A TEN-YEAR ASSESSMENT OF WATER QUALITY IN SIX ACID-RAIN-SENSITIVE BRITISH COLUMBIA LAKES

(1984 - 1994)

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SUMMARY

During 1984, the B.C. Ministry of Environment, Lands and Parks began to study six highly-sensitive lakes to determine if there were measurable impacts from acidic inputs. The study was in response to concerns about acidic deposition in British Columbia and its effects on the aquatic environment. The six lakes chosen on the basis of receiving the most acidic precipitation were Lizard, Spectacle, Old Wolf, and Stocking lakes, all on Vancouver Island; Maxwell Lake on Saltspring Island; and Marion (Jacobs) Lake in the U.B.C. Research Forest near Haney in the Lower Mainland area.

This document represents a summary of all data collected for the period from 1984 to early 1995. An earlier document (Swain *et al.*, 1994) was published as an interim assessment of trends over the first five years of the study (1984 to 1989). Some water chemistry data for 1984 are not included because sampling on each lake began at different times in that year. Based on the water quality data collected over the past decade, it does not appear that any of the lakes are experiencing acidification.

pH, Alkalinity and Metals

No increasing or decreasing trends through time were observed in the lakes for pH. The most sensitive lake studied was Marion (Jacobs) Lake, with a mean pH of about 6.5 measured with the Orion Ross probe and an average alkalinity of about 87 meq/L. The mean pH for the other lakes were all close to pH 7.0. Stocking Lake exhibited the widest range of pH fluctuations, with a difference between the minimum and maximum values of 1.9 units, while the other lakes had a range of pH values between 1.2 and 1.6 units. Hardness values were similar in magnitude to alkalinity data.

Occasionally, in all the lakes, some concentrations of some metals exceeded water quality criteria to protect drinking water supplies or aquatic life. However, when the level of contamination found in blank samples was considered, none of the metals exceeded criteria frequently enough, or at high enough concentrations, to warrant any major concern. Aluminum, the metal of greatest concern when considering potential acidification, was not found to be a problem in any of the lakes, and concentrations were not found to be increasing over time.

Nutrients and Solids

Nutrient concentrations were low in all the lakes, and all the lakes would be classed as being oligotrophic. Nitrate concentrations were highest in winter, and lowest in summer, as a result of biological uptake of nitrogen during the growing season and the biological release and the input of nitrogen from the watersheds during the winter rains. Mean total nitrogen to total phosphorus ratios ranged from 26:1 in Marion Lake to 58.5:1 in Spectacle Lake, suggesting that phosphorus is generally the limiting nutrient for growth in all of the lakes. The lowest mean concentration of dissolved solids was in Marion Lake which likely reflects the low retention time of that lake.

Lake Chemistry Trends

The characteristics considered most important in determining if acidification had occurred (pH, sodium, sulphate, calcium, alkalinity and ammonium) were analyzed for trends in each lake. In the majority of cases, no trends were observed. In Maxwell Lake, sodium and calcium concentrations appeared to increase slightly between 1985 and 1989, and then become relatively stable. Soluble sulphate increased during the same period, and then decreased slightly from 1990 to 1995. Alkalinity appeared to increase slightly throughout the monitoring period in Maxwell Lake. In Old Wolf Lake, sodium and calcium concentrations increased from about 1986 to 1989, then decreased through 1995 to pre-1986 levels. Alkalinity and pH appeared to decrease slightly throughout the monitoring period in Old Wolf Lake. These changes may be attributable to logging that occurred in the Old Wolf Lake watershed in 1986 as opposed to atmospheric inputs. None of the lakes appear to be experiencing the effects of acidification due to atmospheric inputs.

Sediments, Aquatic Plants, and Animal Tissues

Sediments, aquatic plants and rainbow trout tissue samples were collected from each of the lakes once during the first five years. The results of analyzing these samples were documented by Swain *et al.* (1994) and the discussion of these data is included in this document verbatim for the sake of completeness.

In comparison to average concentrations for sediments from 96 coastal lakes in British Columbia, 10 of the 16 metals for all six lakes have concentrations below the B.C.

average. Those not below the B.C. average were aluminum and molybdenum in Marion Lake, cadmium, lead, and zinc in Maxwell Lake, and tin in Spectacle Lake. All metals except molybdenum and lead were within one standard deviation of the mean lake concentration, and molybdenum and lead were within two standard deviations of the mean lake concentration. The sediment concentrations in the six lakes can be considered typical of those for coastal British Columbia, and were not useful as an indicator of acidic inputs.

The aquatic plants present in each of the lakes were mapped twice during the summer of the first five years of the program, once in 1984 or 1985, and a second time during 1989. The same primary observer was used when the survey was repeated in 1989. In this type of visual survey, factors such as the amount of available light on the day of the survey could potentially affect whether plants might be observed. No significant change was noted in the vegetation density or distribution between surveys at Lizard, Marion, Maxwell, Old Wolf, or Spectacle lakes. At Stocking Lake, there appears to have been significant development and maturation of littoral habitat between the 1985 and the 1989 surveys, and diversity and density of vegetation along the sides of the lake has increased noticeably. The inlet ends of the lake were always quite densely populated. Therefore, the utility of using this type of survey to document changing populations related to acidic inputs in this case is questionable and should be evaluated once the 1994 data are available.

Rainbow trout were collected from four of the six lakes during the study. The results of the fish liver analyses from the six lakes indicate that hepatic tissue analyses are an effective bio-monitor for low level cadmium and copper exposure. The metallothionein concentrations in rainbow trout from Maxwell, Stocking, and Lizard lakes represent background conditions for systems with metal concentrations below 1 μg/L. Metallothionein results for rainbow trout from Old Wolf Lake showed a high degree of sensitivity to ambient zinc and copper concentrations. Future analyses should focus on hepatic metallothionein, copper, and cadmium. Axial muscle samples should be used to monitor impacts of zinc. It is not known whether fish are good monitors of ambient lead concentrations, or acidic inputs.

Phytoplankton and Zooplankton

Phytoplankton and zooplankton were collected at the six lakes each year between May and October. A high degree of variability in species composition was evident in all of the lakes, with between 80 and 99 phytoplankton genera and 22 to 31 zooplankton genera appearing over the ten-year study. There is considerable difficulty in trying to distinguish between changes in these populations which may have been caused by acidic inputs from atmospheric inputs and those from other anthropogenic activities such as logging, introduction of fish, or operation of these "lakes" as reservoirs. However, there is no evidence that atmospheric acidic inputs have caused any changes. There were distinct changes which did occur such as the logging and the fish introductions at Old Wolf Lake, and these were reflected in the biological data.

In general, the composition of the dominant and sub-dominant categories of phytoplankton is very similar in all of the lakes. Therefore, the majority of the high degree of variability seen in community composition occurs in the uncommon and rare taxa. Chlorophyll a extreme values ranged from approximately 0.5 to 8.2 µg/L in the six lakes, with the highest mean value of 2.94 µg/L in Maxwell Lake and the lowest mean of 0.97 µg/L in Stocking Lake. The high mean value for Maxwell Lake was curious, as it had the lowest phytoplankton biomass on average. Old Wolf Lake was the most productive in terms of overall numbers of phytoplankton based on the ten-year mean.

The zooplankton community showed similar patterns to those observed in the phytoplankton, with a similar composition of dominant genera in each of the lakes. No trends or events attributable to overall water quality changes were observed in any of the lakes over the ten-year period, primarily due to the lack of identification to species level.

For most of the lakes, species succession was not particularly regular. The phytoplankton and zooplankton communities of all six lakes were unstable and appeared to be under the influence of various types of perturbation.

To improve the phytoplankton and zooplankton monitoring program, routine inter-laboratory comparisons to ensure acceptable results are required. Biological samples should continue to be saved at the B.C. Provincial Museum for future reference. There should be an investigation of the variance of the single samples by replicate sampling. Accuracy and precision should be checked by submitting split and pre-counted samples done by accepted research laboratories.

Quality Assurance/Quality Control

Two quality assurance/quality control programs were initiated. One dealt with submission of blank samples related to sample filtration for dissolved metals, while the second dealt with the precision of replicate samples collected twice per year. This document concentrates on quality assurance/quality control data collected between 1990 and 1995.

Metals Blanks

In the first five years of the study, about 95% of the 36 sample blanks (total of 540 individual analyses) were contaminant-free. In the second five years, this decreased to about 85% (total of 1589 individual analyses). In both timeframes, total iron was the most frequently measured metal, followed by total aluminum, total zinc and total copper. Lizard Lake blanks were contaminated with the greatest number of different metals during both timeframes, and had the highest number of incidents of contamination.

Replicate Samples

Replicate samples (six sequential samples) were collected from Maxwell Lake in February 1990 and August 1990. The precision of the tests was acceptable for all characteristics except acidity measured to pH 8.3. For this characteristic, there was an increasing concentration reported according to the order of collection and analysis in the laboratory. This was later identified to be a problem with the analytical technique.

In the period between August 1990 and 1995, a total of 13 sets of replicates were collected in four of the lakes (Maxwell, Old Wolf, Spectacle and Stocking). The precision of the analyses of the replicates was acceptable for all characteristics except soluble nitrate in Stocking, Maxwell and Old Wolf lakes, turbidity in Maxwell Lake and acidity measured to pH 8.3 in Stocking Lake. A very small sample size was the primary reason for the concern about soluble nitrate in Stocking and Old Wolf lakes and the turbidity data from Maxwell Lake. The identified concern for soluble nitrate in Maxwell Lake may be the result of laboratory problems, as there was a progressive decrease in nitrate concentrations with each replicate sample measured. The concern for acidity measured to pH 8.3 in Stocking Lake is not considered to be a major concern.

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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), eight lakes were selected on which to carry out long-term studies. The number of lakes was reduced to six from eight shortly thereafter on the basis of preliminary surveys of the lakes and cost considerations. When the B.C. Ministry of Environment and Environment Canada entered into the Canada-B.C. Water Quality Monitoring Agreement in October 1985 to pursue a joint water quality monitoring program throughout British Columbia, four of the six lakes were placed under the Agreement (shared costs) while the remaining two were considered as Provincial monitoring sites (costs covered 100% by the B.C. Ministry of Environment).

The six lakes studied and reported on in this report are Lizard, Spectacle, Old Wolf, and Stocking lakes, on Vancouver Island (Figure 1.1); Maxwell Lake on Saltspring Island (Figure 1.1); and Marion (Jacobs) Lake in the U.B.C Research Forest near Haney in the Lower Mainland area of British Columbia (Figure 1.2). The lakes excluded from the Canada-B.C. Agreement are Marion and Stocking lakes.

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.

The data reported herein are generally for the period from late 1984 or early 1985 to early 1995. The exception to this is Spectacle Lake, where monitoring was suspended in early 1993 due to lack of funding, and because preliminary analysis of water quality data presented no evidence to generate concern.

A physical description of each lake follows.

1.1 Lizard Lake

This lake is located on Vancouver Island west from 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 mean monthly precipitation measured at Port Renfrew, the nearest monitoring station, is greatest in the winter months and decreases through the summer (Figure 1.3). This lake receives more annual precipitation than any of the other study lakes.

The whole area around the lake 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 near the south-east end of the lake, and the bottom of the lake near the island is shallow and gravely. The main shoreline is generally quite steep and muddy.

In addition to the logging impacts discussed above, Lizard Lake 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 either the water chemistry or 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 and fish stocking in Lizard Lake may represent a significant disturbance as well.

1.2 Marion (Jacobs) Lake

Marion (Jacobs) Lake is located on the lower Mainland 10 km north-northeast from Haney approximately 50 km east from Vancouver, B.C. (49° 18' 40", 122° 32' 46", map sheet 92G). Marion Lake is located in the University Research Forest, at an elevation of 300 m on the south slope of the coastal mountains in a U-shaped 500 m wide valley, about 300 m deep, with a north-south oriented longitudinal profile. The valley floor is covered with glacial drift, with shallow soils and recent regeneration tree growth after logging and fire.

"It is a small lake of 13 ha with a mean depth of 2.4 m. The climate is mild and wet with an annual precipitation of 240 cm/a. This climate coupled with the impermeable substrata of the watershed and the morphometry of the basin, often result in rapid flushing of the lake. As a result the water column communities are quite unstable with very low productivity" (Hall and Hyatt, 1974).

The lake has a drainage area of about 6.5 km^2. The lake is 200 m across at the widest point and 800 m long. The volume of the lake is 312 dam^3, the maximum depth is about 7 m, while the mean depth is about 2.4 m. "During heavy spates the equivalent of the total volume of the lake may be flushed out in 2.3 days: at times the surface of the water may rise as much as 1m in 24 hours." (Efford, 1967). Precipitation measured at Haney UBC, the nearest monitoring site, is greatest in the winter months and decreases through the summer (Figure 1.3).

1.3 Maxwell Lake

Maxwell Lake is located on Mount Maxwell in the west central portion of Saltspring Island (48^{o} 49' 24", 123^{o} 32' 40", map sheet 92B) at an elevation of 335 m. The lake has a watershed area of 1.2 km^2, with the lake encompassing about 22% of the watershed area. It serves as part of the water supply to the north part of Saltspring Island (North Saltspring Waterworks District). The lake is surrounded by trees, although there is one cottage and a pump station for the waterworks located on its shores.

Maxwell Lake 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. Mean monthly precipitation at Ganges (the nearest monitoring site) over the 10-year period ranged from 20.3 mm in July to 141.8 mm in November (Figure 1.3). The theoretical residence time for mean runoff years is 1.7 years for a recurrence interval of two years (Nordin *et. al.* 1982). The outlet from the lake is through a creek located in a bay at the north-east corner of the lake.

Maxwell Lake is located in the Nanaimo lowlands of the Georgia Depression (Holliday 1964). The surficial geology is sedimentary rocks with volcanic intrusions. Soils and vegetation are described in Nordin *et al.* (1982), although most of the watershed is composed of deep to moderately-deep organic soils that are subject to frequent ponding or high water tables, and underlain by clays at depths from 0.46 m to 1.5 m. Little development exists in the watershed, except for one permanent residence. The perimeter of the lake was logged and cleared in 1992 in preparation for raising the level of the dam so that more water could be stored, and in 1994 the dam and spillway were constructed. Another potential impact to the lake was the introduction of 5000 rainbow trout 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.

1.4 Old Wolf Lake

Old Wolf Lake is located on Vancouver Island, to the north and west from Victoria (48° 30' 00", 123° 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, an area representing about 11% of the total watershed. A second small area (only slightly more than 1% of the watershed) was subsequently logged in 1988. 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). Mean monthly precipitation (measured at Sooke Lake North) over the monitoring period is shown in Figure 1.3.

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. There is no visible inflow to Old Wolf Lake. Old Wolf Creek is the outflow from the lake, eventually discharging to the Sooke River.

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 were introduced 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.

1.5 Spectacle Lake

Spectacle Lake is located on Vancouver Island near the top of the Malahat Drive on the Trans-Canada Highway, north from Victoria (48° 34' 41", 123° 34' 05", map sheet 92B) at an elevation of 381 m. It has a maximum depth of 7 m, a mean depth of 1.9 m, an area of 4 ha., and a volume of 78.2 dam^3. Spectacle Lake has an intermittent inlet at its north end, and its outlet is Spectacle Creek which drains into Saanich Inlet. Mean monthly precipitation at this lake (measured at Sooke Lake North) increases from summer to winter (Figure 1.3).

Spectacle Lake has a large drainage area relative to its total volume, and for this reason has a very short residence time (0.0118 years, or 85/year). The total watershed area was calculated to be 6.2 km^2, and the yield was calculated to be approximately 1073 dam^3/yr. by averaging the known yields of three watersheds in the area (Sooke Lake, Shawnigan Lake, and the Koksilah River).

Spectacle Lake is in a Provincial Park, and there is a picnic area near its eastern end adjacent to Spectacle Creek. A large mobile home park is located within one kilometre from the lake. The shores of the lake are generally forested with lodgepole pine and Douglas-fir. There is a collection of log debris near the lake outlet.

Spectacle Lake has been regularly stocked with Eastern Brook Char ("brook trout") over the last two decades. Two stocking events occurred within the period of sampling, with 2000 juveniles released in 1989 and a further 2000 in 1990. Given the ease of access to the lake angling probably has a significant impact on the fish populations and other parts of the aquatic community.

1.6 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 been converted to a reservoir to provide water to the Town of Ladysmith. Stocking Creek is the outlet stream from the dam, eventually discharging to the south end of Ladysmith Harbour.

Stocking Lake has a volume of 2091 dam^3, a maximum depth of 19 m, a mean depth of 8.4 m, and an area of 23.3 ha. The lake is surrounded by forest, and the only permanent structure is the dam at the spillway. The lake 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. The lake is heavily affected by its use as a water supply, with Ladysmith and the Cowichan Valley Regional District withdrawing about 35% of the inflow to the lake in an average year, and about 78% in a very dry year. There is no outflow from the lake during June to November when the lake is down below the spillway. Mean monthly precipitation as measured at Nanaimo Station A over the monitoring period is given in Figure 1.3.

Four recent stocking events are recorded for Stocking Lake, each time introducing 15,000 Rainbow Trout. Two of these events occurred within the sampling period, once in 1984 and again in 1986. Road access to the lake is restricted by locked gates but fisherman often hike into the lake, so fishing pressures may have some affect both on fish populations and other parts of the aquatic community.

2.0 Quality Assurance/Quality Control

The U.S. EPA (1984) define Quality Assurance (QA) as the "total program for assuring the reliability of monitoring data". Quality control (QC) is limited to "the routine application of procedures for controlling the measurement process."

Quality assurance standards with regards to sample collection were implemented with the start-up of the program, although these were not documented until early in 1988. Blanks were initiated as part of the program in 1988, while replicates were initiated in 1990. These specific quality assurance measures were used to estimate the overall contamination and system precision and detection limits for the water chemistry portion of the survey. Accuracy, in terms of sample spikes (the blind submission of standard reference materials), or split samples with other laboratories was not assessed during this period.

The Environmental Laboratory of the B.C. Ministry of Environment performed all analyses until January 5, 1989. Thereafter, these analyses were performed by Zenon Environmental Laboratories who assumed ownership of the Ministry of Environment Environmental Laboratory on that date. Zenon discontinued washing metals bottles (June 1989 to December 1992) and initially bottles were distributed without caps, allowing possible contamination from dust. Both these laboratories had QA/QC programs; however, documentation and assessment of them is beyond the scope of this report. A series of reports describing the QA/QC programs and associated problems is available through the Laboratory Services and System Management Section of Environmental Protection Department (Dr. M. Clark) in Victoria.

2.1 Analyses of Blanks

The quality assurance program using blank samples dealt mainly with the analysis of samples for metals and contamination which may be present in the samples. Generally, for all sample collectors, blank samples of de-ionized water which had passed through the filtration apparatus were submitted for analysis. For the Water Quality Branch collectors, samples were collected prior to beginning a survey (usually referred to as the Maxwell Lake sample), and upon completion of the survey (usually referred to as the Old Wolf Lake sample). The four lakes were sampled normally in the following sequence: Maxwell

Lake, Stocking Lake, Spectacle Lake, and finally Old Wolf Lake. Occasionally this order was reversed, with samples collected prior to the survey referred to as the Old Wolf Lake sample and samples collected after the survey as the Maxwell Lake sample. In addition, on some occasions Old Wolf Lake was not sampled, and samples collected after the survey were referred to as Stocking Lake samples. There are no blanks directly associated with Spectacle Lake, though due to the sampling methods used it is expected that results for the other three lakes would apply to this lake as well. Blanks were also collected for Lizard Lake and Marion (Jacobs) Lake by regional staff.

For all the blank samples, there were six potential major sources of contamination. These are: contamination from the acid (including contamination from the vials used to transport the acid), contamination introduced in the laboratory, contamination of the de-ionized water, contamination of the filtration equipment, contamination from the air at the site or where the sample preparation took place, or contamination due to dirty bottles. The contamination present is likely to be random, and since different acid vials and sample bottles are used for total and dissolved, then different amounts of contamination could be present in each. However, given that, if both total and dissolved values for the same metal were measurable, filtration equipment can likely be eliminated as a source. If values were measurable only as "total", filtration equipment, the de-ionized water, the ambient air, and the acid can likely be eliminated as sources. If values were measurable only as dissolved, then the de-ionized water and the acid could likely be eliminated as sources of contamination.

Internal checks within the laboratory itself would be required to determine if contamination was present in the laboratory.

2.2 Routine Blank Samples

Data collected for blanks analysis prior to 1991 (prior to 1990 in Marion (Jacobs) Lake) are discussed in the Interim Assessment Report (Swain *et al.*, 1994). In the interim report, it was found that when all metals were considered, about 95% of the samples were contaminant-free. However, an examination of individual metals showed that between 9 and 12% of total aluminum and copper and dissolved iron samples were contaminated (i.e. had concentrations exceeding detection limits), and 33% of total iron blanks contained contamination. Lizard Lake had the highest number and percent of samples collected of incidents of contamination.

Considered in this discussion are blank samples collected for dissolved and/or total metal measurements by the three groups of collectors subsequent to those discussed in the 1994 report (Swain *et al.*, 1994). A summary of the sampling periods and number of samples measured for each lake is given in Table 2.2.1.

Table 2.2.1. Blanks Sampling Regime for the Acid-Rain-Sensitive Lakes.

	Sampling Period	Total Number of Blanks Submitted	Number of Dissolved Measurements	Number of Total Measurements
Lizard Lake	Mar.1991-Oct.1994	35	368	371
Marion (Jacobs) Lake	Apr.1990-Nov.1994	34	174	2
Maxwell Lake	Jan.1991-Mar.1995	32	163	153
Old Wolf Lake	Jan.1991-Jan-1995	34	166	153
Stocking Lake	Jun.1992-Mar.1993	20	20	19

Metals measured at concentrations below the detection limit will not be considered in our analysis due to the uncertainty of the quantity of metal at these low levels. The actual detectable sample results for blanks from the four lakes are summarized in Tables 2.2.2, 2.2.3, 2.2.4 and 2.2.5.

An indication of contamination can be obtained by using the concept of a metal:date, i.e., the detection (value not reported as <) of at least one form of at least one metal being present on one sampling trip. Data are summarized in Table 2.2.6.

Table 2.2.6. Summary of metal:dates measured in blanks from the study lakes.

	Total Number of Measurements	Number of samples with contamination	Percentage of Samples with Contamination
Lizard Lake	739	133	18%
Marion (Jacobs) Lake	176	17	9.7%
Maxwell Lake	316	48	15.2%
Old Wolf Lake	319	43	13.5%
Stocking Lake	39	9	23.1%

The data indicate that blanks at Stocking Lake had the highest percentage (23.1%) of incidents of contamination. This has been skewed by eight samples contaminated with total aluminum. It should be noted that the specified laboratory goal was to have less than 5% false positive values at the detection limit (M. Clark, personal communication). Only occurrences in excess of 5% are likely attributable to contamination.

2.2.1 Aluminum

As noted earlier, aluminum is the metal of prime environmental importance when assessing the impacts on lakes from acidic inputs. A summary of the incidents of contamination of blanks with dissolved and total aluminum is given in Table 2.2.1.1.

Table 2.2.1.1. Incidents of total and dissolved aluminum contamination of blanks from the acid rain lakes.

Lake	Number of samples (and percent of total samples) above detection limits for dissolved aluminum blanks	Number of samples (and percent of total samples) above detection limits for total aluminum blanks
Lizard Lake	5 (14%)	14 (39%)
Marion (Jacobs) Lake	11 (32%)	2 (100%)
Maxwell Lake	3 (10%)	13 (41%)
Old Wolf Lake	1 (3%)	17 (53%)
Stocking Lake	1 (5%)	8 (42%)
All lakes combined	21(14%)	54(45%)

The majority of these values are well above the 5% goal for false positives set by the laboratory, and suggest that contamination was a problem for both dissolved and total aluminum. In addition, the total blanks appear to be contaminated at least three times more often than the dissolved samples. This suggests that contamination was due either to the water used (with the filter removing some of the aluminum associated with suspended particles) or to laboratory procedure.

The magnitude of the aluminum contamination occurring is an important concern. The maximum concentration of dissolved aluminum in any of the blanks was 1.29 mg/L in Lizard Lake, while the concentration of total aluminum was less than detection limits (<0.01 mg/L) at this time. This suggests that contamination in this case was due either to a dirty sample bottle, dirty filter or a problem in the laboratory. With contamination occurring at a maximum of 130 times greater than detection limits for dissolved aluminum and 19 times greater than the detection limit for total aluminum, interpretation of aluminum concentrations in normal samples becomes much more difficult.

2.2.2 Copper

A summary of the incidents of contamination of blanks with dissolved and total copper is given in Table 2.2.2.1.

Table 2.2.2.1. Incidents of total and dissolved copper contamination of blanks from the acid rain lakes.

Lake	Number of samples (and percent of total samples) above detection limits for dissolved copper blanks	Number of samples (and percent of total samples) above detection limits for total copper blanks
Lizard Lake	10 (38%)	8 (31%)
Marion (Jacobs) Lake	2 (14%)	-
Maxwell Lake	4 (33%)	4 (36%)
Old Wolf Lake	3 (25%)	5 (45%)
All lakes combined	19(30%)	17(35%)

Contamination rates far exceeded the laboratory goal of <5% "false" positives, which suggests that contamination is a definite problem for copper.

One extremely high value was recorded for dissolved copper in Lizard Lake, at a concentration of 2.32 mg/L. This value is over 2000 times greater than the detection limit of 0.001 mg/L. The concentration of total copper measured on the same date was <0.001 mg/L, which suggests that there was either a problem in the laboratory, or copper associated with the filter which contaminated the dissolved sample. A very high concentration of dissolved copper (1.11 mg/L) was also measured on a different date in a blank from Marion (Jacobs) Lake, and comments included by the laboratory state that contamination of the sample was suspected.

2.2.3 Iron

A summary of the incidents of contamination of blanks with dissolved and total iron is given in Table 2.2.3.1.

Table 2.2.3.1. Incidents of total and dissolved iron contamination in blanks from the study lakes.

Lake	Number of samples (and percent of total samples) above detection limits for dissolved iron blanks	Number of samples (and percent of total samples) above detection limits for total iron blanks
Lizard Lake	14 (56%)	10 (38%)
Marion (Jacobs) Lake	1 (7%)	-
Maxwell Lake	3 (25%)	7 (64%)
Old Wolf Lake	2 (17%)	6 (55%)
All lakes combined	20(32%)	23(48%)

All values are well above the <5% "false" positive goal set by the laboratory, which suggests that contamination is occurring.

Once again, the highest concentrations of contaminants were present in Lizard Lake. The maximum concentration of dissolved iron in a blank was 0.1 mg/L, and the maximum concentration of total iron was 0.17 mg/L. In both instances, the maximum value occurred while the other form was below detection limits (i.e., total iron concentrations were below detection limits (<0.05 mg/L) when the dissolved iron concentration was 0.1 mg/L, and dissolved iron concentrations were below detection limits (<0.003 mg/L) when the total iron concentration was 0.17 mg/L). In the case of the high dissolved iron concentration, contamination must have occurred in either the filter (with dissolved iron being added by the filter), in the bottle, or in the laboratory. In the case of the high total iron concentration, contamination must have occurred either in the water supply (with iron associated with suspended particles being removed by the filter), in the sample bottle, or in the laboratory.

2.2.4 Lead

A summary of the incidents of contamination of blanks with total lead is given in Table 2.2.4.1.

Table 2.2.4.1. Incidents of total lead contamination in blanks from the acid rain lakes.

Lake	Number of samples (and percent of total samples) above detection limits for total lead blanks
Lizard Lake	2 (8%)
Maxwell Lake	6 (55%)
Old Wolf Lake	4 (36%)
All lakes combined	12(25%)

The maximum concentration of total lead measured was 0.008 mg/L at Lizard Lake. Although the "false" positive rate is as high as other metals measured, and well exceeds the laboratory goal of 5%, it does not appear that the magnitude of contamination is nearly as great. The maximum recorded value is 8 times the detection limit of 0.001 mg/L. While this is by no means acceptable, it is much closer to detection limits than other metals measured. The relatively small number of blanks in which lead was measured (a total of 48, compared to 154 for dissolved aluminum) may have contributed to this accuracy.

2.2.5 Zinc

A summary of the incidents of contamination of blanks with dissolved and total zinc is given in Table 2.2.5.1.

Table 2.2.5.1. Incidents of total and dissolved zinc contamination in blanks from the acid rain lakes.

Lake	Number of samples (and percent of total samples) above detection limits for dissolved zinc blanks	Number of samples (and percent of total samples) above detection limits for total zinc blanks
Lizard Lake	13 (50%)	12 (46%)
Marion (Jacobs) Lake	1 (7%)	-
Maxwell Lake	0 (0%)	4 (36%)
Old Wolf Lake	2 (17%)	2 (18%)
All lakes combined	16(25%)	18(38%)

The maximum concentration of both dissolved and total zinc was measured in blanks from Lizard Lake (1.73 mg/L and 0.05 mg/L, respectively). The high concentration of total zinc occurred when the dissolved concentration was below detection limits (0.002 mg/L), which suggests that contamination occurred either in the water (with the filter removing the majority of the contaminant from the dissolved blank), in the bottle, or at the laboratory. The high concentration of dissolved zinc was concurrent with a reasonably high value of total zinc (0.012 mg/L) which suggests that some contamination may have occurred from the air, from the water, from the acid, or from the laboratory. However, as the concentration of dissolved zinc exceeded the concentration of total zinc, it was obviously contaminated to a greater degree.

2.2.6 Other Detectable Metals

A summary of other metals found in the blank samples is given in Table 2.2.6.1.

Table 2.2.6.1. Metals found in blanks samples at each lake. Data represents total number of samples contaminated (and the percentage of all samples from each lake contaminated). The maximum concentration found in any of the lakes is also included (in mg/L). (Those metals with maximum concentrations less than detection limits had measurable amounts in some samples where a lower detection limit was used).

Lake	B		Ba		Cd		Co	Cr		Mn		Ni	
	D	T	D	T	D	T	T	D	T	D	T	D	T
Lizard Lake	1(4%)	3(15%)	4(26%)	4(15%)	1(4%)		1(4%)	2(8%)	2(8%)	6(23%)	4(15%)	1(4%)	1(4%)
Maxwell Lake					1(8%)	2(18%)			1(10%)				
Old Wolf Lake					1(8%)								
Max. Conc.	0.06	0.06	0.15	<0.01	<0.002	0.017	2.0	0.03	0.01	0.1	0.011	0.012	0.012

2.2.7 Conclusions

For all the metals, about 84% of the blank samples were contaminant-free. Aluminum, copper, iron and zinc were the most-detected metals, and the greatest contamination occurred in the total aluminum blanks (44.6% of all blanks) and total iron blanks (47.9% of all blanks). The high contamination of aluminum may be significant, as it is one of the key metals of concern when determining trends. Lizard Lake blanks samples were contaminated with the greatest number of different metals, as well as the highest number of incidents of contamination. This is due partially to the greater number of metals tested at this site, as well as the larger number of blanks measured at this site than at the other lakes. Stocking Lake had the highest percentage of incidents of contamination due to the small number of blanks analyzed at this lake, as well as the high number of blanks contaminated with total aluminum. However, it appears that contamination is a very real problem at all lakes monitored, and especially at Lizard Lake.

2.3 Replicate Analyses

2.3.1 Sampling Procedure

A replicate sampling program was initiated in 1990 at Maxwell Lake, where two sets of six replicate samples were collected in February and August. These data are discussed in the 1994 report (Swain *et al.*, 1994) and are therefore not included in the following discussion. Subsequent to this, a number of replicate samples were collected at Maxwell, Old Wolf, Spectacle and Stocking lakes. A summary of the number of replicates and when they were collected at each lake is provided in Table 2.3.1.

Table 2.3.1. Summary of Replicate Collection at the Acid Rain Lakes, post-1990.

Lake	Date of Collection	Number of Replicates
Maxwell Lake	January 1993	6
	August 1993	3
	February 1994	3
	March 1995	2
Old Wolf Lake	February 1990	2
	August 1993	3
	January 1994	3
	March 1995	2
Spectacle Lake	August 1991	6
Stocking Lake	January 1992	6
	July 1992	6
	August 1993	3
	January 1994	3

All replicate samples were collected sequentially at a depth of about 0.5 m. Therefore, while they were not true split samples, the results should normally be quite similar since the samples were collected within a very short time (maximum period of five minutes to collect all six replicates).

All the sample bottles were pre-rinsed with lake water three times prior to the samples being collected into the separate bottles, in order to minimize the time between filling successive bottles. All acid used for field preservation was obtained from the same bottle of acid. Between 1987 and 1990, the acid was taken to the field in pre-washed (with nitric acid solution) clear glass vials which had Teflon-lined bakelite caps. However, as the Teflon-lined caps were reused, they eventually degraded and there was a problem with various metals leaching from the caps into the acid. In 1990, it was decided that disposable polypropylene containers should be used to transport the acid to correct this problem, and laboratory analysis of acid stored in these containers showed no evidence of contamination. The vials were maintained upright throughout the sample trip so that the acid only came into contact with the sides prior to being dispensed into the sample.

2.3.2 Data Presentation

The data for replicates collected at Maxwell Lake are summarized in Tables 2.3.2, 2.3.3, 2.3.4, and 2.3.5. Old Wolf Lake replicates are summarized in Tables 2.3.6, 2.3.7, 2.3.8 and 2.3.9, Spectacle Lake replicates are summarized in Table 2.3.10, and Stocking Lake replicates are summarized in Tables 2.3.11, 2.3.12, 2.3.13, and 2.3.14. All data are reported in the sequence ("normal" sample followed by the replicates) that they were collected and subsequently analyzed. Values which are not included were either all less than the detection limit or were detectable, but were all the same. The analytical detection limits for all the characteristics measured are included as Appendix 2.

To determine if there are problems with precision, the United States Environmental Protection Agency (E.P.A.) uses the following criterion: at concentrations greater than ten times the laboratory analytical detection limit, the percent relative standard deviation (%RSD) should not exceed 10%. (The relative standard deviation is calculated as a percent by dividing the standard deviation by the mean concentration and multiplying by 100.) Exceptions are specific conductivity which should be ≤ 2%, and the standard deviation of pH measurements which should be ≤ 0.05 pH units (Silverstein *et al.*, 1987). Presumably, the %RSD would be higher at concentrations less than ten times the analytical detection limit.

Application of this criterion to the data reported in the replicate summary tables (Tables 2.3.4 through 2.3.14) reveals that there were only three characteristics for which the %RSD values exceeded 10% when concentrations were greater than or equal to ten times the detection limit (see Table 2.3.15).

Table 2.3.15. Summary of occasions when %RSD exceeded 10% when concentrations were ≥ 10 times detection limits.

Location	Date of Exceedance	%RSD
Soluble Nitrate		
Stocking Lake	January 1994	15.75%
Maxwell Lake	January 1993	14.53%
Old Wolf Lake	March 1995	14.89%
Turbidity		
Maxwell Lake	March 1995	56.60%
Acidity: pH<8.3		
Stocking Lake	January 1992	10.90%

The high %RSD value for turbidity at Maxwell Lake was due primarily to the small sample size (the "normal" sample plus one replicate) which resulted in a large standard error relative to the mean.

The possibility of outliers in the replicate data was addressed using a technique developed under the Canada/B.C. Water Quality Monitoring program for apparent outliers in a data set. The technique determines if the high or low value is an outlier by eliminating the value in question from the data set, and then re-calculating the mean and standard deviation. The value is considered to be an outlier if it is greater than six times the re-calculated standard deviation from the re-calculated mean concentration (Pommen *et al.*, 1991). Application of this technique to all of the characteristics with %RSD exceeding 10% (including those when results were not greater than 10 times the detection limit) revealed two outliers. These were the concentration of 0.24 mg/L for the third replicate of soluble nitrate measured in Spectacle Lake in August 1991, and the concentration of 0.11 mg/L for the fifth replicate of total aluminum measured in Stocking Lake in July 1992. Removal of these outliers reduced the %RSD from 89.3% to 37% for soluble nitrate in Spectacle Lake for August 1991, and from 56.7% to 17.7% for total aluminum in Stocking Lake in July 1992. In those cases where only three replicates were taken, it was often the case that two of the three values were identical and the third value varied slightly from this number. With only three values involved, this variation was often enough to produce a %RSD value which exceeded the 10% threshold. Use of the above technique to remove the non-identical value would result in a standard deviation of zero and would therefore suggest that the value was an outlier. The re-calculated %RSD value in these cases would then be zero, with no deviation between the two identical values remaining. This was the case in Maxwell Lake for total aluminum, ammonium, soluble nitrate and total phosphorus in August 1993, and for turbidity and total aluminum in February 1994. In Old Wolf

Lake, this situation occurred for turbidity, dissolved aluminum, total aluminum, soluble potassium, and ammonium in August 1993. Finally, in Stocking Lake this phenomenon occurred for total aluminum and soluble nitrate in August 1993 and for turbidity, total aluminum, soluble potassium, soluble nitrate, and total phosphorus in January 1994.

Swain *et al.* (1994) reported that there were considerably more characteristics with %RSD values greater than 10% in the August 1990 survey than in the February 1990 survey and it was suggested that this could be due to the greater biological activity in August. This trend did not continue to nearly the same extent, with 29% of %RSD values exceeding 10% for winter values (January, February, and March) and 32% of %RSD values exceeding 10% for summer values (July and August).

2.4.3 Conclusions

The precision of the tests as determined by the replicate analyses and criteria used by the E.P.A. and others (under the Canada/B.C. Water Quality Monitoring Agreement) was acceptable for all characteristics except soluble nitrate, turbidity, and acidity measured to pH 8.3. A small sample size was probably the main reason for the problem with turbidity at Maxwell Lake in March 1995 and two of the cases of %RSD exceedences for soluble nitrate (at Old Wolf Lake in March 1995 and at Stocking Lake in January 1994), with only two replicates for turbidity and only three replicates for the two cases involving soluble nitrate. The third case concerning the exceedence of the 10% RSD criterion by soluble nitrate occurred in Maxwell Lake in January 1993. In this case, there was a progressive decrease in nitrate in each replicate value measured. This could be indicative of a quality control problem in the laboratory due to an unstable reagent or a machine which was not properly warmed up (M. Clark, pers. comm.). Unfortunately, it is not possible to retrieve the QA/QC data from Zenon for this date. The single case of acidity measured to pH 8.3 exceeded the 10% threshold for %RSD by only 0.9%, and is not considered to be a major concern.

For the remainder of the incidences where the 10% RSD criterion was exceeded, the precision of these variables is judged to be acceptable because the mean concentrations were less than ten times the laboratory detection limit, and the standard deviations were approximately equal to the smallest measurable increments.

3.0 Aquatic Vegetation in the Lakes

The aquatic plants present in each of the lakes were mapped twice during the first five years of the program, once in 1984 or 1985, and a second time during 1989. No further surveys were conducted after 1989, and therefore this section is included verbatim from the interim document (Swain *et al.*, 1994). The mapping was conducted during the summer months, based upon visual observations from a canoe. The same primary observer repeated the survey of the same lake. With this type of visual survey, the amount of light on the day of the survey could affect the result.

3.1 Lizard Lake

A map of Lizard Lake is included as Figure 3.1. This lake was surveyed for the presence of aquatic plants on July 4, 1985 by P. Warrington and R. Nijman, and August 16, 1989 by P. Warrington and L. Swain. The weather for the 1985 survey was not noted; however, the 1989 survey was conducted in overcast conditions, with no direct sun, no wind, and calm water, with good visibility. The location noted as "B" in the Figure is the access point.

The small island indicated as "A" in Figure 3.1 is about 2 m in diameter. Water striders and red-bellied salamanders were evident during both surveys, and in the 1989 survey, four trout and *Pisidium* (small clams) were seen.

Site #1 around the small island is unique and had small amounts of *Eleocharis* sp., *Sparganium* sp., *Chara* sp., and *Potamogeton gramineus* in the deeper water. Most of the shoreline of the lake, except for the north-east corner which was almost barren, had a low density of *Nuphar polysepalum* against the shore, *Fontinalis antipyretica* on logs, scattered *Najas flexilis*, *Potamogeton pusillus*, *Isoetes* sp. and *Potamogeton amplifolius* in deeper water. The areas of Figure 3.1 marked "2" had more littoral development and greater plant density and diversity. Areas of Figure 3.1 marked as "3" indicate patches of *Typha latifolia*.

No significant change was noted in the vegetation density or distribution over the four years between surveys.

3.2 Marion (Jacobs) Lake

A map of Marion (Jacobs) Lake is included as Figure 3.2. This lake was surveyed for the presence of aquatic plants on September 25, 1984 by P. Warrington and B. Retzer, and September 6, 1989 by P. Warrington and L. Swain. The weather for the two surveys was not noted.

Beaver activity was evident at the lake, and the water level had risen as evidenced by the dead trees and flooded terrestrial or wetland vegetation, especially along the gently sloping east shore. The plant density was low, although diversity was high for this type of lake. Plants were confined to a narrow fringe around the margin of the lake except for a sparse bed of *Potamogeton natans* in the shallows at the south-east corner.

The 1984 survey delineated a number of slightly different vegetation zones. These have all been considered as part of a complex in the 1989 survey and only the one marginal zone "B" is identified on Figure 3.2. Zone "B" contained mostly *Carex* sp. with small amounts of *Menyanthes trifoliata*, *Dulichium arundinaceum*, *Nuphar polysepalum* and *Utricularia intermedia* against the shore. In the shallow open water area to a depth of about one metre were found a low density of *Utricularia vulgaris*, *Sparganium* sp., *Potamogeton epihydrus*, *Scirpus subterminalis*, and *Equisetum fluviatile*. There was some *Juncus supiniformis*, primarily around the inlet creeks at the north end, and a little *Potamogeton natans* which was mostly confined to site "A" at the southeast.

No significant change in the vegetation was evident over the five-year period between surveys.

3.3 Maxwell Lake

A map of Maxwell Lake is included as Figure 3.3. This lake was surveyed for the presence of aquatic plants on August 1 and 2, 1985 and August 21, 1989 by R. Nijman and B. Holms. The weather for the two surveys was not noted. In the 1985 survey, water mites (red) were very common, salamanders were noted, as were several dead sticklebacks.

Although a large number (23) of individual species were found in Maxwell Lake including submerged, floating leaf and emergent components, the diversity of submerged plants was low. The only large bed of submerged vegetation was *Potamogeton amplifolius* at the lake outlet indicated as Site #1 on Figure 3.3. The most commonly found plant in the surveys was *Potamogeton robbinsii*; however, it was usually found as individual plants or as small beds around the lake and frequently extending into deeper water.

Vegetation near "A" at Site #1 included *Scirpus lacustris*, *Typha latifolia*, *Potentilla palustris*, *Sium sauve*, *Isoetes* sp., *Chara* sp., and *Carex* sp. Just offshore and in shallow water less than two metres in depth were *Nuphar polysepalum* and quite sparse *Potamogeton robbinsii*, *Ranunculus aquatilis*, and *Isoetes* sp. The bottom was quite organic (H_2S) with a considerable amount of wood debris. Floating logs had *Drosera rotundifolia*, an insectivore. In area "B", between the lily and emergent community and about four metres depth was a regularly spaced population of *Potamogeton amplifolius* growing near the surface. Along the north shore between sites #1 and #2, there was some intermittent vegetation along most of the shore, including *Nuphar polysepalum*, *Sium sauve*, *Carex* sp., and *Eleocharis palustris*. Other common submerged plants included *Isoetes* sp., *Potamogeton epihydrus*, and *Ranunculus flammula*. In addition, *Chara* sp. and *Lysimachia thyrsiflora* (a marginal)were noted in the shallows, and *Lobelia dortmanna* specifically in the rocky shallow areas. A small bed of *Potamogeton amplifolius* was noted in shallow water in one area, as was the only *Potamogeton perfoliatus* plant observed in the lake close to Site #2.

At Site #2, *Scirpus lacustris* was found in shallow water areas, with *Sium sauve* and *Carex* sp. on shore with a couple of *Lysichitum* (skunk cabbage) plants. A filiform

Potamogeton, possibly *Potamogeton obtusifolius* was quite dense within the bed of *Scirpus lacustris*. *Nuphar polysepalum* bordered the bed of *Scirpus*. *Potamogeton robinsii* grew within the *Scirpus* bed as well as in deeper water with *Potamogeton amplifolius*. *Ranunculus flammula* and *Drosera rotundifolia* were both growing on floating log debris.

Between sites #2 and #3 was found the odd small cluster of *Nuphar polysepalum*, and also *Sium sauve* and *Carex* sp. along the shore. At Site #3 was found a population of *Potamogeton robbinsii* and *Chara* sp. offshore from a band of *Scirpus lacustris* and *Nuphar polysepalum*. At Site #4 there was a shallow bed (1.5 m) of *Potamogeton robbinsii* extending out into deep water, as well as some *Chara* sp. Between Sites #4 and #5 along the south shore was found *Lysimachia thyrsiflora*, *Scirpus lacustris*, *Sium sauve*, *Ranunculus flammula*, and *Carex* sp. close to or on the shore, as well as *Nuphar polysepalum*, *Lobelia dortmanna*, and *Isoetes* sp. in shallow water less than two metres deep. The lake bottom in this area was predominantly organic. *Potamogeton robbinsii* was quite rare in shallow water, but the odd small and dense population noted in deeper water suggested that this plant could be much more common in deep water around the lake.

At Site #5, *Nuphar polysepalum* was found in a band closest to the shore, a one metre wide band of *Potentilla palustris* and *Scirpus lacustris* adjacent to the *Nuphar* was then found (in 1989 this band was restricted to the east half of the bay instead of the entire bay as in 1985), followed by an outside band of *Scirpus lacustris* and *Isoetes* sp. Between Sites #5 and #6, the bottom alternated between organic silts and rock with organic debris. Close to the shore was found *Juncus* sp., *Sium sauve*, and *Equisetum* sp., with some beds of *Potamogeton robbinsii* occurring in both shallow and deeper water. *Ranunculus flammula* and *Chara* sp. were observed in shallow water. At Site #6, there was a population of *Eleocharis palustris* to about one metre depth with *Nuphar polysepalum* in both the east and west corners. On shore were *Sium sauve* and *Carex* sp., with *Lobelia dortmanna* and *Potamogeton robbinsii* along the deep water edge of the site.

Between Sites #6 and #1 trees extended almost down to the water. Little aquatic vegetation was noted except for the occasional *Nuphar polysepalum* and *Potamogeton epihydrus*. An area of cliffs with no vegetation except for the occasional *Nuphar* *polysepalum* plant was followed by the *Lysimachia / Sium* community on shore and with the occasional *Nuphar / Potamogeton robbinsii* in deeper water.

The diversity and abundance of aquatic plants did not change significantly during the four years.

3.4 Old Wolf Lake

A map of Old Wolf Lake is included as Figure 3.4. This lake was surveyed for the presence of aquatic plants on September 16, 1984 by P. Warrington and L. Swain, and August 15, 1989 by P. Warrington and R. Nijman. The weather for the 1984 survey was not noted; however, the 1989 survey was conducted in cloudy conditions, with a few sunny breaks, some wind, with satisfactory visibility.

The central portion of the lake, deeper than about two metres, was barren of vegetation . Vegetation was confined to a very narrow band along the sides and across the ends of the lake. The eastern shoreline, which is quite steep, had a narrow fringe of *Nuphar polysepalum*, *Potamogeton epihydrus*, and *Potentilla palustris*. The more gently sloping west side also had *Isoetes* sp. and in the 1984 survey, *Najas flexilis* as well. During the 1989 survey, no rooted *Najas flexilis* was seen, but a few floating segments were encountered.

On Figure 3.4, Site "1" was an area with *Lobelia dortmanna* in shallow gravel. Sites labeled "2" were *Dulichium arundinaceum* with *Carex* sp. wetlands behind. Site "3" was an isolated patch of *Typha latifolia*. *Potamogeton epihydrus* occurred in deeper water at the north end of Site "4". Site "5" was a low-density, evenly mixed bed of *Scirpus lacustris* and *Nuphar polysepalum*. Site "6" had a small amount of *Utricularia vulgaris* in an open stand of *Scirpus lacustris*. Site "8" was a very low density patch of *Nuphar polysepalum*.

Site "7" at the south end of the lake was a mosaic of *Scirpus lacustris* and *Nuphar polysepalum*, with a little *Utricularia vulgaris* in the *Scirpus*. There was an extensive *Carex* marsh behind with some *Dulichium arundinaceum* along the contact zone.

There was no significant change to the vegetation during the five-year period.

3.5 Spectacle Lake

A map of Spectacle Lake is included as Figure 3.5. This lake was surveyed for the presence of aquatic plants on September 18, 1984 by P. Warrington and G. Butcher, and August 14, 1989 by P. Warrington and R. Nijman. The weather for the 1984 survey was not noted; however, the 1989 survey was conducted in cloudy conditions, with a few sunny periods, a thunder and lightning storm and very heavy rain during which period the observers were on the shore. There was good visibility once the storm had subsided.

Many crayfish had been noted in Spectacle Lake on previous visits around 1980. During the 1984 survey, only two crayfish were seen, and none were encountered in 1989 although one dead animal was found. No snails or other aquatic organisms were seen in 1989, although a few small fish were rising.

The central portions of the lake were mostly barren; the only vegetation was a narrow fringing band around the lake margin, usually indicative of virtually non-existent nutrients in the water and sediments. All nutrients in the runoff are taken up by marginal marshes or fringes of aquatic vegetation, and none are available for the remainder of the lake. The lake bottom was mostly fine, brown, organic mud. There were two obvious marginal patches of filamentous green algae on the bottom near Site "4" on Figure 3.5.

Previous surveys of this lake had, prior to 1972, noted the presence of *Potamogeton natans*, *Utricularia vulgaris*, *Ranunulus aquatilis*, *Typha latifolia*, and *Ruppia maritima* in this lake. None of these were found in either the 1984 or 1989 survey. The marginal fringe of aquatic plants at Site "3" consisted of *Nuphar polysepalum* with a little *Potamogeton amplifolius* within the *Nuphar* and adjacent to it on the open water side. Two patches of *Potamogeton amplifolius* (Site "2") occurred in shallow areas where no *Nuphar* was found. Marshy areas (Site "1") occurred at three spots along the east side of the lake and in a very narrow band along most of the west side just outside the marginal fringe (Site "3"). These marshy areas were mostly *Carex* sp. and *Potentilla palustris*. Some *Ranunculus flammula* and a little *Dulichium arundinaceum* also occurred at this site, especially along the west shoreline.

No noticeable changes occurred in the aquatic vegetation or its' distribution pattern between 1984 and 1989.

3.6 Stocking Lake

A map of Stocking Lake is included as Figure 3.6. This lake was surveyed for the presence of aquatic plants on July 9, 1985 by P. Warrington and R. Nijman, and on August 17, 1989 by P. Warrington and L. Swain. The weather for the 1985 survey was not noted; however, the 1989 survey was conducted in overcast conditions, with no direct sun, a little wind and ripples at times, but with generally good visibility.

In 1989, a few salmonids were seen, as well as many red-bellied salamanders. There was a considerable amount of aquatic insect activity and water striders abounded. Due to the flooding to create the reservoir, there was a considerable amount of wood debris along the shore and these branches were commonly covered with sponge.

The central portion of the lake, deeper than about two metres, was bare of sediment. The lake appeared to be nutrient poor and there was not enough surface runoff in this recently disturbed zone to support more than a sparse, narrow, fringing band of vegetation.

Along the shoreline, except the north end inlet bays, plant density generally was quite low and specimens were scattered with only occasional small communities. The plants found included *Nuphar polysepalum* (usually immature plants), *Chara* sp., *Isoetes* sp. (most common), *Lysimachia thyrsiflora*, *Ranunculus flammula* (common), *Eleocharis* sp. (rare), *Sparganium minimum*, and *Sparganium angustifolium*. Sites labeled "8" in Figure 3.6 were patches of (*Bidens*) *Megalodonta beckii*. *Potamogeton amplifolius* was also found sparingly along these shores, but it was quite prevalent in patches labeled "7" on Figure 3.6. In the small bay identified by "6", the bare muddy bottom was covered in *Isoetes* sp. with some *Chara* sp. and a few *Nuphar polysepalum* seedlings. Site "1" was also *Isoetes* sp. and *Chara* sp. with some *Ranunculus flammula* as well. Site "5" was an isolated patch of *Potamogeton natans*.

Most of the diversity and biomass in the lake was at Sites "2", "3", and "4" at the inlets to the lake. There were a considerable number of logs and debris at the latter two sites, but site "2" was mostly open water. Site "2" contained a mosaic of *Nuphar polysepalum*, *Glyceria* sp., and *Potamogeton natans* on the surface with (*Bidens*) *Megalodonta beckii* beneath. Site "3", a former wetland now flooded, had extensive beds of *Menyanthes trifoliata* and *Sparganium minimum* with lesser amounts of *Megalodonta beckii*, *Utricularia vulgaris*, *Fontinalis antipyretica*, *Sparganium angustifolium*. *Isoetes* sp., *Veronica* sp., and *Lysimachia thyrsiflora*. Site "4", also a former wetland now flooded, had extensive beds of *Sparganium minimum*, *Potamogeton natans*, *Myriophyllum verticillatum*, *Nuphar polysepalum*, and *Glyceria* sp. Lesser amounts of *Isoetes* sp., *Potamogeton epihydrus*, *Utricularia vulgaris*, and *Fontinalis antipyretica* were present. The shoreline between Sites "1" and "4" had more than the usual density of large, mature, *Nuphar polysepalum* plants and some *Sparganium* sp.

There appeared to have been significant development and maturation of littoral habitat between the 1985 and the 1989 surveys, and diversity and density of vegetation along the sides of the lake had increased noticeably. The inlet ends of the lake were always quite densely populated.

3.7 Conclusions

No significant change was noted in the vegetation density or distribution between surveys at any of the following five lakes: Lizard Lake, Marion (Jacobs) Lake, Maxwell Lake, Old Wolf Lake, or Spectacle Lake. There is some anecdotal evidence that a number of species have been eliminated at Spectacle Lake since the early 1970's; however, the cause for these possible losses is not known. At Stocking Lake, there appears to have been significant development and maturation of littoral habitat between the 1985 and the 1989 surveys, and diversity and density of vegetation along the sides of the lake has increased noticeably.

4.0 Analysis of Fish from the Lakes

4.1 Introduction

Fish samples were not collected after 1989, and therefore this section is included verbatim from the interim document (Swain *et al.*, 1994).

Rainbow trout (*Oncorhynchus mykiss*) liver and muscle tissue samples were collected from four of the six acid rain lakes for two purposes. First, the samples were to represent the starting point for trend analysis; and second, the hepatic and axial muscle metal concentrations would serve as background stations for fish collected from other freshwater systems impacted by heavy metals (e.g., Buttle Lake, Tsolum River). For comparison purposes, rainbow trout samples collected in 1989 from Buttle Lake represented a system impacted by heavy metals. Deniseger *et al.* (1990) provide a detailed summary of the impacts of heavy metals in the Buttle Lake system.

4.2 Methods

Rainbow trout were collected from Maxwell, Stocking, and Old Wolf lakes in the fall of 1989, and from Lizard Lake in the spring of 1991. Ten fish were collected from Maxwell and Stocking lakes, nine from Old Wolf Lake, and three from Lizard Lake. Fish were not collected from Marion or Spectacle lakes because the systems do not contain rainbow trout.

Livers were excised from freshly killed fish and immediately frozen with dry ice. Later, the axial muscle tissue without bone or skin was removed and frozen in a deep freezer. The muscle samples have not been submitted for chemical analysis at this time.

Livers were sent to C.B.R. International (Sidney, B.C.) for biochemical analysis. Biochemical analysis (C.B.R. 1990) included homogenization and centrifugation of the sample to separate the high molecular weight protein fraction (membrane) from the low molecular weight fraction (cytosol). Metal analyses were determined on the individual membrane and cytosol fractions, as well as on the metallothionein-like proteins. Metallothionein concentrations were determined on the cytosol fraction.

Water chemistry data have been collected for many years by the Ministry of Environment on the six acid rain lakes, and on Buttle Lake near the mine site. Metal speciation estimations were completed by C.B.R. International for Buttle, Old Wolf, Stocking, and Maxwell lakes using the Ministry of Environment data (Table 4.1) and the Gecheq model (C.B.R., 1990).

Statistical analyses were completed by Cross (1991) using SAS. Tests included an F-test to determine homogeneity of variances, and a t-test (alpha=0.05; 2-tailed) to determine differences between lakes. Regression analyses were completed using the simple linear regression function in the Cricket Graph software.

4.3 Results

The results of the metal speciation data are summarized in Table 4.1. Based on the prediction of the Gecheq model (C.B.R., 1990), the free ionic copper concentrations from Old Wolf and Buttle lakes were in a ratio of about 2:1, despite dissolved copper concentrations of about the same ratio, but in reverse (Table 4.1). Acidic inputs do not appear to be having a perceptible impact on the fish. The very low carbonate concentration in Old Wolf Lake was the principal reason for the high percentage of free ionic copper. Zinc was the dominant metal in Buttle Lake, with dissolved concentrations above 300 nmol Zn/L.

The length and weight of the rainbow trout caught from all four lakes are summarized in Table 4.2. Old Wolf Lake was stocked once in 1984 with 1000 fish, while Stocking Lake was stocked with 15,000 rainbow trout per year in 1982, 1983, 1984, and 1986 (Grant, pers. comm.). Fisheries surveys show no suitable spawning sites in either Old Wolf or Stocking lakes; consequently, natural recruitment is unlikely. Assuming the fish caught from Old Wolf and Stocking lakes were from the last stocking event, the fish would be in the 5+ and 3+ age classes, respectively.

Maxwell Lake had a wide range of fish sizes indicating several year classes. Lizard Lake had such a small sample size it is difficult to determine if the fish were from the same age class. Fisheries records show that Lizard Lake has both natural recruitment and regular stocking with rainbow trout (Grant, pers. comm.).

The rainbow trout collected from all four lakes were predominantly male. Three gravid females with ripe eggs were collected from Old Wolf Lake. Because there are no spawning areas in the Old Wolf Lake watershed, it is suspected that the female fish were re-sorbing their eggs.

4.3.1 Metallothionein

Metallothionein concentrations averaged (± standard deviation) from a low of 80±24 nmol/g (dry weight=dw) in Lizard Lake to a high of 182±42 nmol/g (dw) in Old Wolf Lake (Table 4.3). Stocking and Maxwell lakes had metallothionein concentrations (110±22 and 92±26 nmol/g (dw), respectively). Although, the metallothionein concentrations in fish from Old Wolf Lake were not significantly higher (by statistical analysis) than the other acid rain lakes (Cross, 1991), the higher metallothionein concentrations in Old Wolf Lake were likely caused by the presence of detectable free ionic copper (Cu^{2+}) concentrations (Table 4.1).

The metallothionein concentrations in the rainbow trout from all four acid rain lakes were significantly lower than in rainbow trout from Buttle Lake (453±191 nmol/g (dw)), and are thought to represent background concentrations. Buttle and Old Wolf lakes have similar free ion copper concentrations; however, Buttle Lake had much higher free ion zinc concentrations (Table 4.1). These results suggest that the elevated metallothionein concentrations in Buttle Lake were due to differences in ambient zinc concentrations between the two lakes.

Elevated hepatic metallothionein concentrations have been correlated with elevated ambient dissolved copper and zinc in Buttle Lake (Roch and McCarter, 1984; Deniseger, *et al.*, 1990), and with ambient dissolved copper in the Tsolum River (McKean *et. al.* 1991). Thus, metallothionein appears to be an effective bio-indicator for the presence of copper and zinc.

4.3.2 Cadmium

Liver membrane and cytosolic cadmium concentrations in rainbow trout from the acid rain lakes were not significantly different (Cross, 1991), and were consistently less than 1 µg Cd/g dry weight (Table 4.4). In contrast, the cadmium concentrations in rainbow trout from Buttle Lake were significantly higher in both the membrane and cytosolic fractions (C.B.R., 1990). The average cytosolic and membrane cadmium concentrations from Buttle Lake were 9.7±8.0 and 3.0±1.8 µg Cd/g (dw)(n=10). The ambient cadmium concentrations in Buttle Lake averaged 0.1 µg Cd/L, yet resulted in a 25- to 50- fold increase in the cytosolic cadmium concentrations, and 9- to 40- fold increase in the membrane cadmium concentrations when compared to rainbow trout from the acid rain lakes.

Based on the results from the acid rain lakes, it appears that the hepatic cadmium concentrations from the acid rain lakes represent background concentrations, and that the hepatic accumulation of cadmium is a sensitive bio-monitor of low-level increases in ambient cadmium concentrations.

4.3.3 Copper

Copper concentrations in both the membrane and cytosolic protein fractions in fish livers from Old Wolf Lake were statistically higher than those in fish livers from Maxwell and Stocking lakes (Cross, 1991). The higher hepatic copper concentrations in fish from Old Wolf Lake are thought to be the result of the higher ambient free copper ionic concentrations in that lake (Table 4.1). The copper concentrations in the membrane and cytosolic fractions averaged (± standard deviation) 412 ± 292 and 449 ± 323 µg Cu/g (dw), respectively, for rainbow trout livers from Old Wolf Lake.

The Buttle Lake cytosolic copper concentrations (Tables 4.3 to 4.7) were similar to those from Old Wolf Lake at 454 ± 228 µg Cu/g (dw) (n=10), but the membrane copper concentrations were statistically lower at 184 ± 121 µg Cu/g (dw) (Cross, 1991). The free ionic copper concentrations in Buttle Lake were about one-half those found in Old Wolf Lake (Table 4.1), supporting the observation that the elevated copper concentrations in the cytosolic fraction were the result of the presence of free ion copper in the aquatic environment. The lower membrane copper concentrations in Buttle Lake fish were probably the consequence of the higher metallothionein concentrations in the cytosolic fraction, and the removal of copper from the membrane fraction by the metallothionein proteins. This was supported by the observation that the concentration of copper associated with the metallothionein proteins was statistically higher in Buttle Lake fish than in fish from the acid rain lakes (Cross, 1991), and that metallothionein has a high binding affinity for copper (Roch and McCarter, 1984).

It appears that hepatic copper concentrations are a sensitive bio-monitor for small increases in ambient copper (1 to 2 µg/L) if background concentrations are low (< 1 µg/L). However, large changes in ambient copper concentrations do not result in increasing hepatic copper concentrations. Large changes in ambient copper are best monitored with metallothionein concentrations, and by measuring the partitioning of copper between the membrane, cytosolic, and metallothionein proteins.

4.3.4 Lead

The average cytosolic lead concentrations for rainbow trout livers from the acid rain lakes (Table 4.6) ranged between 0.00 and 0.6 μg Pb/g (dw), while the average membrane lead concentrations were generally lower at 0.06 to 0.40 μg Pb/g (dw). The membrane lead concentrations were not significantly different (statistically) among rainbow trout from the acid rain lakes. However, the cytosol lead concentrations were statistically higher in Old Wolf Lake trout than in Stocking Lake trout, which in turn were statistically higher than Maxwell Lake trout (Cross, 1991). It is difficult to determine if the variability of the cytosolic lead results reflected differences in lead concentrations, as the water chemistry results from the acid rain lakes were below the detection levels (Table 4.1).

Old Wolf Lake had a significant positive correlation ($r=0.77$; $n=9$) between fish weight and lead membrane concentrations, but an insignificant negative correlation ($r=-0.47$) between fish weight and lead cytosolic concentrations. The relationships between fish weight and hepatic lead concentrations in the other acid rain lakes were all insignificant. It is difficult to determine if the fish weight/lead liver concentration relationship is valid for older age classes (e.g., Old Wolf Lake), and invalid for lakes with younger fish populations, or if other environmental factors not measured in this study are influencing hepatic lead concentrations.

Average cytosolic and membrane concentrations in rainbow trout from Buttle Lake were 0.406 ± 0.223 and 0.500 ± 0.440 μg Pb/g (dw), respectively. The membrane lead concentrations were not statistically different from those found at any of the acid rain lakes (Cross, 1991). However, the cytosolic lead concentrations were statistically lower in Buttle Lake fish than in fish from Old Wolf Lake, but statistically higher than in fish from Maxwell Lake.

The differences in hepatic lead concentrations between the lakes is difficult to relate to water chemistry as all ambient lead concentrations were below the 1 μg/L detection level. Consequently, we cannot determine from these data if hepatic lead results are good indicators of lead contamination of the aquatic environment.

4.3.5 Zinc

The cytosolic zinc fraction was larger than the membrane zinc fraction for fish from the acid rain lakes. The cytosolic zinc concentrations were similar (Cross, 1991), with concentrations ranging between 85 to 105 µg Zn/g (dw) (Table 4.7).

The membrane zinc fractions were between two to four times lower, with concentrations ranging between 15 to 40 µg Zn/g (dw) (Table 4.7). The membrane zinc concentrations were different between fish from the acid rain lakes. Old Wolf Lake fish levels were significantly (statistically) higher than Maxwell Lake levels, which in turn were statistically higher than Stocking Lake (Cross, 1991). For the acid rain lakes, there was a statistically significant positive relationship ($r=0.73$, $n=39$) between the membrane zinc data and the fish weight. Consequently, the statistical differences in membrane zinc between the acid rain lakes can be explained by differences in fish weight (i.e., age class).

Except for Lizard Lake, the variability of zinc in both the membrane and cytosolic fractions was low. The cytosolic zinc fraction had approximately 10% variance around the mean concentration, while the membrane zinc fraction was larger (15 to 25 %). The higher variability in Lizard Lake was the result of a small sample size.

The rainbow trout cytosolic and membrane zinc concentrations (101.6 ± 34 and 47.4 ± 13 µg Zn/g (dw), respectively), from Buttle Lake were not statistically different from trout from the acid rain lakes (Cross, 1991). The Buttle Lake ambient dissolved zinc and free ionic zinc concentrations (Table 4.1) were much higher than in the acid rain lakes, indicating that zinc does not accumulate in the hepatic tissues.

Based on the results from this study, it appears that membrane zinc concentrations increase with increasing size (i.e., fish age), and that hepatic zinc concentrations are not correlated with the ambient zinc concentrations. Thus, this is not likely a good test.

4.4 Conclusions

The results of the fish liver analyses from the acid rain lakes indicate that hepatic tissue analyses are an effective bio-monitor for low level cadmium and copper exposure. Hepatic lead results were inconclusive. Zinc hepatic results showed no accumulation of zinc despite exposure to high ambient concentrations. The membrane zinc concentrations were correlated with fish size.

The metallothionein concentrations in rainbow trout from Maxwell, Stocking, and Lizard lakes are thought to represent background conditions for systems with metal concentrations below 1 µg/L. Metallothionein results for rainbow trout from Old Wolf Lake showed a high degree of sensitivity to ambient zinc and copper concentrations.

For the purpose of trend studies to detect changes in the effects on fish exposed to heavy metals resulting from the acidification of the watershed, future analyses should focus on hepatic metallothionein, copper, and cadmium. The data presented in this report are inadequate to determine if fish are good monitors of ambient lead concentrations.

5.0 Chemistry of the Lake Sediments

The chemistry of the lake sediments is summarized in Table 5.1, while a summary of lake sediment chemistry for about 96 lakes on Vancouver and Queen Charlotte islands is in Table 5.2. For each of the lakes, including those in this study, only one grab sample using an Eckman or Ponar dredge was taken from each lake, often at the deepest point in the lake. In the future, replicate samples should be collected to determine variability.

No sediment samples were collected during the remainder of the monitoring program, and this section is therefore included verbatim from the original document (Swain *et al.*, 1994).

The highest concentrations for nine of the sixteen metals which were detected in at least one lake reported in Table 5.1 were found in Maxwell Lake, which also had the highest concentration of organic carbon present (234 000 µg/g). Of the remaining seven metals, four were highest at Marion (Jacobs) Lake, two were highest at Spectacle Lake, and chromium was the same concentration in all three lakes.

When the values in the six lakes in this study are compared to average concentrations for up to 96 coastal lakes in British Columbia (Table 5.2), 10 of the 16 metals for all six lakes have metal concentrations below the average. Those metals above the average were aluminum and molybdenum in Marion Lake, cadmium, lead, and zinc in Maxwell Lake, and tin in Spectacle Lake. All metals except molybdenum and lead were within one standard deviation of the mean lake concentration, and molybdenum and lead were within two standard deviations from the mean lake concentration.

Thus the sediment concentrations can be considered typical of those for coastal British Columbia. Measurements of metals in sediments do not appear to be good media to detect impacts from acidic inputs.

6.0 Chemistry of the Lake Water

This section of the report provides a general description of the water chemistry of the six acid rain lakes, and compares it to available water quality criteria. Section 7.0 examines the water chemistry data for any trends over time.

6.1 Sampling Periods

Data presented in this section were generally collected on a monthly basis from 1985 to early 1995. Earlier data are included for both Maxwell and Old Wolf lakes, and data were not collected for some months at most lakes primarily due to inaccessibility. Data for the six lakes are summarized in Tables 6.1, 6.2, 6.3, 6.4, 6.5, and 6.6 (Lizard Lake, Marion (Jacobs) Lake, Maxwell Lake, Old Wolf Lake, Spectacle Lake and Stocking Lake, respectively).

All variables were not necessarily measured for all samples. Sampling periods and months where no data were collected are summarized in Table 6.1.1.

Table 6.1.1 Sampling periods and missing data for the six study lakes.

Lizard Lake	
Sampling Period:	February 1985-June 1995
Missing Data:	December 1985
	June 1993
	March - June, 1994
	January - April, 1995
Marion (Jacobs) Lake	
Sampling Period:	April 1985 - September 1994
Missing Data:	March, November and December 1985
	January and February 1986
	January to March 1989
	February to April 1990
	January to March and December, 1991
	January and February, 1992
	January to April and December 1993
	January to April 1994

Table 6.1.1 (cont.) Sampling periods and missing data for the six study lakes.

Maxwell Lake	
Sampling Period:	January 1984 to March 1995
Missing Data:	June and July, 1984
	March to June 1994
Old Wolf Lake	
Sampling Period:	June 1982 - March 1995
Missing Data:	July and August 1983
	December 1985
	September 1990
	April 1991
	September 1993
	March and April 1994
	January 1995
Spectacle Lake	
Sampling Period:	September 1984 - March 1993
Missing Data:	None
Stocking Lake	
Sampling Period:	February 1985 - March 1995
Missing Data:	December 1985
	January 1986
	January 1993
	March and April 1994

6.2 pH and Alkalinity

The pH was measured in all lakes using both Orion Ross and Metrohm probes. An analysis of the comparative precision and accuracy of these two probes was conducted as part of the interim assessment (Swain *et al.*, 1994). Based on this comparison, it was recommended that the Orion Ross probe be used in cases such as this study, where inter-laboratory and intralaboratory precision objectives are applied to pH data. Therefore, in cases where a discrepancy occurs between the two probes, the Orion Ross data should be considered to be more accurate.

Similar seasonal trends were observed in all lakes throughout the monitoring program, with maximum pH values occurring in the summer and minimum values during the winter months. This trend is attributable to both the higher influx of low-pH rainwater in the winter months (when precipitation is much greater), and the higher in-lake alkalinity generation processes such as photosynthesis which occur in the summer. These generation processes are reflected in the alkalinity data, which show a similar seasonal trend of maximum values during the summer months for all six lakes. Swain (1987) defines lakes with total alkalinity of <200 meq/L (<10 mg/L) as highly sensitive to acid inputs, while those with concentrations of 200 to 400 meq/L (10-20 mg/L) are defined as moderately sensitive. Under this definition, all lakes are either moderately or highly sensitive to acid inputs, especially during winter months.

The Metrohm pH of Lizard Lake ranged from 6.5 to 8.0, with a mean value of 7.18. The pH measured by the Orion Ross probe, ranging from 6.59 to 7.74 with a mean of 7.08, was virtually identical. Alkalinity ranged from 150 to 330 meq/L, with a mean concentration of 208 meq/L. Thus, on average Lizard Lake would be considered on the border of being moderately sensitive and highly sensitive to acidic inputs (Swain, 1987).

The mean pH of Marion Lake measured with the Metrohm probe was 6.8, with a range of 5.7 to 7.7. The mean value over the 10-year period using the Orion Ross probe was similar at 6.54, with values ranging from 5.63 to 7.18. The mean alkalinity of Marion Lake was 86.5 meq/L, with values ranging from 12.9 to 218 meq/L. Marion Lake would therefore be defined as highly sensitive to acid inputs on average (Swain, 1987).

The mean pH of Maxwell Lake was identical for both the Metrohm and Orion Ross probes, at 7.2. The range of values was also similar, with Metrohm measurements ranging from 6.4 to 7.8 and Orion Ross measurements ranging from 6.13 to 7.72. The mean total alkalinity in Maxwell Lake was 272 meq/L, with values ranging from 99.4 to 330 meq/L. Therefore on average Maxwell Lake would be considered moderately sensitive to acidic inputs (Swain, 1987).

The pH of Old Wolf Lake ranged from 6.2 to 7.6, with a mean of 6.96 using the Metrohm probe. The pH measured with the Orion Ross probe was similar, with a mean of 6.86 and a range of 6.04 to 7.51. Old Wolf Lake would be considered highly sensitive to acid inputs, with a mean total alkalinity of 124 meq/L and a range of values from 49.9 to 179 meq/L.

The pH of Spectacle Lake ranged from 6.3 to 7.7 using the Metrohm probe, with a mean value of 7.03. The mean Orion Ross pH was very similar at 6.94, with values ranging from 6.10 to 7.59. The mean total alkalinity for Spectacle Lake was 252, with values ranging from 81 to 366 meq/L. With this mean alkalinity, Spectacle Lake would be considered moderately sensitive to acid inputs (Swain, 1987).

Metrohm pH values ranged from 5.7 to 7.6, with a mean of 7.0. Orion Ross pH values were virtually identical, with a mean of 6.96 and a range of 5.60 to 7.49. The mean total alkalinity over the 10-year monitoring period was 182 meq/L, with values ranging from 31 to 356 meq/L. Therefore, on average, Stocking Lake would be considered highly sensitive to acid inputs (Swain, 1987).

6.3 Hardness and Metals

The hardness of water is important when determining its suitability as a water supply with respect to soap consumption and scaling. In addition where aquatic life are present, the water hardness is an important factor in ameliorating the toxic effects of metals. Water hardness was generally very low in all of the lakes sampled, which make them potentially excellent water supplies (though corrosion may be a problem) but also means that metal concentrations must be low to prevent toxic effects.

Metals concentrations were generally measured using either ICP or graphite furnace methods. The graphite furnace method has lower detection limits and was used when possible, but ICP data were used when graphite furnace data were not available. Therefore, detection limits for many metals vary in Tables 6.1 through 6.6. The majority of metals tested for were present in concentrations less than lower detection limits and/or less than approved water quality criterion for the protection of aquatic life and drinking water supplies at all six lakes (Nagpal, 1995). Concentrations which exceed criteria are discussed in Sections 6.3.1 through 6.3.6.

6.3.1 Lizard Lake

The average water hardness of Lizard Lake was 11.9 mg/L, which means that the water is very soft. Therefore, metal concentrations must be low to prevent toxic effects.

Concentrations of total cadmium exceeded the criterion for the protection of freshwater aquatic life of 0.0002 mg/L at a hardness of less than 30 mg/L (Canadian Council of Resource and Environment Ministers, 1987) in 2 of 97 samples. Cadmium concentrations in these samples were barely at the detection limit of 0.0005 mg/L.

A total of 8 of 98 samples had total chromium concentrations exceeding the threshold of 0.002 mg/L for the protection of phyto- and zooplankton (Canadian Council of Resource and Environment Ministers, 1987) with a maximum concentration of 0.03 mg/L. The maximum concentration of total chromium measured in a blank sample from Lizard Lake was 0.01 mg/L (Section 2.2.7), which suggests that this high value may reflect the true concentration of total chromium in the lake.

The criterion for the protection of freshwater aquatic life of 0.002 mg/L for total copper (Singleton, 1987) was exceeded in 5 of 97 samples, with maximum values equal to the detection limit of 0.01 mg/L occurring in samples collected in early 1985. These values are well below the maximum concentration of 0.09 mg/L found in a blank from Lizard Lake (Section 2.2.2), and could therefore be due to contamination.

A total of 4 of 97 samples had total lead concentrations exceeding the 30-day average criterion of 0.004 mg/L for the protection of freshwater aquatic life (Nagpal, 1987). Detection limits for lead ranged from <0.001 mg/L to 0.1 mg/L, and the maximum measured concentration was barely equal to the higher detection limit of 0.1 mg/L.

The criterion for total zinc of a maximum concentration of 0.03 mg/L for the protection of freshwater aquatic life (Canadian Council of Resource and Environment Ministers, 1987) was exceeded in 2 of 97 samples, with a maximum concentration of 0.04

mg/L. This value falls below the maximum concentration of 0.05 mg/L found in a blank from Lizard Lake, and could therefore be due to contamination.

The primary metal of concern when considering acid inputs is aluminum, due to its increased toxicity in lower pH. The mean concentration of dissolved aluminum of 0.047 mg/L is barely below the criterion of 0.05 mg/L for the protection of freshwater aquatic life, and the maximum value meets the criterion for a maximum of 0.1 mg/L (Butcher, 1988). However, the mean value is biased due to 17 values which were less than the high detection limit (0.1 mg/L) but considered to be 0.1 mg/L for the purpose of calculating the mean. Disregarding these values, the mean is 0.028 mg/L. In addition, a very high value of dissolved aluminum was measured in a blank from Lizard Lake (1.29 mg/L, Section 2.2.1), suggesting that contamination had occurred. Therefore, it does not appear that aluminum concentrations are a concern in Lizard Lake.

6.3.2 Marion (Jacobs) Lake

The mean hardness of Marion (Jacobs) Lake was very low, at 5.9 mg/L. Therefore, metal concentrations must also remain low to prevent toxicity to freshwater aquatic life. Concentrations of total metals were not analyzed in the blanks associated with Marion (Jacobs) Lake, so the potential contamination in these samples is unknown.

A total of 11 of 43 samples contained dissolved aluminum concentrations exceeding the maximum criterion of 0.1 mg/L for the protection of freshwater aquatic life (Butcher, 1988), with a maximum concentration of 0.14 mg/L. In addition, the mean concentration (0.086 mg/L) exceeded the 30-day average criterion of 0.05 mg/L. However, large amounts of dissolved aluminum were also measured in blanks associated with Marion (Jacobs) Lake, with a maximum concentration of 0.65 mg/L (Section 2.2.1). As concentrations of dissolved aluminum do not appear to be increasing over time, it does not appear that this metal is a concern in Marion Lake.

Two of 66 samples contained total cadmium concentrations exceeding the water quality criterion of 0.0002 mg/L for the protection of freshwater aquatic life (Canadian

Council of Resource and Environment Ministers, 1987), with a maximum concentration of 0.04 mg/L.

Detection limits for total chromium (0.01 mg/L) exceeded the criterion for the protection of phyto- and zooplankton of 0.002 mg/L (Canadian Council of Resource and Environment Ministers, 1987) so a majority of the data cannot be evaluated with respect to criterion. A total of thirteen of the 67 samples contained concentrations of total chromium exceeding this detection limit and therefore the criterion, with a maximum recorded concentration of 0.09 mg/L.

Both the water quality criterion mean and maximum concentration for total copper (0.002 and 0.0025 mg/L respectively at a mean hardness of 5.88 mg/L) were exceeded in 7 of 66 samples, with a maximum concentration of 0.03 mg/L.

The maximum concentration of total iron was 0.61 mg/L, and six of 67 samples exceeded the water quality criterion of 0.3 mg/L for the protection of freshwater aquatic life. However, the concentration of dissolved iron was much lower, with a maximum concentration of only 0.16 mg/L. This suggests that high iron concentrations are due to suspended materials and therefore will not affect aquatic life.

Concentrations of total lead exceeded the maximum concentration criterion for the protection of freshwater aquatic life of 0.003 mg/L (Nagpal, 1987) in 12 of 65 samples, with a maximum concentration of 0.5 mg/L.

The water quality criterion for total nickel for the protection of freshwater aquatic life is 0.025 mg/L (Canadian Council of Resource and Environment Ministers, 1987), and was exceeded by 2 of 68 samples collected at Marion (Jacobs) Lake. There were also three other samples which were tested at a detection limit of 0.05 mg/L, so it is possible that nickel concentrations in these samples also exceeded the criterion.

A total of 2 of 67 samples contained total zinc concentrations which exceeded the tentative maximum water criterion for the protection of freshwater aquatic life of 0.03

mg/L, with a maximum concentration of 0.48 mg/L. Both this value and the second value exceeding the criteria (0.121 mg/L) were much higher than the median concentration of <0.01 mg/L for total zinc.

6.3.3 Maxwell Lake

The mean hardness of Maxwell Lake throughout the monitoring period was 18.4 mg/L, with values ranging from 6.5 to 34.8 mg/L. At this concentration of hardness the water is very soft and is considered to be an excellent water supply, but concentrations of metals must be low to prevent toxic effects.

The detection limits used to measure total cadmium concentrations (ranging from 0.0005 to 0.01 mg/L) exceeded the water quality criterion of 0.0002 mg/L for this metal (Canadian Council of Resource and Environment Ministers, 1987), so interpretation of these data with respect to the criterion is difficult. A total of three of 89 samples had concentrations which exceeded detection limits, and the maximum recorded concentration of total cadmium was 0.0035 mg/L. This value is well below the maximum value of 0.009 mg/L detected in a blank associated with Maxwell Lake (Section 2.2.7), and therefore may be due to contamination rather than actual high values in Maxwell Lake.

Similarly, the majority of the samples measured for total chromium concentrations were tested at a detection limit of 0.01 mg/L, which exceeds the water quality criterion of 0.0.002 mg/L for the protection of freshwater aquatic life (Canadian Council of Resource and Environment Ministers, 1987). However, two of 90 samples exceeded this detection limit, with a maximum concentration of 0.03 mg/L of total chromium. The maximum concentration of total chromium measured at Maxwell Lake was only 0.01 mg/L (Section 2.2.7), which suggests that the high values measured here may be due to actual high ambient concentrations rather than contamination.

A total of 4 of 91 samples collected over the ten-year period contained total copper concentrations which exceeded the water quality criterion for the protection of freshwater aquatic life of 0.002 mg/L (Singleton, 1987), with a maximum concentration of 0.04 mg/L.

The maximum concentration also exceeds the maximum concentration measured in a blank associated with Maxwell Lake (0.016 mg/L, Section 2.2.2), suggesting actual high levels rather than contamination.

One of 90 samples contained total iron concentrations exceeding the water quality criterion of 0.3 mg/L for the protection of freshwater aquatic life (Canadian Council of Resource and Environment Ministers, 1987), at a concentration of 0.35 mg/L. However, this iron is probably associated with suspended particles and is therefore of no concern, since dissolved iron concentrations were low throughout the sampling period (maximum concentration 0.1 mg/L).

Of the 90 samples tested for total lead concentrations, only one had levels exceeding the water quality 30-day average criterion of 0.004 mg/L for the protection of freshwater aquatic life (Nagpal, 1987), at a level of 0.007 mg/L. However, the detection limits for much of the data collected during this period exceeded the criterion and therefore make interpretation difficult. Contamination of lead also appears to be common, as six of eleven blanks associated with Maxwell Lake had detectable amounts of total lead, and the maximum concentration of lead measured in these blanks was 0.006 mg/L (Section 2.2.4).

While none of the 91 samples tested for total nickel contained concentrations exceeding the water quality criterion of 0.025 mg/L, the majority of the data were tested at a detection limit of 0.05 mg/L which exceeds the criterion and makes interpretation of this data difficult.

Of the 90 samples tested for total zinc concentrations, three exceeded the tentative water quality criterion of 0.03 mg/L maximum for the protection of freshwater aquatic life. The maximum concentration was 0.07 mg/L.

Concentrations of aluminum, the metal of greatest concern when considering the effects of acidity, were all lower than the 30-day average criterion and therefore too low to be of concern throughout the monitoring period.

6.3.4 Old Wolf Lake

The mean concentration of hardness at Old Wolf Lake was very low at 7.4 mg/L, with values ranging from 3.35 to 9.9 mg/L. Although this makes the water a potentially excellent water supply, corrosion may be a concern. As well, concentrations of metals must remain low to prevent toxic effects.

Cadmium concentrations were below detection limits in the vast majority of samples tested, with only 2 of 86 samples having detectable concentrations of total cadmium (maximum concentration 0.0012 mg/L). However, detection limits (varying between 0.01 and 0.0005 mg/L) were higher than the water quality criterion for the protection of freshwater aquatic life of 0.0002 mg/L (Canadian Council of Resource and Environment Ministers, 1987), so the data has little value for interpretation with regards to the criterion.

The water quality criterion for chromium is 0.002 mg/L for the protection of freshwater aquatic life (Canadian Council of Resource and Environment Ministers, 1987), and this criterion was exceeded by 5 of 86 samples collected over the 10-year sampling period. However, while the remainder of the samples were below detection limits, these limits (<0.01 mg/L) exceeded the water quality criterion, which makes interpretation of these data difficult.

The water quality criterion of 0.002 mg/L for total copper concentrations was exceeded by 6 of 87 samples, with a maximum concentration of 0.04 mg/L.

One of 86 ambient water samples contained concentrations of total iron which barely exceeded the water quality criterion of 0.3 mg/L, at a level of 0.32 mg/L. However, as the maximum dissolved iron concentration was only 0.14 mg/L, and since this is the form that affects aquatic life, iron is not considered a problem in Old Wolf Lake.

The criterion for the maximum concentration of total lead of 0.003 mg/L at a hardness of ≤ 8 mg/L was barely exceeded by one of 87 samples, at a level of 0.004 mg/L.

Total nickel concentrations did not exceed the water quality criterion of 0.025 mg/L (Canadian Council of Resource and Environment Ministers, 1987) in any of the 87 samples, but detection limits (0.05 mg/L) were often greater than this level.

The tentative maximum water quality criterion for total zinc concentrations of 0.03 mg/L for the protection of freshwater aquatic life (Canadian Council of Resource and Environment Ministers, 1987) was exceeded in only one of 86 samples, at a level of 0.07 mg/L.

6.3.5 Spectacle Lake

The mean hardness of Spectacle lake was very low at 16.0 mg/L, with values ranging from 5.04 to 21.37 mg/L. The water is thus very soft and an excellent potential water supply, though problems with corrosion may occur. At this level of hardness, metal concentrations must remain low to prevent toxicity to freshwater aquatic life.

One of 63 samples contained dissolved aluminum concentrations exceeding 0.1 mg/L, the water quality criterion for the protection of freshwater aquatic life (Butcher, 1988). This may indicate that aluminum is a concern, as it is the most sensitive metal to acid inputs and may be highly toxic at lower pHs. However, concentrations of dissolved aluminum do not appear to be increasing with time, so with a stable pH this metal should not be a concern.

A total of 3 of 88 samples contained total cadmium concentrations exceeding detection limits ranging from <0.0005 to <0.01, with a maximum concentration of 0.0009 mg/L. As detection limits exceed the water quality criterion for total cadmium of 0.0002 mg/L (Canadian Council of Resource and Environment Ministers, 1987), this data offers little insight into possible exceedences of the criterion.

The maximum total chromium concentration of 0.12 mg/L exceeded the water quality criterion of 0.002 mg/L for the protection of freshwater aquatic organisms

(Canadian Council of Resource and Environment Ministers, 1987), as did six other samples out of a total of 47 collected during the 10-year program.

Of the 89 samples tested for total copper concentrations, 7 exceeded the water quality criterion of 0.002 mg/L for the protection of freshwater aquatic life (Singleton, 1987). The maximum concentration of total copper measured was 0.02 mg/L.

Iron concentrations in Spectacle Lake were very high at times, with a maximum concentration of 2.95 mg/L. This exceeds the water quality criterion of 0.3 mg/L for the protection of freshwater aquatic life (Canadian Council of Resource and Environment Ministers, 1987) by a factor of 10. Although much of the total iron concentration is usually associated with suspended particles, in Stocking Lake the maximum dissolved iron concentration was also high at 0.5 mg/L, so iron may be a concern.

The maximum water quality criterion for total zinc of 0.03 mg/L (Canadian Council of Resource and Environment Ministers, 1987) was exceeded by only sample of 87, at a concentration of 0.04 mg/L.

6.3.6 Stocking Lake

The mean hardness of Stocking Lake was very low at 11.1 mg/L, with a range of values from 3.65 to 15.46 mg/L. As with all other lakes monitored for this study, this makes the water a potentially excellent water supply, although corrosion may be a problem. As with the other lakes studies, metals concentrations must remain low to prevent toxicity.

The maximum concentration of total cadmium measured in Stocking Lake was 0.02 mg/L, one hundred times the water quality criterion of 0.0002 mg/L for the protection of freshwater aquatic life. A total of 5 of 81 samples contained total cadmium concentrations which exceeded detection limits. However, these limits (<0.0005 to <0.01 mg/L) were themselves above the criterion and make interpretation of the data difficult.

Eleven of 82 samples tested for total chromium had concentrations exceeding the criterion of 0.002 mg/L to protect aquatic life, with a maximum concentration of 0.03 mg/L.

The criterion for maximum total copper concentration to protect aquatic life of 0.003 mg/L (Singleton, 1987) was exceeded in one of 81 samples, at a level of 0.04 mg/L.

While the maximum total iron concentration of 0.41 mg/L exceeded the water quality criterion of 0.3 mg/L for the protection of freshwater aquatic life, the mean concentration (0.08 mg/L) and the maximum concentration of dissolved iron (0.18 mg/L) were well below the criterion. This suggests that high total iron values are associated with suspended particles and therefore are not a concern since this type of iron does not affect aquatic organisms.

Concentrations of total lead exceeded the maximum water quality criterion for the protection of aquatic life of 0.003 mg/L in 3 of 81 samples. The maximum concentration was 0.3 mg/L, much higher than the median value of <0.1 mg/L.

The remainder of metals tested for were present in concentrations below water quality criteria. The maximum concentration of dissolved aluminum barely met the maximum criterion of 0.1 mg/L for the protection of freshwater aquatic life (Butcher, 1988) and the mean concentration (0.04 mg/L) of dissolved aluminum was less than the 30-day average criterion of 0.05 mg/L (ibid.). While this metal is of extreme importance in determining the impact of acidity on freshwater aquatic life, dissolved aluminum concentrations do not appear to be a concern in Stocking Lake.

Pommen (1995) found that all metals concentrations met drinking water guidelines with the exception of iron, which exceeded the aesthetic guideline on rare occasions.

6.4 Nutrients

The limiting factor for lake productivity is generally the amount of phosphorus available to aquatic life, and lakes containing mean concentrations of total phosphorus <0.010 mg/L are considered to be oligotrophic (Nordin, 1985). Under this definition, all of the six lakes studied would be considered oligotrophic, with the highest mean concentration of total phosphorus (0.009 mg/L) occurring in Maxwell Lake. Lizard and Spectacle lakes had the lowest mean concentrations of total phosphorus (0.004 mg/L), Stocking and Marion (Jacobs) lakes both had a mean concentration of 0.005 mg/L, and Old Wolf Lake had a mean concentration of 0.008 mg/L.

Total nitrogen to total phosphorus ratios also give a good indication as to whether biological production in a water body is limited by nitrogen or by phosphorus. In lakes where the nitrogen:phosphorus ratio (by weight) is greater than 15:1, production is generally limited by phosphorus. Nitrogen:phosphorus ratios less than 5:1 are indicative of a nitrogen limitation, while those between 5:1 and 15:1 suggest that co-limitation is occurring. For samples collected prior to July of 1986, total nitrogen was calculated in all lakes by summing the Kjeldahl nitrogen concentration and the dissolved nitrate/nitrite concentration. After 1988, dissolved nitrate/nitrite was no longer measured so total nitrogen concentrations were calculated by summing the Kjeldahl nitrogen concentration with the total nitrate concentration. The range of N:P ratios and the mean ratio were similar for all lakes (Table 6.3.1). The mean values (ranging from 26:1 in Marion Lake to 58.5:1 in Spectacle Lake) suggest that phosphorus is generally the limiting nutrient for growth. In each lake, the minimum N:P ratio was near 15, suggesting that occasionally co-limitation may be occurring between these two nutrients.

The concentration of all nitrogen forms in the six lakes was generally very low. Nitrate levels were well below the maximum water quality criterion of 10 mg/L to protect drinking water supplies (Nordin and Pommen, 1986). Isolated incidents of very high soluble nitrate concentrations occurred in Lizard, Maxwell and Stocking lakes. The fact that concentrations before and after these extremes were well within the average range for these lakes suggest that these values were a result of contamination, and were therefore not included in the data. These concentrations were: 1.18 mg/L in November of 1991 from Lizard Lake, 11.7 mg/L in December 1990 and 1.62 in April 1992 from Maxwell Lake, and 3.34 mg/L in December 1990 and 5.2 mg/L in May 1994 from Stocking Lake. Maximum concentrations of total nitrate in the lakes after these anomalous data were omitted were: 0.37 mg/L in Lizard Lake, 0.97 mg/L in Marion (Jacobs) Lake, 0.52 mg/L in Maxwell Lake, 2.64 mg/L in Old Wolf Lake, 4.9 mg/L in Spectacle Lake, and 1.04 mg/L in Stocking Lake. The relatively high maximum concentrations measured in Old Wolf and Spectacle lakes was not considered to be anomalous, as the concentrations in the months preceding and following the high values were themselves quite high (Figures 6.1 and 6.2) and part of an obvious seasonal trend.

Table 6.4.1 Comparison Table of Nutrients and Solids for All Lakes

	Lizard	Marion	Maxwell	Old Wolf	Spectacle	Stocking
Total dissolved solids	22.4	19.7	40	25.3	38.4	25.6
Specific conductivity	33.5	17.1	54.1	25.1	45.2	30.4
TDS:SpCond ratio	0.67	1.22	0.74	0.98	0.84	0.83
Colour	4.4	11.3	5.2	7.49	14.8	6.2
Phosphorus - total	0.004	0.004	0.009	0.008	0.008	0.005
Nitrogen - total	0.019	0.2	0.288	0.32	0.37	0.17
N:P ratio	40.6	26	33.9	47.3	58.5	39.1
Dominant anions	Cl^- (2.27)	$SO4^-$ (1.65)	Cl^- (4.4)	Cl^- (2.67)	Cl^- (3.03)	$SO4^-$ (1.86)
	$SO4^-$ (1.4)	Cl^- (0.68)	$SO4^-$ (3.9)	$SO4^-$ (0.7)	$SO4^-$ (2.66)	Cl^- (1.76)
Dominant cations	Ca^+ (3.88)	Ca^+ (1.86)	Ca^+ (5.3)	Na^+ (1.93)	Ca^+ (5.07)	Ca^+ (3.51)
	Na^+ (1.57)	Na^+ (0.84)	Na^+ (2.9)	Ca^+ (1.83)	Na^+ (2.08)	Na^+ (1.29)
	Mg^+ (0.5)	Mg^+ (0.21)	Mg^+ (1.16)	Mg^+ (0.62)	Mg^+ (0.81)	Mg^+ (0.49)
	K^+ (0.096)	K^+ (0.1)	K^+ (0.3)	K^+ (0.19)	K^+ (0.13)	K^+ (0.28)

*all measurements in mg/L except colour (colour units), specific conductivity (µS/cm), TDS:SpCond ratio (no units), and N:P ratio (no units)

6.5 Solids and Colour

6.5.1 Lizard Lake

Dissolved concentrations of solids in Lizard Lake over the 10 year sampling period ranged from 16 to 28 mg/L, with a mean concentration of 22.4 mg/L. The average specific conductivity was 33.5 µS/cm over the same period, with values ranging from 24 to 46 µS/cm. The ratio of total dissolved solids to specific conductivity ranged from 0.51 to 0.93, with a mean value of 0.67.

The ion present in the highest concentration was soluble calcium, with an average concentration of 3.88 mg/L, followed by soluble chloride (2.27 mg/L), soluble sodium (1.57 mg/L), soluble sulfate (1.4 mg/L), soluble magnesium (0.5 mg/L) and soluble potassium (0.096 mg/L). All ions appeared to fluctuate seasonally in concentration, with highest levels occurring in the winter months. The concentration of total calcium was measured at less than detection limits (<0.02 mg/L) on four occasions (May and June 1985, December 1993 and December 1994), and these values were omitted from the data because they were implausibly low.

6.5.2 Marion (Jacobs) Lake

The concentration of dissolved solids in Marion (Jacobs) Lake ranged from 8 to 32 mg/L, with a mean value of 19.7 mg/L. The specific conductivity ranged from 9 to 30 µS/cm, with an average value of 17.1 µS/cm. The ratio of total dissolved solids to specific conductivity ranged from 0.38 to 2.18, with a mean of 1.22. This mean value was higher than that of the other lakes monitored, and the range of values was also greater.

Soluble calcium was the ion present in the highest concentration, with a mean value of 1.86 mg/L. Other ions present, in decreasing order of average concentrations, were: soluble sulphate (1.65 mg/L), soluble sodium (0.84 mg/L), soluble chloride (0.68 mg/L), soluble magnesium (0.21 mg/L), and soluble potassium (0.10 mg/L).

6.5.3 Maxwell Lake

The mean concentration of dissolved solids in Maxwell Lake was 40.0 mg/L, with values ranging from 16 to 56 mg/L. Specific conductivity values ranged from 26 to 65 µS/cm, with a mean value of 54.1 µS/cm. The mean total dissolved solids:specific conductivity ratio was 0.74, with values ranging from 0.57 to 1.18.

Soluble calcium was the ion present in the highest concentration, with a mean value of 5.3 mg/L, followed by soluble chloride (4.4 mg/L), soluble sulphate (3.9 mg/L), soluble sodium (2.9 mg/L), soluble magnesium (1.16 mg/L), and soluble potassium (0.3 mg/L). Total calcium was not detected in one sample (<0.02 mg/L in February 1989), and total magnesium was not detected in one sample (<0.02 mg/L in February 1989) and was very low in another (0.001 mg/L in February 1990). These data were omitted as being implausibly low.

6.5.4 Old Wolf Lake

Dissolved solids concentrations in Old Wolf Lake had a mean concentration of 25.3 ± 0.6 mg/L, and values ranging from 10 to 36 mg/L. Specific conductivity levels ranged from 13 to 36 µS/cm, with a mean value of 25.1 µS/cm. The ratio of total dissolved solids to specific conductivity ranged from 0.53 to 1.42, with a mean value of 0.98.

The ion present in the highest concentration in Old Wolf Lake was soluble chloride, with a mean concentration of 2.67 mg/L. Other ions present, in decreasing order of average concentration, were soluble sodium (1.93 mg/L), soluble calcium (1.83 mg/L), soluble sulphate (0.7 mg/L), soluble magnesium (0.62 mg/L), and soluble potassium (0.19 mg/L).

6.5.5 Spectacle Lake

Dissolved solids concentrations in Spectacle Lake ranged from 10 to 54 mg/L, with a mean value of 38.4 mg/L. The mean specific conductivity was 45.2 µS/cm, with values ranging from 17 to 58 µS/cm. The mean ratio of total dissolved solids to specific conductivity in Spectacle Lake was 0.84, with values ranging from 0.59 to 1.14.

Soluble calcium was the ion present in the highest concentration in Spectacle Lake over the 10-year monitoring period, with a mean value of 5.07 mg/L and concentrations ranging from 1.9 to 6.7 mg/L. Other ions (and their mean concentrations) in decreasing order were: soluble chloride (3.03 mg/L), soluble sulphate (2.66 mg/L), soluble sodium (2.08 mg/L), soluble magnesium (0.81 mg/L) and soluble potassium (0.13 mg/L).

6.5.6 Stocking Lake

The concentration of dissolved solids in Stocking Lake ranged from 12 to 42 mg/L, with a mean value of 25.6 mg/L. The mean specific conductivity was 30.4 μS/cm, with values ranging from 13 to 38 μS/cm. The ratio of total dissolved solids to specific conductance ranged from 0.51 to 1.13, with a mean of 0.83.

The ion with the highest concentration was calcium, with a mean value of 3.51 mg/L, followed by soluble sulphate (1.86 mg/L), soluble chloride (1.76 mg/L), soluble sodium (1.29 mg/L), soluble magnesium (0.49 mg/L) and soluble potassium (0.28 mg/L).

7.0 Trends in Lake Chemistry

The major characteristics of concern with regard to the effects of potential acidification are the following: pH, sodium, sulphate, calcium, alkalinity, and aluminum. A decrease in pH or alkalinity, or an increase in sodium, sulphate or calcium ions, would suggest that some impact is occurring due to acidic inputs. The effects of potential impacts that are of most immediate concern are those due to the increased toxicity of aluminum with decreasing pH. A fairly strong seasonal trend was observed at all lakes, with pH, sodium, calcium, and alkalinity all increasing over the summer and decreasing through the winter, and sulphate following the reverse trend (increasing over the winter and decreasing through the summer). Concentrations of aluminum remained relatively constant throughout the sampling period. Some variability was evident at the individual lakes, and is discussed in the following sections.

7.1 Lizard Lake

The pH of Lizard Lake was stable over the 10-year period using both the Orion Ross and Metrohm measurements, aside from the seasonal trends noted above (Figures 7.1.1 and 7.1.2). A peak in sodium, sulphate and calcium concentrations appeared in approximately November of 1989 (Figures 7.1.3, 7.1.4 and 7.1.5). Aside from these few high values, sodium and calcium, as well as alkalinity (Figure 7.1.6) remained relatively constant throughout the monitoring period. Sulphate concentrations appeared to decrease slightly after the late 1989 peak, and continued to decline until early 1992 when concentrations then recovered to pre-1989 levels. Therefore there do not appear to be any overall trends in the variables analyzed.

7.2 Marion Lake

The pH of Marion Lake showed the same seasonal trends as the other lakes for both Orion Ross and Metrohm values (Figures 7.2.1 and 7.2.2), but there was a greater range in the actual values. This relatively high degree of variability was also evident in the sodium, calcium, sulphate and alkalinity concentrations (Figures 7.2.3, 7.2.4, 7.2.5 and 7.2.6, respectively). This variability seemed highest for sodium, calcium and alkalinity between 1985 and 1989, with higher summer peaks in these years. Peak summer concentrations are often related to precipitation and temperature during these months, with low rainfall and warm weather resulting in high evaporation rates and a concentration of ions in the remaining water. However, this does not appear to be the cause of these high values, as the mean precipitation for the summer months (July, August and September) from 1985 to 1989 was 2.0 mm/day, only marginally lower than the mean of 2.4 mm/day for the summers of 1990 through 1994. The relatively small size of the lake, coupled with its potential for extremely rapid turnover, also contribute to this variability. However, there do not appear to be any trends, either increasing or decreasing, in the concentration of any of these characteristics.

7.3 Maxwell Lake

The pH of Maxwell Lake remained relatively constant throughout the monitoring period, with a strong seasonal fluctuation in both the Metrohm and the Orion Ross measurements (Figures 7.3.1 and 7.3.2, respectively). The minimum pH measured using the Metrohm probe occurred on March 8, 1989, and the lowest pH measured on the Orion Ross probe occurred on December 6, 1990. Neither of these dates were preceded by particularly high rainfall, so it is unclear what caused these high peak values.

Sodium concentrations appeared to increase slightly between 1985 and 1989, and then became fairly consistent with only occasional extreme high or low values (Figure 7.3.3). The 5-year average for soluble sodium from 1985 to 1989 was 2.8 mg/L, and this increased to 3.0 mg/L for the period from 1990 to 1995. Calcium concentrations followed the same general trend, with values increasing to 1989 and then remaining fairly consistent for the remainder of the monitoring program (Figure 7.3.4). Soluble sulphate concentrations, on the other hand, increased from 1985 to 1989, and then decreased slightly from 1990 to 1995 (Figure 7.3.5). Alkalinity appeared to increase in both concentration and variability throughout the sampling period (Figure 7.3.6). Therefore, it does not appear that there was any impact on the water quality of Maxwell Lake from acidic inputs.

7.4 Old Wolf Lake

The pH of Old Wolf Lake measured with the Metrohm probe appeared to be reasonably consistent, with the same pattern of seasonal variation as noted in the other lakes (Figure 7.4.1). The pH measured with the Orion Ross probe appeared to decrease slightly throughout the monitoring period (Figure 7.4.2), and the mean pH from 1985 to 1989 of 6.94 decreased to 6.79 from 1990 to 1995.

The logging that occurred in the Old Wolf Lake watershed appeared to affect the concentrations of some ions more than others, and over different time scales. Sodium concentrations increased from 1986 to 1989, and then decreased to near or below pre-1986 levels (Figure 7.4.3). Calcium concentrations increased to a peak in early 1988, and also decreased to pre-1986 levels over the next few years (Figure 7.4.4). Suspended sulphate concentrations remained very stable over the 10-year monitoring period, but a few very high concentrations of dissolved sulphate were measured between May 10, 1988 and August 3, 1988 (Figure 7.4.5). As these were the only concentrations of dissolved sulphate measured after 1986, discussion of these data is difficult. It would appear that these values are probably due to contamination from some source, as there was no concurrent increase in suspended sulphate at the time these values were measured. Alkalinity also appeared to decrease throughout the monitoring period, though the high degree of seasonal variability, coupled with extremely low values in January 1991 and February 1993, make this trend rather subtle (Figure 7.4.6). Therefore, it appears that while changes in the concentration of some variables has occurred, the majority of these are re-equilibrating at concentrations near those measured at the beginning of the study. The apparent decrease in both pH and alkalinity over the monitoring period are probably not sufficient to cause any problems in Old Wolf Lake, though both variables should be monitored to establish whether the trends continue in the future.

7.5 Spectacle Lake

The pH at Spectacle Lake was very constant throughout the monitoring period, with a strong, regular seasonal variation in both the Metrohm and Orion Ross measurements (Figure 7.5.1 and 7.5.2, respectively).

Similarly, the sodium, calcium, sulphate and alkalinity concentrations were relatively constant with no evidence of either increasing or decreasing trends. All characteristics showed a high degree of seasonal variability (Figures 7.5.3, 7.5.4, 7.5.5, and 7.5.6, respectively), probably due to the extremely short residence time (see Section 1.5) and subsequent sensitivity to rainfall inputs of Spectacle Lake. Therefore, it does not appear that there are any effects of acidification in Spectacle Lake.

7.6 Stocking Lake

The pH of Stocking Lake was relatively constant throughout the monitoring period, with seasonal trends visible in both the Metrohm and Orion Ross data (Figures 7.6.1 and 7.6.2, respectively). An extremely low pH value was measured on February 13, 1991, on both the Metrohm and Orion Ross probes (5.7 and 5.6, respectively). High precipitation was not recorded at the Nanaimo monitoring station immediately prior to this date, so it is unclear what contributed to the low pH.

