determining the effect of this process on the plankton communities. Marmorek (1990) conducted a comprehensive review of studies looking at acidification on zooplankton taxa, and prepared a scheme that characterises observable effects on the zooplankton in response to increased acidic inputs. Of particular value to this study are the whole community level and order and genus level indicators proposed. According to Marmorek the following dynamics have been reported in association with lake acidification.

At the whole community level:

- A decrease in the total number of crustacea per unit volume.
- A decrease in crustacean dry weight biomass.
- A decrease in the total number of rotifera per unit volume.
- An increase in rotifer biomass relative to total zooplankton biomass.

At the order and genus level:

- A decrease in cyclopoid biomass relative to total crustacean biomass.
- A decrease in Daphnia biomass relative to total crustacean biomass.

The phytoplankton community has received some attention with regard to the effects of acid loading as well. Both controlled acidification experiments and analysis of long term phytoplankton data sets have been completed, with a range of effect being observed. The following is a summary of the effects of declining pH on the phytoplankton community reported in two such studies:

Findlay (1990)

- reduced community diversity
- diatoms and cyanophytes eliminated below pH 6.0
- cyanophytes eliminated below pH 5.3
- shift in community structure from chrysophycean dominance to chlorophyte and dinoflagellate dominance
- no increase or decline in epilimnetic biomass

Findlay (1991)

- shift in community structure to cyanophyte and dinoflagellate dominance
- increased proportion of smaller phytoplankton genera
- species diversity decreased by 30%
- phytoplankton biomass increased by 40%

None the above trends appear in the phytoplankton or zooplankton such as to indicate a trend to acidification in any of the study lakes. Analysis of the chemical data presently underway (Phippen, 1995) reveals that pH values (Orion Ross method) in the study lakes remained at near neutral over the ten year study period, with a low value of 5.6 observed once in Jacobs Lake. Both Marmorek and Findlay report that few of the above listed effects are observable in the phytoplankton and zooplankton at these pH levels, with most effects obsevable below 5.6. Given this information it appears that the plankton communities in these lakes are unaffected by acidic inputs. If trends associated with acidification were noted it would be difficult to attribute them to increased acidic inputs given the extent of the disturbances (detailed in earlier chapters) that occurred within the lakes over the period of study.

There is considerable difficulty in distinguishing disturbance caused changes in the plankton populations of these lakes from trends or changes which may be part of natural processes. Wetzel (1975) reports that seasonal changes in phytoplankton are very repetitious from year to year, and that species composition follows a regular, predictable cycle. Reynolds (1984) and Hutchinson (1957) reports similar findings. A dominant feature of the six study lakes is a very high degree of variability in numbers of individual taxa and community composition, with values often ranging over several orders of magnitude for a single parameter. This occurs both on a seasonal and year to year basis for many taxa. The result is what appears to be a marked lack of periodicity within the plankton of these lakes. Current work with the Spectra 3 statistical filter designed by Commonwealth Scientific Ltd. of Victoria further confirms the lack of periodicity (Clark, 1995). Dr. Clark has examined the 5 most dominant phytoplankton taxa for each of the six lakes and found that none of these displays consistent perioicity. It is unclear if this variability is a natural feature of a small coastal B.C. lake, or if it is disturbance induced. Cross referencing plankton dynamics with trends observed in the chemical data should allow correction for some of the disturbances.

Table 8.1. provides a summary of some key phytoplankton and zooplankton community characteristics. This table reveals a number of similarities, as well as some significant differences All of the study lakes show a high level of community diversity, with between 80 and 99 phytoplankton genera and 22 to 31 zooplankton genera appearing over the ten year study period. The dominant phytoplankton in Maxwell, Old Wolf, and Spectacle lakes is *Dinobryon*, a Chrysophyte genera. *Dinobryon* is significant in the other 3 lakes as well, being the second most dominant phytoplankton in Lizard and Jacobs, and the third most dominant in Stocking. Jacobs is the only study lake dominated by a diatom genera, specifically *Navicula* , and Lizard Lake is the only one of the set dominated by *Oocystis*, a Chrysophyte. In general the composition of the dominant and sub dominant categories is very similar in all the lakes. This indicates that although there is much fluctuation in phytoplankton community composition overall, the majority of this variability occurs in the uncommon and rare taxa.

which 4?

Chlorophyll a values range from approximately 0.5 to 6.0 ug/L for four of the lakes. Stocking has the lowest maximum value at 2.2 ug/L, and Old Wolf displays the highest maximum value at 8.2 ug/L. Maxwell Lake has the highest mean chlorophyll a value of 2.94 ug/l, and Stocking the lowest at 0.97 ug/L. It is curious that Maxwell should display the highest mean chlorophyll concentration given that it has the lowest phytoplankton biomass on average. Total number of phytoplankton expressed as a ten year mean indicates that Old Wolf is the most productive of the lakes in terms of overall numbers of phytoplankton, however, total numbers are influenced greatly by isolated bloom events which may skew numbers upward. Such is the case in Jacobs Lake. Two figures are given for mean total number in Jacobs; the first number includes an *Aphanothecē* bloom of 234,000 cells/mL, while the second figure excludes this event. Maxwell has the lowest mean total number of phytoplankton next to Jacobs, which is indicative of the low biomass measurements for Maxwell. The low numbers observed in Jacobs are consistent with the physical features of this lake discussed in earlier chapters.