The sodium concentrations in Stocking Lake appeared to increase very slightly from 1985 to about 1991, and then decrease until about 1992 where values tended to remain relatively stable (Figure 7.6.3). A similar decrease in calcium concentrations was evident in 1991, and again concentrations after this time remained relatively stable at the decreased concentration (Figure 7.6.4). Sulphate and alkalinity concentrations showed only the usual seasonal trends (maximum concentrations in winter for sulphate and in the summer for alkalinity), with no increasing or decreasing trends overall (Figures 7.6.5 and

7.6.6, respectively). This assessment concurs with the findings of Pommen (1995), who found no indication of acidification or other adverse trends in Stocking Lake over the last decade.

7.7 Results of CUSUM and Shewhart Statistical Analyses of Data

A CUSUM and Shewhart analysis was conducted on the data from the six lakes for alkalinity, soluble calcium, soluble sodium, soluble sulphate, Metrohm pH and Orion Ross pH. Total aluminum was not included in this analysis because of the difficulty in interpreting values less than detection limits, as well as the fact that detection limits changed throughout the monitoring period.

The CUSUM test calculates the mean and the standard deviation based on the first one-third of the data set, and then calculates the sum of the deviations of the individual data points from this mean. If at any time this sum exceeds the upper or lower control limits, the data are considered to be "out of control", i.e., the mean and standard deviation are considered to be significantly different from that calculated for the first one-third of the data (Laidlaw, 1994).

The Shewhart analysis displays the data set with a line representing the mean and two dashed lines representing plus and minus 2.96 standard deviations. The mean and standard deviation are also calculated from the first one-third of the data set. This graph is included for ease of interpreting the actual change detected by the CUSUM test with respect to time. Results of these analyses in which a significant trend occurred are included in Appendix 3, and a summary is given in Table 7.7.1. The magnitude of the observed trend is not included in this summary table because there appears to be some problem with the magnitude of the new mean calculated.

A number of factors must be considered when interpreting the trends shown in the CUSUM graph. First, a series of seven consecutive data points on the same side of the mean (i.e. either greater than or less than the calculated mean) will tend to put the system "out of control". In cases such as pH, where there is a very strong seasonal trend, this tends to occur when a number of measurements are taken in the same season. Therefore, in cases where strong seasonality exists, a proper interpretation of the data would require that the seasons be considered separately (e.g., data collected in the winter of one year compared only with winter data from other years). For this reason, the results of the pH analyses are not included in the summary table.

Second, in cases where the first one-third of the data are not representative of the remaining data (e.g. when several extreme values, or a very low standard deviation occurs), it is much more likely that a trend will be observed using the CUSUM method. In these cases, it is sometimes possible to use the mean and standard deviation from a more representative section of the data set though this was not done for our analyses.

Third, the CUSUM test assumes that the data are normally distributed, and this is not always the case (see Table 7.7.1). It is not known how robust the CUSUM is with regards to normality, or how it behaves in cases where the data is not normal. Also, the CUSUM analysis used in this study assumes periodic monitoring, with the same time period between samples. It is not known how data gaps and periods of unequal duration will affect the accuracy of the CUSUM result.

Finally, there was a change in the agency conducting the chemical analyses on the samples, from the provincial Ministry of the Environment Environmental Laboratory to Zenon Laboratories, in 1989. Any major changes in the data during this period should be considered in this light.

In consideration of these factors, as well as the relatively small magnitude of the majority of the trends indicated by the CUSUM analyses, there appears to be little reason to change the interpretation offered in Sections 7.1 to 7.6.

Table 7.7.1 Summary of results of CUSUM analyses which indicated trends.

Lake and Characteristic	Overall Trend	Probability of Trend	Distribution Type
Lizard Lake			
Sodium	decreasing	P<0.03	not normally distributed
Sulphate	decreasing	P<0.01	normally distributed
Marion Lake			
Sulphate	decreasing	P<0.03	normally distributed
Maxwell Lake			
Alkalinity	increasing	P<0.01	not normally distributed
Calcium	increasing	P<0.01	not normally distributed
Sodium	increasing	P<0.01	not normally distributed
Sulphate	increasing	P<0.01	normally distributed
Old Wolf Lake			
Alkalinity	decreasing	P<0.01	not normally distributed
Calcium	decreasing	P<0.01	not normally distributed
Sodium	decreasing	P<0.01	not normally distributed
Sulphate	increasing	P<0.01	not normally distributed
Spectacle Lake			
Alkalinity	decreasing	P<0.03	not normally distributed
Calcium	decreasing	P<0.03	normally distributed
Stocking Lake			
Sodium	decreasing	P<0.01	not normally distributed
Sulphate	decreasing	P<0.01	normally distributed

7.8 Conclusions

From the above discussion, it does not appear that there has been an impact on water chemistry in any of the lakes due to acidic input except for perhaps Old Wolf Lake. In this case, it is difficult to isolate the effects of possible acidic inputs from the effects of logging on the watershed and on the lake itself. Further monitoring would be necessary to determine if concentrations of major ions continue to recover to pre-logging levels as the effects of this impact decrease with time.

8.0 Analysis of Phytoplankton and Zooplankton from the Lakes

8.1 Goals

Very little work has been directed towards characterizing 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 (LeBrasseur, 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 characterize 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 understanding 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 analyze. 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 characterized 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 characterize 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

8.2 Sampling Methods

All the lakes were sampled monthly between May and October at the normal sampling locations cited in Section 6 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 at 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 cm^2 mouth area (except Marion Lake which is discussed below). The samples were preserved with buffered formalin and identified using standard keys at the MoE Environmental Lab or subsequently at Zenon or Fraser Environmental Services.

8.3 Data Analysis

Phytoplankton taxa were 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 were then further broken down by mean concentration. Certain opportunistic genera, particularly the blue greens *Aphanothece* sp. and *Merismopedia* sp. showed very high peak numbers but generally occurred infrequently. Concentrations of these opportunists were often several orders of magnitude higher than other genera present. 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 a 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 was much less diverse than the phytoplankton, so division into categories was not necessary. Biomass was estimated using length to weight ratios as outlined in the literature (Wetzel and Likens 1991, Dumont *et. al.* 1975, Nauwerck 1963). Length data was not 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 8.3.1. These estimates should be interpreted with caution, as much disagreement as to weights of specific taxa exists in the literature. 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 taxa, and as such values for certain animals were estimated from the weights of similar organisms. Other organisms that occurred at low concentrations were omitted from calculations

Analysis of both phytoplankton and zooplankton was conducted to the genera level only. Schubert (1984) states that 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 zooplankton *Diaptomus* sp. is the most prominent example. *Diaptomus* was the dominant copepod in most lakes, and a number of species were identified. This identification was inconsistent however, with this organism identified as *franciscanus, novomexicanus, tyrrelli, orogonensis*, or *bakeri*, or lacking species designation depending on the lake in question. If more than one of the above taxa were reported at the same time, it would provide some evidence that only one species was present but this was seldom the case. Over the period of sampling, at least four taxonomists conducted 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 were 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.

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 planktivorous 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.

8.4 Lizard Lake

8.4.1 Phytoplankton

The phytoplankton community is very diverse, with 82 genera reported in the ten years of sampling. There are many genera which are reported once or at most, a few times. The dominant and sub dominant taxa are displayed in Table 8.4.1.1. 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 603 cell/mL, as is consistent with most of the other lakes (though in the case of Lizard Lake, this high mean is a result of relatively few very high density samples). Other means for the dominant and sub dominant groups range from 17 cells/mL for *Quadrigula* to 441 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 8.4.1.1 to 8.4.1.7, 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. *Elaktothrix*, 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 occurred over the study period. Chlorophyll a (Figure 8.4.1.8) showed a definite peak in 1989, with values ranging from 1.5 to 6 µg/L. Coincident with this peak was 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 8.4.1.9). 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 8.4.1.10) showed 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 8.4.1.11) exhibited a similar trend.

Biomass as measured by total cells per millilitre was relatively low, with peak concentrations generally below 7500 cells/mL (Figure 8.4.1.12). An overall decline in total numbers was evident. Chlorophyll a values reflected the low biomass, with a mean chlorophyll concentration of 1.21 µg/mL, and a range of 0.5 to 6.0 µg/L. Chlorophyll data show an opposite trend to the other biomass estimates, increasing slightly over the study period (Figure 8.4.1.8). It is difficult to determine whether the chlorophyll a and total numbers data correlate well given that chlorophyll a 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 8.4.1.2 contains a yearly summary of chlorophyll a data.

In summary, Lizard Lake phytoplankton can be characterized 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 8.4.1.3 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.

8.4.2 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 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 8.4.2.1). *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 8.4.2.2). The fact that *Cyclops* is reported in the early part of the study and *Diacyclops* is reported at the end (1992-1994), and that this occurs in other lakes as well (see 8.5.2, 8.6.2, 8.7.2, 8.8.2), coupled with the fact that these genera are very similar, indicates that these are probably the same genera. Nauplii and copepodite stages were observed throughout the study and appear to be fairly stable over time with no long-term trend evident (Figure 8.4.2.3).

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 8.4.2.4). 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 8.4.2.5) is absent from the lake during the periods 1985 to 1986 and 1989 to 1992, and *Holopedium* (Figure 8.4.2.6) 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 8.4.2.7) 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 8.4.2.8 to 8.4.2.11.

Analysis of biomass by dry weight demonstrates the relative contributions made by the cladoceran, copepod, and rotifer communities (Figure 8.4.2.12). This confirms that the cladocerans are the dominant group of zooplankton, 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 8.4.2.13).

8.5 Marion (Jacobs) Lake

Unlike the other lakes there has been a considerable amount of work done on Marion (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. Both the phytoplankton and zooplankton communities were characterized by very low total numbers and biomass. Dickman (1968) correlates this low productivity with the high flushing rate noted in Section 1.2. 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 nanoplankton, 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 Marion (Jacobs) Lake as sampled in this study.

8.5.1 Phytoplankton

The phytoplankton sampling and analysis methods used over the course of this study of Marion (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 3 m, 4 m or 13 m vertical tows. Marion Lake has a maximum depth of 7m at high water and a mean depth of only 2.3 m, thus a 13 m vertical tow seems implausible. This raises the question of whether some or all of these tows were 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/0.59 m^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.

Marion (Jacobs) Lake exhibits the greatest diversity among the study lakes, with 99 genera reported between 1985 and 1993. All genera exhibit a high degree of variability in numbers and period of occurrence. The dominant and sub-dominant genera are displayed in Table 8.5.1.1. *Navicula* is the most consistent of the dominants, present in 90% of all samples but 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 8.5.1.1 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 artifact of the change in sampling method. These taxa are displayed in Figures 8.5.1.1 to 8.5.1.6.

Phytoplankton standing crop as measured by total cells/mL (Figure 8.5.1.7) 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 8.5.1.8) reflects this pattern, increasing from a mean concentration of 1.75 µg/L to 3.63 µg/L, then decreasing to a mean of 1.60 µg/L for 1993 and 1994. A value of 22.4 µg/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 (Jacobs) Lake, however the data for the 1986 to 1988 period appear to be particularly low. Chlorophyll a data for this period shows values similar to those in 1993 and 1994, during which the calculated biovolumes are significantly higher. Chlorophyll a 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 (as biovolume or numbers) for 1986 to 1988 are in part a result of the inadequate collection technique. In addition there was a change in chlorophyll a 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 a concentration occurred prior to this. In general the chlorophyll a values for Marion (Jacobs) Lake are similar to the other lakes in the study, despite the relatively low numbers/biovolumes observed. Yearly summaries of phytoplankton and chlorophyll a values are shown in Tables 8.5.1.2 and 8.5.1.3.

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 8.5.1.4 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 (numbers/biovolumes) 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 8.5.1.1 and 8.5.1.4 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, but they nonetheless may be significant.

8.5.2 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 4 m. As in the phytoplankton the data were recorded in a number of different units (numbers per total sample, animals/m^3, animals/0.59 m^3, animals/m^2). The data was converted to animals per m^2 to be comparable with the other lakes.

Unlike the high diversity exhibited by the phytoplankton, Marion (Jacobs) Lake 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 8.5.2.1) 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 8.5.2.2) but they are likely the same taxa (see 8.4.2). 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 8.5.2.3).

Bosmina (Figure 8.52.4) and *Diaphanasoma* (Figure 8.5.2.5) are the two prominent cladoceran genera in Marion (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 8.5.2.6 to 8.5.2.8). 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 8.5.2.9). *Keratella* is reported five times, at levels between 70 and 600 /mL. *Polyarthra* and *Conochilus* are present once each, at 19,706 /mL and 1 /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 Marion Lake, followed by a much lesser contribution from the cladocera and very small amount from the rotifers (Figure 8.5.2.10). A slight decline in zooplankton biomass (Figure 8.5.2.11) and total numbers (Figure 8.5.2.12) 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 8.5.2.1. 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.

8.6 Maxwell Lake

8.6.1 Phytoplankton

As with the previous lakes, the diversity of the Maxwell Lake phytoplankton community is very high with 84 taxa reported. The dominant and sub-dominant taxa and mean concentration are displayed in Table 8.6.1.1. *Dinobryon* is the most conspicuous of the dominants, present in 95% of all samples with the highest mean concentration of this group, 110 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 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 8.6.1.1 to 8.6.1.10. 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 *Elaktothrix* all show a trend to increased numbers over the study period. *Dinobryon, Perediniun, 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 8.6.1.11) 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 Lake. *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 8.6.1.12). 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 8.6.1.13).

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, and 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 8.6.1.14). Total numbers peak in 1990 at concentrations under 2500/mL, significantly less than in Marion Lake, the next lowest. Maxwell Lake does not suffer from a short water residence time like Marion Lake. 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 8.6.1.15) show no clear trends and do not correlate with the dynamics of the total/mL data. The chlorophyll a values for 1985, 1986 and 1990 seem high given the low standing crop. Phytoplankton total numbers and chlorophyll a values are summarized by year in Tables 8.6.1.2 and 8.6.1.3.

8.6.2 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. However, the composition of the population shows some distinctive characteristics. The only copepod genera consistently present is *Cyclops* (Figure 8.6.2.1) It occurs from 1984 through 1989 and then is absent in all subsequent samples through 1994, though *Diacyclops* is present in later years and is probably the same taxa (see 8.4.2). *Diaptomus and Epishura* have been identified from Maxwell Lake, but are very rare and present only at low concentrations (Figure 8.6.2.2). 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 8.6.2.3).

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 8.6.2.4). *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 8.6.2.5 and 8.6.2.6.

The rotifer component the community is the most abundant and diverse of the Maxwell Lake zooplankton, with 12 genera reported. Of these *Keratella* (Figure 8.6.2.7) and *Kellicottia* (Figure 8.6.2.8) 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 8.6.2.9) show slight increases. *Testudinella* (Figure 8.6.2.10) 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 8.6.2.11).

Estimates show that the contribution of the three components of the zooplankton community to total biomass varies from year to year (Figure 8.6.2.12). Cladocerans make up the majority of the biomass for six 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 8.6.2.13 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 8.6.2.14).

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

8.7. Old Wolf Lake

8.7.1 Phytoplankton

The phytoplankton community of Old Wolf Lake exhibits a similar diversity to the lakes described previously, with 88 genera reported over the period of study. The dominant and sub-dominant taxa are listed in Table 8.7.1.1. 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%), *Elaktothrix* (80%), and *Oocystis* (77%). The dominant and sub dominant taxa are displayed graphically in Figures 8.7.1.1 to 8.7.1.16.

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 8.7.1.3) and *Aphanothece* (Figure 8.7.1.4), which have mean concentrations of 4227 and 13,529 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 1666 cells/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 (Figures 8.7.1.1, 8.7.1.2). 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* (Figures 8.7.1.4, 8.7.1.3, 8.7.1.7, 8.7.1.9, 8.7.1.8, 8.7.1.6, and 8.7.1.15, respectively). 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 8.7.1.14), which makes two appearances at low concentrations late in 1984 and early in 1985, appears in larger numbers in 1989, then is present in 90% of the remaining samples at a high mean concentration of 1309 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 8.7.1.16). 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 is absent prior to this. *Sphaerocystis* exhibits an almost identical trend in Maxwell and Stocking Lakes (Figure 8.7.1.17).

Standing crop as measured by the total number of phytoplankton (Figure 8.7.1.18) reflected 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. 8.7.1.19) is incomplete for Old Wolf, but unlike the other lakes a strong correlation exists between the total cell/mL and the measured chlorophyll a. Total numbers of phytoplankton and chlorophyll a are summarized by year in Tables 8.7.1.2 and 8.7.1.3.

8.7.2 Zooplankton

The zooplankton community of Old Wolf Lake 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 between late 1986 and early 1987, and one absence in 1994 (Figure 8.7.2.1). *Cyclops* is reported eight times at relatively low concentrations between 1984 and 1987, and *Diacyclops* was reported twice at very low numbers in 1993 (Figure 8.7.2.2). *Epishura* is reported once in 1986 (Figure 8.7.2.2). *Diaptomus* exhibits a similar pattern to most of the major zooplankton taxa in Old Wolf Lake. 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 8.7.2.3) occur consistently throughout the study, and mirror the trend shown by *Diaptomus.*

Five cladoceran genera were observed. Of these, *Bosmina*, *Daphnia*, *Holopedium*, and *Diaphanosoma* all show roughly similar numbers, as well as a general pattern to increased concentration in 1987 and 1988, followed by a decline (Figures 8.7.2.4 and 8.7.2.5). *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/m^2 (Figure 8.7.2.6).

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 8.7.2.7), showing roughly equal concentrations some years and one or the other dominate at different times throughout the study. Both of these rotifers show a slight overall increase in numbers. *Testudinella* (Figure 8.7.2.8) 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 8.7.2.9) 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 8.7.2.10 and 8.7.2.11.

Old Wolf shows the highest incidence of *Chaoborus* (Figure 8.7.2.20) found in any of the study lakes.

Total numbers of zooplankton (Figure 8.7.2.13) 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 8.7.2.14) reveal that the cladocerans are the major 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 8.7.2.15).

8.8 Spectacle Lake

8.8.1 Phytoplankton

The phytoplankton community of Spectacle Lake is similar in diversity to the other lakes discussed, with 80 genera in total appearing between 1984 and 1992, when sampling ceased. The dominant and subdominant taxa are displayed in Table 8.8.1.1. *Dinobryon* again was the most consistent, being present in 96% of all samples. *Cryptomonas* was present in 87% of samples, followed by *Chroomonas* (85%), *Oocystis* (83%), and *Merismopedia* (83%). *Merismopedia*, characteristically, showed a very high mean concentration of 3525 cells/mL. Other means fell between 221 cells/mL for *Dinobryon* to 0.8 cells/mL for *Cymbella*. This range is consistent with the other study lakes.

As with the other lakes the variation for individual taxa is high both on a monthly and yearly basis. *Dinobryon* (Figure 8.8.1.1) seems to exhibit mid-summer and fall blooms, but these are not consistent. *Dinobryon* does not exhibit a clear trend over the sampling period. *Merismopedia* appears to increase in concentration from 1986 through 1992, but this trend is interrupted by low numbers in 1990. Both *Chroomonas* and *Cryptomonas* 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 *Elaktothrix, 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 8.8.1.1 to 6.1.14. *Sphaerocystis* (Figure 8.8.1.6) 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 139 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* in every sample taken in 1990 (Figure 8.8.1.15), coincident with a sharp decline in total cells/mL concentration for that year (Figure 8.8.1.16). *Euglena* was not recorded from any other sample taken from Spectacle Lake. *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. However, concentrations of dissolved oxygen do not appear to be any lower in 1990 than in previous years (Table 8.8.1.2).

The chlorophyll a data for Spectacle is incomplete, with no values available for 1984, 1989, or 1992 (Figure 8.8.1.17). 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 a concentrations appear to decrease, while the total cells/mL data show an increase. Total numbers of phytoplankton and chlorophyll a values are summarized in Tables 8.8.1.3 and 8.8.1.4.

8.8.2 Zooplankton

Twenty one zooplankton genera are identified in Spectacle Lake between 1984 and 1992. Four copepod genera are reported, of which only *Diaptomus* occurs consistently throughout the period of sampling (Figure 8.8.2.1). *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 in 1987 and 1992, respectively (Figure 8.8.2.2). Copepodite and nauplii stages are consistently present, with copepodites occurring at higher numbers in 1988 and 1989 (Figure 8.8.2.3).

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 8.8.2.4). *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 8.8.2.5). *Diaphanosoma* is reported several times, and shows high concentrations in 1989, a year that most taxa exhibit a decline in numbers (Figure 8.8.2.6). *Alonella* is reported twice in 1988 at very low concentrations.

Kellicottia and *Keratella* are the most consistent of the nine rotifer genera reported, with *Keratella* showing higher concentrations most years (Figure 8.8.2.7). 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 8.8.2.8 and 8.8.2.9

Spectacle Lake has the highest occurrence of *Chaoborus* next to Old Wolf Lake. It is present in at least one sample each year except 1984 and 1987, and was recorded in every sample taken in 1991 (Figure 8.8.2.10).

The zooplankton biomass as measured by total number of individuals/m^2 seems to decline slightly over the study period (Figure 8.8.2.11). 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 8.8.2.12). 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 8.8.2.13).

8.9 Stocking Lake

8.9.1 Phytoplankton

The diversity of the phytoplankton community in Stocking Lake is consistent with the other lakes, with 84 genera reported. The dominant and sub-dominant taxa are listed in Table 8.9.1.1. *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 *Elaktothrix* (84%) complete the dominant group. Mean concentrations range from 6 to 261 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 8.9.1.1) and *Asterionella* (Figure 8.9.1.2) 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 8.9.1.3) appears to decrease in concentration, while *Cryptomonas* (Figure 8.9.1.4) 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 most prominent blue green genera in Stocking Lake are *Merismopedia, Chroococcus, Aphanothece, Lyngbya, Anabaena*, and *Aphanocapsa*, though none are present in concentrations high enough to be considered dominant or sub-dominant. All these taxa show higher numbers and occurrence in the 1987-1992 period. Dominant and sub dominant taxa are displayed in Figures 8.9.1.1 to 8.9.1.12. *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 8.9.1.6).

Standing crop as measured by total cells/mL is roughly similar to the other lakes, excepting the low numbers in Marion, and shows an apparent decline over the ten year sampling period (Figure 8.9.1.13). 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 a 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 1.0 µg/mL (Figure 8.9.1.14). Total numbers of phytoplankton and chlorophyll a values are summarized by year in Tables 8.9.1.2 and 8.9.1.3.

8.9.2 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. *Diaptomus* (Figure 8.9.2.1) is the 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 8.9.2.2). *Cyclops* is present until 1991 at concentrations below 5000/m^2, and then *Diacyclops* is reported thereafter (Figure 8.9.2.3). *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 8.9.2.4).

There are six cladoceran genera reported in Stocking Lake. *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 8.9.2.5 to 8.9.2.8.

The rotifers are the most diverse component of the Stocking Lake zooplankton community with 9 genera reported. *Keratella* (Figure 8.9.2.9) is the most numerous, with one recorded sample of over 1.5 million individuals/m^2 in 1986. *Kellicottia* shows elevated numbers in 1987 and 1988 (Figure 8.9.2.10). *Trichocera, Filinia* and *Testudinella* show increased concentrations or occurrence during this period as well (Figure 8.9.2.11). The dynamics of the less numerous rotifers are displayed in Figure 8.9.2.12.

There are five recorded observations of *Chaoborus* in Stocking Lake (Figure 8.9.2.13).

Biomass estimates, both using total individuals/m^2 (8.9.2.14) and dry weight estimates for the individual taxa (Figure 8.9.2.15) clearly reflect the declines noted above. Total biomass (Figure 8.9.2.16) 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.

8.10 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 characterizes 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 in the phytoplankton or zooplankton appear to indicate a trend to acidification in any of the six lakes. The extreme minimum pH measured in any of the lakes was 5.6 in Marion (Jacobs) Lake (Section 6.2.2). 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 only observable below pH 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 Section 1) 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) report similar findings. A dominant feature of the six 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 five most dominant phytoplankton taxa for each of the six lakes and found that none of these displays consistent periodicity. It is unclear if this variability is a natural feature of a small coastal B.C. lake, or if it is disturbance induced.

Table 8.10.1 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 Marion lakes, and the third most dominant in Stocking Lake. Marion 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 chlorophyte. 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.

Chlorophyll a values range from approximately 0.5 to 6.0 µg/L for four of the lakes. Stocking Lake has the lowest maximum value at 2.2 µg/L, and Old Wolf Lake displays the highest maximum value at 8.2 µg/L. Maxwell Lake has the highest mean chlorophyll a value of 2.94 µg/L, and Stocking the lowest at 0.97 µg/L. It is curious that Maxwell Lake 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 Lake is the most productive 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 Marion Lake. Two figures are given for mean total number in Marion: the first number includes an *Aphanothece* bloom of 234,000 cells/mL, and the second figure excludes this event. Maxwell has the lowest mean total number of phytoplankton next to Marion Lake, which is indicative of the low biomass measurements found in 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 Marion, 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 zooplankton. 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. 2.2.20) 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 to 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 *Elaktothrix*. Excluding Marion 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.

9.0 Analysis of Water Chemistry and Biology

9.1 Lizard Lake

In Section 8.4, it was found that chlorophyll a and zoospore concentrations peaked in 1989, while the total number of cells decreased in this year. In addition, *Aphanothece* spp. disappeared from the lake at about this time (Figure 8.4.1.10). In the zooplankton community, no trends were obvious for any of the species of copepods. However, of the cladoceran species present, an unidentified chydorid species and a species of Leptodora appeared in 1989, and the five most common cladocerans declined in numbers and occurrence from 1989 through to 1991 or 1992. Rotifers were absent from all 1990 samples. These changes were concurrent with a decrease in both soluble sodium and soluble sulphate that occurred in late 1988 or early 1989 (see Table 7.7.1). It is possible that these factors may be related and indicative of some unknown impact to the lake during this period.

9.2 Marion Lake

The small volume and potentially short residence time is evident in the biological and chemical composition of Marion Lake. There is a high degree of variability in all of the major ions present in the lake, and the highest diversity of phytoplankton in any of the study lakes. However, there is less zooplankton diversity in Marion Lake than in the other study areas. Smaller species of plankton also tend to dominate, as larger species are more susceptible to flushing.

There are no obvious trends in the phytoplankton community, with all taxa generally present in very low concentrations. The increase in standing crop of phytoplankton from 1989 through 1992 is not reflected in the zooplankton community, where a slight decline in biomass was evident over the study period. However, there was a shift in the dominant copepod genus between 1991 and 1992, and the two prominent cladoceran genera peaked in 1992. No trends were noted in the concentration of major ions or in the pH of Marion Lake, except for an apparent slight downward trend in sulphate concentrations over the 10 year period in the CUSUM analysis. This trend is probably due to the higher degree of periodicity in the first few years of the study, in the period where the mean and standard deviation were determined for the analysis (See Appendix 3).

9.3 Maxwell Lake

The chemical composition of Maxwell Lake appears to undergo two types of minor trends. Both alkalinity and sodium appear to increase very gradually throughout the monitoring period, while calcium and sulphate concentrations appear to increase slightly from 1985 through 1988, and then level off from 1989 through 1995 (see Appendix 3 for CUSUM graphs). These trends may be reflected in the general increase in numbers of the dominant phytoplankton genera throughout the monitoring period. There is no obvious change in the chemistry of the lake in May 1988 that would explain the sudden bloom of *Gloeotrichia* recorded in this month.

It is difficult to explain the low standing crop of phytoplankton in cells/mL present in Maxwell Lake on the basis of nutrient availability. The mean concentration of all nutrients are similar between the lakes, and the total nitrogen:total phosphorus ratio is also similar.

The disappearance of the dominant copepod genus, *Cyclops*, in 1989 may be linked to the increasing trends in ion concentrations noted above, or some other factor. The high peaks recorded for the various cladoceran genera do not appear to reflect any changes in chemical concentrations at these times. However, the overall increase in zooplankton biomass up to 1988, followed by a decline through 1994, may reflect a response to the increase in the calcium, sulphate, sodium and alkalinity noted during this period, or both the chemical and biological changes may be responses to some other external factor.

9.4 Old Wolf Lake

Both the chemistry and biology of Old Wolf Lake appear to have been strongly affected by the logging that occurred along the eastern shore in the autumn of 1986. Alkalinity, calcium and sodium all increased after the logging occurred, and then decreased through 1989 - 1990 and reached pre-logging levels by early 1991. Sulphur concentrations, on the other hand, appeared to increase throughout the monitoring period. These changes in chemical concentrations are evident in the appearance or increasing concentration of a number of species of phytoplankton in 1986 and 1987, including *Aphanothece*, *Merismopedia*, *Chroococcus*, and *Gomphosphaeria*, which subsequently decrease in number or disappear completely. The appearance of three taxa in 1989 (*Lyngbya*, *Aphanocapsa* and *Sphaerocystis*) may reflect a new species equilibrium occurring as the chemistry of the lake begins to return to pre-logging levels. The peak total number of phytoplankton present as standing crop is also responsive to the logging event, with a peak appearing in 1986/1987 and in 1992/1993. The second peak may represent a recovery in the community as the chemistry begins to equilibrate.

The zooplankton community follows a similar trend, with numbers generally increasing through 1987 and 1988, and then decreasing through 1992. Numbers then begin to increase again to the end of the monitoring period, reflecting a response to the available food supply (i.e., phytoplankton).

9.5 Spectacle Lake

The high degree of variability in both water chemistry and phytoplankton community composition evident in Spectacle Lake is similar to that seen in Marion Lake, and is probably caused by similar factors. Spectacle Lake also has a very small volume and a very short residence time, which would result in rapid changes. The majority of phytoplankton species do not exhibit any obvious trends, and the trend suggested by the CUSUM analysis for alkalinity and calcium is probably due to the high degree of periodicity that these two ions exhibit (see Appendix 3).

9.6 Stocking Lake

A slight decrease in both soluble sodium and soluble sulphate concentrations occurred during the monitoring period. The CUSUM analysis shows the change occurring in early 1991 for both ions. These ions may be related to the apparent decline in standing crop of phytoplankton, where higher concentrations were measured between 1986 and 1991. Cyanophyte concentrations were also higher between 1986 and 1992, and contributed to the overall trend of higher standing crop during this period. Chlorophyll a concentrations, on the other hand, appeared to increase throughout the monitoring period.

Changes occurring in the zooplankton community during this period include the appearance of *Epishura* in 1992, and the switch from *Cyclops* to *Diacyclops* between 1991 and 1992. The cladoceran genus *Bosmina* decreased in concentration through 1991, but increased in concentration over the next two years. The remainder of the cladoceran genera observed decreased in numbers and/or occurrence throughout the duration of the study, as did biomass estimates using both total individuals/m^2 and dry weight estimates.

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Figures:

Figure 1.1 - Map of southern Vancouver Island

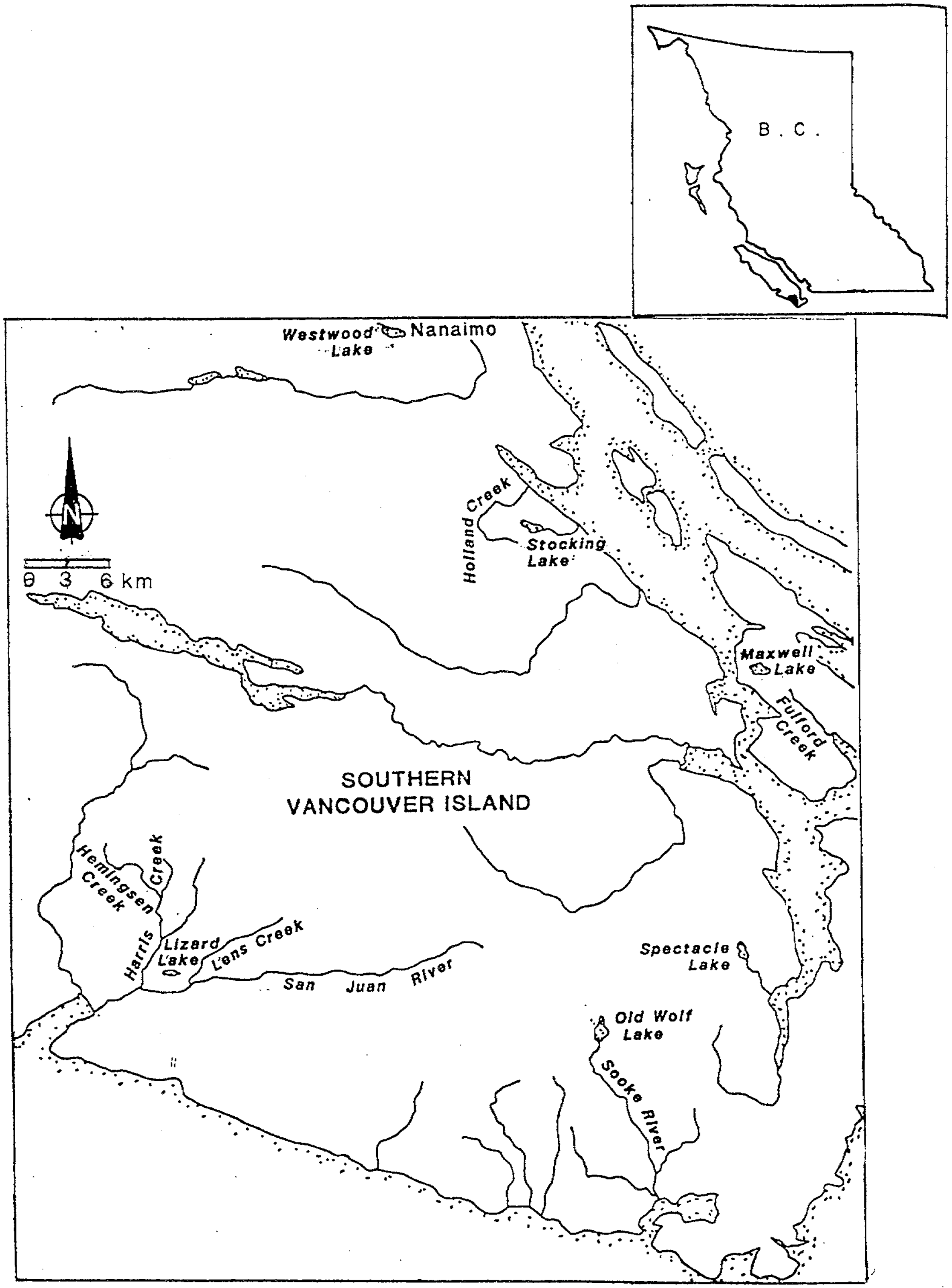


Figure 1.2 - Map of Lower Mainland, showing Marion (Jacobs) Lake

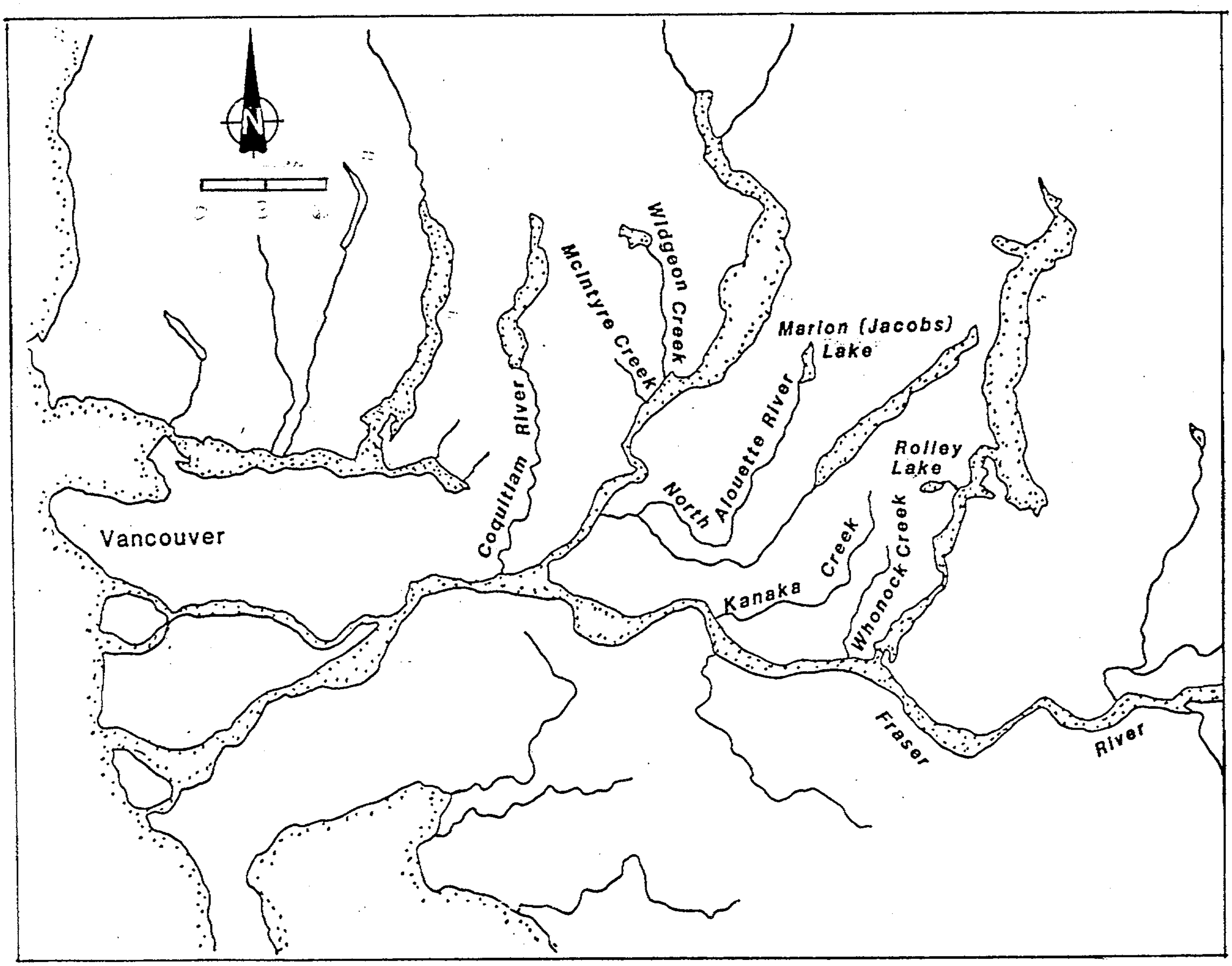


Figure 1.3. Average total monthly rainfall (mm) from 1985 to 1994 at the monitoring sites nearest the six lakes

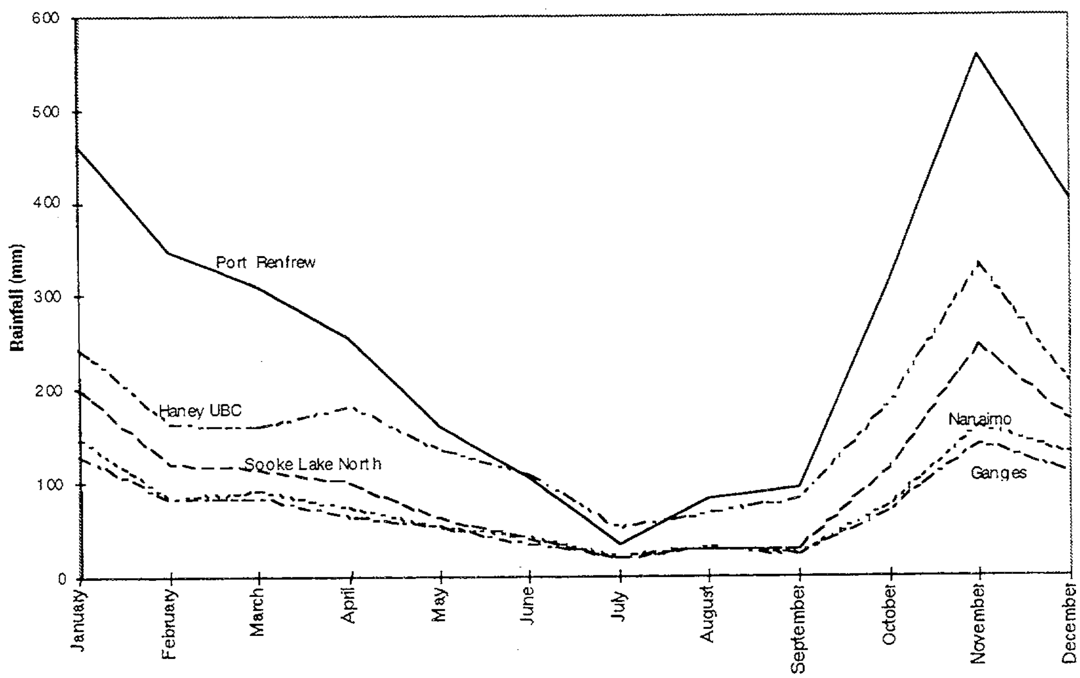


Figure 3.1 Bathymetry of Lizard Lake

Bathymetry in feet
"A" is an island
"B" is public access
Zones 1, 2, 3 described in text

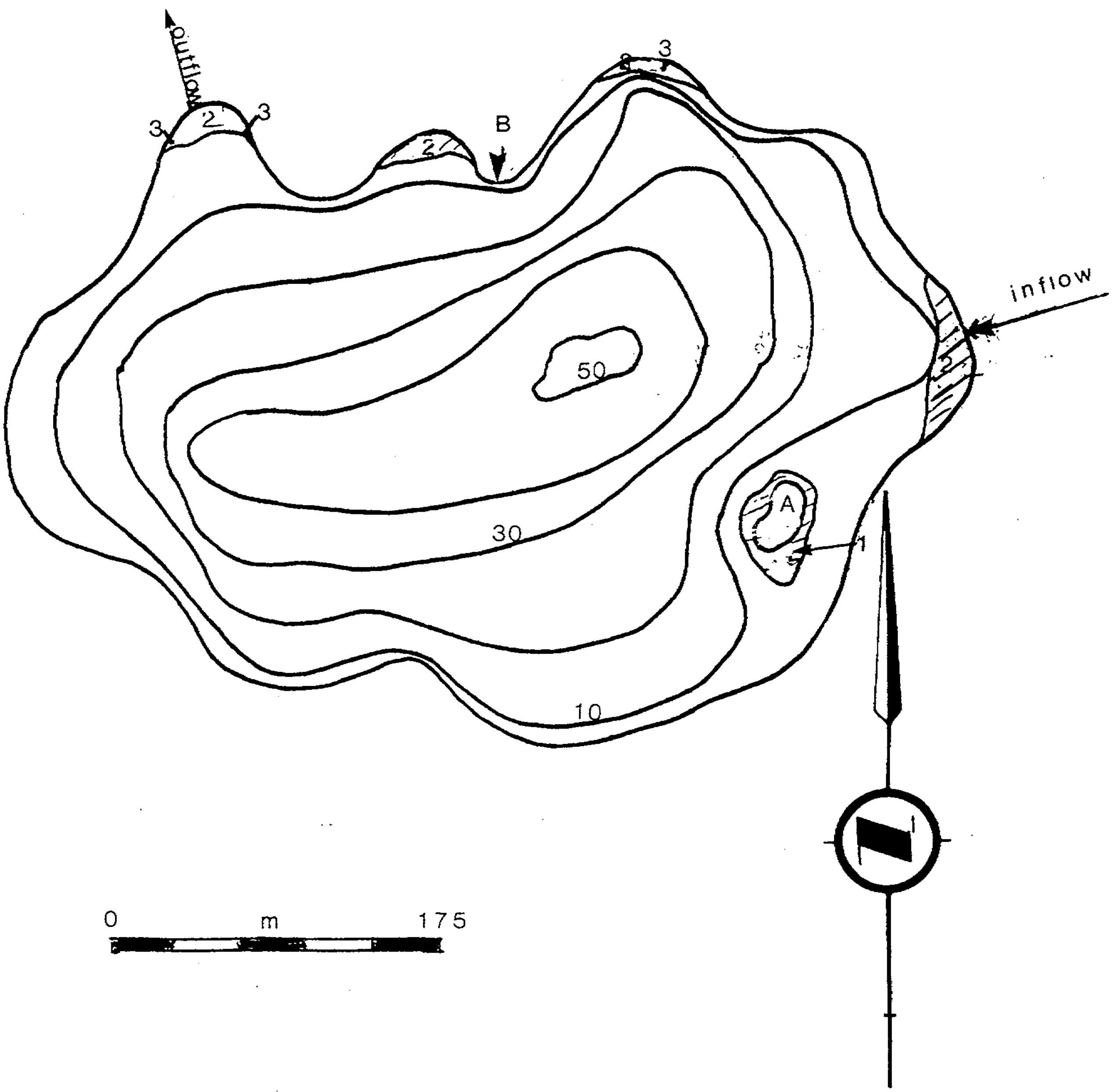


Figure 3.2 Bathymetry of Marion (Jacobs) Lake

Depths are as metres
A & B are described in text

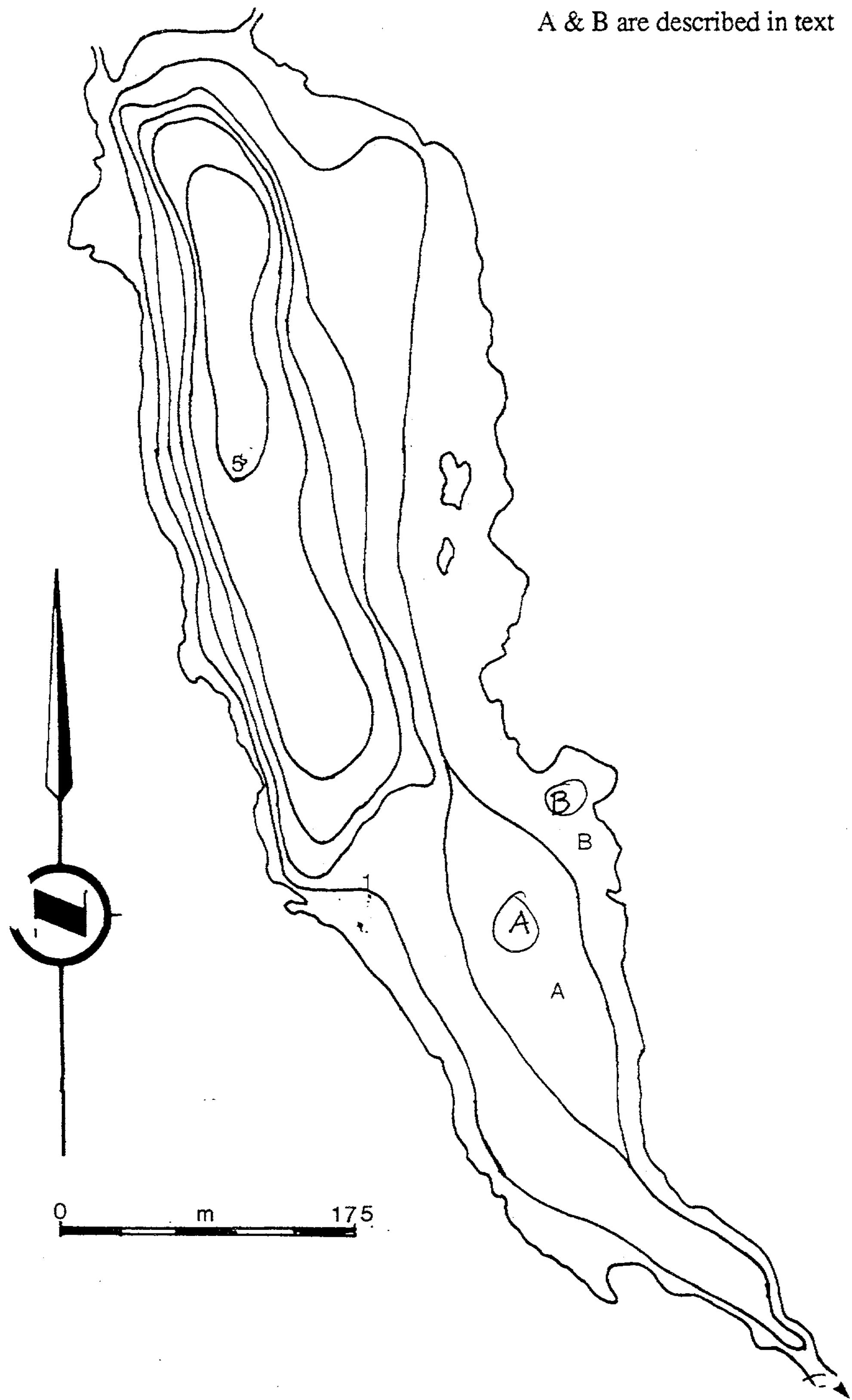


Figure 3.3 Bathymetry of Maxwell Lake

1, 2, 3, etc. ...are described in text

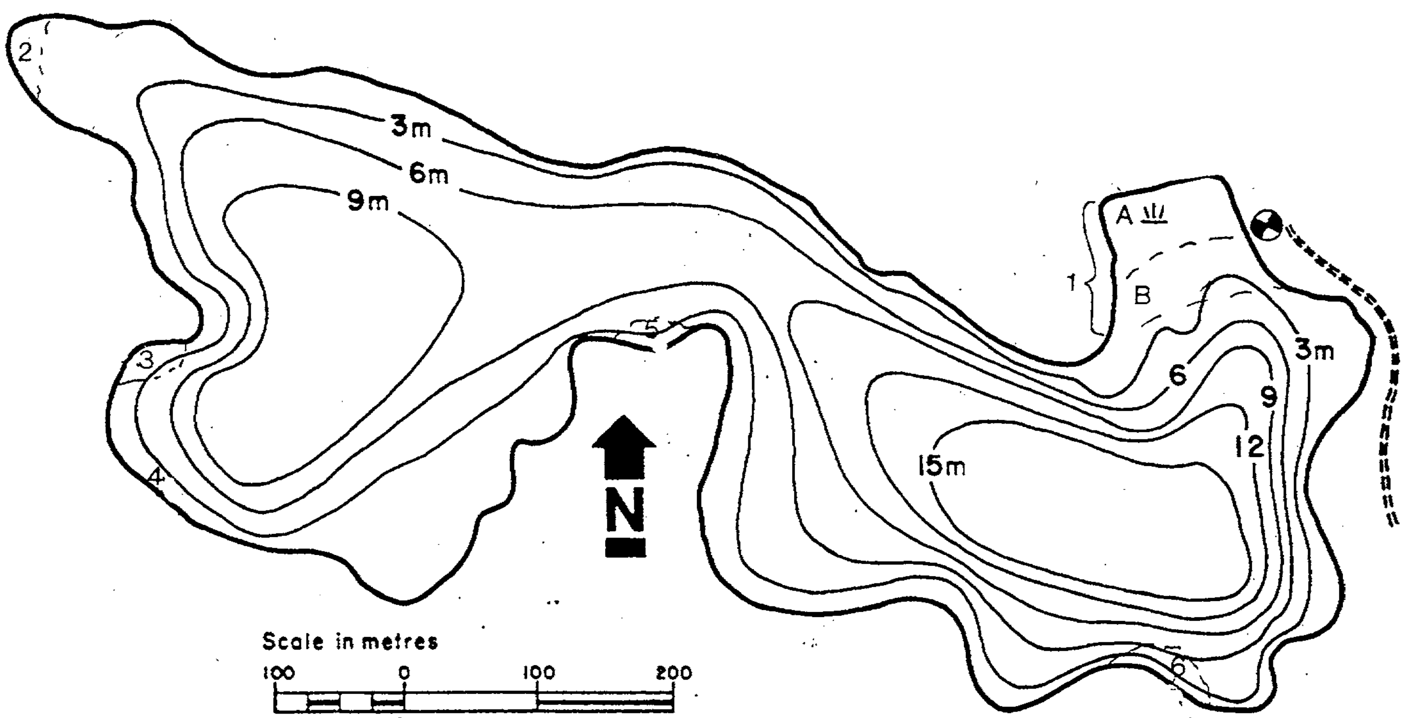


Figure 3.4 Bathymetry of Old Wolf Lake

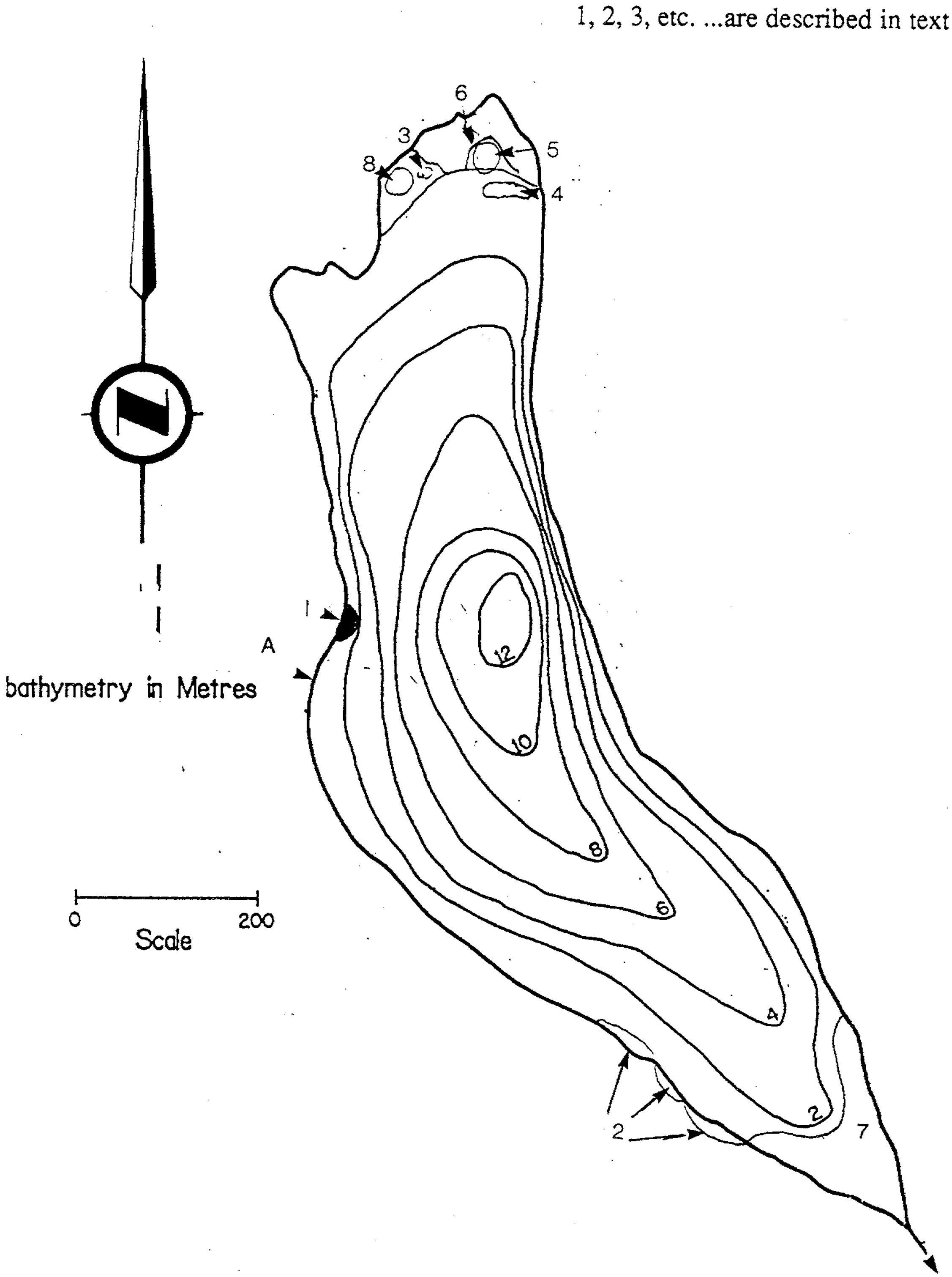


Figure 3.5 Bathymetry of Spectacle Lake

Bathymetry in metres
1, 2, 3, etc. ...are described in text

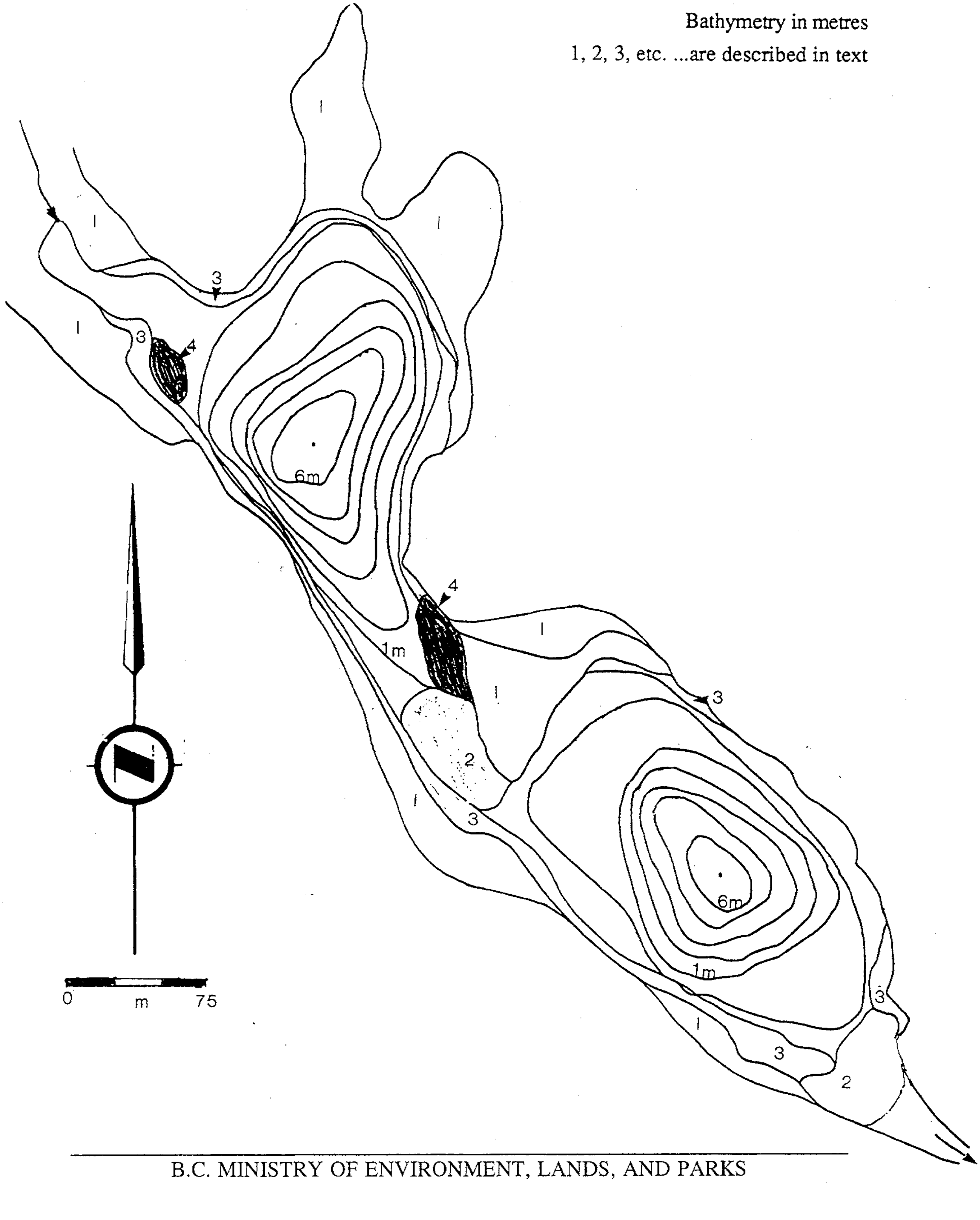


Figure 3.6 Bathymetry of Stocking Lake

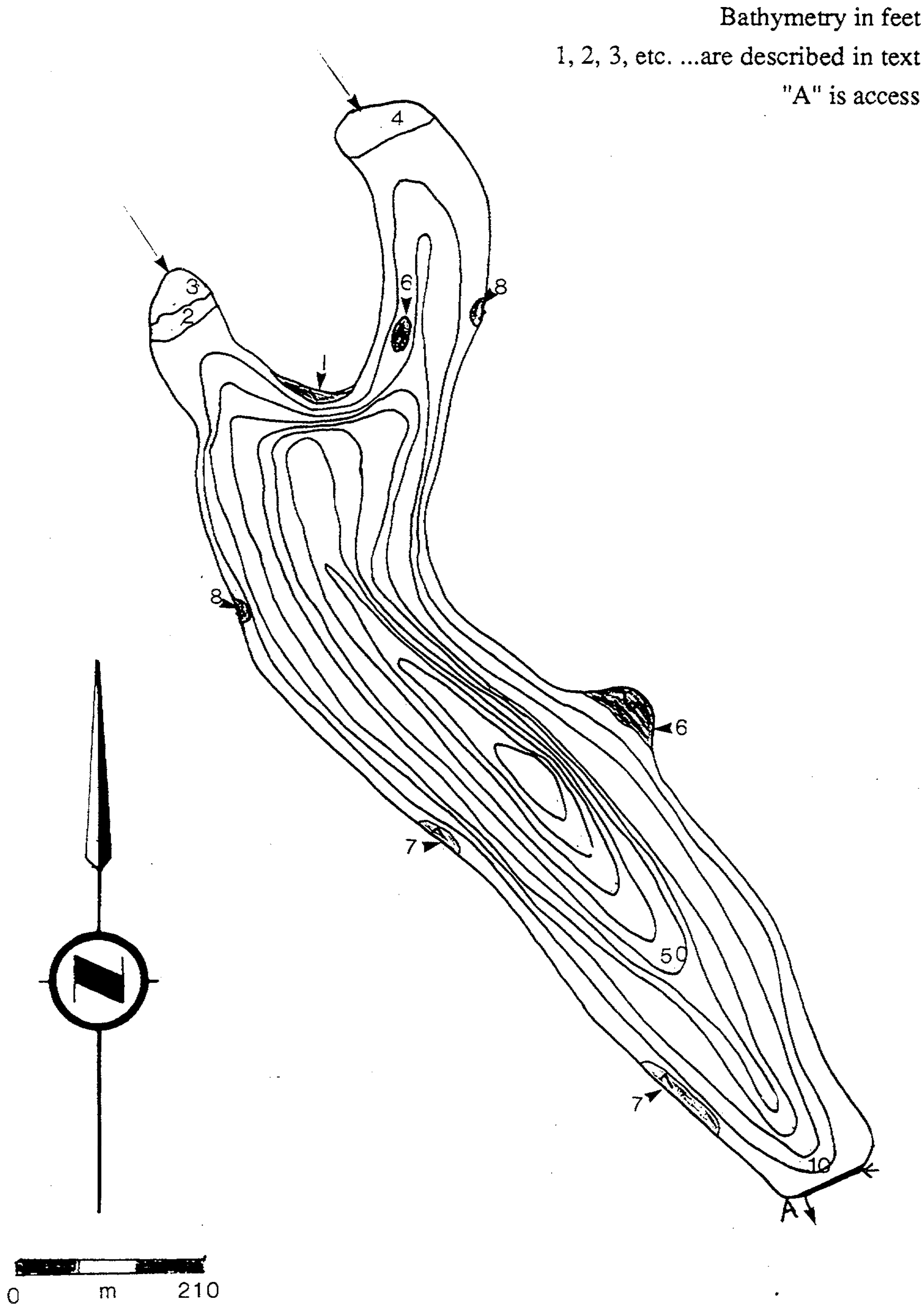


Figure 7.1.1. Lizard Lake pH (Orion Ross)

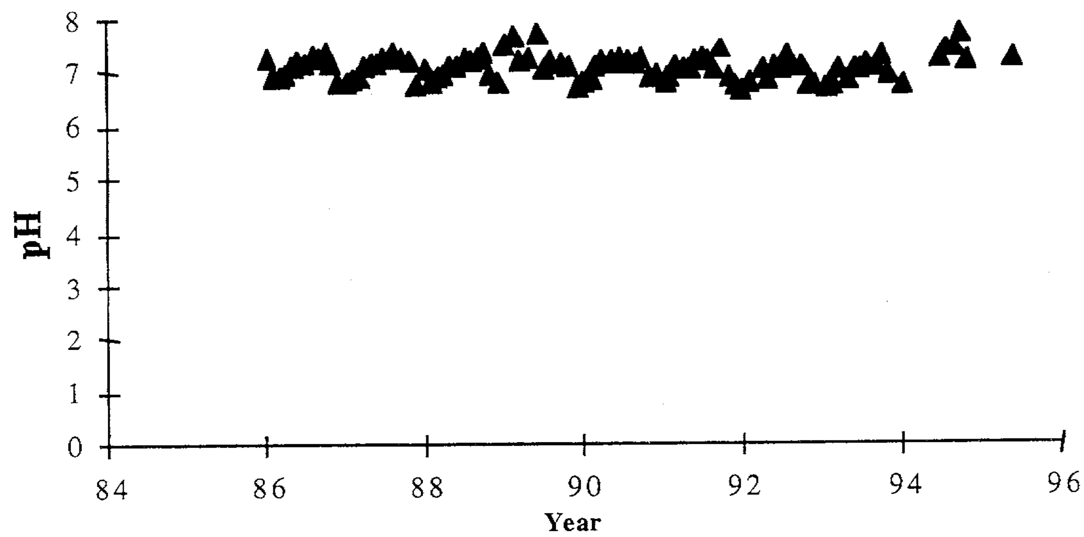


Figure 7.1.2. Lizard Lake pH (Metrohm)

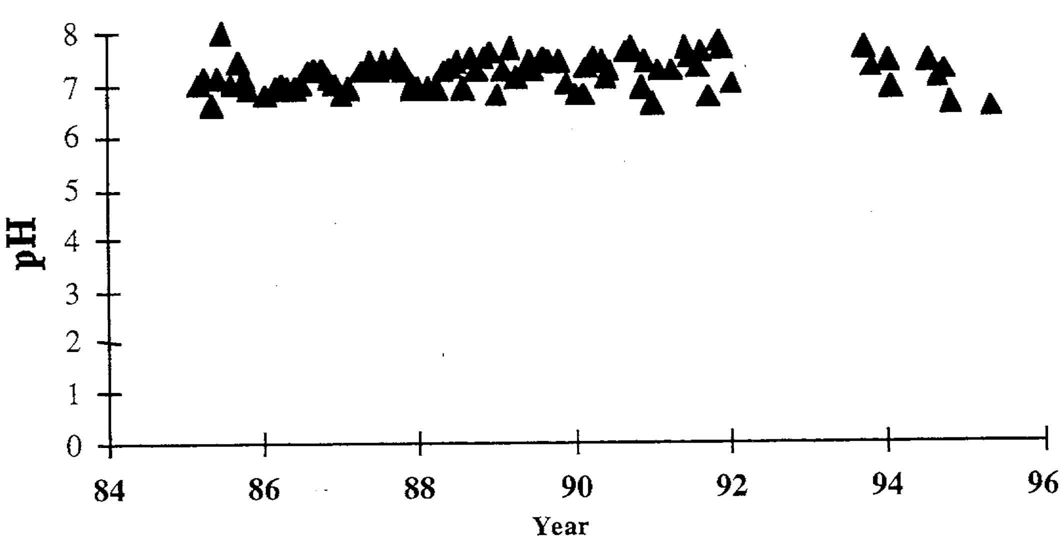


Figure 7.1.3. Lizard Lake sodium concentrations (mg/L)

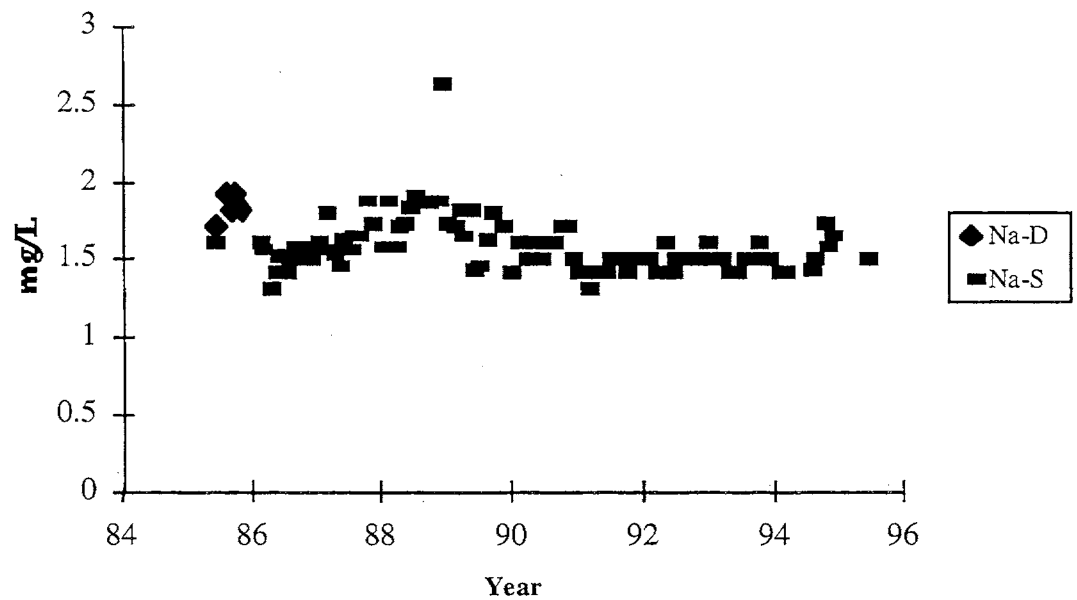


Figure 7.1.4. Lizard Lake sulphate concentrations (dissolved and soluble) (mg/L)

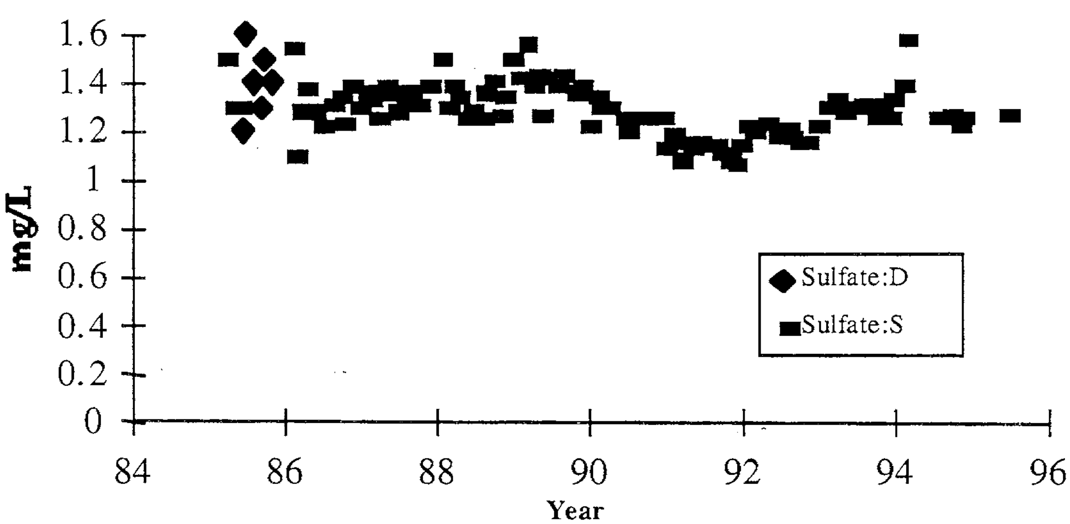


Figure 7.1.5. Lizard Lake calcium concentrations (mg/L)

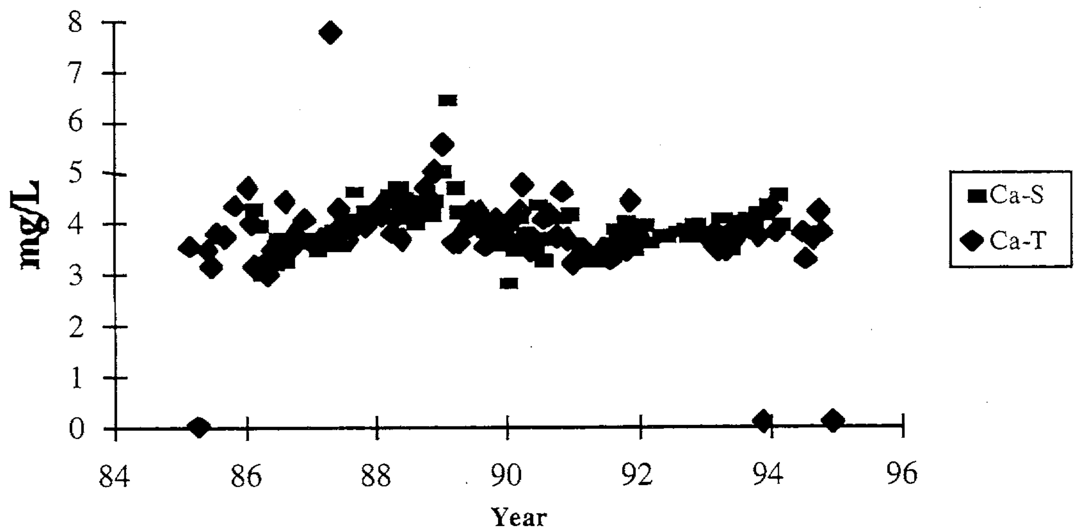


Figure 7.1.6. Lizard Lake alkalinity (meq/L).

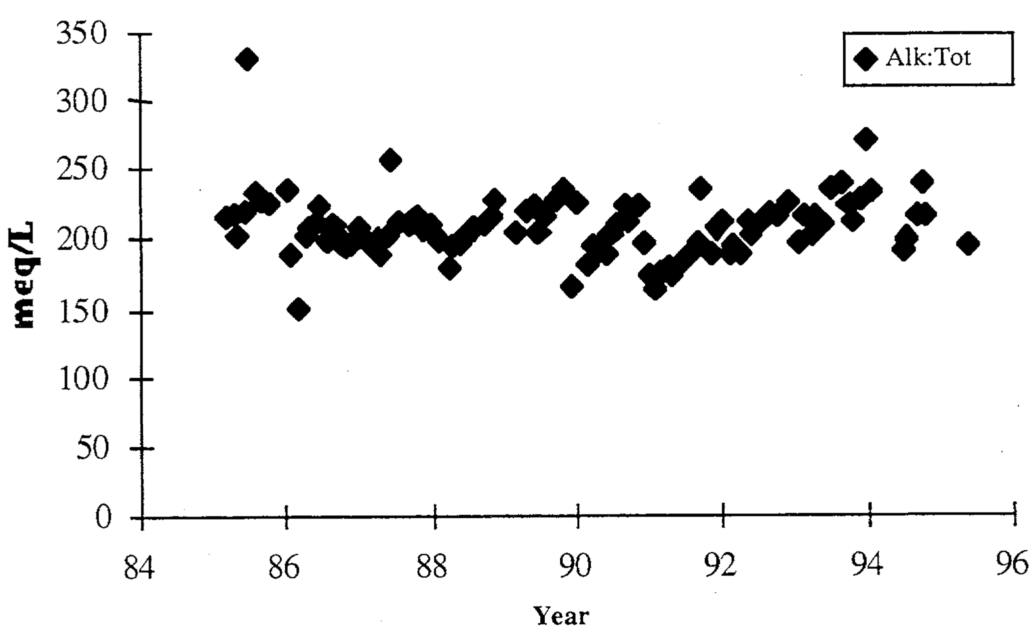


Figure 7.2.1. Marion Lake pH (Orion Ross)

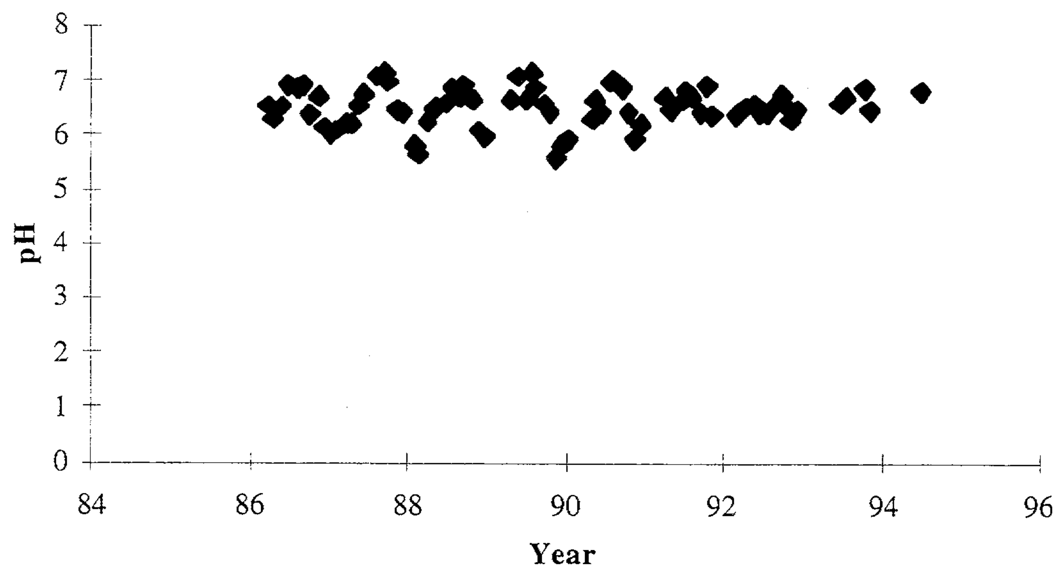


Figure 7.2.2. Marion Lake pH (Metrohm)

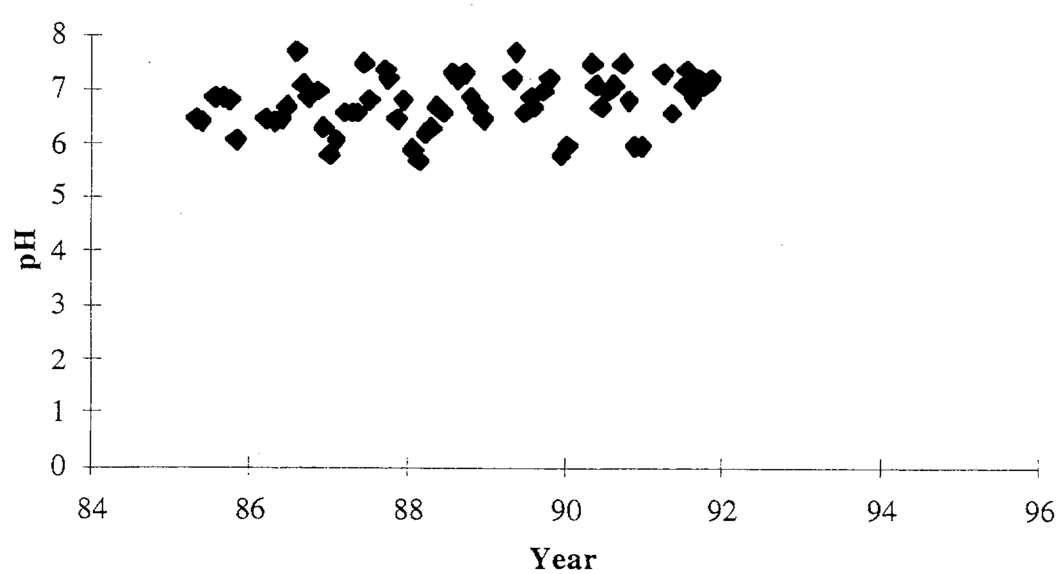


Figure 7.2.3. Marion Lake sodium concentrations (mg/L)

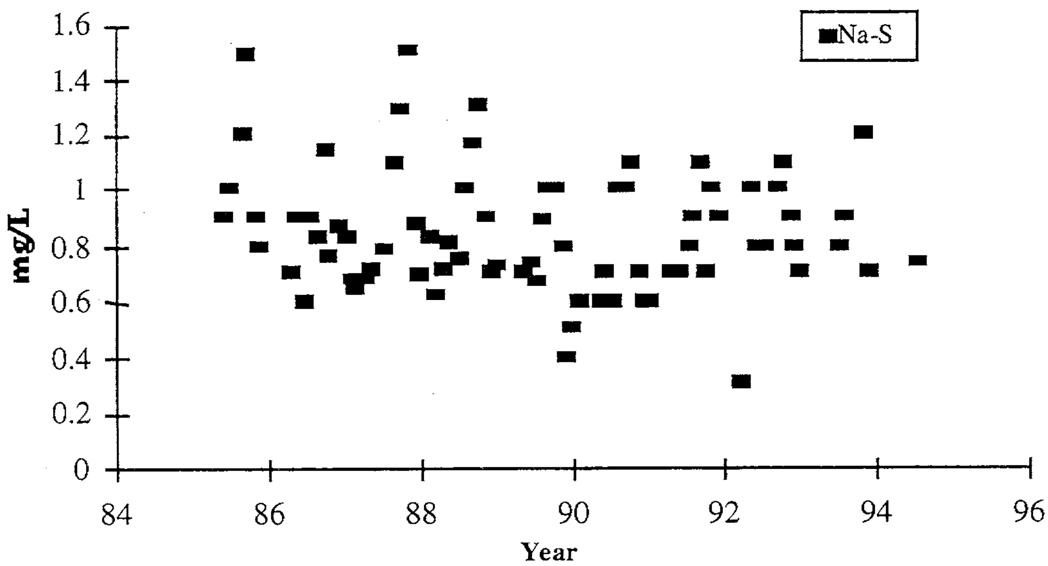


Figure 7.2.4. Marion Lake soluble and total calcium concentrations (mg/L)

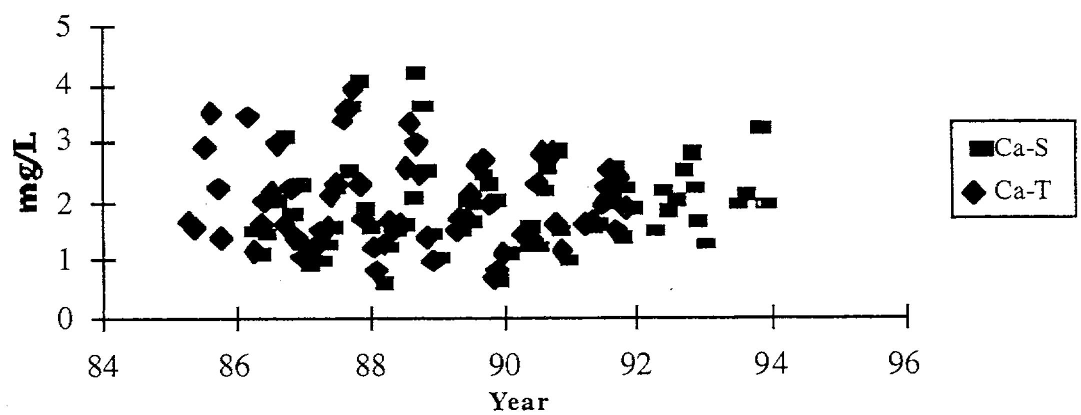


Figure 7.2.5. Marion Lake sulphate concentrations (mg/L)

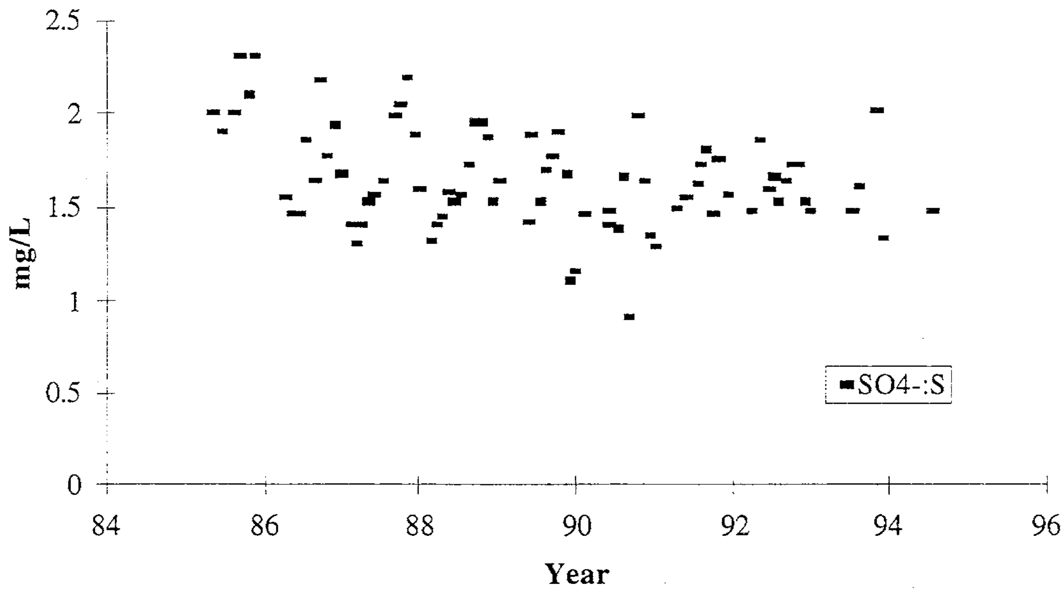


Figure 7.2.6. Marion Lake alkalinity (meq/L)

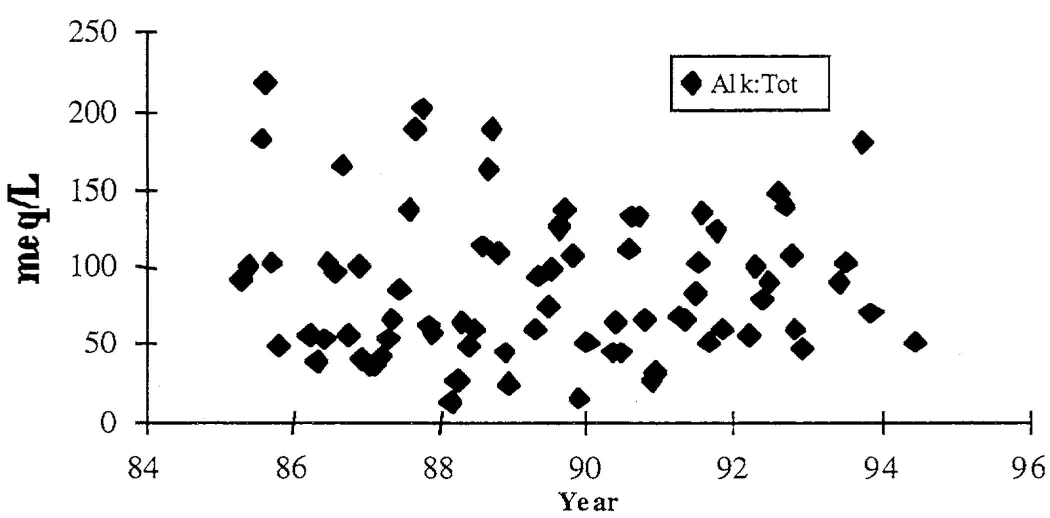


Figure 7.3.1. Maxwell Lake pH (Metrohm)

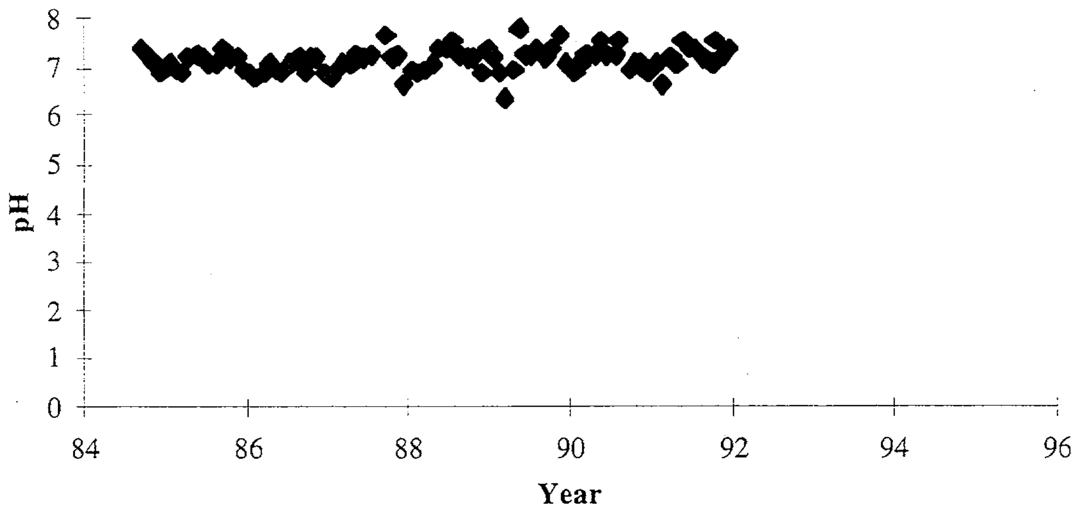


Figure 7.3.2. Maxwell Lake pH (Orion Ross)

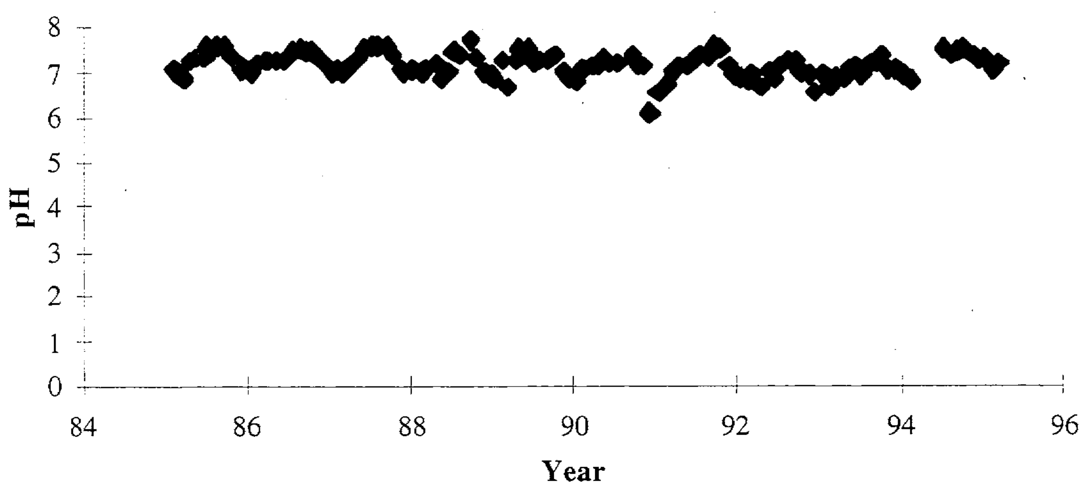


Figure 7.3.3. Maxwell Lake sodium concentrations (soluble and dissolved)(mg/L)

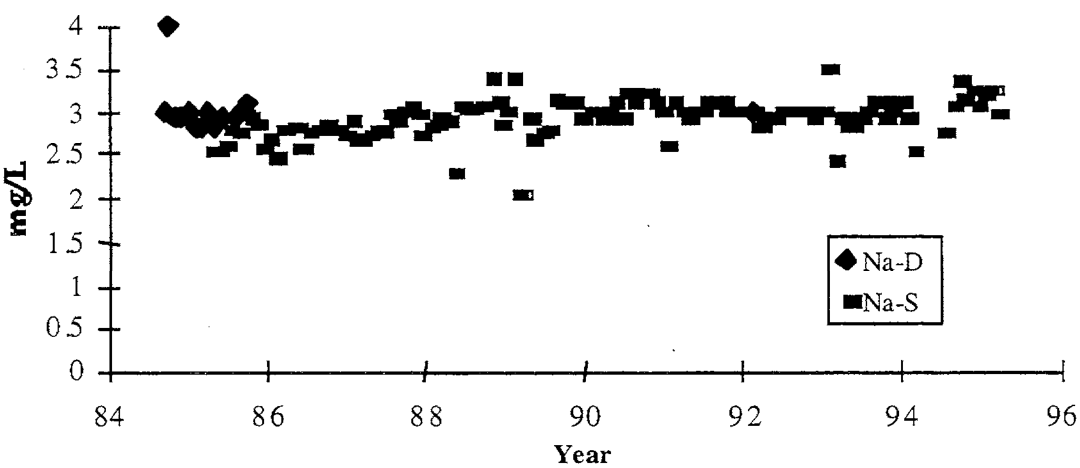


Figure 7.3.4. Maxwell Lake calcium concentrations (soluble and total)(mg/L)

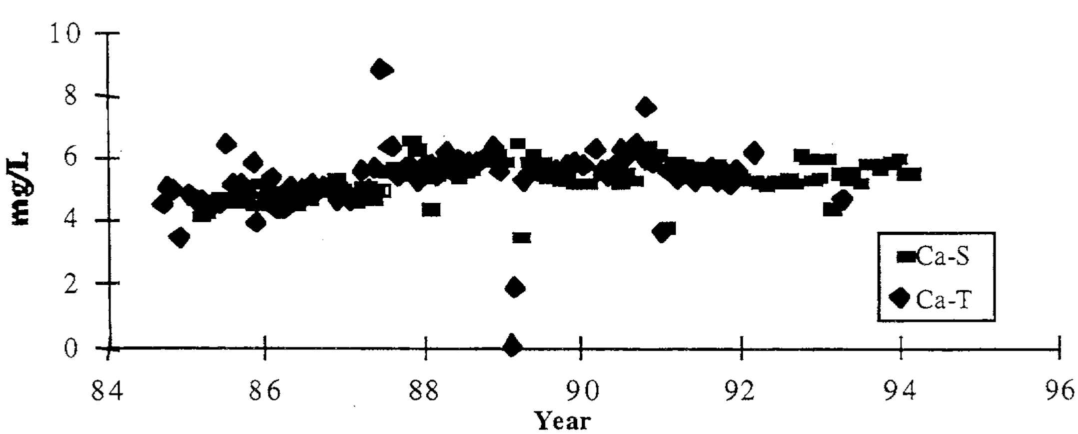


Figure 7.3.5. Maxwell Lake sulphate concentrations (dissolved and soluble)(mg/L)

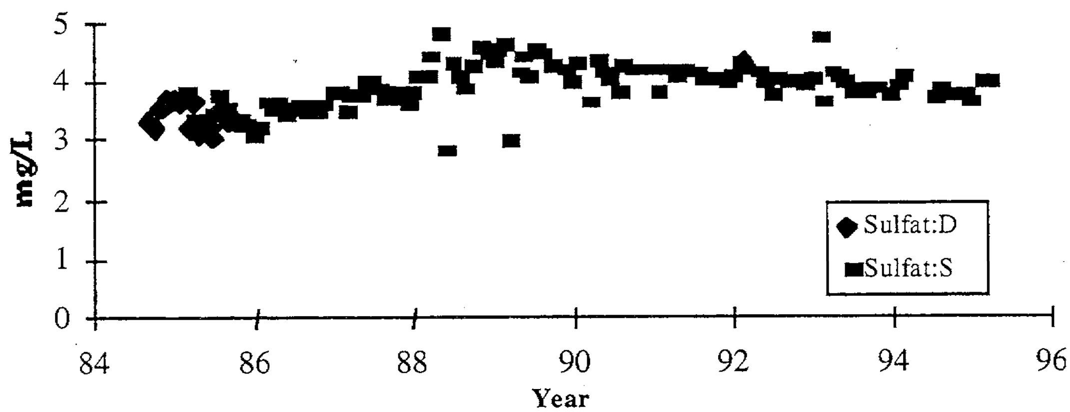


Figure 7.3.6. Maxwell Lake alkalinity (meq/L)

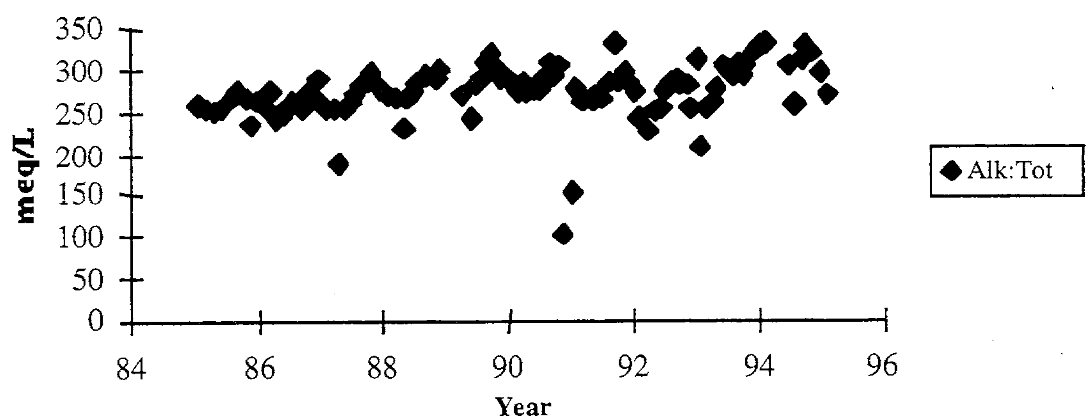


Figure 7.4.1. Old Wolf Lake pH (Metrohm)

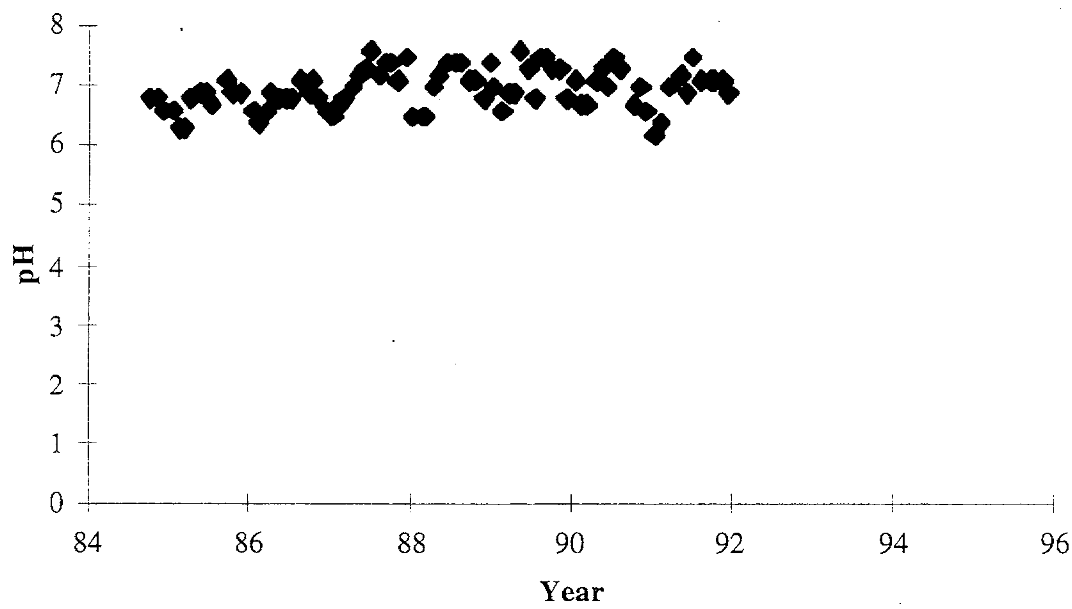


Figure 7.4.2. Old Wolf Lake pH (Orion Ross)

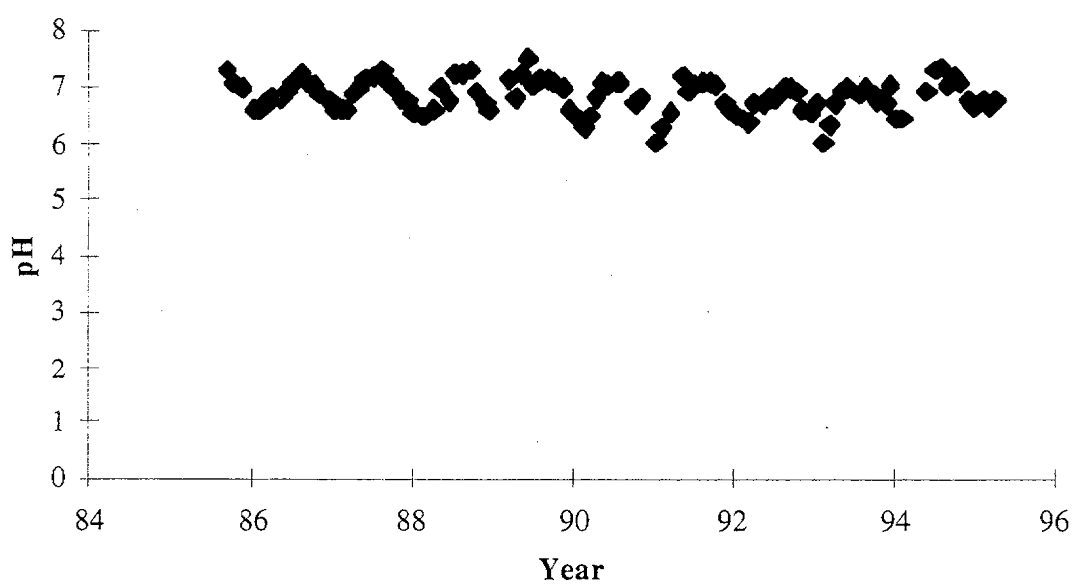


Figure 7.4.3. Old Wolf Lake sodium concentrations (dissolved and soluble)(mg/L)

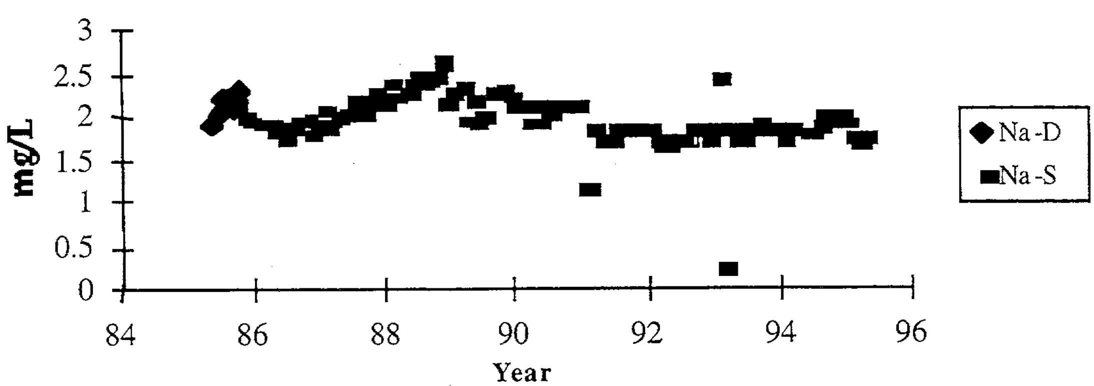


Figure 7.4.4. Old Wolf Lake calcium concentrations (soluble and total)(mg/L)

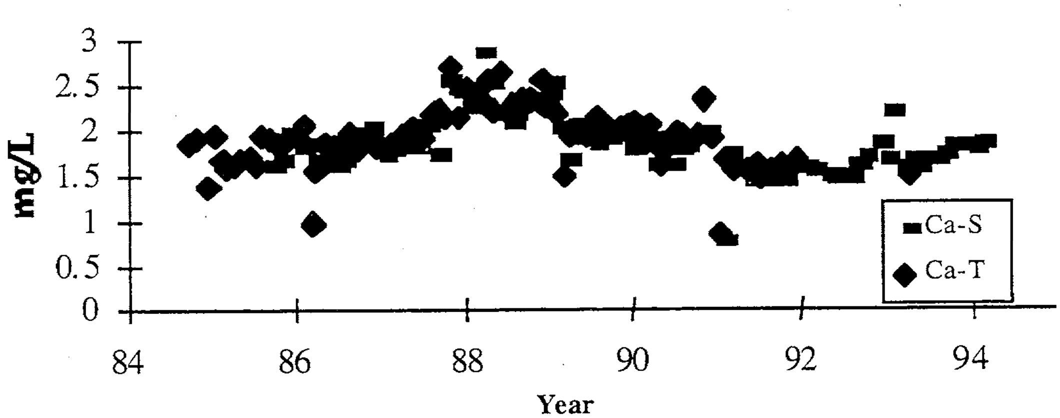


Figure 7.4.5. Old Wolf Lake sulfate (dissolved and soluble)(mg/L)

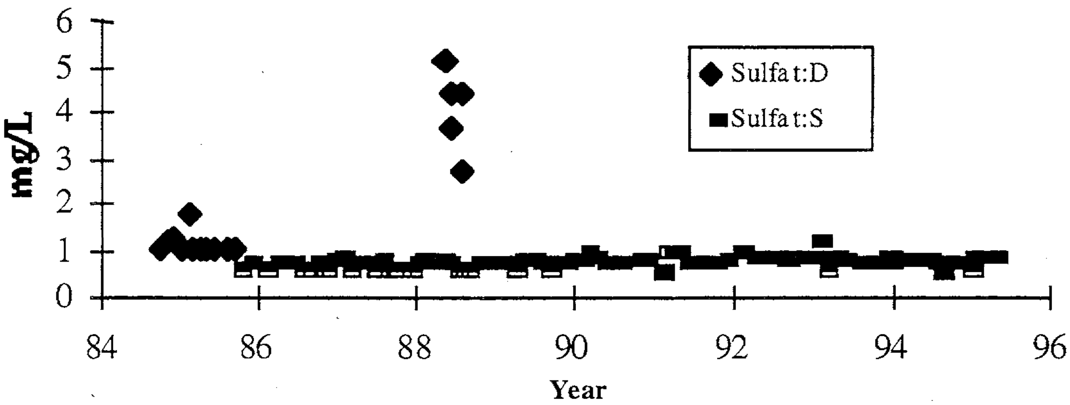


Figure 7.4.6. Old Wolf Lake alkalinity (meq/L)

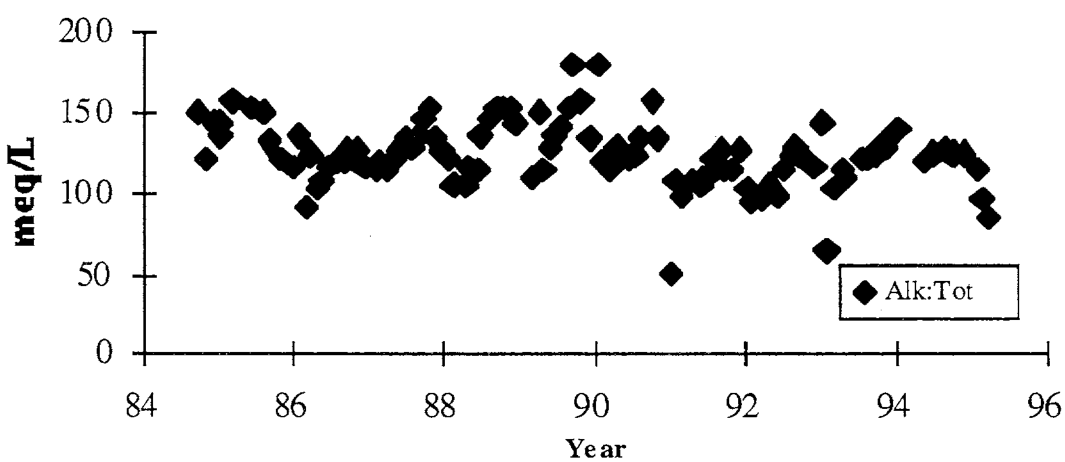


Figure 7.5.1. Spectacle Lake pH (Metrohm)

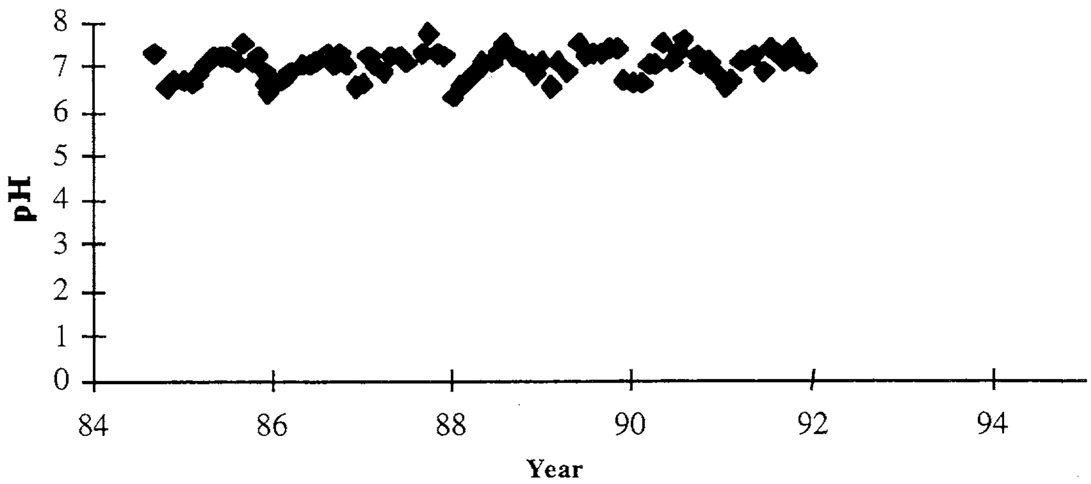


Figure 7.5.2. Spectacle Lake pH (Orion Ross)

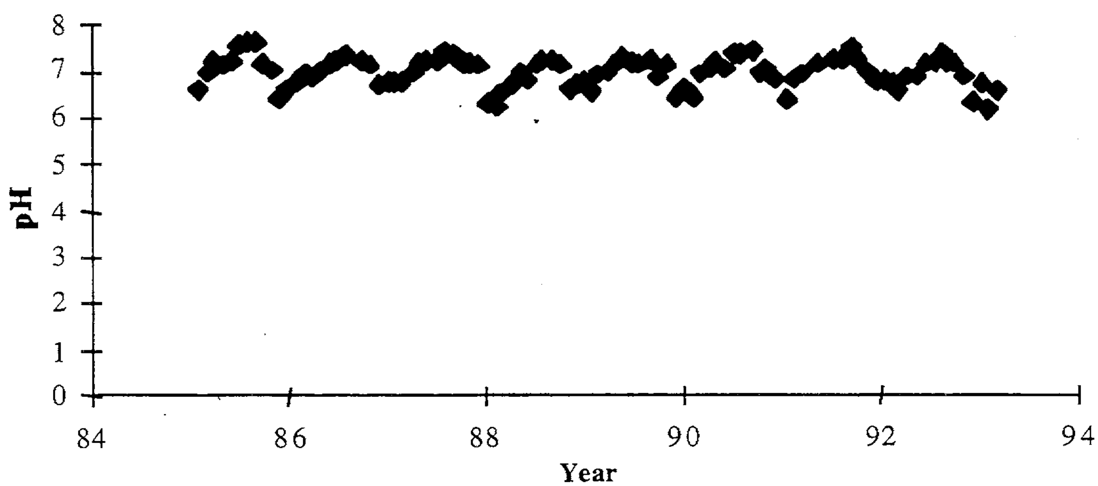


Figure 7.5.3. Spectacle Lake sodium concentrations (dissolved and soluble)(mg/L)

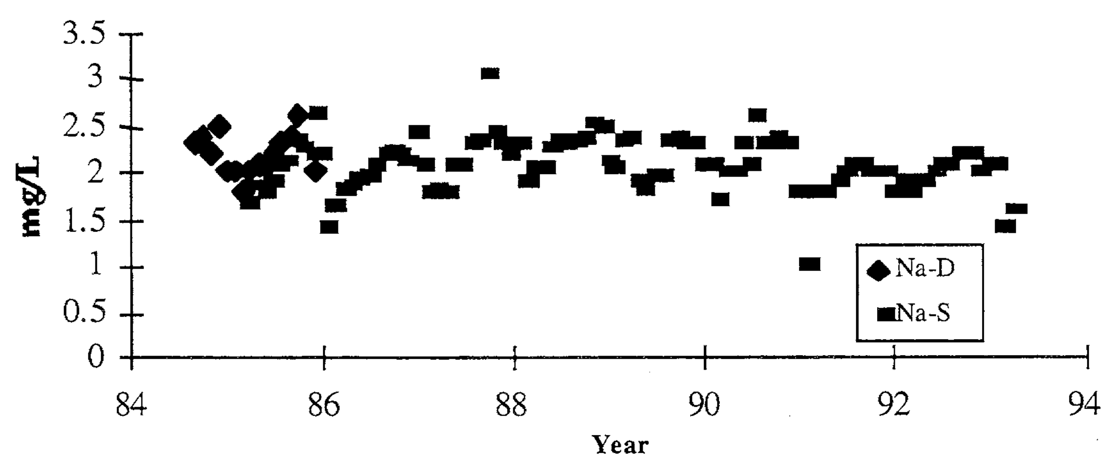


Figure 7.5.4. Spectacle Lake calcium concentrations (soluble and total)(mg/L)

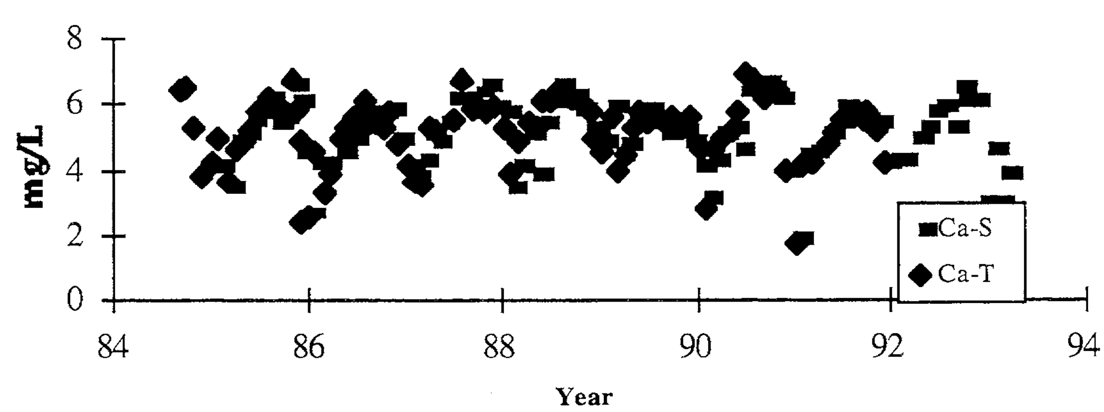


Figure 7.5.5. Spectacle Lake sulfate concentrations (dissolved and soluble)(mg/L)

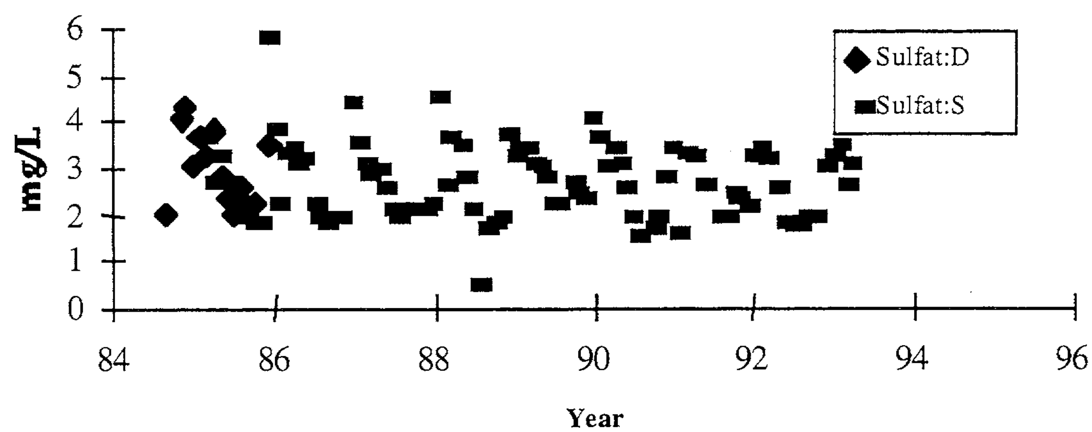


Figure 7.5.6. Spectacle Lake alkalinity (meq/L)

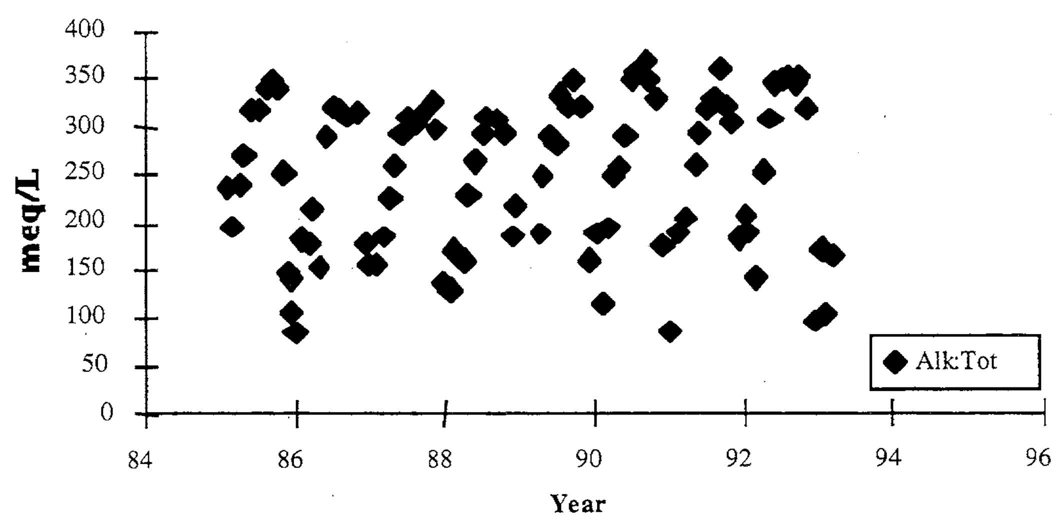


Figure 7.6.1. Stocking Lake pH

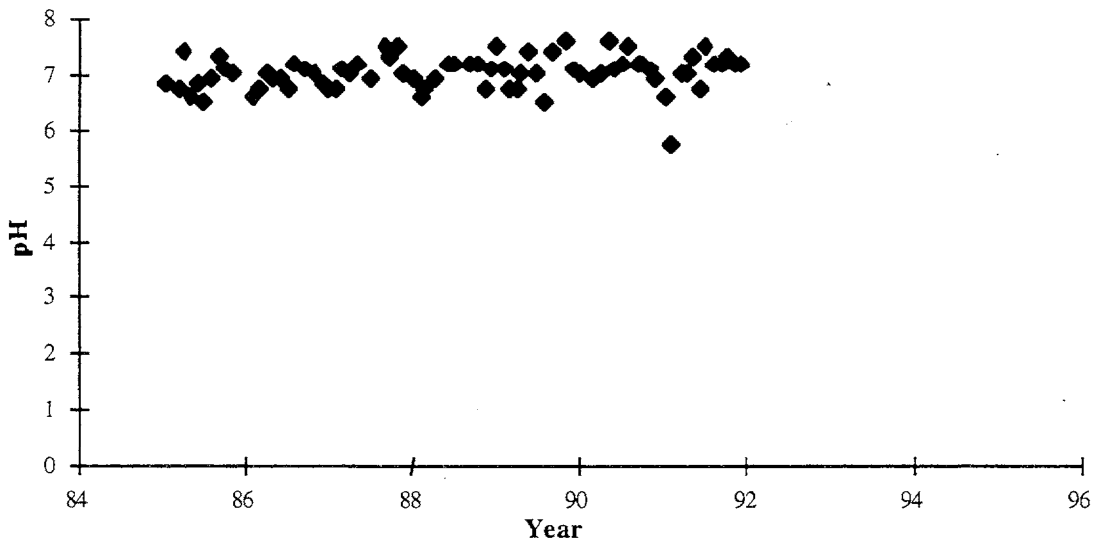


Figure 7.6.2. Stocking Lake pH (Orion Ross)

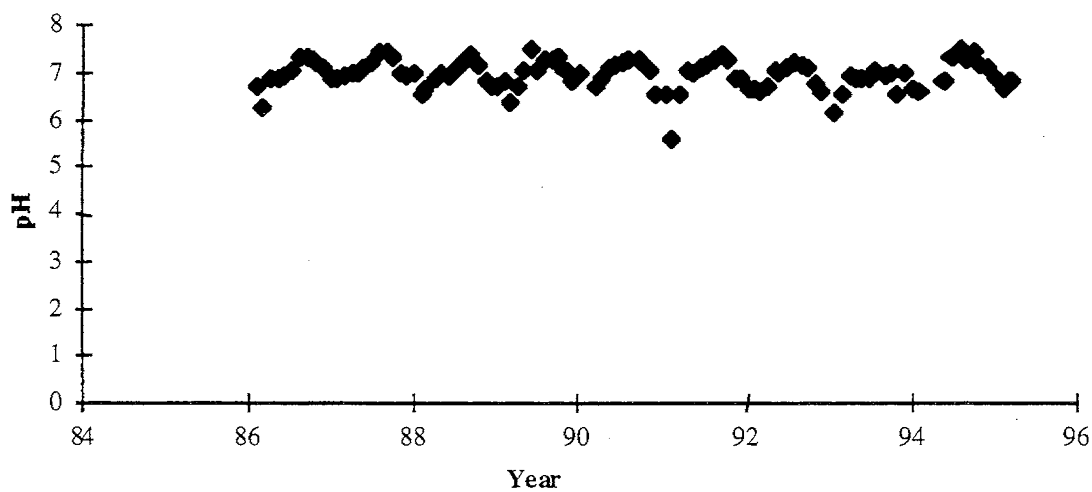
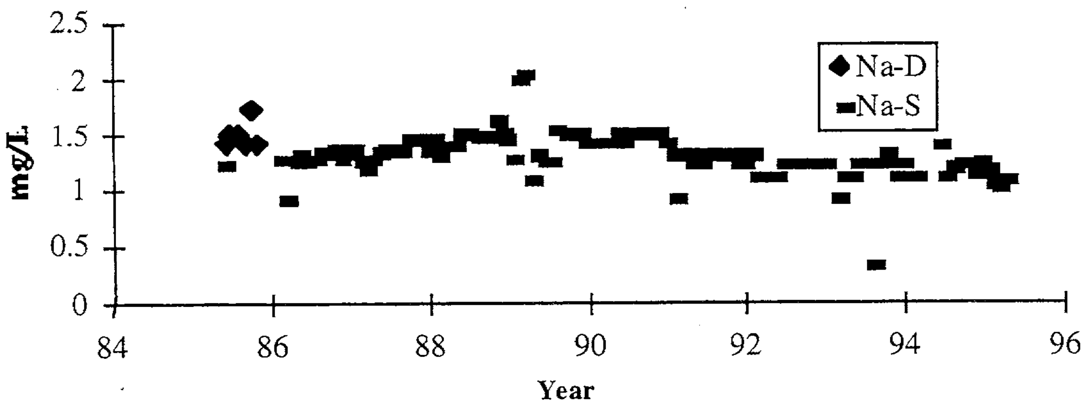


Figure 7.6.3. Stocking Lake sodium concentrations (dissolved and soluble)(mg/L)



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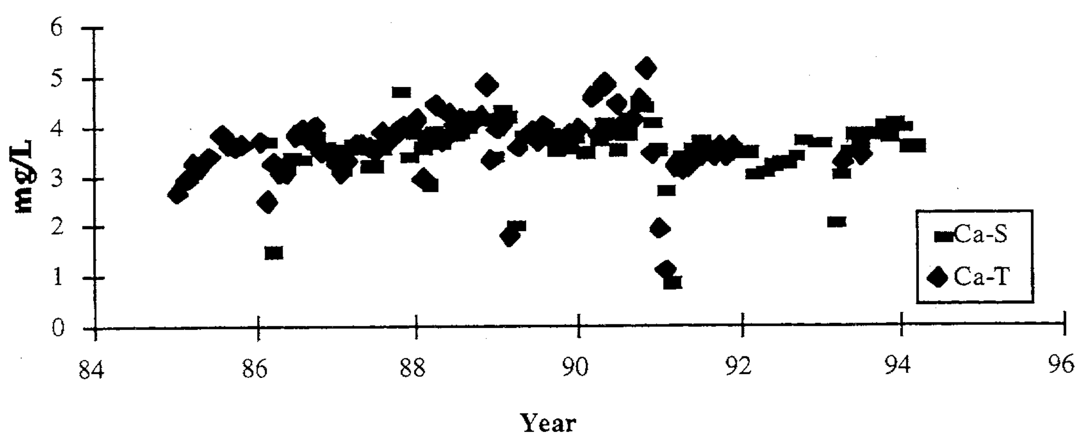


Figure 7.6.5. Stocking Lake sulfate concentrations (dissolved and soluble)(mg/L)

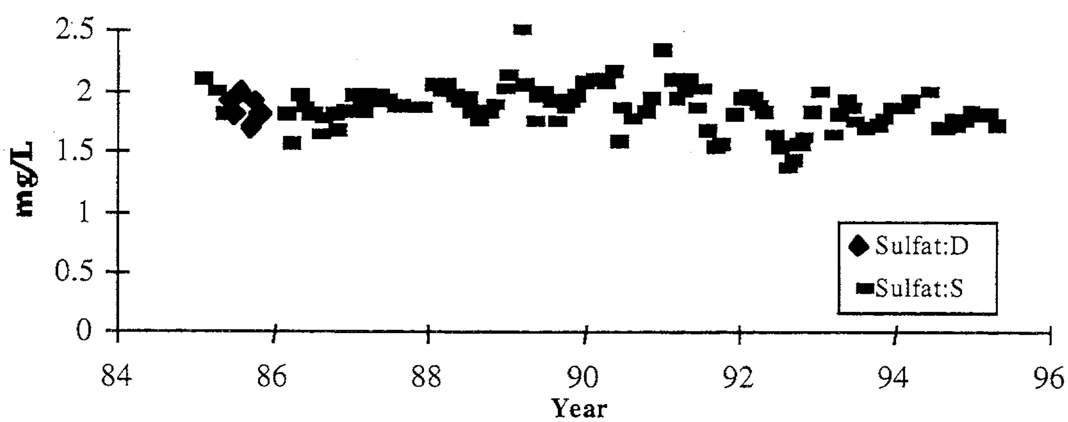


Figure 7.6.6. Stocking Lake alkalinity (meq/L)

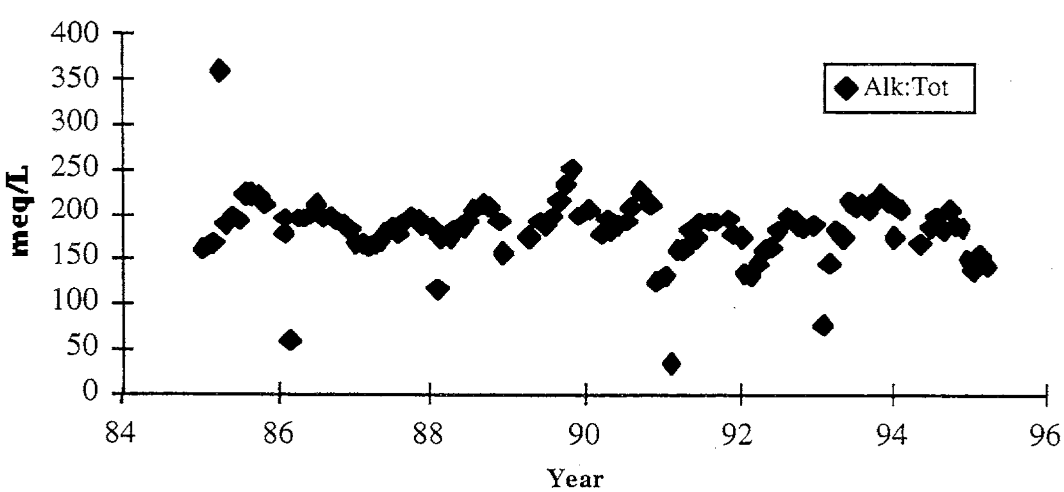


Figure 8.4.1.1. Lizard Lake Phytoplankton: *Oocystis*

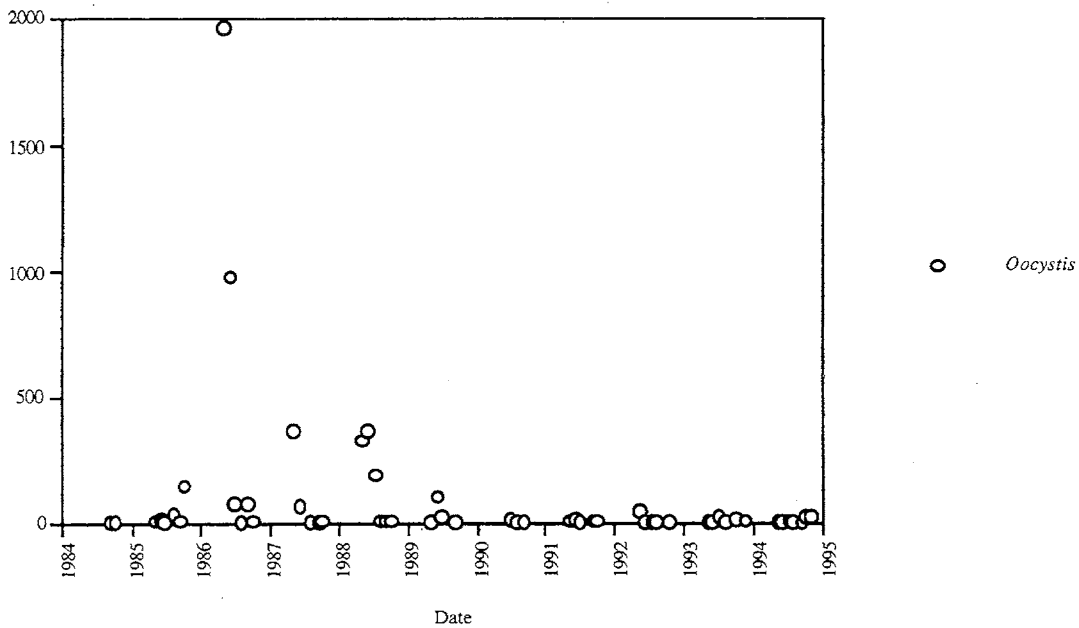


Figure 8.4.1.2. Lizard Lake Phytoplankton: *Crucigenia/Dinobryon*

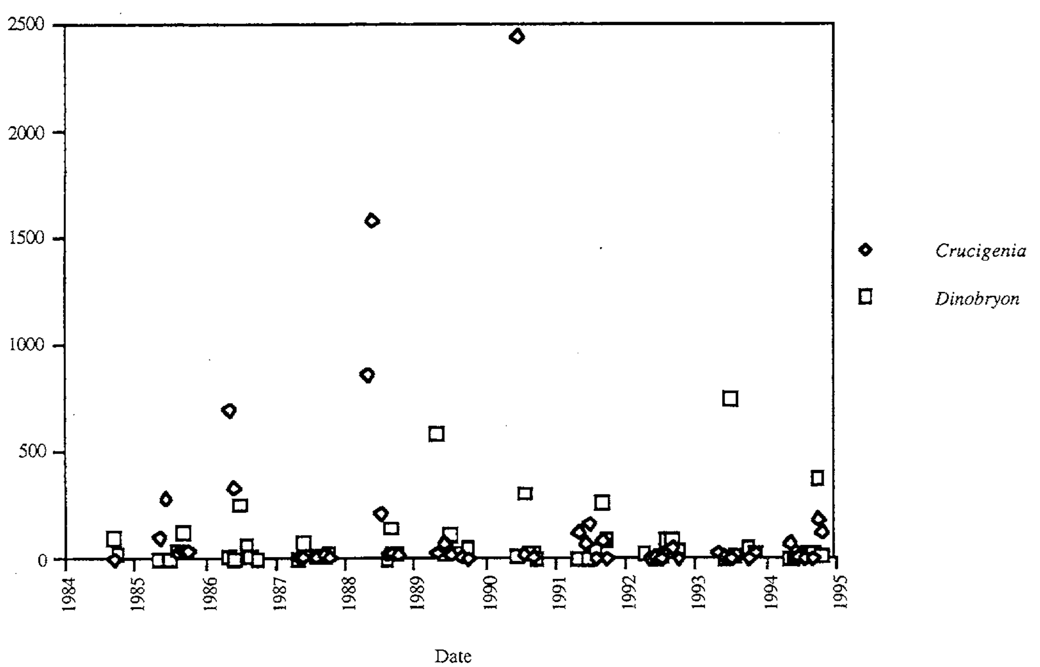


Figure 8.4.1.3. Lizard Lake Phytoplankton: *Chroomonas*.

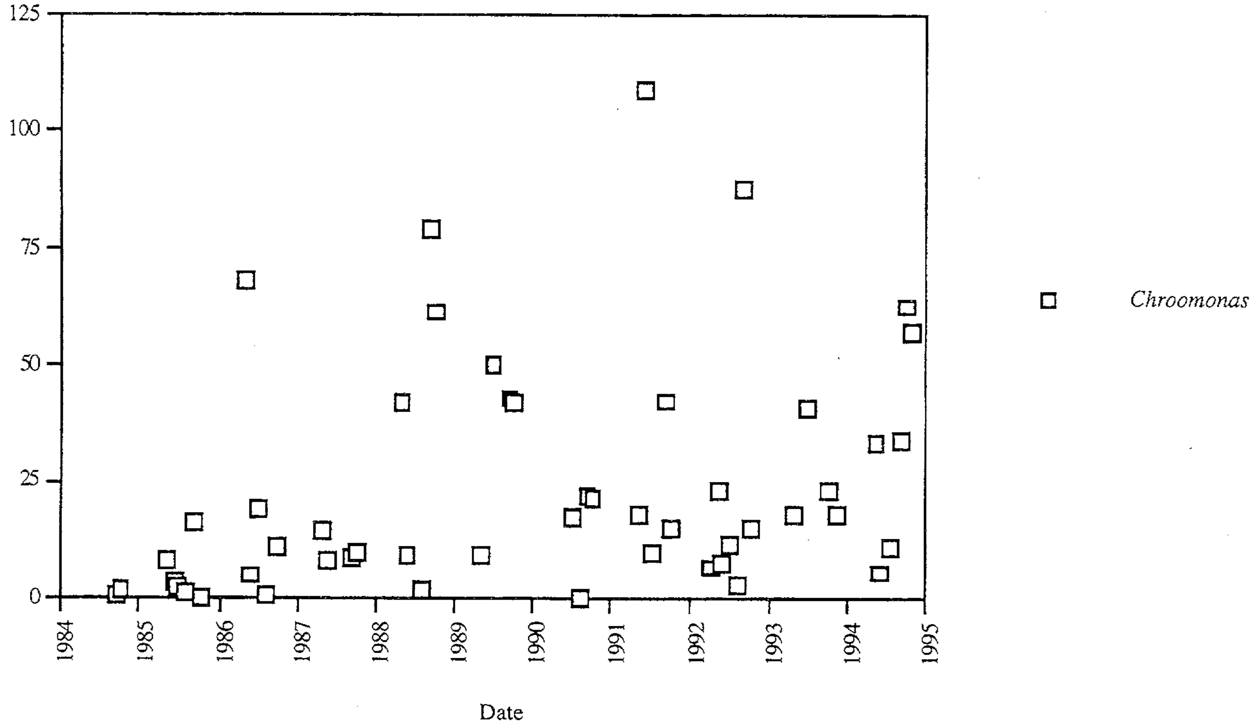


Figure 8.4.1.4. Lizard Lake Phytoplankton: *Merismopedia/Botryococcus*.

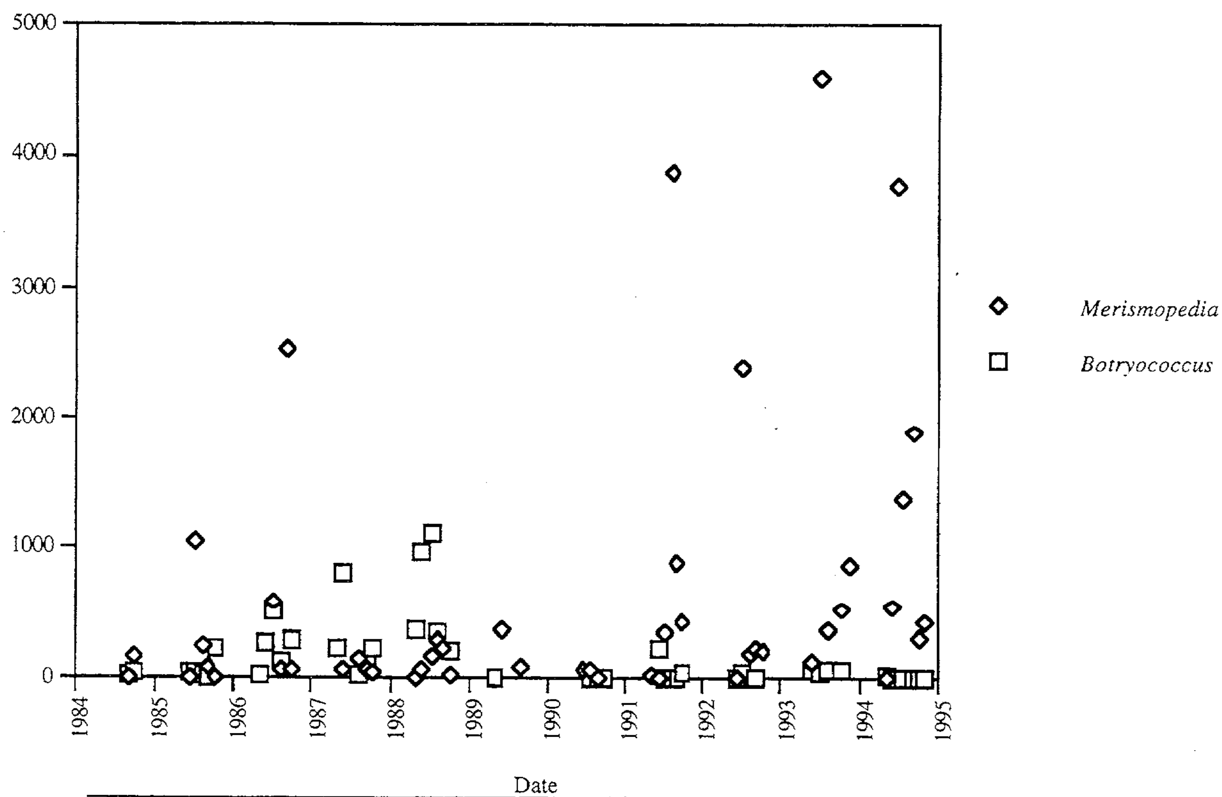


Figure 8.4.1.5. Lizard Lake Phytoplankton: *Chroococcus*

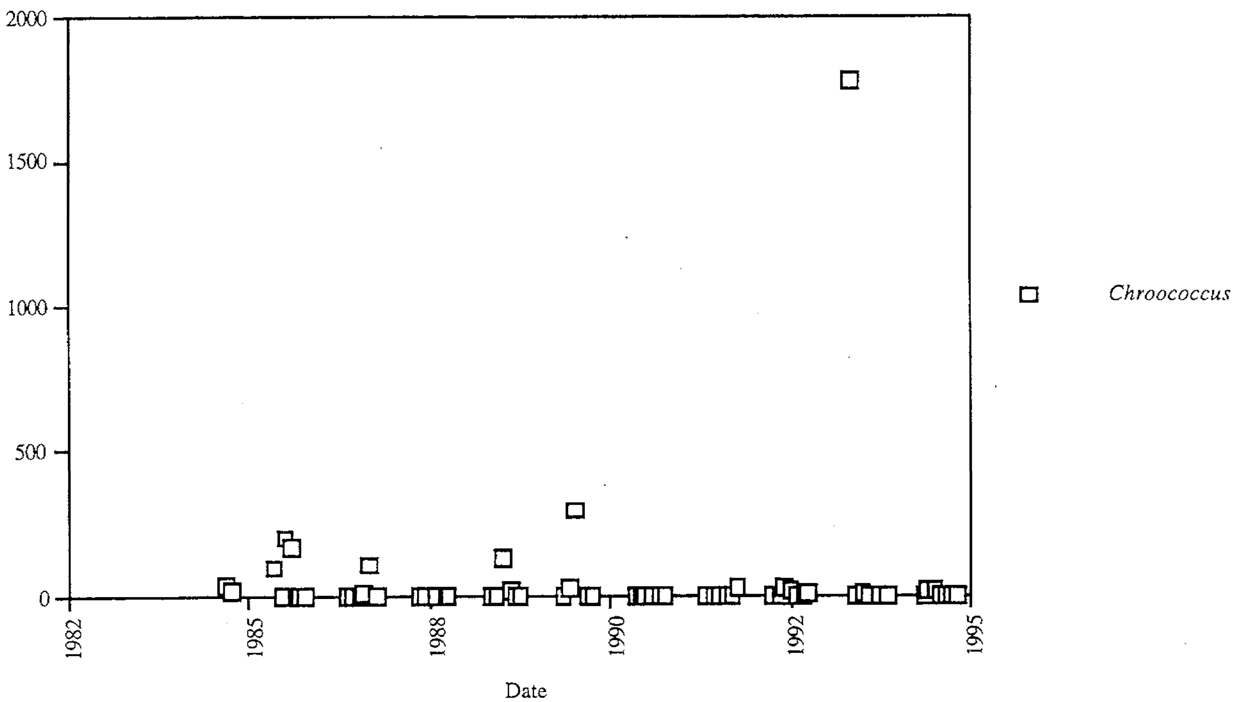


Figure 8.4.1.6. Lizard Lake Phytoplankton: *Quadrigula/Elakothrix*

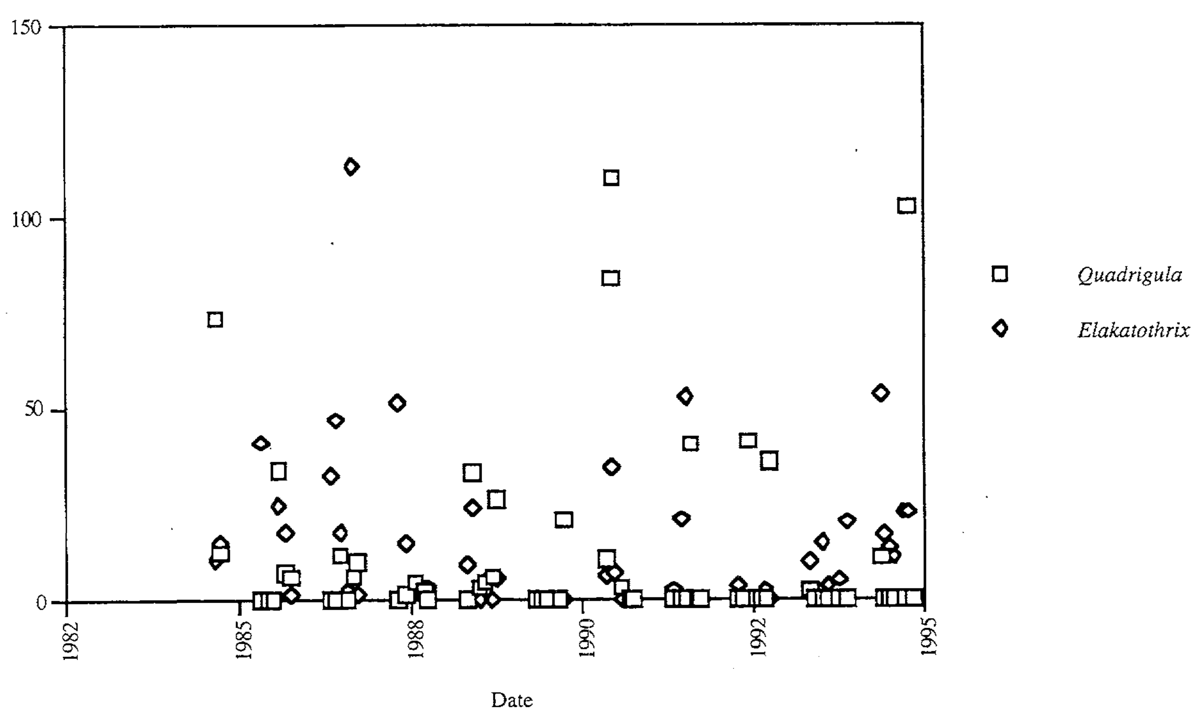


Figure 8.4.1.7. Lizard Lake Phytoplankton: *Cryptomonas*.

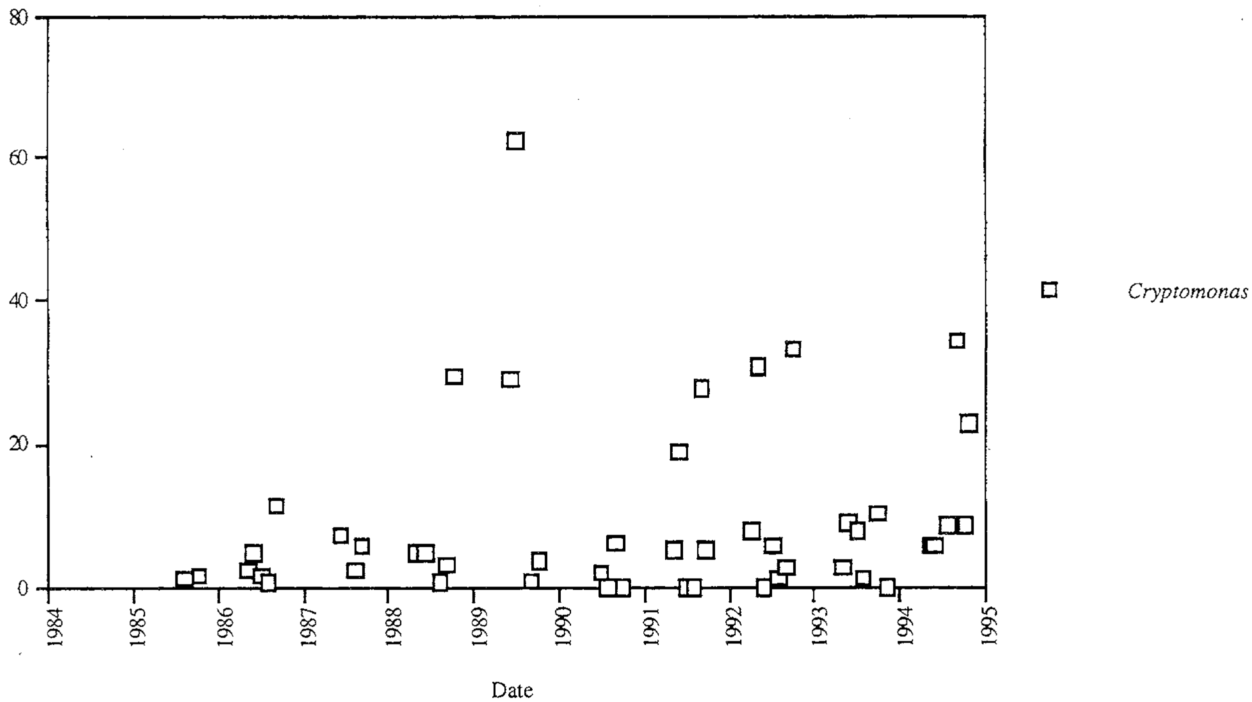


Figure 8.4.1.8. Lizard Lake Phytoplankton: Chlorophyll a

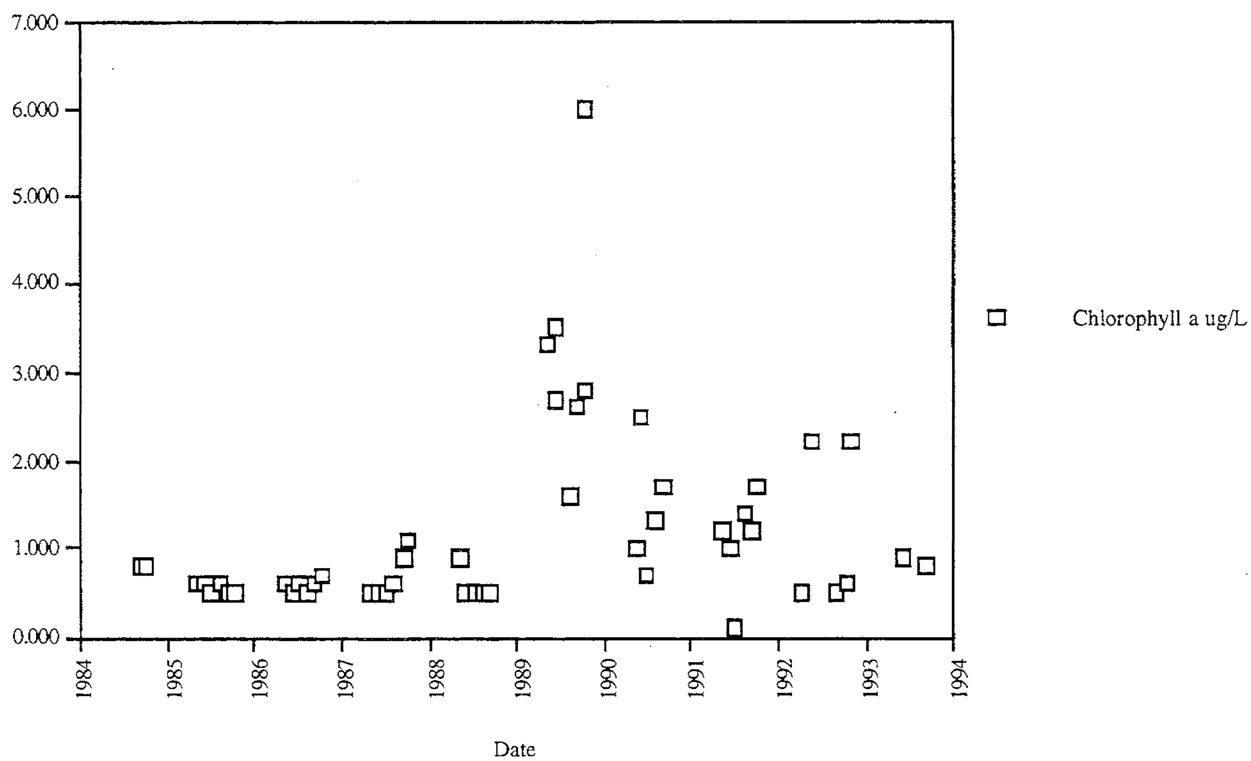


Figure 8.4.1.9. Lizard Lake Phytoplankton: Zoospores.

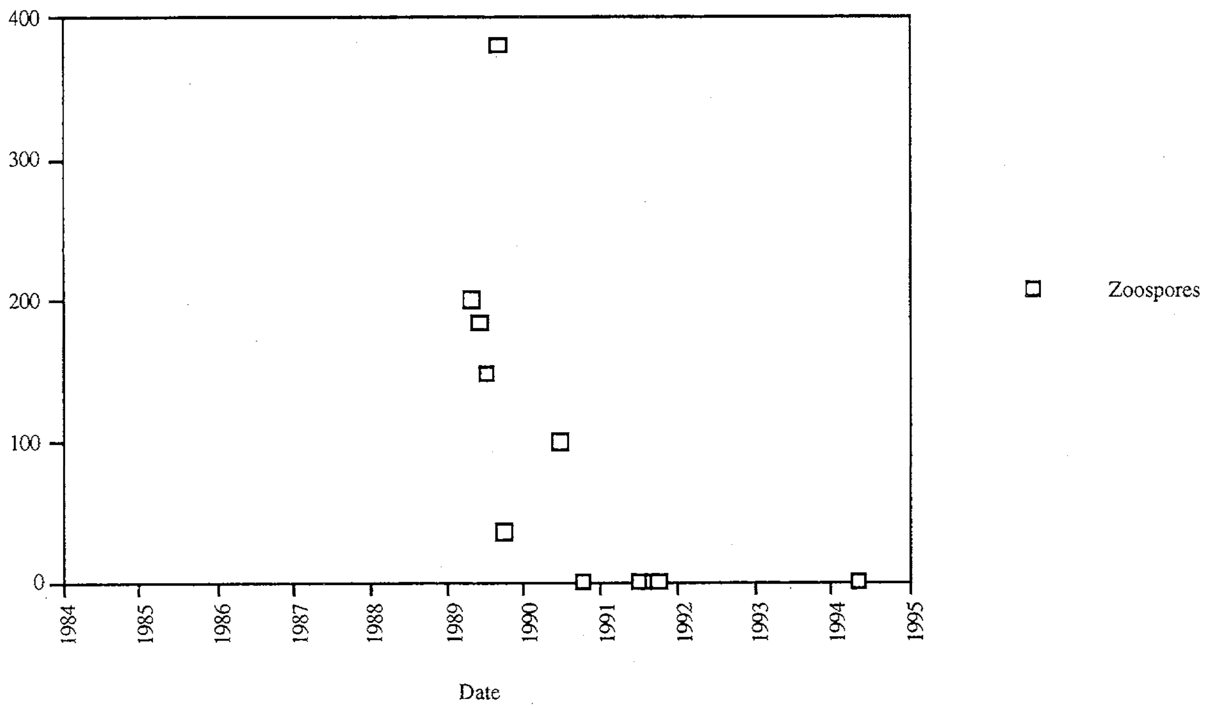


Figure 8.4.1.10. Lizard Lake Phytoplankton: *Aphanothece*.

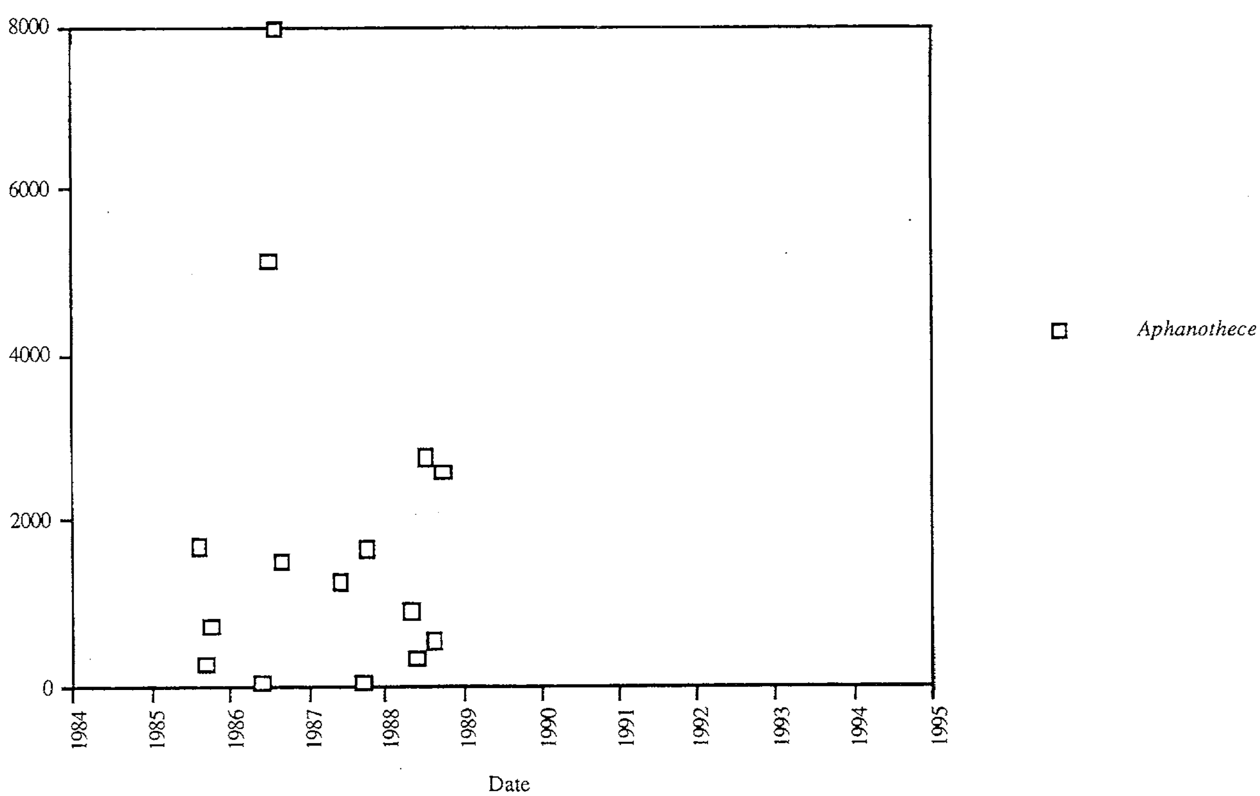


Figure 8.4.1.11. Lizard Lake Phytoplankton: *Microcystis*.

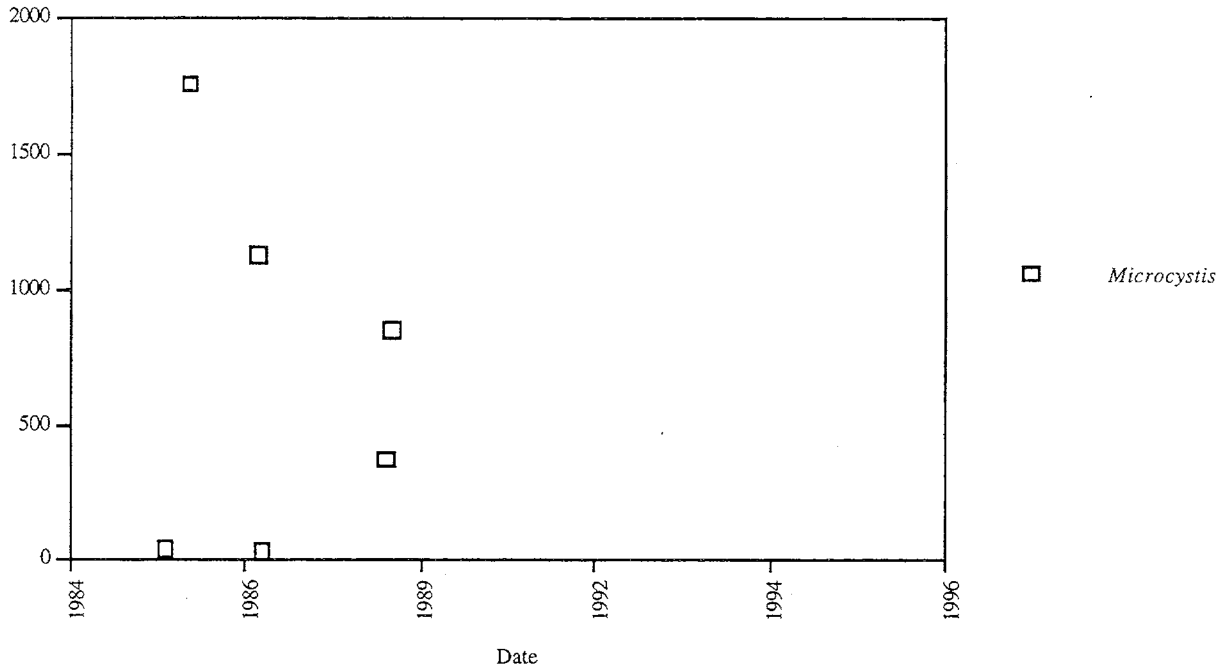


Figure 8.4.1.12. Lizard Lake Phytoplankton: Total Cells/mL

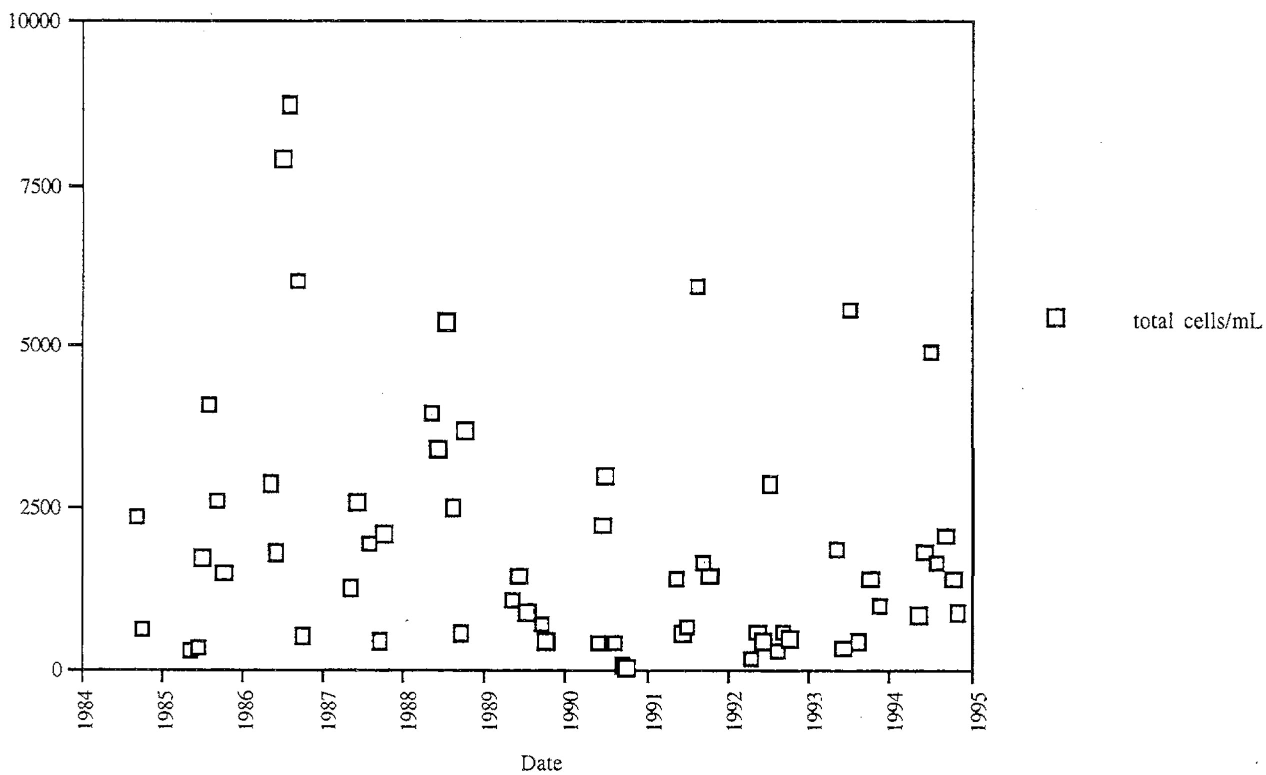


Figure 8.4.2.1. Lizard Lake Zooplankton: *Diaptomus.*

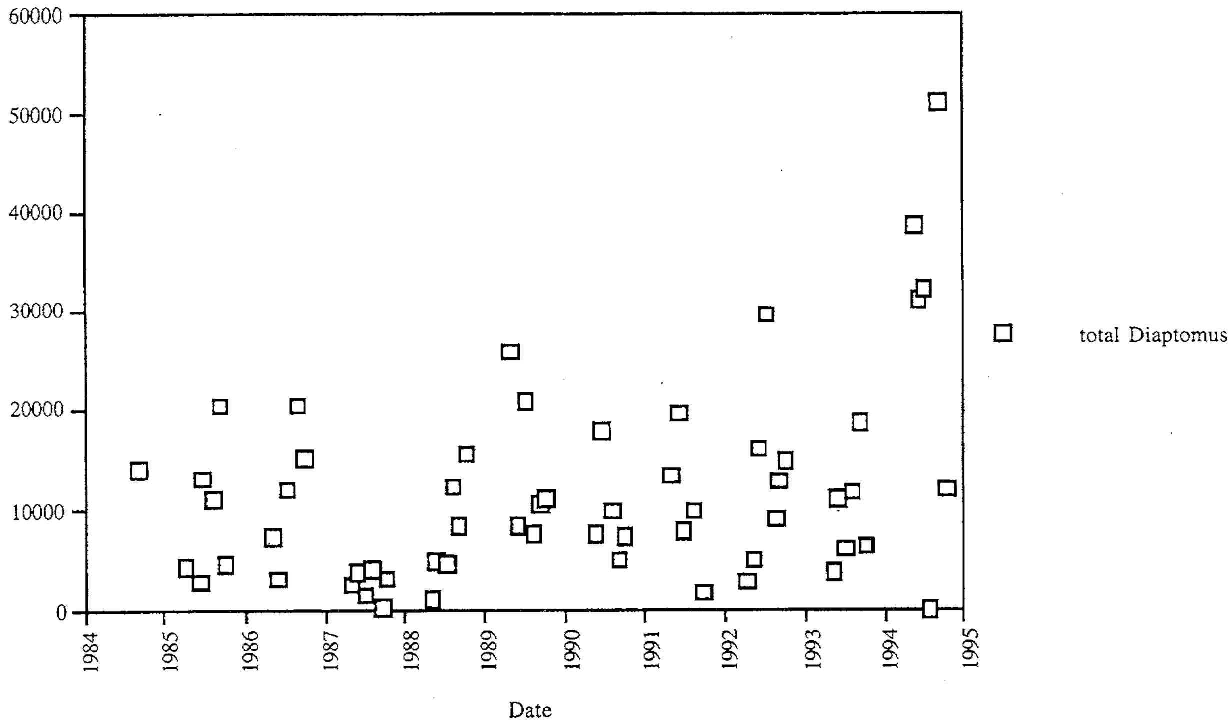


Figure 8.4.2.2. Lizard Lake Zooplankton: *Cyclops/Diacyclops.*

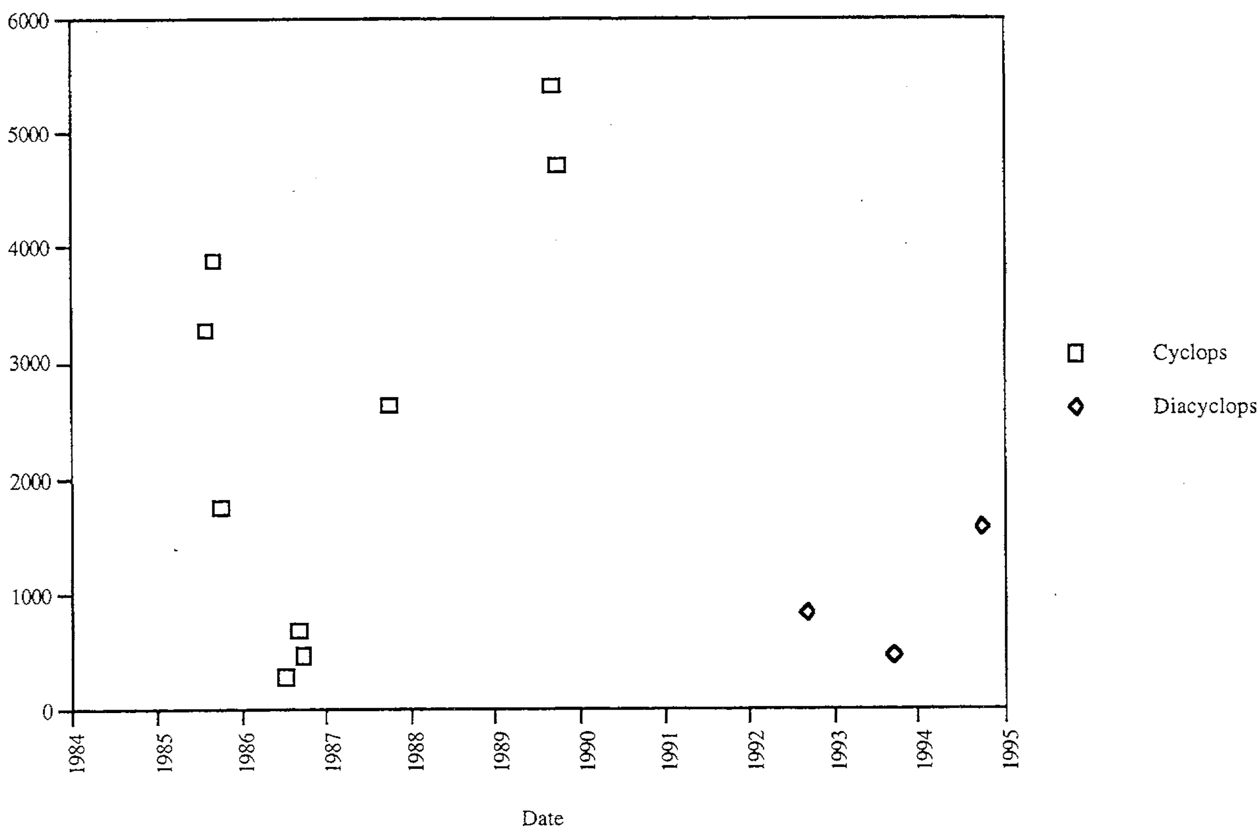


Figure 8.4.2.3. Lizard Lake Zooplankton: Copepodites/Nauplii

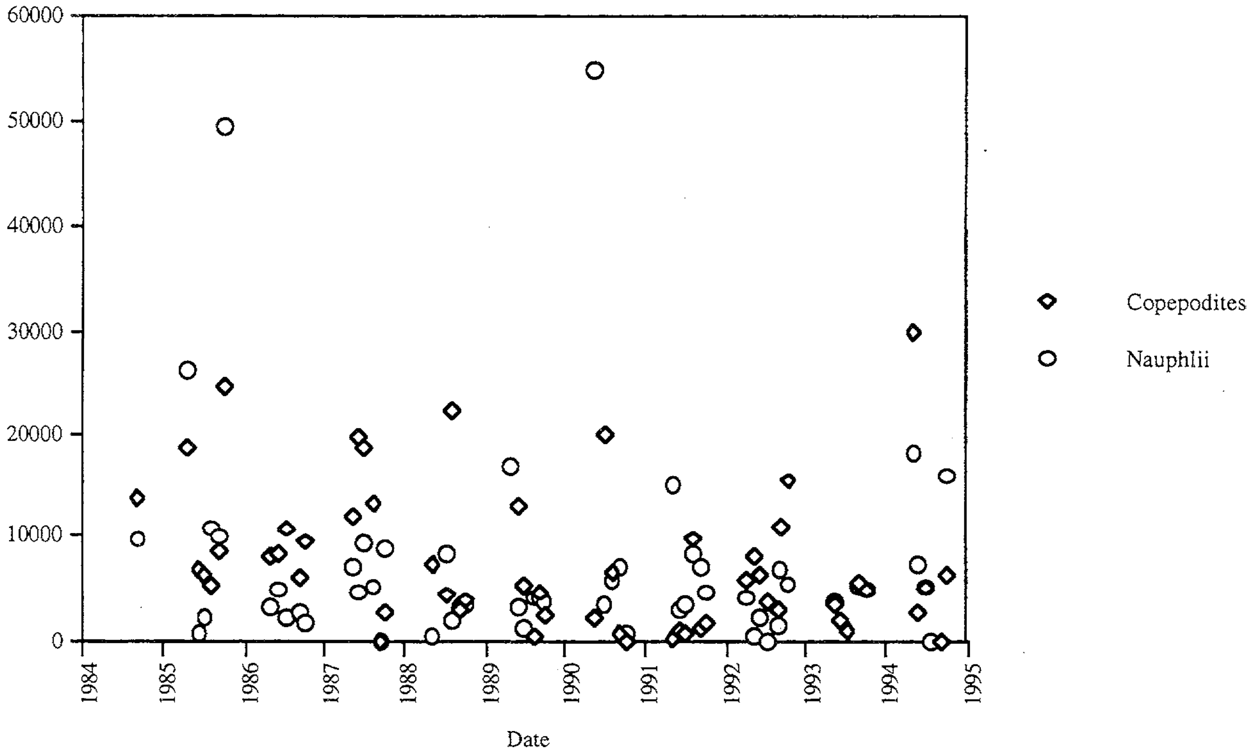


Figure 8.4.2.4. Lizard Lake Zooplankton: *Diphanosoma/Daphnia*.

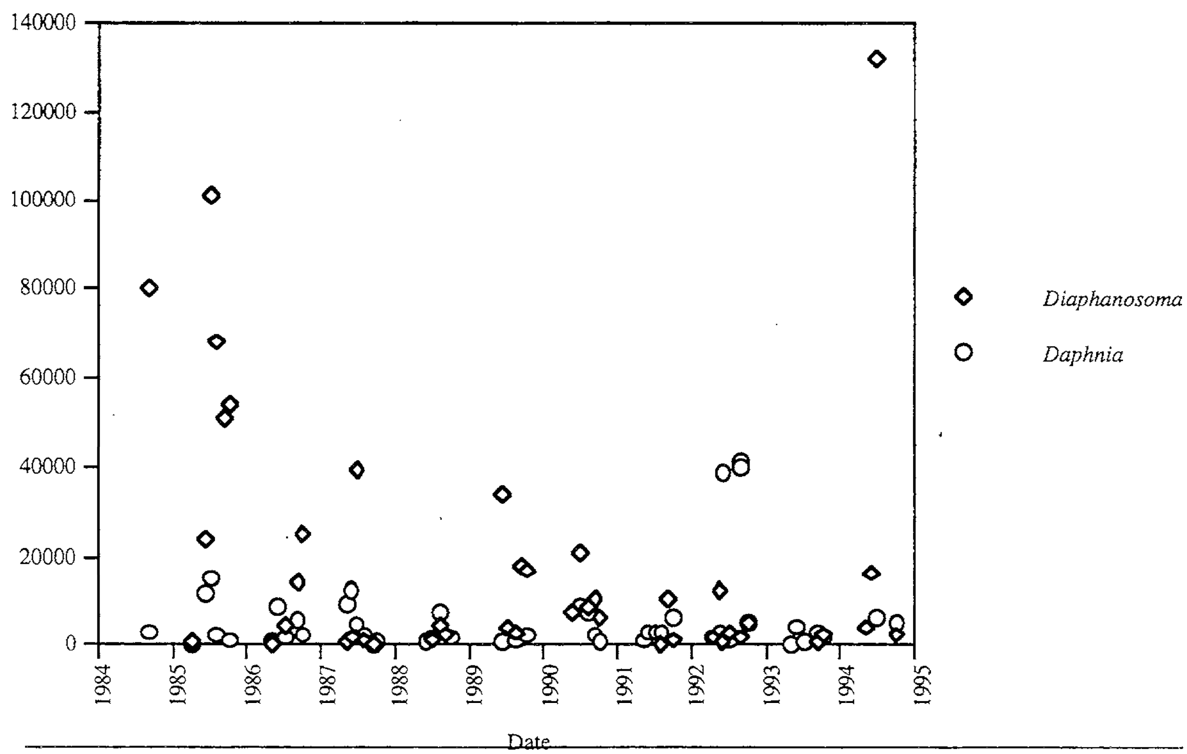


Figure 8.4.2.5. Lizard Lake Zooplankton: *Ceriodaphnia*.

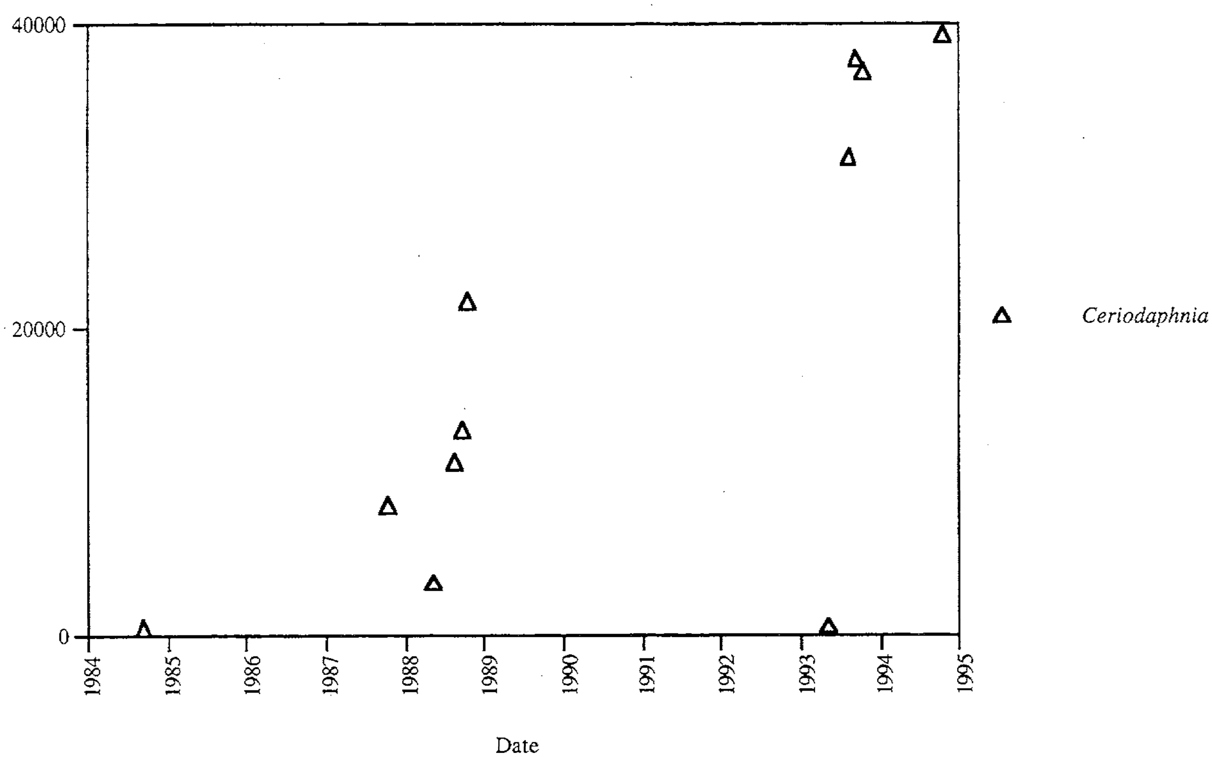


Figure 8.4.2.6. Lizard Lake Zooplankton: *Holopedium/Bosmina*.

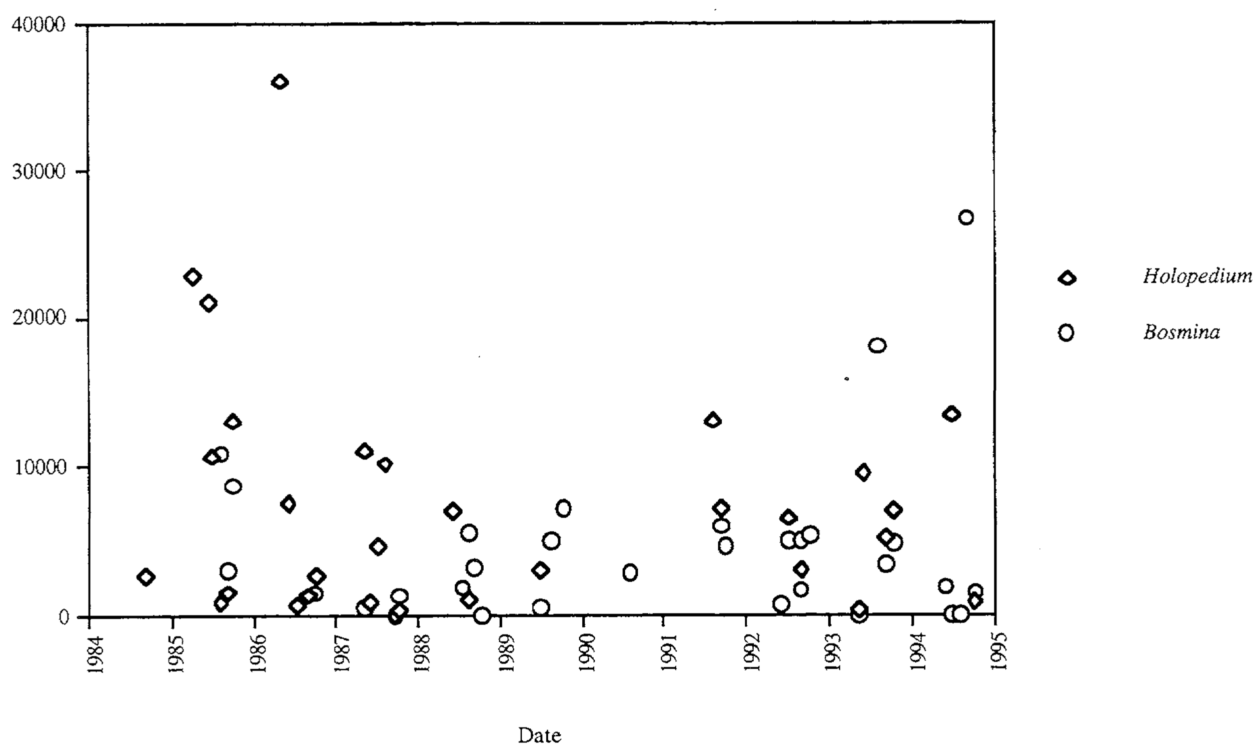


Figure 8.4.2.7. Lizard Lake Zooplankton: Total/m2

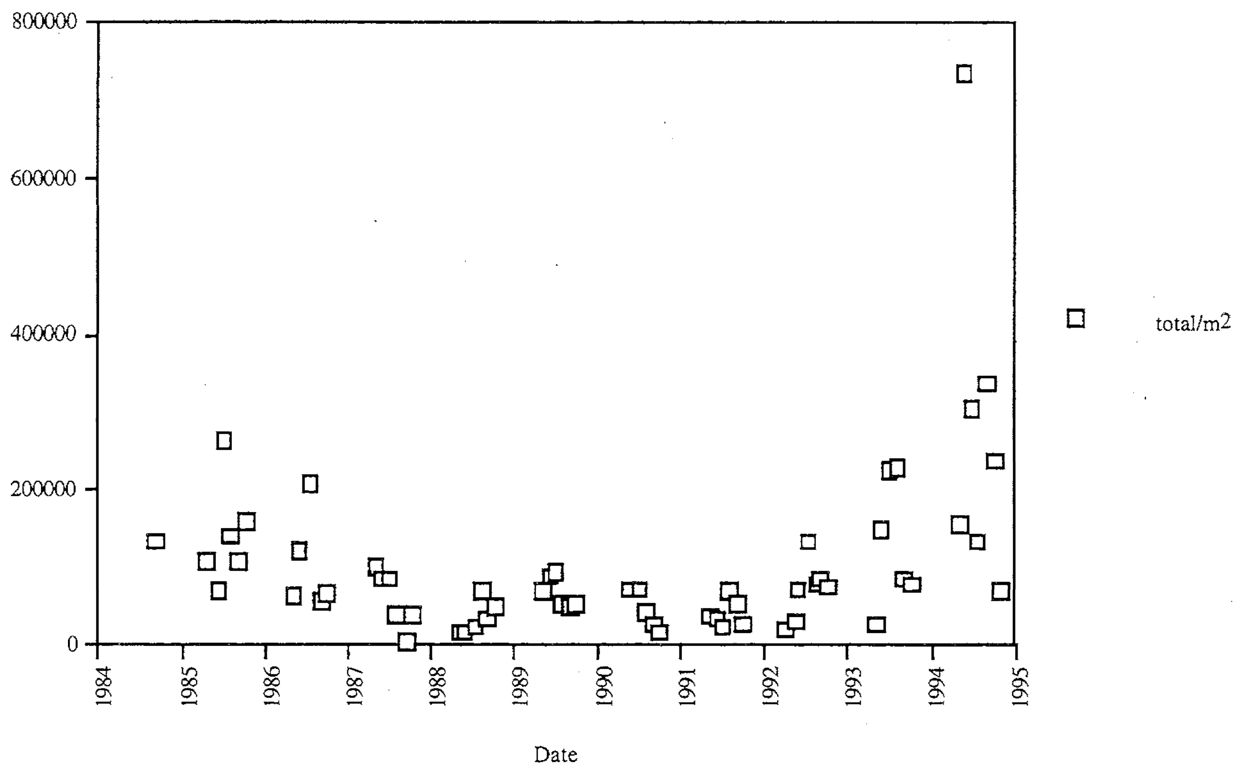


Figure 8.4.2.8. Lizard Lake Zooplankton: *Kellicottia*.

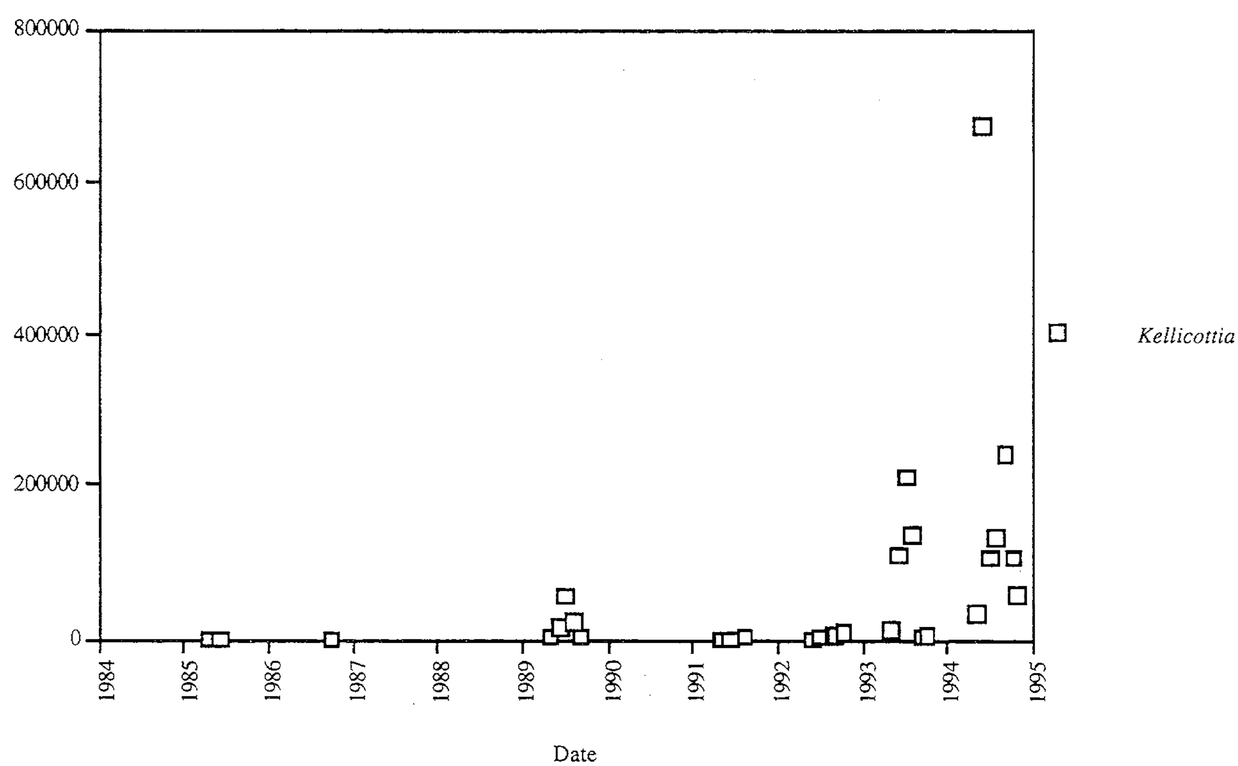


Figure 8.4.2.9. Lizard Lake Zooplankton: *Conochilus/Keratella.*

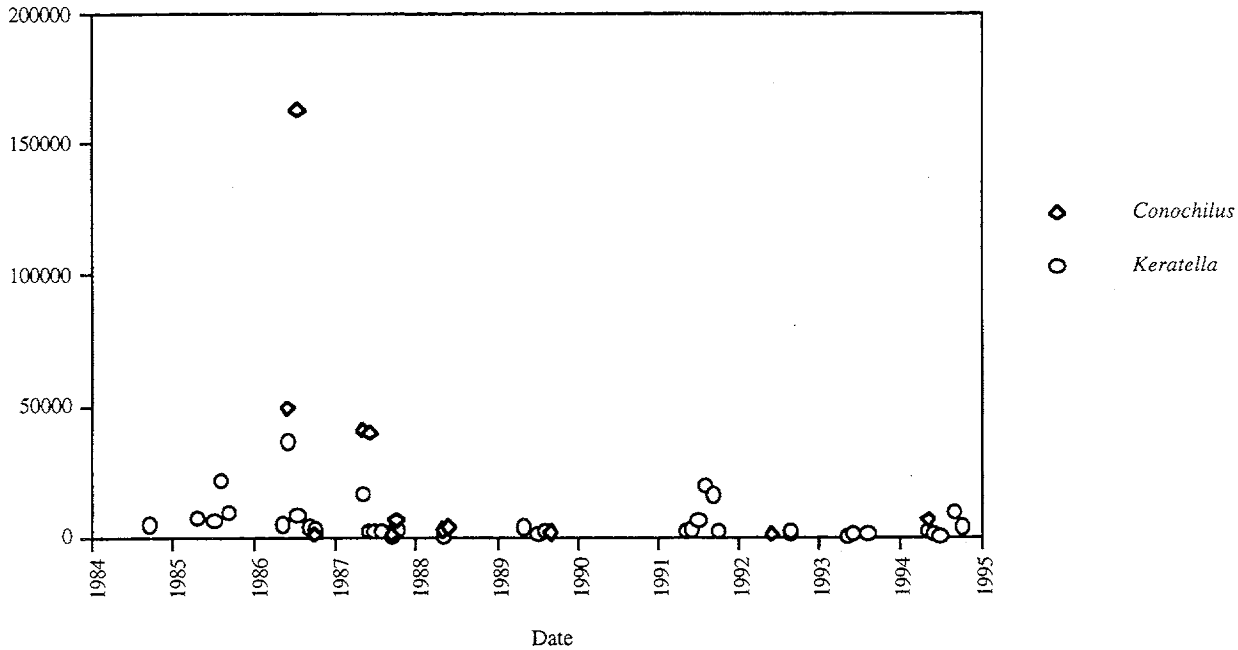


Figure 8.4.2.10. Lizard Lake Zooplankton: *Polyarthra.*

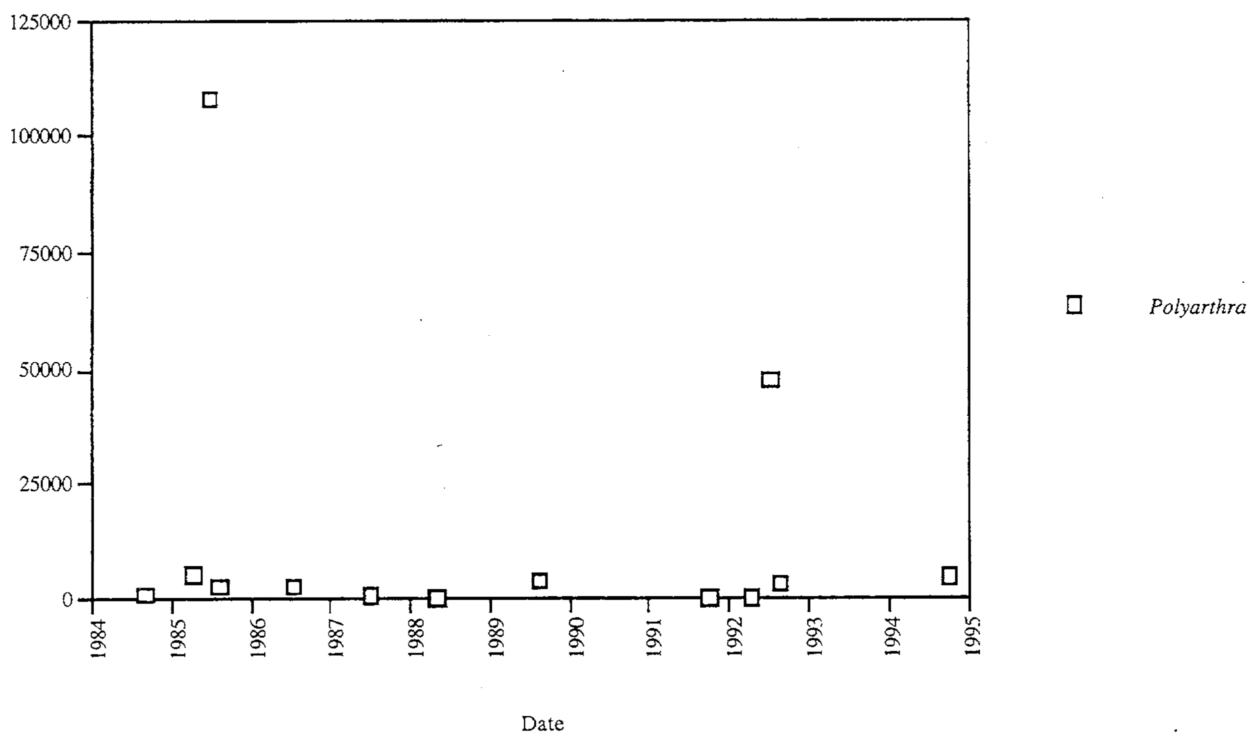


Figure 8.4.2.11. Lizard Lake Zooplankton: Rare Rotifers.

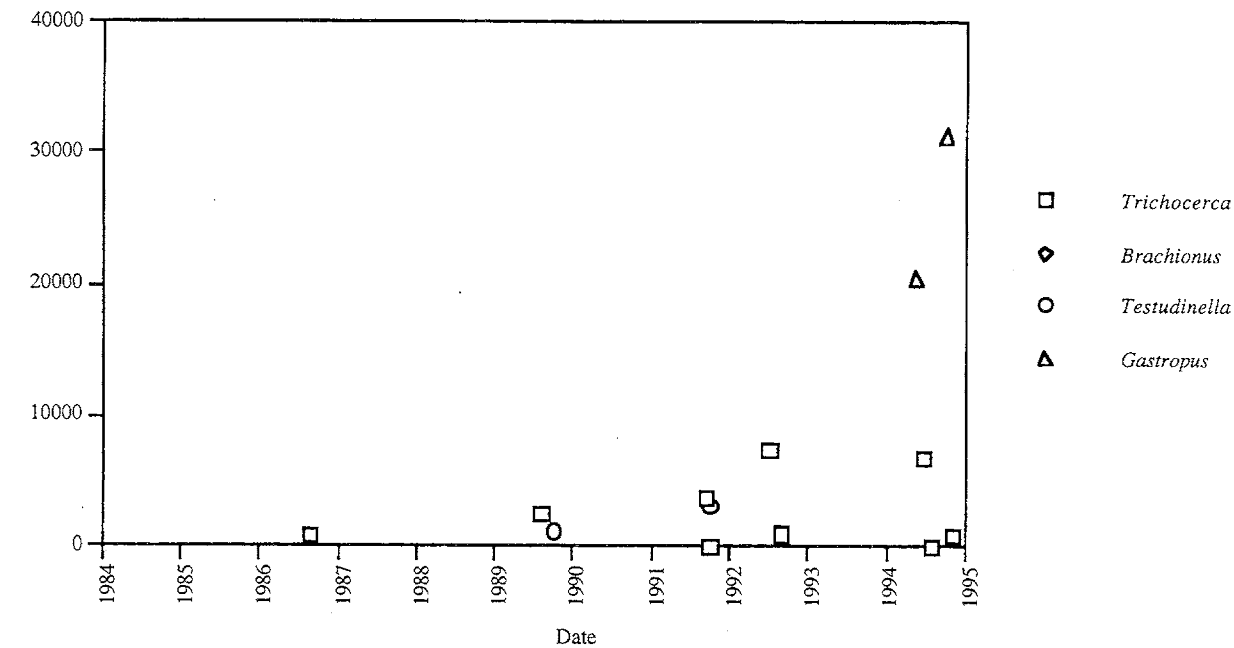


Figure 8.4.2.12. Lizard Lake Zooplankton; Biomass Comparisons.

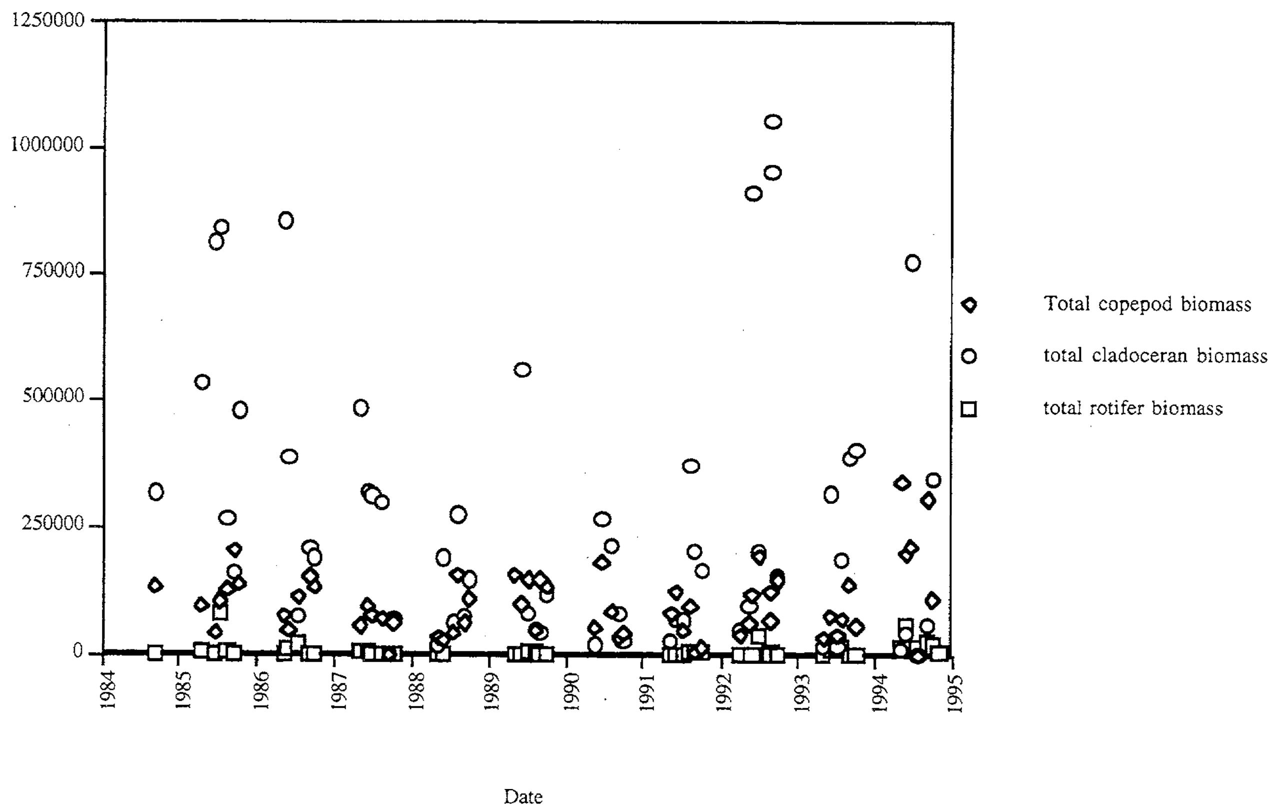


Figure 8.4.2.13. Lizard Lake Zooplankton: Total Biomass μg/m2

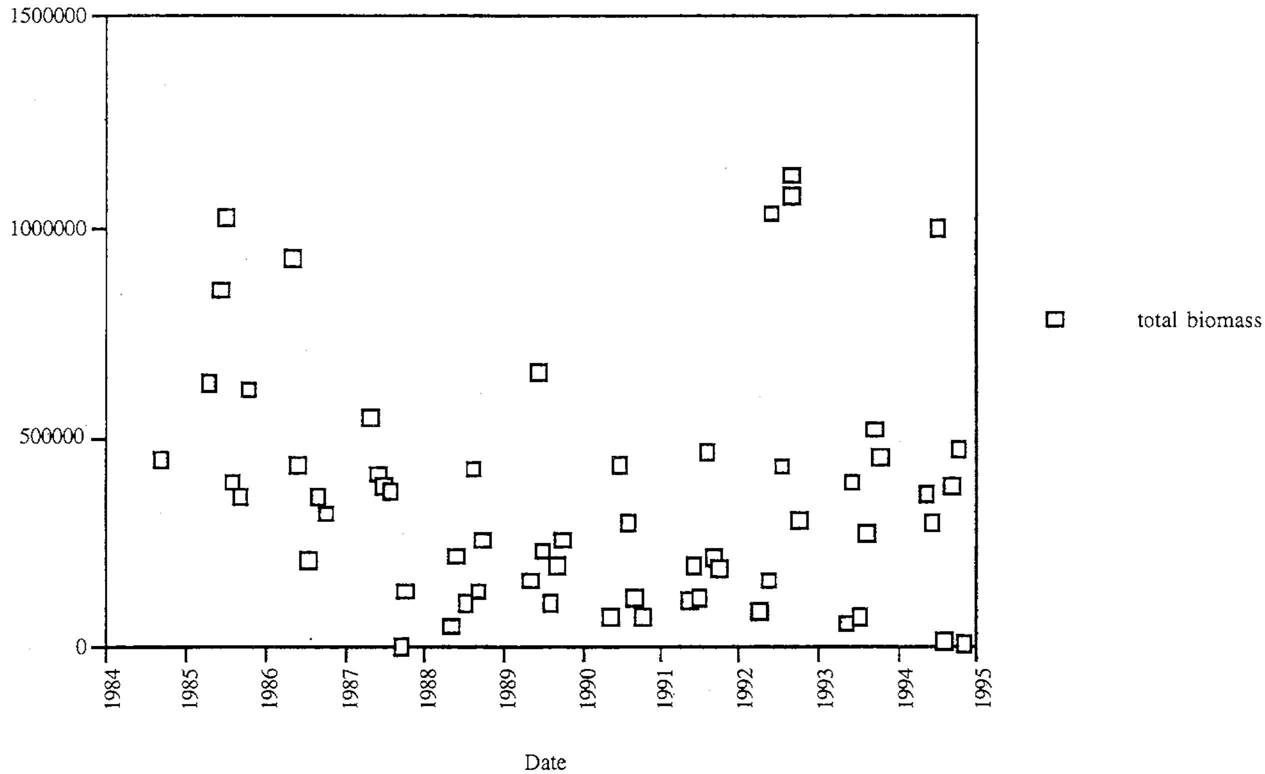


Figure 8.5.1.1. Marion Lake Phytoplankton: *Ankistrodesmus*.

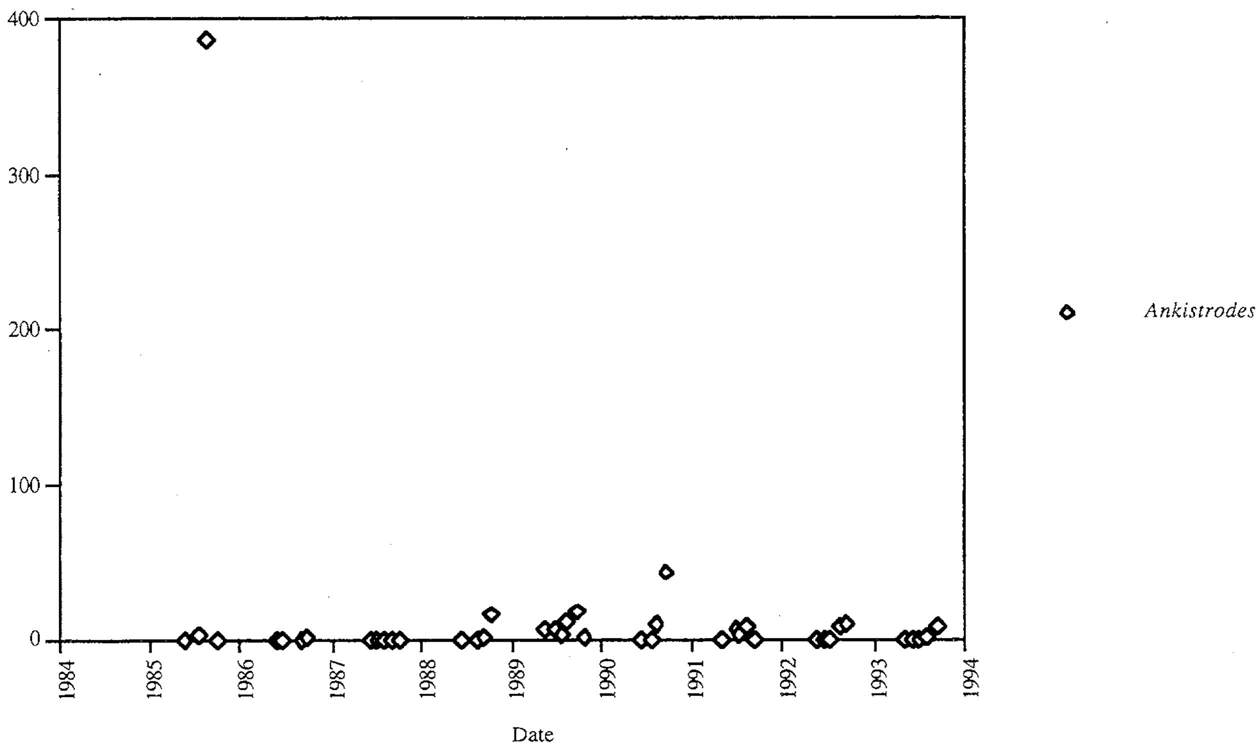


Figure 8.5.1.2. Marion Lake Phytoplankton: *Dinobryon*.

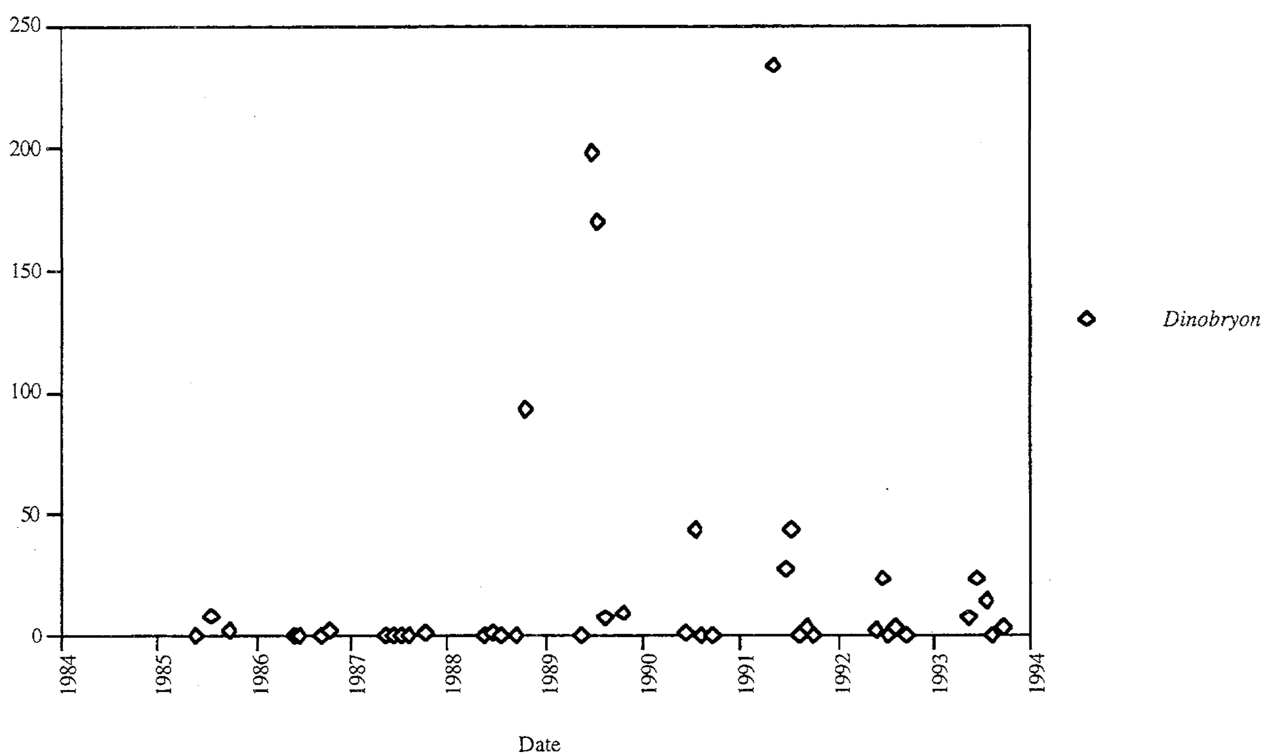


Figure 8.5.1.3. Marion Lake Phytoplankton: *Cryptomonas*.

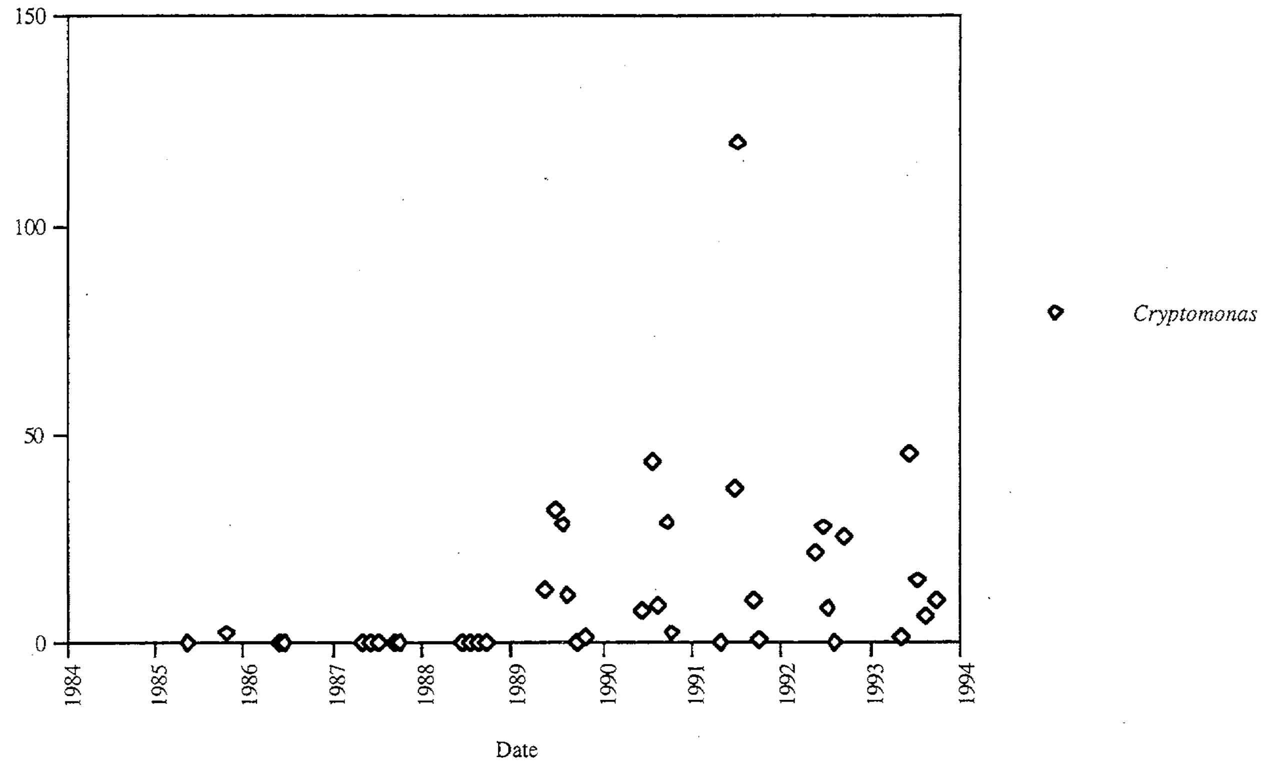


Figure 8.5.1.4. Marion Lake Phytoplankton: *Oocystis/Scendesmus*.

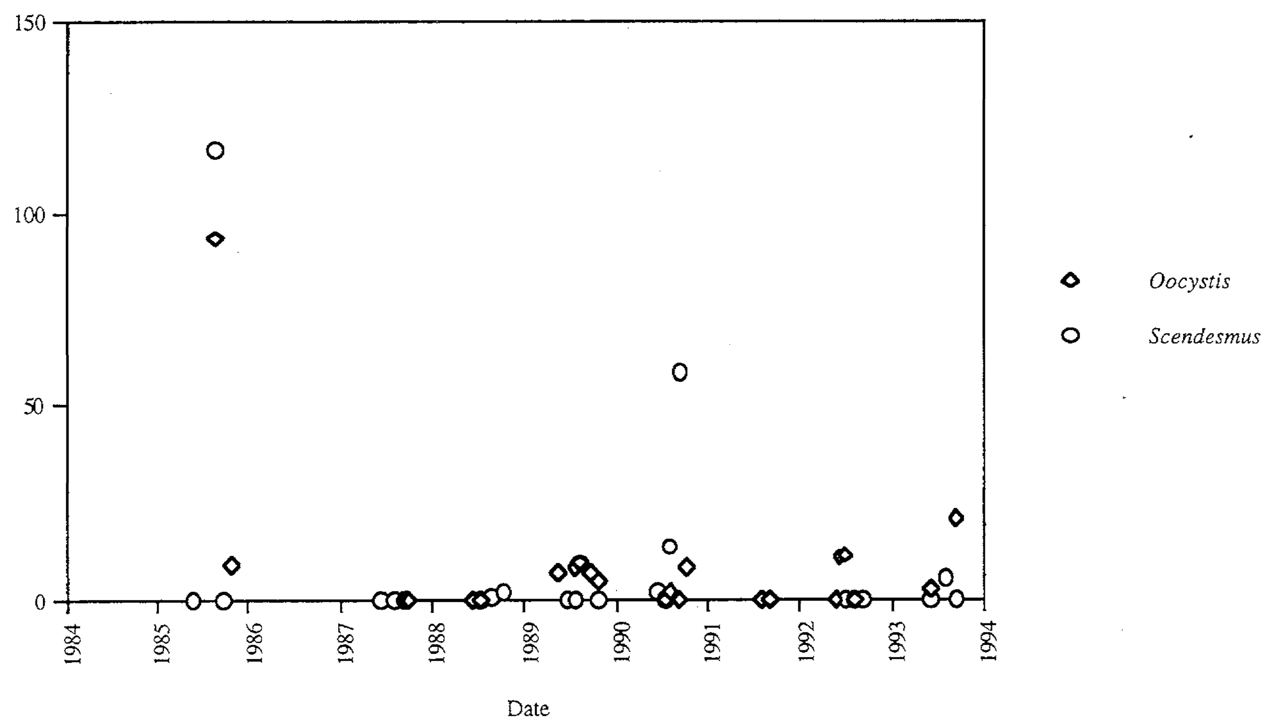


Figure 8.5.1.5. Marion Lake Phytoplankton: *Merismopedia*.