The zooplankton community within the study lakes shows a similar pattern to that observed in the phytoplankton. The dominant copepod in five of the six lakes is *Diaptomus*. The exception to this is Maxwell lake which is dominated by *Cyclops*. The cladoceran component of the zooplankton is dominated by *Bosmina* in Jacobs, Stocking, and Maxwell lakes, and *Daphnia* in Lizard, Old Wolf and Spectacle lakes. In all six lakes *Keratella* is the dominant rotifer.

An important component of the zooplankton data was the observation of *Chaoborus* in a number of samples from four of the study lakes. *Chaoborus* is a Dipteran taxa with a large, predatory aquatic larval stage. The largest invertebrate animal in the pelagic zone, *Chaoborus* larvae are particularly vulnerable to predation by fish, and in turn predate heavily upon the larger of the copepod and cladoceran zooplankters. As a result Chaoborus can be assumed to have a significant effect on both numbers and species composition of the zooplankton. Additional effects are likely to occur in the phytoplankton as well given the predation on phytoplankton by zooplankton.

Chaoborus larvae are strong swimmers. This enables them to avoid capture, and hence they require specific sampling technique. Consequently the net tows used to collect the zooplankton samples in this study cannot be considered to have sampled this animal quantitatively. However, the presence or absence of this organism may allow some inference of fish/plankton interactions. One dynamic observed in Old Wolf Lake zooplankton may exemplify this. As noted earlier there was an introduction of juvenile Rainbow Trout in the spring of 1984. *Chaoborus* (Fig. 5.2.12) was absent in 1986, then generally increased in presence and/or concentration thereafter. Coincident with this increase are generally declining copepod and cladoceran numbers. This pattern could be indicative of heavy predation on *Chaoborus* by smaller trout, gradually lessening as the fish increased in size and switched other, larger food organisms such as benthic invertebrates and terrestrial insects. As predation pressure lessened on the *Chaoborus* larvae the copepods and cladocerans would be decreased by the increasing *Chaoborus* population. Further analysis of this data is required to identify any other effects in the plankton communities that may be attributable to the presence of *Chaoborus*.

The similarity within the dominant and sub dominant phytoplankton taxa, as well as in the copepod, cladoceran, and rotifers may provide a basis for the development of biota-based water quality criteria. An initial attempt at the development of such a criteria for the phytoplankton of the study lakes has been made. Based on the consistency of the dominant and sub dominant groups, a "Criteria Group" of genera have been identified. This is composed of the genera that appear to be common to most of the lakes. These are *Chroomonas, Cryptomonas, Dinobryon, Oocystis,* and *Elakothrix*. Excluding Jacobs Lake, the sum of the concentrations of this group compose more than 10% of the sample in between 75% and 95% of all samples. The composition of the zooplankton is more regular, with the Copepods dominated by either *Diaptomus* or *Cyclops*, the cladocerans by *Bosmina* or *Daphnia*, and the rotifers by *Keratella*. Thus the composition of the dominant phytoplankton and zooplankton can be predicted with some accuracy, although numbers of individual genera are still unpredictable. This is quite a rudimentary approach to criteria development for these lakes, and with additional analysis it is probable that more accurate and useful schemes could be developed.

Interpretation of water quality based on the data collected in this study is difficult. With the exception of the appearance of *Euglena* in Spectacle lake, no trends or events attributable to overall water quality changes have been observed. The primary reason for this is the lack of identification to species. A broad range of ecological conditions can be tolerated by the organisms grouped into a single genus, and thus a large degree of the resolution that may have been provided by these data has been lost. Attempts to confirm the species designation of even just the numerically dominant organisms in a subset of the surviving samples would provide much information. Some samples are preserved at the Ministry of Environment warehouse facility as well as the Royal British Columbia Museum, and thus this opportunity is not wholly lost. In future every attempt should be made to identify phytoplankton and zooplankton taxa to species.

The data set that composes this study is unique and valuable. Further analysis can provide a wealth of information regarding small temperate lakes such as these. Given the intensive resource extraction and other types of development that occur proximate to these water bodies such information will be required in the near future.

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FROM: Parks, Chris D.
DATE: 10/02/95 15:36
TO: Nordin, Rick

CC:
SUBJECT: for your information
PRIORITY:
ATTACHMENTS:

Hi Rick,

I've just discovered something important that I should have mentioned in the report. Many of the figures in the text show marked changes between the 1988 and
1989 sampling seasons. This is (I think) the period in
which the Ministry
lab became Zenon, and hence it is possible that the observed changes are an artifact of a change in tecnique/equipment/taxonomist/etc. This effect is evident in the following figures:
2.1.8
2.1.9
2.1.10
2.1.11
3.1.3
3.2.7
4.1.4
4.1.12
5.1.14
5.1.16
5.1.17
5.1.18
7.1.5
7.2.1
7.2.4
7.2.6
7.2.8

Oops. I doubt thast this is the only obvious connection I have missed. I'll let you know if/when I see any more.

So long for now

Chris.