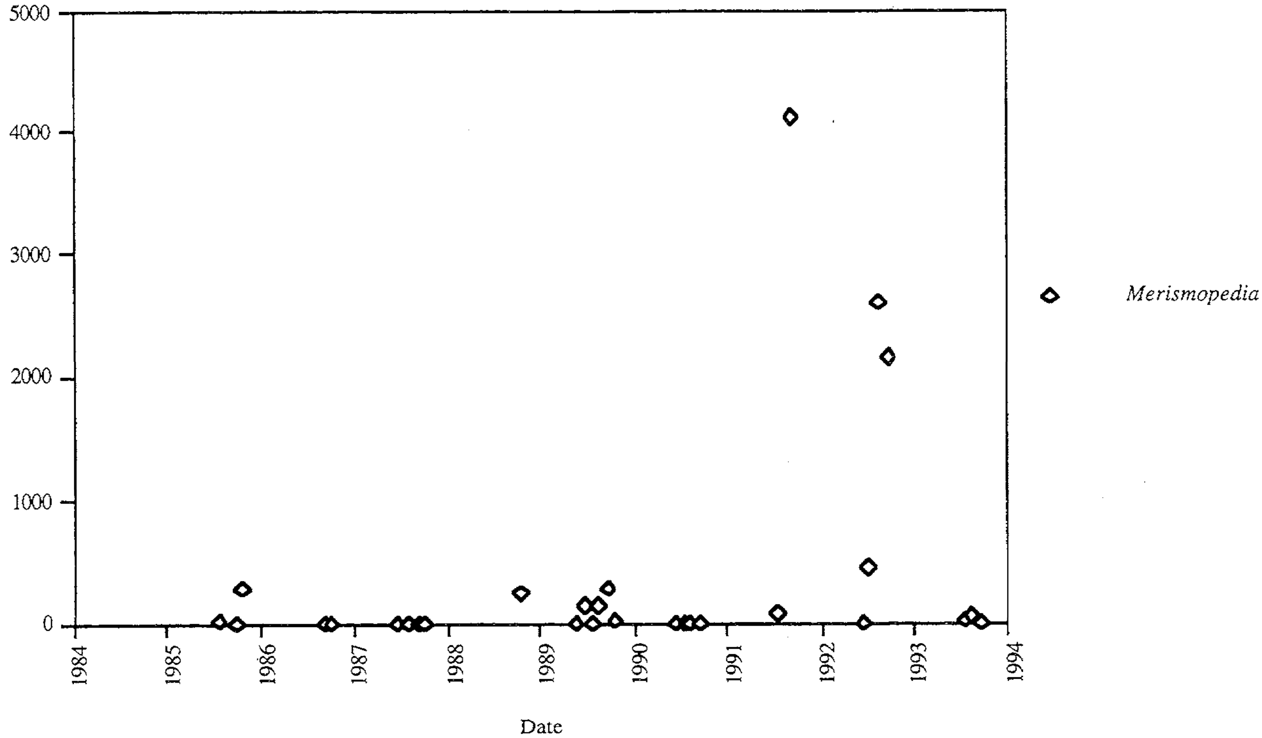


Figure 8.5.1.6. Marion Lake Phytoplankton: *Aphanothece*.

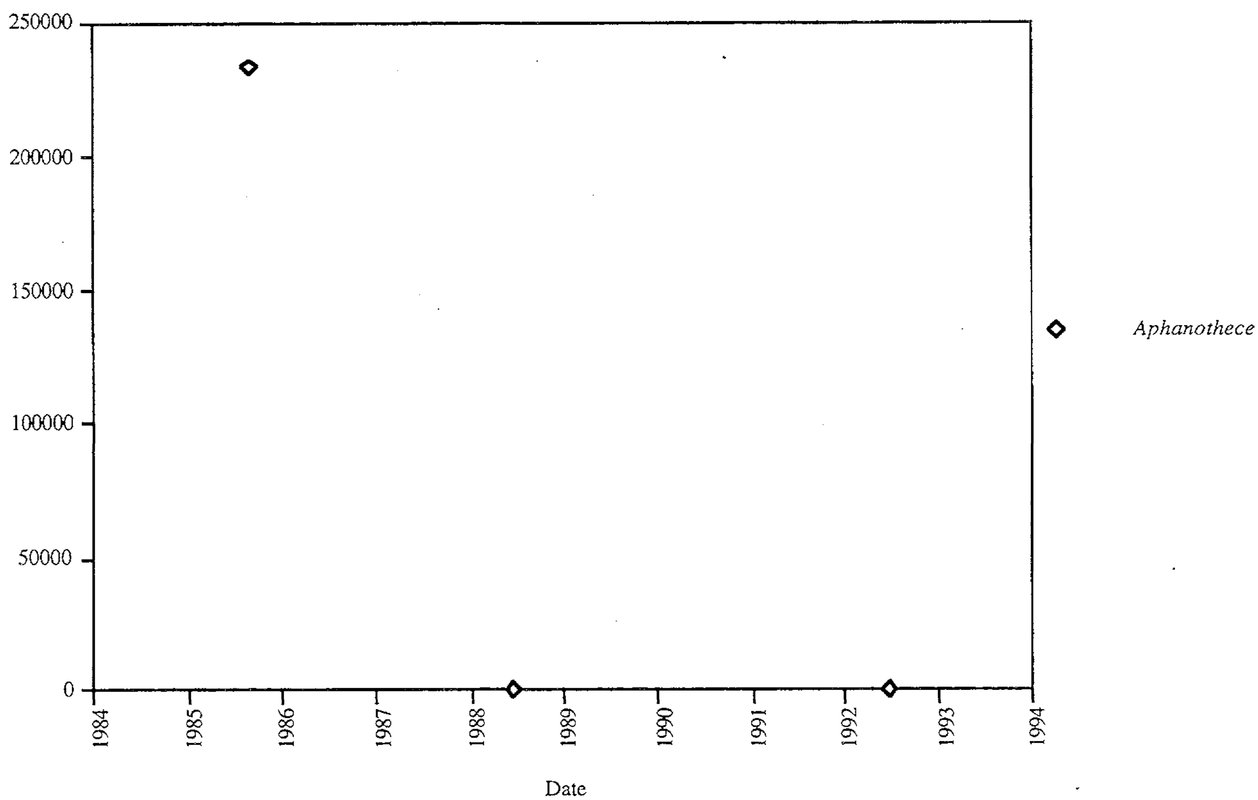


Figure 8.5.1.7. Marion Phytoplankton: Total Cells/mL - *Aphanothece*.

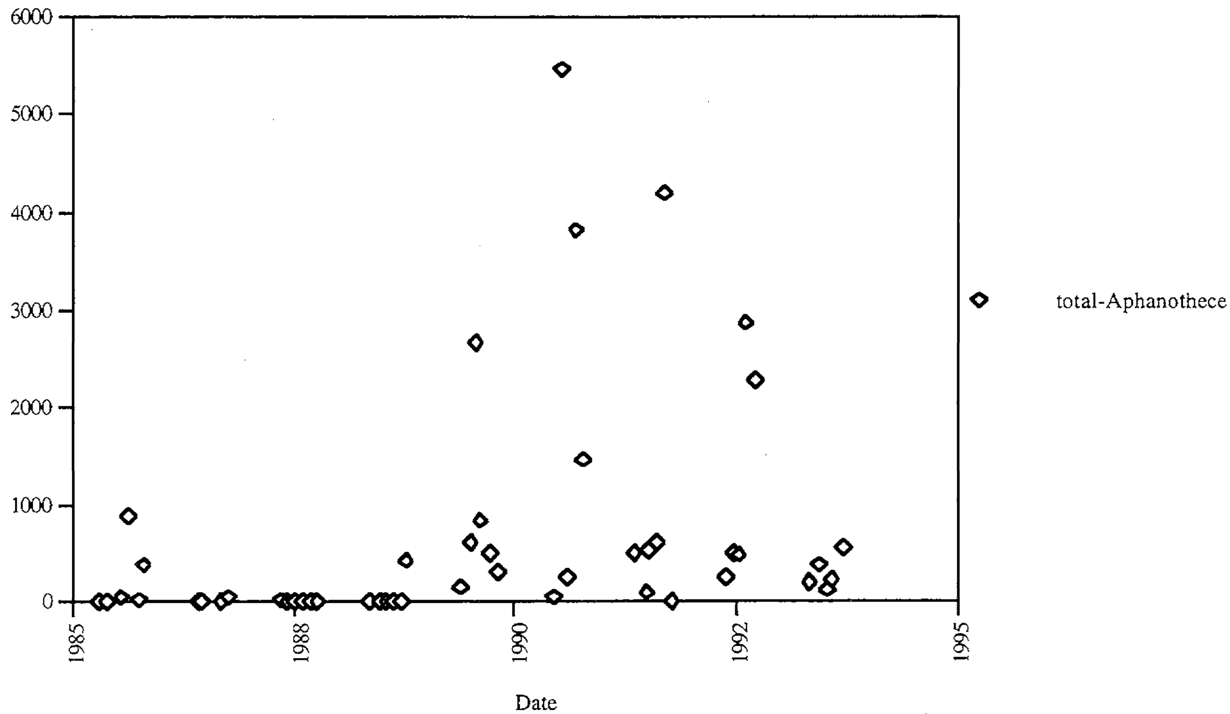


Figure 8.5.1.8 Marion Lake Phytoplankton: Chlorophyll a

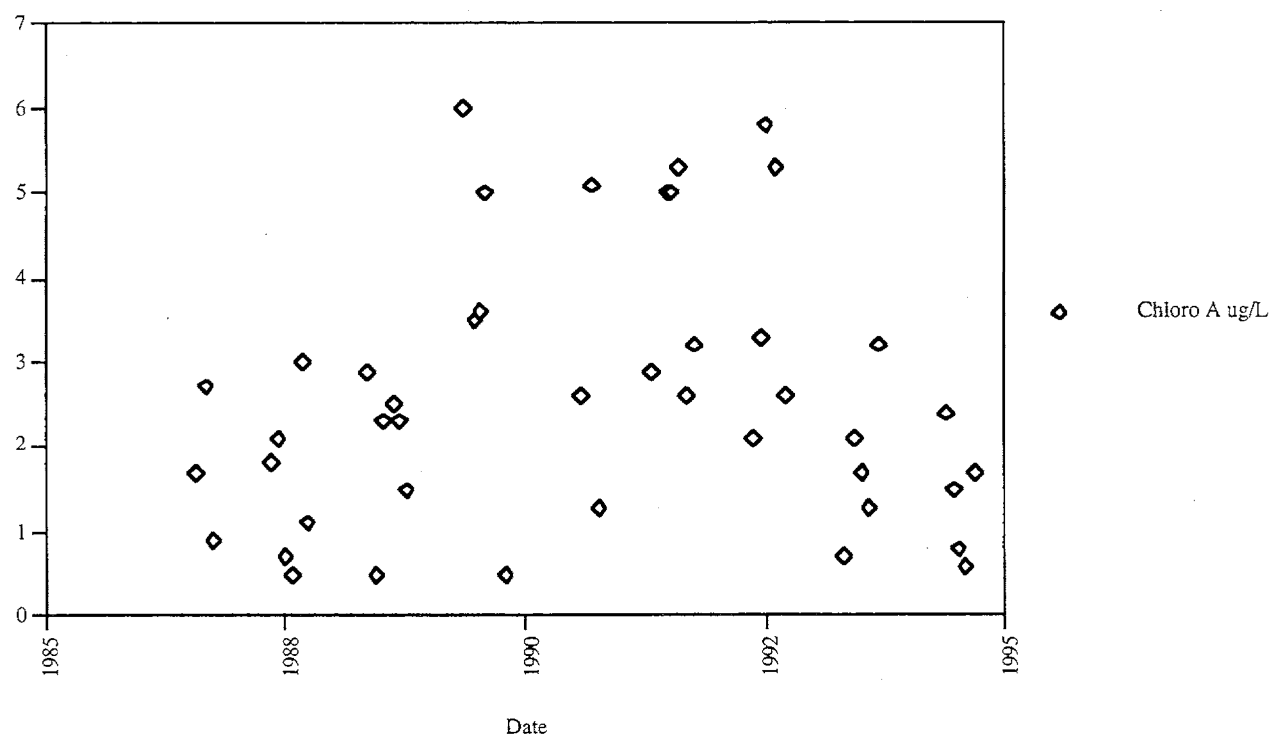


Figure 8.5.2.1 Marion Lake Zooplankton: *Diaptomus.*

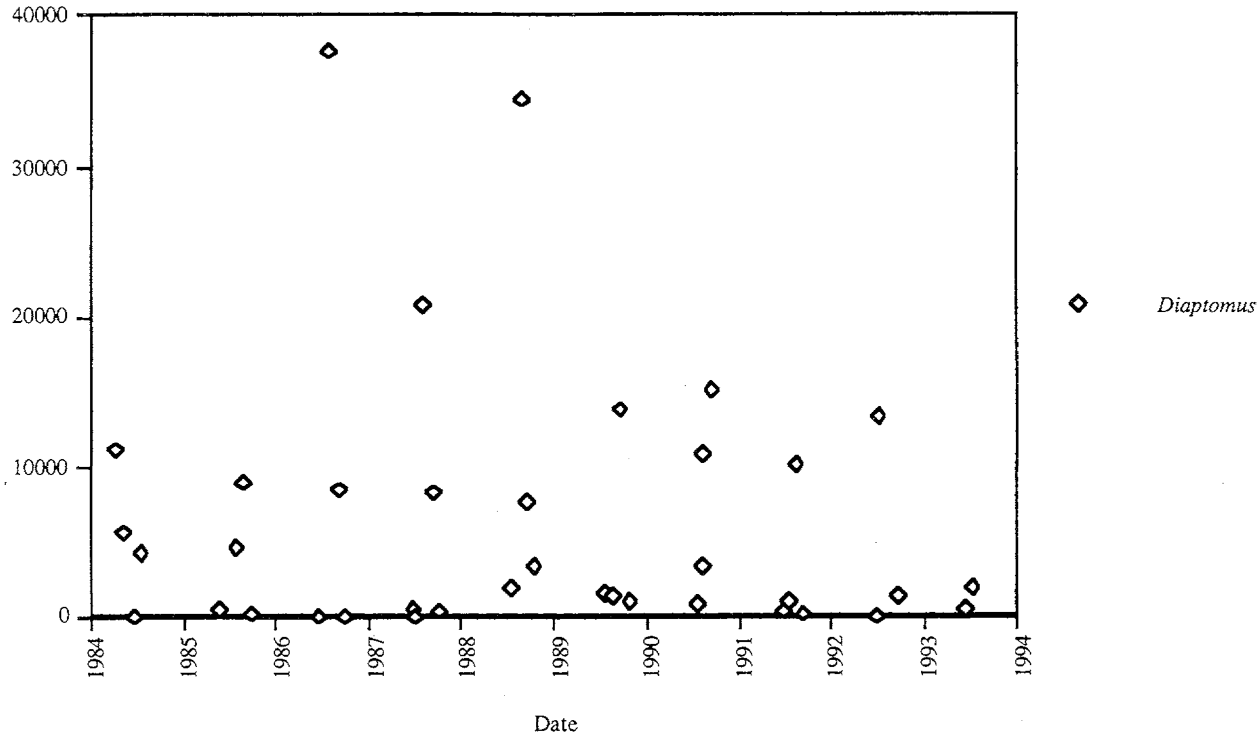


Figure 8.5.2.2. Marion Lake Zooplankton: *Cyclops/Diacyclops*

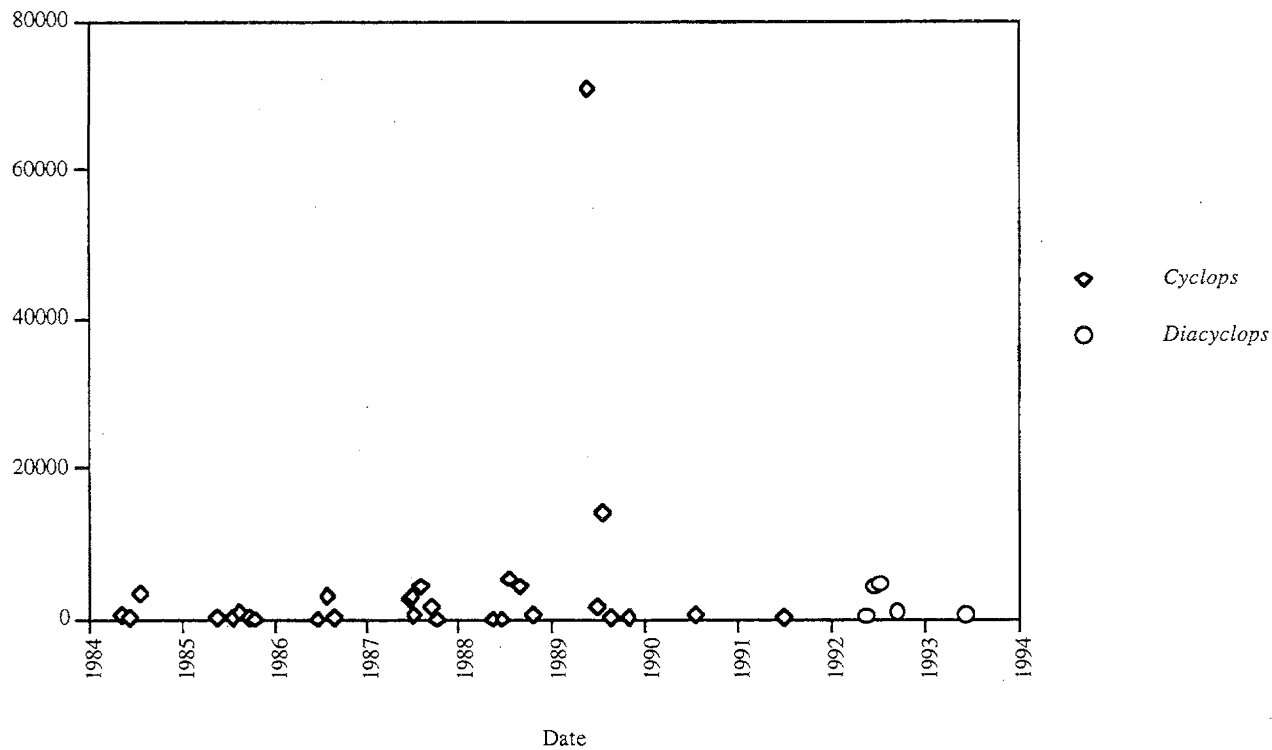


Figure 8.5.2.3. Marion Lake Zooplankton: Copepodites/Nauplii.

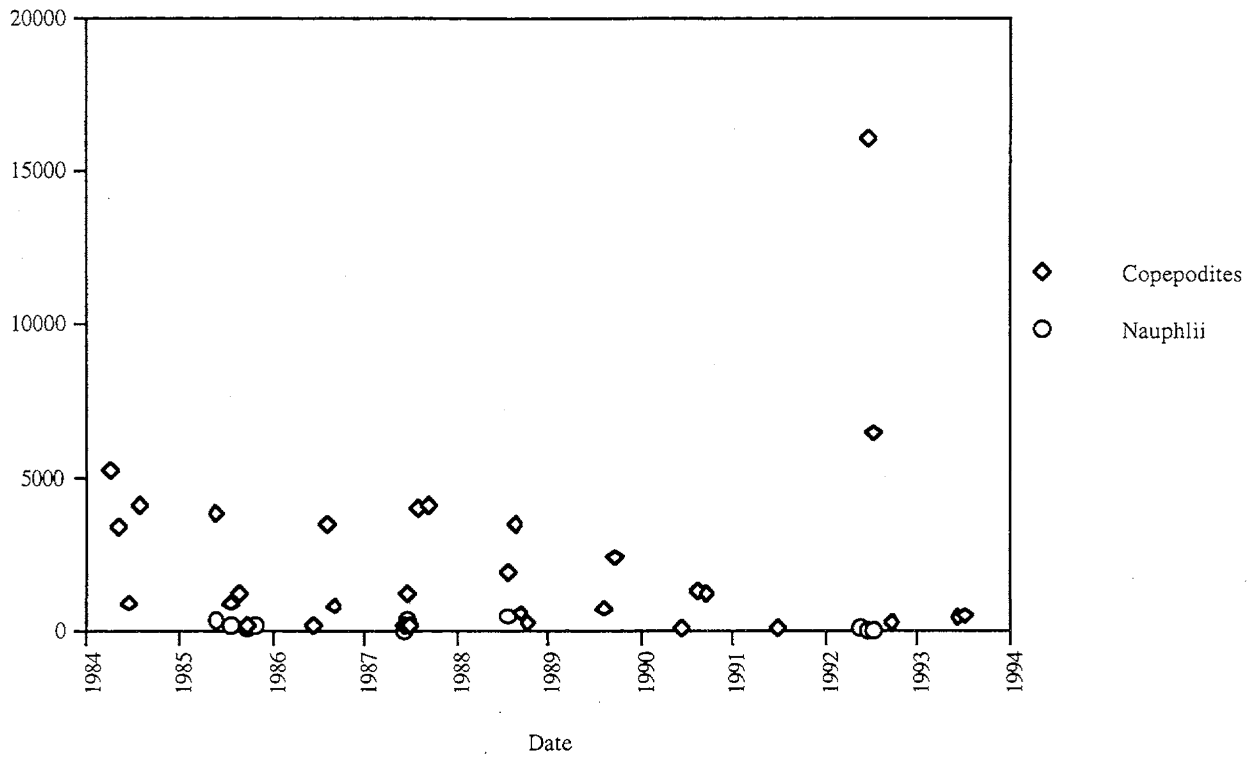


Figure 8.5.2.4. Marion Lake Zooplankton: *Bosmina.*

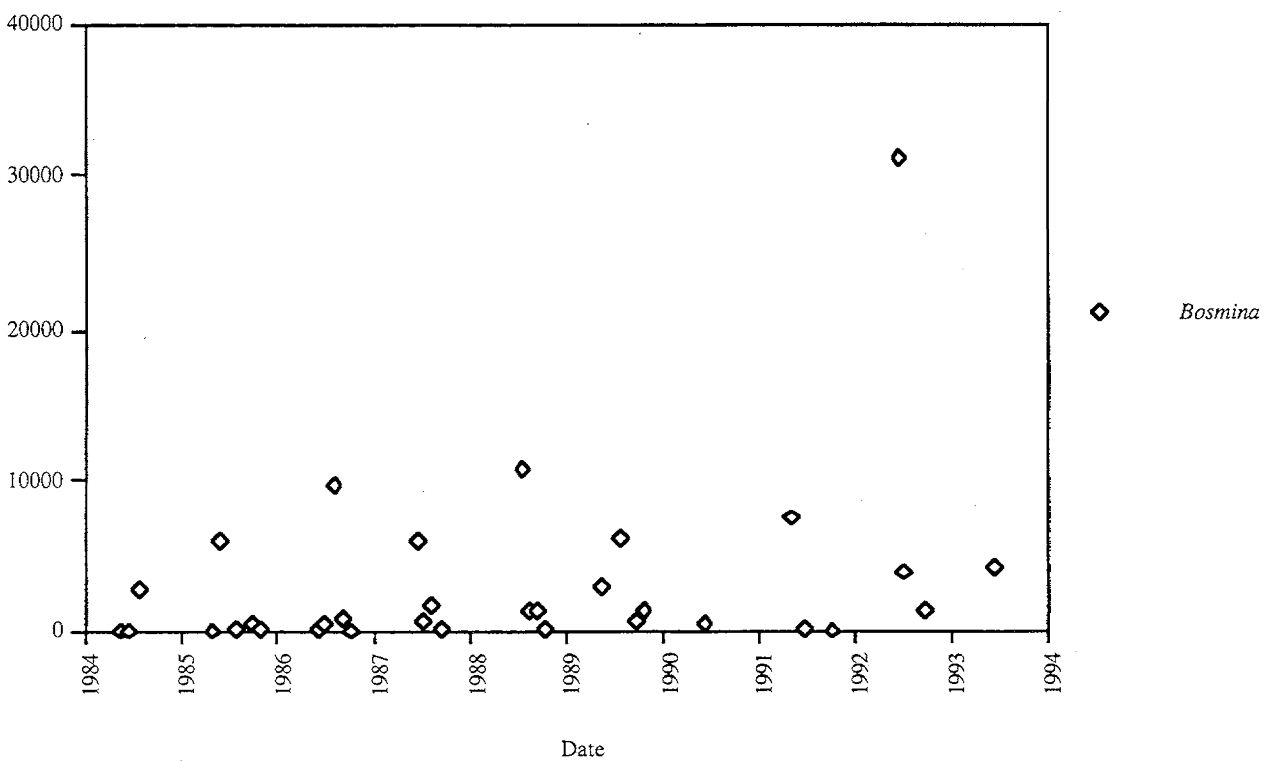


Figure 8.5.2.5. Marion Lake Zooplankton: *Diphanosoma.*

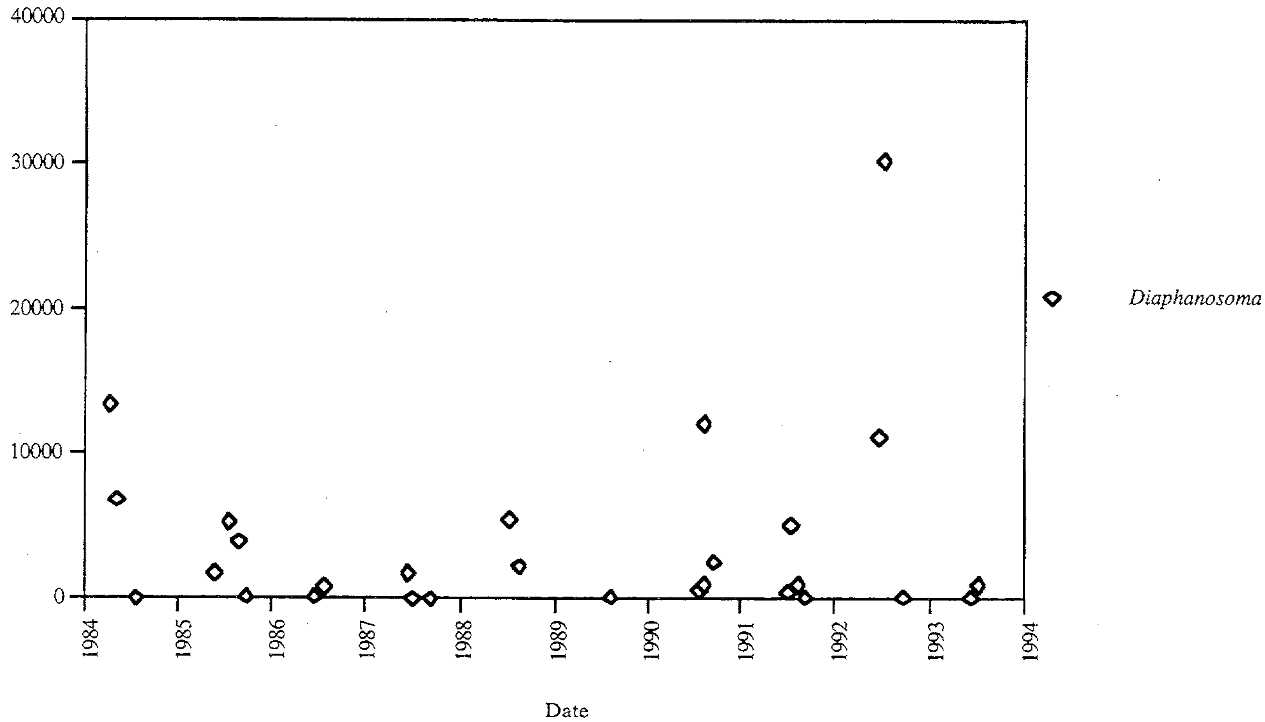


Figure 8.5.2.6. Marion Lake Zooplankton: *Holopedium/Eubosmina.*

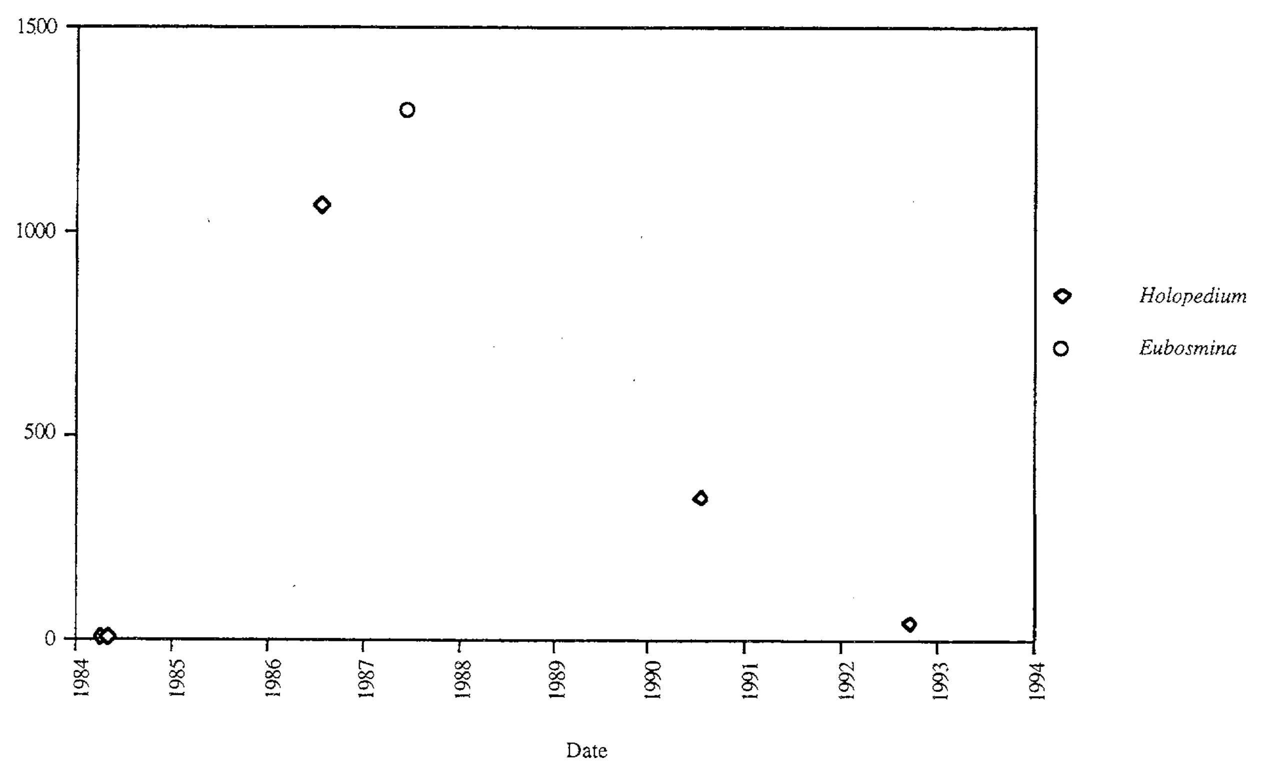


Figure 8.5.2.7. Marion Lake Zooplankton: *Ceriodaphnia/Daphnia.*

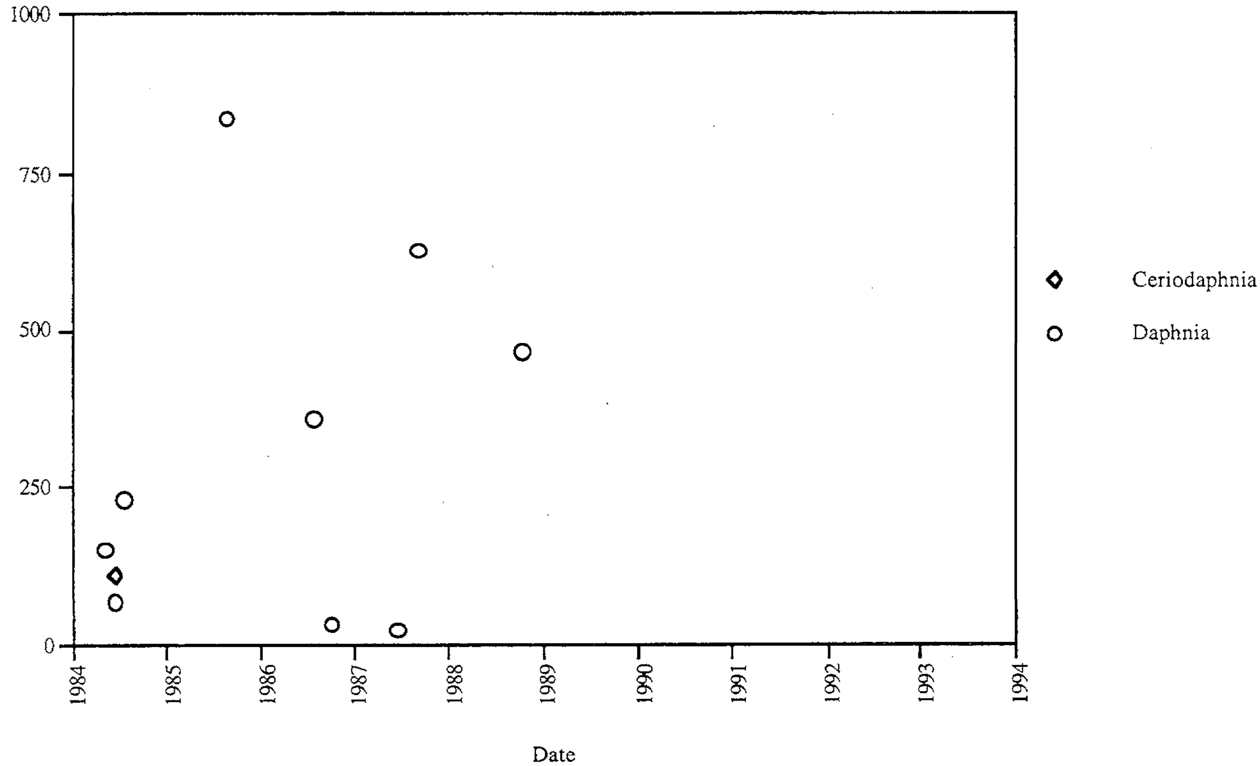


Figure 8.5.2.8. Marion Lake Zooplankton: *Leptodera/Graptolebris/Sida.*

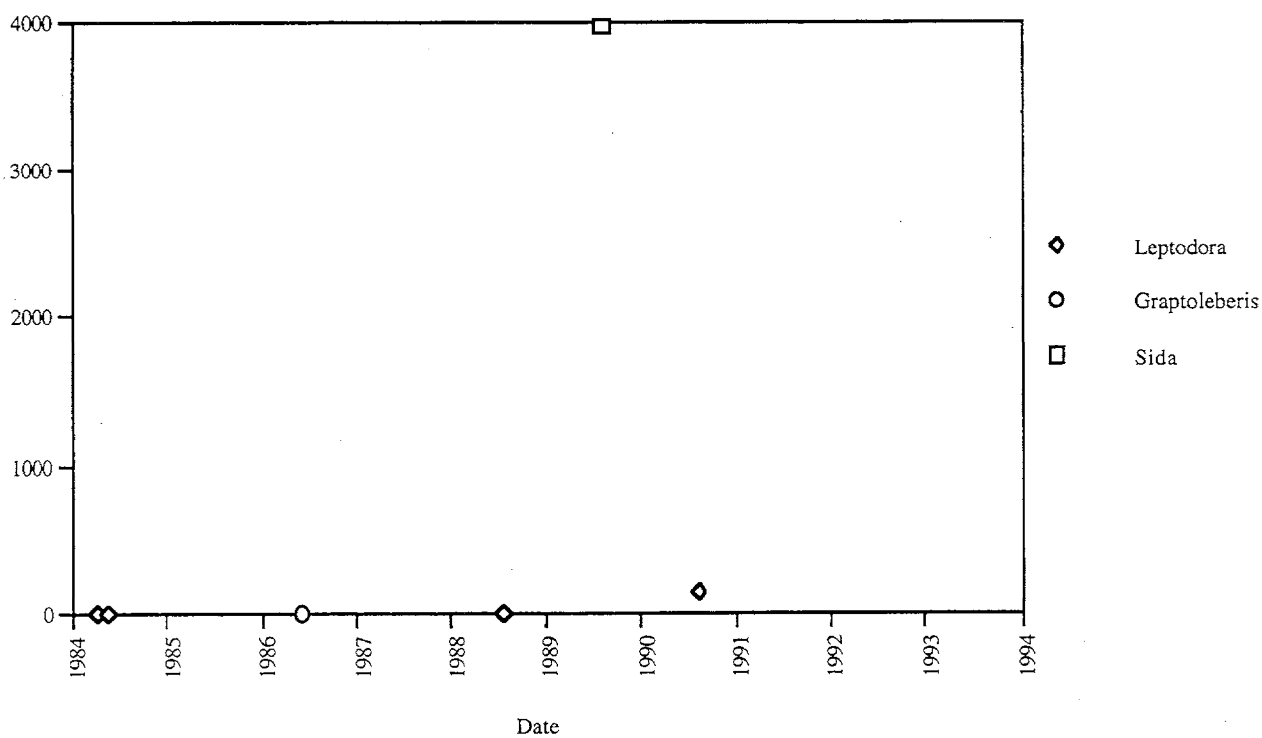


Figure 8.5.2.9. Marion Lake Zooplankton: *Keratella/Conochilus/Polyarthra.*

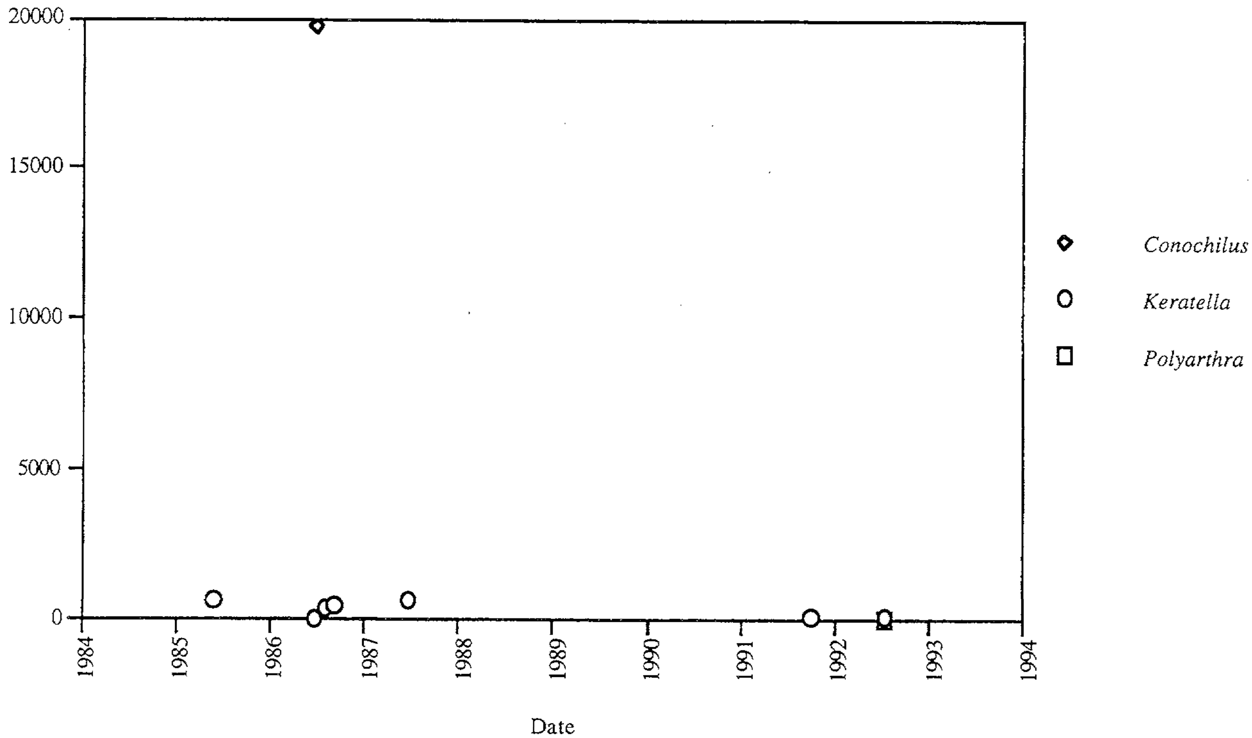


Figure 8.5.2.10. Marion Lake Zooplankton: Crustacean and Rotifer Biomass Comparison.

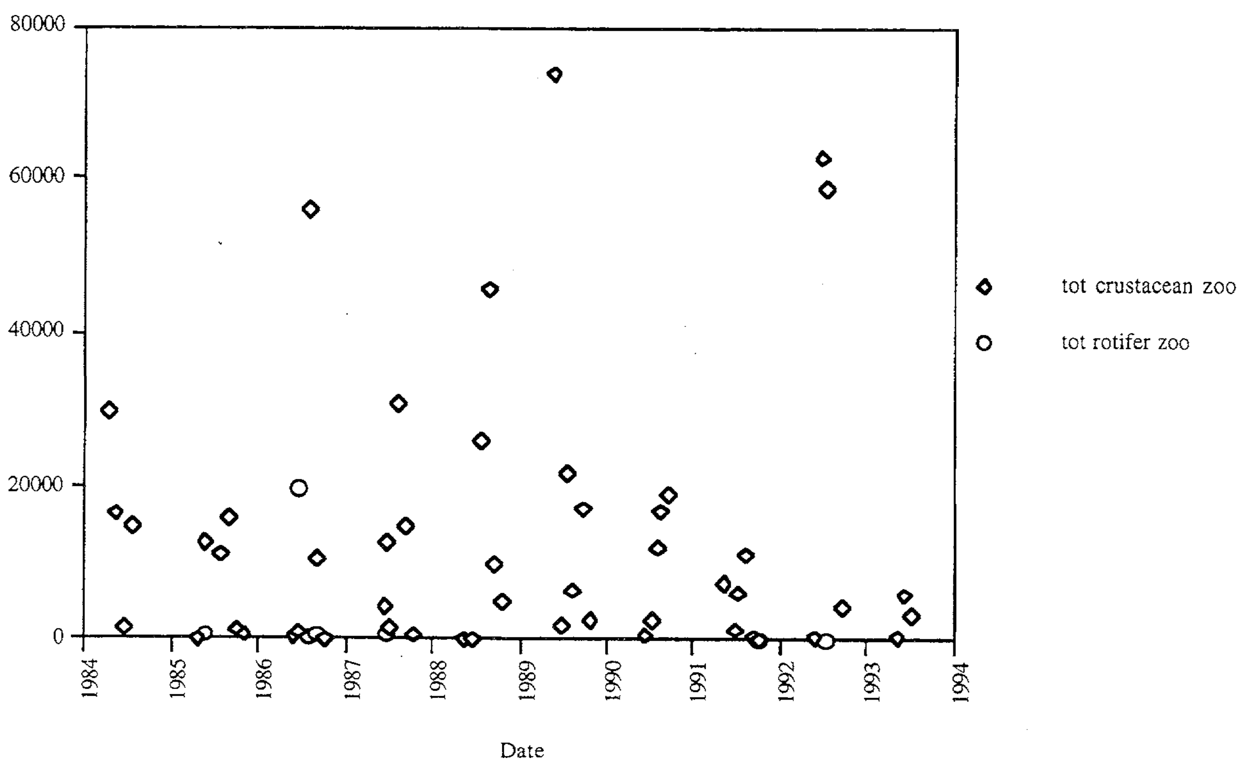


Figure 8.5.2.11. Marion Lake Zooplankton: Total biomass μg/m2

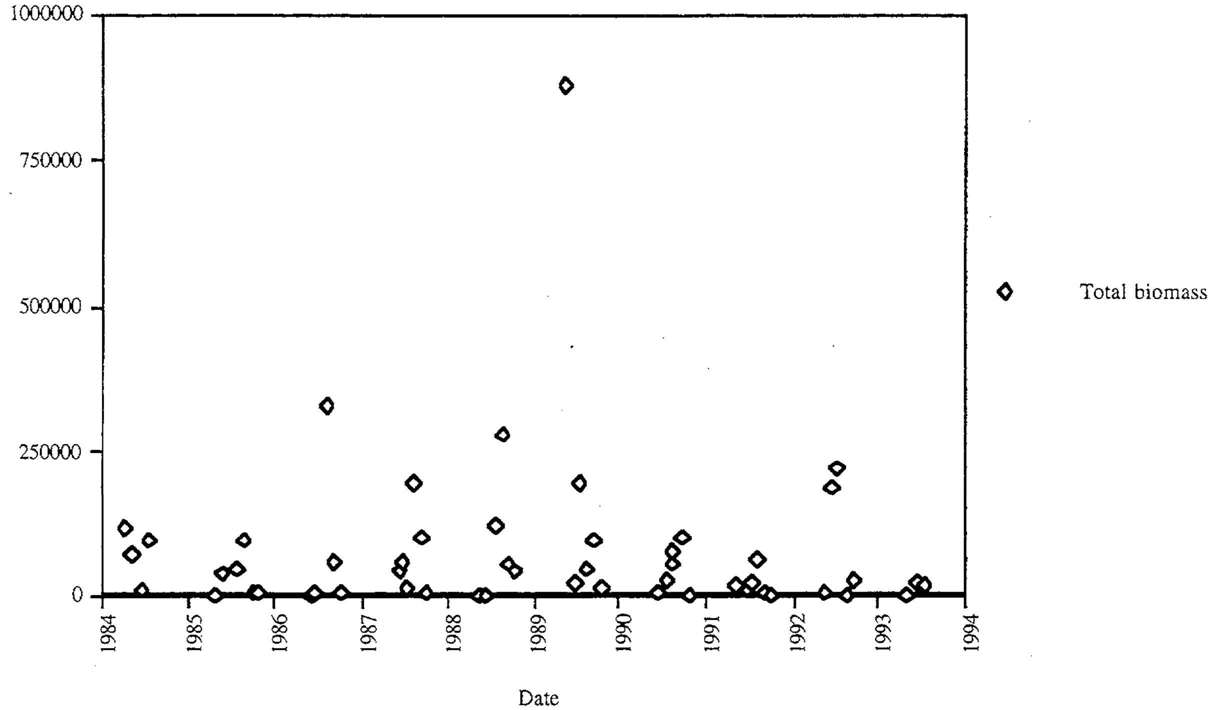


Figure 8.5.2.12. Marion Lake Zooplankton: Total Zooplankton/m2.

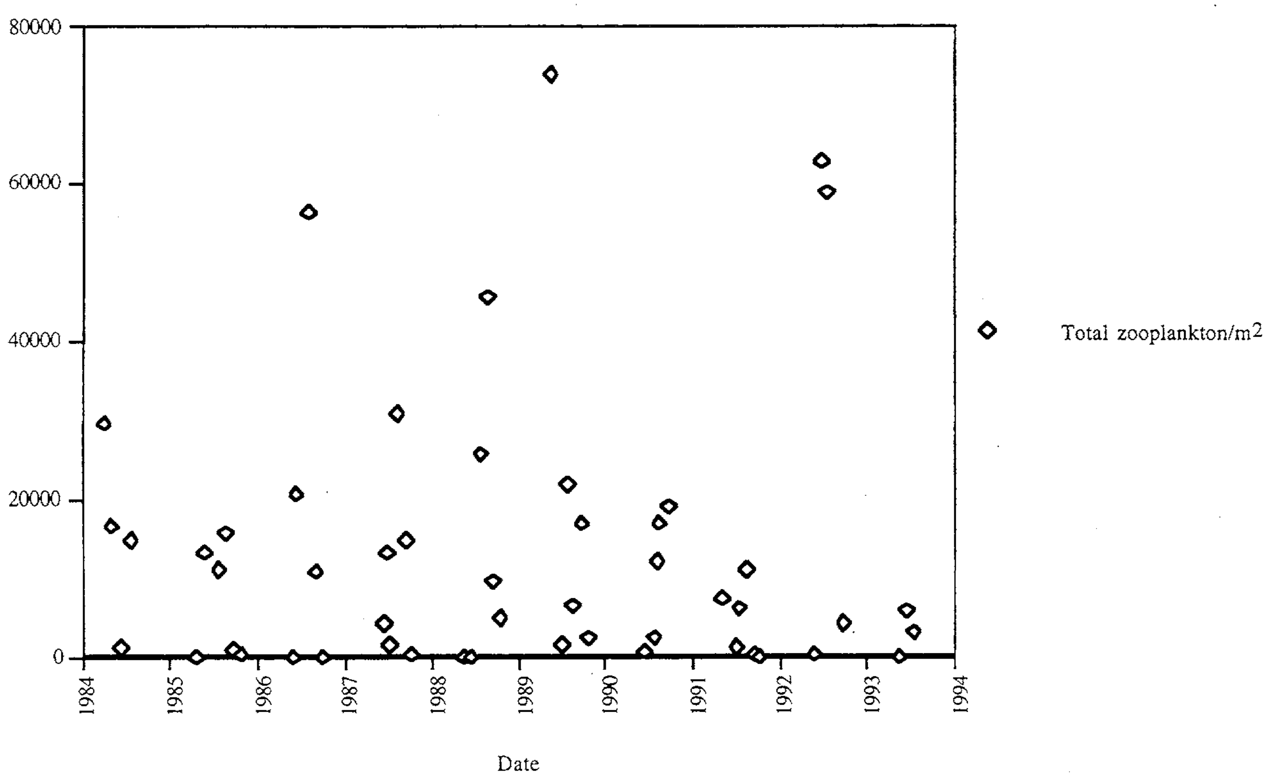


Figure 8.6.1.1. Maxwell Lake Phytoplankton: *Dinobryon*

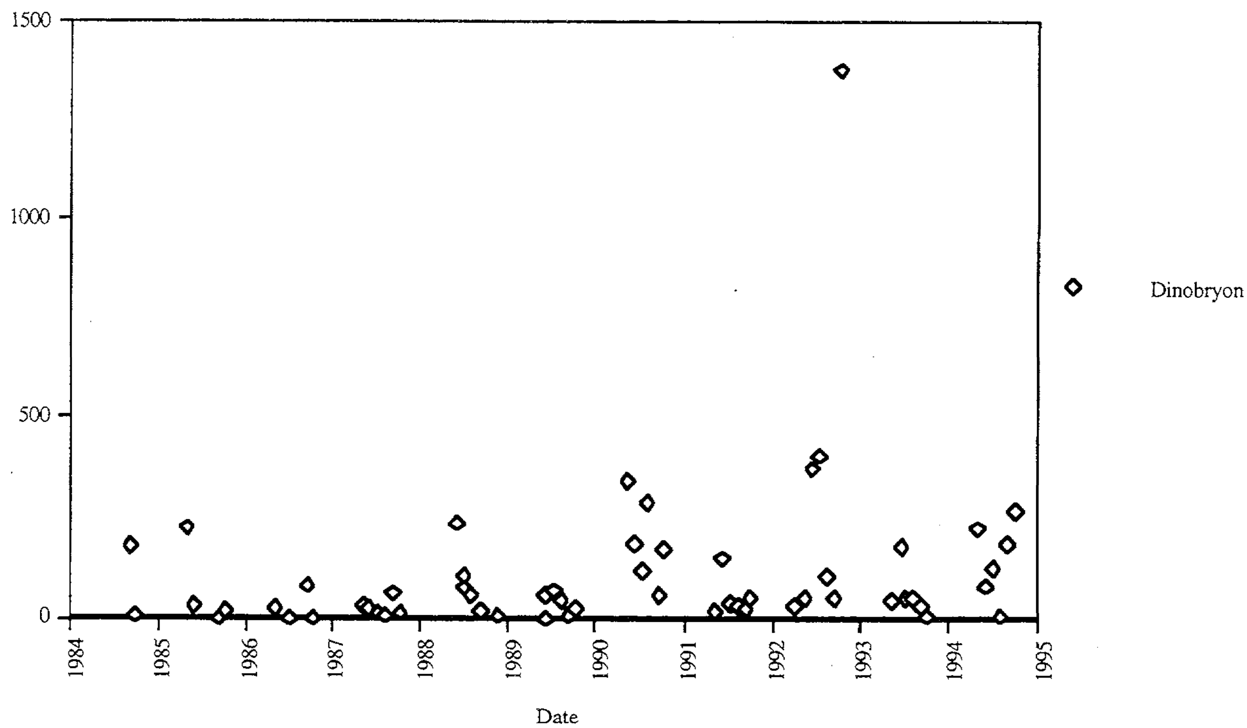


Figure 8.6.1.2. Maxwell Lake Phytoplankton: *Arthrodesmus/Crucigenia.*

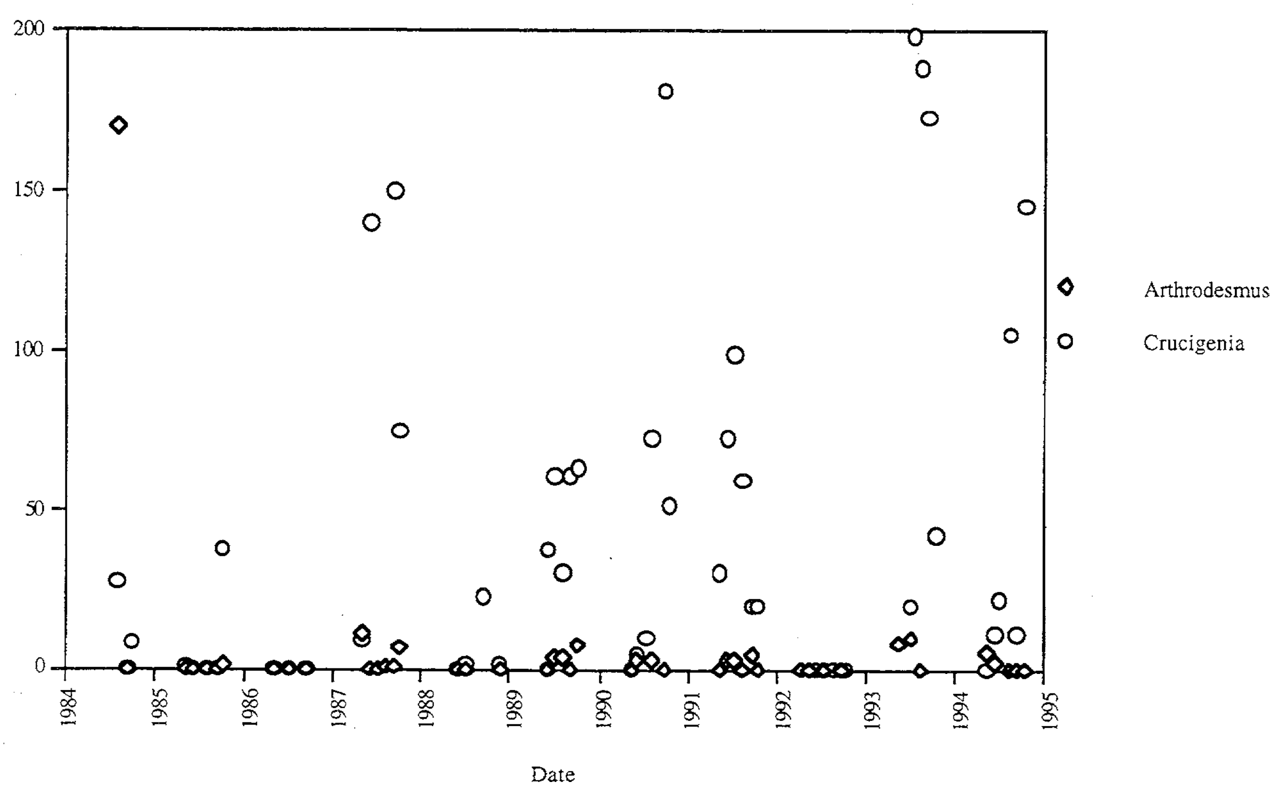


Figure 8.6.1.3. Maxwell Lake Phytoplankton: *Anabaena/Peredinium.*

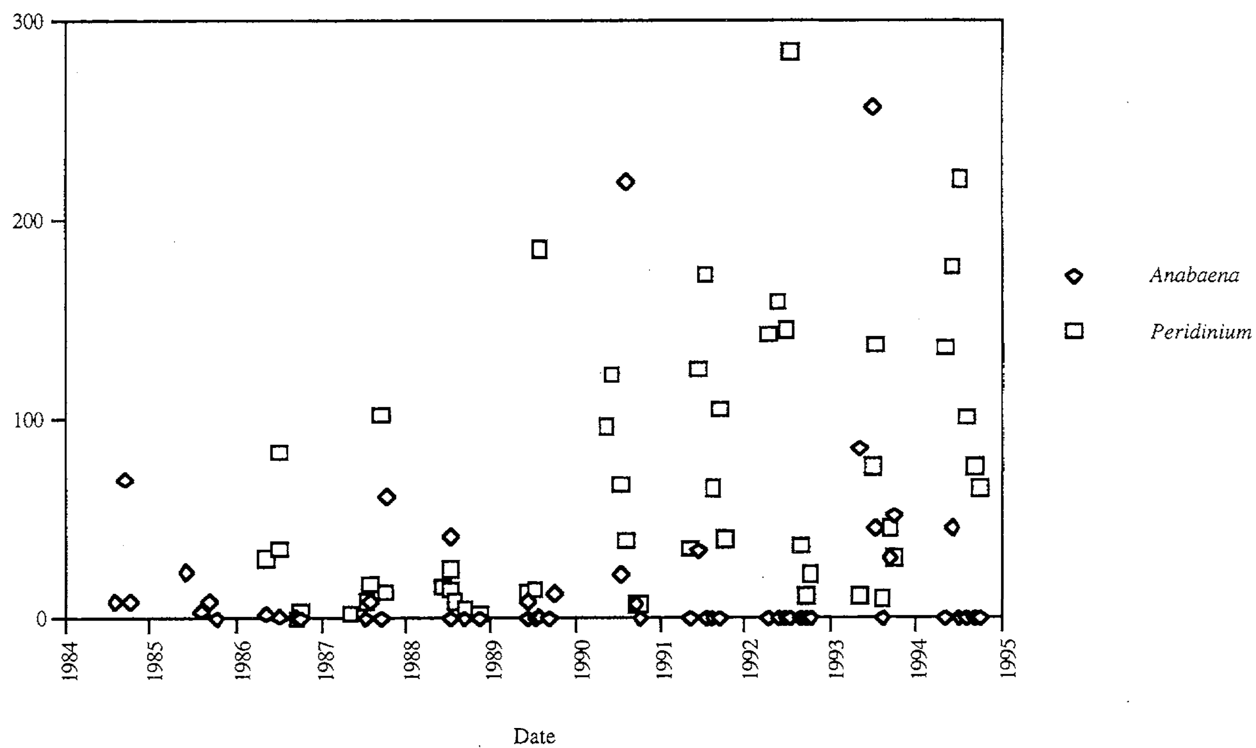


Figure 8.6.1.4. Maxwell Lake Phytoplankton: *Cryptomonas*

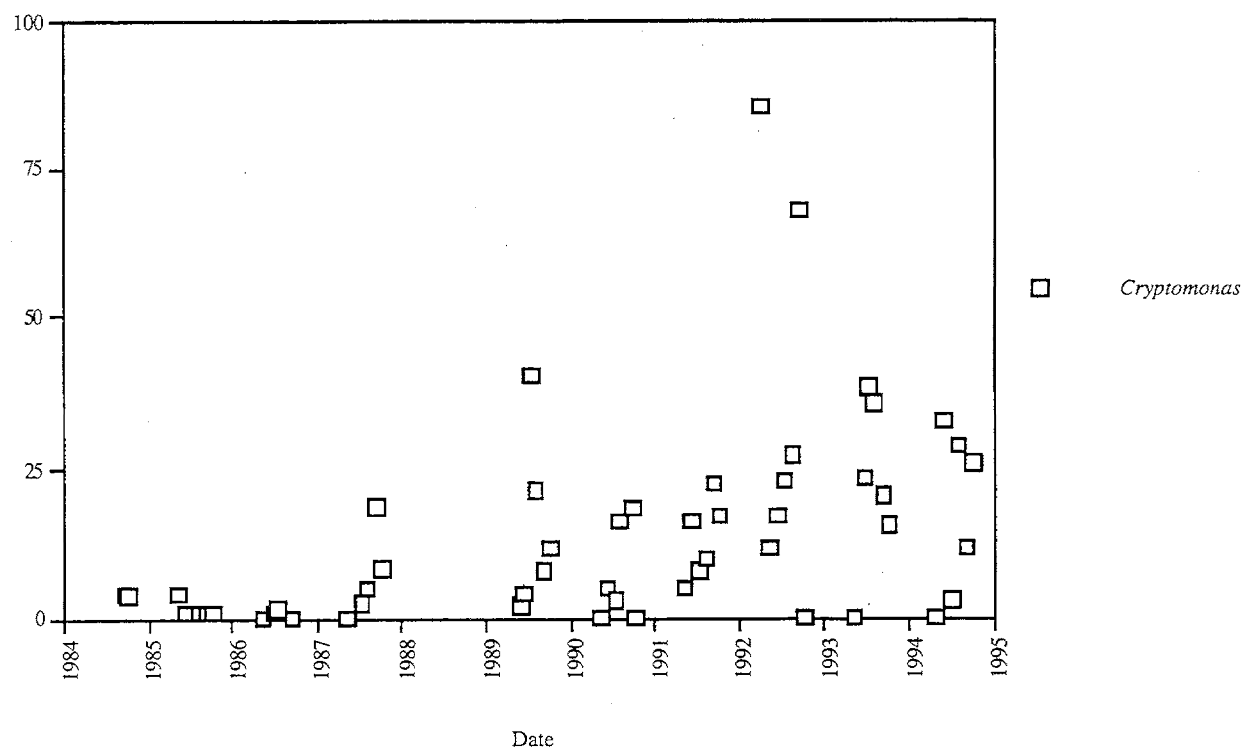


Figure 8.6.1.5. Maxwell Lake Phytoplankton: *Asterionella.*

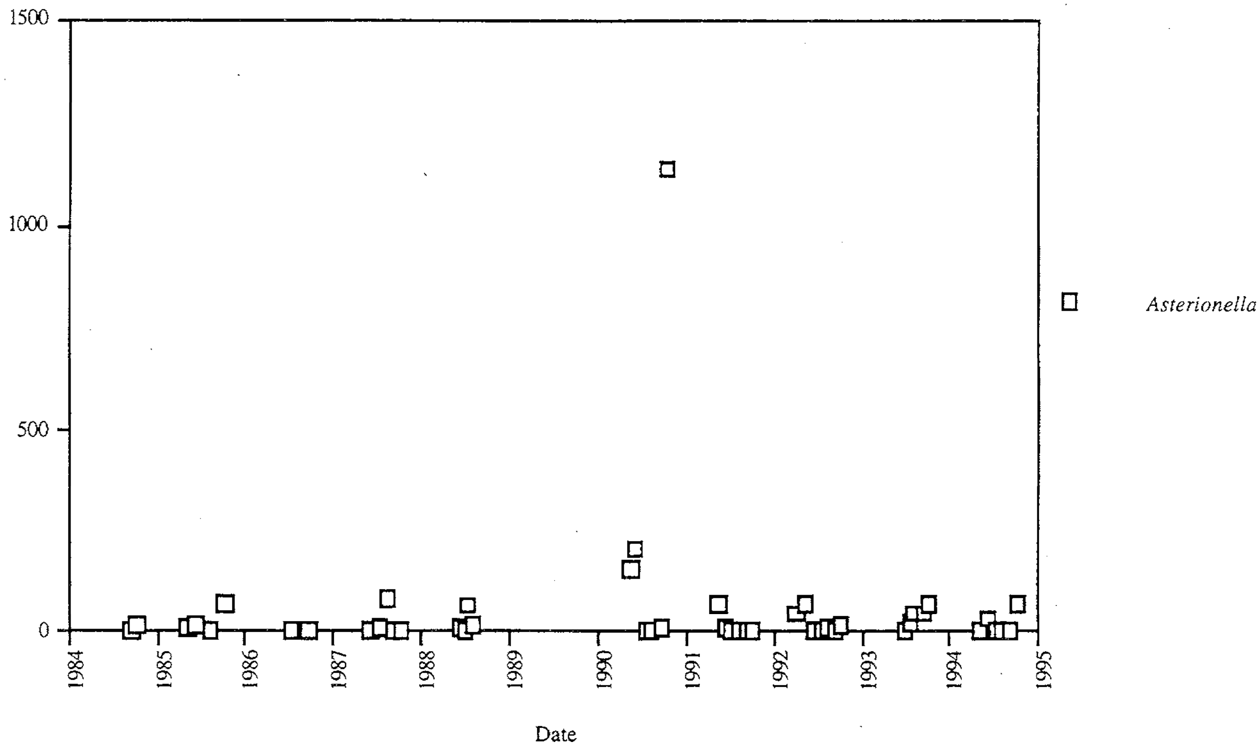


Figure 8.6.1.6. Maxwell Lake Phytoplankton: *Synedra/Tetraedron*

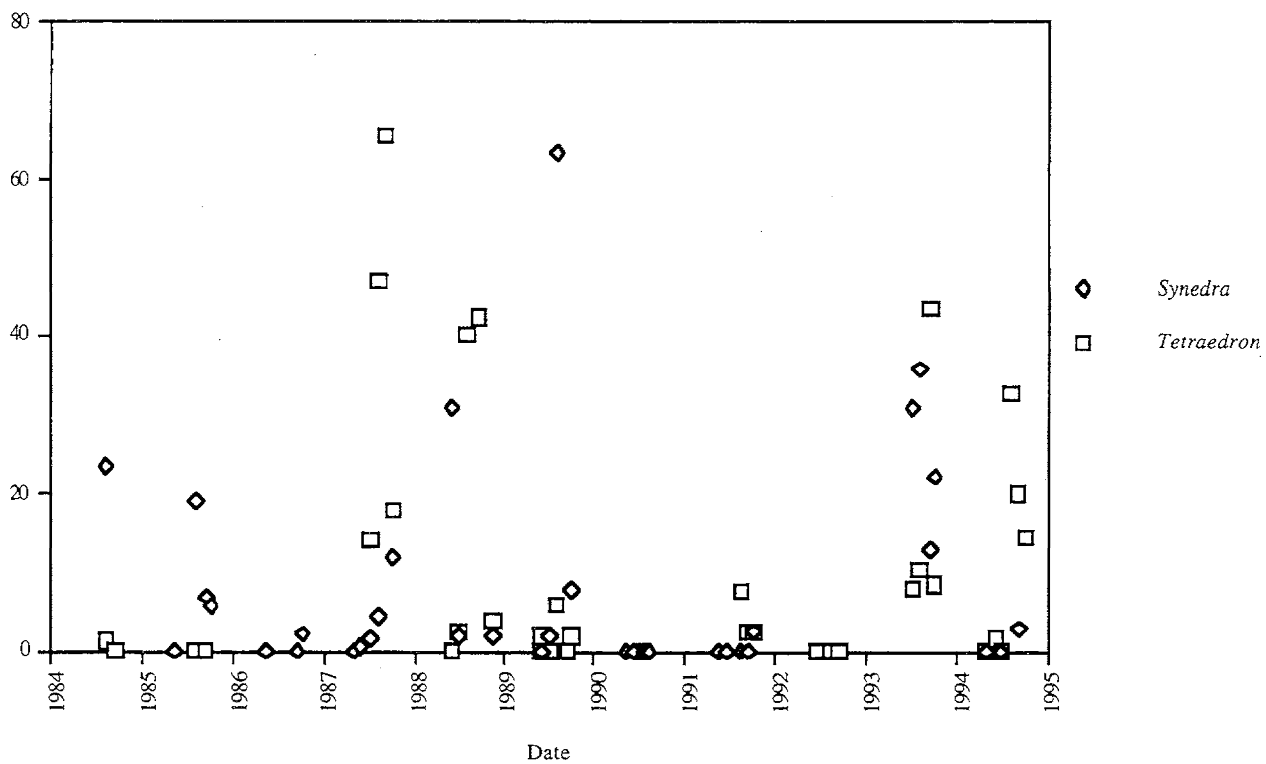


Figure 8.6.1.7. Maxwell Lake Phytoplankton: *Scendesmus/Elakothrix*

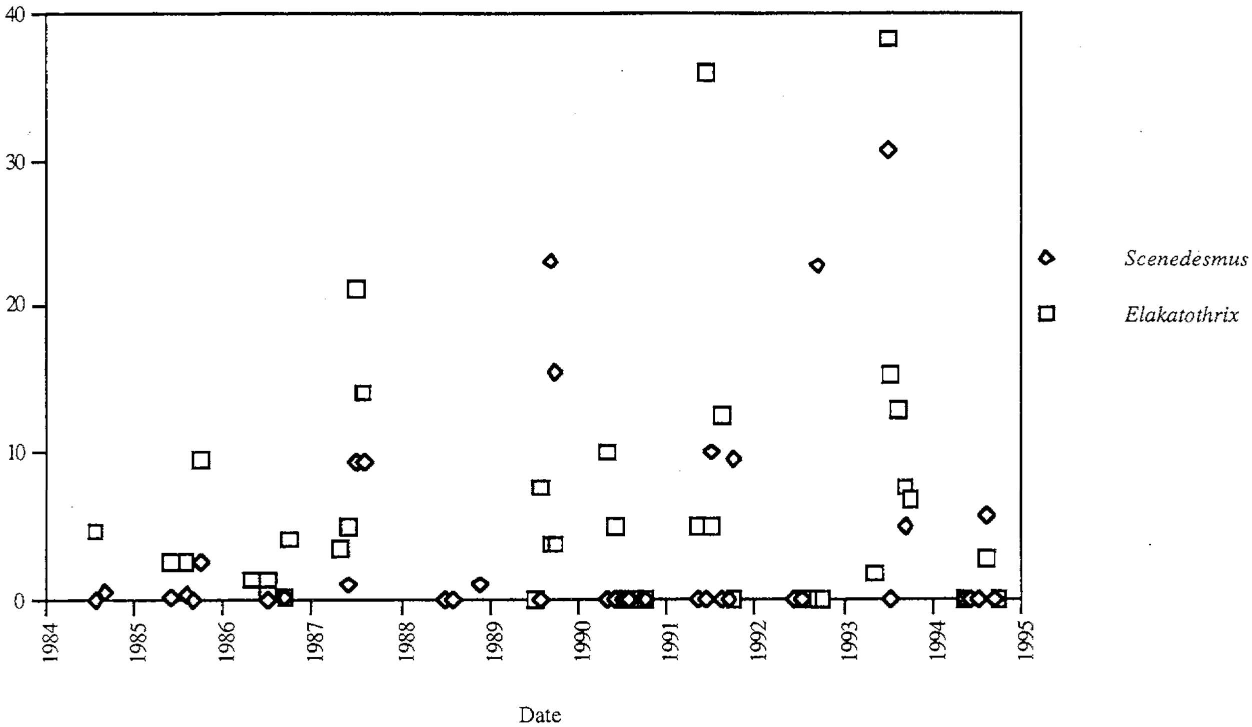


Figure 8.6.1.8. Maxwell Lake Phytoplankton: *Navicula*

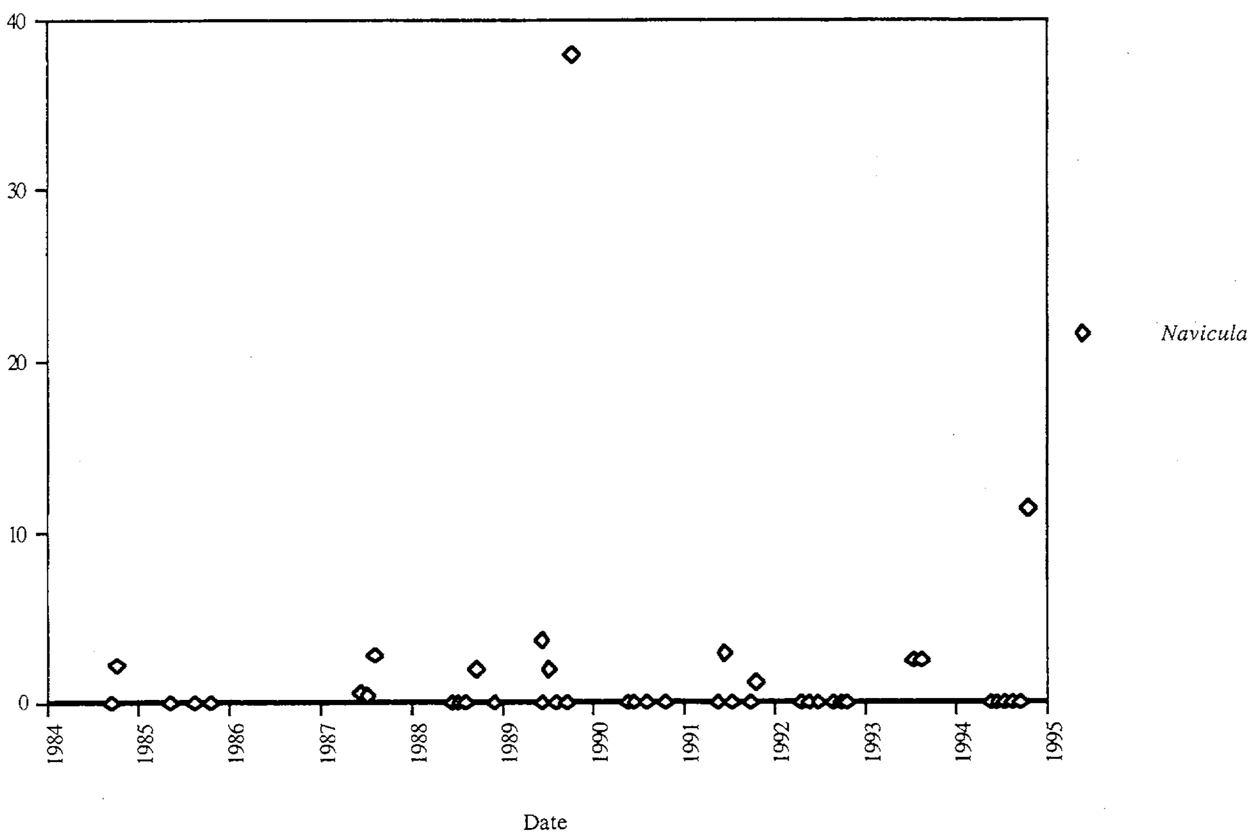


Figure 8.6.1.9. Maxwell Lake Phytoplankton: *Tabellaria*

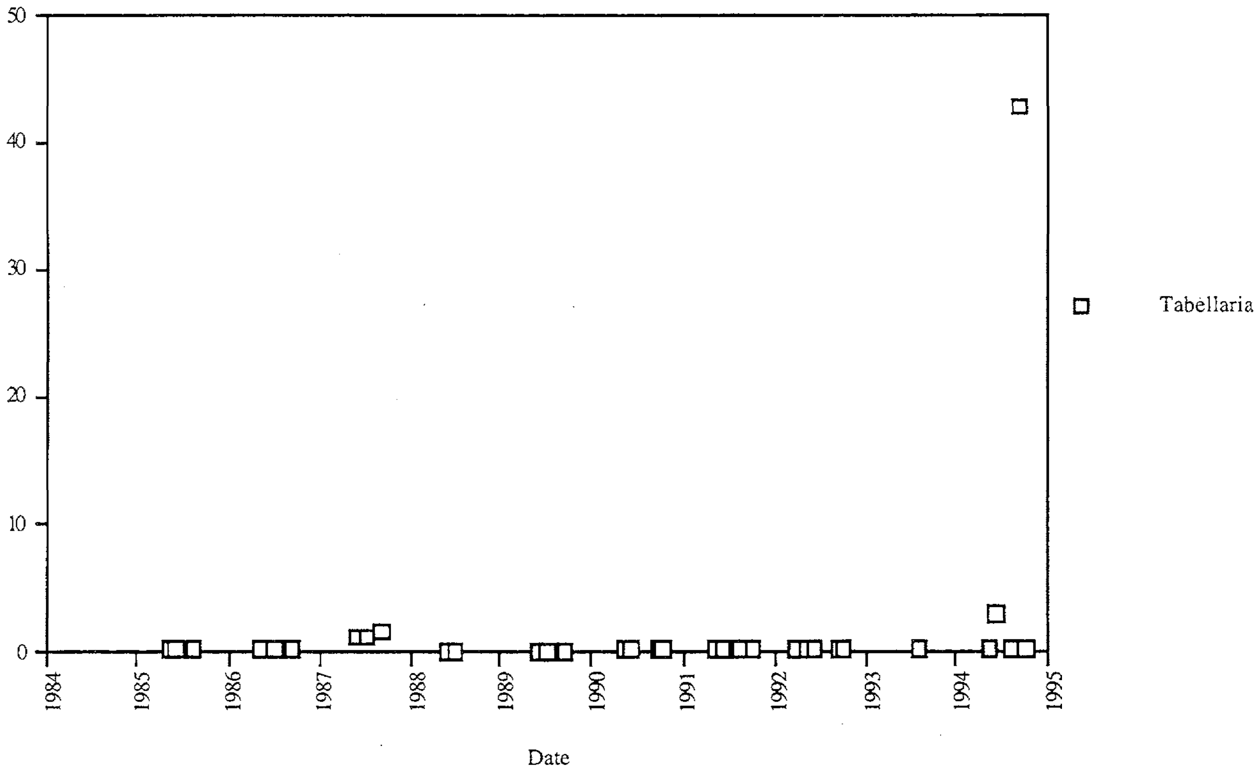


Figure 8.6.1.10. Maxwell Lake Phytoplankton: *Chroomonas/Rhisosolenia*

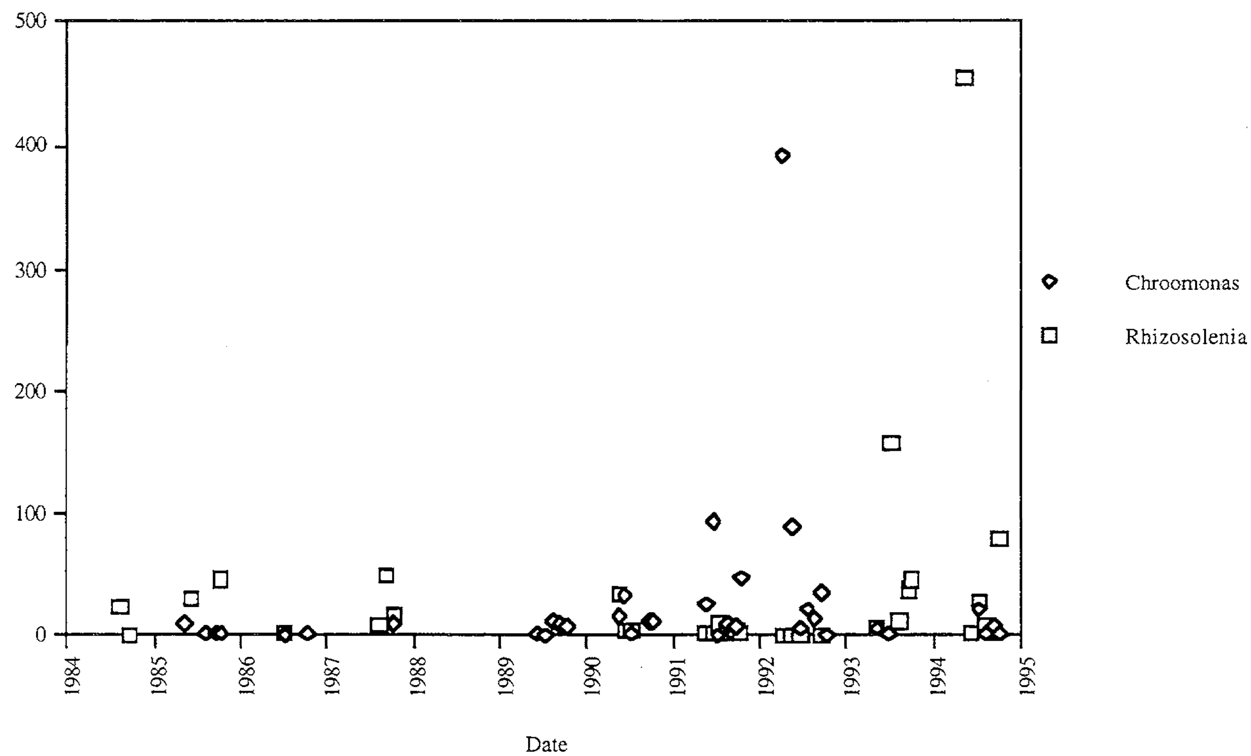


Figure 8.6.1.11. Maxwell Lake Phytoplankton: *Aphanothece*

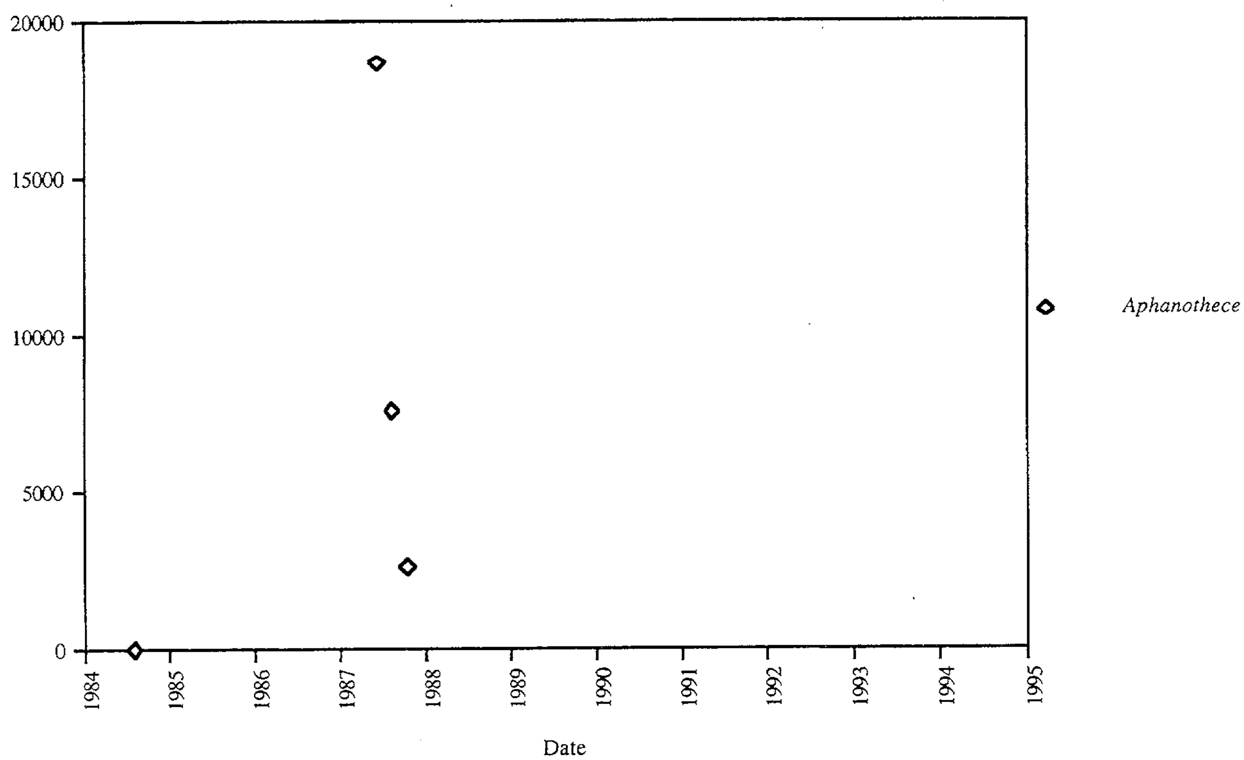


Figure 8.6.1.12. Maxwell Lake Phytoplankton: *Selenastrum/Sphaerocystis*

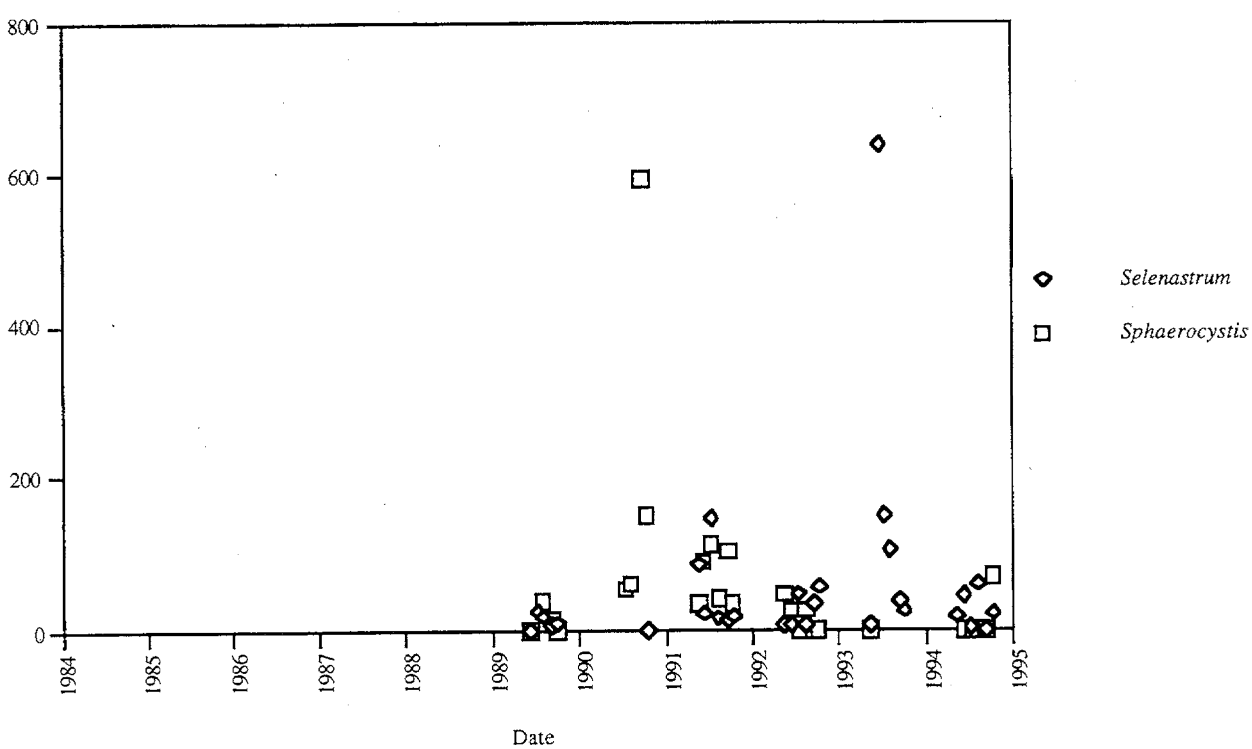


Figure 8.6.1.13. Maxwell Lake Phytoplankton: Haematococcoid Cyst-Like Cells.

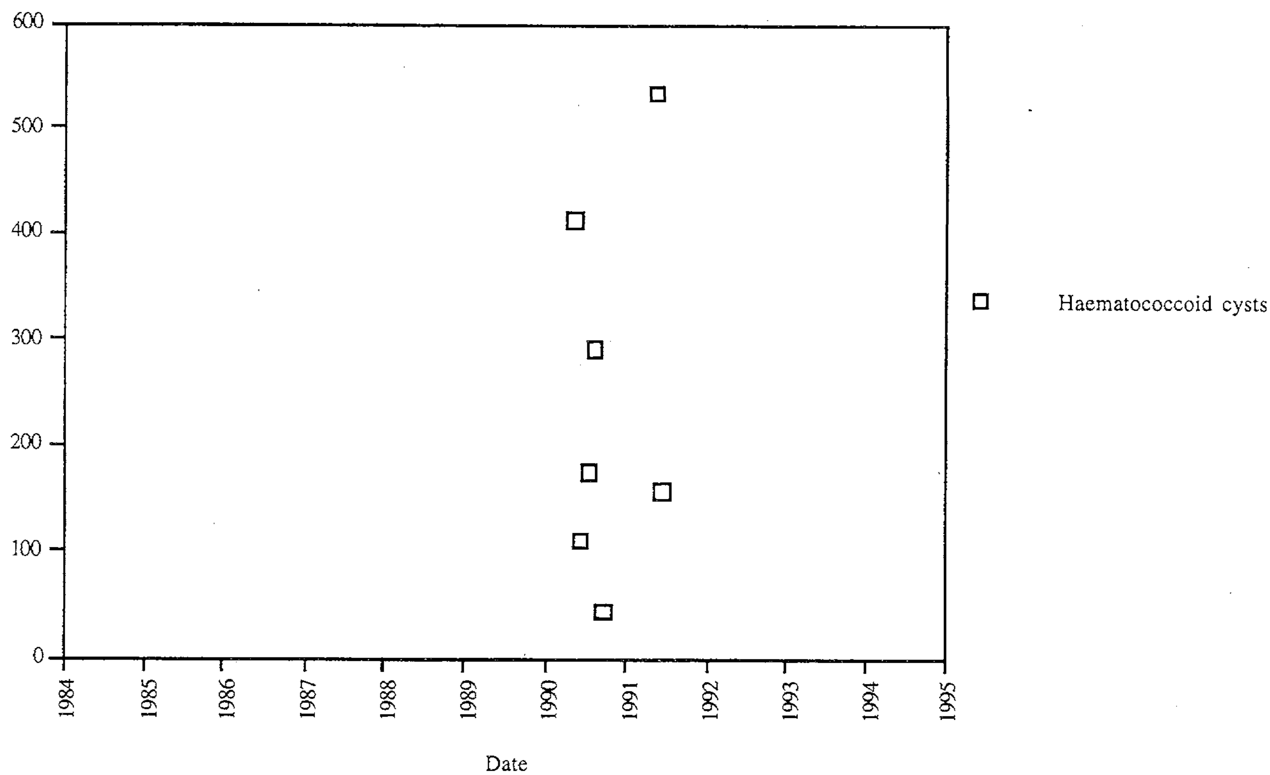


Figure 8.6.1.14. Maxwell Lake Phytoplankton: Total Cells/mL.

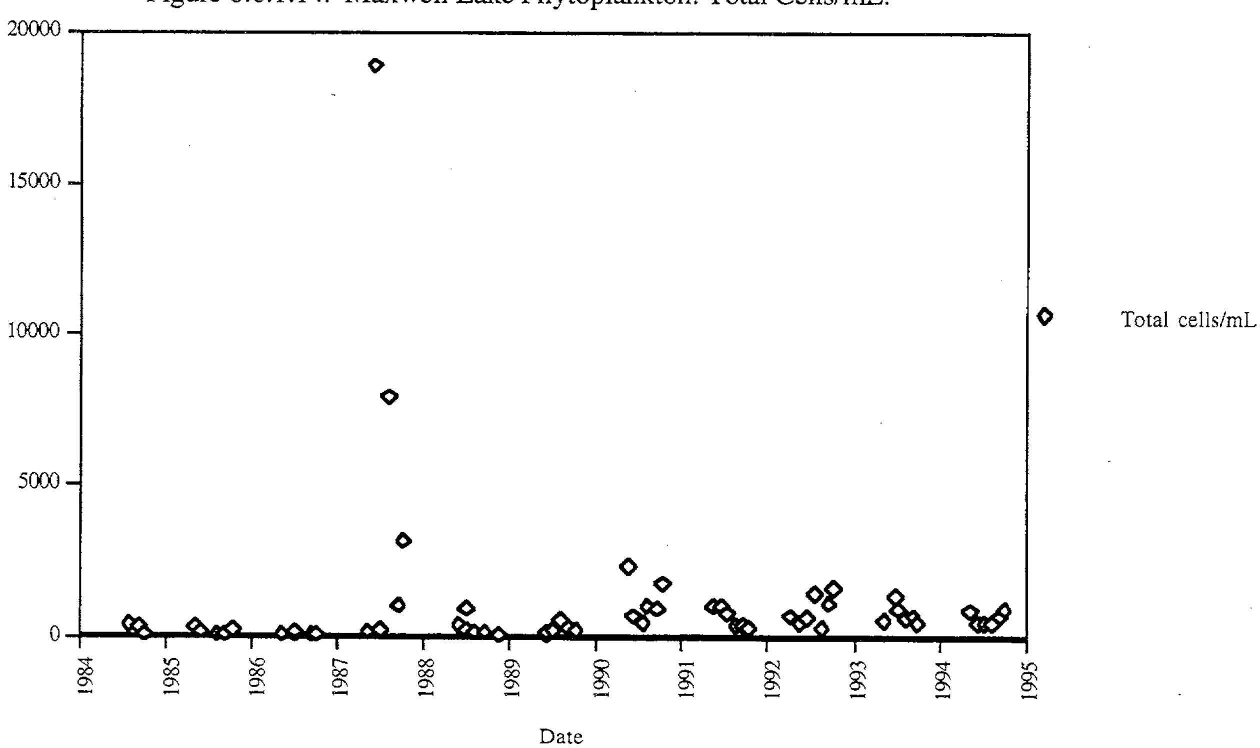


Figure 8.6.1.15. Maxwell Lake Phytoplankton: Chlorophyll a

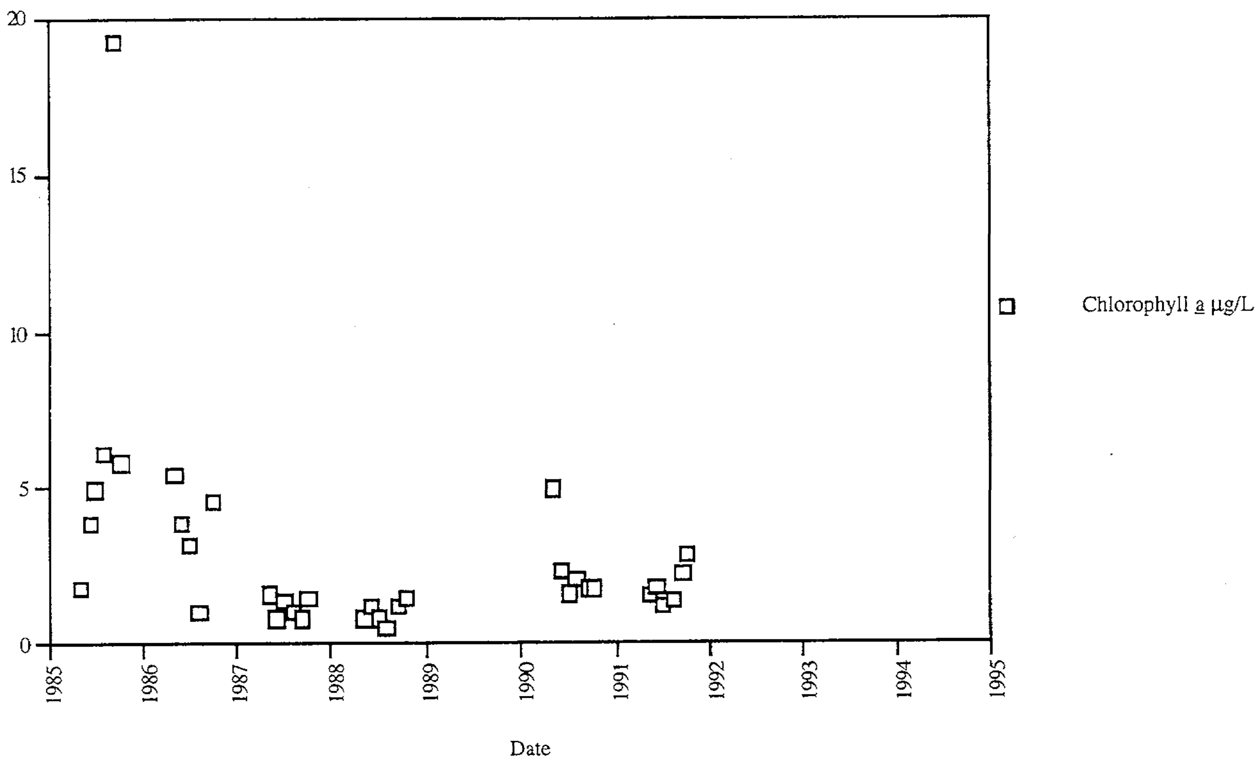


Figure 8.6.2.1. Maxwell Lake Zooplankton: *Cyclops*

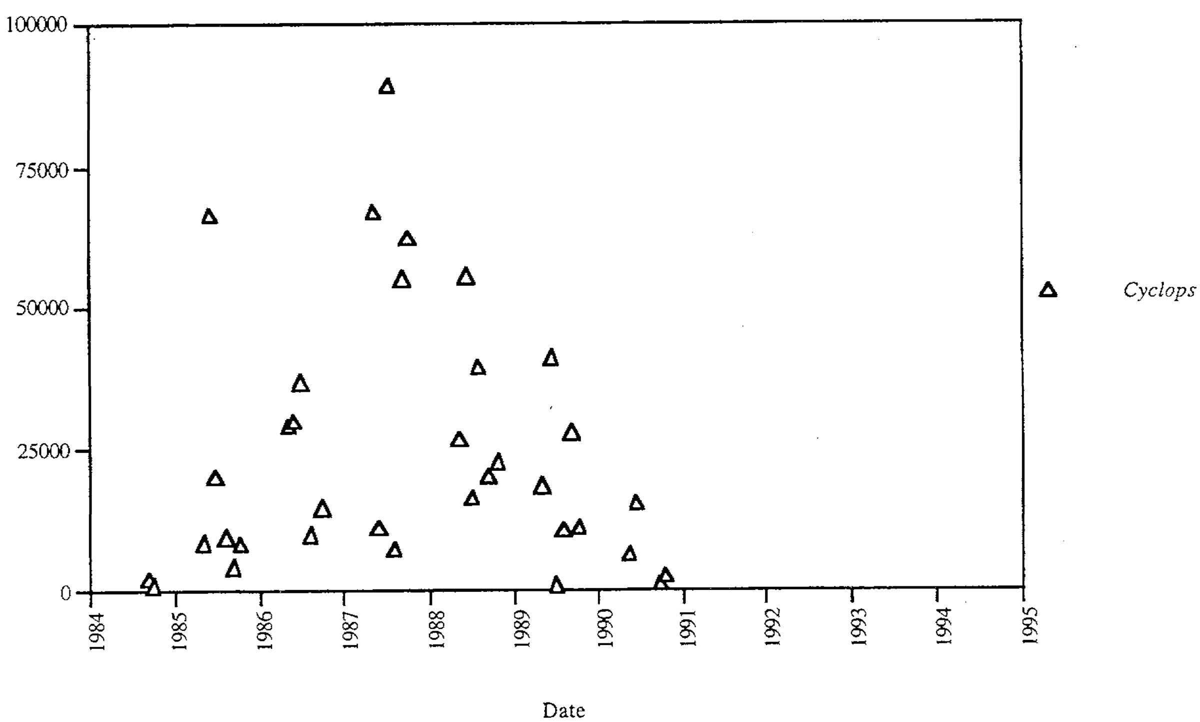


Figure 8.6.2.2. Maxwell Lake Zooplankton: Copepods.

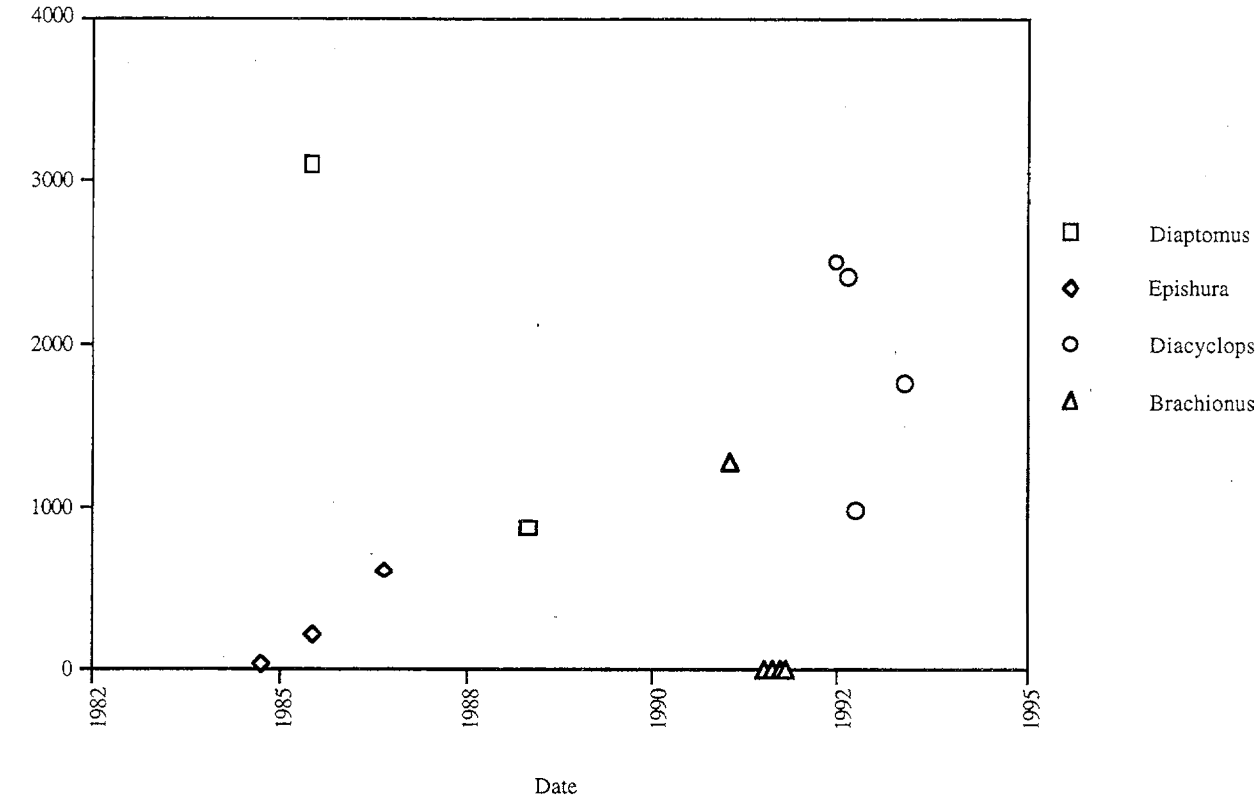


Figure 8.6.2.3. Maxwell Lake Zooplankton: Copepodites/Nauplii

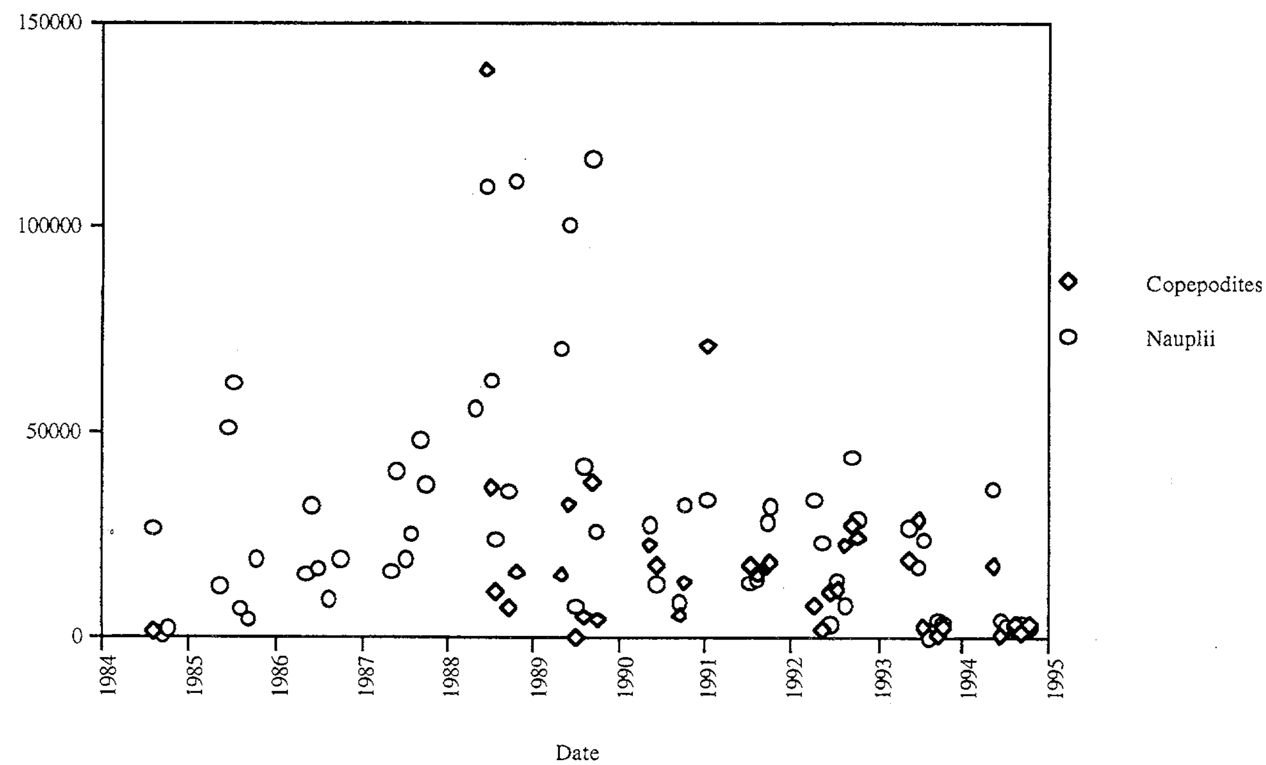


Figure 8.6.2.4. Maxwell Lake Zooplankton: Bosmina

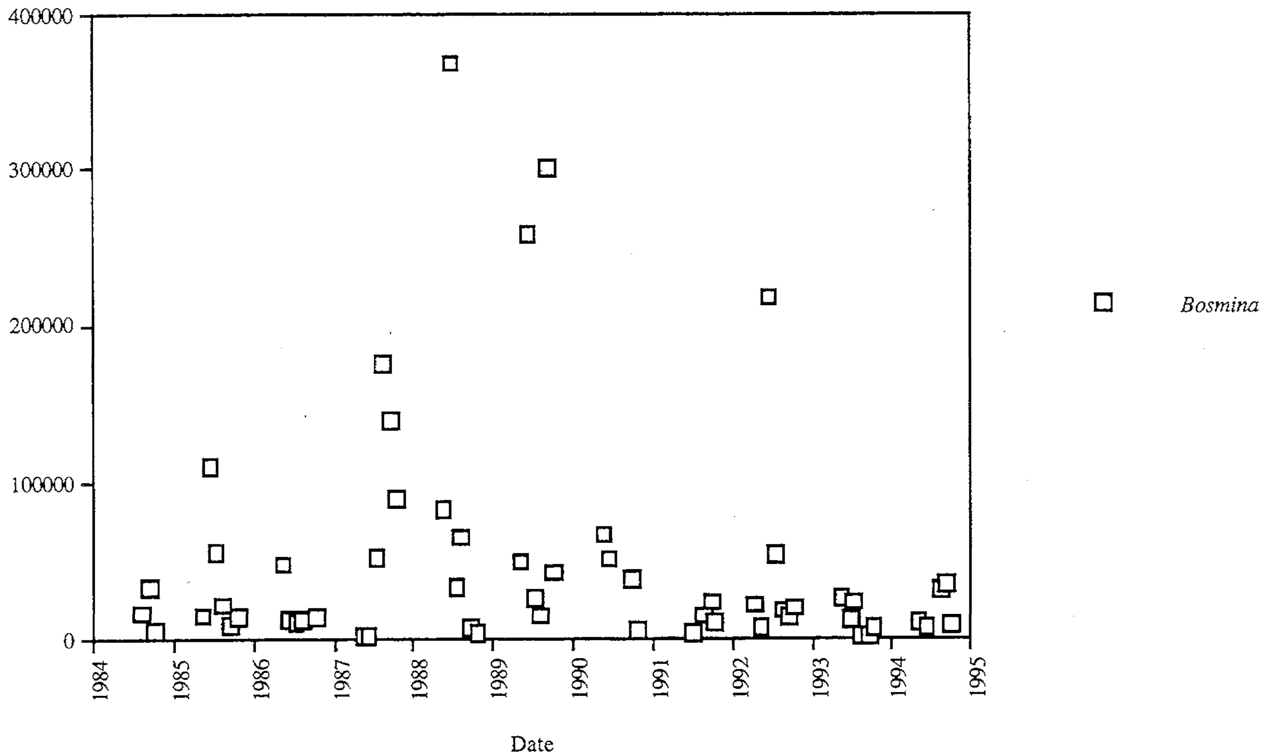


Figure 8.6.2.5. Maxwell Lake Zooplankton: *Holopedium/Eubosmina/Diaphanosoma*

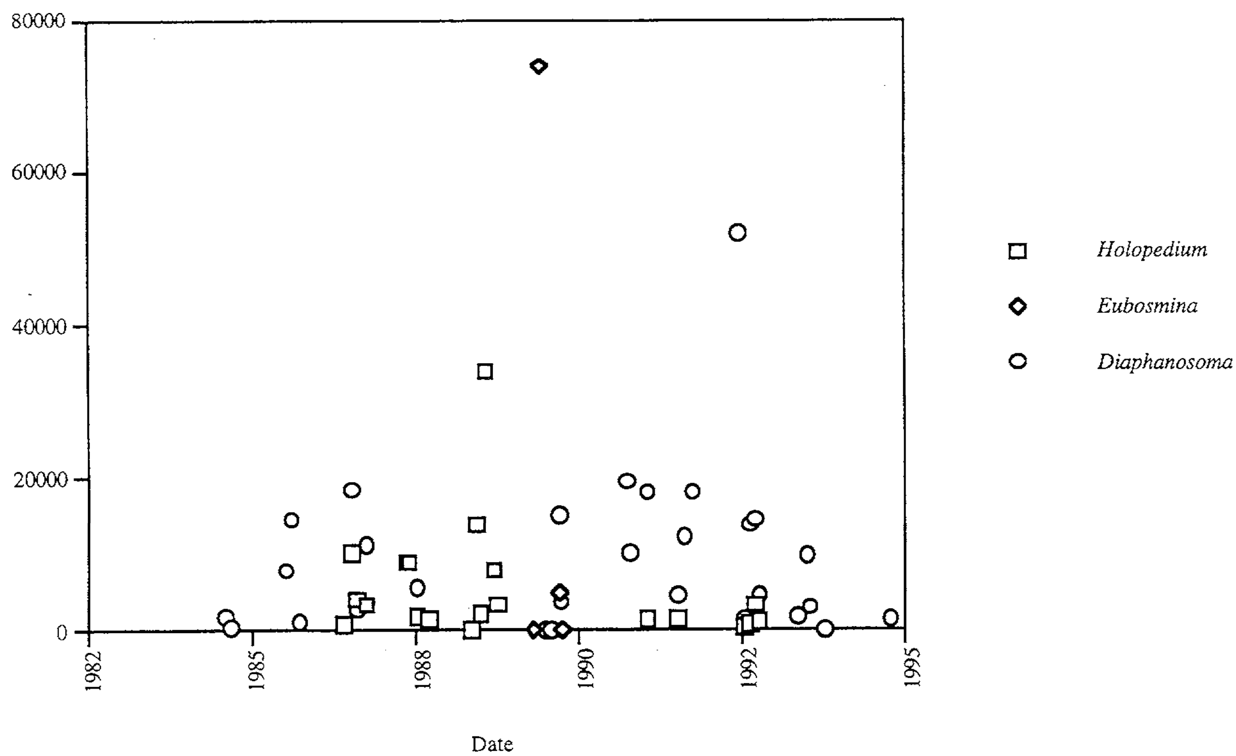


Figure 8.6.2.6. Maxwell Lake Zooplankton: *Daphnia/Ceriodaphnia.*

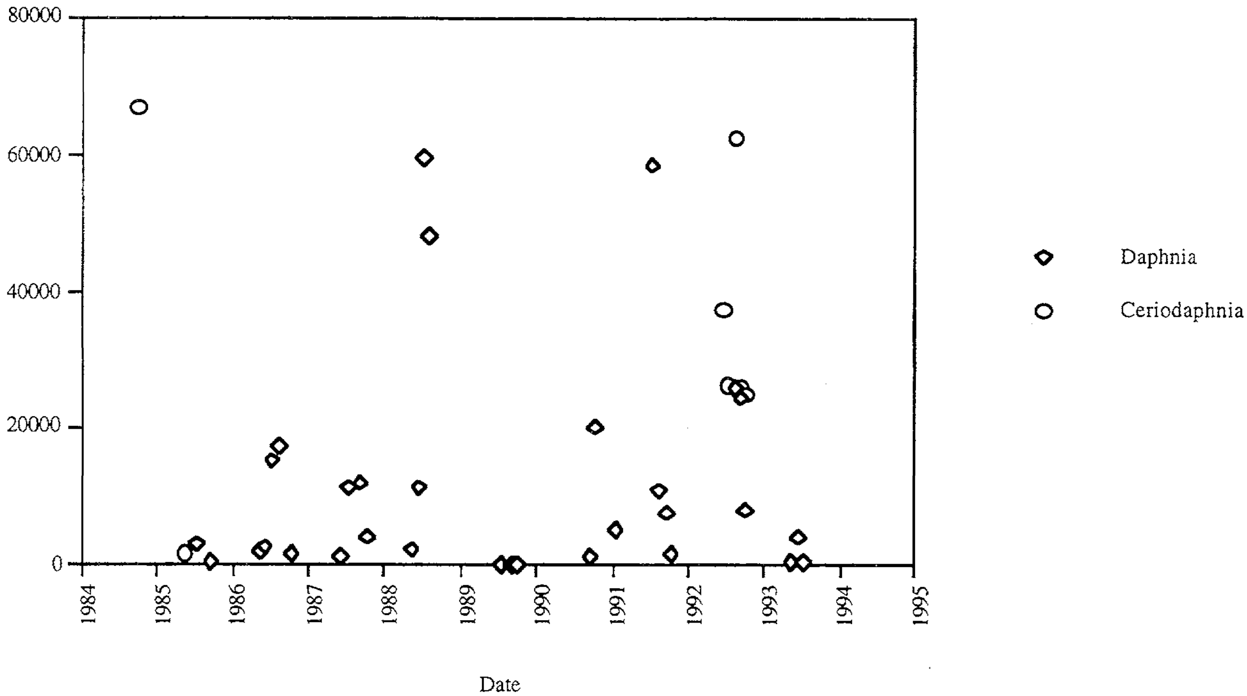


Figure 8.6.2.7. Maxwell Lake Zooplankton: *Keratella*

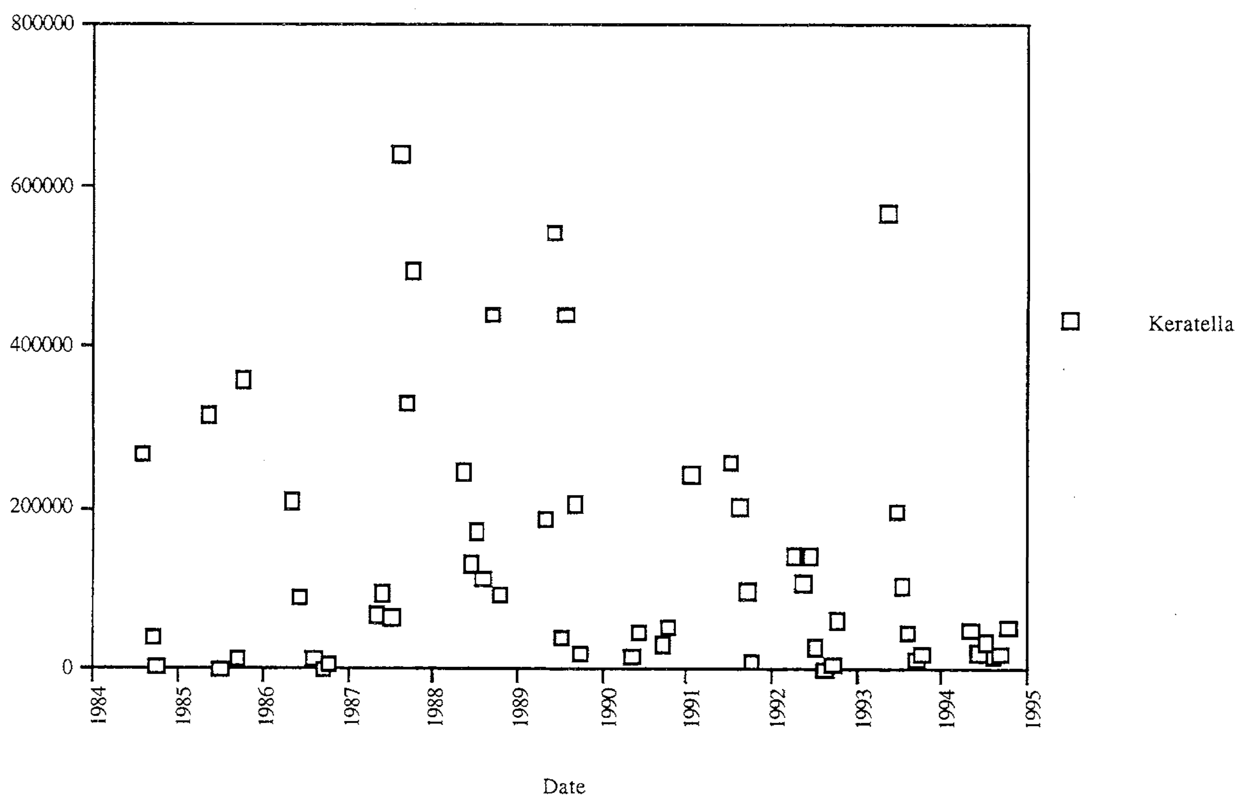


Figure 8.6.2.8. Maxwell Lake Zooplankton: *Kellicottia.*

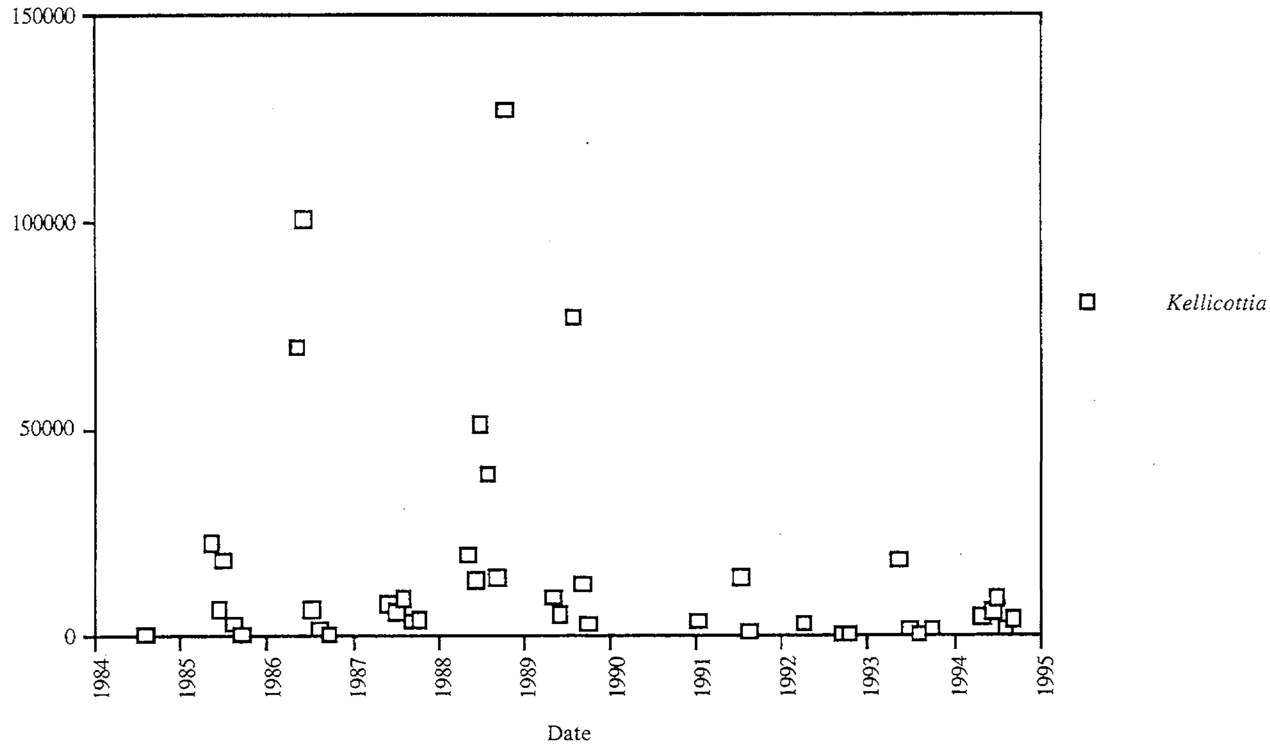


Figure 8.6.2.9. Maxwell Lake Zooplankton: *Polyarthra/Asplancha*

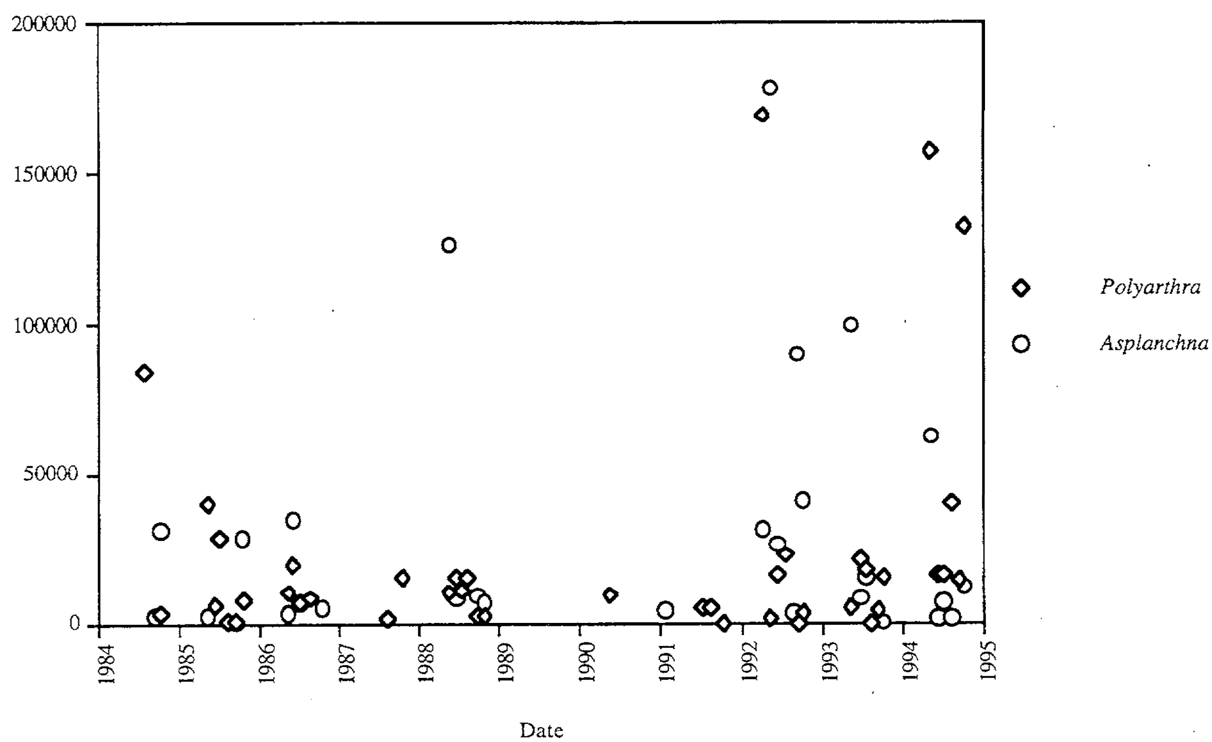


Figure 8.6.2.10. Maxwell Lake Zooplankton: Rotifers #1

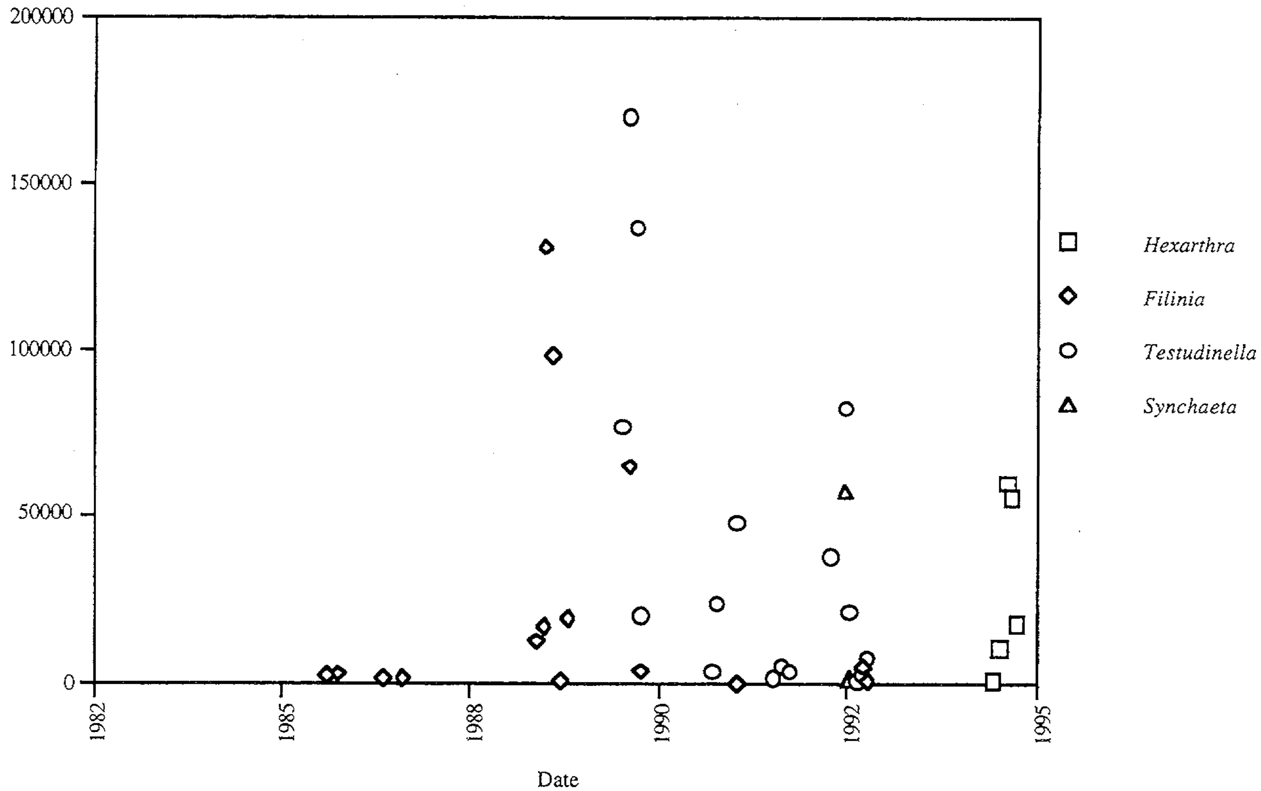


Figure 8.6.2.11. Maxwell Lake Zooplankton: Rotifers #2.

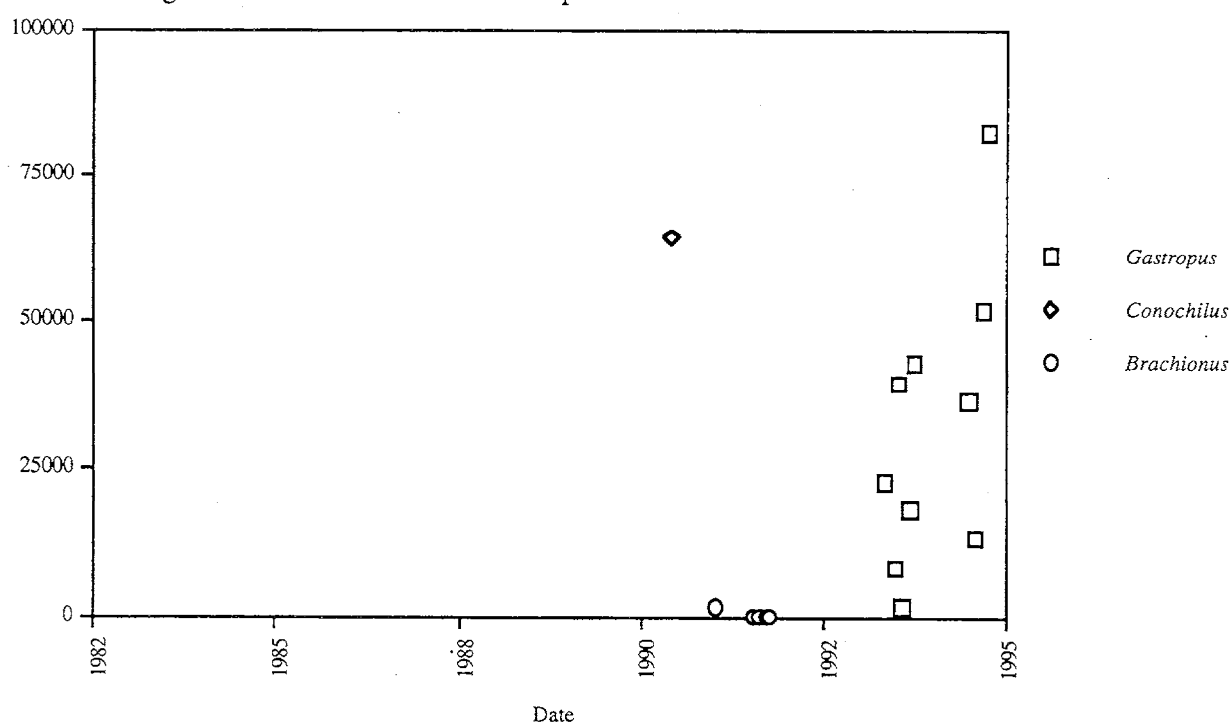


Figure 8.6.2.12. Maxwell Lake Zooplankton: Zooplankton Biomass Comparisons.

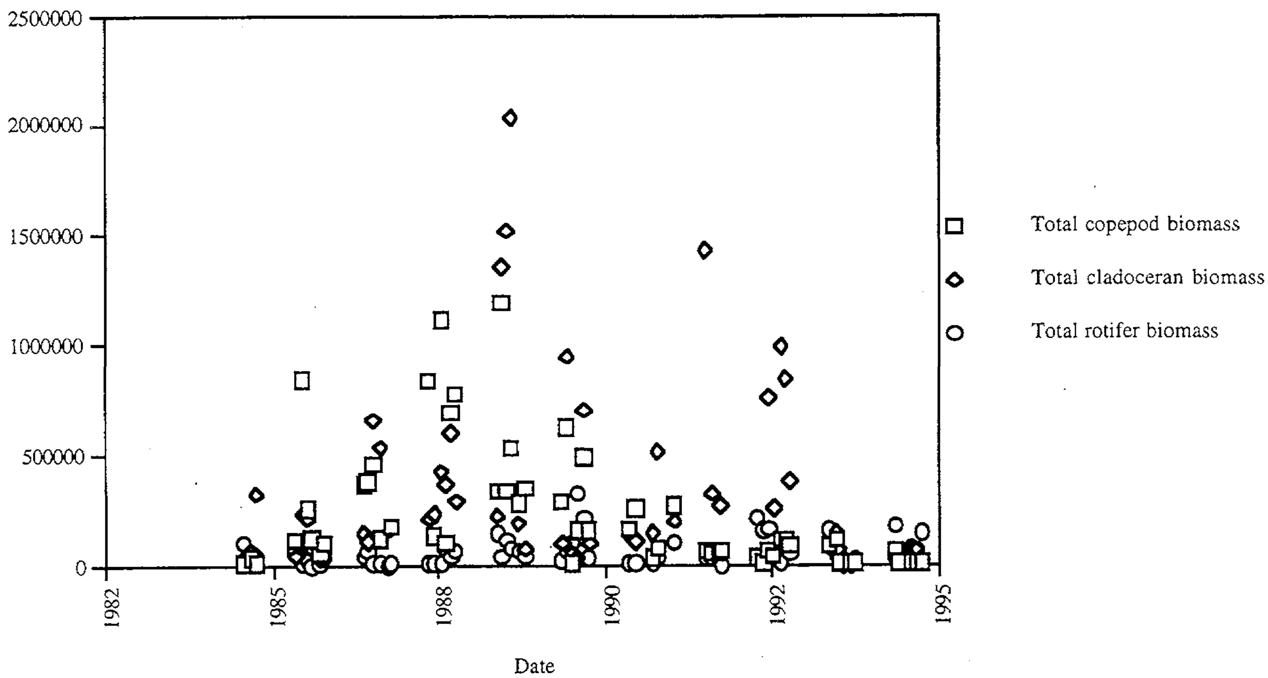


Figure 8.6.2.13. Maxwell Lake Zooplankton: Biomass mg/m2

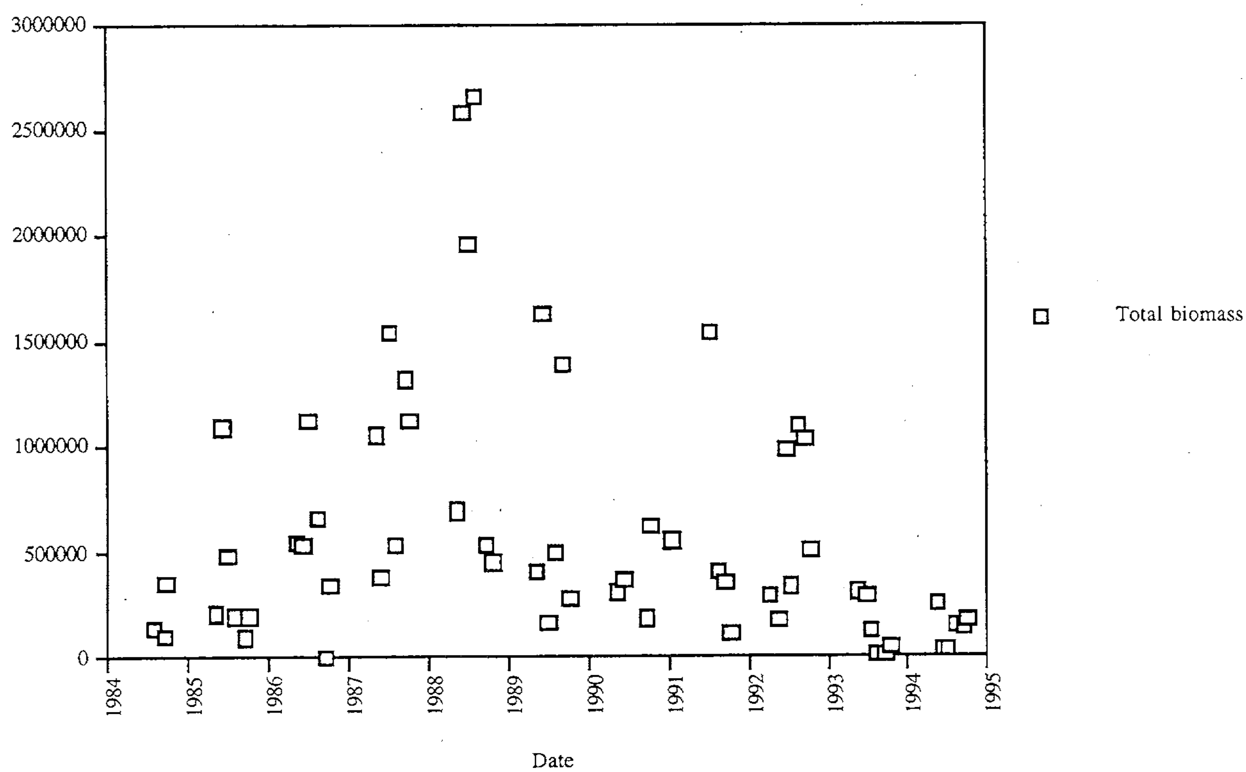


Figure 8.6.2.14. Maxwell Lake Zooplankton: Total Zooplankton/m2

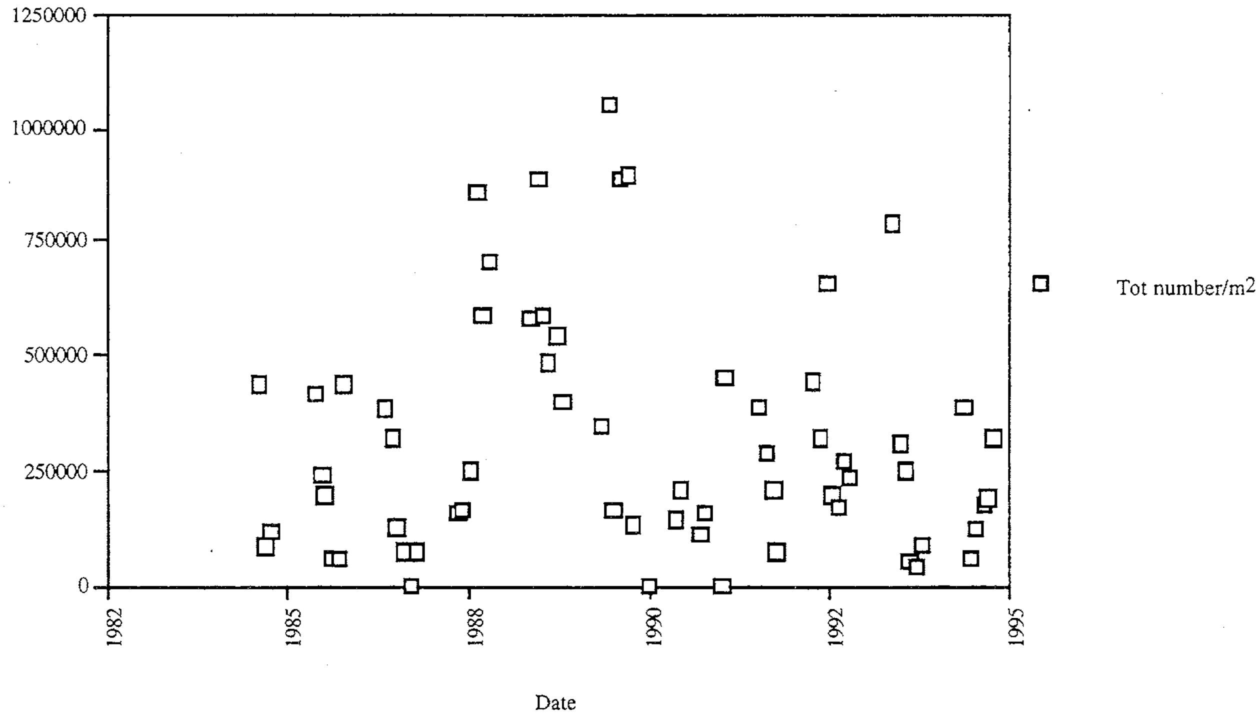


Figure 8.7.1.1. Old Wolf Lake Phytoplankton: *Dinobryon/Crucigenia*

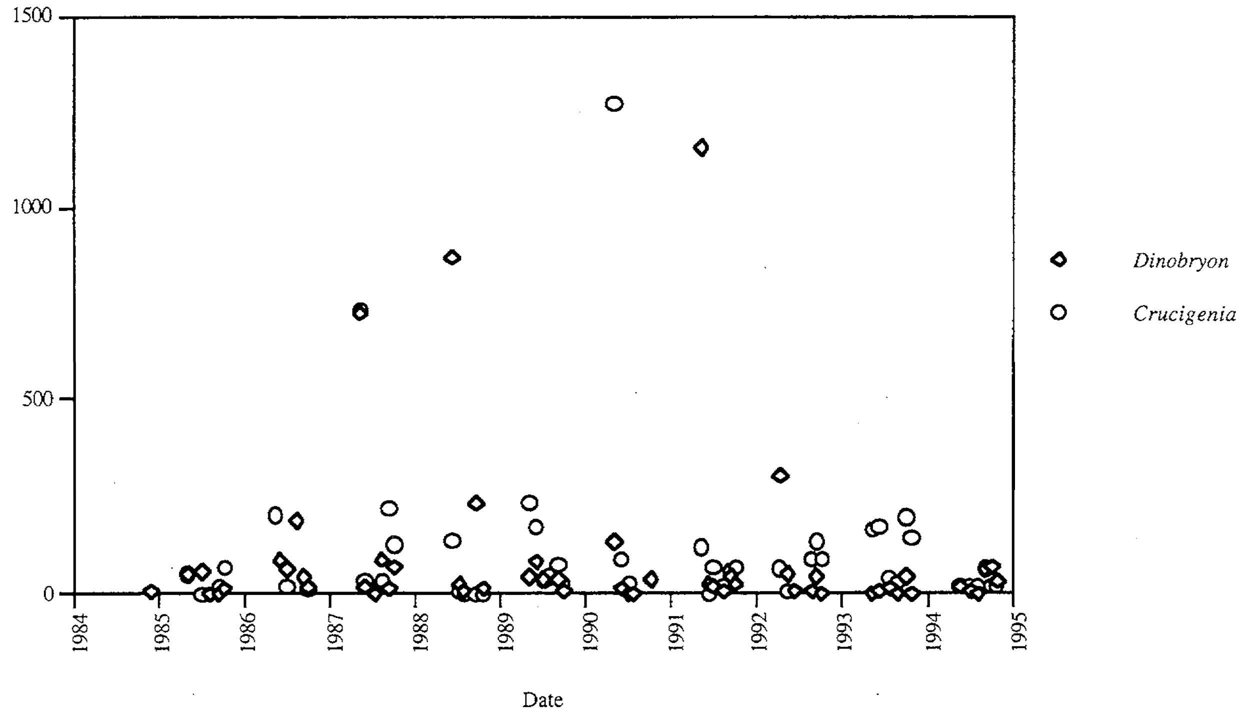


Figure 8.7.1.2. Old Wolf Lake Phytoplankton: *Cryptomonas*.

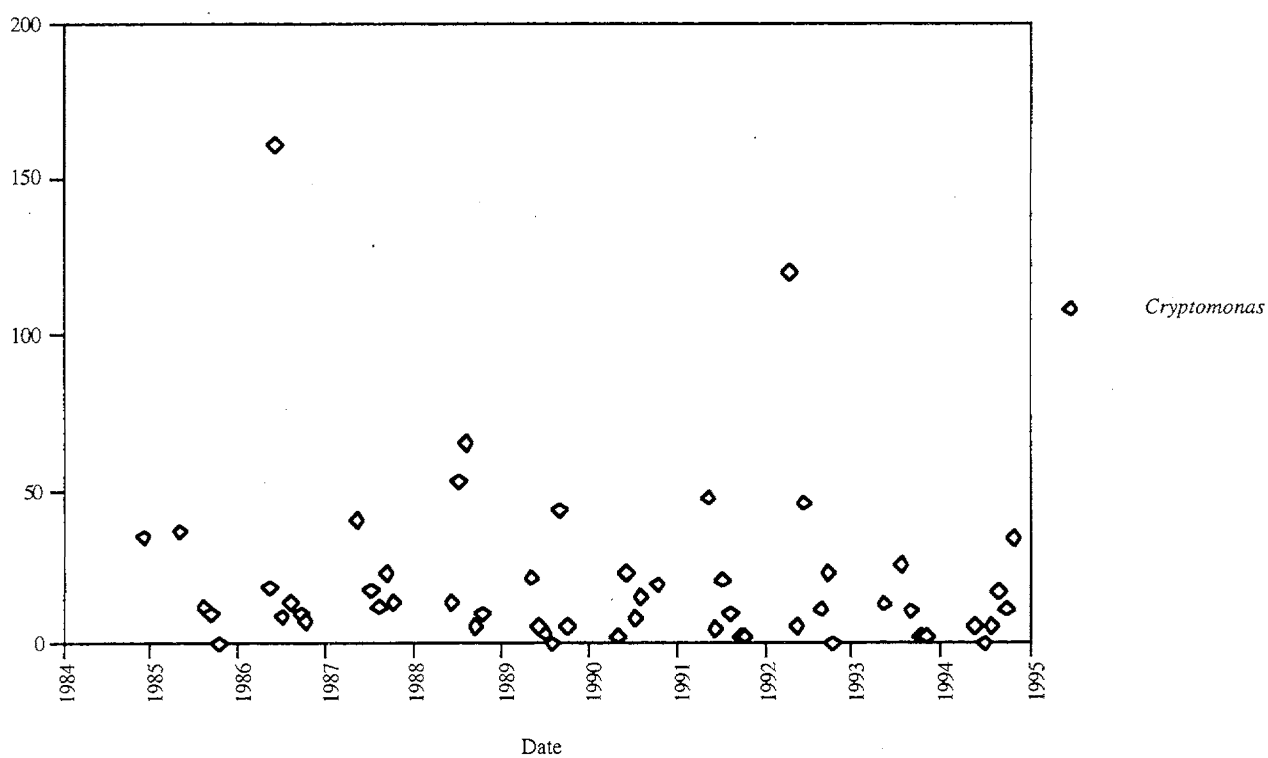


Figure 8.7.1.3. Old Wolf Lake Phytoplankton: *Merismopedia*

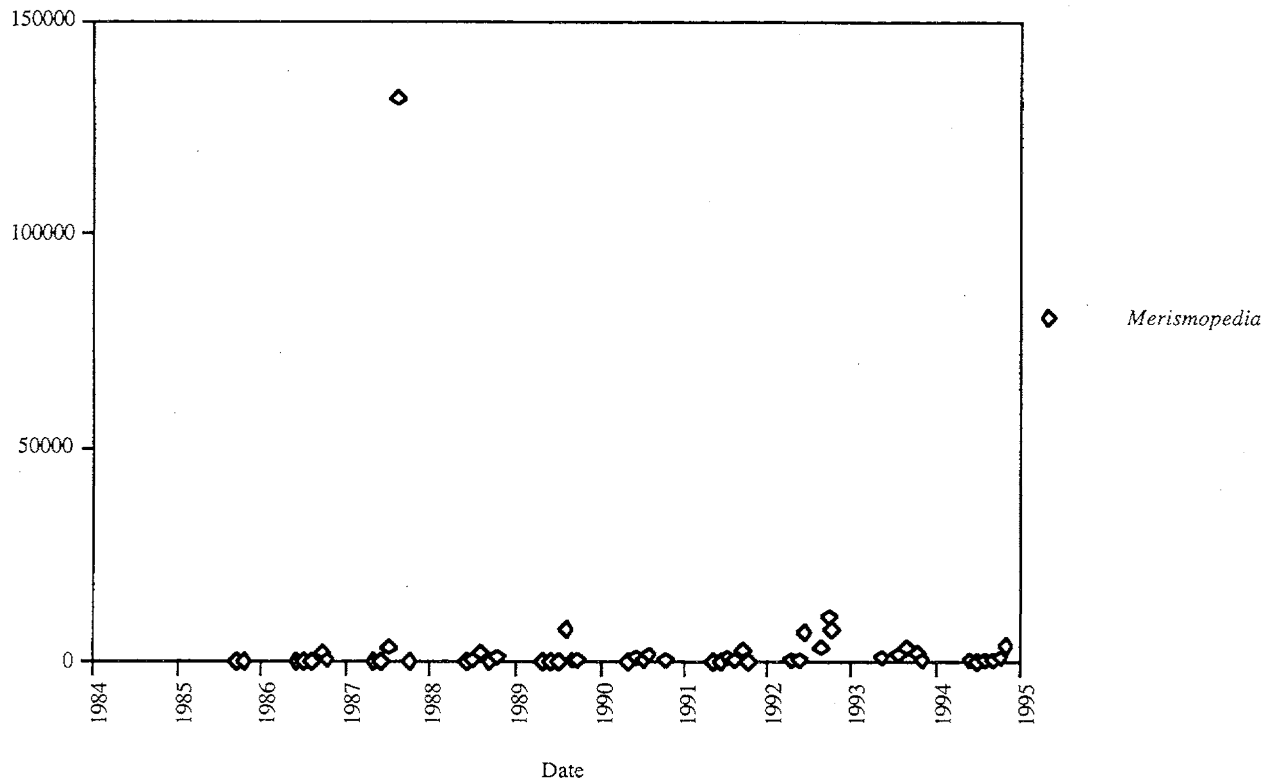


Figure 8.7.1.4. Old Wolf Lake Phytoplankton: *Aphanothece*

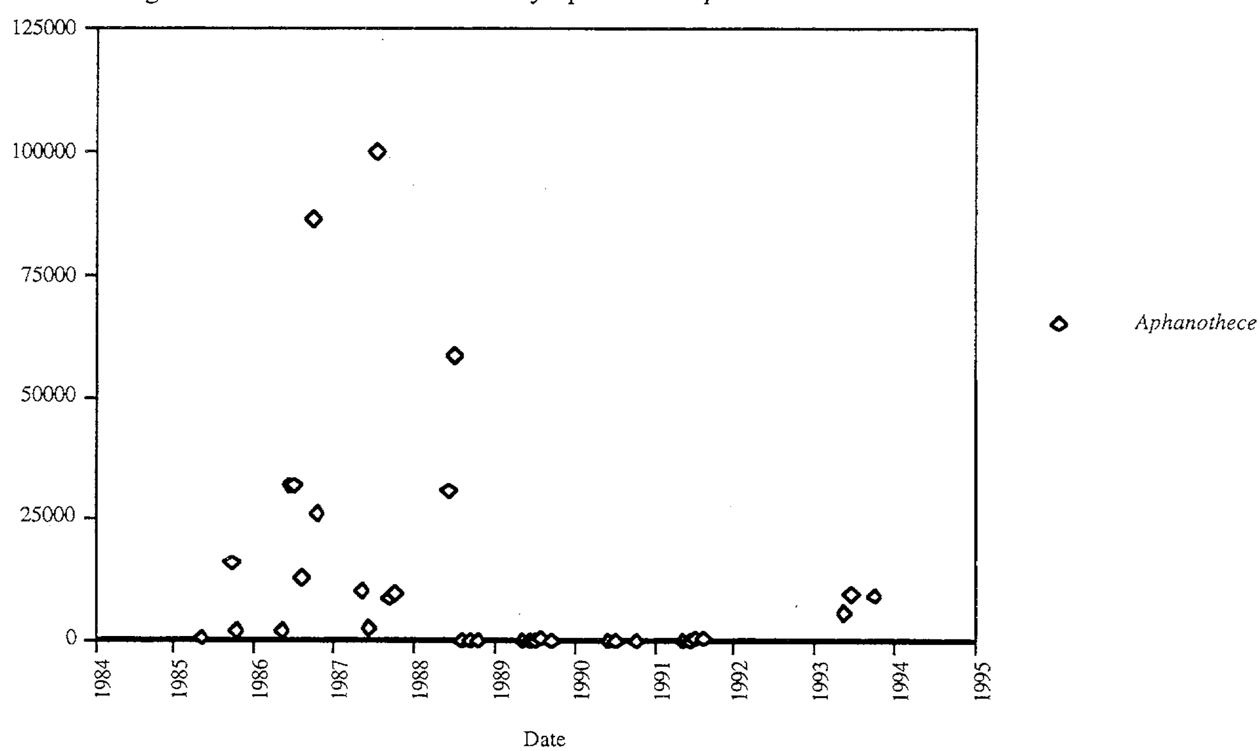


Figure 8.7.1.5. Old Wolf Lake Phytoplankton: *Tabellaria/Navicula*

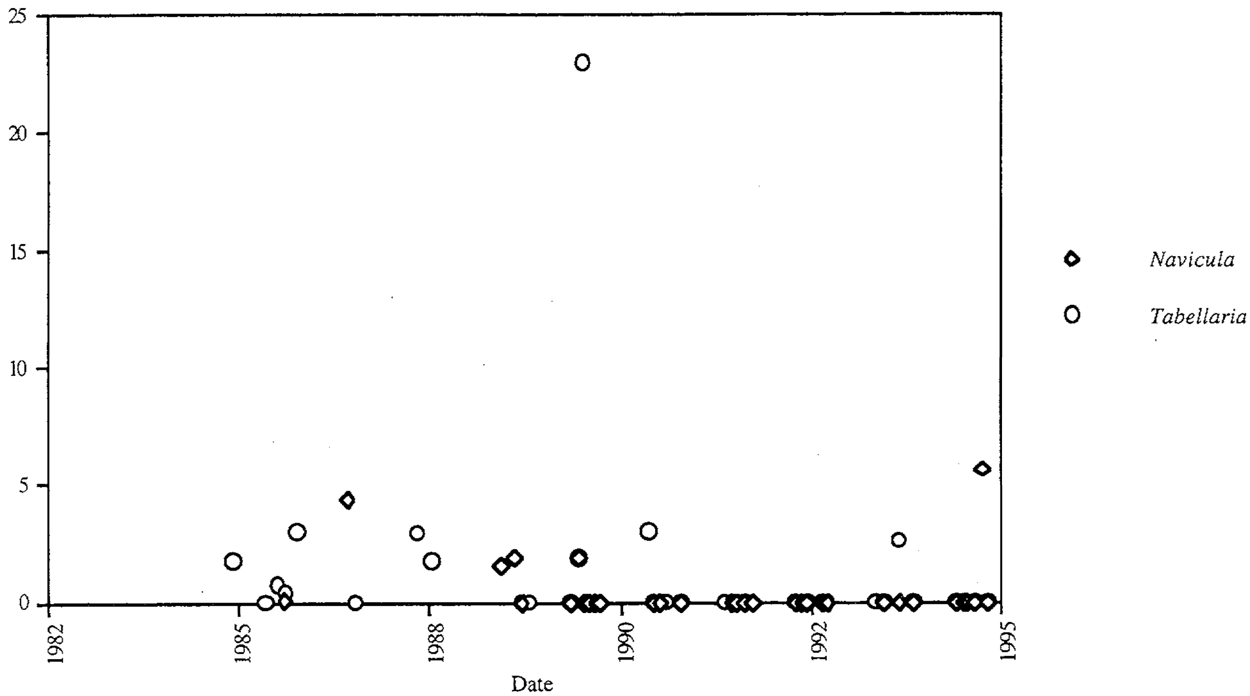


Figure 8.7.1.6. Old Wolf Lake Phytoplankton: *Scenedesmus/Elakothrix*

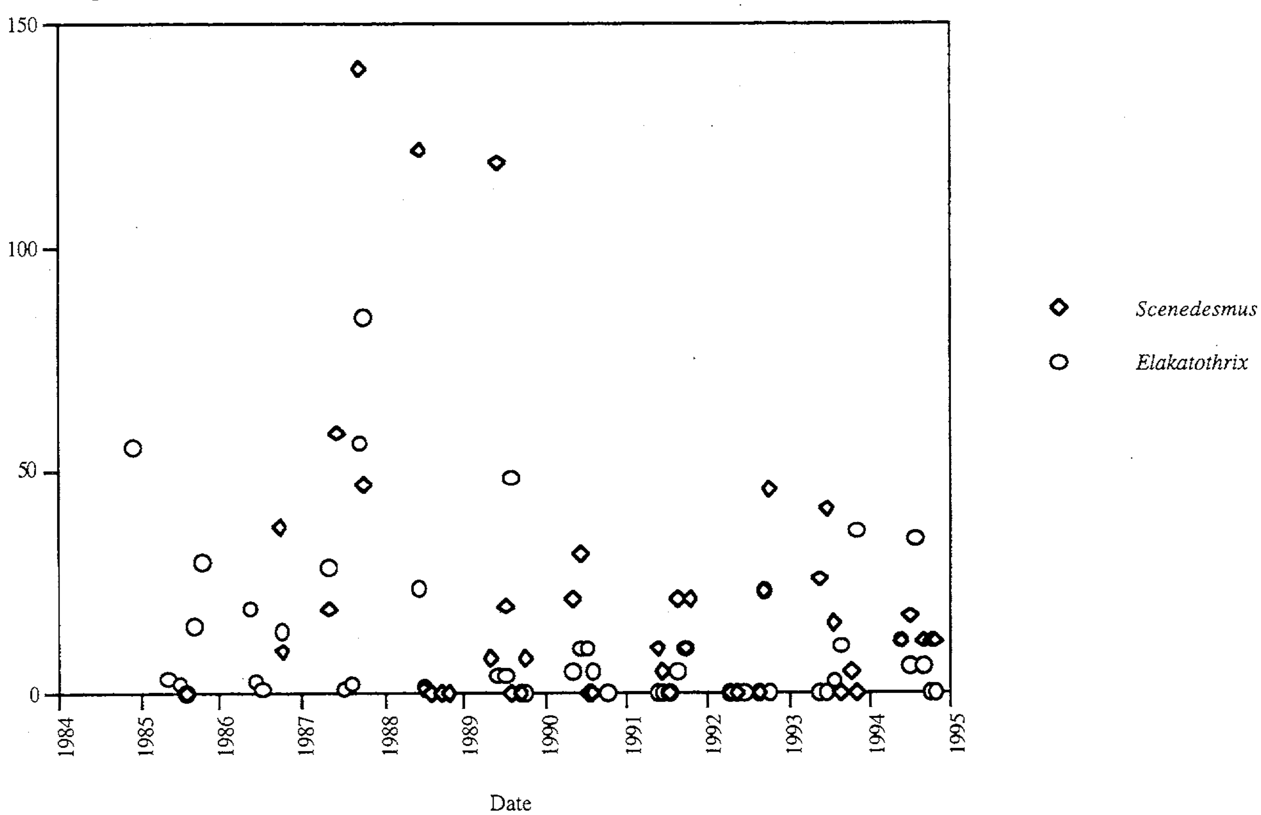


Figure 8.7.1.7. Old Wolf Lake Phytoplankton: *Chroococcus.*

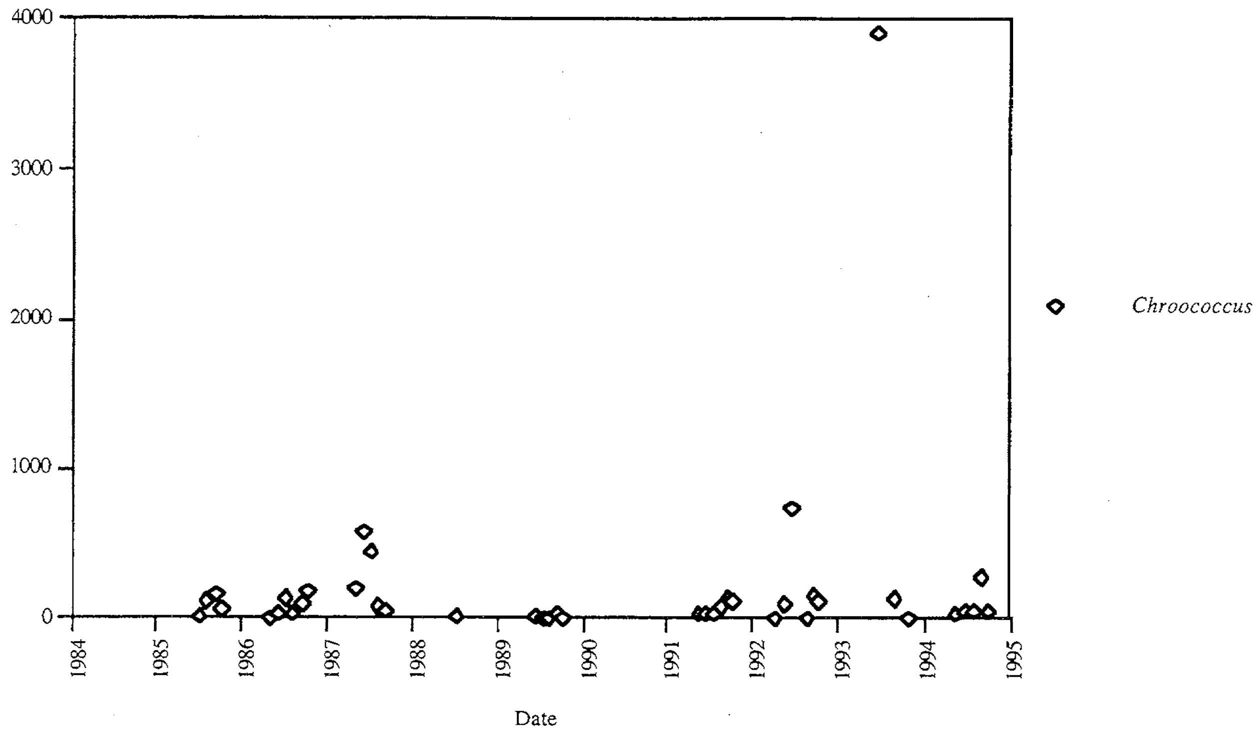


Figure 8.7.1.8. Old Wolf Lake Phytoplankton: *Gloeocystis.*

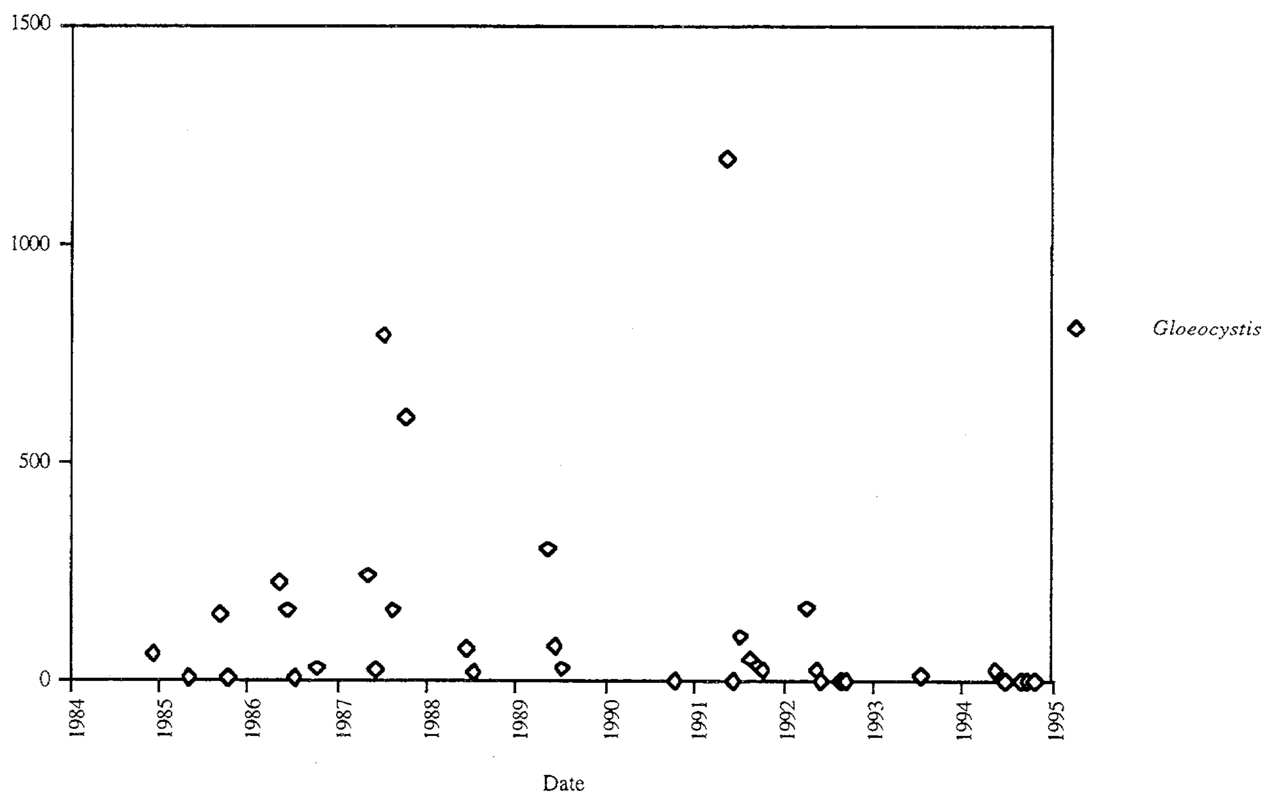


Figure 8.7.1.9. Old Wolf Lake Phytoplankton: *Botryococcus/Chroomonas*.

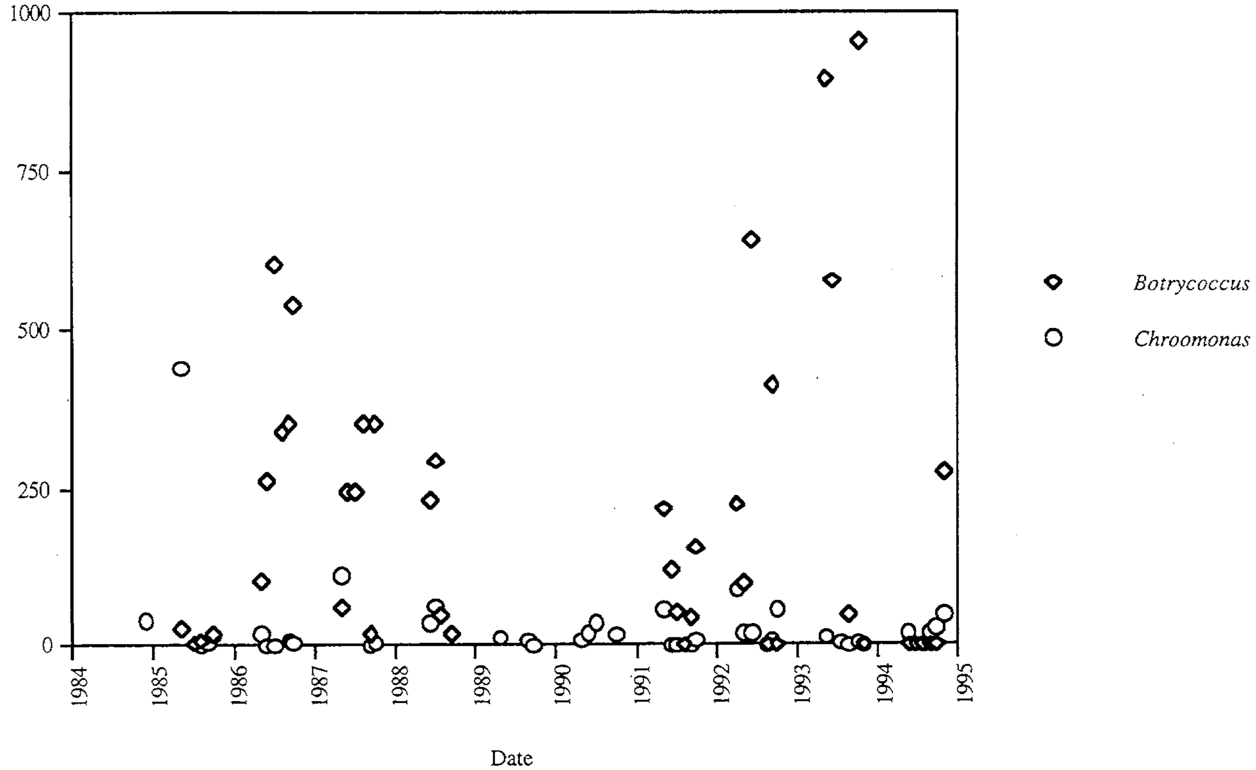


Figure 8.7.1.10. Old Wolf Lake Phytoplankton: *Chroococcus*.

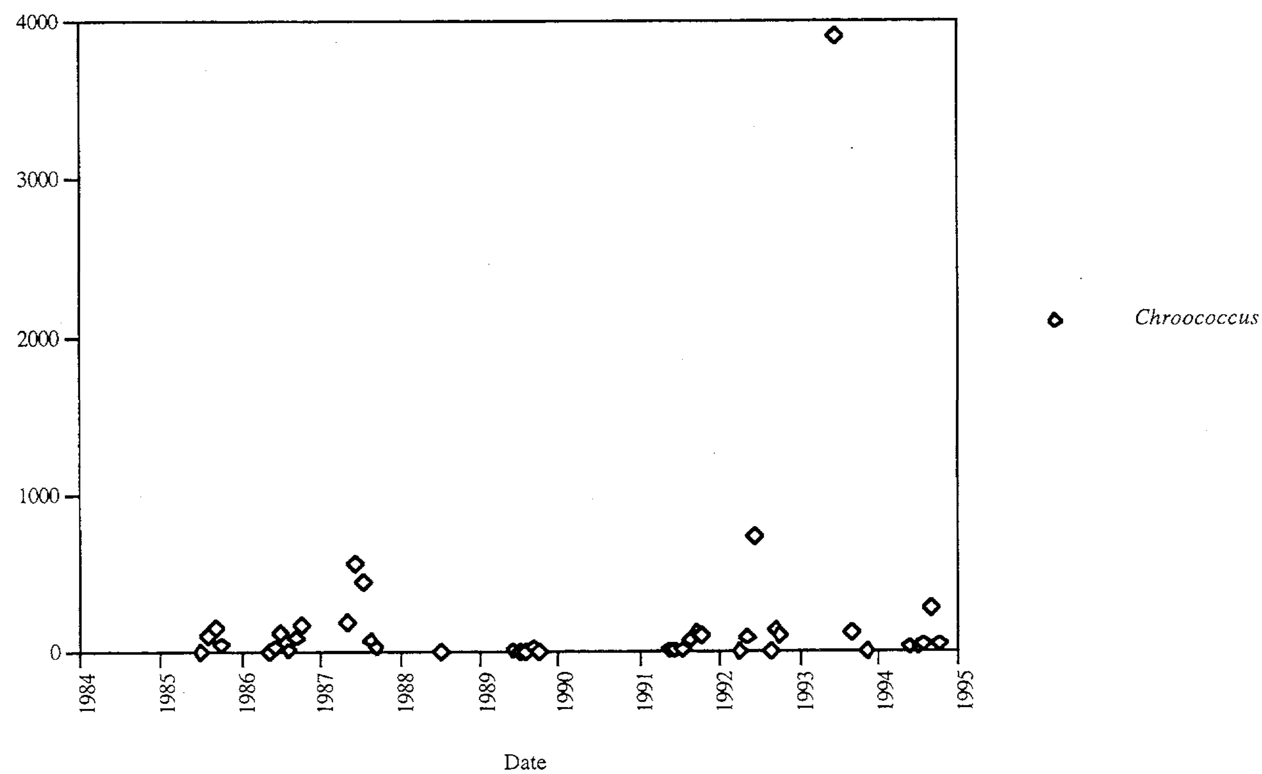


Figure 8.7.1.11. Old Wolf Lake Phytoplankton: *Pediastrum*

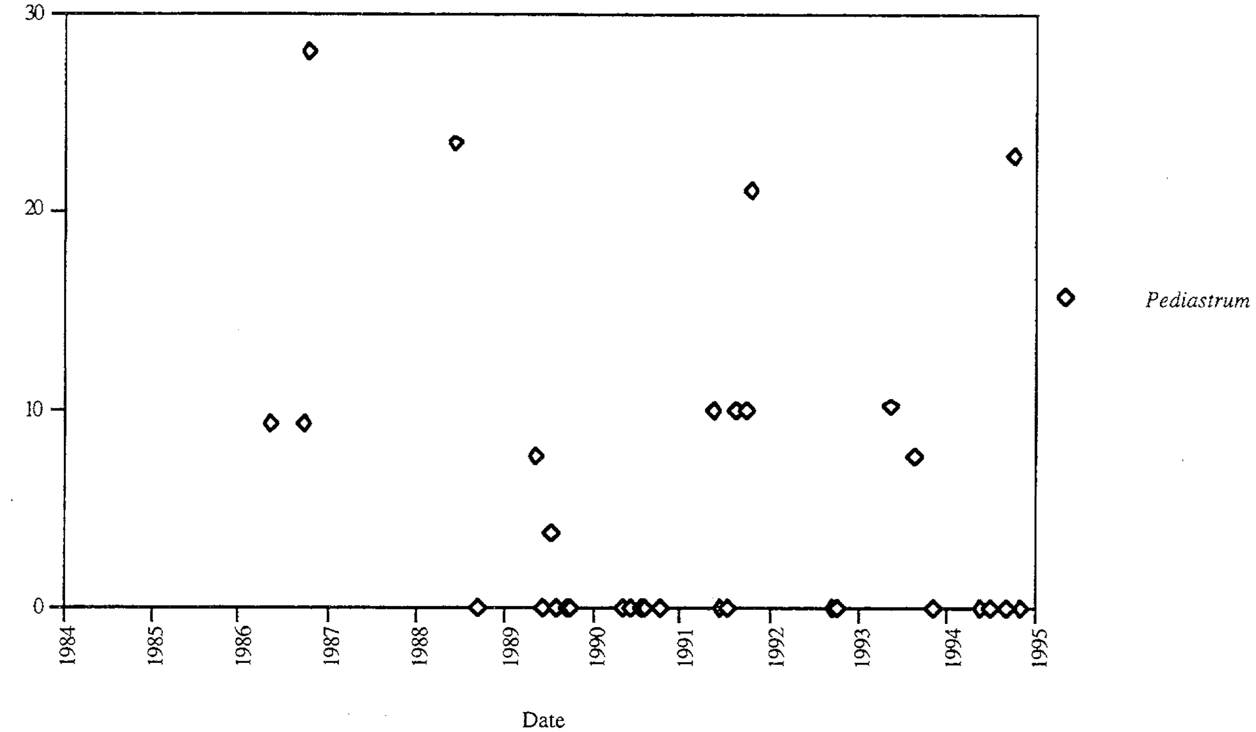


Figure 8.7.1.12. Old Wolf Lake Phytoplankton: *Quadrigula*

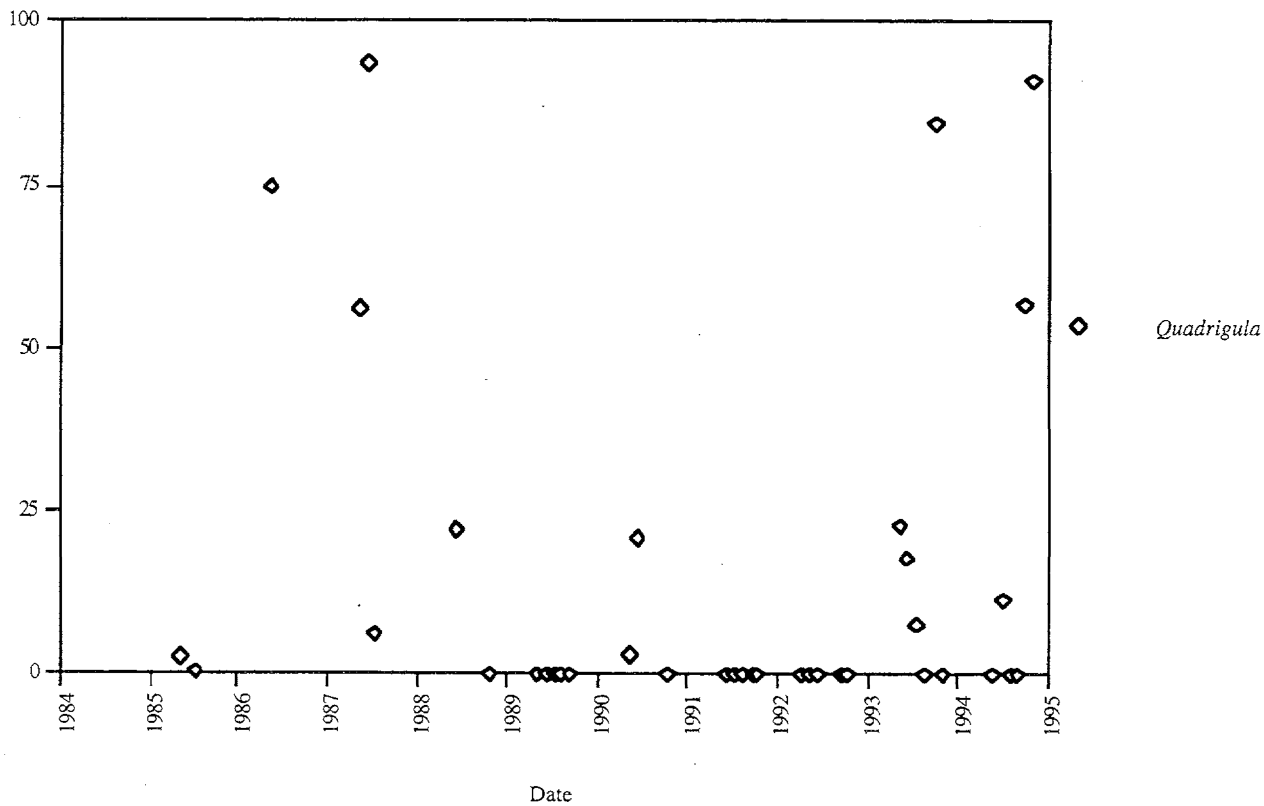


Figure 8.7.1.13. Old Wolf Lake Phytoplankton: *Arthrodesmus*

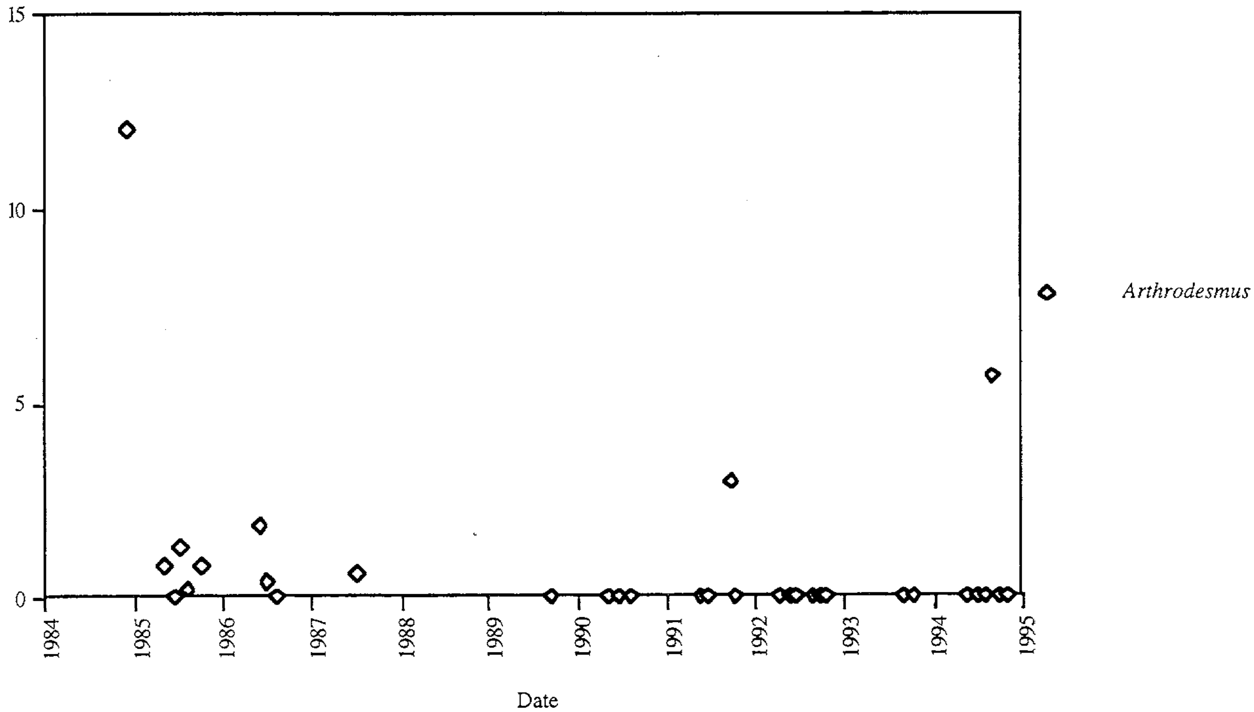


Figure 8.7.1.14. Old Wolf Lake Phytoplankton: *Lyngbya.*

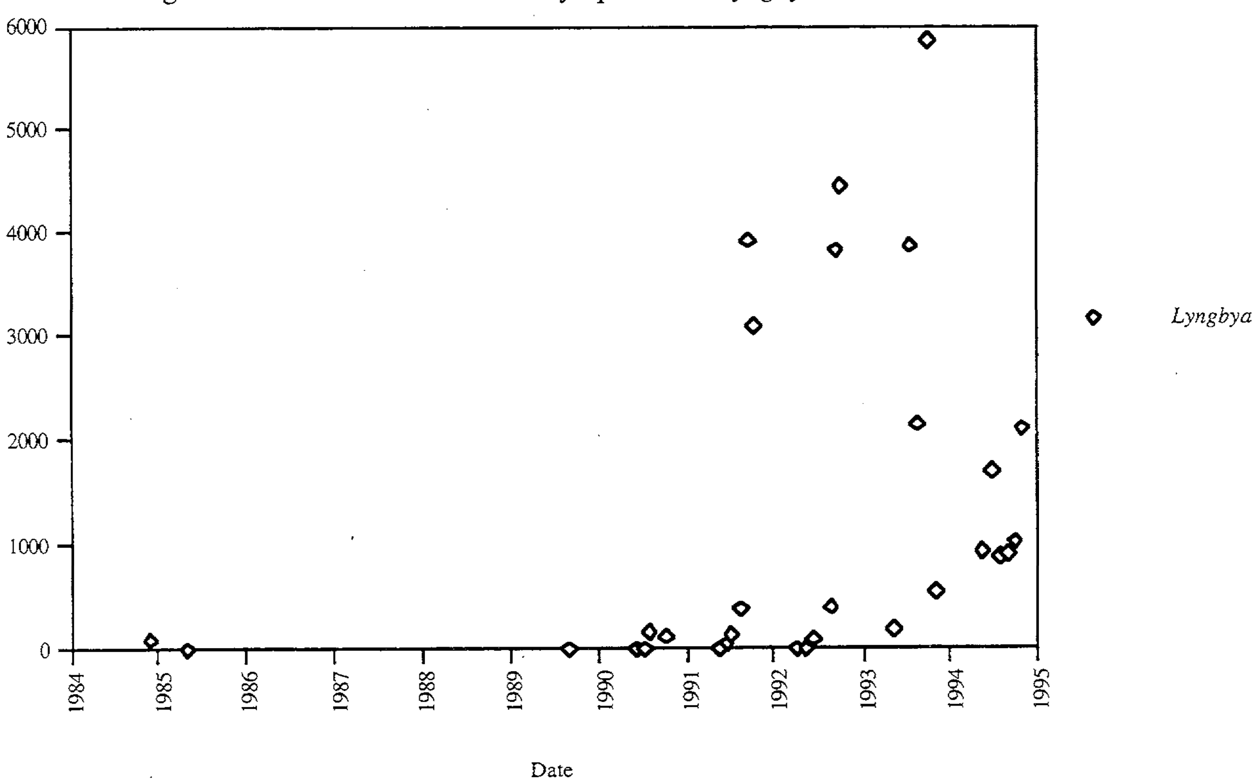


Figure 8.7.1.15. Old Wolf Lake Phytoplankton: *Rhaboderma.*

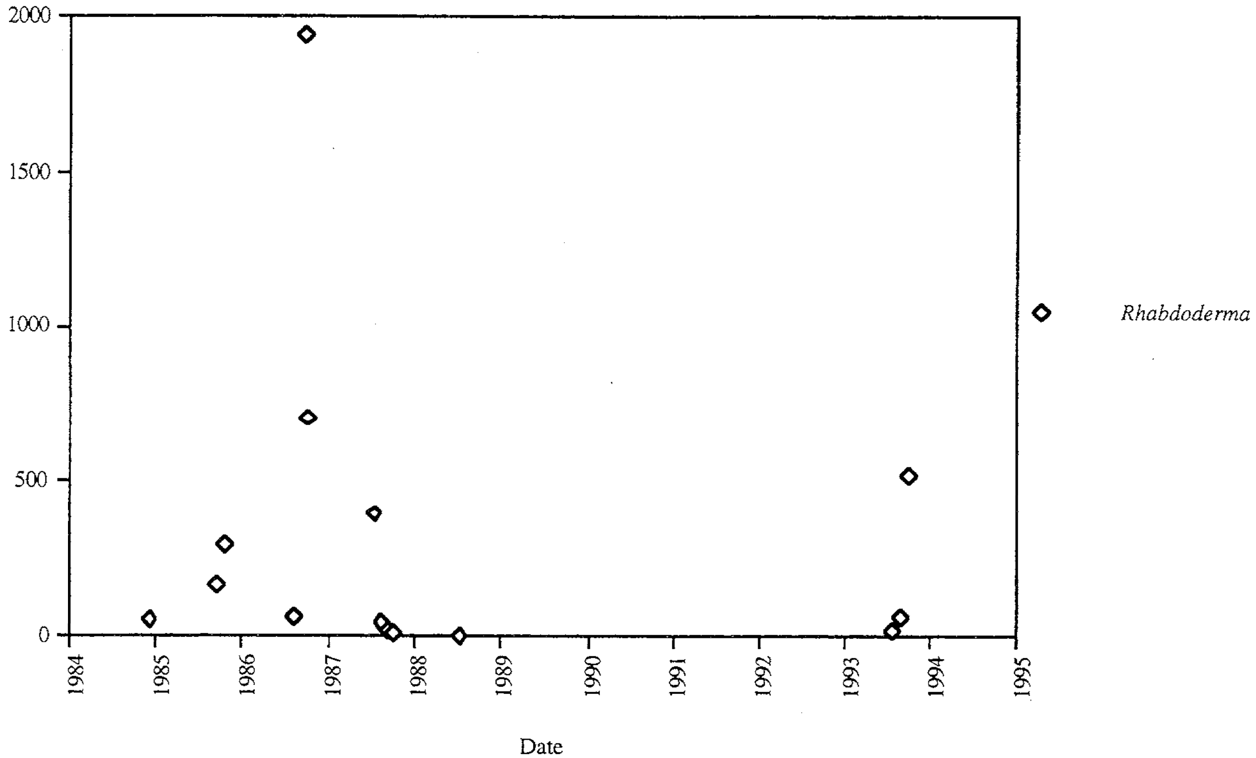


Figure 8.7.1.16. Old Wolf Lake Phytoplankton: *Aphanocapsa.*

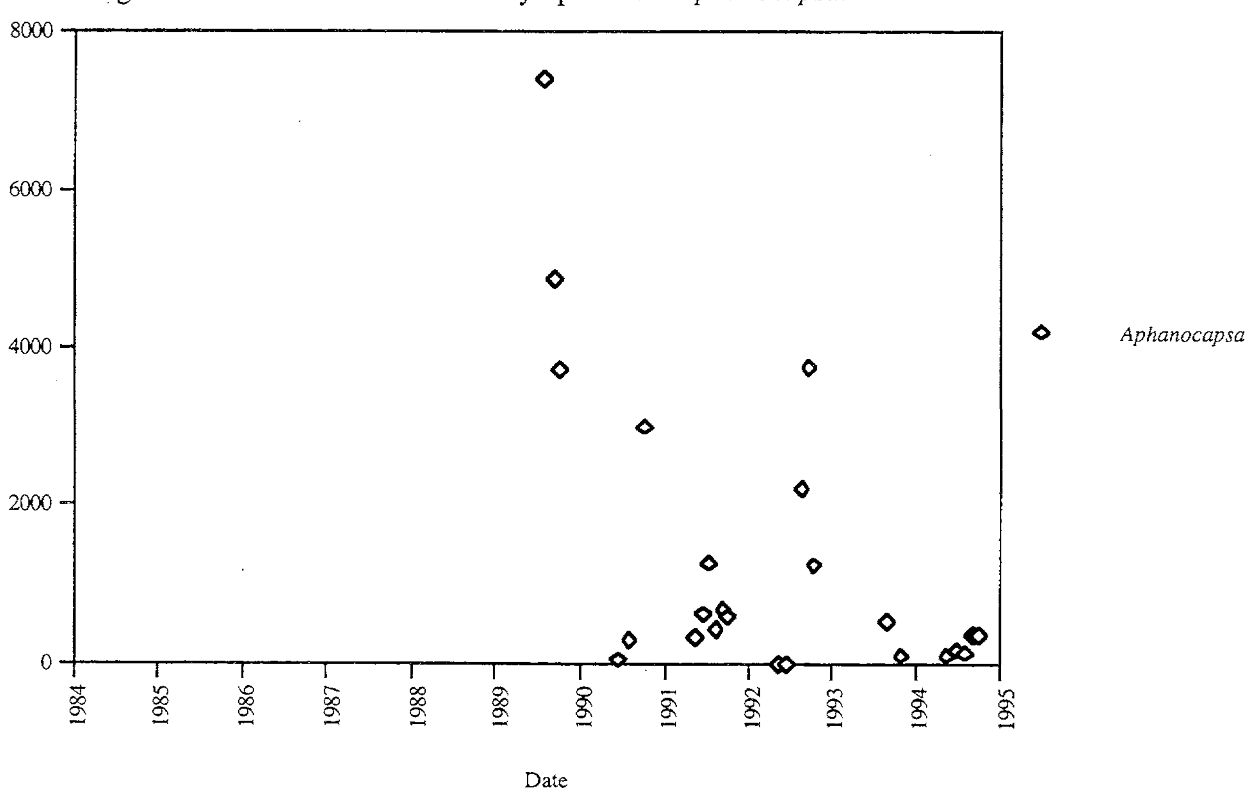


Figure 8.7.1.17. Old Wolf Lake Phytoplankton: *Sphaerocystis*

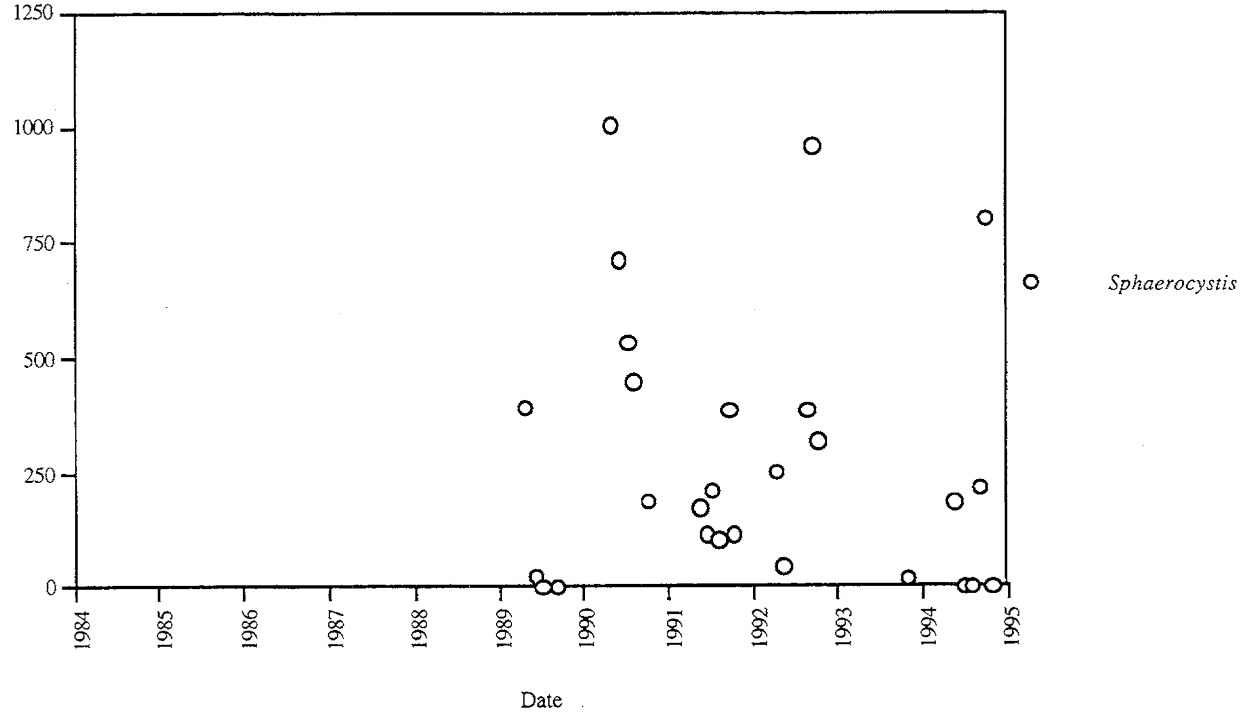


Figure 8.7.1.18. Old Wolf Lake Phytoplankton: Total Cells/mL.

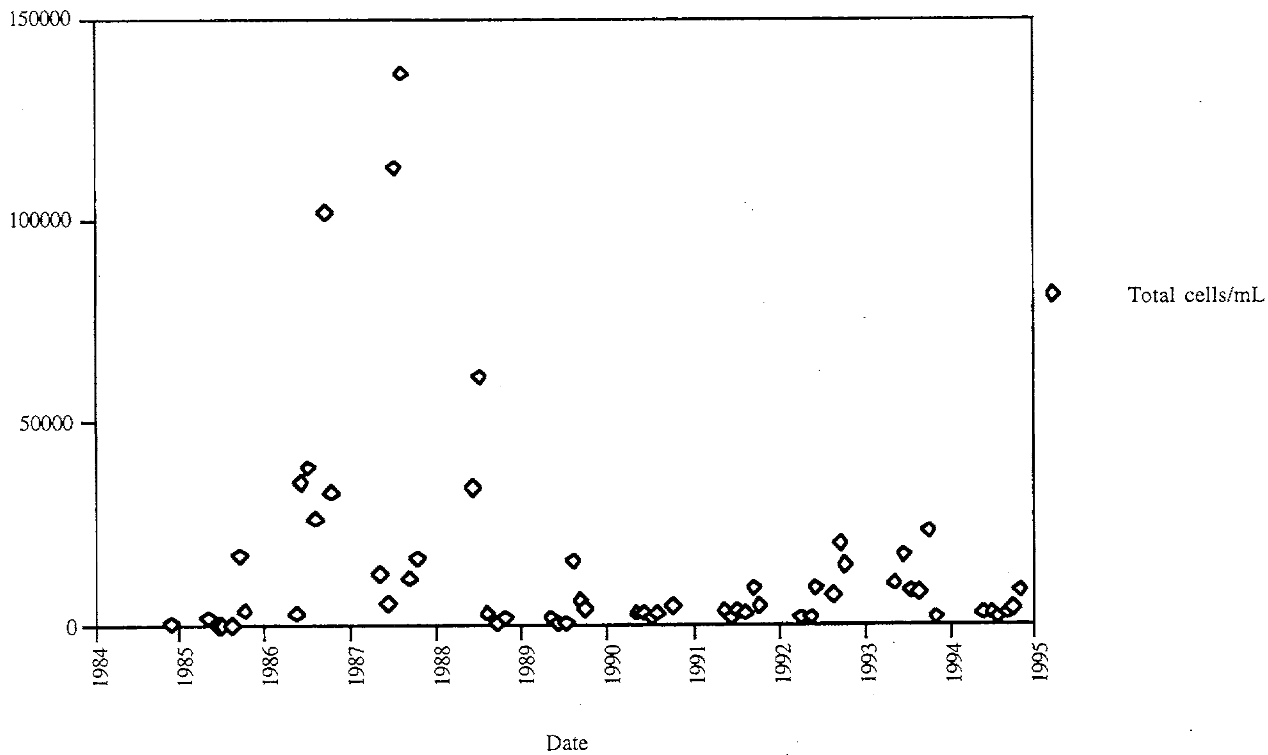


Figure 8.7.1.19. Old Wolf Lake Phytoplankton: Chlorophyll a, µg/L

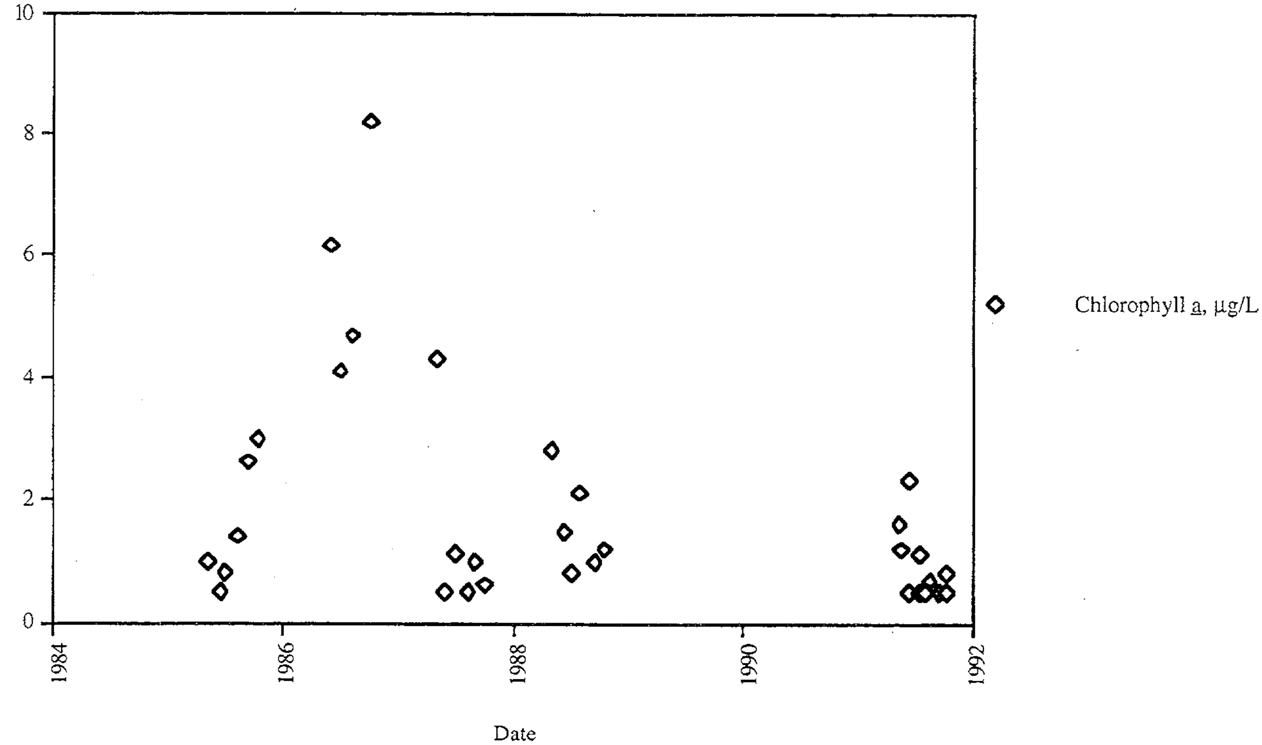


Figure 8.7.2.1. Old Wolf Lake Zooplankton: *Diaptomus*

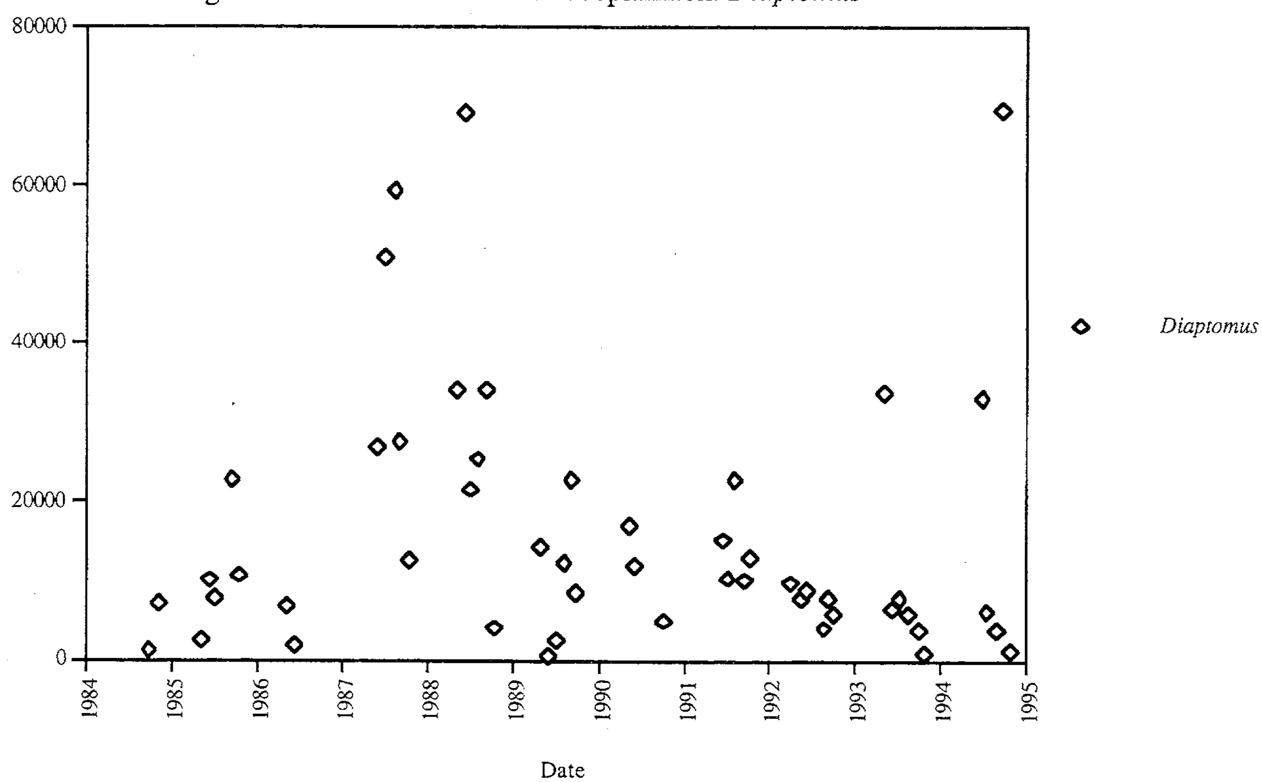


Figure 8.7.2.2. Old Wolf Lake Zooplankton: *Epishura/Cyclops/Diacyclops*

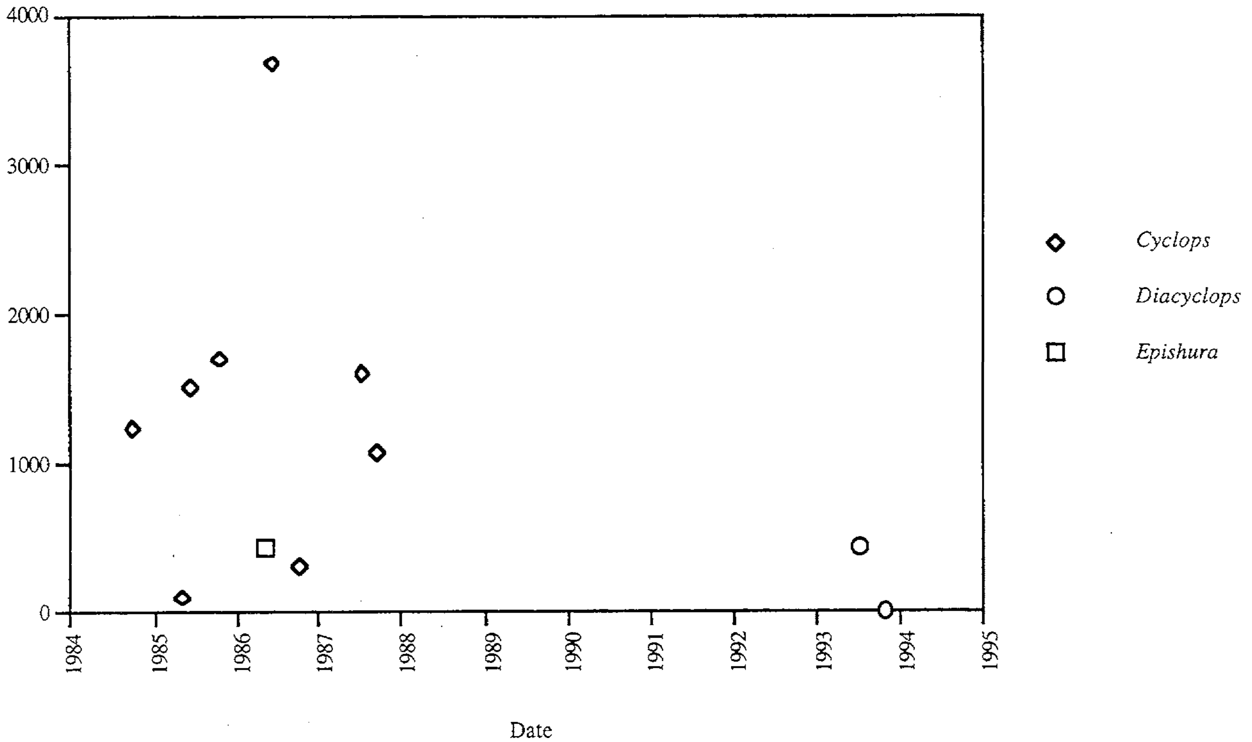


Figure 8.7.2.3. Old Wolf Lake Zooplankton: Copepodites/Nauplii

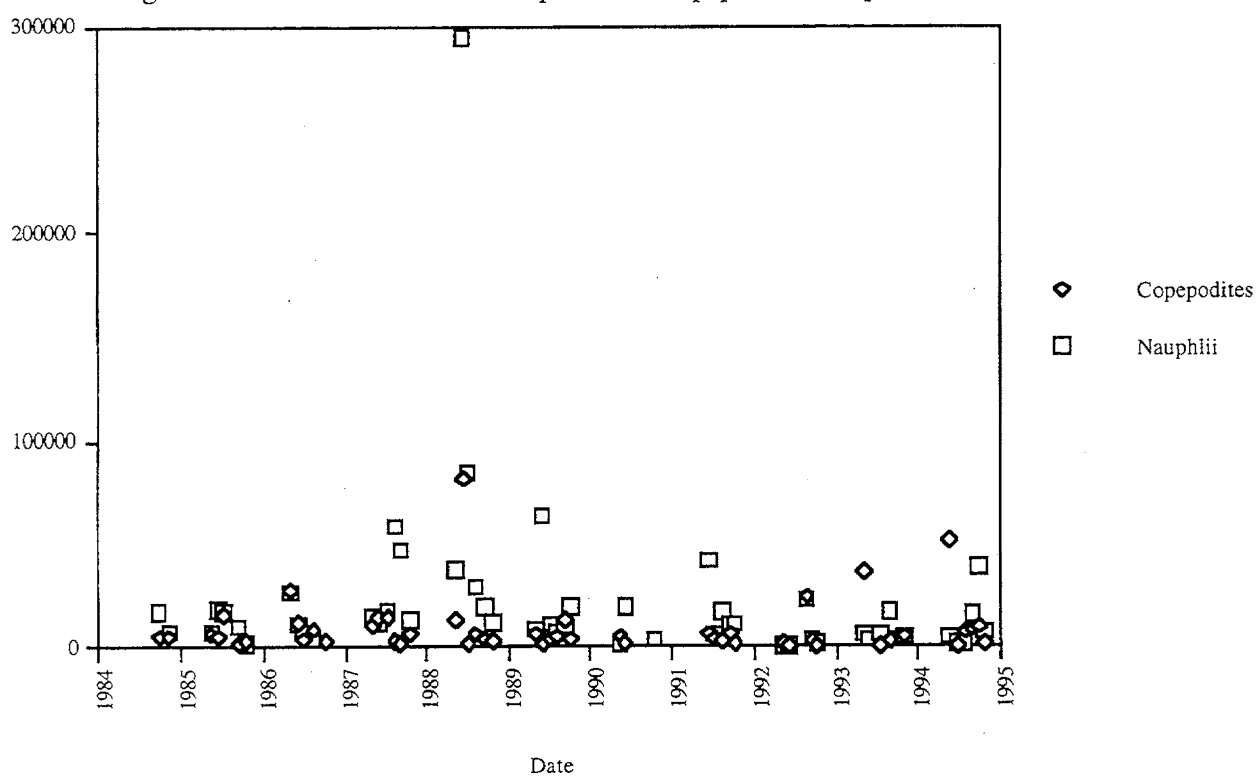


Figure 8.7.2.4. Old Wolf Lake Zooplankton: *Bosmina/Daphnia*

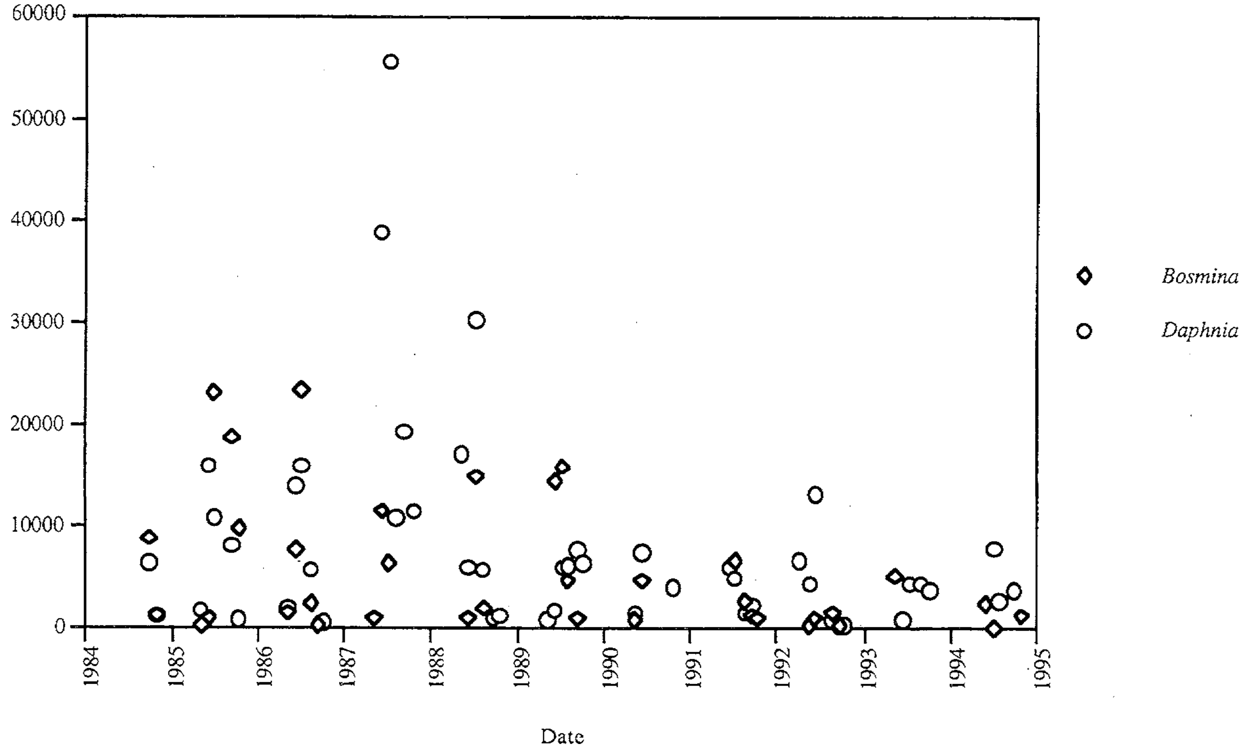


Figure 8.7.2.5. Old Wolf Lake Zooplankton: *Holopedium/Diaphanosoma*

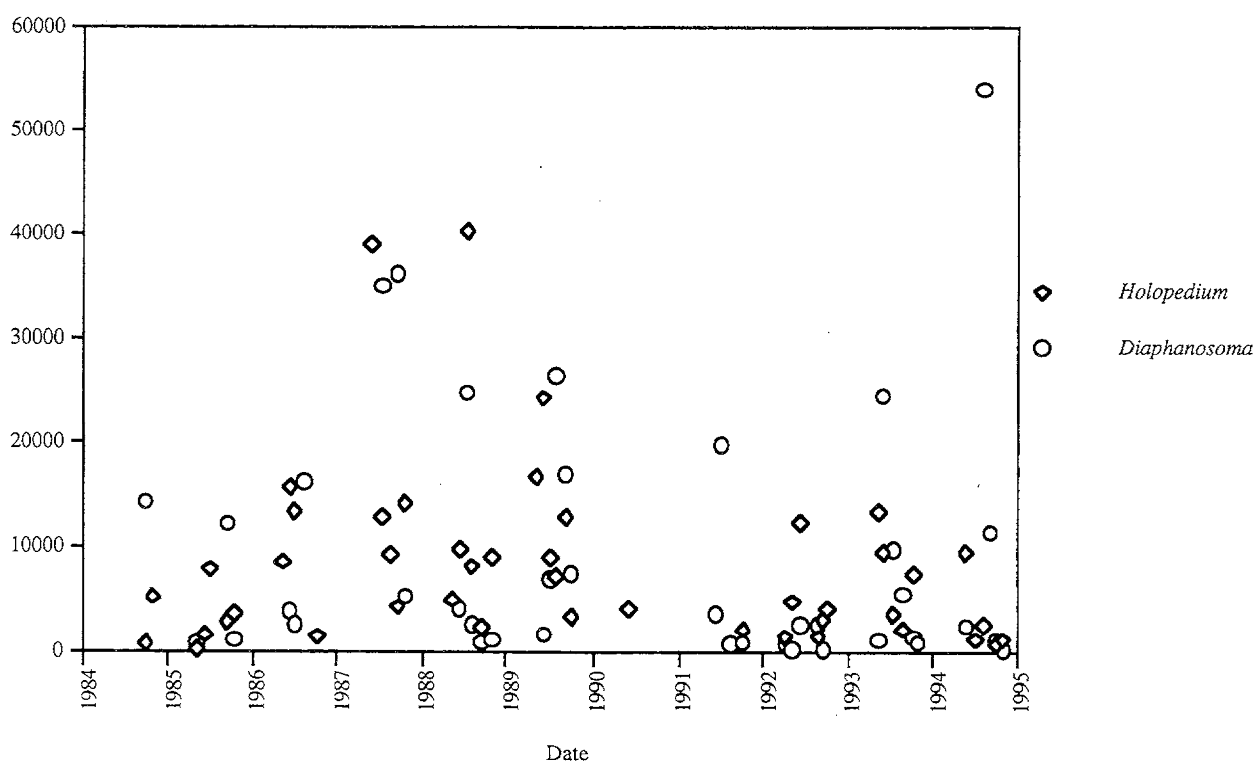


Figure 8.7.2.6. Old Wolf Lake Zooplankton: *Ceriodaphnia*

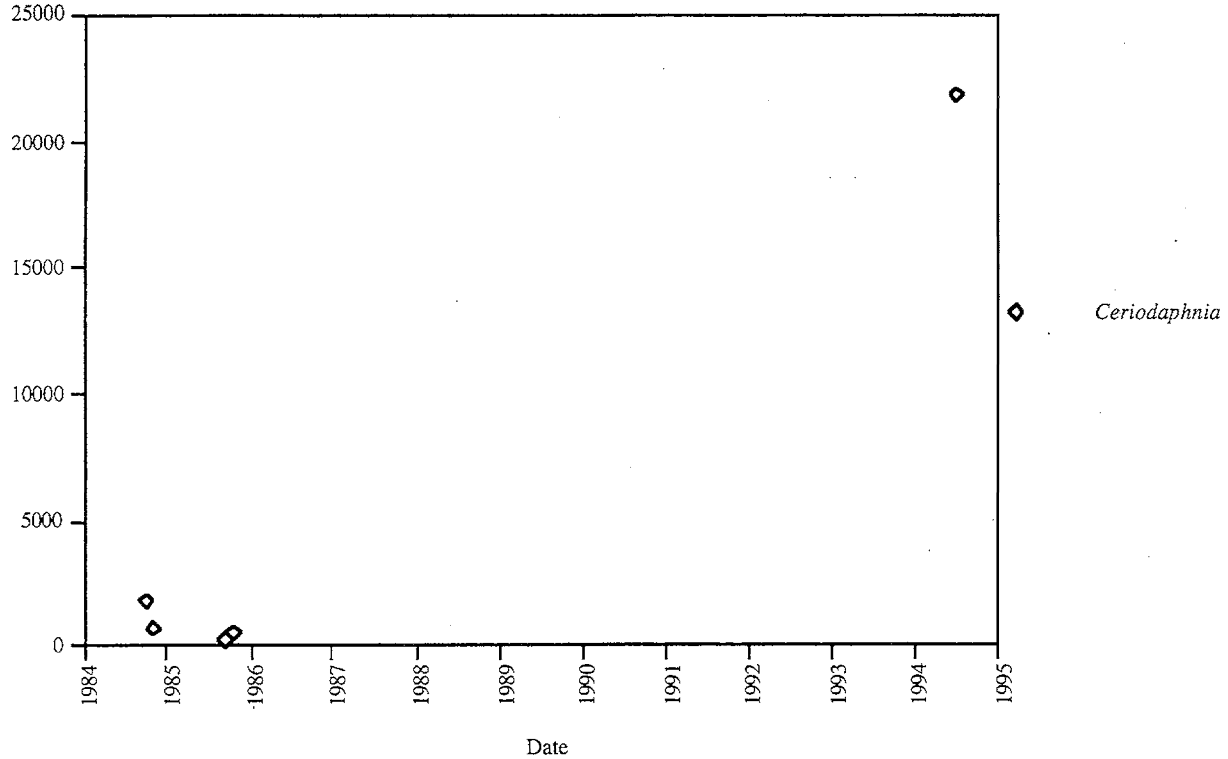


Figure 8.7.2.7. Old Wolf Lake Zooplankton: *Kellicottia/Keratella*

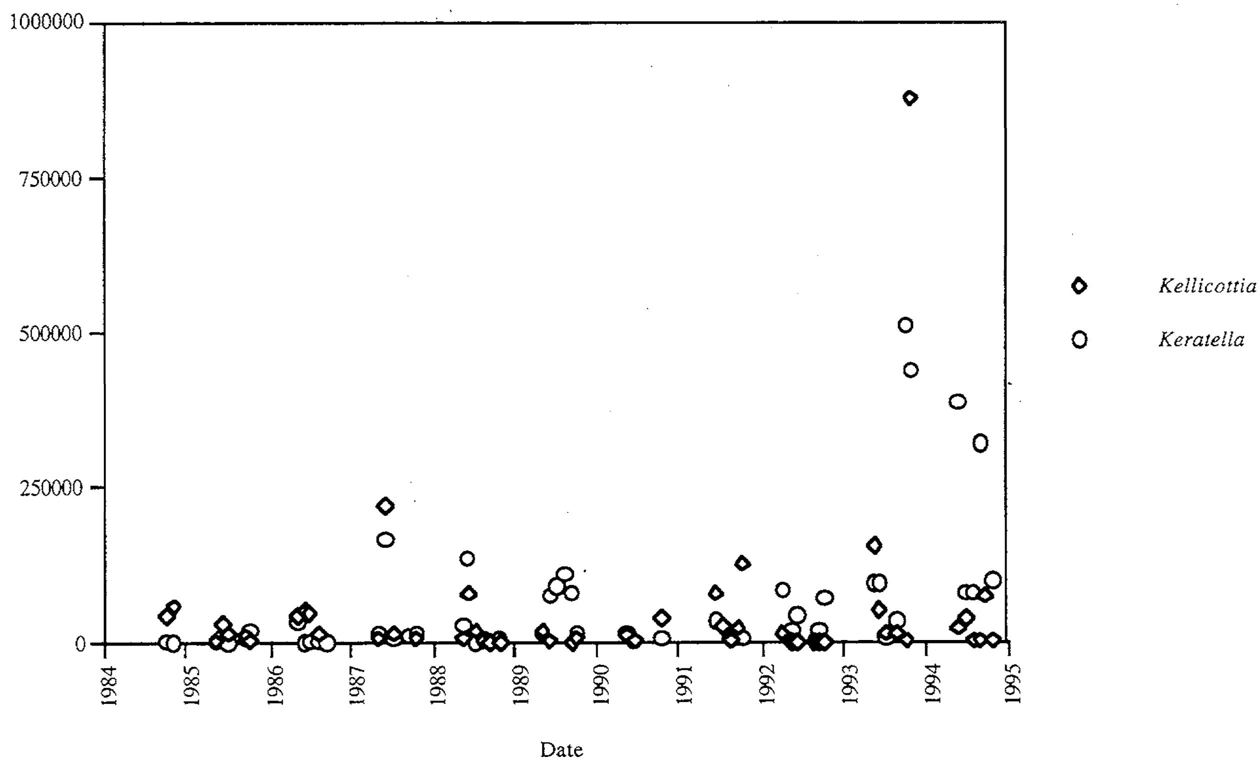


Figure 8.7.2.8. Old Wolf Lake Zooplankton: *Testudinella.*

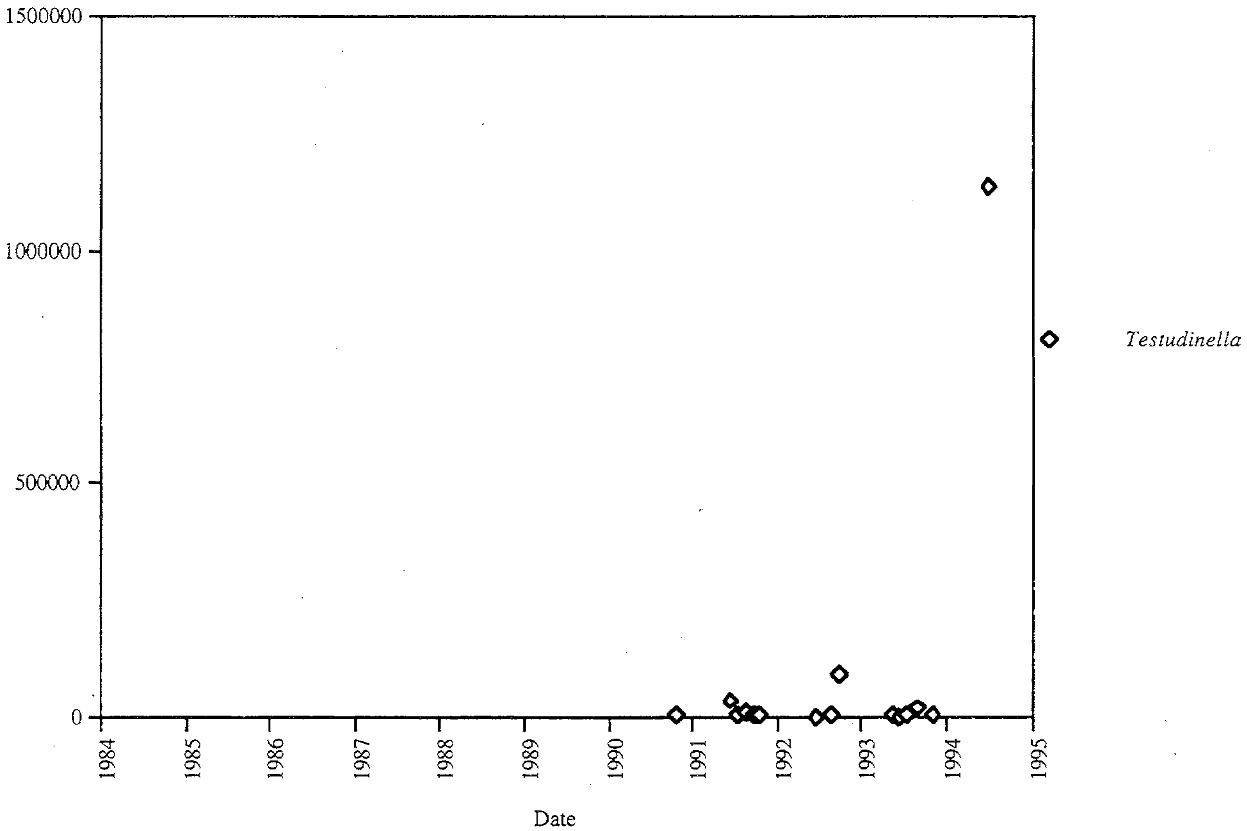


Figure 8.7.2.9. Old Wolf Lake Zooplankton: *Conochilus.*

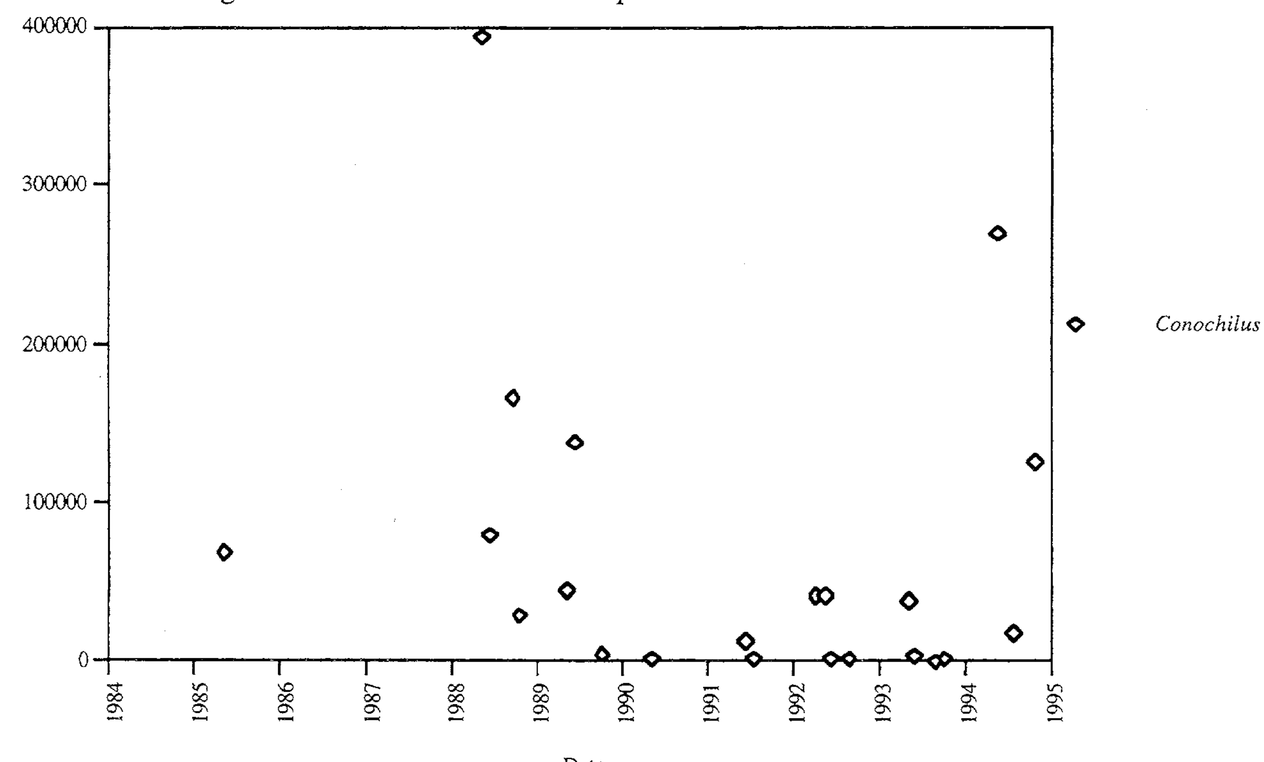


Figure 8.7.2.10. Old Wolf Lake Zooplankton: *Trichocera/Filinia*

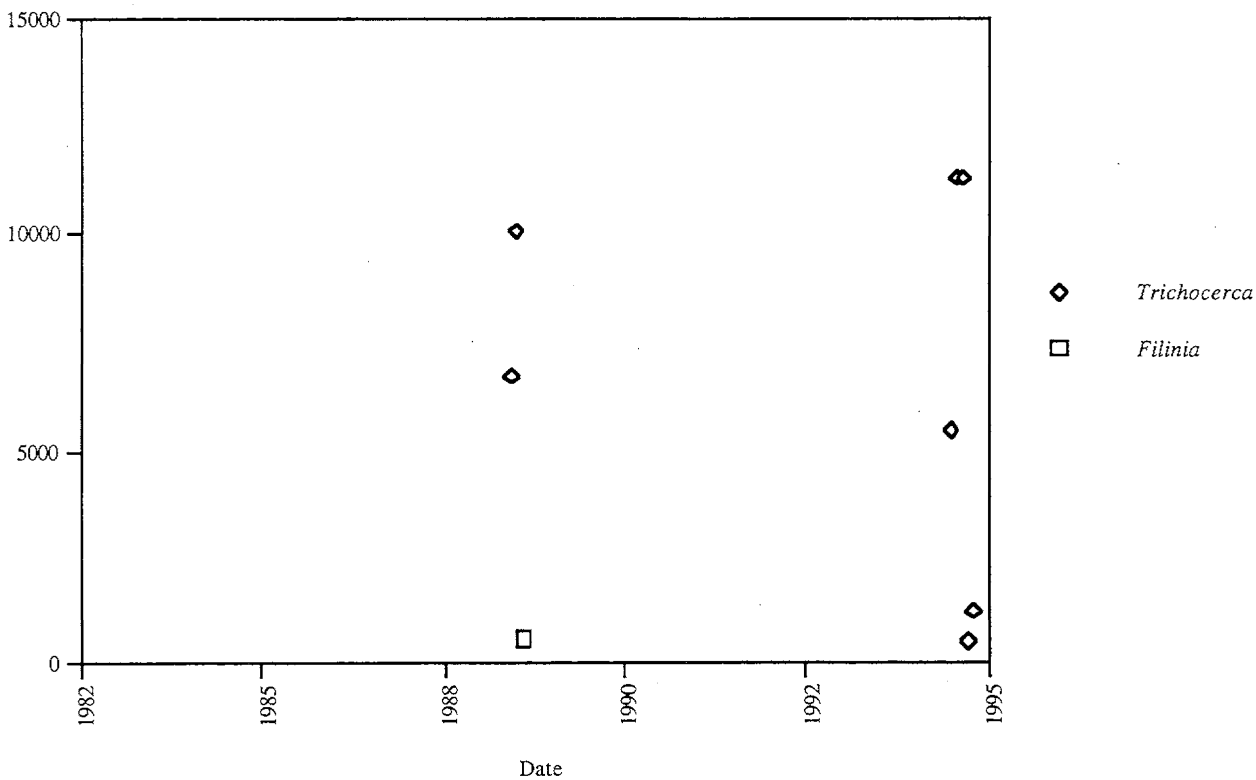


Figure 8.7.2.11. Old Wolf Lake Zooplankton: Rare Rotifers

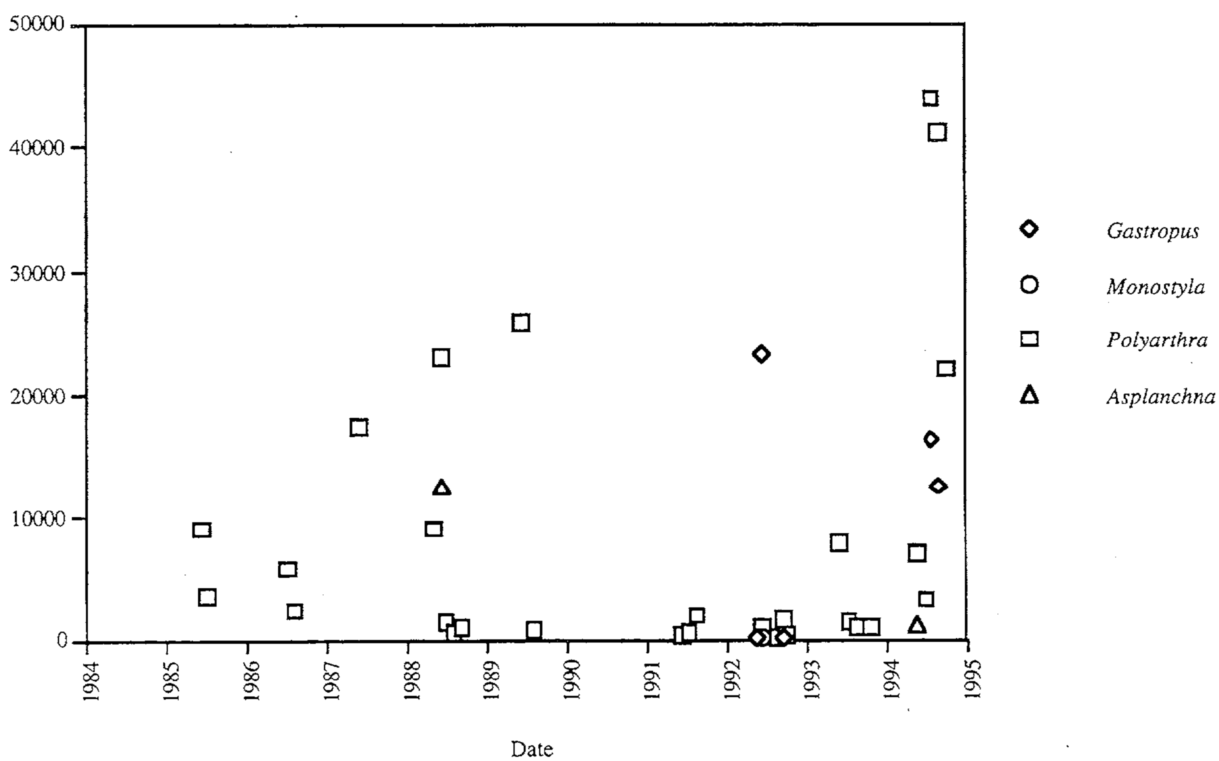


Figure 8.7.2.12. Old Wolf Lake Zooplankton: *Chaoborus*

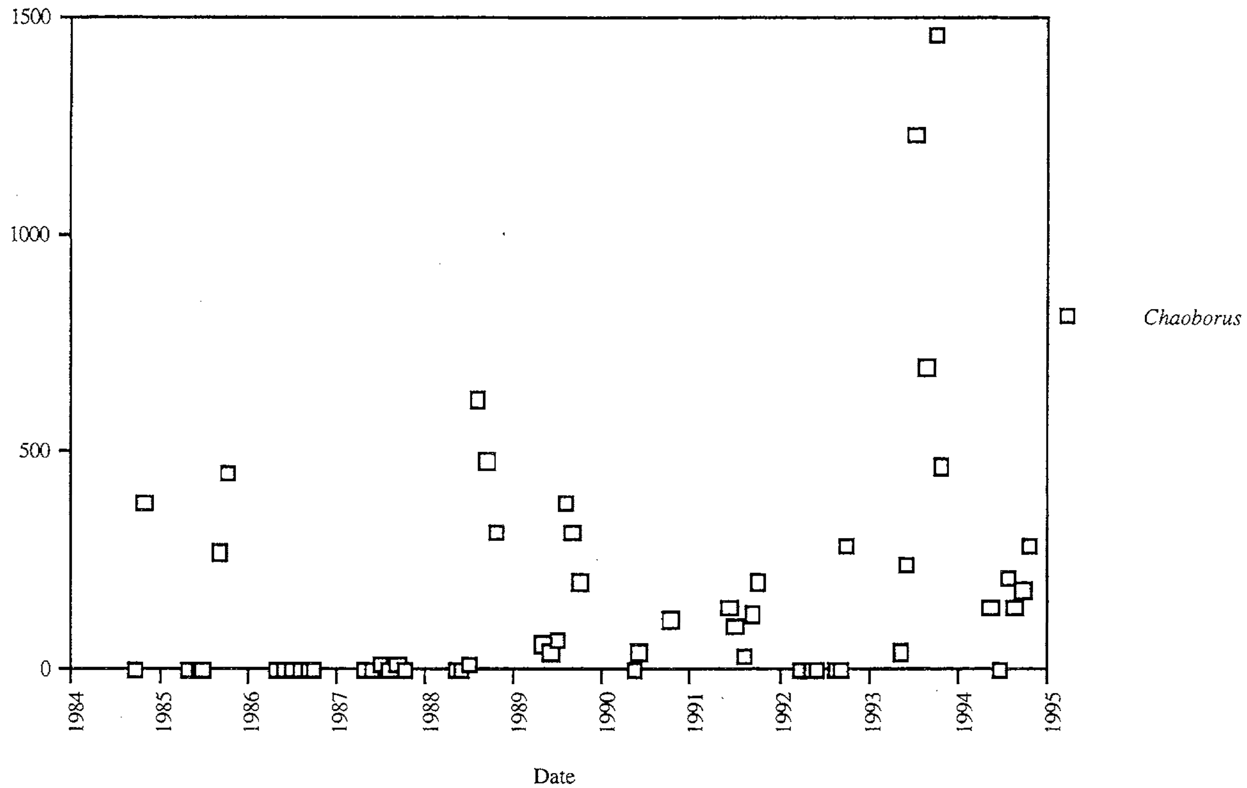


Figure 8.7.2.13. Old Wolf Lake Zooplankton: Total Animals/m2

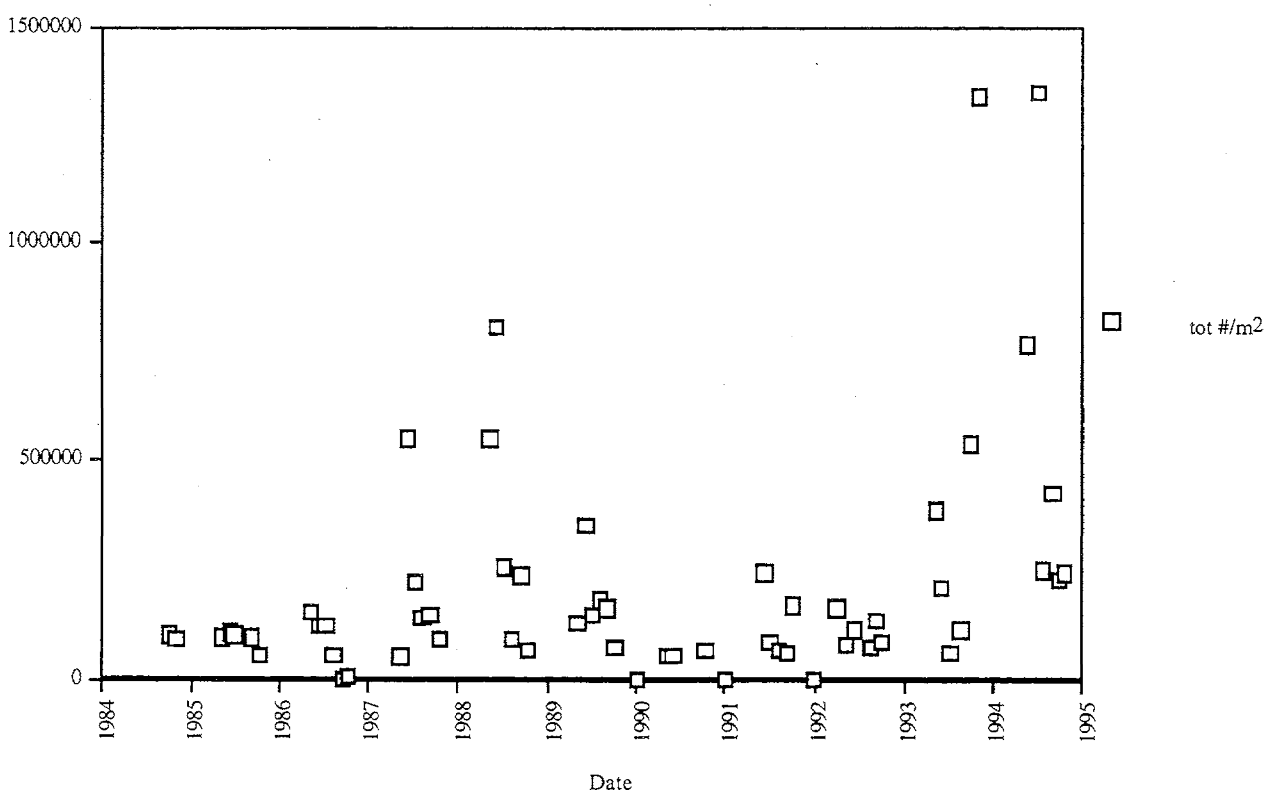


Figure 8.7.2.14. Old Wolf Lake Zooplankton: Biomass Comparisons.

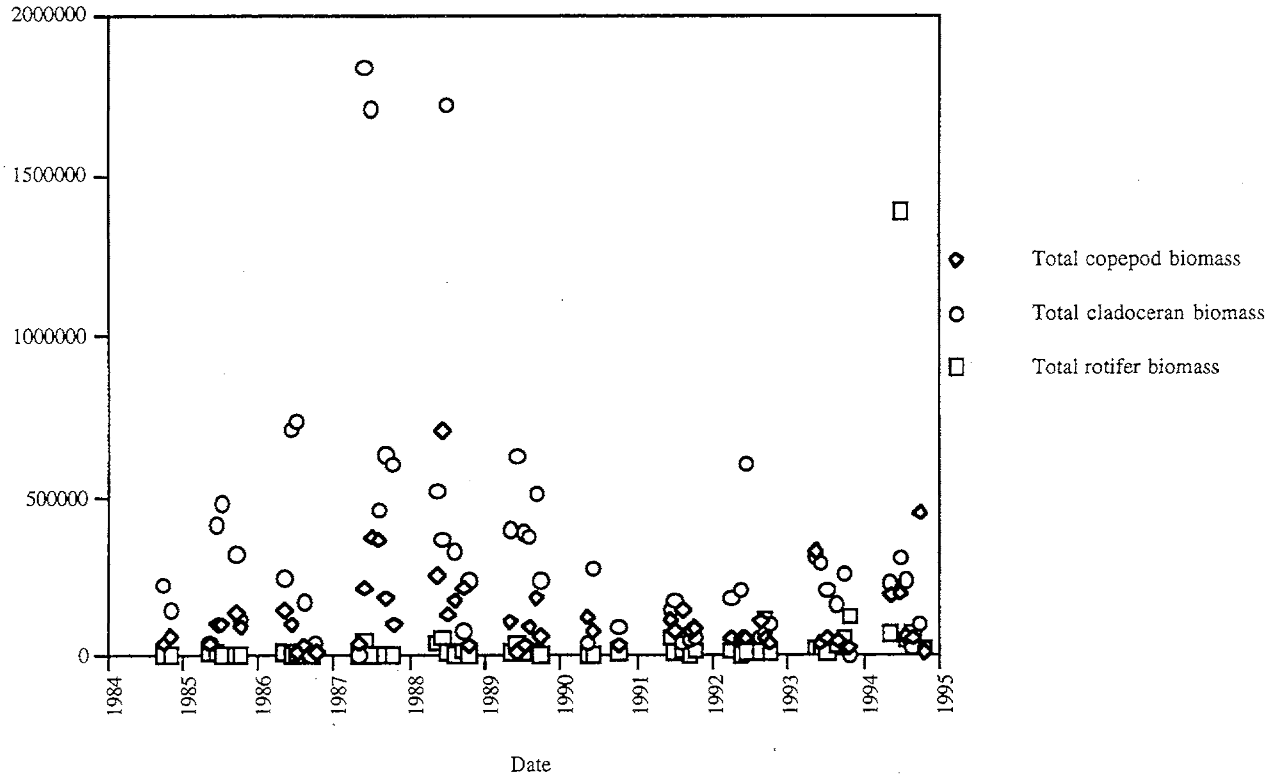


Figure 8.7.2.15. Old Wolf Lake Zooplankton: Total Zooplankton Biomass mg/m2

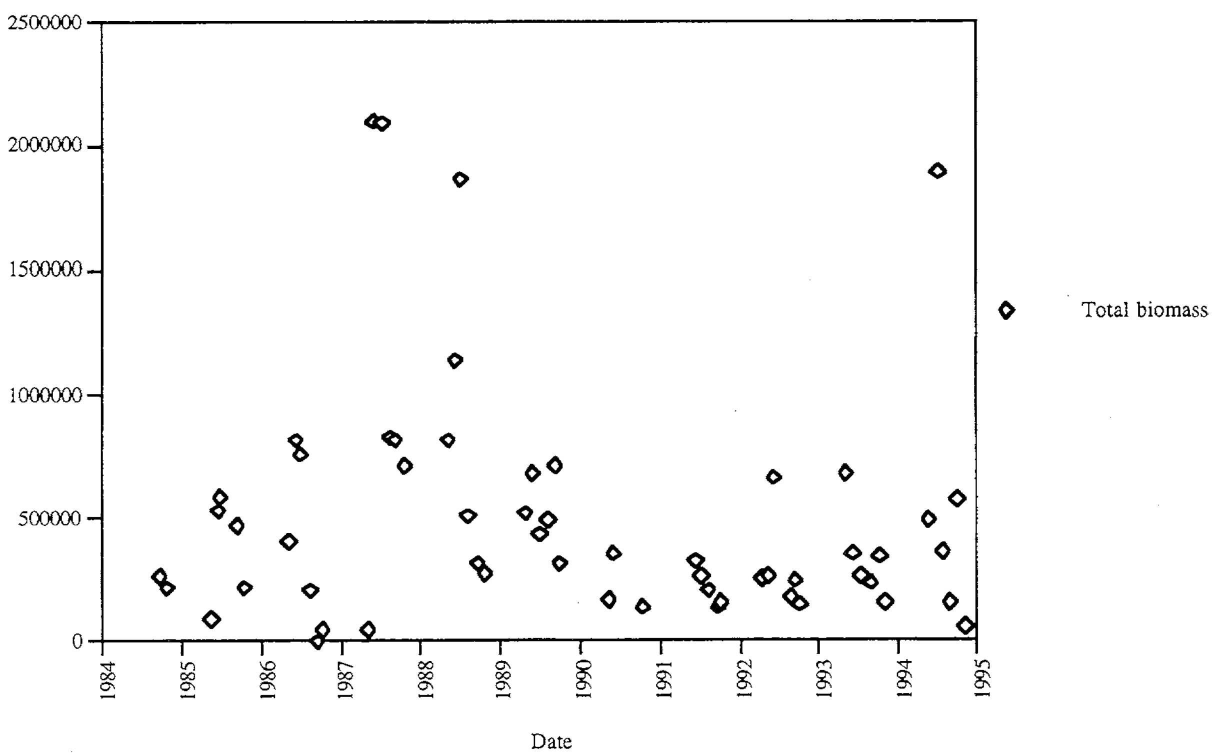


Figure 8.8.1.1. Spectacle Lake Phytoplankton: *Dinobryon.*

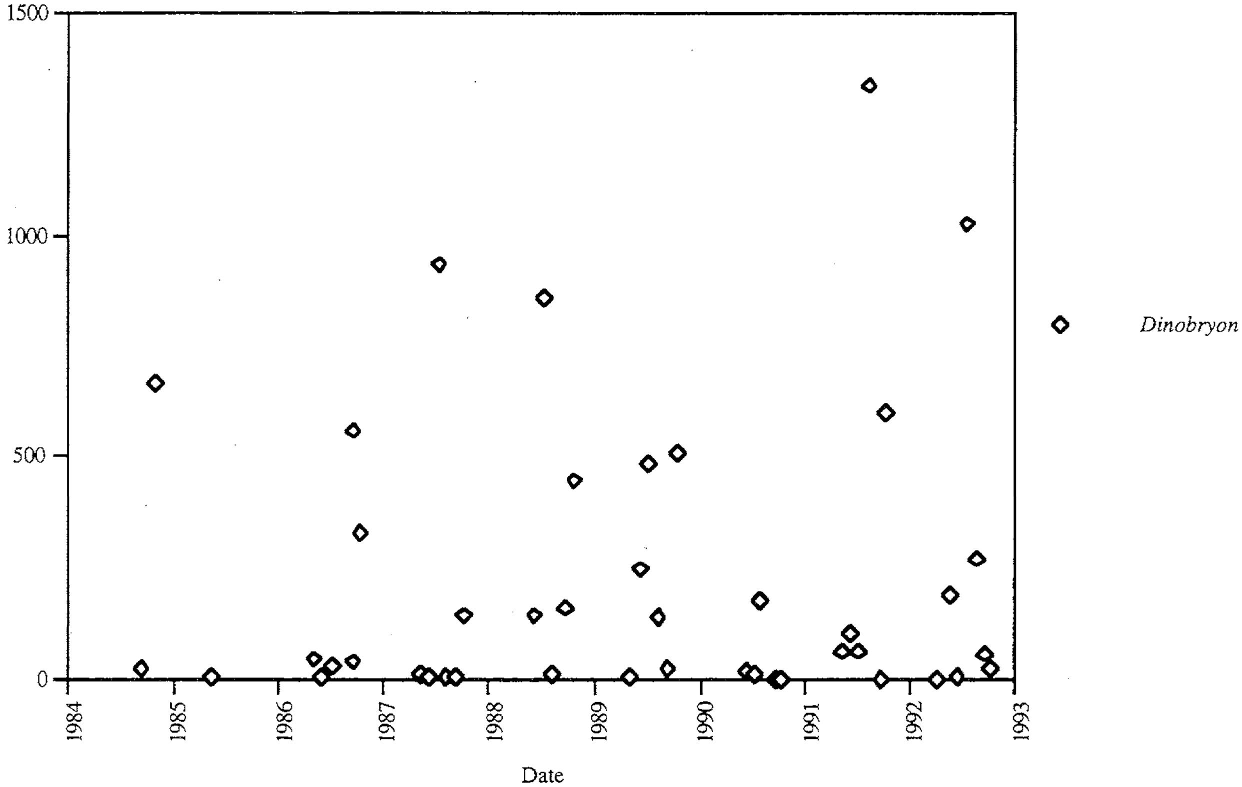


Figure 8.8.1.2. Spectacle Lake Phytoplankton: *Merismopedia.*

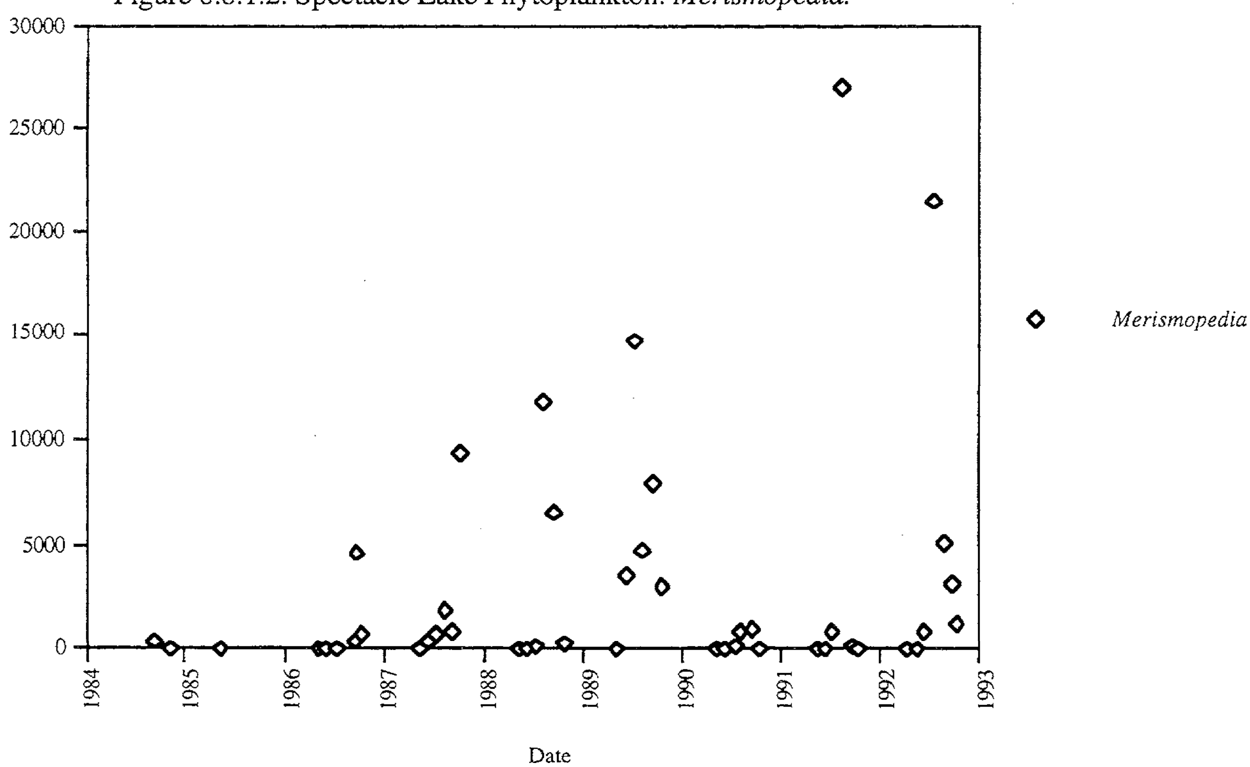


Figure 8.8.1.3. Spectacle Lake Phytoplankton: *Cryptomonas/Oocystis.*

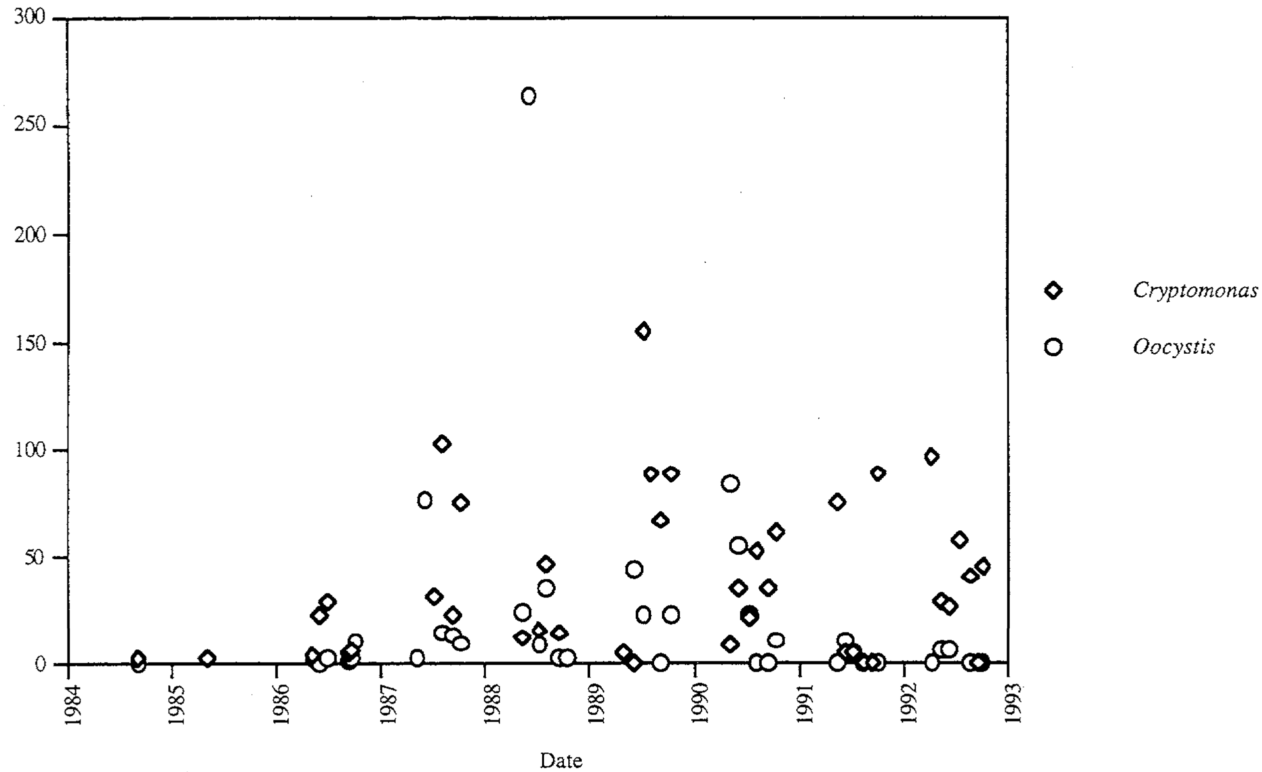


Figure 8.8.1.4. Spectacle Lake Phytoplankton: *Mallomonas/Chroomonas.*

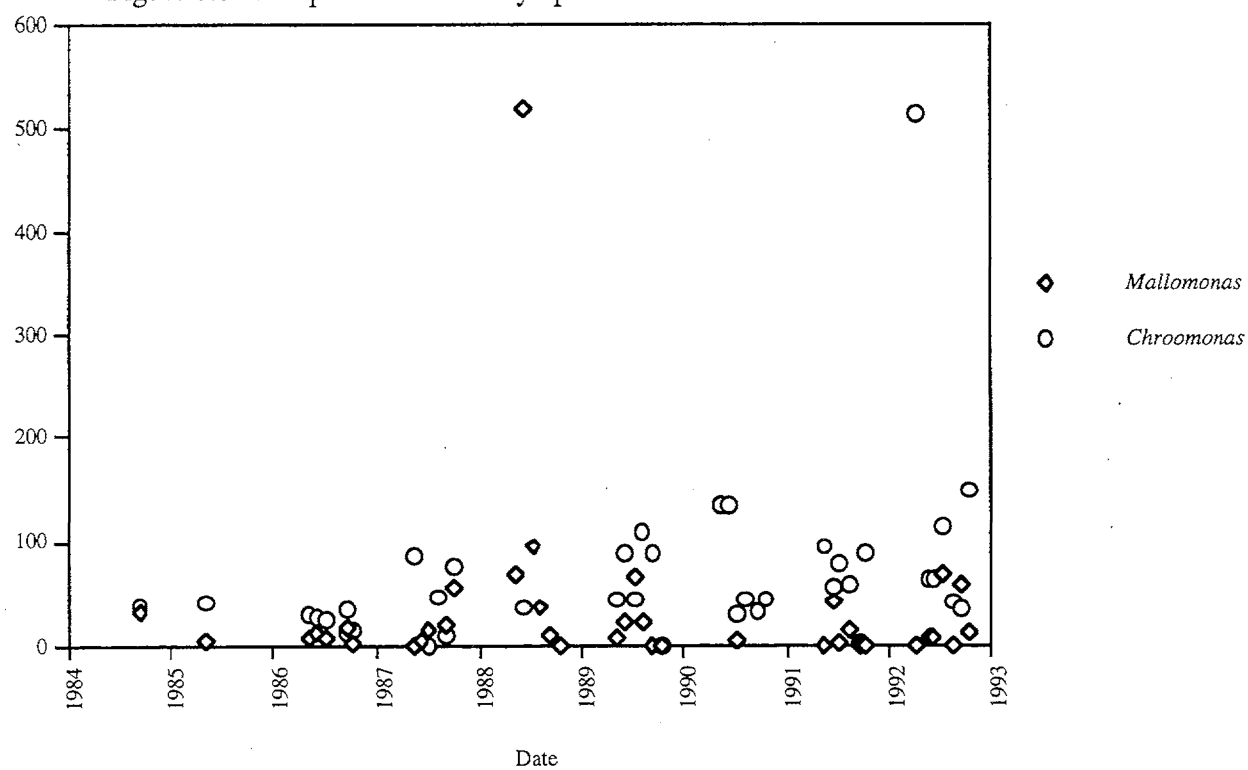


Figure 8.8.1.5. Spectacle Lake Phytoplankton: *Elakothrix.*

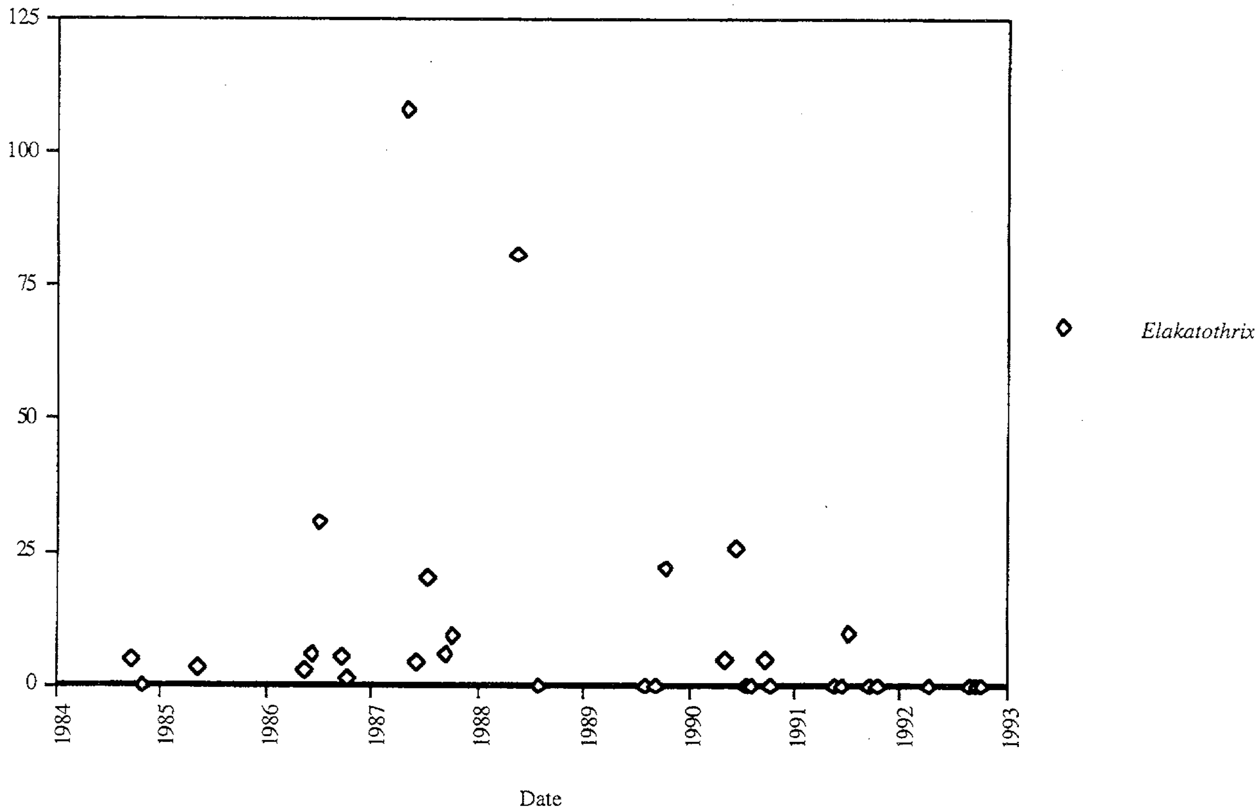


Figure 8.8.1.6. Spectacle Lake Phytoplankton: *Sphaerocystis/Gloeocystis/Botryococcus.*

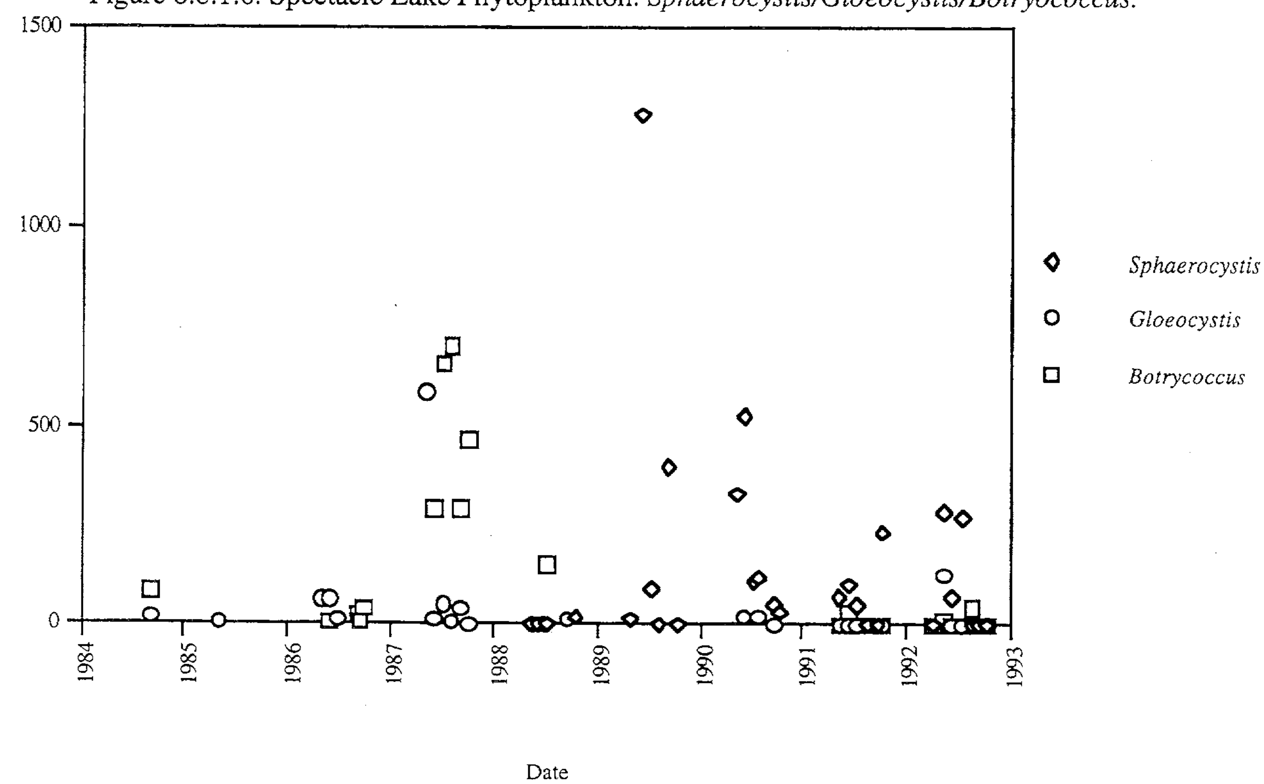


Figure 8.8.1.7. Spectacle Lake Phytoplankton: *Crucigenia/Quadrigula.*

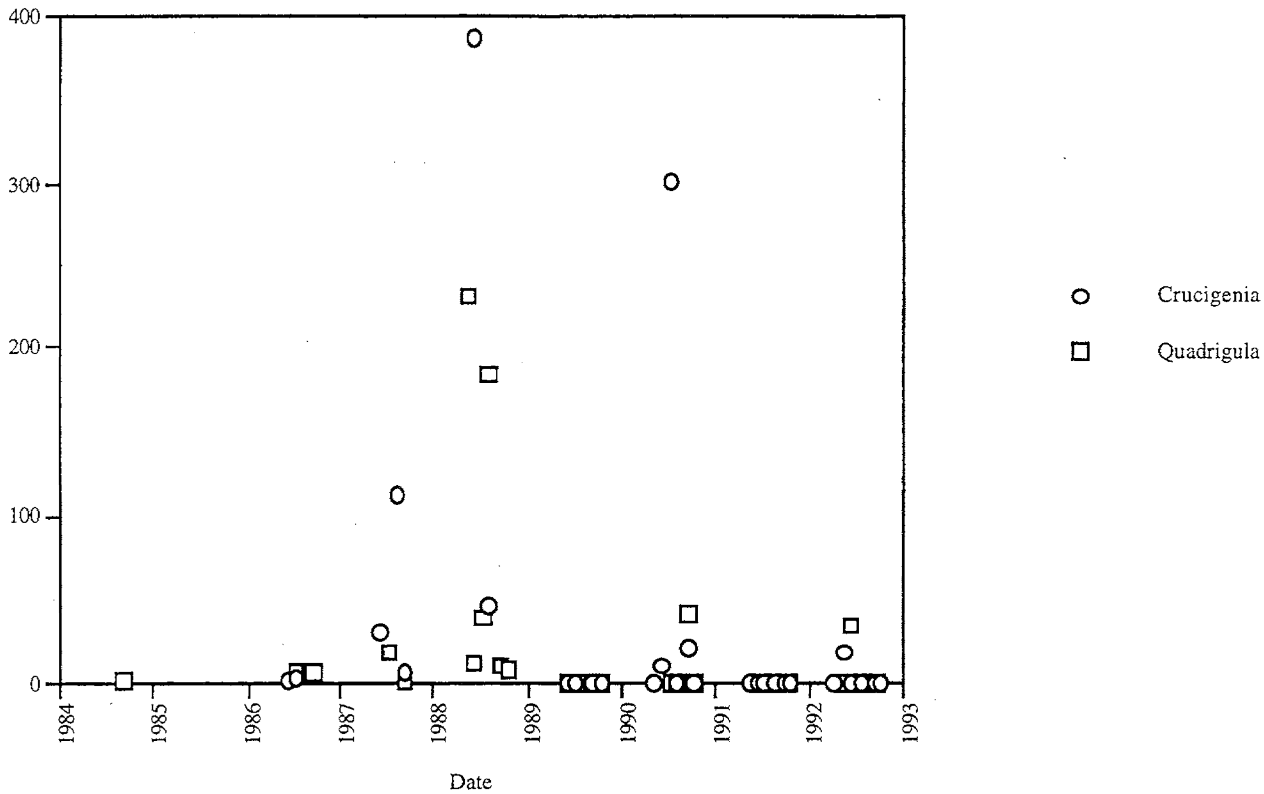


Figure 8.8.1.8. Spectacle Lake Phytoplankton: *Chroococcus.*

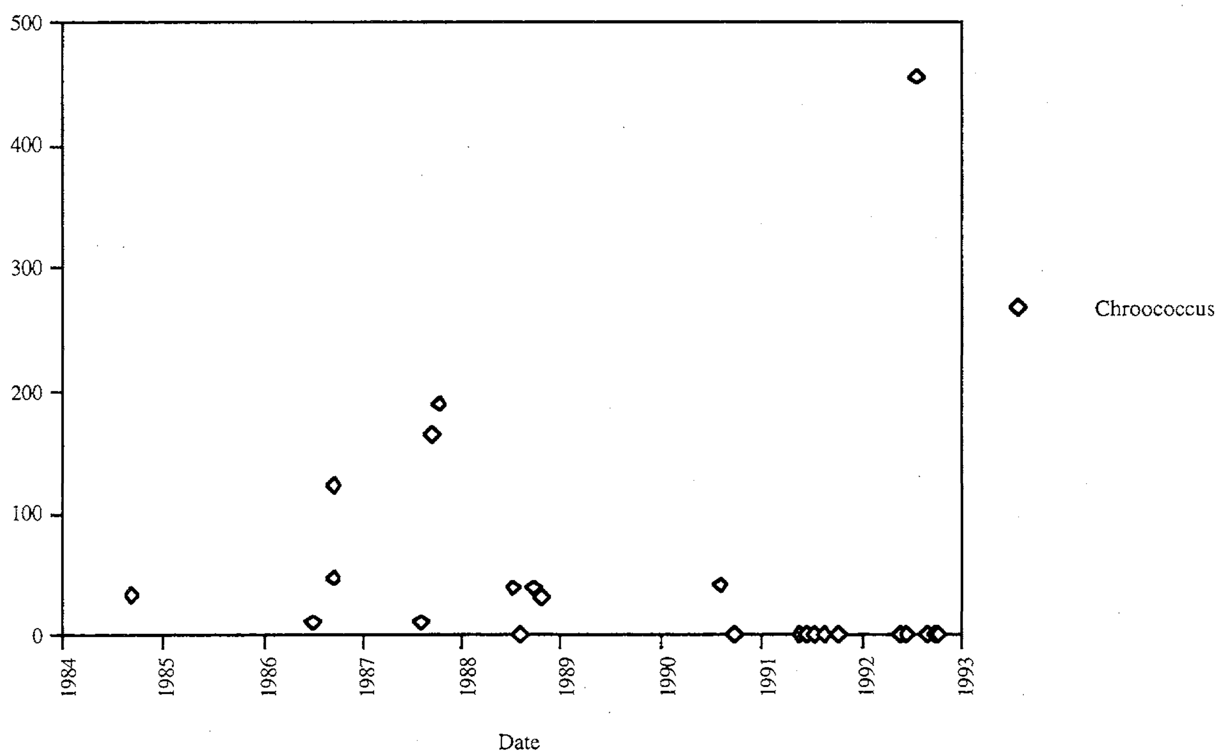


Figure 8.8.1.8. Spectacle Lake Phytoplankton: *Gomphosphaeria.*

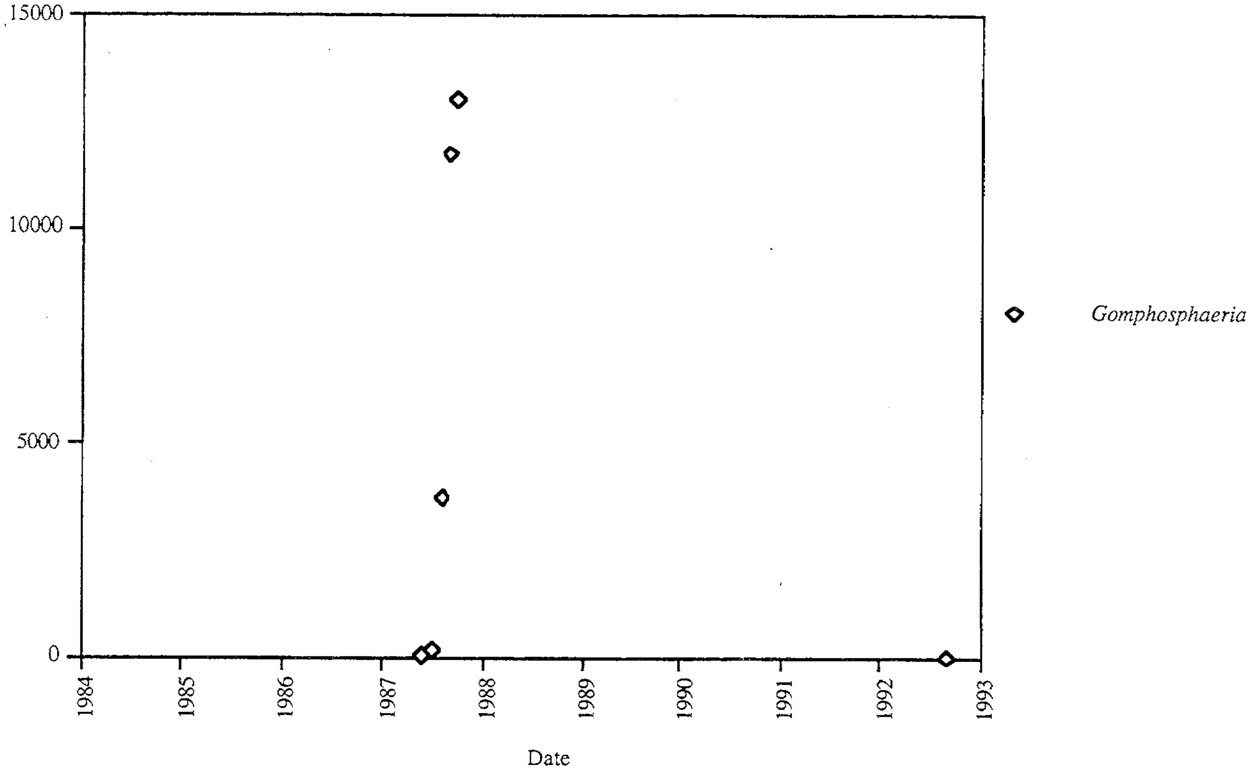


Figure 8.8.1.10. Spectacle Lake Phytoplankton: *Achnanthes/Navicula..*

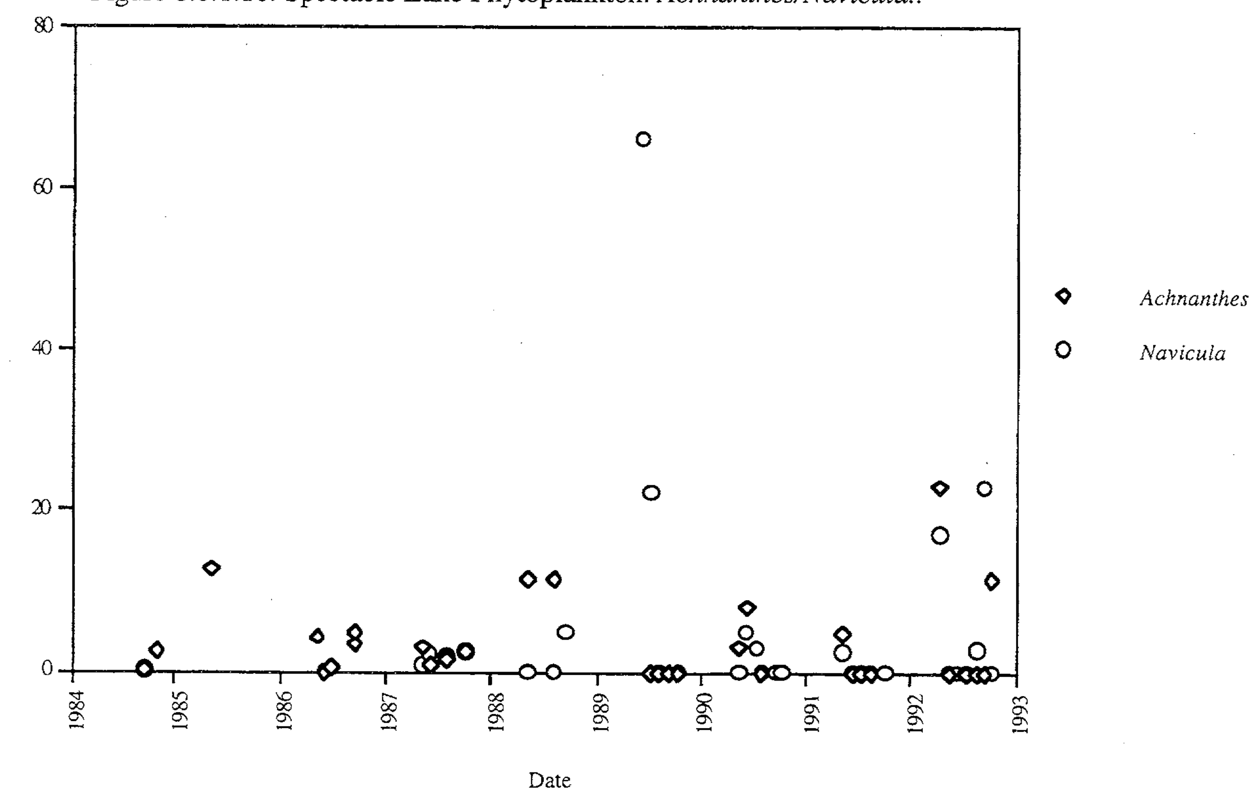


Figure 8.8.1.11. Spectacle Lake Phytoplankton: *Cymbella/Tabellaria.*

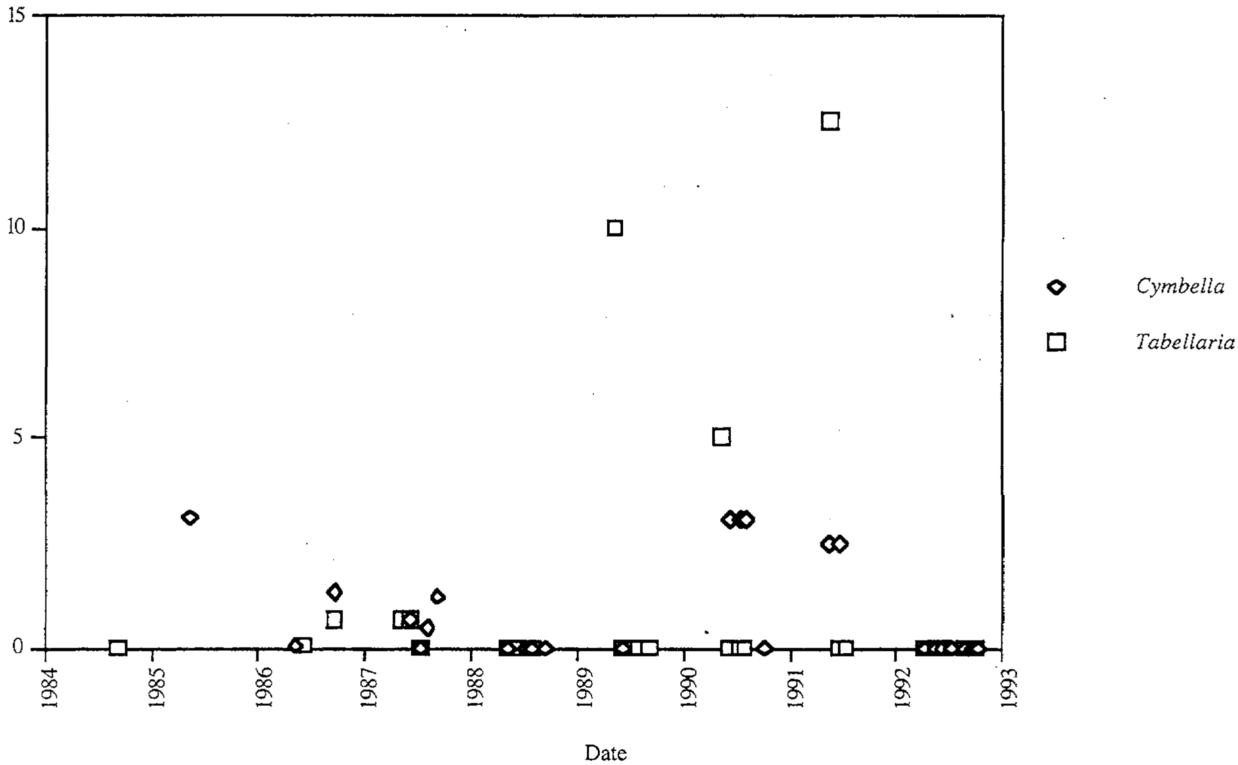


Figure 8.8.1.12. Spectacle Lake Phytoplankton: *Chrysosphaerella.*

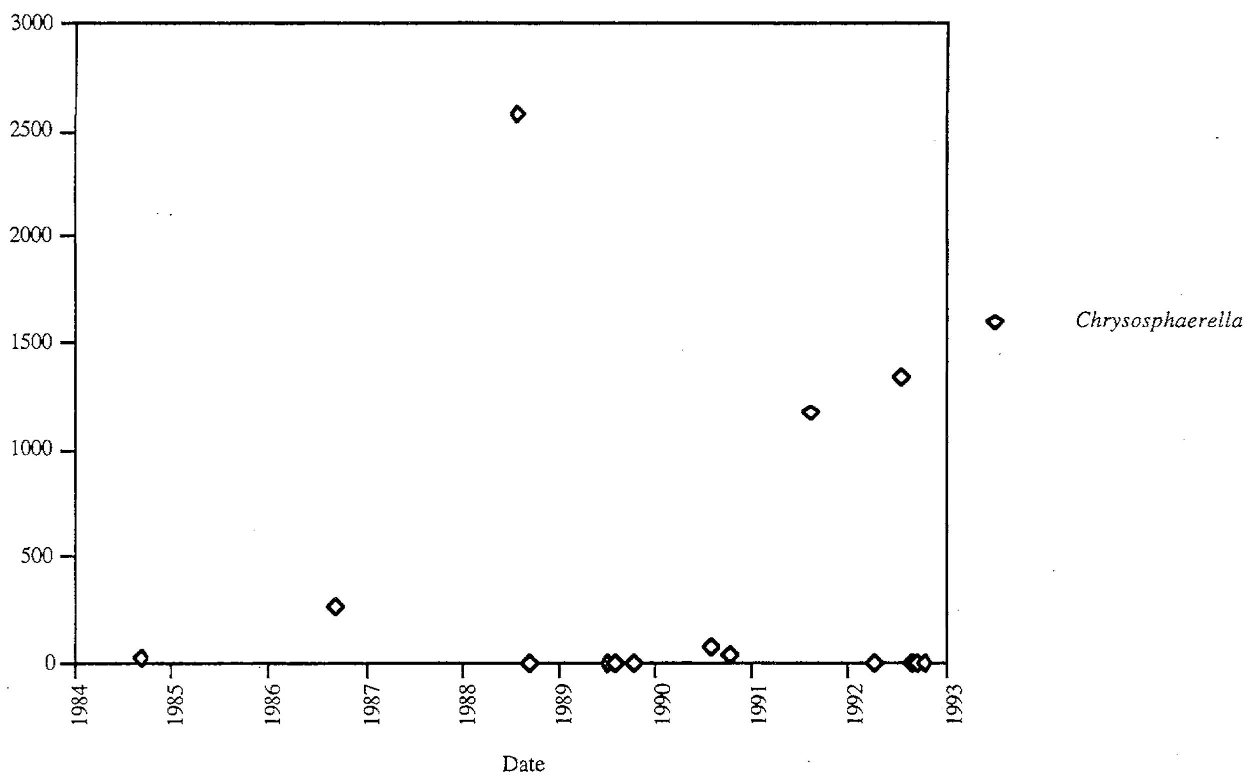


Figure 8.8.1.13. Spectacle Lake Phytoplankton: *Synura/Microcystis/Cyclotella.*

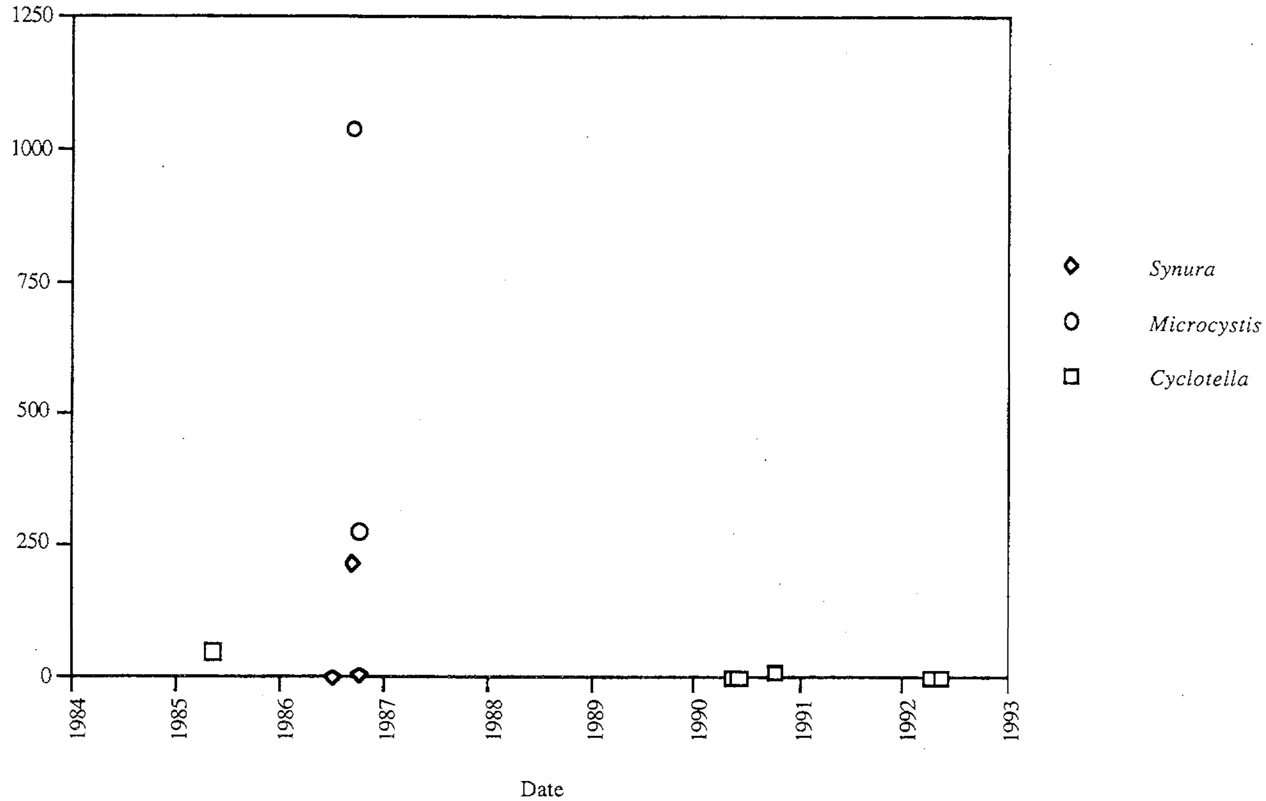


Figure 8.8.1.14. Spectacle Lake Phytoplankton: *Aphanothece/Aphanocapsa.*

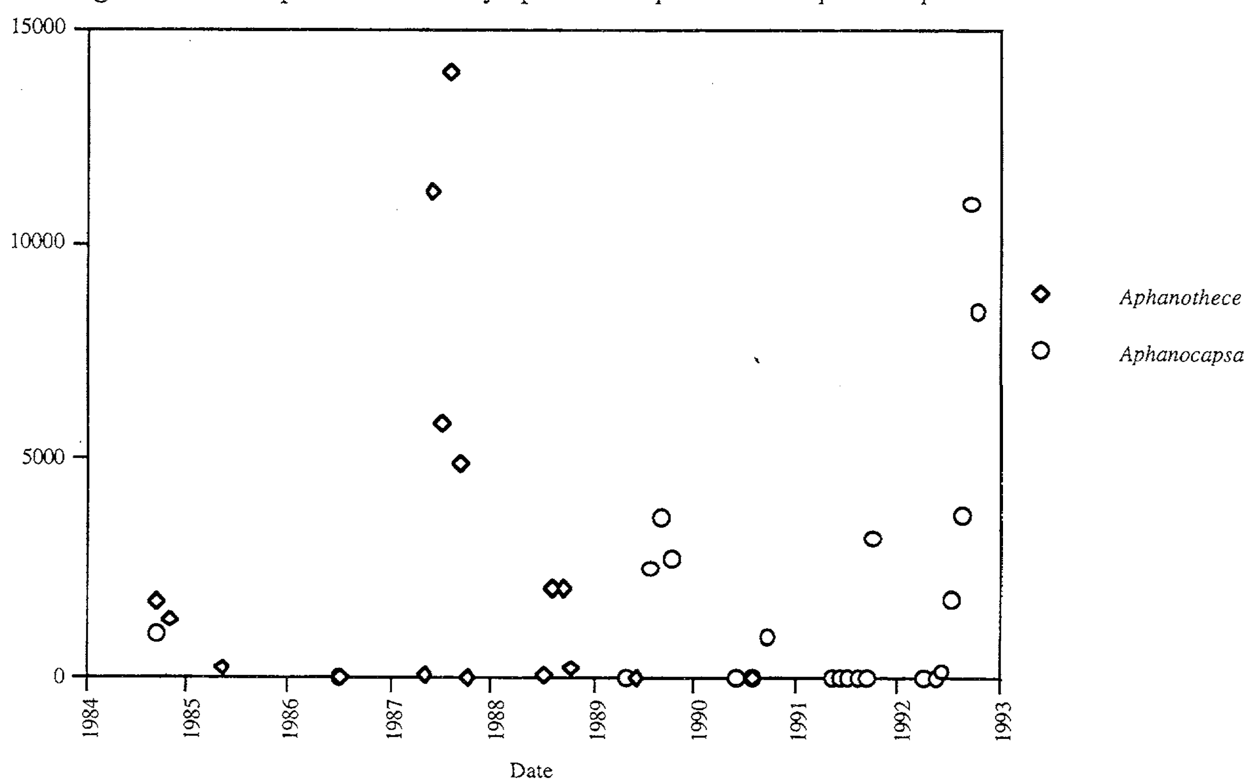


Figure 8.8.1.15. Spectacle Lake Phytoplankton: *Euglena*

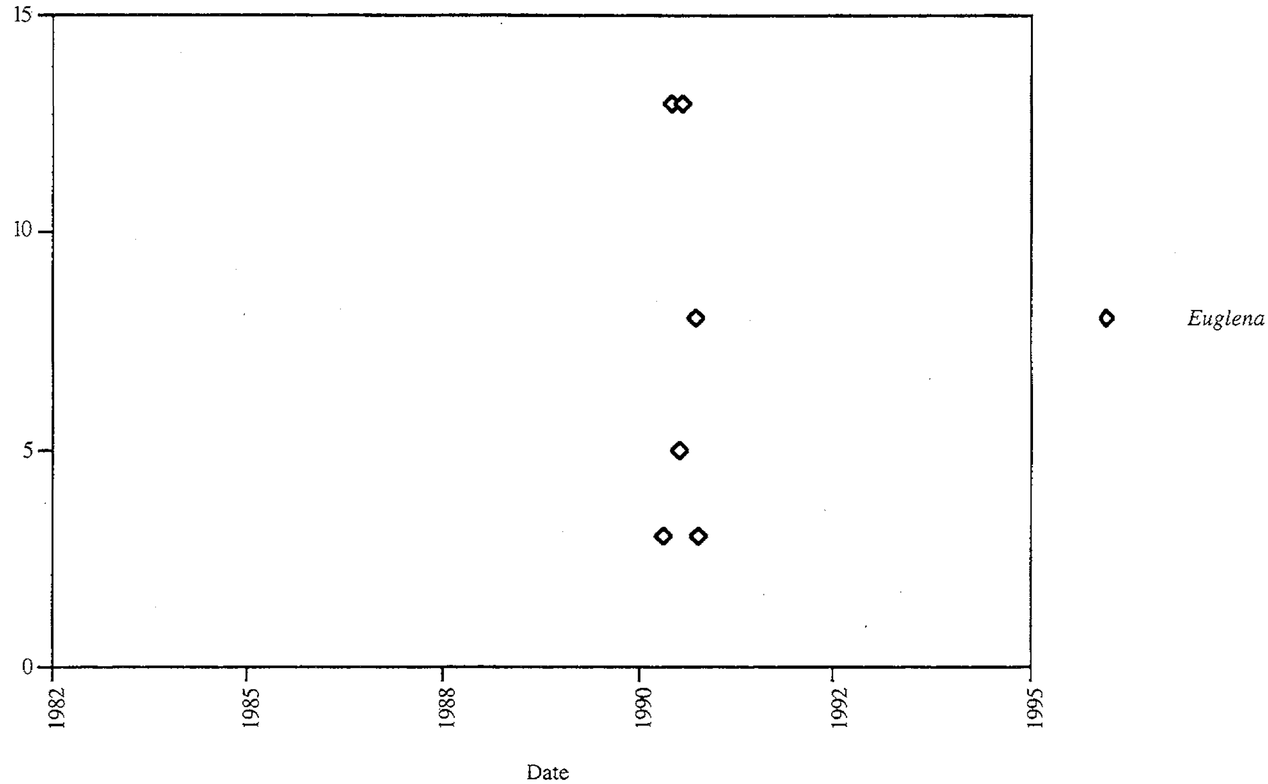


Figure 8.8.1.16. Spectacle Lake Phytoplankton: Total Cells/mL.

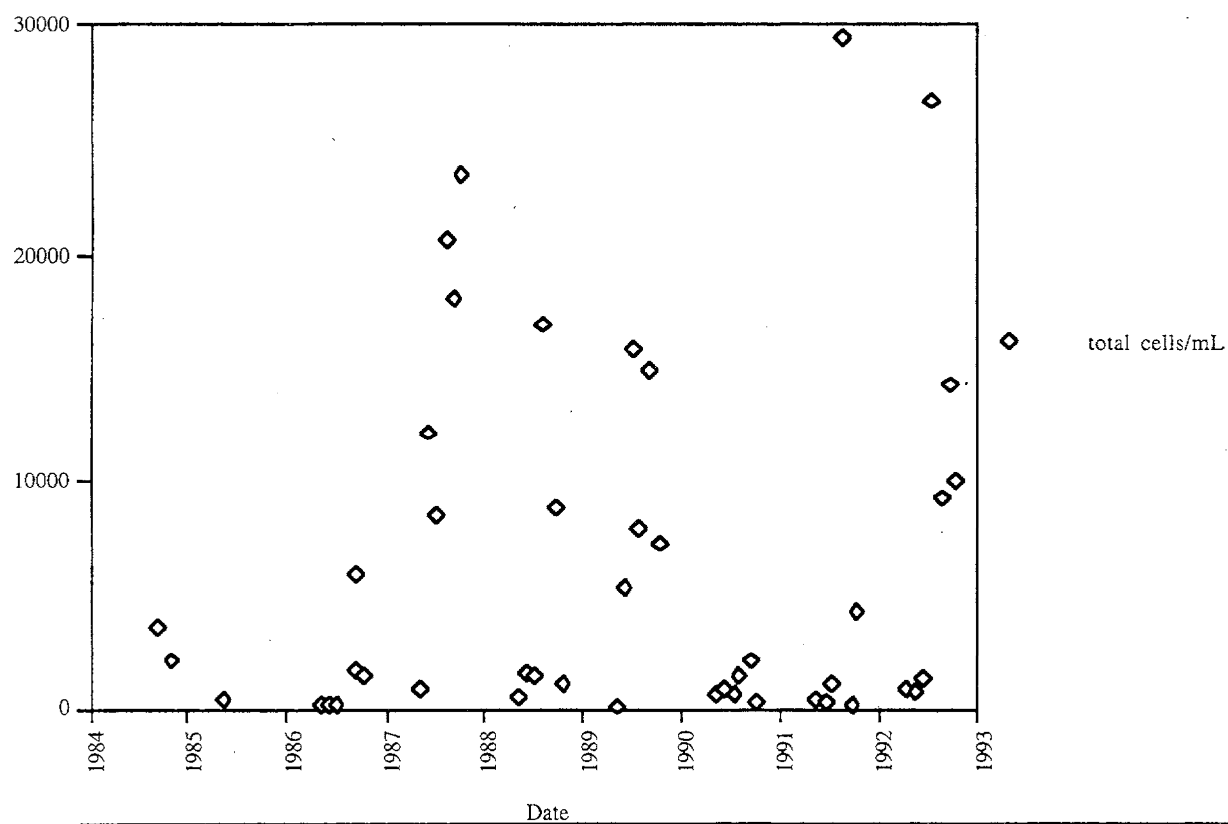


Figure 8.8.1.17. Spectacle Lake Phytoplankton: Chlorphyll a, μg/L

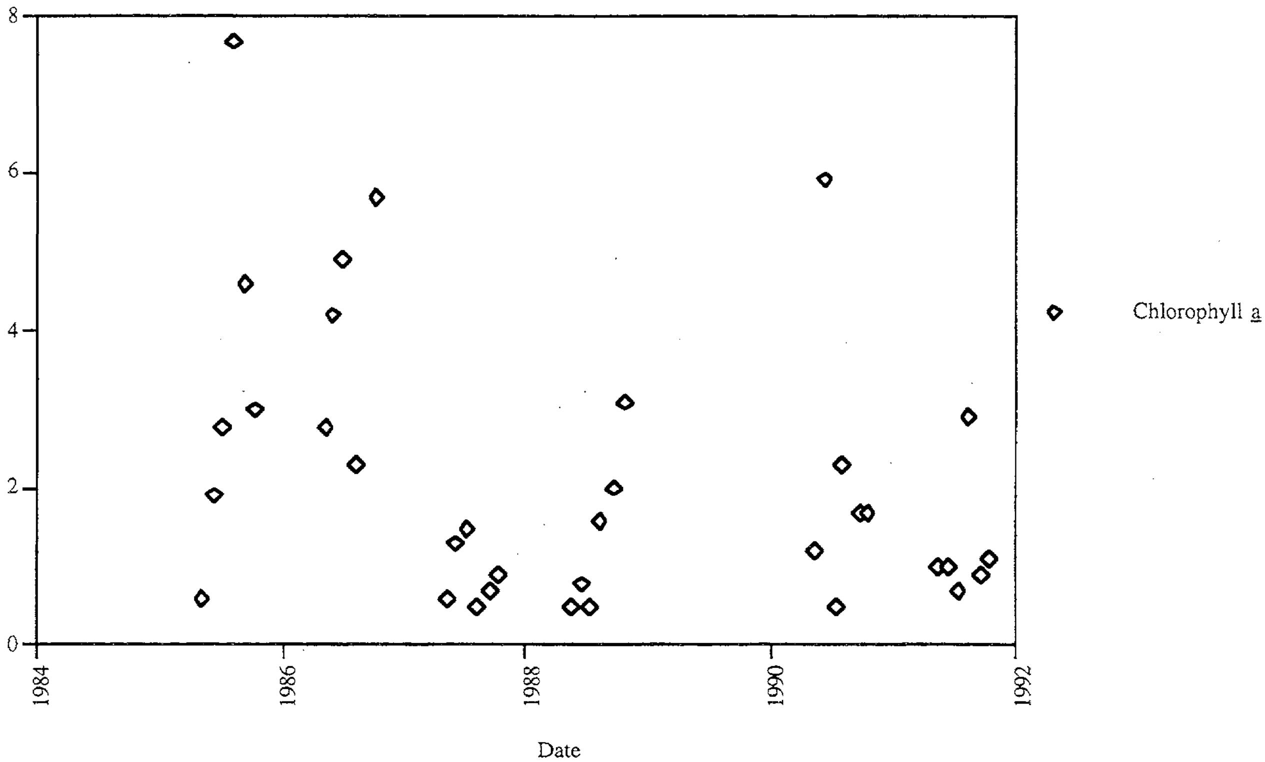


Figure 8.8.2.1. Spectacle Lake Zooplankton: *Diaptomus.*

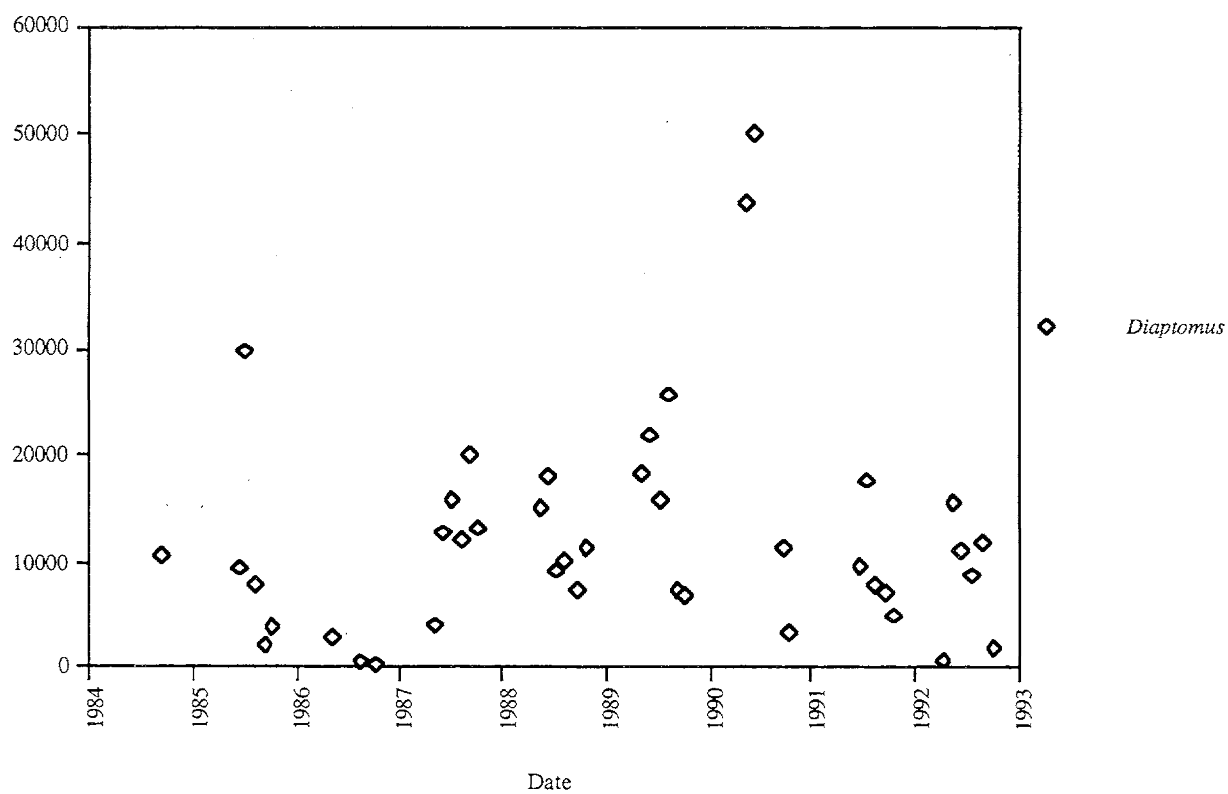


Figure 8.8.2.2. Spectacle Lake Zooplankton: *Cyclops/Diacyclops/Epishura.*

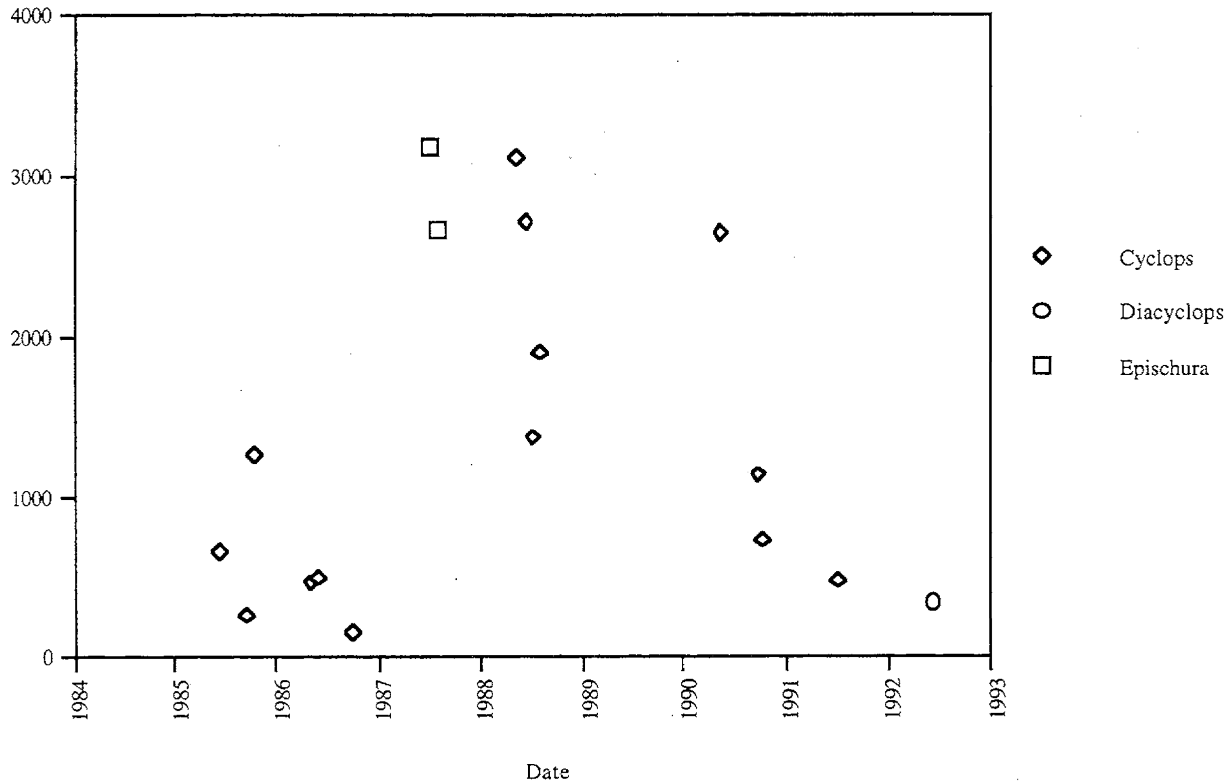


Figure 8.8.2.3. Spectacle Lake Zooplankton: Copepodites/Nauplii.

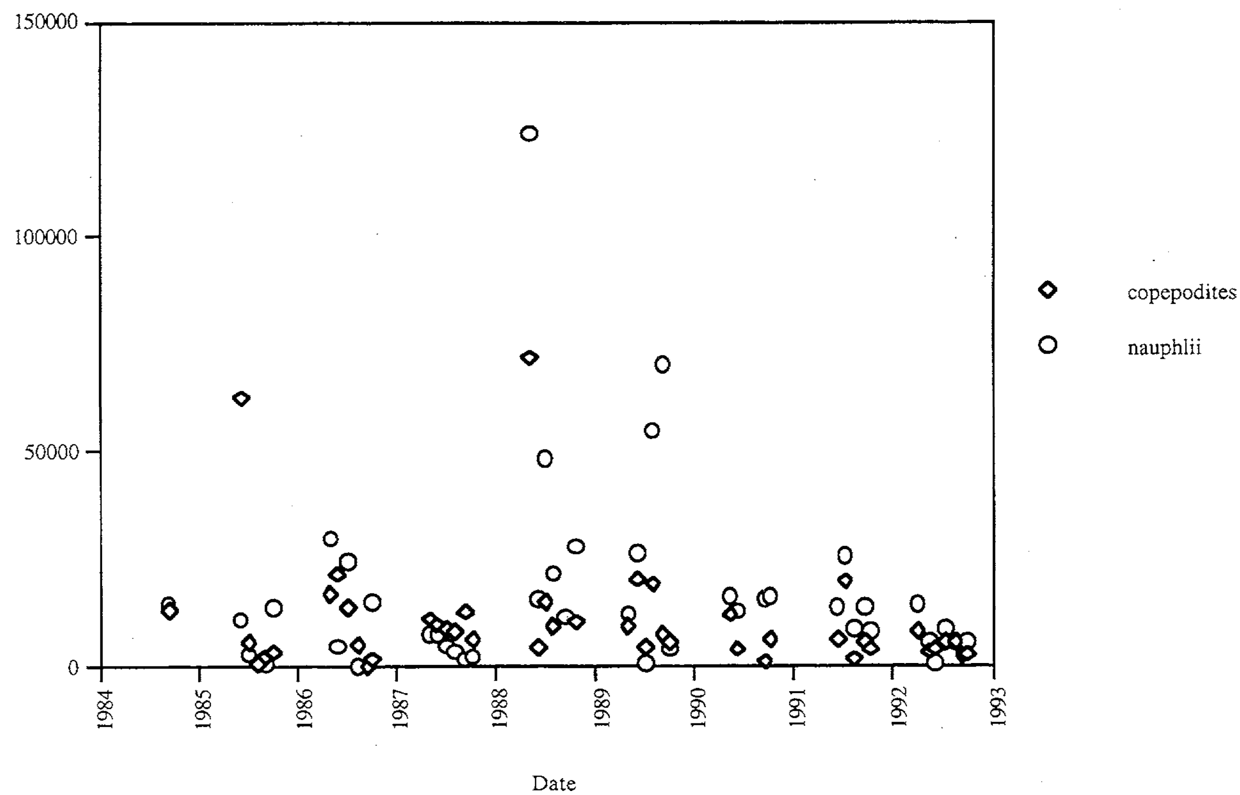


Figure 8.8.2.4. Spectacle Lake Zooplankton: *Daphnia.*

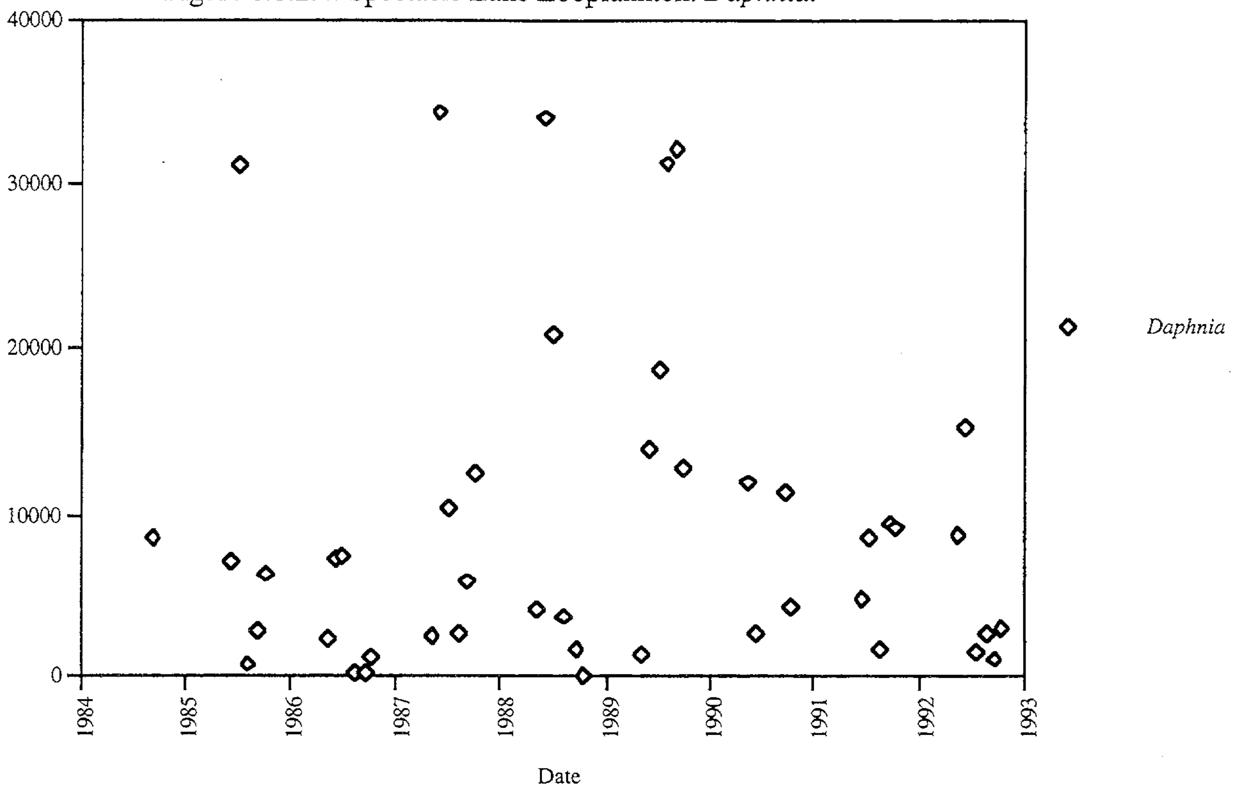


Figure 8.8.2.5. Spectacle Lake Zooplankton: *Holopedium/Bosmina.*

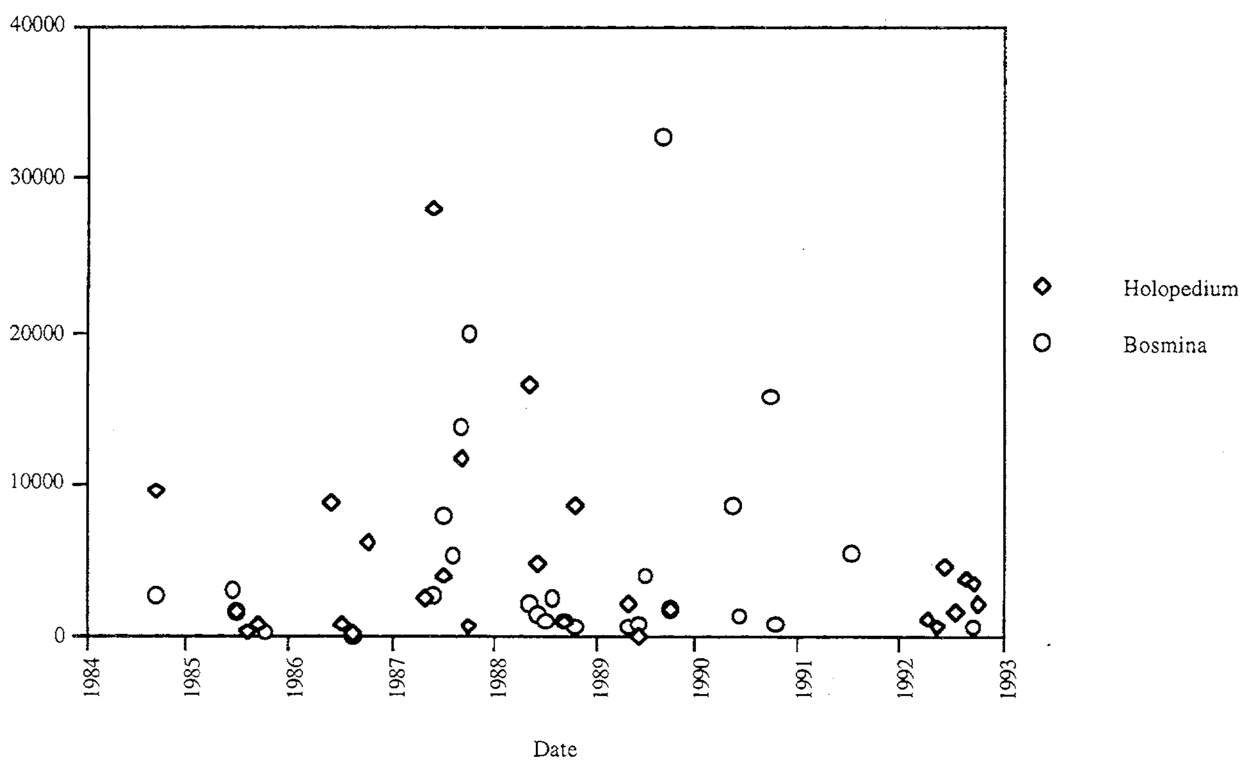


Figure 8.8.2.6. Spectacle Lake Zooplankton: *Diaphanosoma/Alonella.*

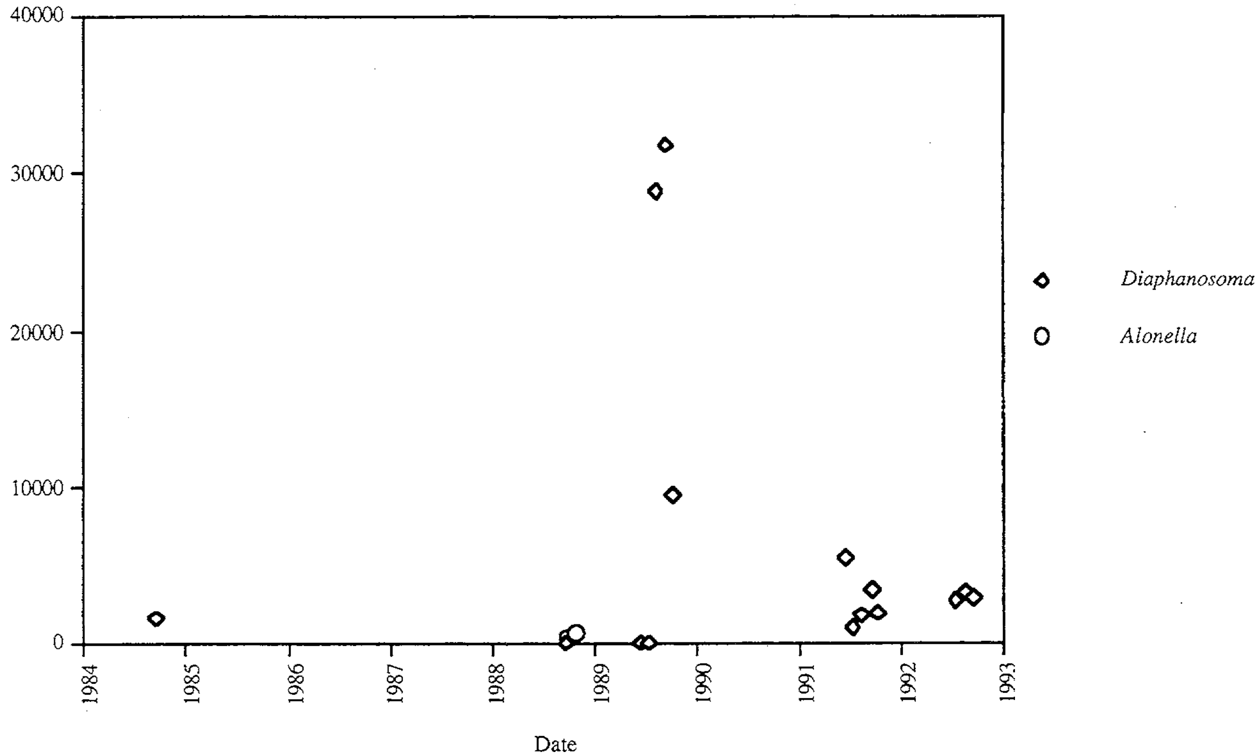


Figure 8.8.2.7. Spectacle Lake Zooplankton: *Kellicottia/Keratella.*

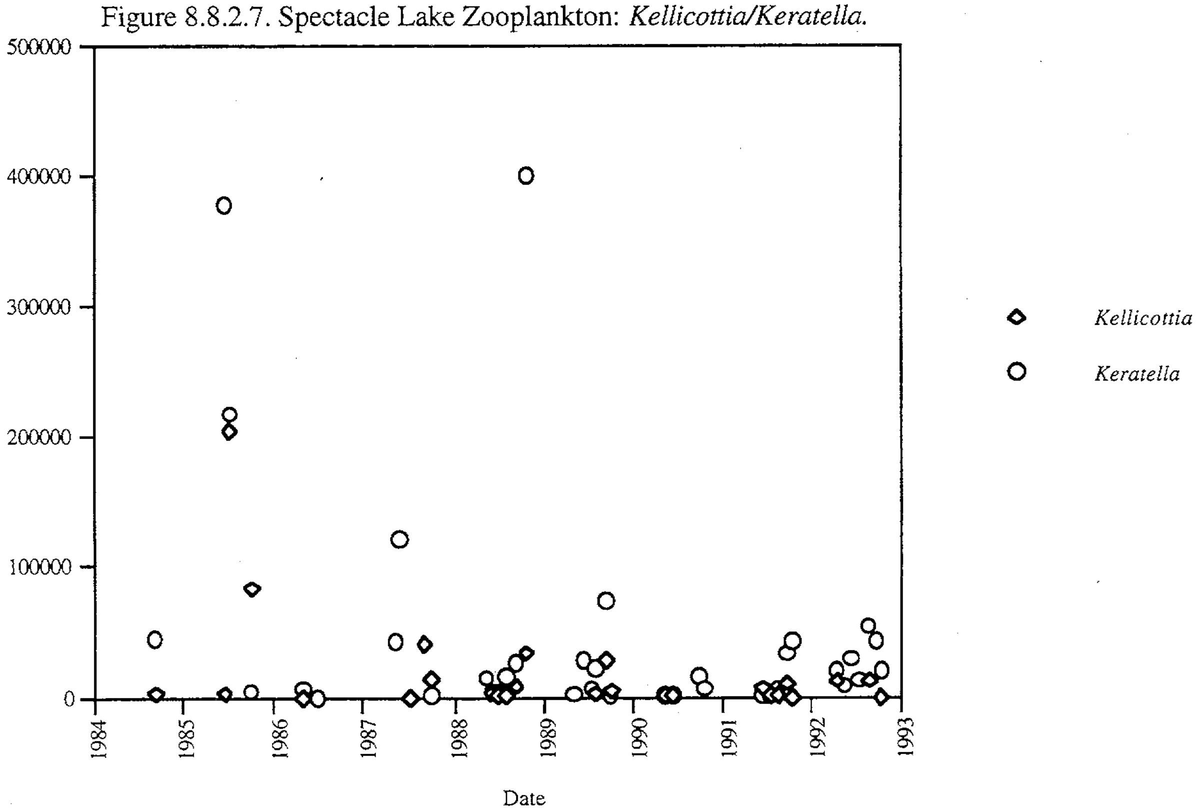


Figure 8.8.2.8. Spectacle Lake Zooplankton: Rare Rotifers.

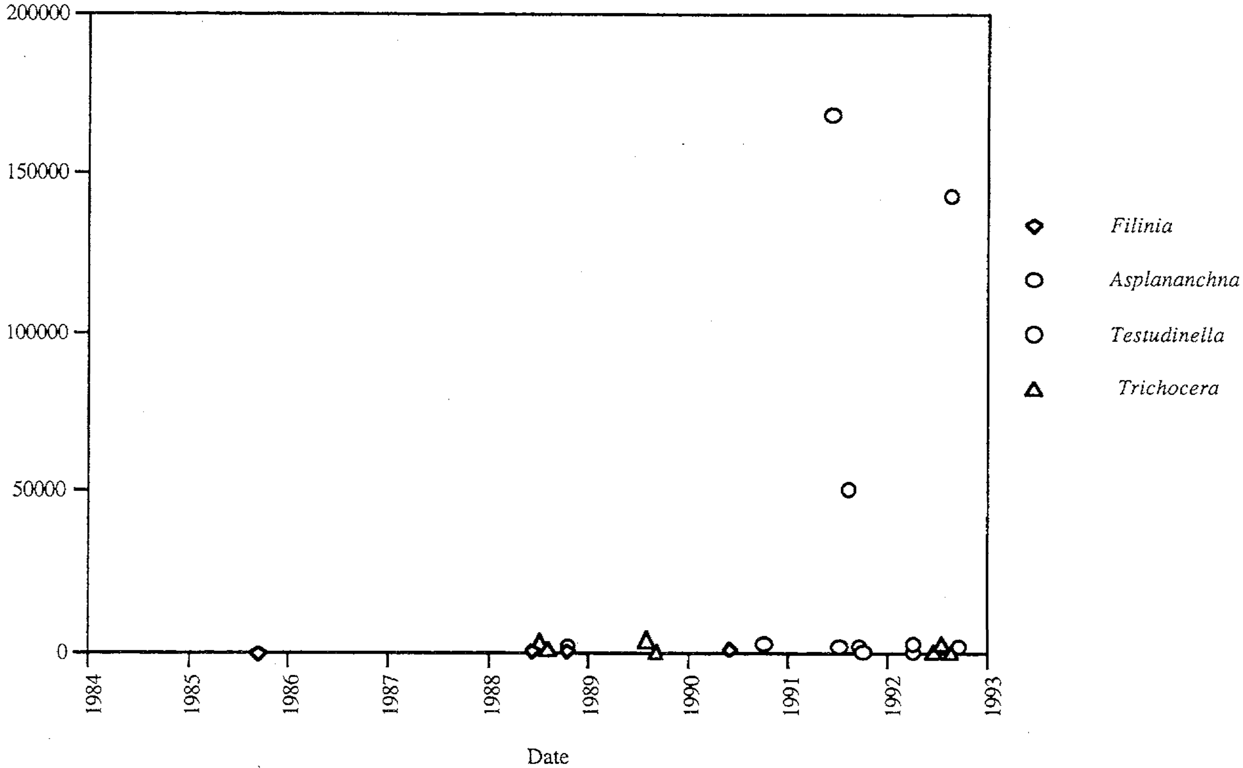


Figure 8.8.2.9. Spectacle Lake Zooplankton: Rare Rotifers 2

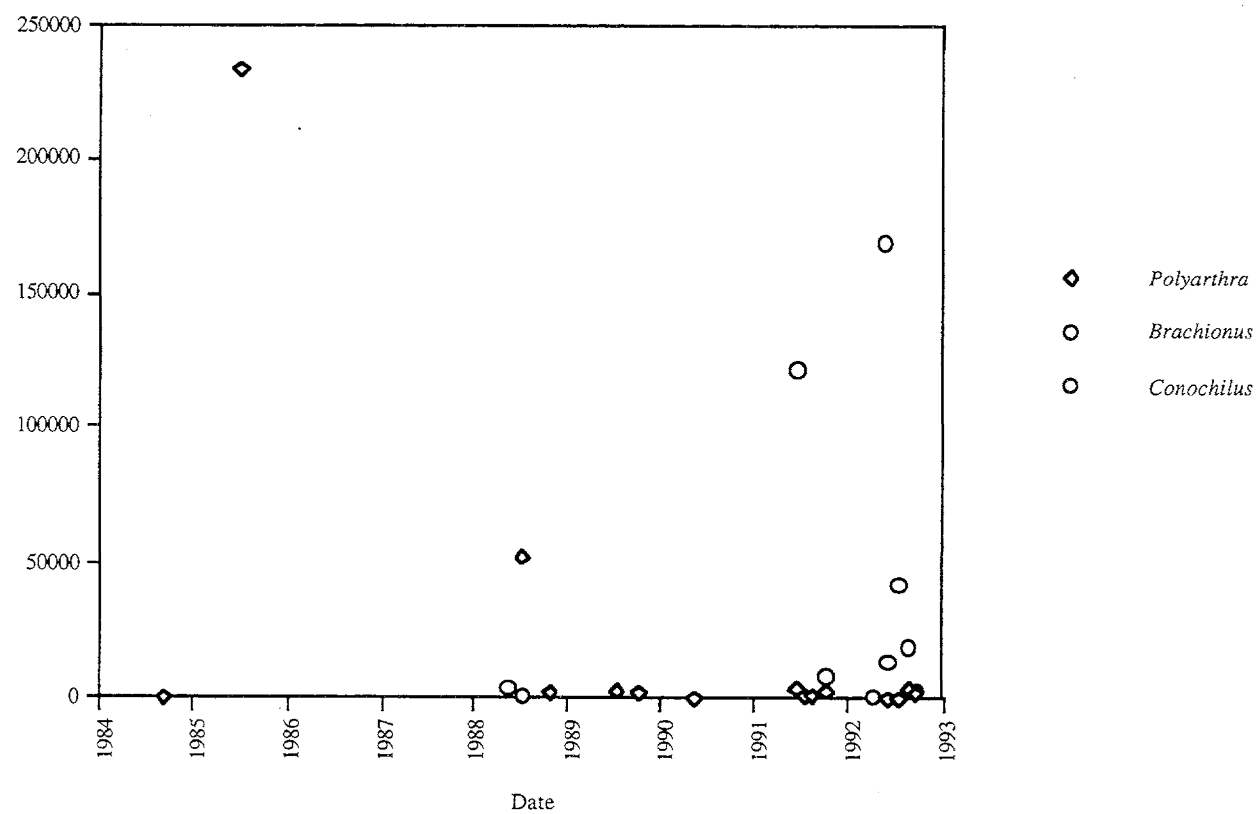


Figure 8.8.2.10. Spectacle Lake Zooplankton: *Chaoborus.*

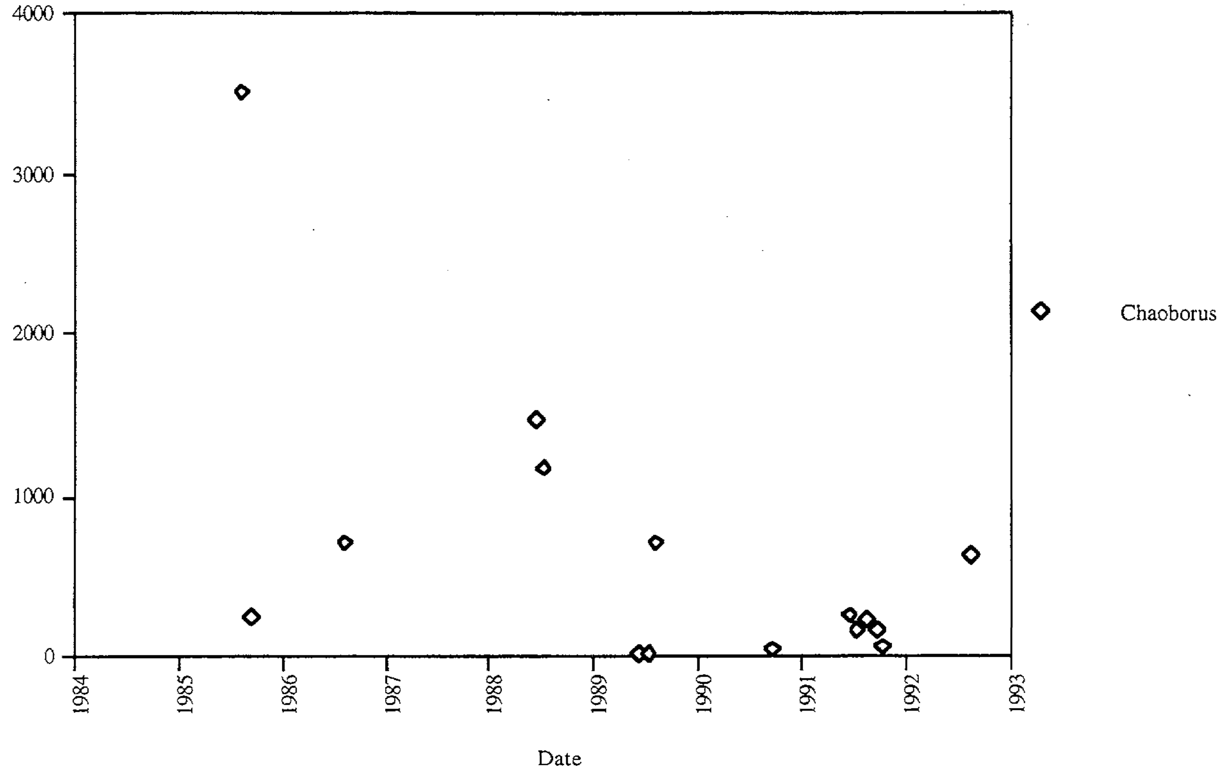


Figure 8.8.2.11. Spectacle Lake Zooplankton: Total Animals/m2.

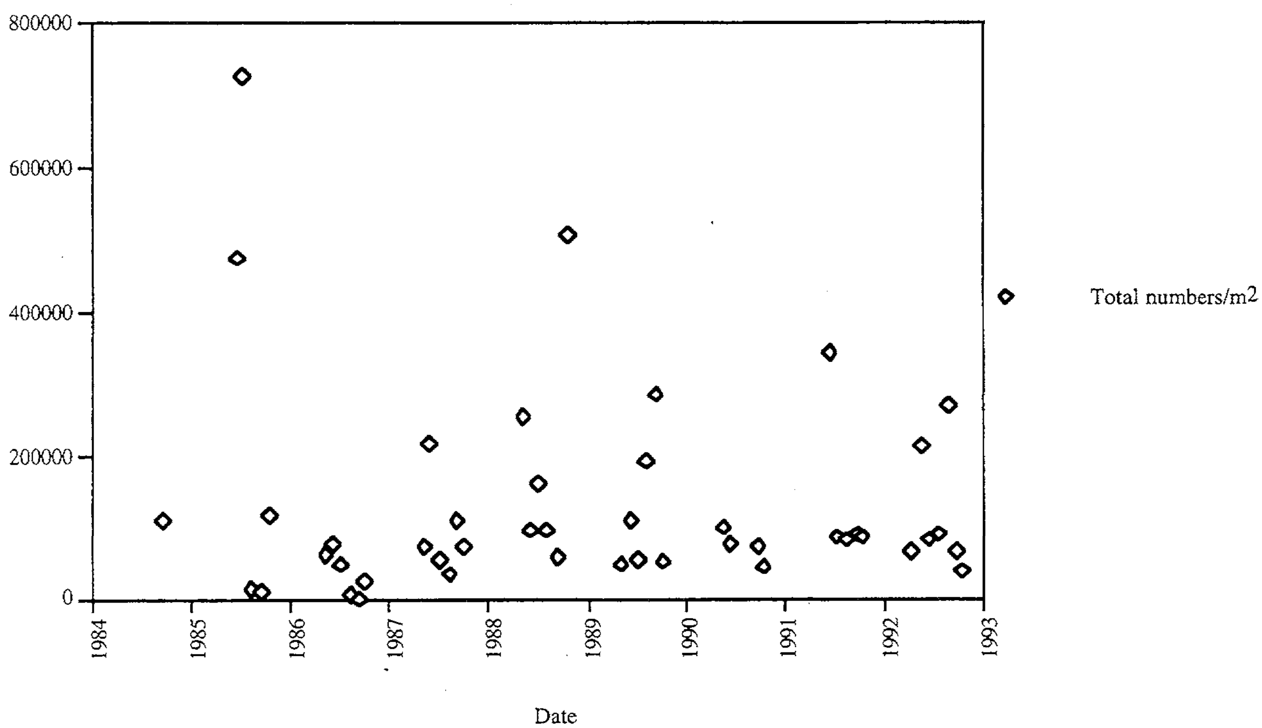


Figure 6.2.12. Spectacle Lake Zooplankton: Total Biomass μg/m2.

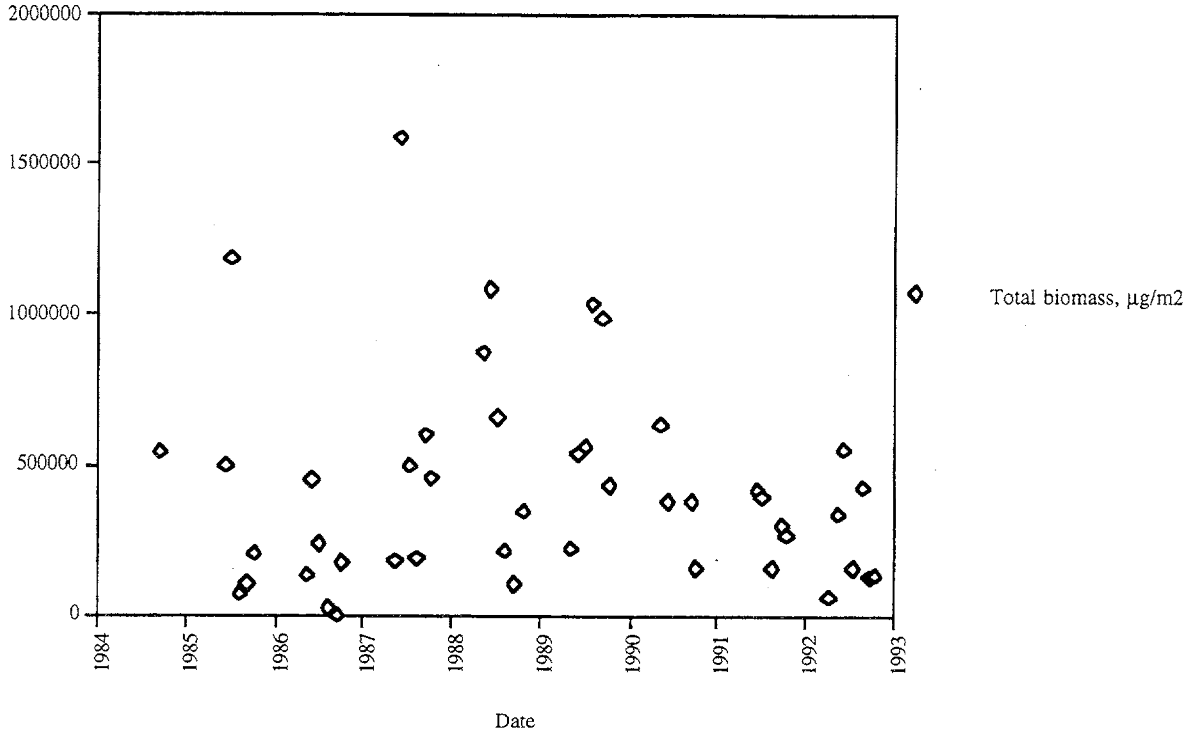


Figure 8.2.2.13. Spectacle Lake Zooplankton: Biomass Comparisons.

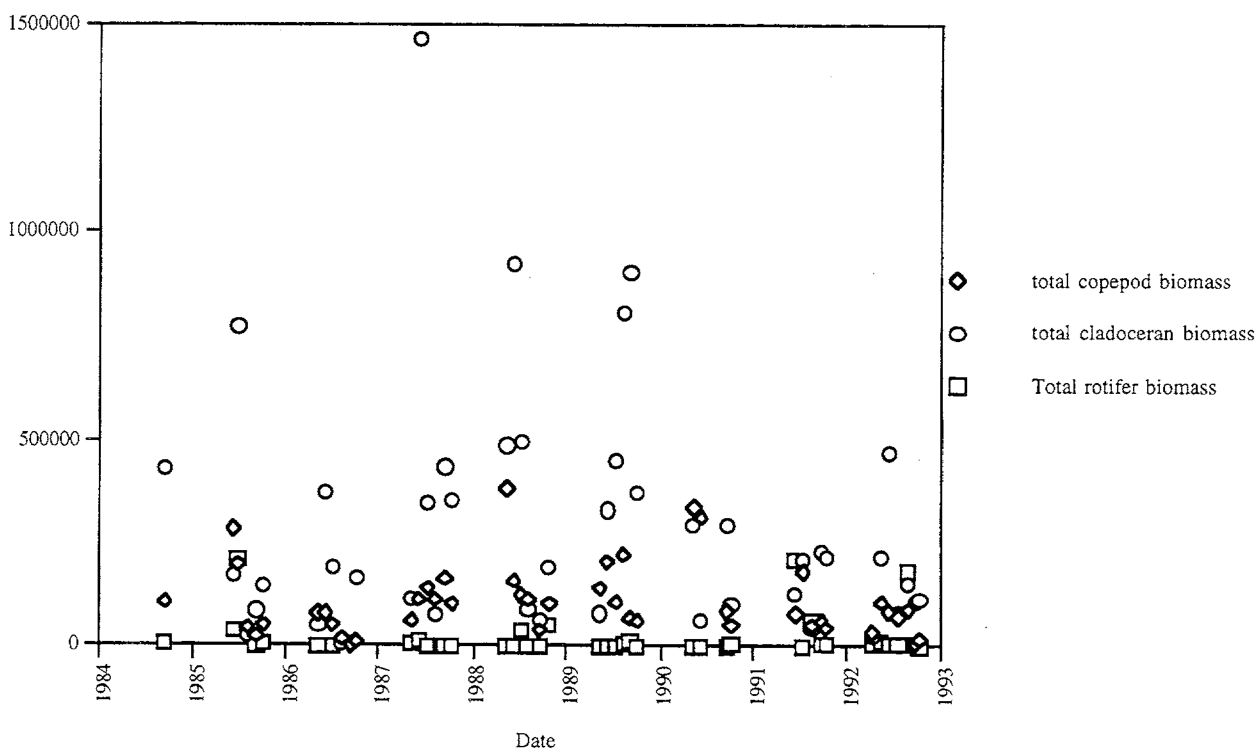


Figure 8.9.1.1. Stocking Lake Phytoplankton: *Dinobryon.*

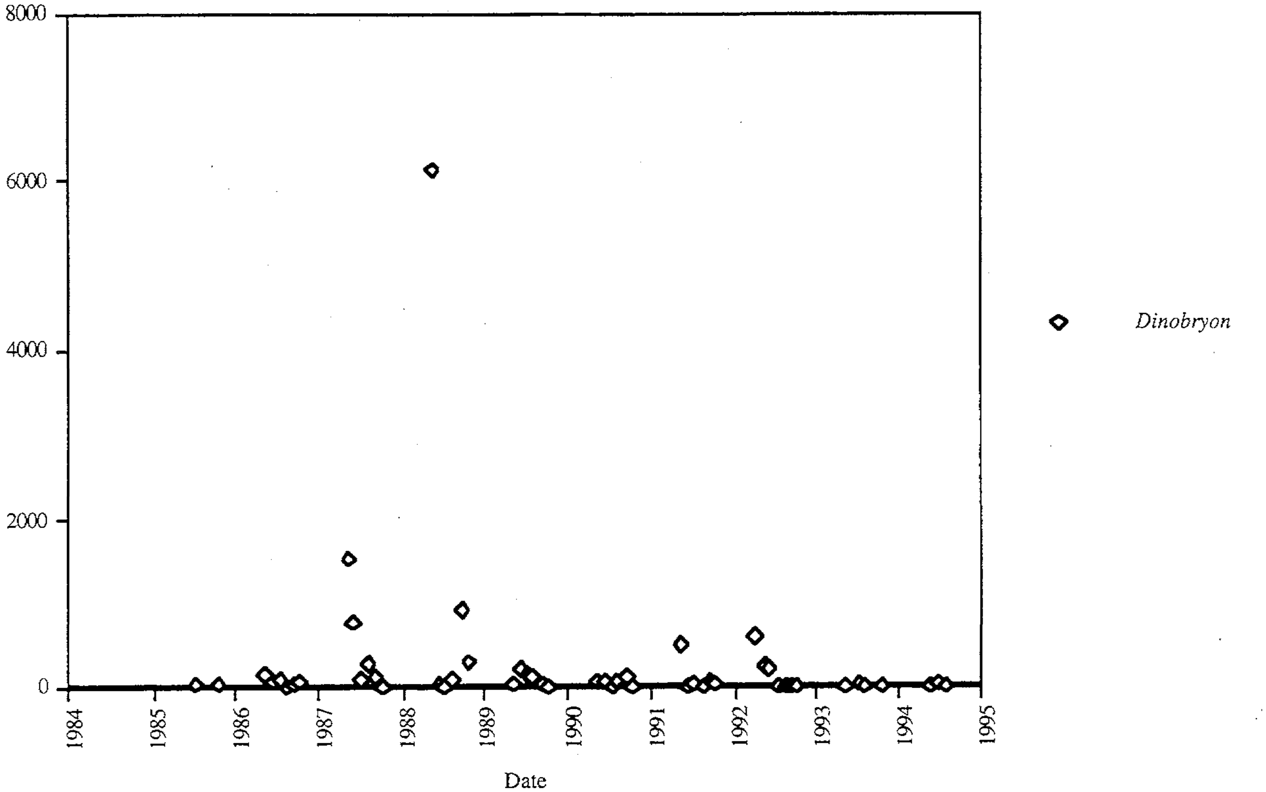


Figure 8.9.1.2. Stocking Lake Phytoplankton: *Cryptomonas.*

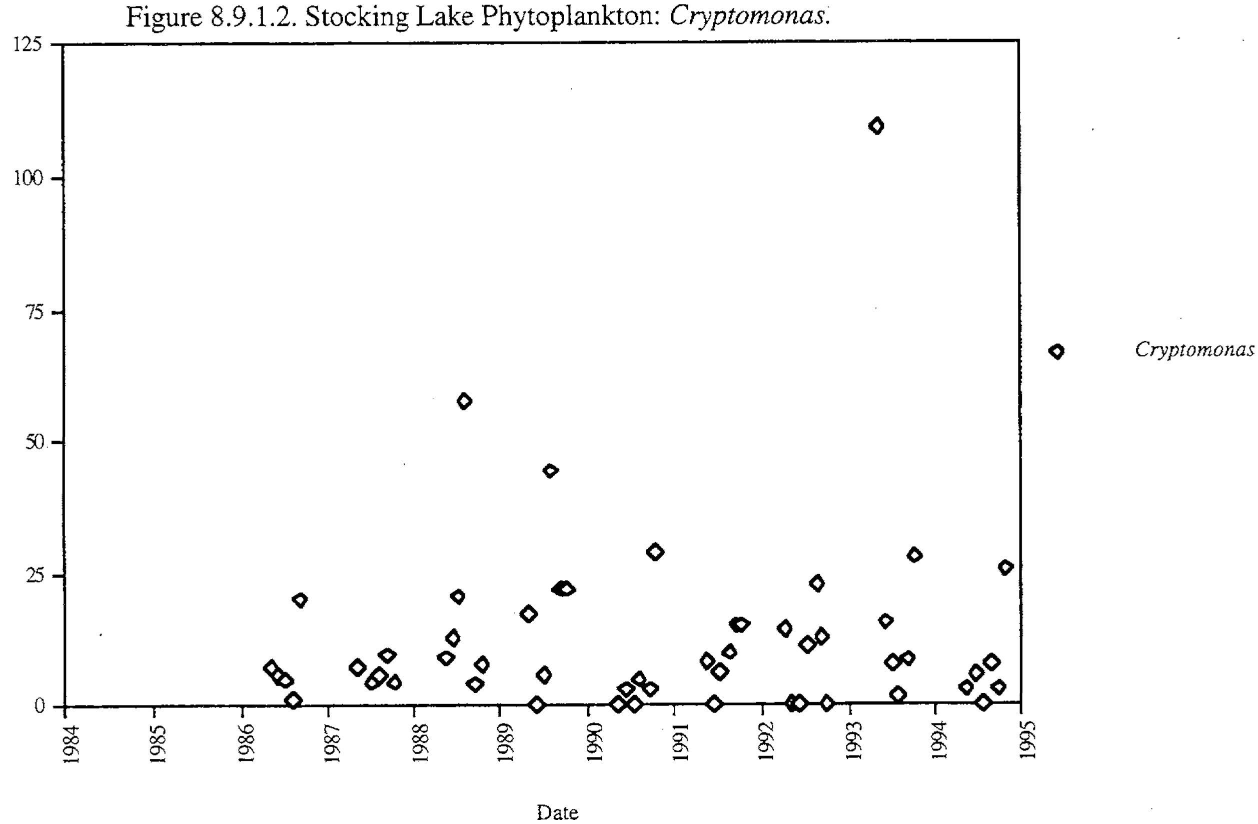


Figure 8.9.1.3. Stocking Lake Phytoplankton: *Crucigenia/Oocystis.*

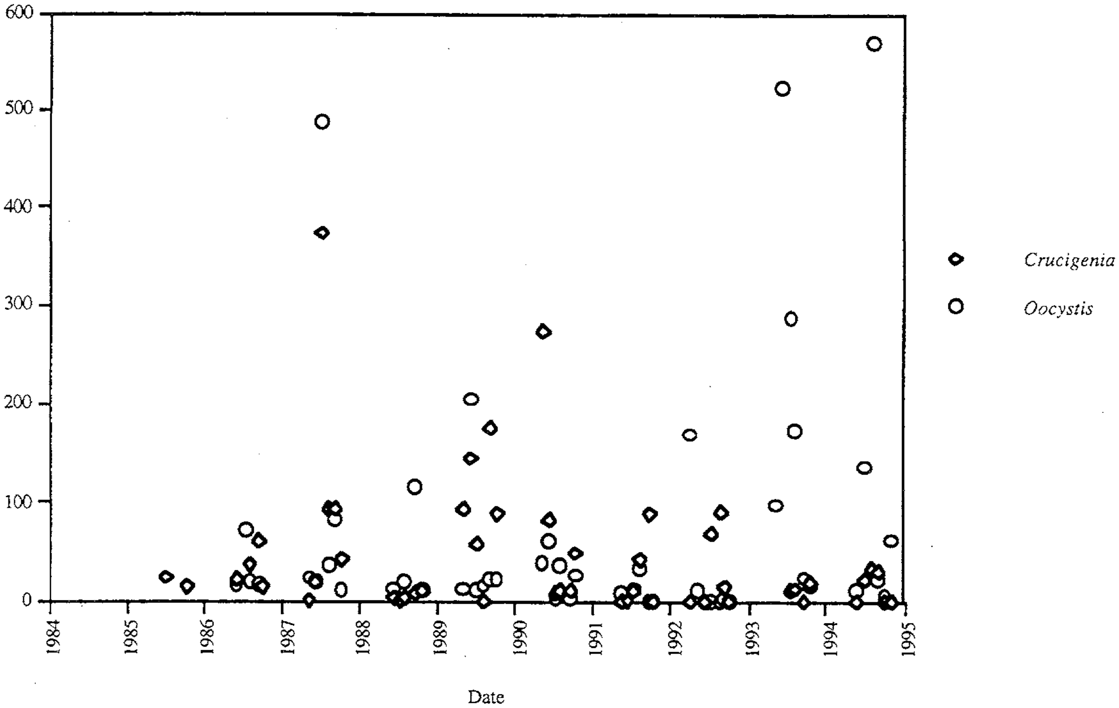


Figure 8.9.1.4. Stocking Lake Phytoplankton: *Chroomonas/Elakothrix.*

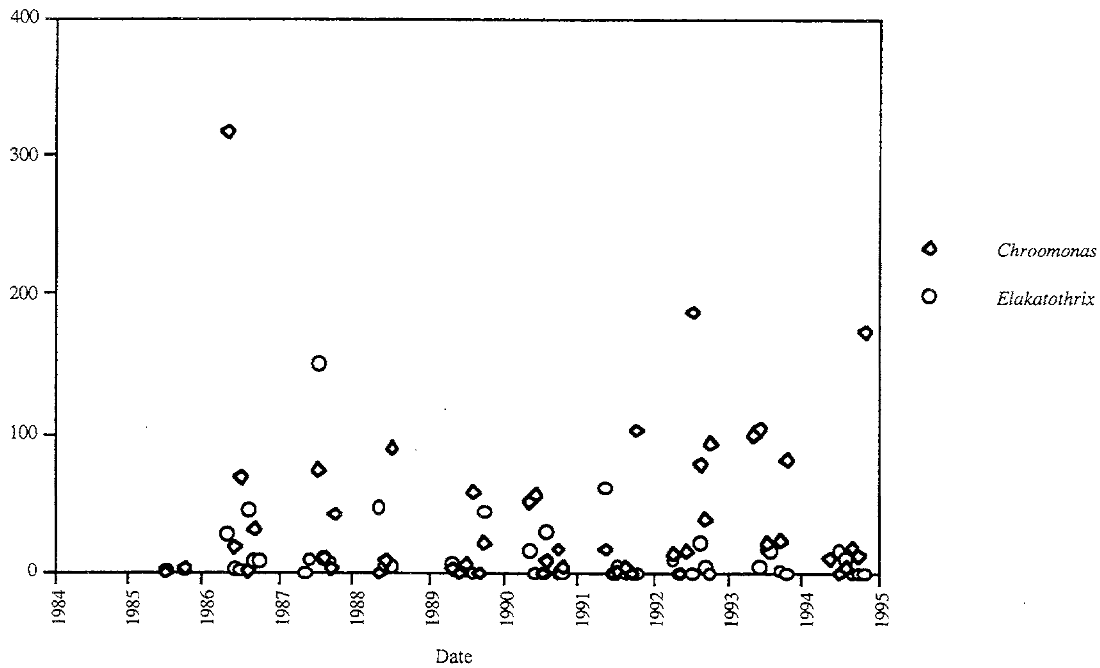


Figure 8.9.1.5. Stocking Lake Phytoplankton: *Sphaerocystis*.

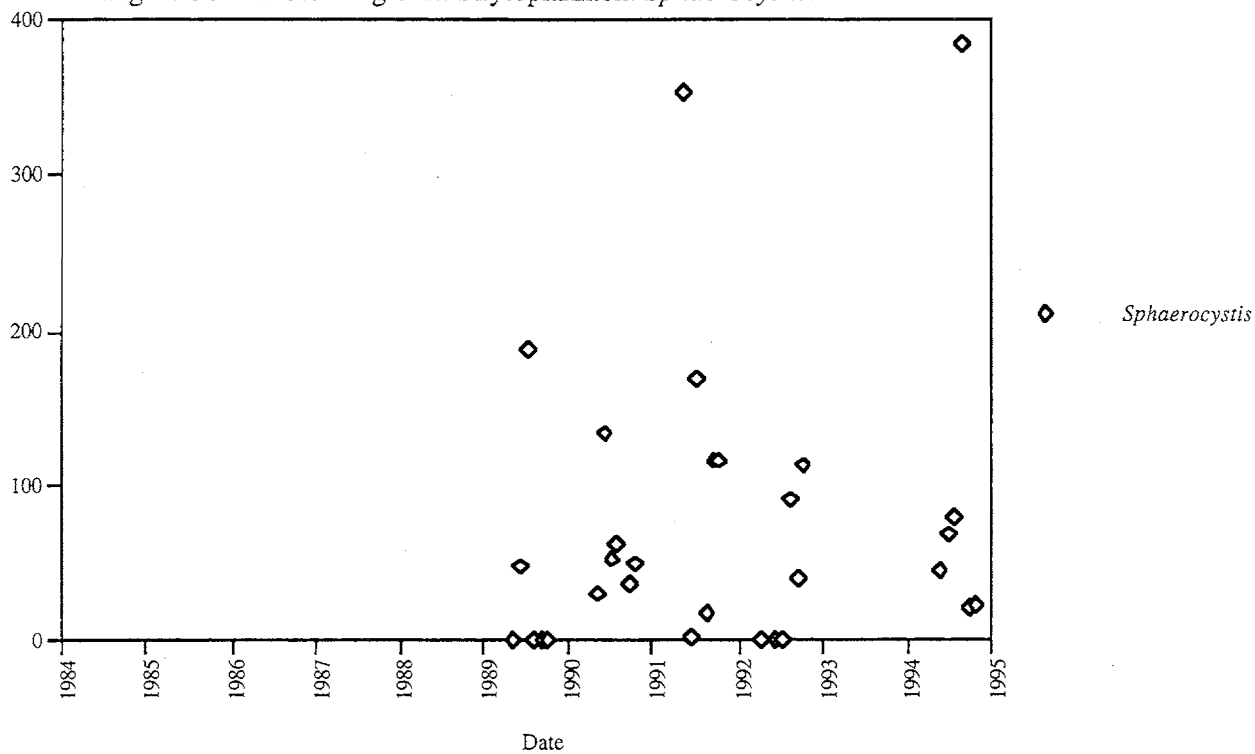


Figure 8.9.1.6. Stocking Lake Phytoplankton: *Quadrigula*.

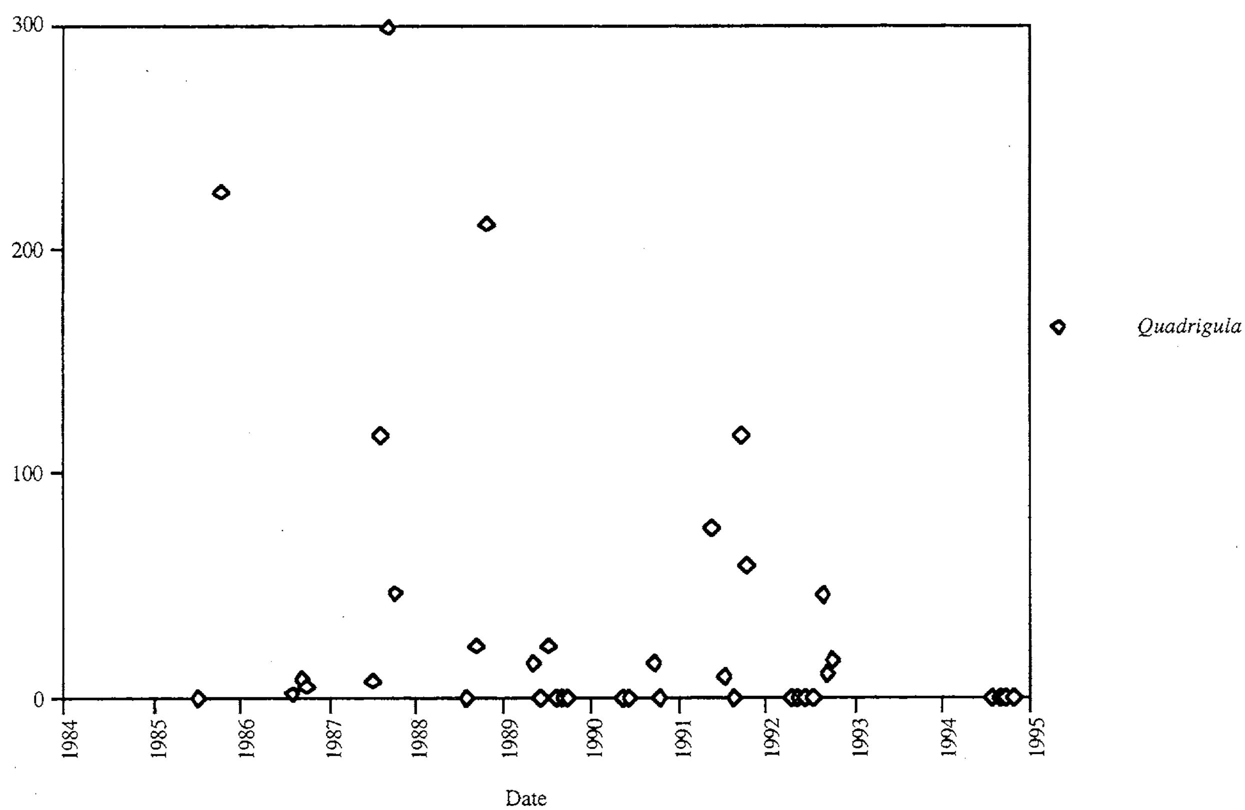


Figure 8.9.1.7. Stocking Lake Phytoplankton: *Nephrocytium*.

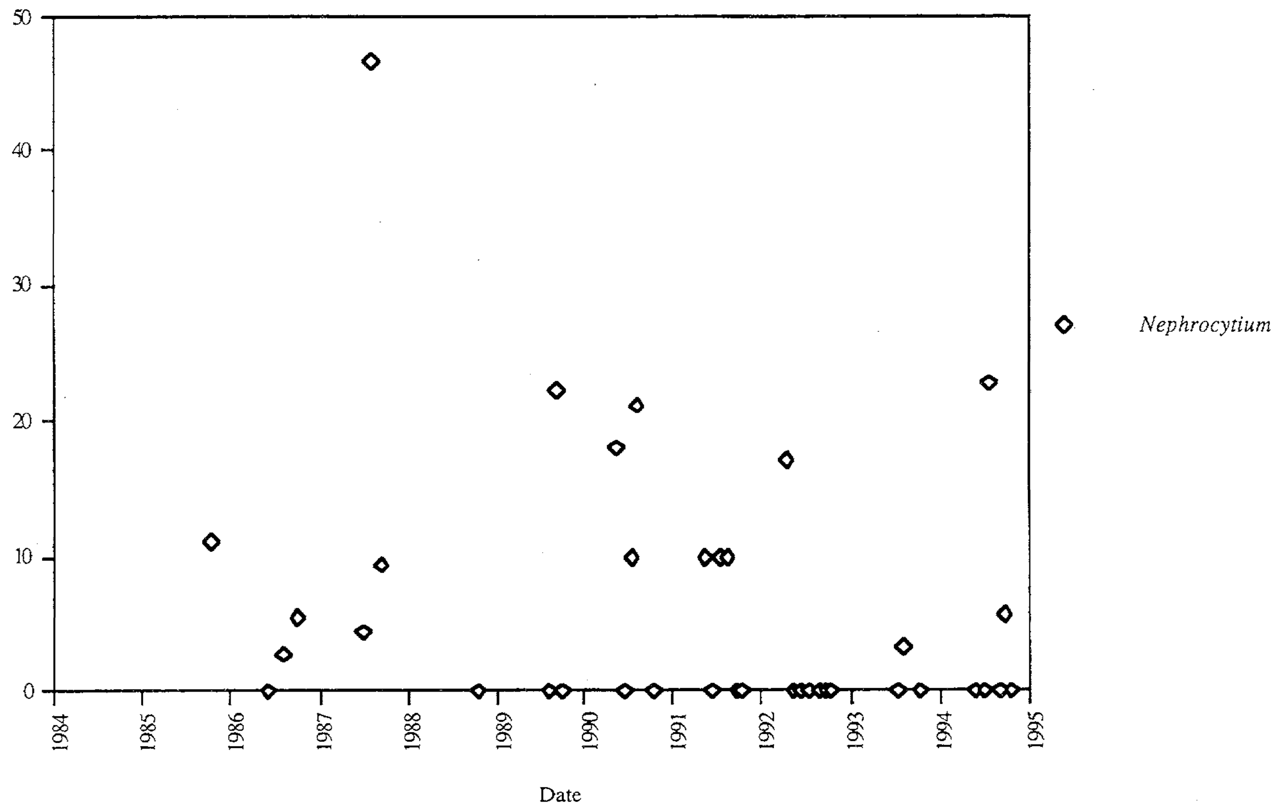


Figure 8.9.1.8. Stocking Lake Phytoplankton: *Botryococcus*.

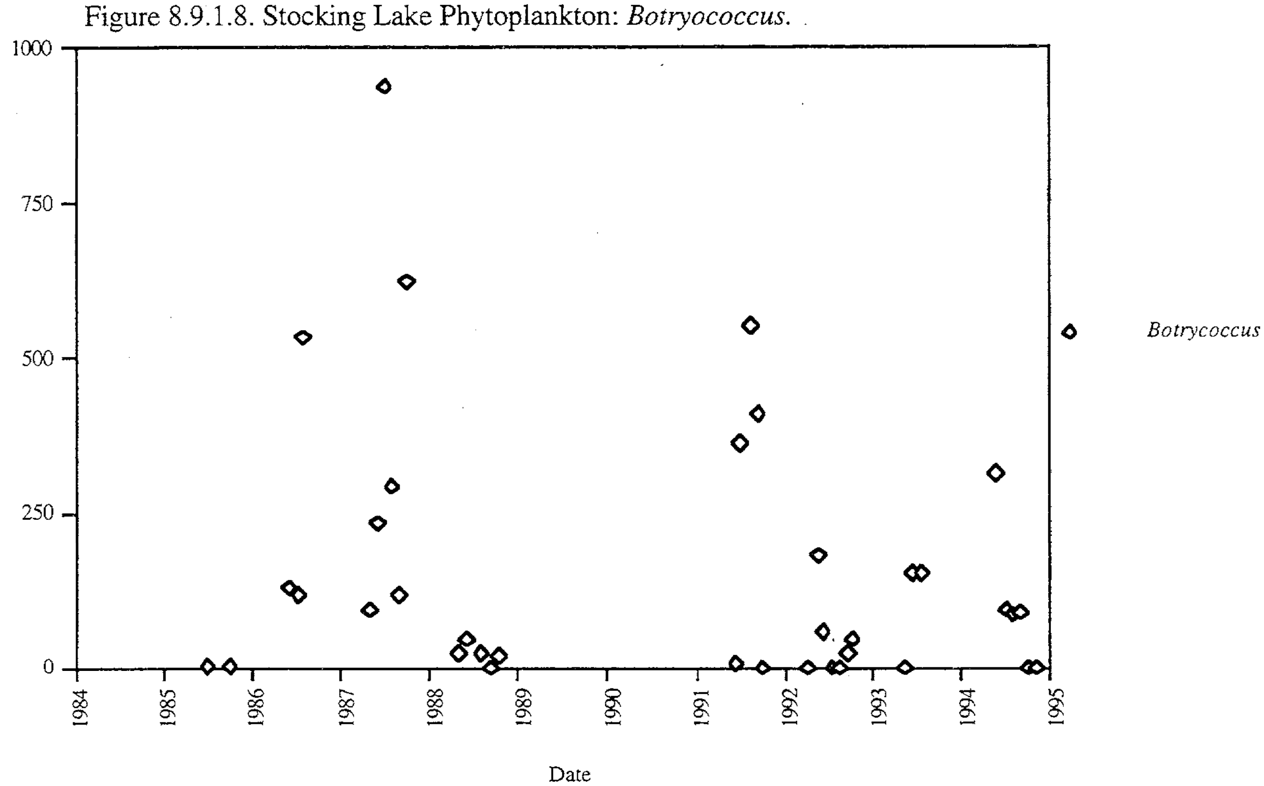


Figure 8.9.1.9. Stocking Lake Phytoplankton: *Gloeocystis.*

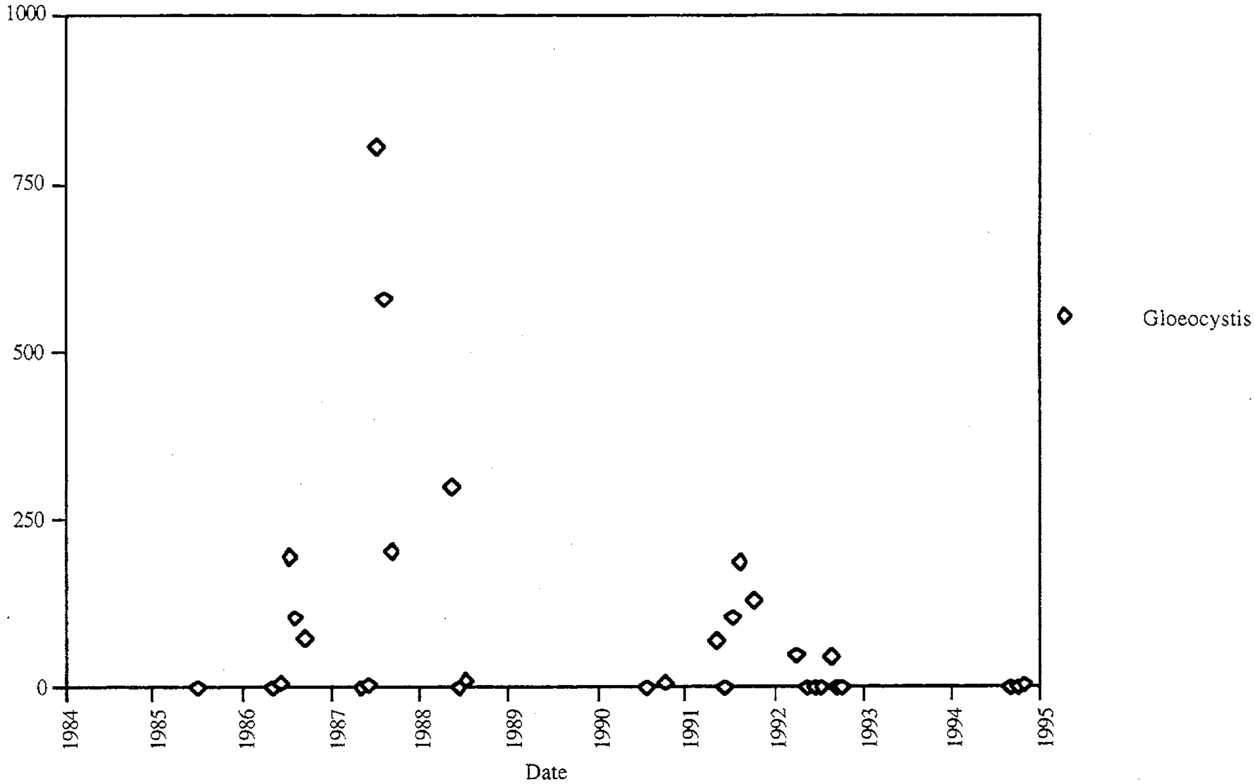


Figure 8.9.1.10. Stocking Lake Phytoplankton: Selenastrum.

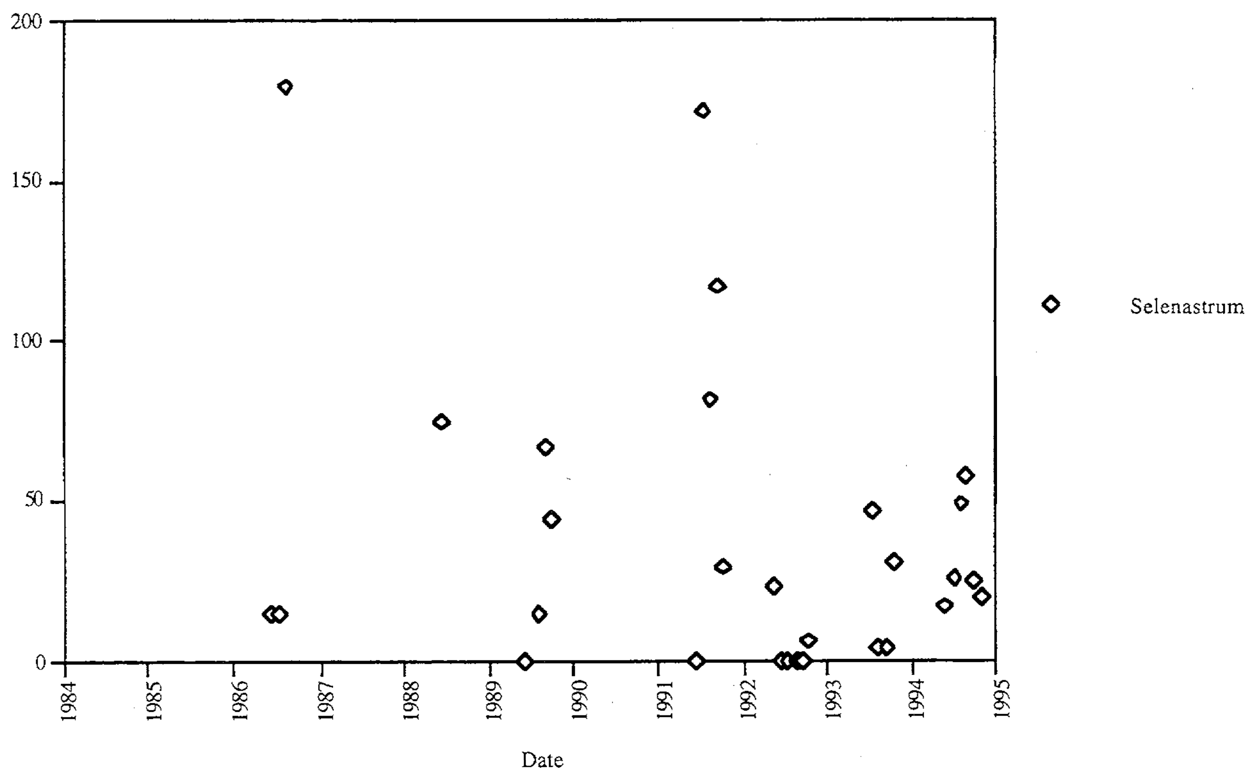


Figure 8.9.1.11. Stocking Lake Phytoplankton: *Melosira.*

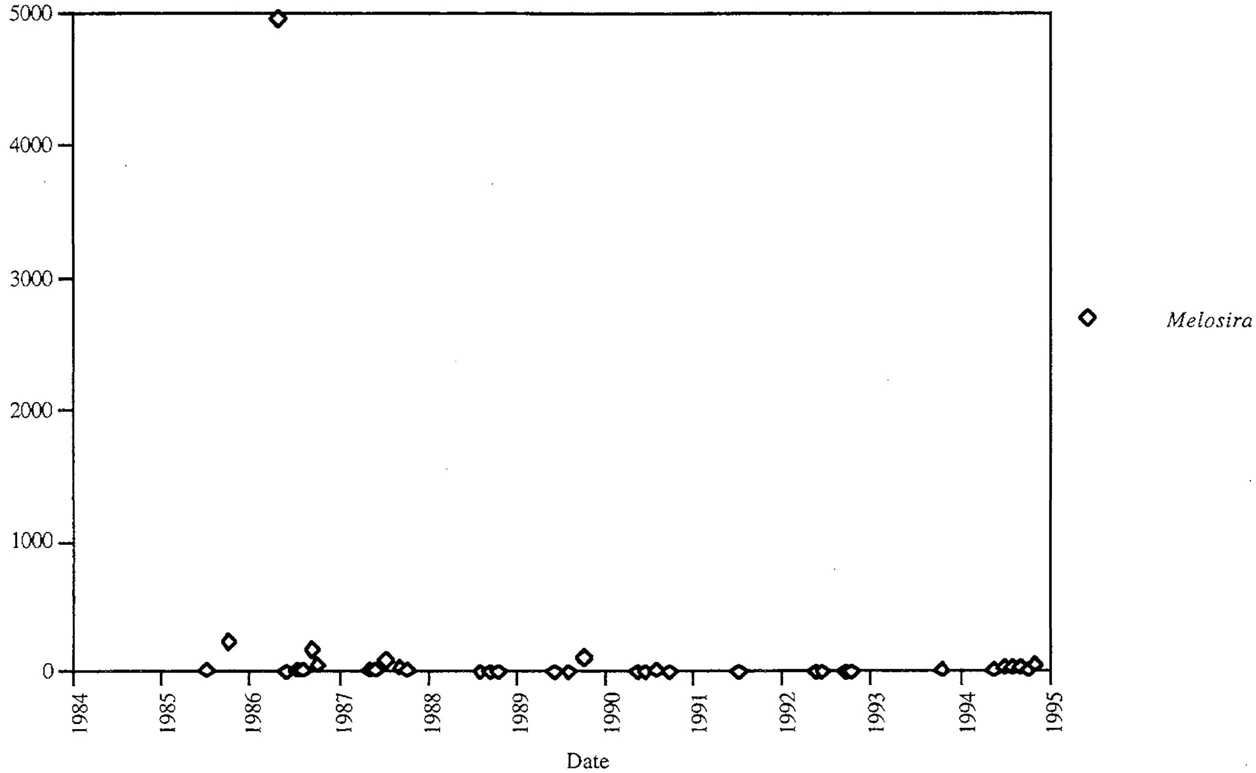


Figure 8.9.1.12. Stocking Lake Phytoplankton: *Asterionella.*

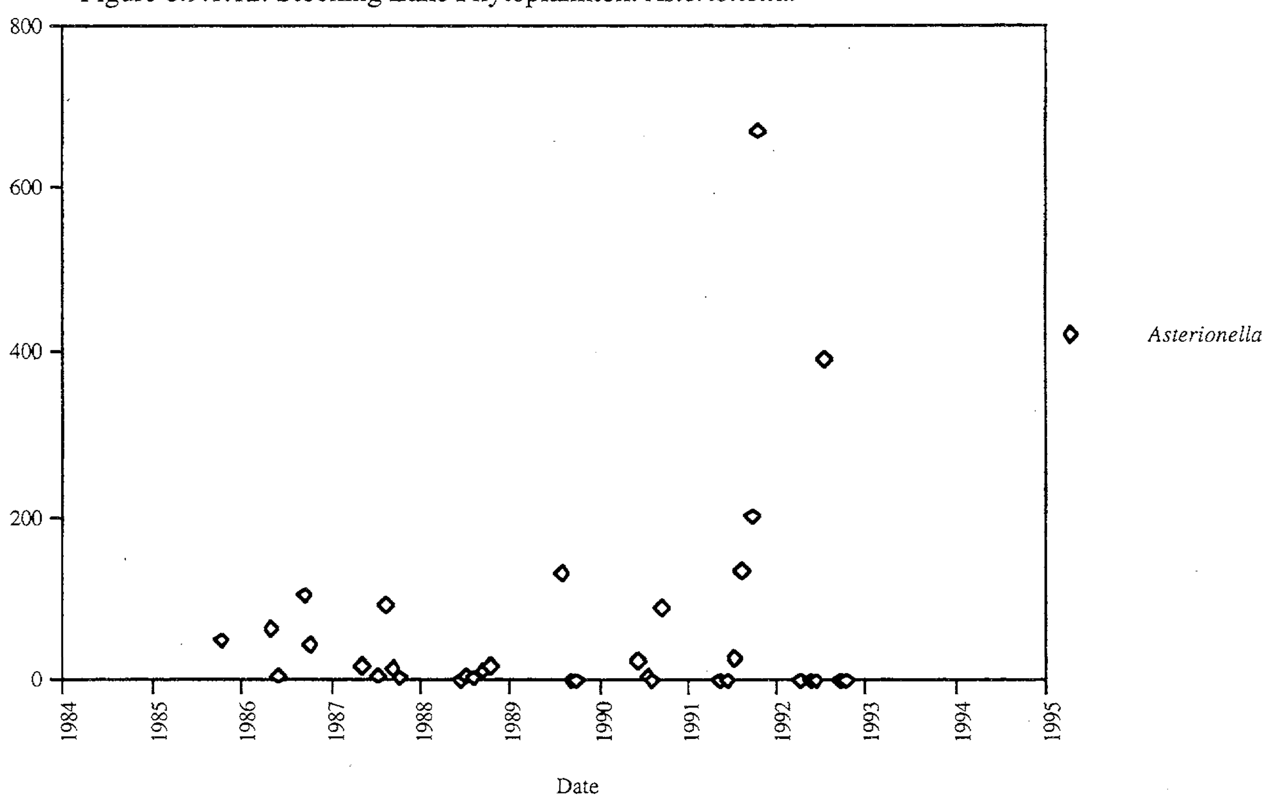


Figure 8.9.1.13. Stocking Lake Phytoplankton: Total Cells/mL

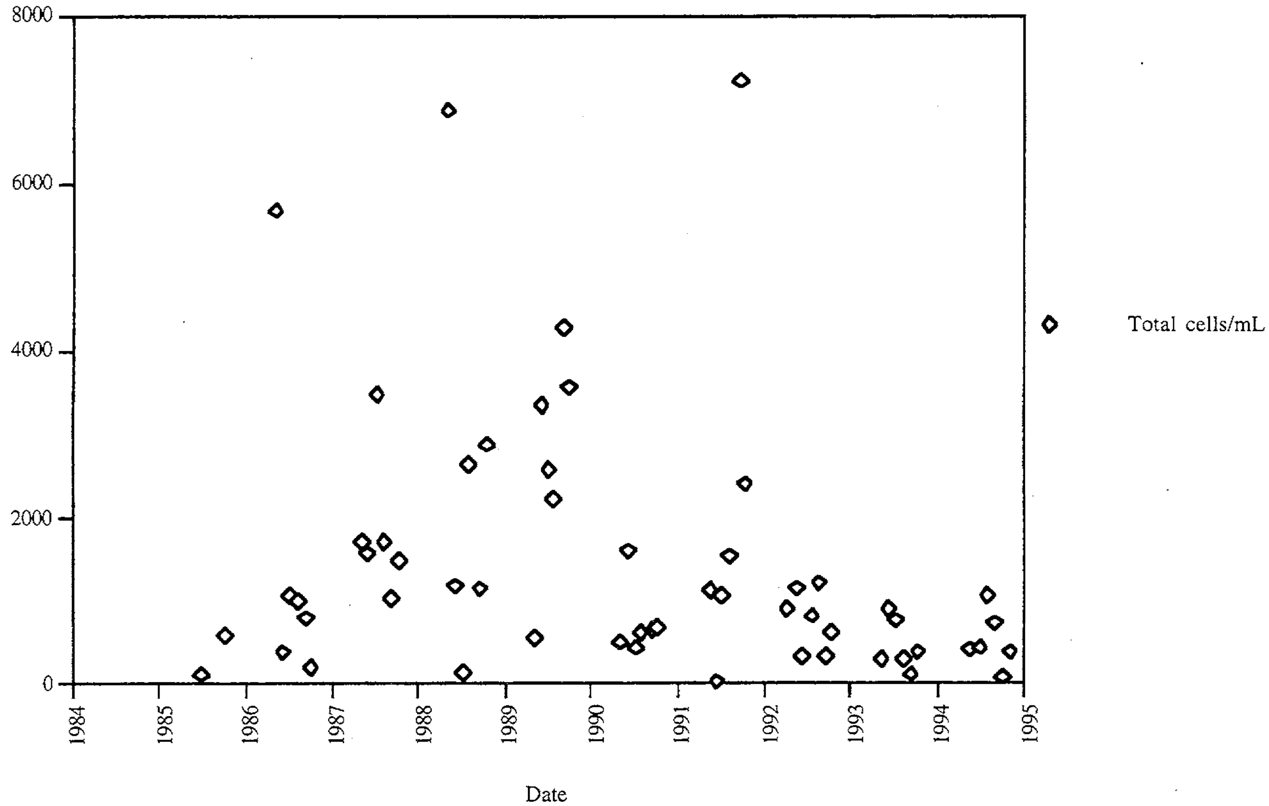


Figure 8.9.1.14. Stocking Lake Phytoplankton: Chlorophyll a, µg/L.

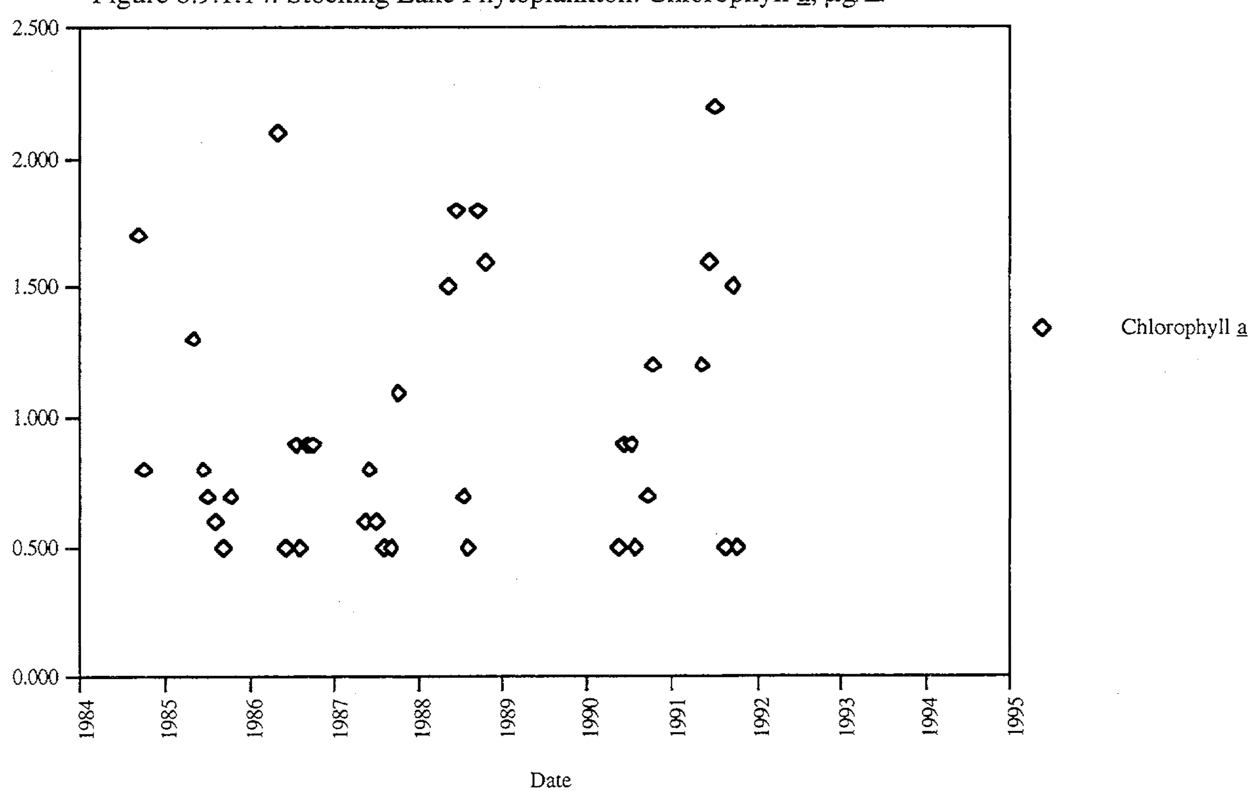


Figure 8.9.2.1. Stocking Lake Zooplankton. *Diaptomus.*

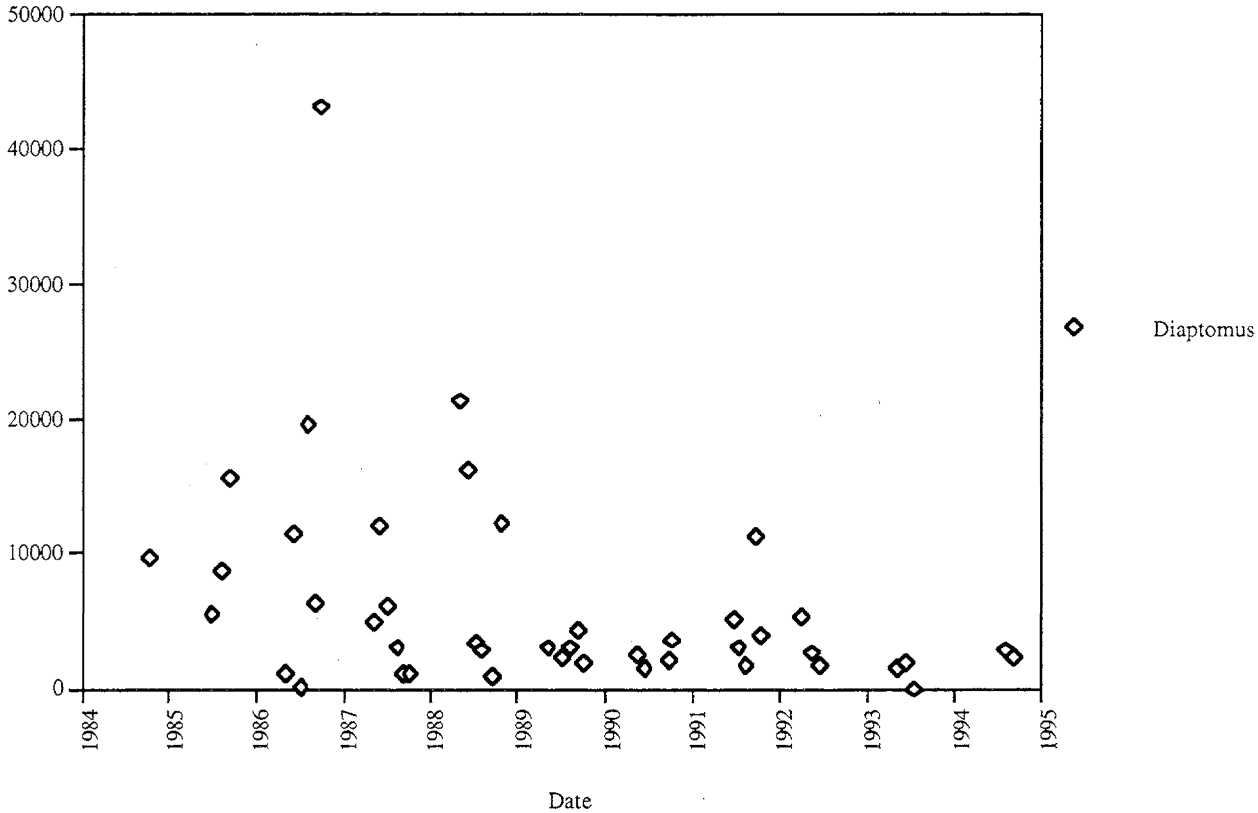


Figure 8.9.2.2. Stocking Lake Zooplankton: *Epishura*

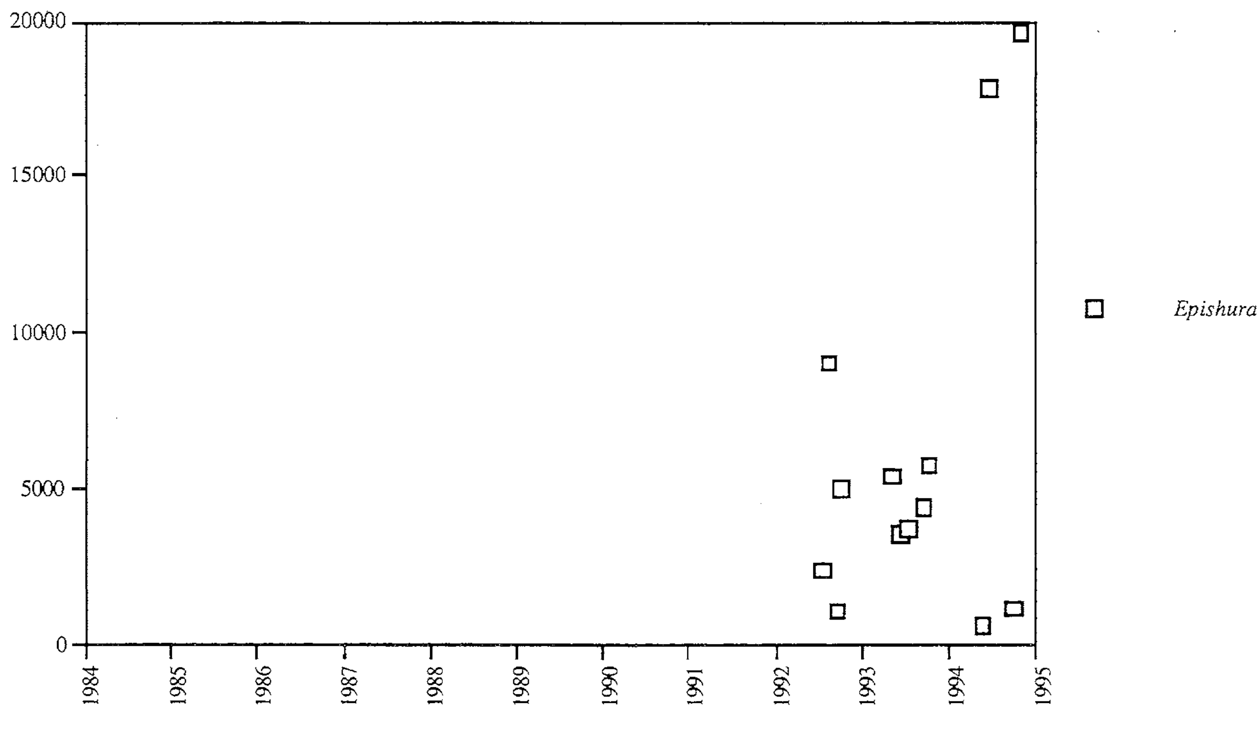


Figure 8.9.2.3. Stocking Lake Zooplankton. *Cyclops/Diacyclops.*

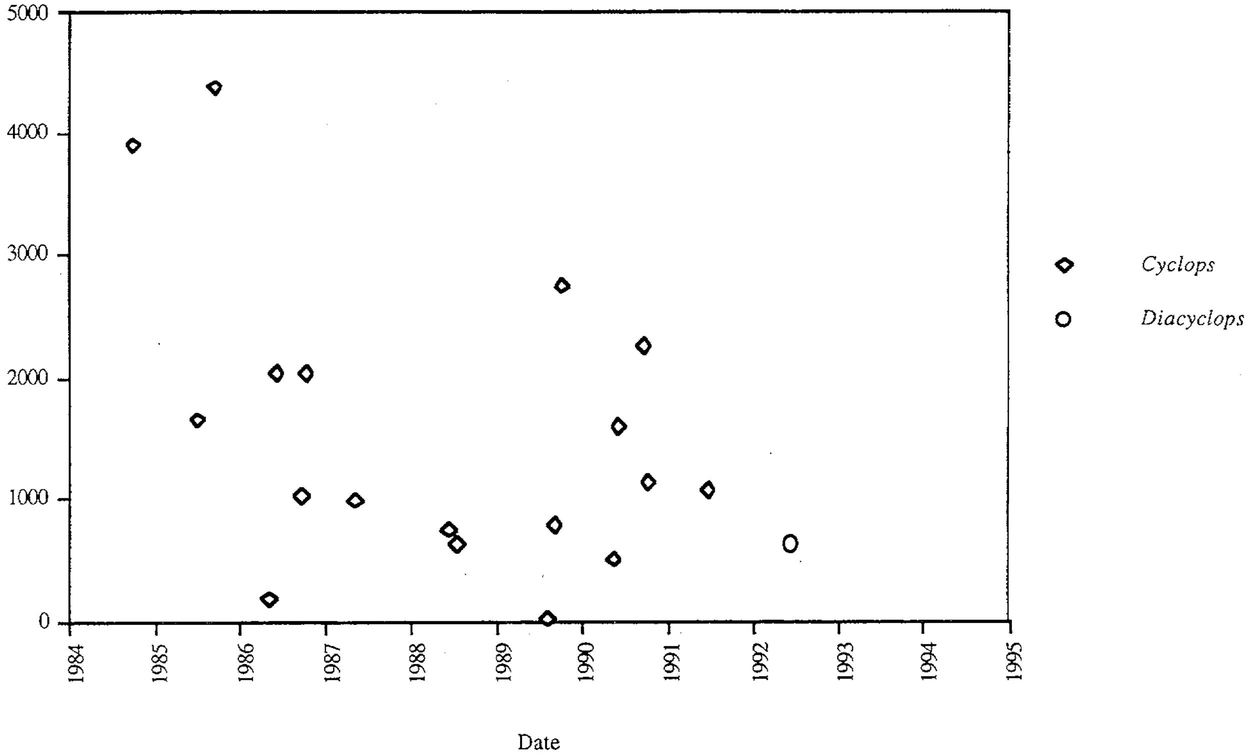


Figure 8.9.2.4. Stocking Lake Zooplankton. Copepodites/Nauplii.

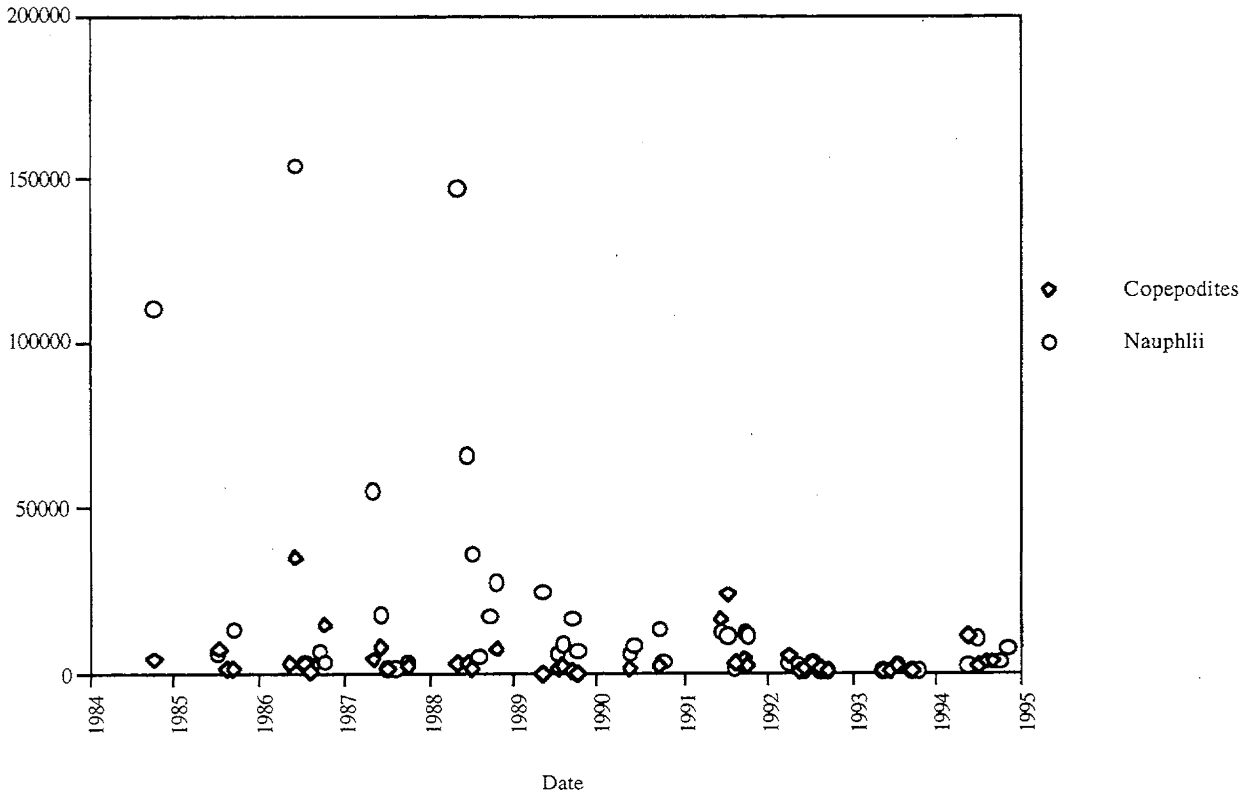


Figure 8.9.2.5. Stocking Lake Zooplankton: *Bosmina*.

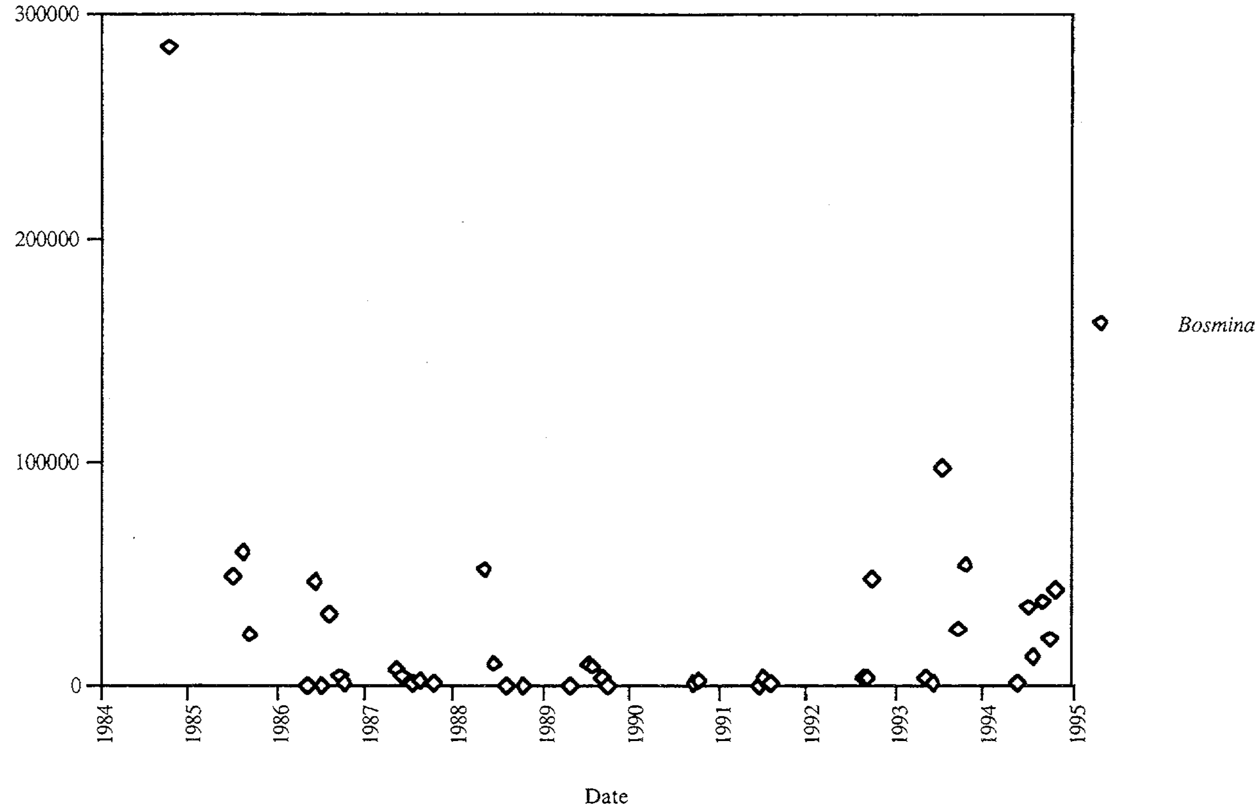


Figure 8.9.2.6. Stocking Lake Zooplankton: *Holopedium*.

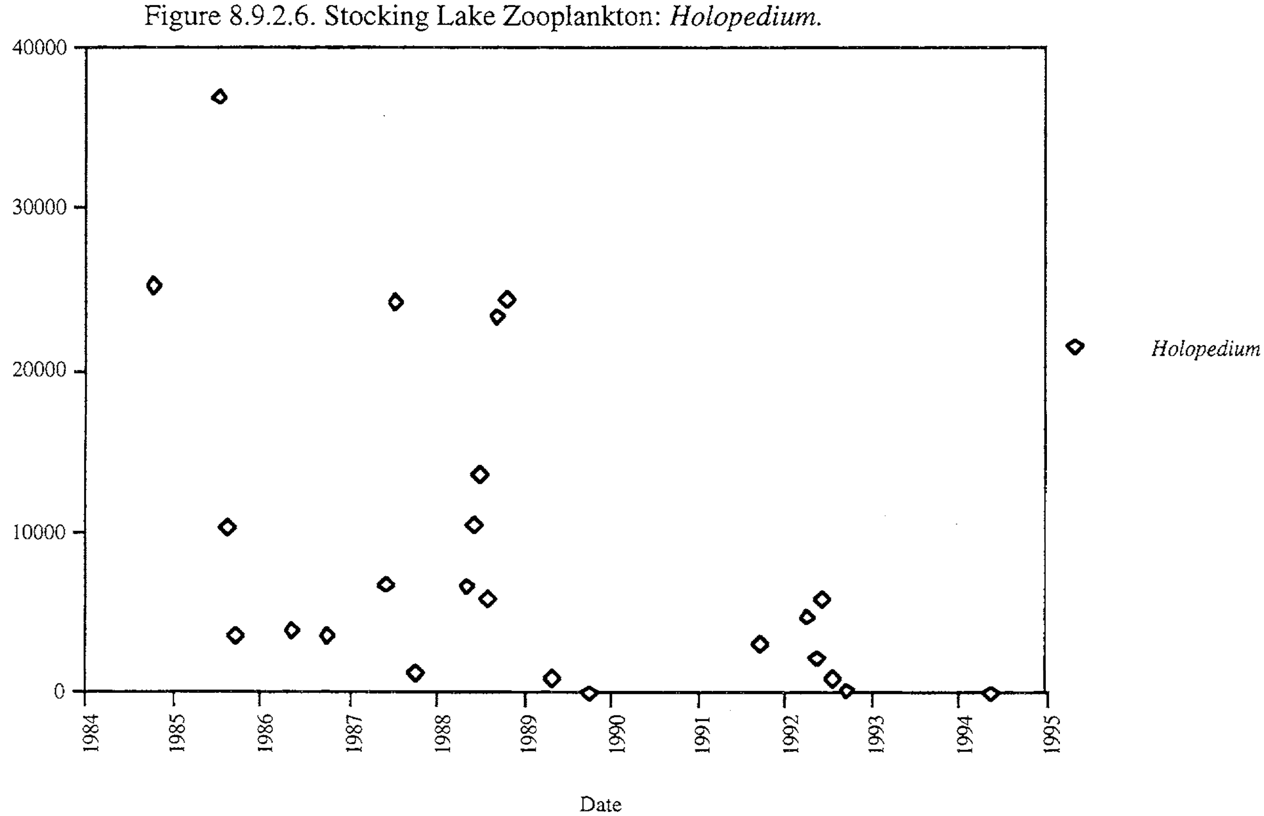


Figure 8.9.2.7. Stocking Lake Zooplankton: *Diaphanosoma/Daphnia.*

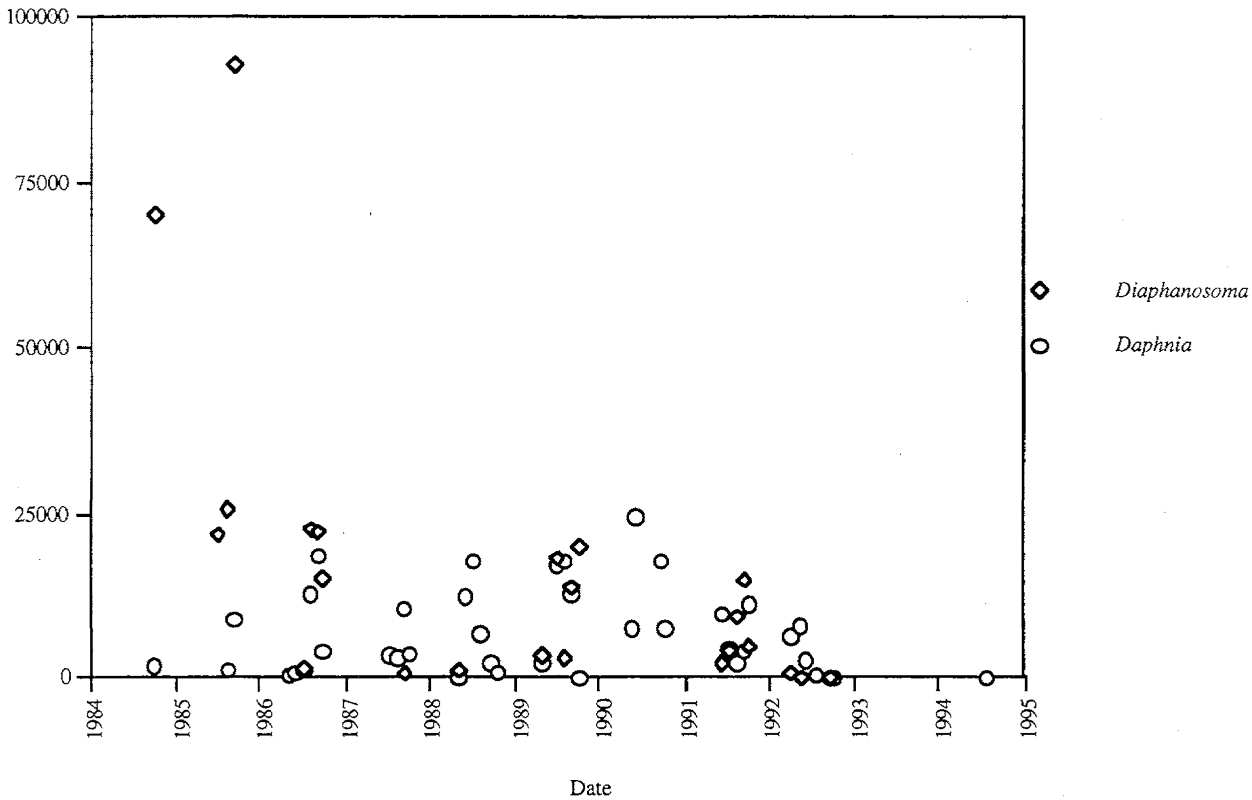


Figure 8.9.2.8. Stocking Lake Zooplankton: *Polyphemus/Ceriodaphnia.*

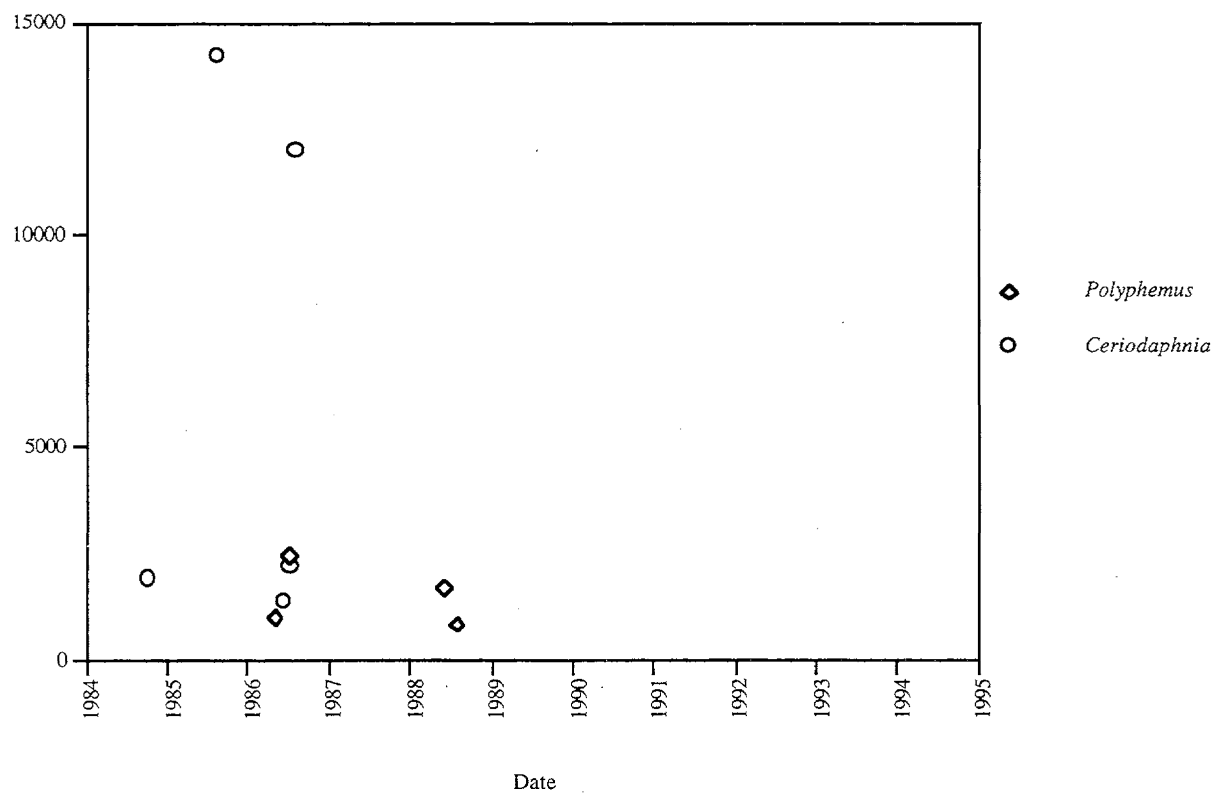


Figure 8.9.2.9. Stocking Lake Zooplankton: *Keratella.*

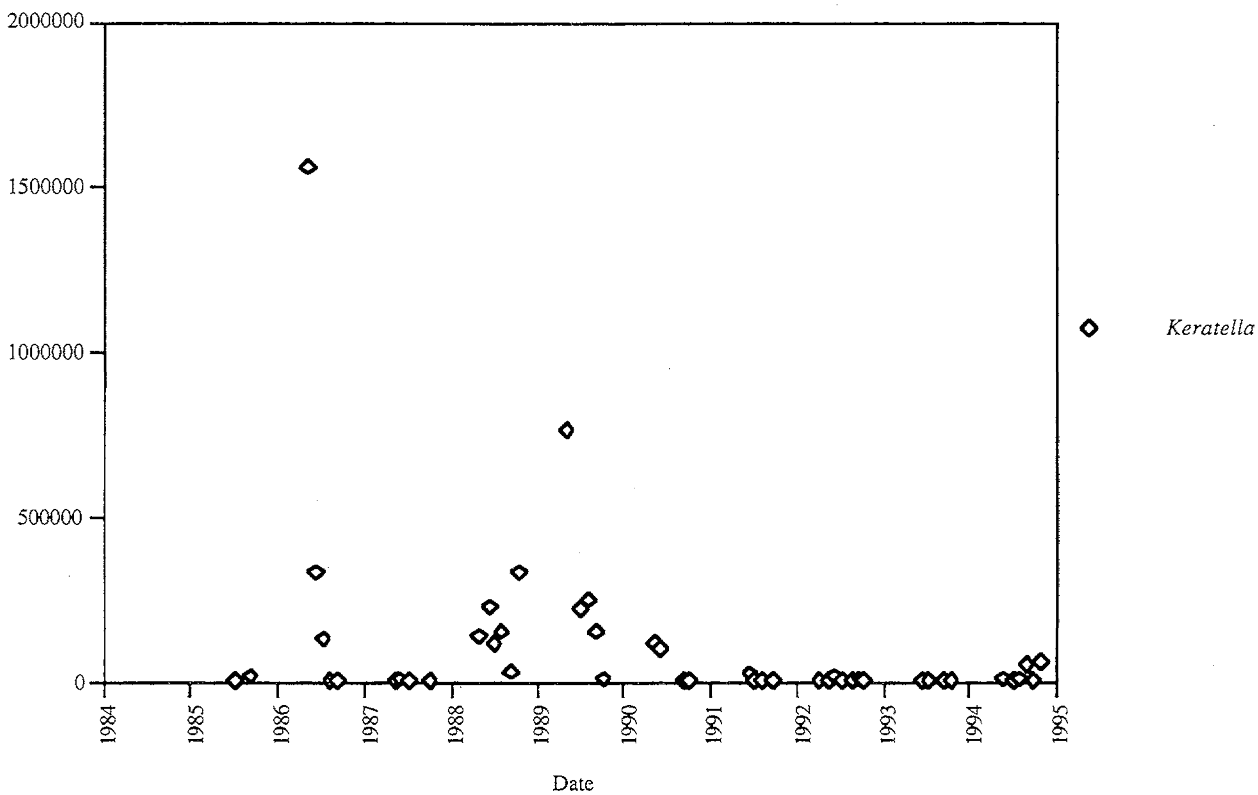


Figure 8.9.2.10. Stocking Lake Zooplankton: *Kellicottia*.

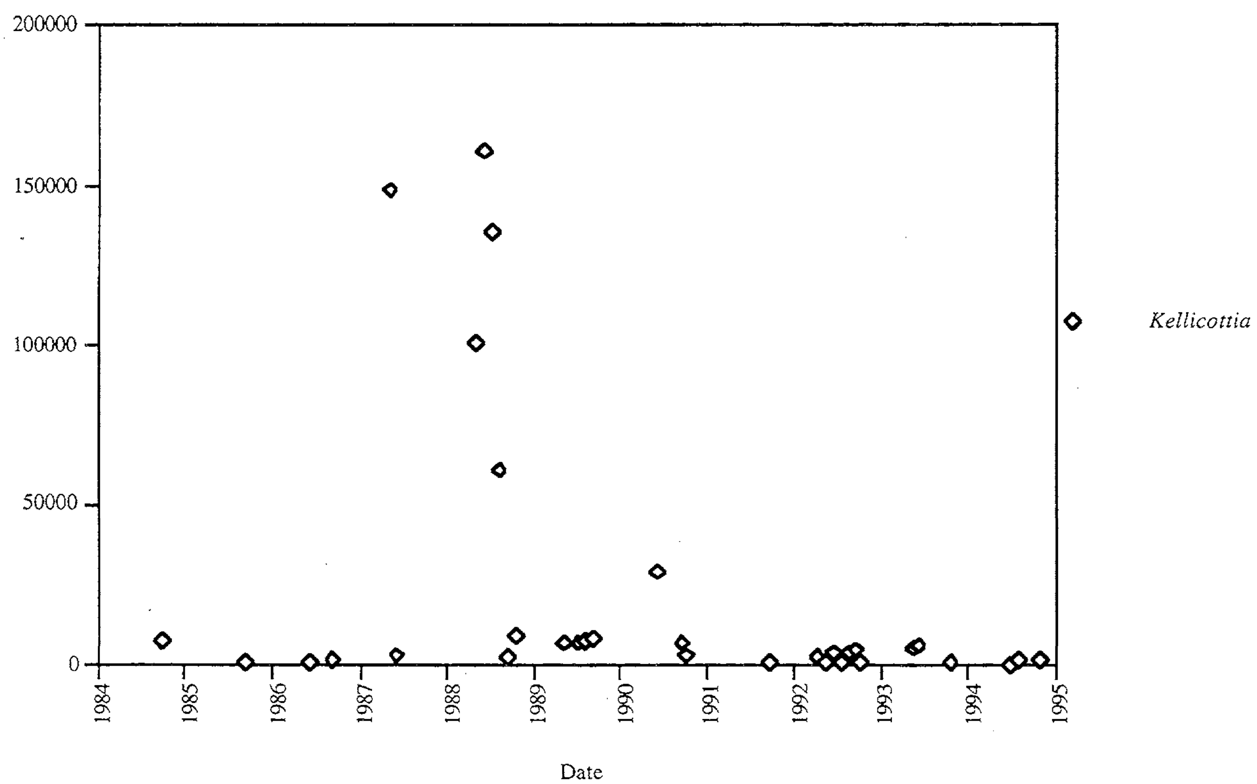


Figure 8.9.2.11. Stocking Lake Zooplankton: *Trichocera/Filinia/Testudinella*

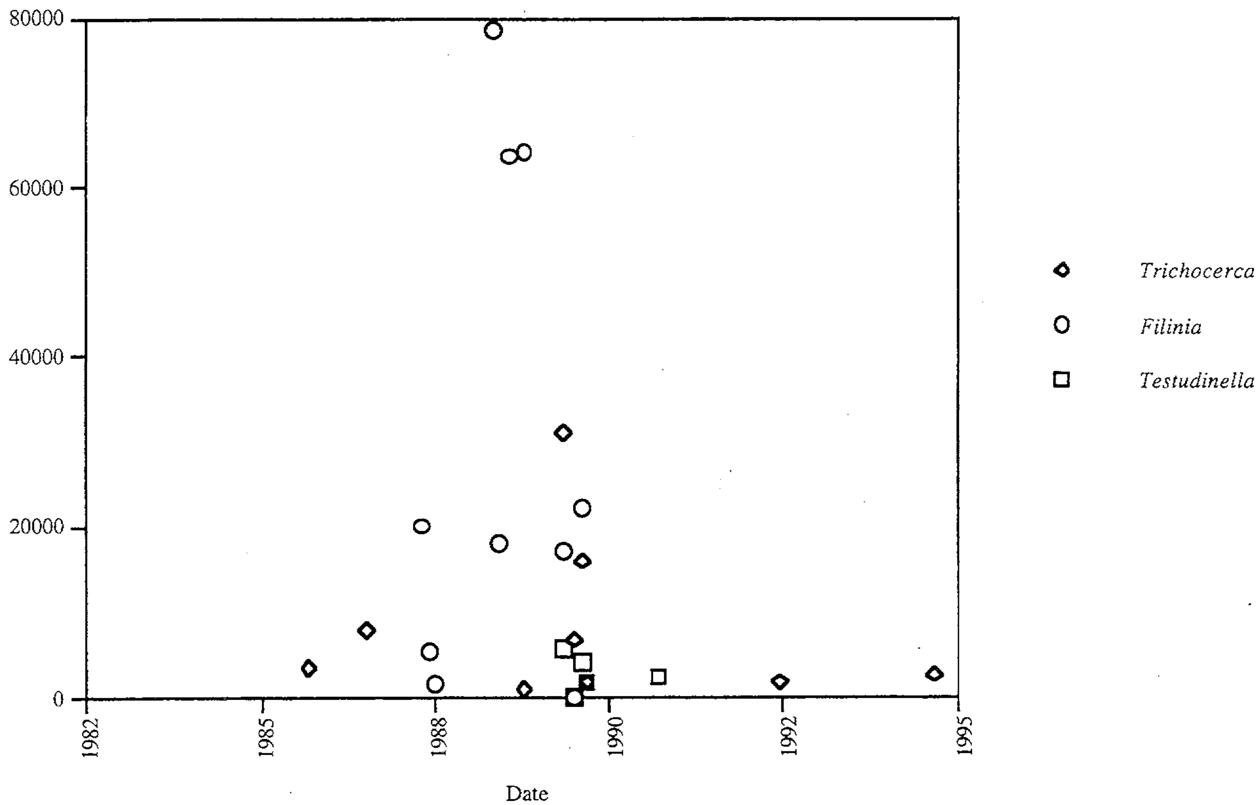


Figure 8.9.2.12. Stocking Lake Zooplankton: Rare Rotifers.

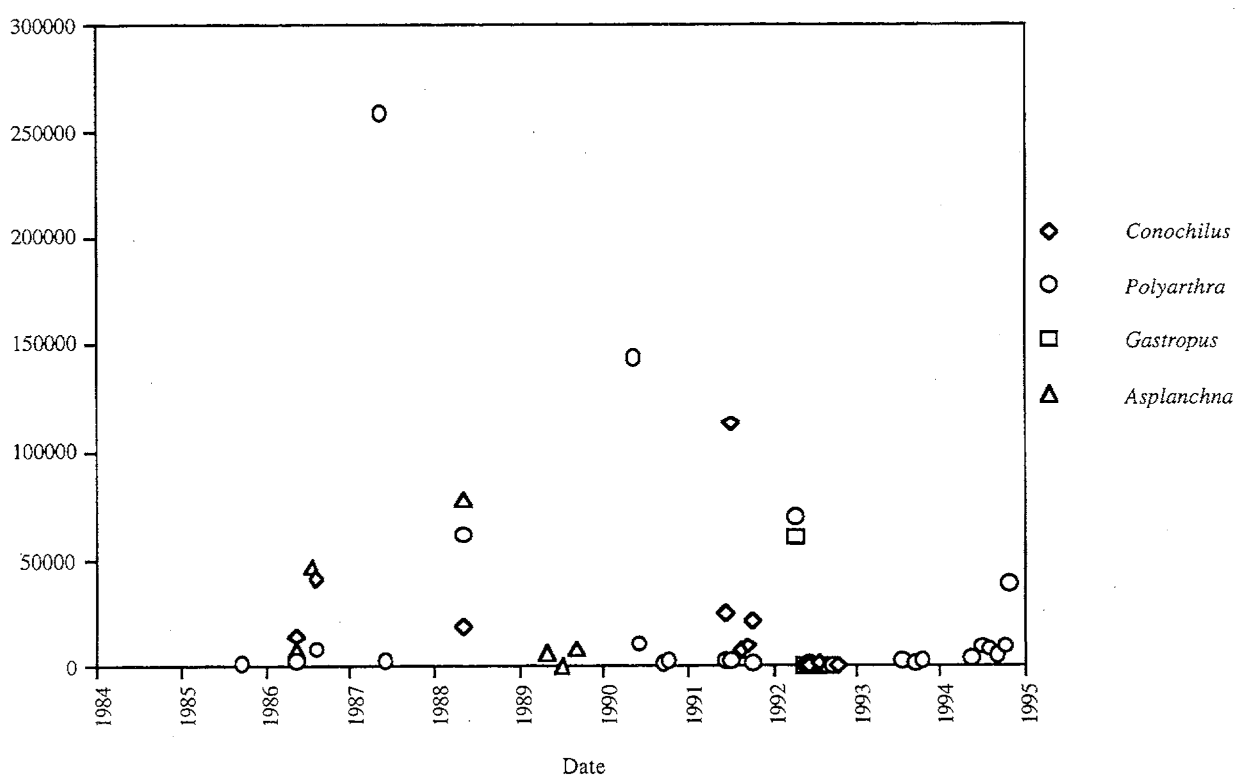


Figure 8.9.2.13. Stocking Lake Zooplankton: Total Animals/m2.

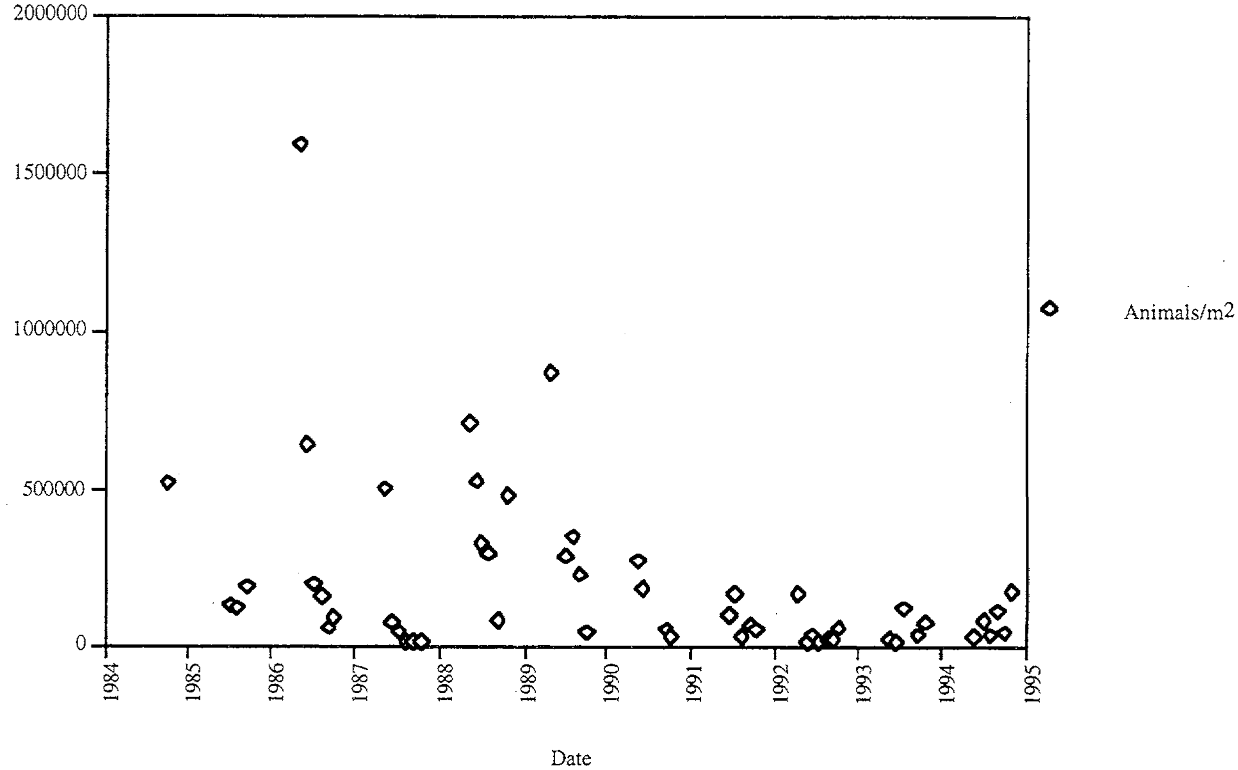


Figure 8.9.2.14. Stocking Lake Zooplankton: Biomass Comparisons.

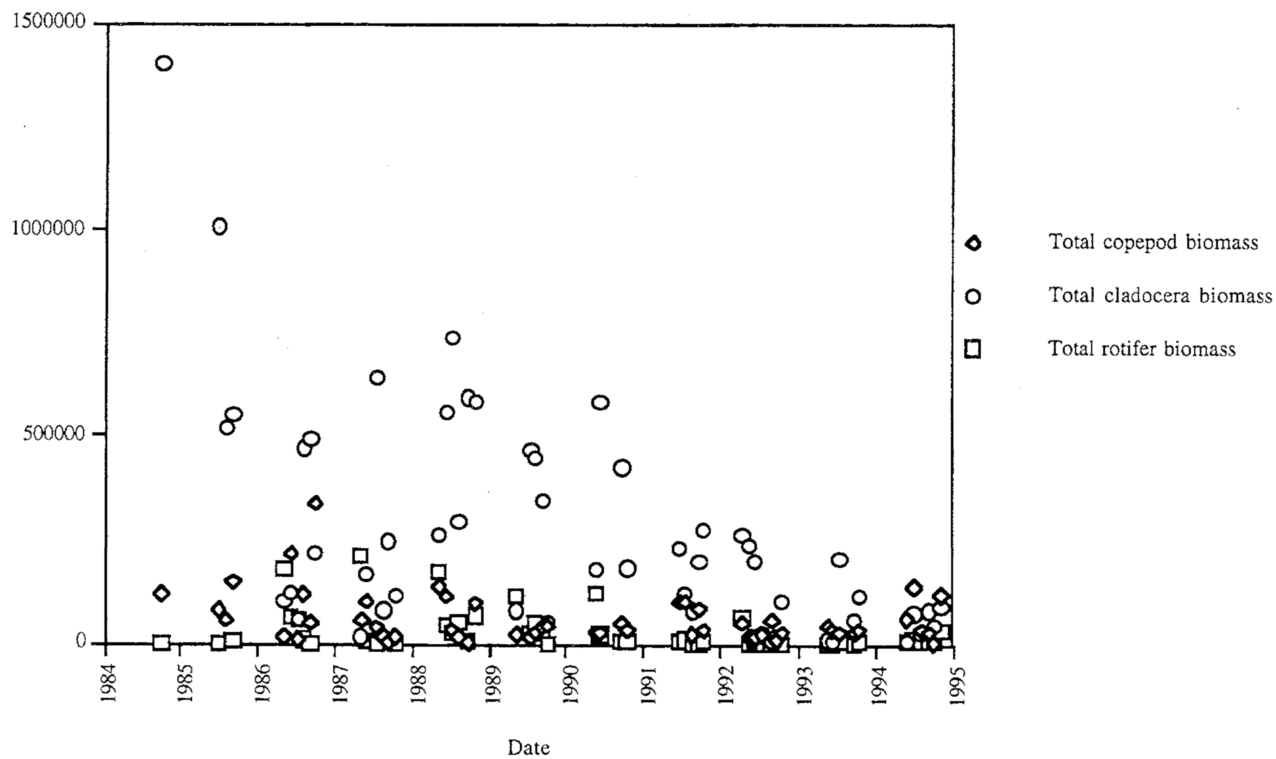


Figure 8.9.2.15. Stocking Lake Zooplankton: Total Biomass, µg/m2.

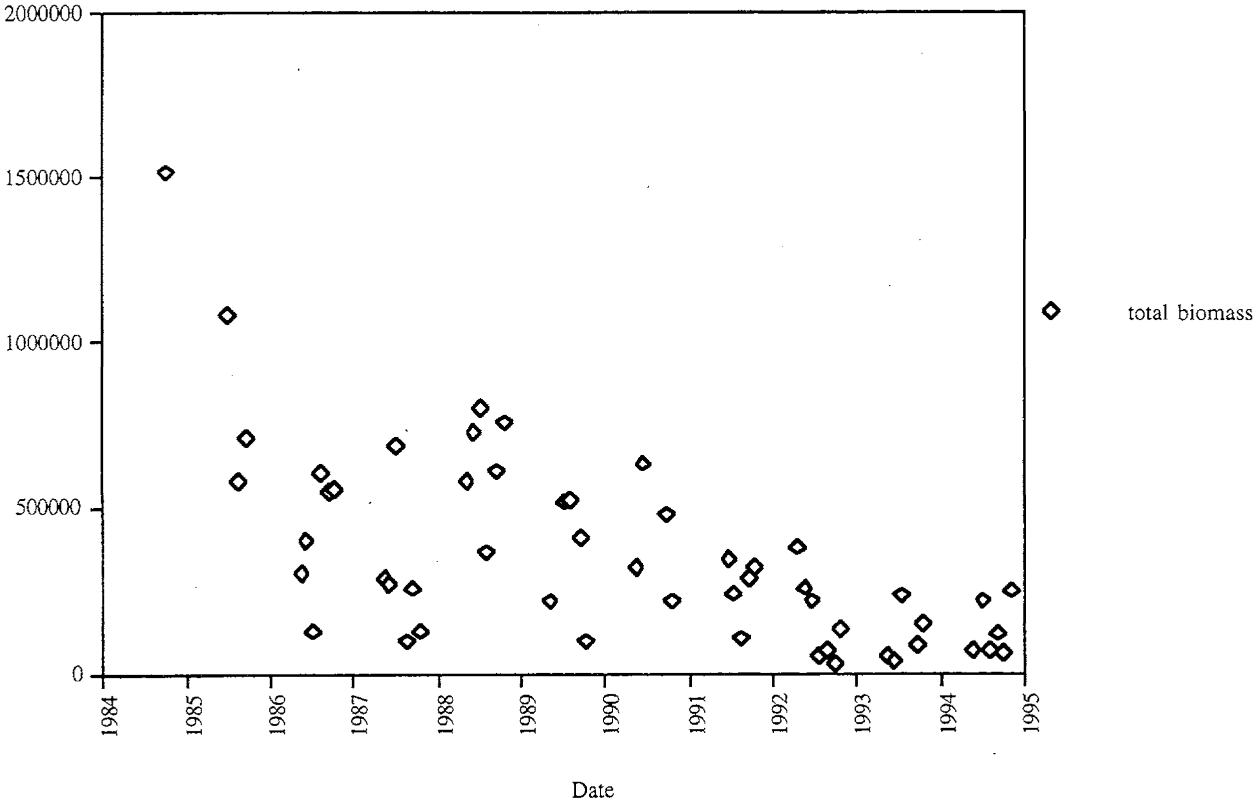


Table 2.2.2. Summary of detected characteristics in blanks associated with Lizard Lake.

Characteristic	Number of Blanks	% Below Detection	% Above Detection	Max. conc. reported
Al-D	35	0.86	0.14	1.29
Al-T	36	0.61	0.39	0.19
B--D	26	0.96	0.04	0.06
B--T	16	0.81	0.19	0.06
Ba-D	26	0.85	0.15	0.15
Ba-T	27	0.85	0.15	0.01
Cd-D	26	1.00	0.00	<0.002
Cd-T	26	0.96	0.04	0.02
Co-D	26	1.00	0.00	0.10
Co-T	26	0.96	0.04	2.00
Cr-D	26	0.92	0.08	0.03
Cr-T	26	0.92	0.08	0.01
Cu-D	26	0.62	0.38	2.32
Cu-T	26	0.69	0.31	0.09
Fe-D	25	0.44	0.56	0.1
Fe-T	26	0.62	0.38	0.17
K--D	16	1.00	0.00	<0.6
K--T	16	1.00	0.00	<0.4
Mn-D	26	0.77	0.23	0.1
Mn-T	26	0.85	0.15	0.011
Mo-D	26	1.00	0.00	<0.01
Mo-T	26	1.00	0.00	<0.01
Na-D	16	0.06	0.94	1.73
Ni-D	26	0.96	0.04	0.012
Ni-T	26	0.96	0.04	0.012
Phosph:D	16	1.00	0.00	<0.04
Phosph:T	16	1.00	0.00	<0.04
Pb-T	26	0.92	0.08	0.008
Zn-D	26	0.50	0.50	1.12
Zn-T	26	0.54	0.46	0.05

Table 2.2.3. Summary of detected characteristics in blanks associated with Marion (Jacobs) Lake.

Characteristic	Number of Blanks	% Below Detection	% Above Detection	Max. conc. reported
Al-D	34	0.68	0.32	0.65
Al-T	2	0.00	1.00	0.2
B--D	14	1.00	0.00	<0.01
Ba-D	14	1.00	0.00	<0.01
Cd-D	14	1.00	0.00	<0.005
Co-D	14	1.00	0.00	<0.01
Cr-D	14	1.00	0.00	<0.01
Cu-D	14	0.86	0.14	1.11
Fe-D	14	0.93	0.07	0.02
Mn-D	14	1	0.00	<0.01
Mo-D	14	1	0.00	<0.01
Ni-D	14	1	0.00	<0.005
Zn-D	14	0.93	0.07	0.05

Table 2.2.4. Summary of detected characteristics in blanks associated with Maxwell Lake.

Characteristic	Number of Blanks	% Below Detection	% Above Detection	Max. conc. reported
Al-D	31	0.90	0.10	0.03
Al-T	32	0.59	0.41	0.04
B--D	12	1.00	0.00	<0.01
Ba-D	12	1.00	0.00	<0.01
Ba-T	11	1.00	0.00	<0.01
Cd-D	12	0.92	0.08	0.0007
Cd-T	11	0.82	0.18	0.0086
Co-D	12	1.00	0.00	<0.1
Co-T	11	1.00	0.00	<0.1
Cr-D	12	1.00	0.00	<0.01
Cr-T	11	0.91	0.09	0.01
Cu-D	12	0.67	0.33	0.011
Cu-T	11	0.64	0.36	0.016
Fe-D	12	0.75	0.25	0.03
Fe-T	11	0.36	0.64	0.05
Mn-D	12	1.00	0.00	<0.01
Mn-T	11	1.00	0.00	<0.01
Mo-D	12	1.00	0.00	<0.01
Mo-T	11	1.00	0.00	<0.01
Ni-D	12	1.00	0.00	<0.005
Ni-T	11	1.00	0.00	<0.005
Pb-T	11	0.45	0.55	0.006
Zn-D	12	1.00	0.00	<0.005
Zn-T	11	0.64	0.36	0.021

Table 2.2.5. Summary of detected characteristics in blanks associated with Old Wolf Lake.

Characteristic	Number of Blanks	% Below Detection	% Above Detection	Max Conc. Measured
Al-D	34	0.97	0.03	0.01
Al-T	32	0.47	0.53	0.11
B--D	12	1.00	0.00	<0.01
Ba-D	12	1.00	0.00	<0.01
Ba-T	11	1.00	0.00	<0.01
Cd-D	12	0.92	0.08	0.0009
Cd-T	11	1.00	0.00	0.0005
Co-D	12	1.00	0.00	<0.1
Co-T	11	1.00	0.00	<0.1
Cr-D	12	1.00	0.00	<0.01
Cr-T	11	1.00	0.00	<0.01
Cu-D	12	0.75	0.25	0.017
Cu-T	11	0.55	0.45	0.017
Fe-D	12	0.83	0.17	0.03
Fe-T	11	0.45	0.55	0.05
Mn-D	12	1.00	0.00	<0.01
Mn-T	11	1.00	0.00	<0.01
Mo-D	12	1.00	0.00	<0.01
Mo-T	11	1.00	0.00	<0.01
Ni-D	12	1.00	0.00	<0.005
Ni-T	11	1.00	0.00	<0.005
Pb-T	11	0.64	0.36	0.003
Zn-D	12	0.83	0.17	0.006
Zn-T	11	0.82	0.18	0.008

Table 2.3.2. Replicate sample summary for Maxwell Lake, January 1993.

Characteristic	Maximum	Minimum	Mean	Std. Dev	%R.S.D.	Detection Limits
Specific Conductance	65	64	64.8	0.4	0.63	
Acidity <8.3	76.9	72.3	74.1	1.7	2.34	
Alkalinity - total	312	306	309.5	2.3	0.76	
Calcium - soluble	6	5.54	5.88	0.17	2.91	
Chloride - soluble	5.19	4.84	5.06	0.12	2.47	
Magnesium - soluble	1.5	1.44	1.47	0.02	1.46	
Ammonium	0.12	0.06	0.08	0.03	32.79	<0.01
Nitrate - soluble	**0.31**	**0.22**	**0.25**	**0.04**	**14.53**	**<0.01**
Sodium - soluble	3.7	3.5	3.62	0.08	2.08	
Phosphorus - diss.	0.006	0.005	0.005	0.001	9.68	
Sulphate - soluble	4.8	4.7	4.76	0.04	0.74	
pH - Orion Ross	6.99	6.98	6.99	0.01	0.08	

Table 2.3.3. Replicate sample summary for Maxwell Lake, August 1993.

Characteristic	Normal Sample	Replicate #1	Replicate #2	Mean	Std. Dev	%R.S.D.	Detection Limits
Specific Conductance	56	56	55	55.7	0.6	1.04	
Acidity <8.3	37.2	41.8	42.8	40.6	3.0	7.36	
Alkalinity - total	291	303	276	290	14	4.66	
Aluminum - total	0.03	0.03	0.01	0.02	0.01	49.49	<0.01
Calcium - soluble	5.68	5.55	5.4	5.5	0.1	2.53	
Chloride - soluble	4.21	4.19	4.18	4.19	0.02	0.36	
Magnesium - soluble	1.19	1.18	1.19	1.19	0.01	0.49	
Ammonium	0.04	0.04	0.03	0.037	0.006	15.75	<0.01
Nitrate - soluble	0.04	0.03	0.03	0.033	0.006	17.32	<0.01
Phosphorus - diss.	0.011	0.007	0.005	0.0	0.0	39.85	<0.003
Phosphorus - total	0.01	0.013	0.01	0.011	0.002	15.75	<0.003
Sulphate - soluble	3.79	3.83	3.8	3.8	0.0	0.55	

Table 2.3.4. Replicate sample summary for Maxwell Lake, February 1994.

Characteristic	Normal Sample	Replicate #1	Replicate #2	Mean	Std. Dev	%R.S.D.	Detection Limits
Specific Conductance	57	56	63	58.7	3.8	6.45	
Turbidity	0.6	0.6	0.1	0.43	0.29	66.62	<0.1
Colour (TAC)	5	9	7	7	2	28.57	<1
Acidity <8.3	46.8	48.2	47.7	47.57	0.71	1.49	
Alkalinity - total	329	335	318	327.3	8.6	2.63	
Aluminum - total	0.02	0.02	0.03	0.023	0.006	24.74	<0.01
Calcium - soluble	5.42	5.44	5.42	5.427	0.012	0.21	
Magnesium - soluble	1.17	1.21	1.2	1.19	0.02	1.74	
Phosphorus - diss.	0.006	0.008	0.004	0.006	0.002	33.33	<0.003
Phosphorus - total	0.013	0.01	0.007	0.01	0.003	30.00	<0.003
Sulphate - soluble	4.04	3.99	4.03	4.020	0.026	0.66	

Table 2.3.5. Replicate sample summary for Maxwell Lake, March 1995.

Characteristic	Normal Sample	Replicate #1	Mean	Std. Dev	%R.S.D.	Detection Limits
Specific Conductance	55	56	55.5	0.7	1.27	
Turbidity	**1.4**	**0.6**	**1**	**1**	**56.57**	**<0.1**
Colour (TAC)	10	9	9.5	0.7	7.44	
Acidity <8.3	42.9	44.3	43.6	1.0	2.27	
Alkalinity - total	264	270	267	4	1.59	
Aluminum - diss.	0.01	0.02	0.015	0.007	47.14	<0.01
Phosphorus - diss.	0.013	0.011	0.012	0.001	11.79	<0.003
Phosphorus - total	0.014	0.013	0.0135	0.0007	5.24	
Sulphate - soluble	3.94	3.97	3.955	0.021	0.54	
pH - Orion Ross	7.2	7.17	7.185	0.021	0.30	

Table 2.3.6. Replicate sample summary for Old Wolf Lake, February 1990.

Characteristic	Normal Sample	Replicate #1	Mean	Std. Dev.	%R.S.D.	Detection Limits
Aluminum - diss.	0.5	<0.01	-	-	-	<0.01
Aluminum - total	0.5	<0.01	-	-	-	<0.01
Calcium -dissolved	1.71	<0.02	-	-	-	<0.02
Calcium - total	1.83	<0.02	-	-	-	<0.02
Copper - total	0.003	0.001	0.002	0.001	70.71	<0.001
Magnesium - diss.	0.62	<0.02	-	-	-	<0.02
Magnesium - total	0.65	<0.02	-	-	-	<0.02

Table 2.3.7. Replicate sample summary for Old Wolf Lake, August 1993.

Characteristic	Normal Sample	Replicate #1	Replicate #2	Mean	Std. Dev.	%R.S.D.	Detection Limits
Turbidity	0.3	0.2	0.2	0.23	0.06	24.74	<0.1
Acidity <8.3	38.5	42.1	36.4	39.0	2.9	7.39	
Alkalinity - total	122	123	130	125	4	3.49	
Aluminum - diss.	0.02	0.01	0.01	0.01	0.01	43.30	<0.01
Aluminum - total	0.04	0.03	0.04	0.04	0.01	15.75	<0.01
Calcium - soluble	1.73	1.74	1.72	1.73	0.01	0.58	
Chloride - soluble	2	2	1.99	2.00	0.01	0.29	
Potassium - soluble	0.2	0.1	0.1	0.13	0.06	43.30	<0.05
Magnesium - diss	0.6	0.63	0.64	0.62	0.02	3.34	
Ammonium	0.01	0.01	0.02	0.01	0.01	43.30	<0.01
Nitrate - soluble	<0.01	<0.01	0.01	-	-	-	<0.01
Phosphorus - total	<0.003	<0.003	0.004	-	-	-	<0.003
Sulphate - soluble	0.65	0.66	0.65	0.65	0.01	0.88	

Table 2.3.8. Replicate sample summary for Old Wolf Lake, January 1994.

Characteristic	Normal Sample	Replicate #1	Replicate #2	Mean	Std. Dev.	%R.S.D.	Detection Limits
Specific Conductance	25	23	25	24	1	4.75	
Turbidity	0.5	0.9	1	0.8	0.3	33.07	<0.1
Colour TAC	7	6	7	7	1	8.66	
Acidity <8.3	64.8	69.3	64.4	66.2	2.7	4.11	
Alkalinity - total	137	135	138	137	2	1.12	
Calcium - soluble	1.78	1.76	1.78	1.77	0.01	0.65	
Chloride - soluble	2.12	2.13	2.13	2.13	0.01	0.27	
Magnesium - diss	0.61	0.61	0.64	0.62	0.02	2.79	
Nitrate - soluble	0.36	0.34	0.34	0.35	0.01	3.33	
Phosphorus - diss.	0.005	0.007	0.006	0.006	0.001	16.67	<0.003
Phosphorus - total	0.007	0.007	0.006	0.007	0.001	8.66	
Sulphate - soluble	0.72	0.71	0.72	0.72	0.01	0.81	
pH - Orion Ross	6.47	6.56	6.56	6.53	0.05	0.80	

Table 2.3.9. Replicate sample summary for Old Wolf Lake, March 1995.

Characteristic	Normal Sample	Replicate #1	Mean	Std. Dev.	%R.S.D.	Detection Limits
Turbidity	0.4	0.3	0.35	0.07	20.20	<0.1
Colour TAC	12	11	11.5	0.7	6.15	
Acidity - free	0.2	0.3	0.25	0.07	28.28	<0.1
Acidity <8.3	56	57.8	56.9	1.3	2.24	
Alkalinity - total	94.6	90.7	92.7	2.8	2.98	
Chloride - soluble	2.15	2.16	2.16	0.01	0.33	
Potassium - soluble	0.14	0.13	0.14	0.01	5.24	
Ammonium	<0.01	0.01	0.01	-	-	<0.01
Nitrate - soluble	**0.17**	**0.21**	**0.19**	**0.03**	**14.89**	**<0.01**
Sodium - soluble	1.66	1.69	1.68	0.02	1.27	
Sulphate - soluble	0.77	0.8	0.79	0.02	2.70	
pH - Orion Ross	6.66	6.6	6.63	0.04	0.64	

Table 2.3.10. Replicate sample summary for Spectacle Lake, August 1991.

Characteristic	Maximum	Minimum	Mean	Std. Dev	%R.S.D.	Detection Limits
Solids - dissolved	46	38	42	3	6.38	
N-Kjeldahl	0.34	0.24	0.29	0.03	11.90	<0.04
Acidity <8.3	53.2	51.7	52.4	0.6	1.05	
Alkalinity - total	332	327	330	2	0.53	
Aluminum - total	0.05	0.03	0.04	0.01	23.90	<0.01
Aluminum - diss.	0.07	0.05	0.07	0.01	12.87	<0.01
Calcium - total	5.61	4.99	5.37	0.25	4.75	
Calcium - soluble	5.77	5.64	5.70	0.05	0.92	
Chloride - soluble	1.84	1.81	1.83	0.01	0.64	
Copper - total	0.001	<0.001	-	-	-	<0.001
Iron - total	0.11	0.09	0.10	0.01	6.32	
Magnesium - diss.	0.92	0.91	0.92	0.01	0.60	
Magnesium - total	0.92	0.8	0.87	0.04	4.98	
Ammonium	0.02	0.01	0.02	0.01	30.98	<0.01
Nitrate - soluble	0.24	0.04	0.09	0.08	89.28	<0.01
Phosphorus - diss.	0.004	<0.003	-	-	-	<0.003
Phosphorus - total	0.006	0.003	0.005	0.001	30.63	<0.003
Lead - total	0.002	0.001	0.002	0.001	36.51	<0.001
Sulphate - soluble	1.92	1.88	1.91	0.01	0.77	
Zinc - total	0.009	0.005	0.007	0.002	22.27	<0.005
pH - Orion Ross	7.22	7.2	7.21	0.01	0.12	

Table 2.3.11. Replicate sample summary for Stocking Lake, January 1992.

Characteristic	Maximum	Minimum	Mean	Std. Dev.	%R.S.D.	Detection Limits
Acidity - free	0.3	0.2	0.27	0.05	19.36	<0.1
Acidity <8.3	**110**	**80.1**	**97.1**	**10.5**	**10.86**	**<0.1**
Alkalinity - total	171	154	165	7	4.33	
Aluminum - total	0.06	0.04	0.05	0.01	17.89	<0.01
Aluminum - diss.	0.04	<0.01	0.04	0.01	30.99	<0.01
Calcium - soluble	3.47	3.43	3.45	0.01	0.43	
Chloride - soluble	1.47	1.38	1.4	0.0	2.23	
Magnesium - diss.	0.46	0.45	0.45	0.01	1.14	
Ammonium	0.04	0.01	0.03	0.01	55.14	<0.01
Nitrate - soluble	0.14	0.11	0.13	0.01	9.56	
Sodium - soluble	1.3	1.2	1.3	0.1	4.08	
Phosphorus - diss.	0.003	<0.003	-	-	-	<0.003
Sulphate - soluble	1.98	1.95	1.96	0.01	0.62	
pH - Orion Ross	6.71	6.55	6.61	0.06	0.86	

Table 2.3.12. Replicate sample summary for Stocking Lake, July 1992.

Characteristic	Maximum	Minimum	Mean	Std. Dev.	%R.S.D.	Detection Limits
Specific conductance	29	28	28	1	1.93	
Acidity <8.3	37.7	35.4	36.6	1.0	2.75	
Alkalinity - total	187	170	180	6	3.40	
Aluminum - total	0.11	0.03	0.05	0.03	56.65	<0.01
Calcium - soluble	3.33	3.2	3.26	0.05	1.59	
Chloride - soluble	1.25	1.24	1.24	0.01	0.44	
Magnesium - soluble	0.45	0.44	0.44	0.01	1.23	
Phosphorus - diss.	0.005	<0.003	-	-	-	<0.003
Sulphate - soluble	1.41	1.36	1.38	0.02	1.36	
pH - Orion Ross	7.14	7.07	7.10	0.03	0.43	

Table 2.3.13. Replicate sample summary for Stocking Lake, August 1993.

Characteristic	Normal Sample	Replicate #1	Replicate #2	Mean	Std. Dev.	%R.S.D.	Detection Limit
Acidity <8.3	38.2	37.3	38.3	37.9	0.6	1.45	
Alkalinity - total	211	206	212	210	3	1.53	
Aluminum - total	0.03	0.05	0.03	0.04	0.01	31.49	<0.01
Calcium - soluble	3.82	3.79	3.88	3.83	0.05	1.20	
Chloride - soluble	1.46	1.45	1.46	1.46	0.01	0.40	
Magnesium - diss.	0.54	0.55	0.55	0.55	0.01	1.06	
Nitrate - soluble	0.04	0.01	0.05	0.03	0.02	62.45	<0.01
Sulphate - soluble	1.71	1.71	1.7	1.71	0.01	0.34	
pH - Orion Ross	7.02	7.01	7.03	7.02	0.01	0.14	

Table 2.3.14. Replicate sample summary for Stocking Lake, January 1994.

Characteristic	Normal Sample	Replicate #1	Replicate #2	Mean	Std. Dev.	%R.S.D.	Detection Limit
Specific conductance	28	32	30	30	2	6.67	
Turbidity	1.2	0.5	0.5	0.7	0.4	55.11	<0.1
Acidity <8.3	71.6	75.3	61.3	69.4	7.3	10.45	<0.1
Alkalinity - total	170	173	173	172	2	1.01	
Aluminum - total	0.05	0.05	0.06	0.05	0.01	10.83	<0.01
Calcium - soluble	3.51	3.41	3.36	3.43	0.08	2.23	
Chloride - soluble	1.44	1.44	1.43	1.44	0.01	0.40	
Potassium - soluble	0.2	0.3	0.3	0.3	0.1	21.65	<0.05
Magnesium - diss.	0.5	0.49	0.49	0.49	0.01	1.17	
Nitrate - soluble	**0.1**	**0.1**	**0.13**	**0.11**	**0.02**	**15.75**	**<0.01**
Phosphorus - total	0.006	0.005	0.005	0.005	0.001	10.83	<0.003
Phosphorus - diss.	0.005	0.004	0.008	0.006	0.002	36.74	<0.003
Sulphate - soluble	1.86	1.88	1.9	1.88	0.02	1.06	
pH - Orion Ross	6.65	6.66	6.66	6.66	0.01	0.09	

Table 4.1. Metal Speciation Data for Buttle, Old Wolf, Stocking, and Maxwell Lakes using the Gecheq Model (from C.B.R., 1990).

Characteristic	Buttle Lk.	Old Wolf Lk.	Stocking Lk.	Maxwell Lk.
pH	7.3	7.1	7.4	7.4
CO_3 (mg/L)	3.04	0.94	1.33	2.09
Cu- Diss (nmol/L)	31.5	15.7	<16	<16
Free $Cu(II)^{2+}$	5.2	9.7	<6	<6
$Cu(II)(OH)^{+}$	7.7	3.7	<5	<5
Cd- Diss (nmol/L)	0.9	<0.9	<0.9	<0.9
Free $Cd(II)^{2+}$	0.83	<0.8	<0.8	<0.8
Pb- Diss (nmol/L)	<5	<5	<5	<5
Free $Pb(II)^{2+}$	<1	<1	<1	<1
$Pb(OH)^{+}$	<1	<1	<1	<1
$PbHCO_3^{+}$	<1	<1	<1	<1
Zn- Diss. (nmol/L)	373	<75	<75	<75
Free $Zn(II)^{2+}$	328	<75	<75	<75

Table 4.2 Length and Weight data for the Rainbow Trout from the Acid Rain Lakes

	Lizard Lake		Maxwell Lake		Old Wolf Lake		Stocking Lake	
	Length	Weight	Length	Weight	Length	Weight	Length	Weight
Average	27.5	252	42.0	870	48.8	1408	28.0	240
Std. Dev.	3.5	80.2	4.6	357	3.9	368	0.8	14
Sample Size	3	3	10	10	9	9	10	10

Length in centimetres; weight in grams

Table 4.3. Metallothionein Concentrations (nmol/gram dry weight) in Rainbow Trout from the Acid Rain Lakes

	Lizard Lk.	Maxwell Lk.	Old Wolf Lk.	Stocking Lk.
Average	80	92	182	110
Std. Dev.	24	26	42	22
Sample Size	3	10	9	10

Table 4.4. Cytosolic and Membrane Cadmium Concentrations in Rainbow Trout from the Acid Rain Lakes

	Lizard Lake		Maxwell Lake		Old Wolf Lake		Stocking Lake	
	Cytosolic	Membrane	Cytosolic	Membrane	Cytosolic	Membrane	Cytosolic	Membrane
Average	0.119	0.065	0.162	0.072	0.393	0.333	0.691	0.103
Std. Dev.	0.074	0.015	0.079	0.048	0.215	0.177	0.376	0.069
Sample Size	3	3	10	10	9	9	10	10

Table 4.5. Cytosolic and Membrane Copper Concentrations from the Acid Rain Lakes

	Lizard Lake		Maxwell Lake		Old Wolf Lake		Stocking Lake	
	Cytosolic	Membrane	Cytosolic	Membrane	Cytosolic	Membrane	Cytosolic	Membrane
Average	27.9	15.0	234.8	161.9	449.4	412.1	71.7	21.1
Std. Dev.	9.6	1.4	168.4	129.9	323.3	292.9	98.1	33.9
Sample Size	3	3	10	10	9	9	10	10

Table 4.6. Cytosolic and Membrane Lead Concentrations from the Acid Rain Lakes

	Lizard Lake		Maxwell Lake		Old Wolf Lake		Stocking Lake	
	Cytosolic	Membrane	Cytosolic	Membrane	Cytosolic	Membrane	Cytosolic	Membrane
Average	0.00	0.401	0.163	0.065	0.559	0.339	0.388	0.147
Std. Dev.	0.00	0.017	0.014	0.016	0.084	0.142	0.095	0.050
Sample Size	3	3	10	10	9	9	10	10

Table 4.7. Cytosolic and Membrane Zinc Concentrations from the Acid Rain Lakes

	Lizard Lake		Maxwell Lake		Old Wolf Lake		Stocking Lake	
	Cytosolic	Membrane	Cytosolic	Membrane	Cytosolic	Membrane	Cytosolic	Membrane
Average	51.9	15.9	88.4	25.9	86.1	40.5	103.0	16.5
Std. Dev.	7.1	2.5	9.2	5.6	9.9	6.1	10.2	4.2
Sample Size	3	3	10	10	9	9	10	10

Table 5.1 Summary of Sediment Chemistry Data

VARIABLE	LIZARD LAKE	MARION LAKE	MAXWELL LAKE	OLD WOLF LAKE	SPECTACLE LAKE	STOCKING LAKE
METALS						
Aluminum	11600	24500	11500	11000	9670	12600
Arsenic	1.7	<25	27.7	<25	<25	4.5
Barium	45	76	82	46	58	59
Cadmium	<1	<1	2	<1	<1	<1
Cobalt	<10	-	<10	<10	<10	<10
Chromium	10	18	18	8	18	13
Copper	23	52	43	22	39	32
Iron	14400	29400	15700	5790	10600	5660
Mercury	0.11	0.15	0.18		0.16	0.14
Manganese	410	398	877	153	196	339
Molybdenum 3	23	8	3	7	14	
Nickel	15	8	19	9	12	8
Lead	26	39	113	24	50	<10
Selenium	<10	<10	11	<10	<10	<10
Tin	<5	11	<5	<5	13	<5
Strontium	22	23	21	19	25	25
Zinc	42	58	90	28	55	30
NUTRIENTS						
Kjeldahl-N	13000	9200	17100	19000	-	13300
Total Phos.	1430	898	989	1840	746	2400
PHYSICAL PARAMETERS						
Tot.Vol.Res.	42.8	44.6	51.1	47	60.8	43.6
T.I.C.	3710	2300	2960	75000	-	2950
Tot Carbon	196000	182000	237000	235000	-	193000

All units are as µg/g (dry) except Total Vol. Residue as %.

Table 5.2. Summary of Sediment Chemistry for Lakes on Vancouver and Queen Charlotte Islands.

CHARACTERISTIC	NO.OF VALUES	VALUES MAXIMUM	MINIMUM	MEAN	STD. DEV.
METALS					
Aluminum	96	46500	3840	20130	10430
Arsenic	96	1300	1	46.2	142.1
Barium	95	301	7	82.3	57.4
Cadmium	96	8	1	1.2	0.8
Cobalt	96	460	10	23.7	46.7
Chromium	94	242	6	36.9	31.9
Copper	95	320	8	57.3	49
Iron	96	133	2.6	32.4	28.9
Mercury	95	0.63	0.05	0.19	0.11
Manganese	96	57700	29	2310	7325
Molybdenum	96	44	1	8.5	7.9
Nickel	96	62	5	22.3	12.7
Lead	96	243	10	37.2	39.8
Selenium	96	41	10	14.5	7.6
Tin	76	123	5	9.5	13.9
Zinc	96	157	12	70.8	32.9
NUTRIENTS					
Kjeldahl-N	96	24	1.4	11.2	5.9
Total Phosphorus	96	4440	342	1310	641
PHYSICAL PARAMETERS					
Tot.Vol.Res.	96	68.2	7.8	40.7	13.9
T.I.C.	96	9700	500	3330	2160
Tot Carbon	96	343000	9000	170300	75000

All units are as μg/g (dry) except Total Vol. Residue as %.

Table 6.1. Summary of Water Quality Data for Lizard Lake.

	No. of	Values			Standard
Characteristic	**Values**	**Maximum**	**Minimum**	**Mean**	**Error**
GENERAL IONS					
Acidity-free	102	0.3	<0.01	0.120	0.004
Acidity <8.3	104	300	1	52.1	3.4
Alkalinity - total	108	330	150	208.1	2.2
Chloride-soluble	106	3.57	1.65	2.27	0.043
Colour - TAC	89	15	<1	4.4	0.3
Hardness-total	94	21.9	9.2	11.9	0.2
pH - Metrohm	87	8.0	6.5	7.18	0.03
- Orion Ross	102	7.74	6.59	7.077	0.02
Potassium - soluble	105	0.2	<0.05	0.096	0.002
-dissolved	6	0.1	<0.1	0.1	-
Sodium - soluble	103	2.62	1.30	1.57	0.02
-dissolved	6	1.9	1.7	1.8	0.04
Solids-dissolved	26	28	16	22.4	0.60
Solids-suspended	7	2	<1	1.4	0.20
Solids-total	13	30	18	23.7	0.92
Specific Conductance	107	46	24	33.5	0.33
Sulphate - soluble	6	1.6	1.2	1.4	0.06
-dissolved	105	1.57	1.06	1.28	0.01
Turbidity	6	0.4	0.3	0.38	0.017
METALS					
Aluminum - total	94	0.23	<0.01	0.053	0.004
-dissolved	65	0.1	<0.01	0.047	0.004
Cadmium - total	97	<0.01	<0.0005	median <0.01	
-dissolved	51	<0.002	<0.0005	median <0.0005	
Calcium - total	94	7.72	3.01	3.89	0.061
-soluble	96	6.4	2.77	3.88	0.048
Chromium - total	98	0.03	<0.002	0.009	0.0005
-dissolved	51	0.03	<0.002	0.008	0.0008
Copper - total	97	0.01	<0.001	median <0.002	
-dissolved	49	0.011	<0.001	median <0.001	
Iron - total	98	0.19	<0.01	0.042	0.0033
-dissolved	51	0.13	<0.003	0.019	0.0029
Lead - total	97	0.1	<0.001	median <0.1	
Nickel-total	97	<0.05	0.001	median <0.01	
-dissolved	51	<0.008	0.002	0.004	0.0004
Magnesium - total	97	0.75	0.40	0.53	0.007
-soluble	96	0.75	0.34	0.50	0.006
Manganese - total	98	0.02	<0.002	median <0.01	
- dissolved	51	0.02	<0.002	median <0.01	
Molybdenum - total	98	0.01	<0.004	median <0.01	
Zinc - total	97	0.04	<0.005	median <0.01	
-dissolved	49	0.009	<0.002	median <0.005	
NUTRIENTS					
N-ammonium	102	0.05	0.01	0.014	0.001
N-Kjeldahl	88	0.26	0.03	0.094	0.004
N-nitrate	101	0.37	0.01	0.10	0.010
N - total	22	0.49	0.06	0.19	0.027
P-tot. diss.	86	0.006	<0.003	median <0.003	
P-total	106	0.012	<0.003	0.004	0.0002
N:P ratio	22	110.0	12.0	40.6	6.1
TDS:SpCond ratio	26	0.93	0.51	0.67	0.02

Table 6.2. Summary of Water Quality Data for Marion (Jacobs) Lake.

Characteristic	No. of Values	Values			Standard Error
		Maximum	Minimum	Mean	
GENERAL IONS					
Acidity-free	74	2.4	0.1	0.41	0.051
Acidity <8.3	74	219	28.3	63.90	2.980
Alkalinity - total	78	218	12.9	86.5	5.3
Chloride-soluble	80	1.4	0.41	0.678	0.022
Colour - TAC	67	24	4	11.299	0.517
Hardness-total	67	15.43	2.36	5.883	0.297
pH - Metrohm	65	7.7	5.7	6.78	0.060
- Orion Ross	74	7.18	5.63	6.546	0.040
Potassium - soluble	80	0.22	<0.05	0.10	0.003
Sodium - soluble	80	1.51	0.30	0.84	0.024
Solids-dissolved	66	32	8	19.7	0.74
Solids-suspended	3	2	1	1.3	0.33
Solids-total	10	28	11	18.7	1.58
Specific Conductance	81	30	9	17.1	0.51
Sulphate - soluble	80	2.3	0.92	1.65	0.030
METALS					
Aluminum - total	75	0.75	0.01	0.132	0.012
-dissolved	43	0.14	<0.01	0.086	0.005
Cadmium - total	66	0.04	<0.0005	median <0.0005	
-dissolved	29	<0.0005	<0.0005	<0.000	0
Calcium - total	67	3.84	0.7	1.932	0.0920
-soluble	72	4.15	0.56	1.859	0.0883
Chromium - total	67	0.09	<0.01	median <0.01	
-dissolved	29	<0.01	<0.01	<0.01	0
Copper - total	66	0.3	<0.001	median <0.01	
-dissolved	27	<0.01	<0.001	median <0.001	
Iron - total	67	0.61	<0.01	0.144	0.0143
-dissolved	29	0.16	<0.01	0.059	0.0070
Lead - total	65	0.5	<0.001	0.048	0.0092
Nickel-total	66	0.13	<0.001	0.010	0.0028
-dissolved	29	0.006	<0.001	0.003	0.0002
Magnesium - total	67	1.68	0.1	0.257	0.0248
-soluble	73	0.37	0.08	0.212	0.0074
Manganese - total	67	0.11	<0.01	median <0.01	
- dissolved	29	0.02	<0.01	median <0.01	
Molybdenum - total	67	<1	<0.01	median <0.01	
Zinc - total	67	0.48	<0.005	median <0.01	
-dissolved	28	0.01	<0.005	median <0.05	
NUTRIENTS					
N-ammonium	74	0.37	<0.01	0.035	0.006
N-Kjeldahl	65	0.37	0.04	0.134	0.008
N-nitrate	74	0.97	<0.01	0.202	0.020
N - total	20	0.26	0.04	0.132	0.011
P-tot. diss.	80	0.011	<0.003	0.004	0.0001
P-total	66	0.012	<0.003	0.005	0.0002
N:P ratio	20	43.3	13.3	26.0	2.0
TDS:SpCond ratio	66	2.18	0.38	1.22	0.05

Table 6.3. Summary of Water Quality Data for Maxwell Lake.

Characteristic	No. of Values	Values Maximum	Minimum	Mean	Standard Error
GENERAL IONS					
Acidity-free	117	0.80	<0.01	0.11	0.007
Acidity <8.3	105	226	0	49.8	2.86
Alkalinity - total	114	330.0	99.4	271.6	3.00
Chloride-soluble	117	5.17	3.14	4.37	0.036
Colour TAC	104	12	<1	5.2	0.21
-TC	24	10	<5	5.8	0.39
Hardness-total	82	34.7	6.5	18.4	0.34
pH - Metrohm	87	7.8	6.4	7.2	0.026
- Orion Ross	117	7.72	6.13	7.20	0.024
Potassium - soluble	118	0.51	<0.01	0.30	0.007
-dissolved	14	0.60	0.20	0.27	0.030
Sodium - soluble	118	3.50	2.03	2.91	0.021
- dissolved	15	4.0	2.8	3.0	0.07
Solids-dissolved	82	56	16	39.99	0.661
Solids-suspended	13	2	<1	1.31	0.133
Solids-total	23	50	32	38.39	0.829
Specific Conductivity	122	65	26	54.12	0.433
Sulphate - soluble	117	4.77	2.79	3.90	0.033
- dissolved	15	4.3	3.0	3.43	0.084
Turbidity	36	1.8	0.2	0.60	0.052
METALS					
Aluminum - total	122	0.20	<0.01	0.04	0.003
-dissolved	81	<0.1	<0.01	median <0.01	
Cadmium - total	89	<0.01	<0.0005	median <0.0005	
-dissolved	47	0.010	<0.0005	median <0.0005	
Calcium - total	88	8.84	1.82	5.31	0.090
-soluble	108	6.53	3.39	5.26	0.054
Chromium - total	90	0.030	0.0005	median <0.01	
-dissolved	49	0.020	0.0005	median <0.01	
Copper - total	91	0.040	<0.001	median <0.01	
-dissolved	48	0.010	<0.001	0.004	0.0006
Iron - total	90	0.35	<0.01	0.06	0.006
-dissolved	49	0.10	<0.01	0.02	0.003
Lead - total	90	<0.1	<0.001	median <0.01	
Nickel-total	91	<0.05	<0.002	median <0.05	
-dissolved	49	0.050	<0.002	0.018	0.0032
Magnesium - total	88	3.07	0.48	1.22	0.03
-soluble	108	1.48	0.79	1.17	0.01
Manganese - total	90	0.080	<0.01	0.021	0.0015
- dissolved	49	0.020	<0.002	median <0.01	
Molybdenum - total	90	<0.01	<0.004	median <0.01	
Zinc - total	90	0.070	<0.004	median <0.01	
-dissolved	49	0.011	<0.005	median <0.005	
NUTRIENTS					
N-ammonium	117	0.15	<0.01	0.02	0.002
N-Kjeldahl	85	0.42	0.15	0.26	0.005
N-nitrate	116	0.52	<0.01	median <0.01	
N-total	35	0.460	0.180	0.288	0.0101
P-tot. diss.	116	0.013	<0.003	0.004	0.0002
P-total	103	0.017	<0.003	0.009	0.0003
N:P ratio	28	72.0	14.0	33.9	2.6
TDS:SpCond ratio	82	1.18	0.57	0.74	0.01

Table 6.4. Summary of Water Quality Data for Old Wolf Lake.

Characteristic	No. of Values	Values Maximum	Minimum	Mean	Standard Error
GENERAL IONS					
Acidity-free	107	1.1	<0.1	0.19	0.016
Acidity <8.3	7	6.8	1.5	3.36	0.70
Alkalinity - total	114	179.0	49.5	123.2	1.8
Chloride-soluble	107	4.11	1.46	2.67	0.064
Colour - TAC	102	14	<1	7.49	0.285
Colour - TC	26	20	5	7.12	0.743
Hardness-total	86	9.9	3.35	7.39	0.133
pH - Metrohm	84	7.6	6.2	6.96	0.036
- Orion Ross	107	7.51	6.04	6.86	0.028
Potassium - soluble	109	1.2	0.07	0.19	0.010
- dissolved	13	0.2	<0.1	0.12	0.010
Sodium - soluble	109	2.6	0.2	1.93	0.027
- dissolved	6	2.3	1.9	2.12	0.060
Solids-dissolved	84	36	10	25.3	0.57
Solids-suspended	14	4	1	1.9	0.23
Solids-total	13	28	21	24.5	0.66
Specific Conductance	119	36	13	25.2	0.37
Sulphate - soluble	108	1	1	0.7	0.01
- dissolved	19	5.1	1.0	1.9	0.33
Turbidity	28	0.7	0.3	0.4	0.02
METALS					
Aluminum - total	122	0.50	<0.01	0.06	0.005
-dissolved	84	0.10	<0.01	0.05	0.003
Cadmium - total	85	<0.01	<0.0005	median <0.01	
-dissolved	46	<0.01	<0.0005	median <0.0005	
Calcium - total	86	2.69	0.83	1.89	0.035
-soluble	98	2.86	0.76	1.83	0.032
Chromium - total	86	0.030	<0.002	median <0.01	
-dissolved	48	0.030	<0.002	median <0.01	
Copper - total	86	0.040	<0.001	median <0.01	
-dissolved	48	<0.01	<0.001	0.004	0.0006
Iron - total	86	0.32	<0.01	0.06	0.006
-dissolved	48	0.14	<0.01	0.03	0.003
Lead - total	86	<0.1	<0.001	median <0.1	
Nickel-total	86	<0.05	<0.002	median <0.05	
-dissolved	48	<0.05	<0.002	0.017	0.0031
Magnesium - total	86	0.87	0.16	0.65	0.013
-soluble	98	0.89	0.28	0.62	0.010
Manganese - total	86	0.02	<0.005	median <0.01	
- dissolved	48	0.01	<0.005	median <0.01	
Molybdenum - total	86	0.05	<0.004	median <0.01	
Zinc - total	86	0.07	<0.005	median <0.01	
-dissolved	47	0.015	<0.005	median <0.005	
NUTRIENTS					
N-ammonium	109	0.19	<0.01	0.02	0.002
N-Kjeldahl	83	0.37	0.13	0.21	0.005
N-nitrate	108	2.64	0.01	0.29	0.041
N-total	33	0.65	0.22	0.32	0.019
P-tot. diss.	112	0.006	<0.003	0.003	0.0001
P-total	105	0.18	<0.003	0.008	0.0018
N:P ratio	30	120.0	18.6	48.7	4.7
TDS:SpCond Ratio	84	1.42	0.53	0.98	0.02

Table 6.5. Summary of Water Quality Data for Spectacle Lake.

Characteristic	No. of Values	Values			Standard Error
		Maximum	Minimum	Mean	
GENERAL IONS					
Acidity-free	98	0.80	<0.1	0.18	0.014
Acidity <8.3	85	343	33.1	82.6	5.8
Alkalinity - total	97	366	81.0	251.2	8.1
Chloride-soluble	98	5.97	0.17	3.03	0.099
Colour - TC	4	30	5	16.3	5.54
-TAC	89	27	6	14.8	0.47
-SW	1	17	17	17.0	-
Hardness-total	84	21.37	5.04	16.15	0.343
pH - Metrohm	89	7.70	6.30	7.03	0.032
- Orion Ross	96	7.59	6.10	6.94	0.034
Potassium - soluble	98	0.40	0.05	0.13	0.005
-dissolved	15	0.40	<0.1	0.14	0.024
Sodium - soluble	98	3.05	1.00	2.08	0.029
-dissolved	15	2.60	1.80	2.19	0.057
Solids-dissolved	83	54	10	38.4	0.8
Solids-suspended	15	2	1	1.4	0.1
Solids-total	25	50	19	37.4	1.6
Specific Conductivity	103	58	17	45.2	0.6
Sulphate - soluble	96	5.8	0.5	2.66	0.088
-dissolved	15	4.3	2.0	2.89	0.207
Turbidity	15	1.0	0.5	0.69	0.038
METALS					
Aluminum - total	102	0.17	<0.01	0.07	0.003
-dissolved	62	0.13	<0.01	0.05	0.004
Cadmium - total	88	<0.01	<0.0005	median <0.01	
-dissolved	45	<0.01	<0.0005	median <0.0005	
Calcium - total	89	6.86	1.59	5.11	0.108
-soluble	98	6.71	1.90	5.07	0.098
Chromium - total	47	0.12	<0.01	median <0.01	
-dissolved	89	0.12	<0.01	median <0.01	
Copper - total	89	0.020	0.001	median <0.001	
-dissolved	46	0.010	0.001	median <0.001	
Iron - total	89	2.95	<0.01	0.15	0.034
-dissolved	47	0.50	<0.01	0.07	0.011
Lead - total	87	<0.1	<0.001	median <0.1	
Nickel-total	87	<0.05	<0.002	median <0.05	
-dissolved	46	<0.05	<0.002	0.017	0.0033
Magnesium - total	89	1.11	0.07	0.829	0.0192
-soluble	98	1.04	0.29	0.805	0.0141
Manganese - total	89	0.05	<0.01	median <0.01	
- dissolved	47	0.02	<0.01	median <0.01	
Molybdenum - total	89	0.02	<0.01	median <0.01	
Zinc - total	87	0.04	0.005	median <0.01	
-dissolved	43	0.02	0.005	median <0.005	
NUTRIENTS					
N-ammonium	98	0.08	<0.01	0.02	0.002
N-Kjeldahl	88	1.34	0.07	0.23	0.015
N-nitrate	98	4.90	0.01	0.44	0.078
N-total	50	1.42	0.18	0.37	0.031
P-tot. diss.	100	0.009	<0.003	0.004	0.0001
P-total	89	0.025	<0.003	0.008	0.0003
N:P Ratio	32	190.0	12.8	58.5	8.0
TDS:SpCond ratio	83	1.14	0.59	0.84	0.01

Table 6.6. Summary of Water Quality Data for Stocking Lake.

Characteristic	No. of Values	Values Maximum	Minimum	Mean	Standard Error
GENERAL IONS					
Acidity-free	106	2.50	<0.1	0.17	0.024
Acidity <8.3	109	222	0	57.2	3.36
Alkalinity - total	114	356	31.3	181.9	3.37
Chloride-soluble	110	3.24	0.82	1.76	0.041
Colour - TC	30	20	<5	6.2	0.572
-TAC	100	18	<1	6.2	0.284
-SW	1	10	10	10.0	-
Hardness-total	82	15.46	3.65	11.14	0.197
pH - Metrohm	78	7.6	5.7	7.0	0.04
- Orion Ross	106	7.49	5.60	6.96	0.03
Potassium - soluble	110	1.20	0.10	0.28	0.012
-dissolved	6	0.30	0.20	0.25	0.022
Sodium - soluble	107	2.03	0.30	1.29	0.019
-dissolved	6	1.70	1.40	1.48	0.048
Solids-dissolved	81	42	12	25.6	0.59
Solids-suspended	7	2	<1	1.3	0.18
Solids-total	12	30	19	24.8	0.95
Specific Conductivity	115	38	13	30.4	0.37
Sulphate - soluble	110	2.49	1.37	1.86	0.016
-dissolved	6	2.0	1.7	1.85	0.043
Turbidity	32	1.2	0.2	0.42	0.031
METALS					
Aluminum - total	114	0.2	<0.01	0.05	0.003
-dissolved	82	0.1	<0.01	0.04	0.003
Cadmium - total	81	0.020	<0.0005	median <0.01	
-dissolved	46	<0.01	<0.0005	median <0.0005	
Calcium - total	82	5.12	1.05	3.58	0.068
-soluble	95	4.67	0.85	3.51	0.056
Chromium - total	82	0.03	<0.002	median <0.01	
-dissolved	48	0.04	<0.002	median <0.01	
Copper - total	81	0.04	<0.001	median <0.01	
-dissolved	47	0.01	<0.001	median <0.001	
Iron - total	82	0.41	<0.01	0.08	0.008
-dissolved	49	0.18	<0.01	0.04	0.004
Lead - total	81	0.300	<0.001	median <0.1	
Nickel-total	81	<0.05	<0.002	mdian <0.05	
-dissolved	48	0.05	<0.002	0.017	0.003
Magnesium - total	82	0.85	0.25	0.53	0.009
-soluble	95	0.62	0.22	0.49	0.007
Manganese - total	82	0.040	<0.004	median <0.01	
- dissolved	48	0.020	<0.004	median <0.01	
Molybdenum - total	82	0.080	<0.004	median <0.01	
Zinc - total	82	0.020	<0.005	median <0.01	
-dissolved	44	0.019	<0.002	median <0.0005	
NUTRIENTS					
N-ammonium	106	0.16	<0.01	median <0.01	
N-Kjeldahl	78	0.35	0.06	0.14	0.005
N-nitrate	104	1.04	<0.01	0.09	0.015
N-total	36	0.56	0.10	0.17	0.014
P-tot. diss.	110	0.006	<0.003	median <0.003	
P-total	100	0.011	<0.003	0.005	0.0002
N:P ratio	25	186.7	14.3	39.1	6.8
TDS:SpCond ratio	79	1.13	0.51	0.83	0.02

Table 8.4.1.1:Lizard Lake Phytoplankton: Dominant and Sub-dominant taxa.

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

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

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 8.5.1.1. Marion Lake Phytoplankton: Dominant and Sub-Dominant taxa.

	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		*Merismopedia*	59	379.07

Table 8.5.1.2 Marion Lake Phytoplankton: Summary of total numbers of phytoplankton (cells/mL) by year.

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 8.5.1.2 Marion Lake Phytoplankton: Mean and range of Chlorophyll a measurements by year (µg/L)

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 8.5.1.4. Marion Lake Phytoplankton: Dominant taxa recorded in Dickman (1968).

	Dominant	Sub-Dominant	Mean Conc
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
		Sponsylosium	3.90
		Scenedesmus	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	*Rhabadomonas*		342.00
Pyrrophyte		*Glenodinium*	16.00
		Gymnodinium	48.00

Table 8.5.2.1. Marion Lake Zooplankton: Comparison of zooplankton taxa recorded in three Marion Lake studies.

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

Table 8.6.1.1. Maxwell Lake Phytoplankton: Dominant and Sub-dominant taxa.

	Dominant	Sub-Dominant	% Presence	Mean Conc.
Chrysophyte	*Dinobryon*		95	110.35
Chlorophyte	*Crucigenia*		89	41.43
	Arthrodesmus		76	5.38
		Elakothrix	66	5.98
		Scenedesmus	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 8.6.1.2 Maxwell Lake Phytoplankton: Summary of total numbers of phytoplankton/mL by year

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 8.6.1.3. Maxwell Lake Phytoplankton: Mean and range of chlorophyll a measurements by year (µg/L).

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

	Dominant	Sub-Dominant	% Presence	Mean Conc.
Chrysophyte	*Dinobryon*		92	90.75
Chlorophyte	*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
Cryptophyte	*Crucigenia*		81	107.88
	Elakothrix		80	11.56
	Oocystis		77	41.25
		Scenedesmus	72	20.99
		Botryococcus	70	205.98
		Quadrigula	62	15.04
		Gloeocystis	59	127.17
		Arthrodesmus	52	0.83
		Pediastrum	51	5.60
Diatom		*Tabellaria*	59	1.14
		Navicula	50	0.50

Table 8.7.1.2. Old Wolf Lake Phytoplankton: Summary of total numbers of phytoplankton/mL by year.

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 8.7.1.3. Old Wolf Lake Phytoplankton: Mean and range of chlorophyll a measurements by year (µg/L).

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 8.8.1.1 Spectacle Lake Phytoplankton: Dominant and Sub-Dominant taxa.

	Dominant	Sub-Dominant	% Presence	Mean Conc.
Chrysophyte	*Dinobryon*		96	220.60
	Mallomonas		8.	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	*Merismopoedia*		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 8.8.1.2. Spectacle Lake Phytoplankton: Summary of total numbers of phytoplankton/mL by year.

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 8.8.1.3. Spectacle Lake Phytoplankton: Mean and range of chlorophyll a measurements by year (µg/L)

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 8.9.1.1. Stocking Lake Phytoplankton: Dominant and Sub-Dominant taxa.

	Dominant	Sub-Dominant	% Presence	Mean Conc.
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	38.28
Diatom		*Melosira*	61	168.77
		Asterionella	60	62.92

Table 8.9.1.2. Stocking Lake Phytoplankton: Summary of total numbers of phytoplankton/mL by year.

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 8.9.1.3. Stocking Lake Phytoplankton: Mean and range of chlorophyll a measurements by year (µg/L)

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 8.10.1. Summary of phytoplankton and zooplankton community key characteristics.

	Lizard	**Marion**	**Maxwell**
# phytoplankton genera	82	99	84
dominant phytoplankton	*Oocystis*	*Navicula*	*Dinobryon*
mean total number of phytoplankton	1512	5426/650*	999
chlorophyll a mean	1.21	2.57	2.94
chlorophyll a range	0.5-6.0	0.6-5.8	0.5-6.1
# zooplankton genera	28	22	28
dominant copepod	*Diaptomus*	*Diaptomus*	*Cyclops*
dominant cladoceran	*Daphnia*	*Bosmina*	*Bosmina*
dominant rotifer	*Keratella*	*Keratella*	*Keratella*

	Old Wolf	**Spectacle**	**Stocking**
# phytoplankton genera	88	80	84
dominant phytoplankton	*Dinobryon*	*Dinobryon*	*Cryptomonas*
mean total number of phytoplankton	14186	6202	1433
chlorophyll a mean	1.82	2.15	0.97
chlorophyll a range	0.5-8.2	0.5-5.9	0.5-2.2
# zooplankton genera	29	28	31
dominant copepod	*Diaptomus*	*Diaptomus*	*Diaptomus*
dominant cladoceran	*Daphnia*	*Daphnia*	*Bosmina*
dominant rotifer	*Keratella*	*Keratella*	*Keratella*

APPENDIX 1

Fish Stocking Events

Lake	Date	Number Released
Lizard Lake	April, 1984	1000
	April, 1986	1000
	June, 1987	2000
	May, 1988	1000
	May, 1989	2000
	April, 1991	2000
	April, 1992	1000
	April, 1993	1000
	April, 1994	1000
Maxwell Lake	June, 1984	5000
Old Wolf Lake	April, 1984	1000
Spectacle Lake	May, 1989	2000
	April, 1990	2000
Stocking Lake	July, 1982	15000
	July, 1983	15000
	June, 1984	15000
	July, 1986	15000

APPENDIX 2

Analytical Detection Limits

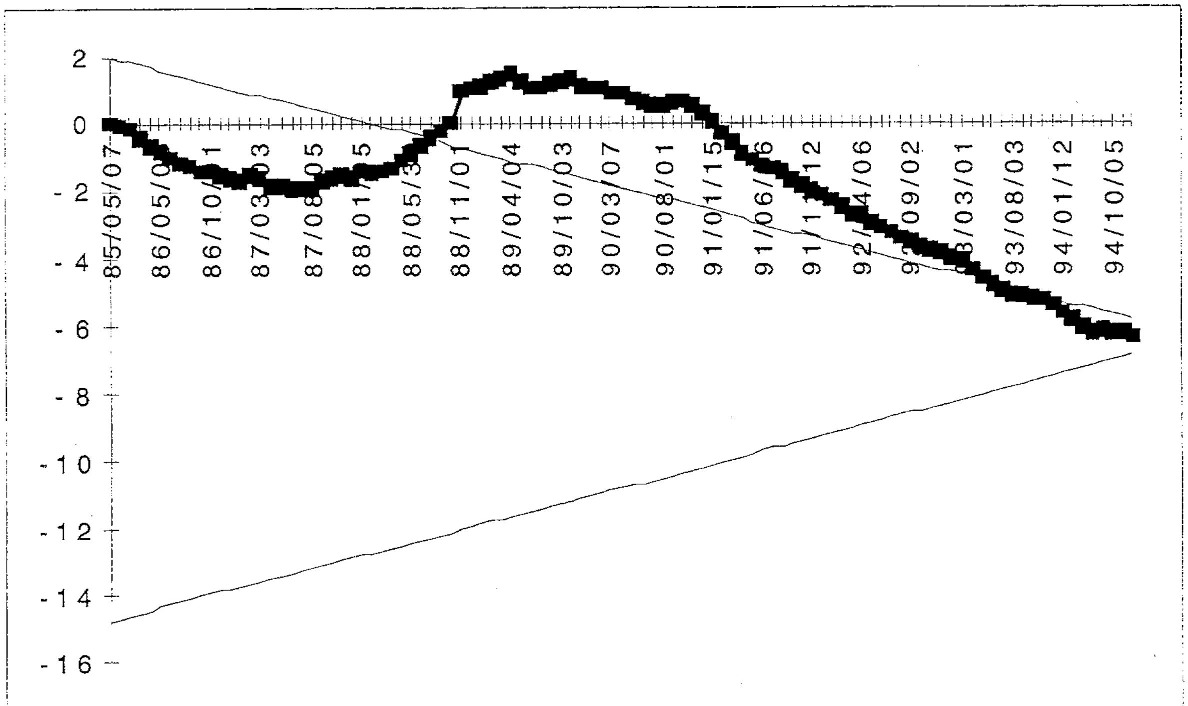
CHARACTERISTIC	M.D.L.	CHARACTERISTIC	M.D.L.
Acidity-Free	0.1 µeq/L	Acidity pH 8.3	0.1 µeq/L
Alkalinity	0.1 µeq/L	Aluminum	0.10 mg/L
Ammonium	0.01 mg/L	Barium	0.01 mg/L
Calcium	0.02 mg/L	Cadmium	0.5 µg/L
Chloride-sol	0.01 mg/L	Chromium	0.01 mg/L
Cobalt	0.1 mg/L	Colour TAC	1 TAC
Copper	1 µg/L	Iron	0.01 mg/L
Hardness	0.1 mg/L	Lead	1 µg/L
Magnesium	0.02 mg/L	Manganese	0.01 mg/L
Molybdenum	0.01 mg/L	Nickel	0.005 mg/L
Nitrate-sol	0.01 mg/L	Nitrogen-Kjeldahl	0.01 mg/L
pH	-	Phosphorus-tot & diss	0.003 mg/L
Potassium-sol	0.01 mg/L	Residue-Filtrable	1 mg/L
Specific Conductivity	1 µS/cm	Sulphate	0.01 mg/L
Vanadium	0.01 mg/L	Zinc	5 µg/L

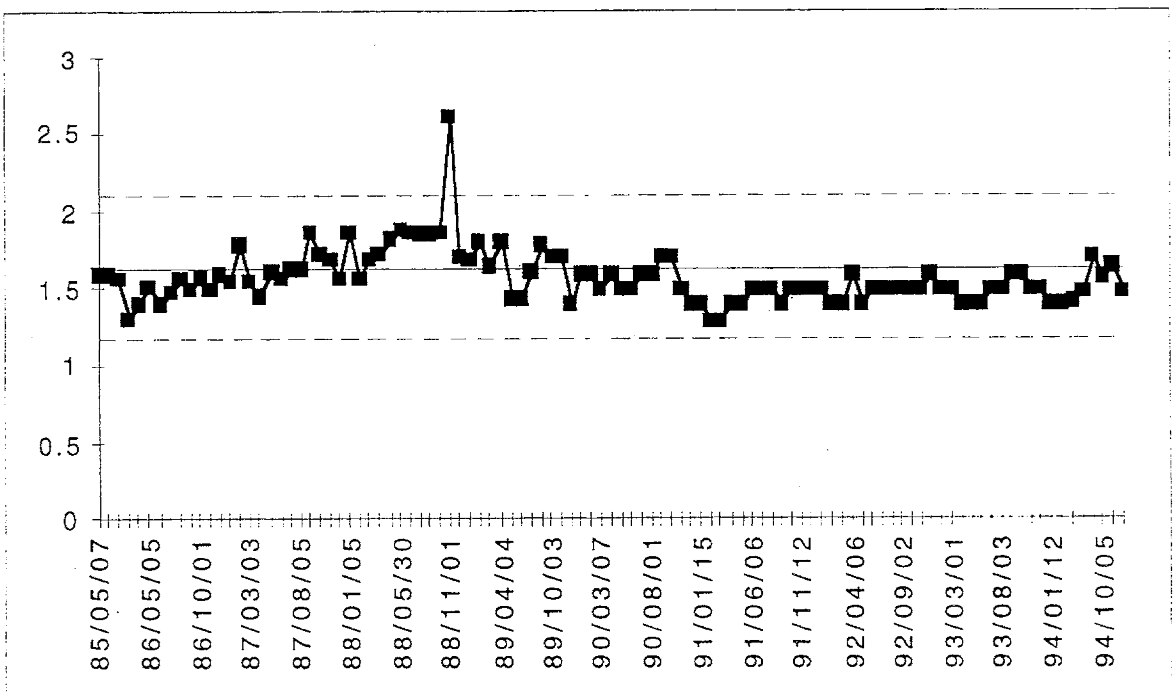
APPENDIX 3

Summary of Significant CUSUM Analyses

Lizard Lake: Sodium

There is a 97.1% chance that an downwards shift of 0.153 has occurred from the original mean of 1.63.

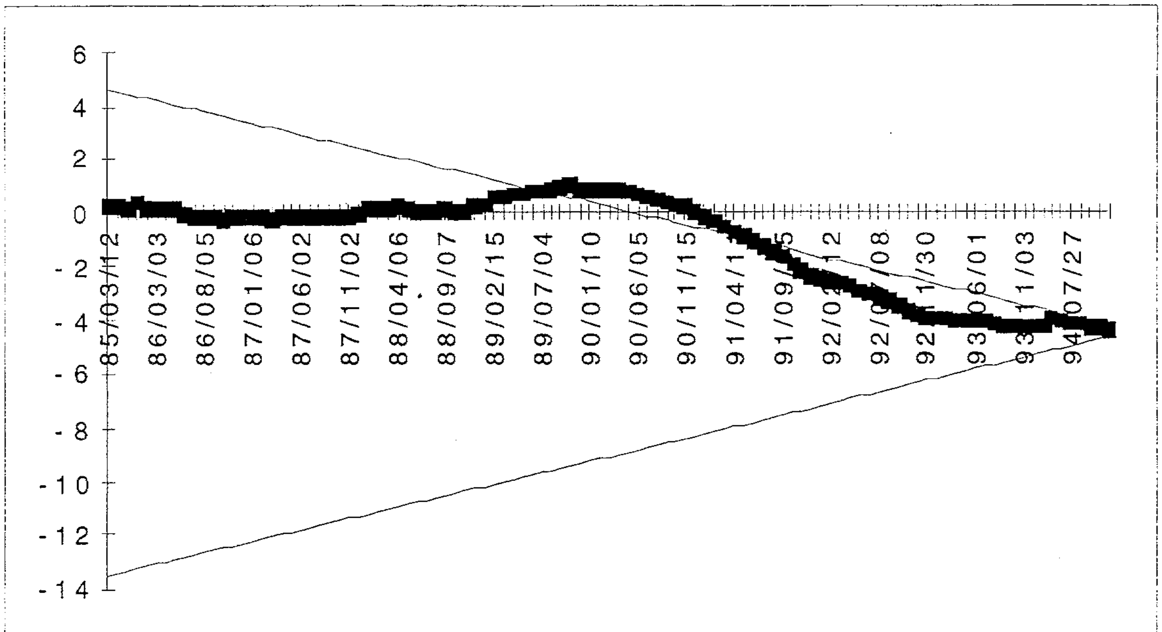


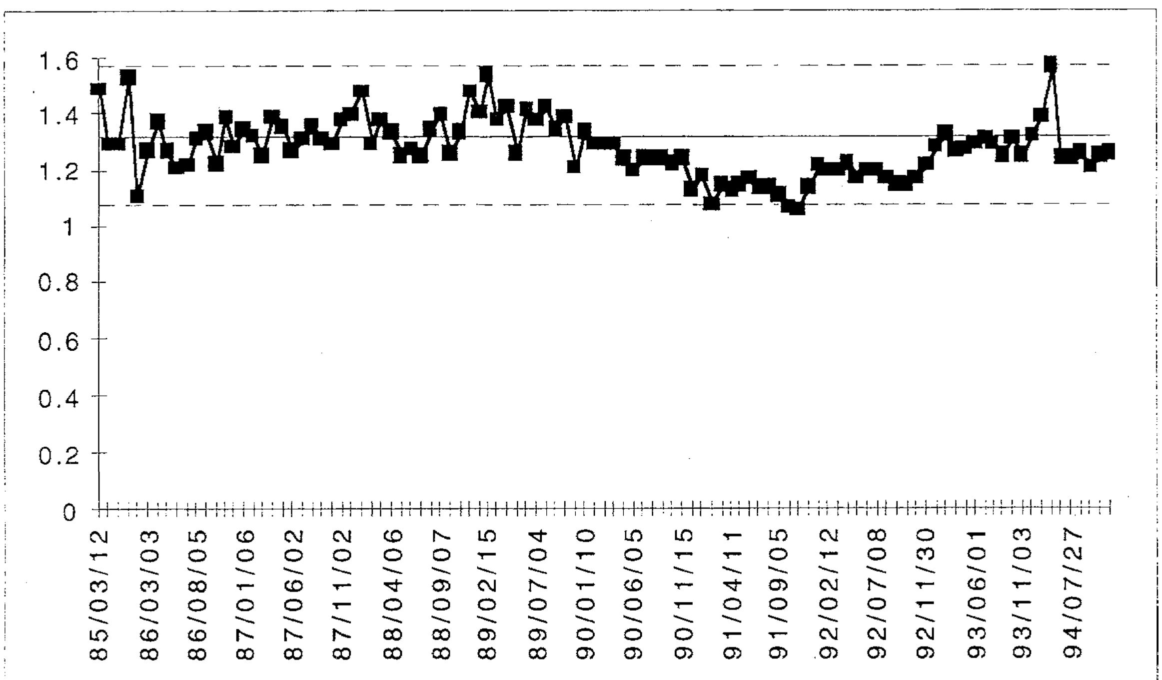


APPENDIX 3 (continued)

Lizard Lake : Sulphate

There is a 99.4% chance that an downwards shift of 0.1703 has occurred from the original mean of 1.32.

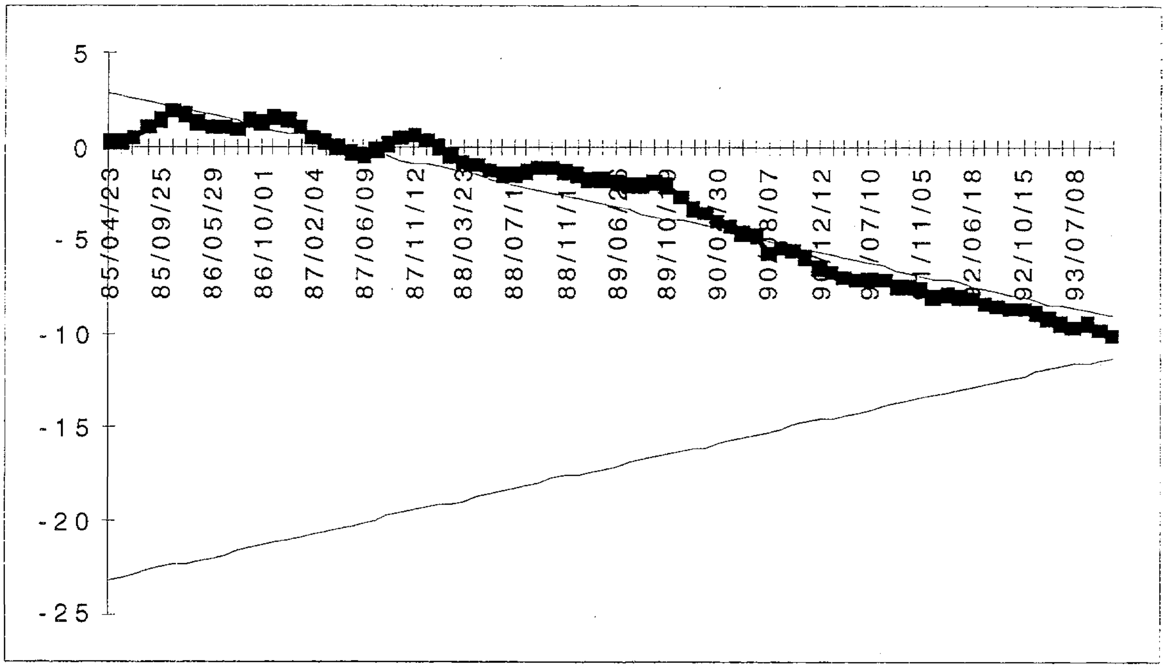


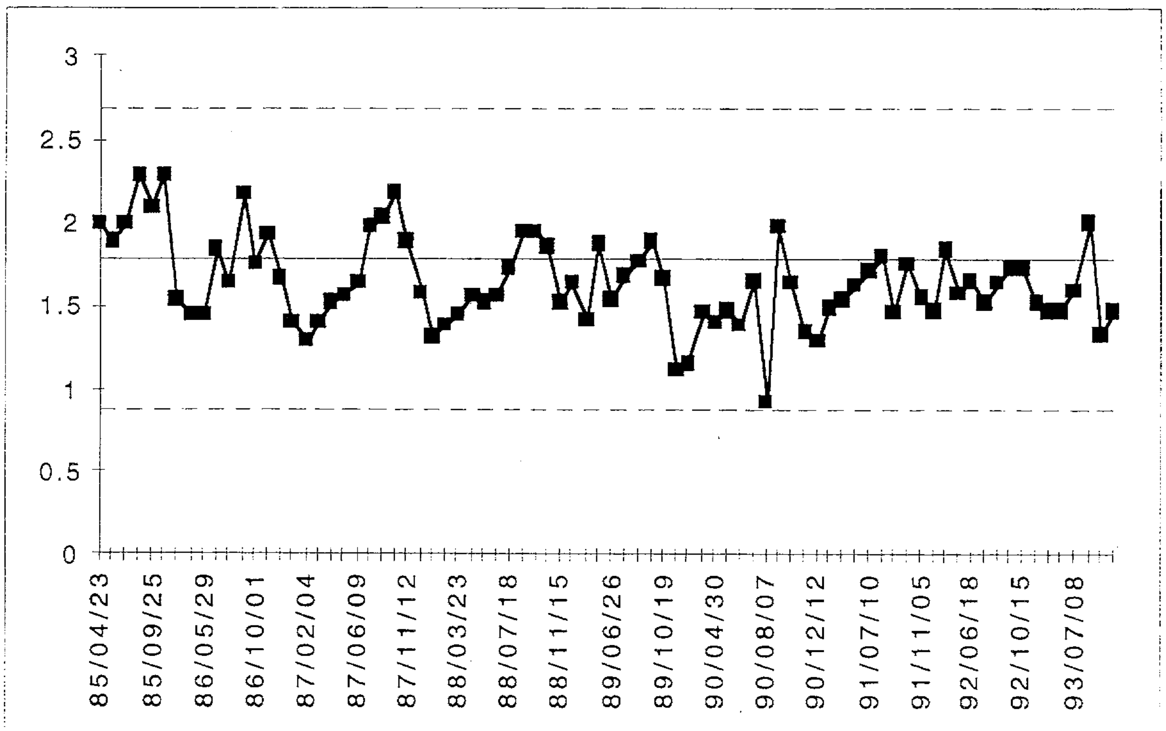


APPENDIX 3 (continued)

Marion (Jacobs) Lake: Sulphate

There is a 97.1% chance that an downwards shift of 0.303 has occurred from the original mean of 1.78.

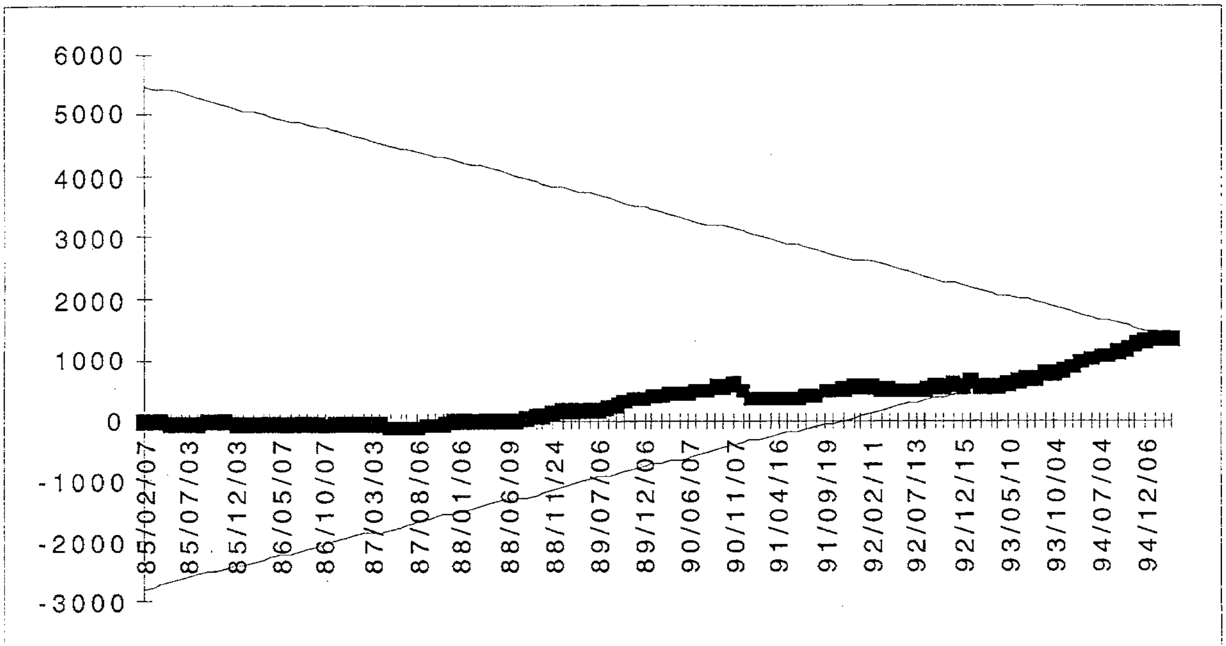


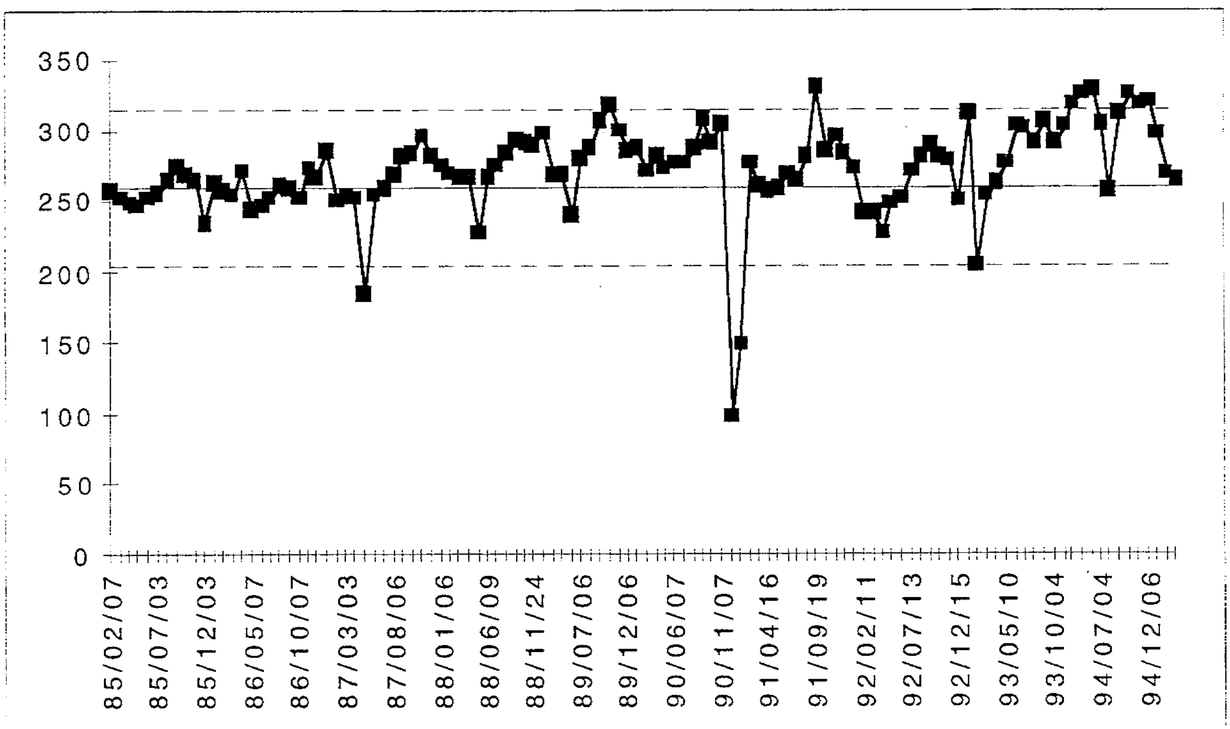


APPENDIX 3 (continued)

Maxwell Lake: Alkalinity

There is a 100% chance that an upwards shift of 72.3 has occurred from the original mean of 260.

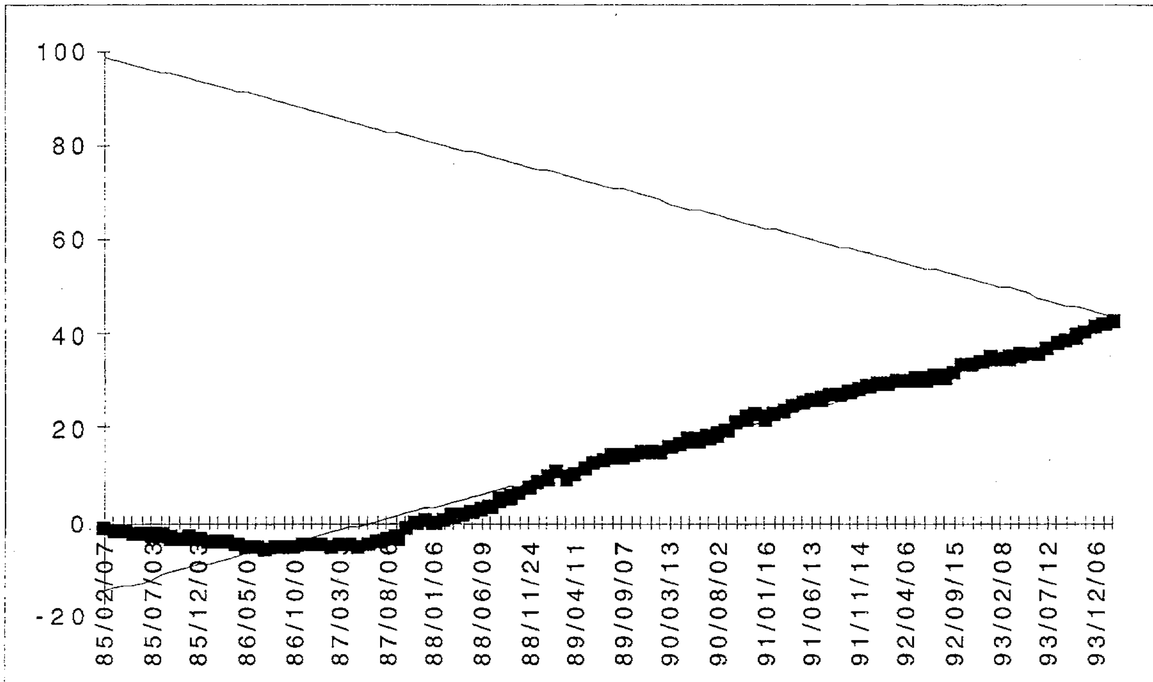


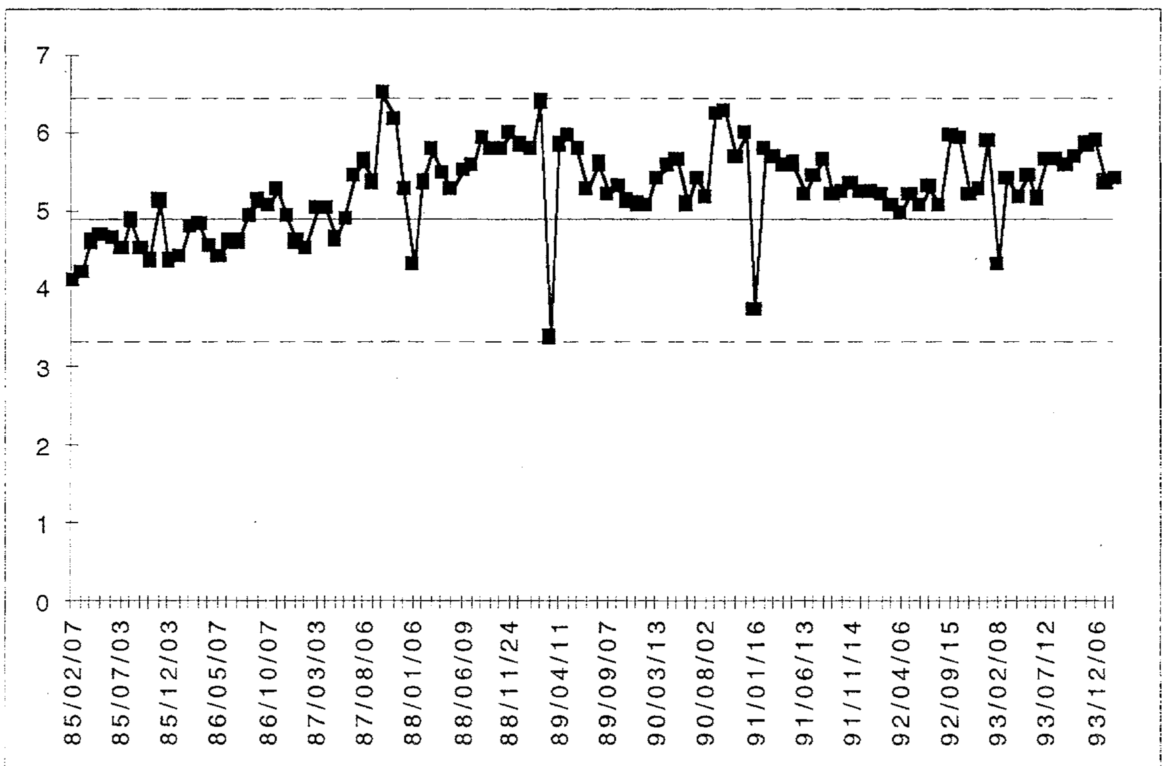


APPENDIX 3 (continued)

Maxwell Lake: Calcium

There is a 99.4% chance that an upwards shift of 1.03 has occurred from the original mean of 4.87.

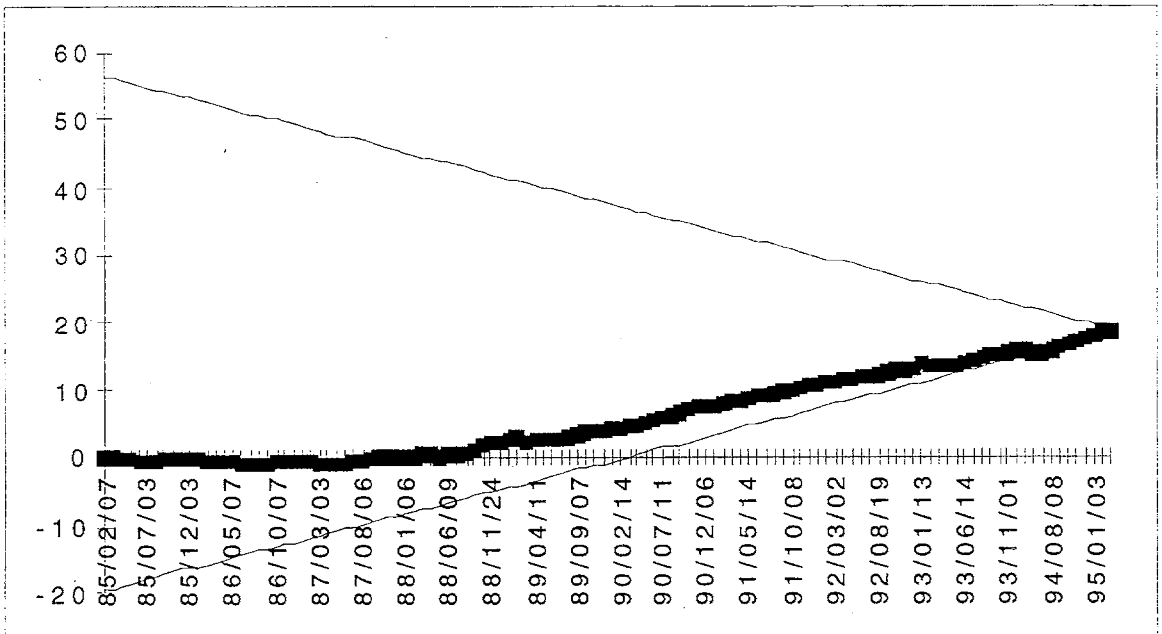


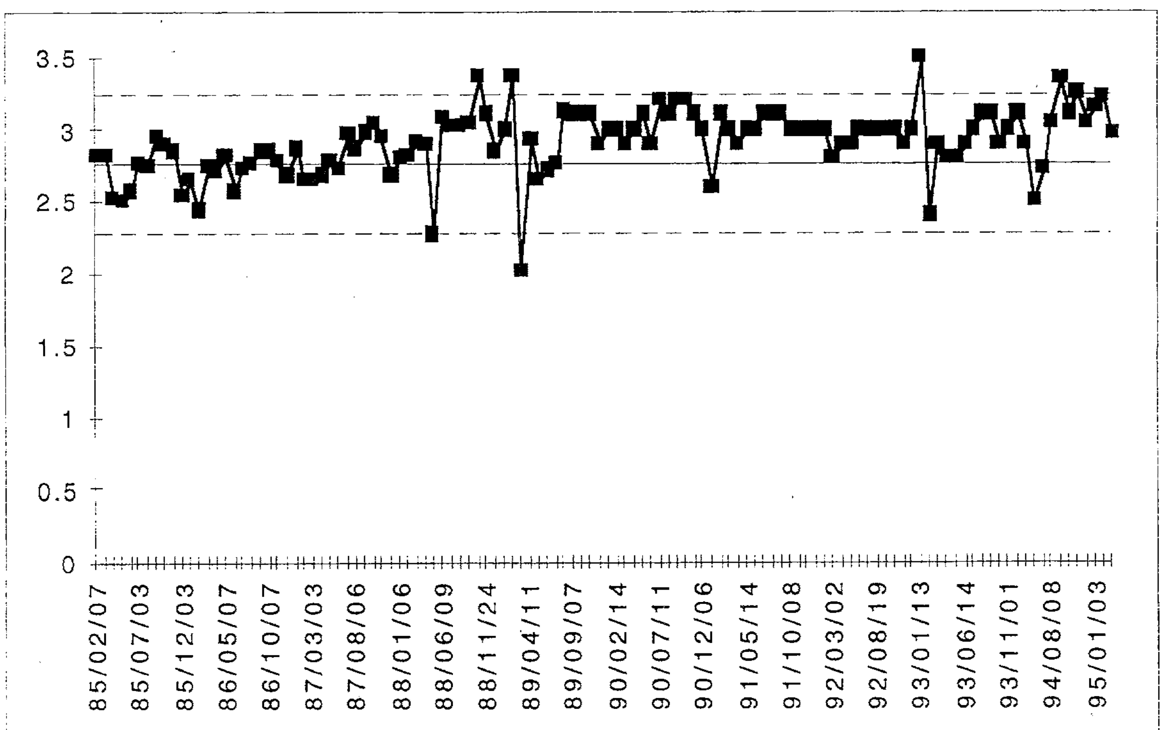


APPENDIX 3 (continued)

Maxwell Lake: Sodium

There is a 100% chance that an upwards shift of 0.642 has occurred from the original mean of 2.75.

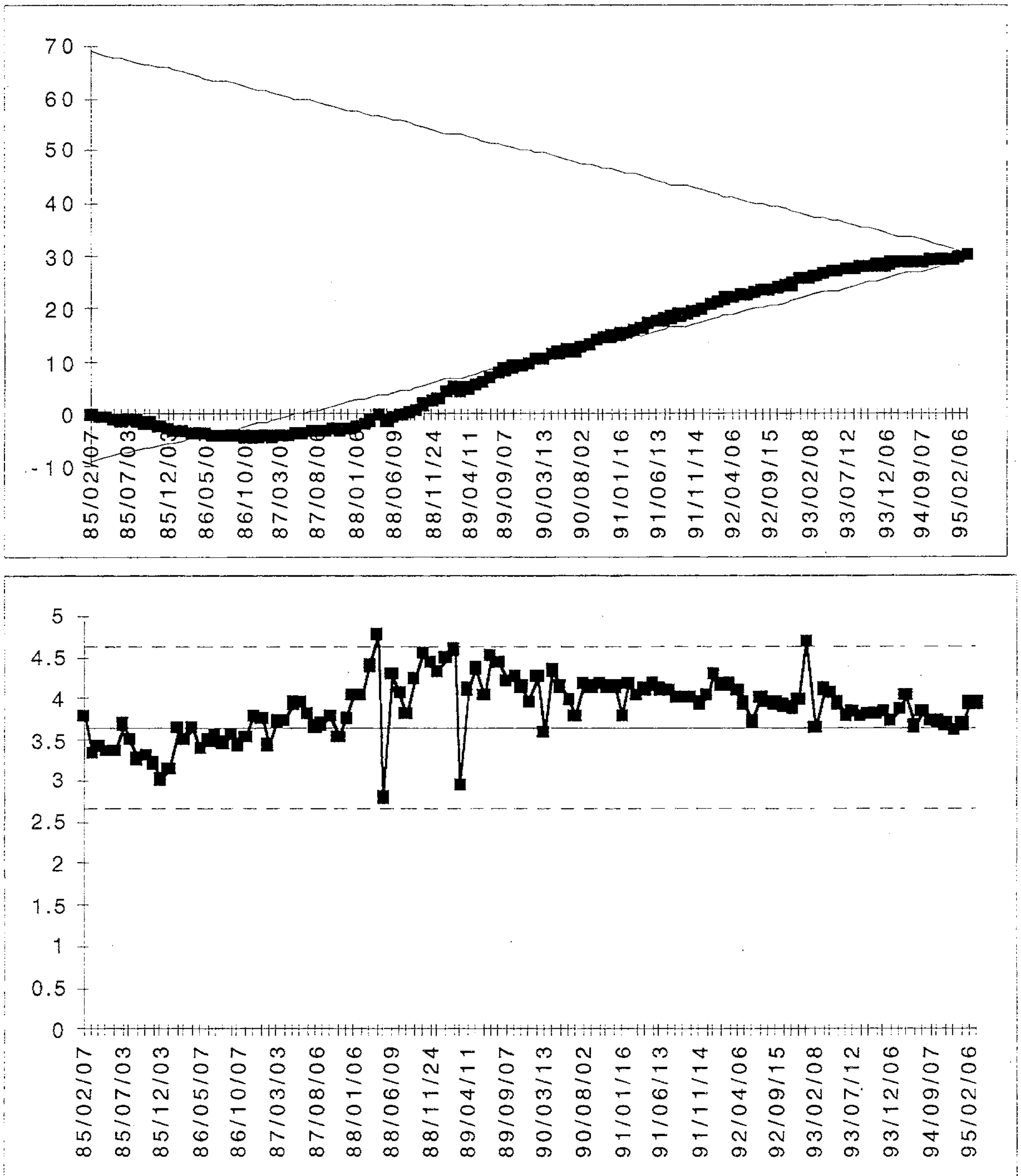




APPENDIX 3 (continued)

Maxwell Lake: Sulphate

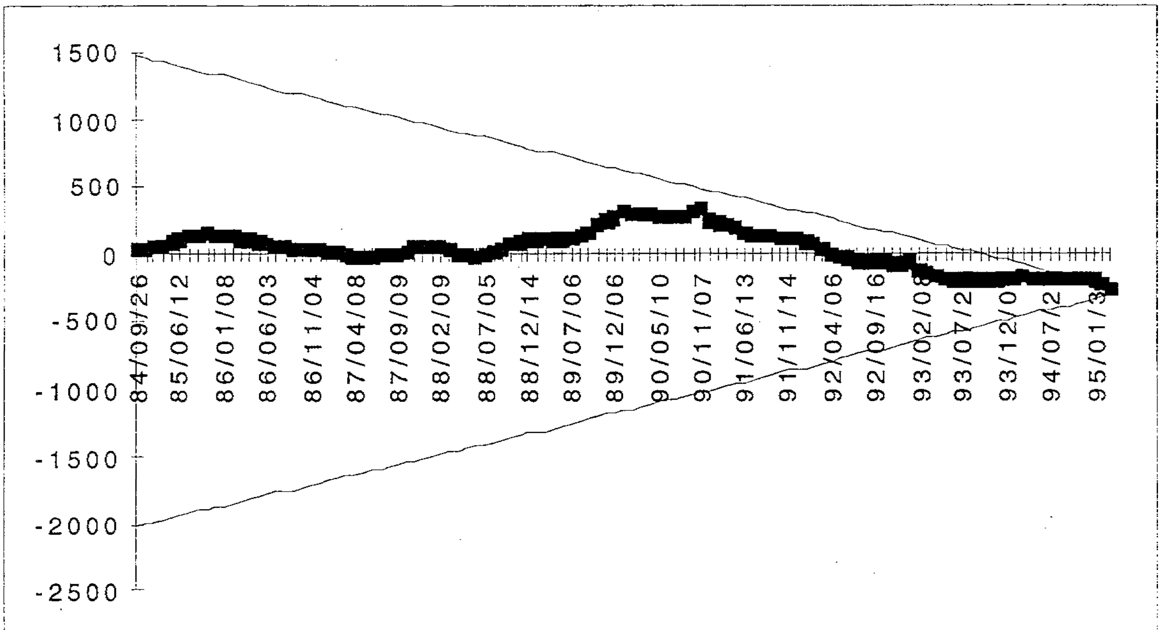
There is a 99.4% chance that an upwards shift of 0.654 has occurred from the original mean of 3.64.

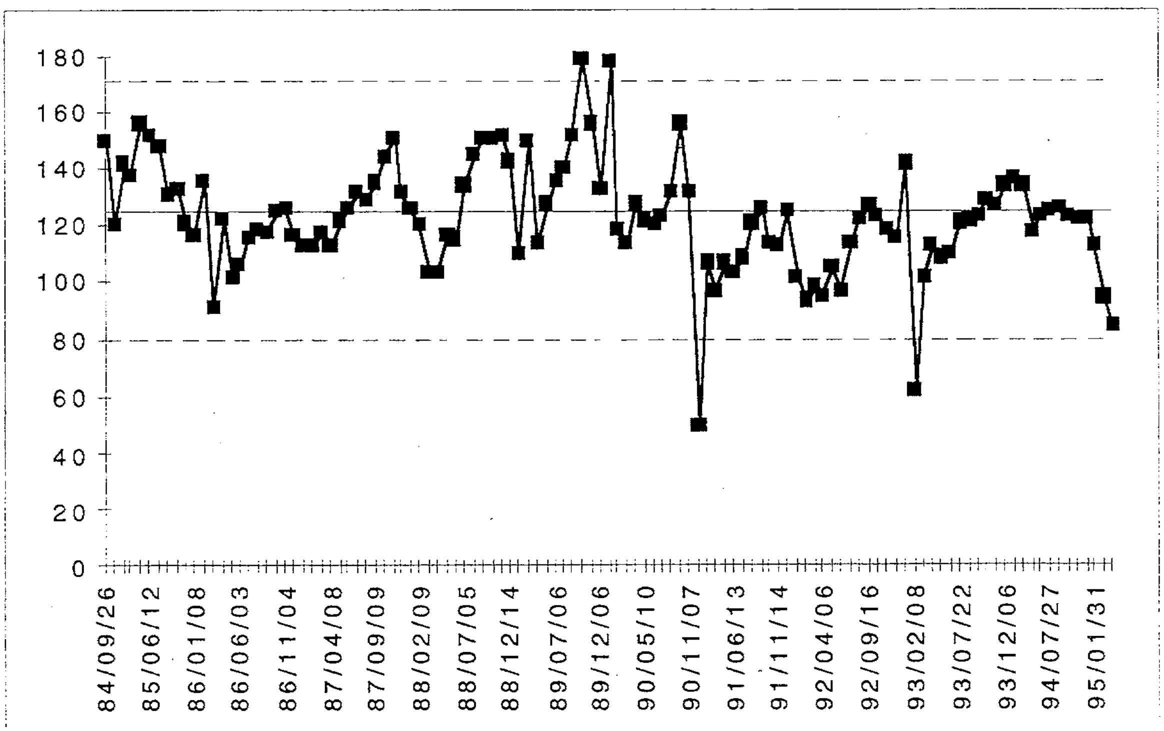


APPENDIX 3 (continued)

Old Wolf Lake: Alkalinity

There is a 99.4% chance that an downwards shift of 30.4 has occurred from the original mean of 126.

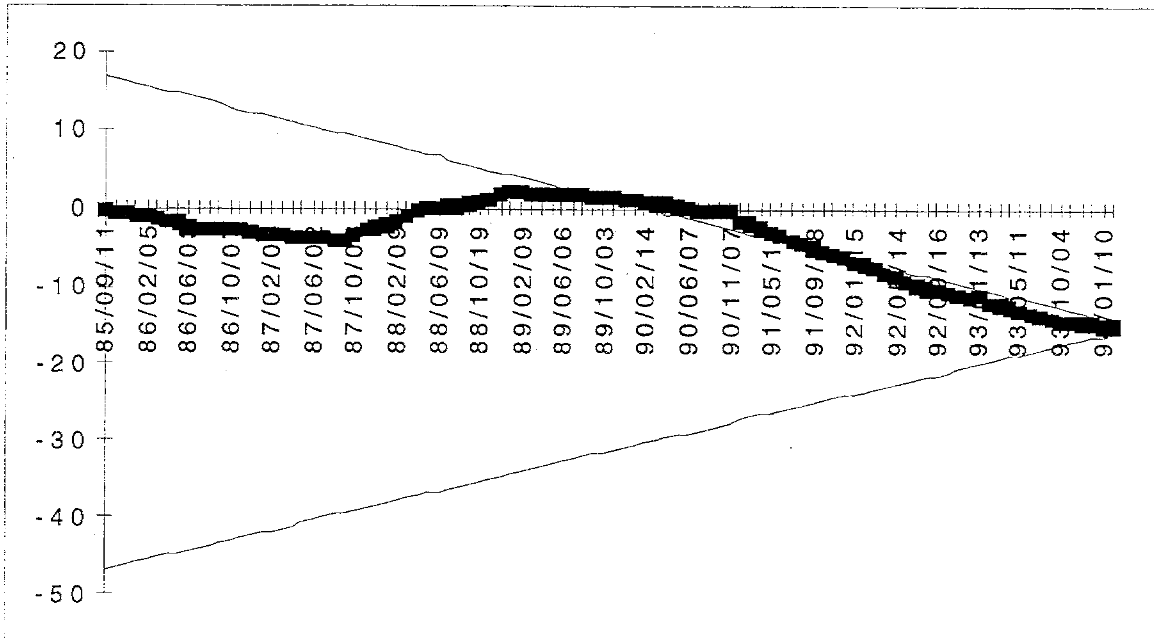


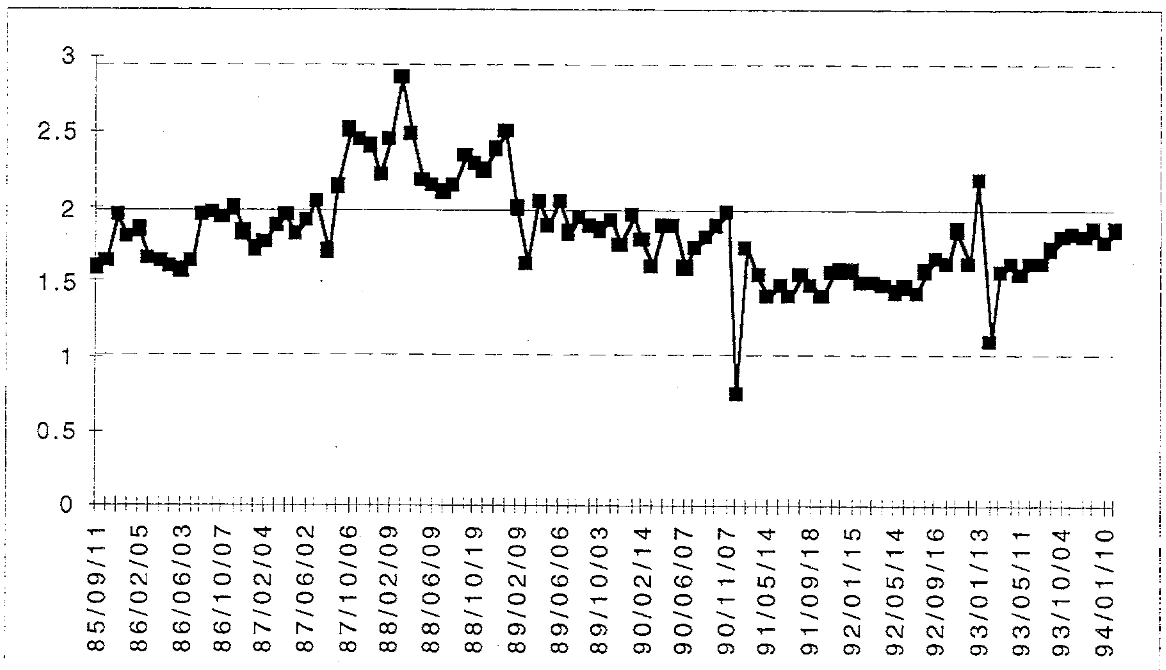


APPENDIX 3 (continued)

Old Wolf Lake: Calcium

There is a 99.4% chance that an downwards shift of 0.638 has occurred from the original mean of 1.98.

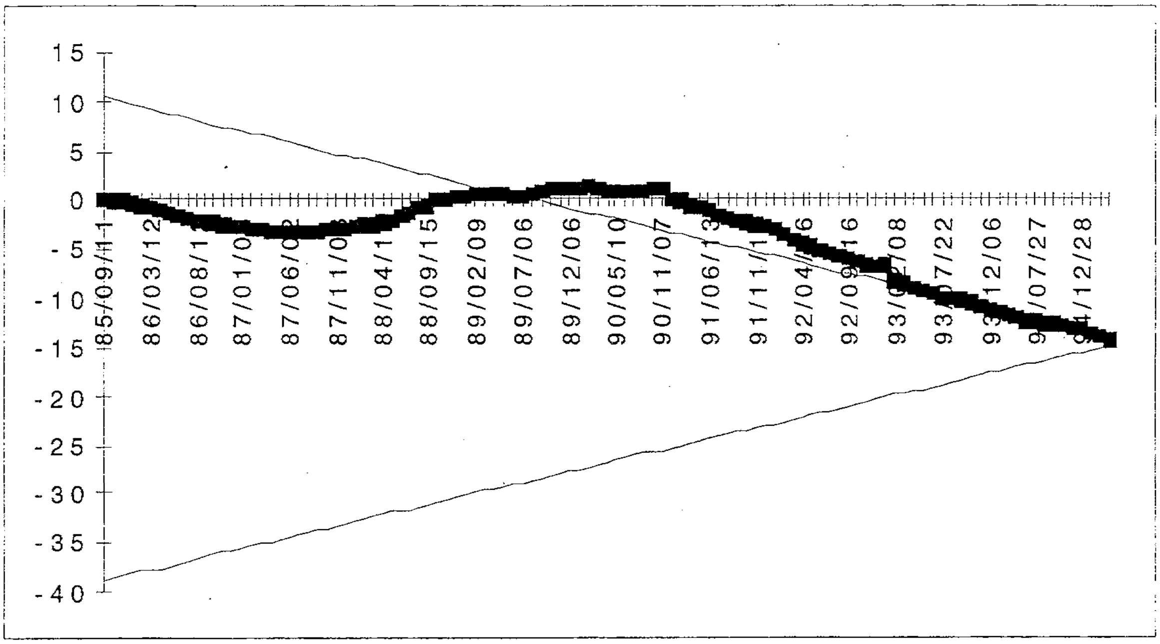


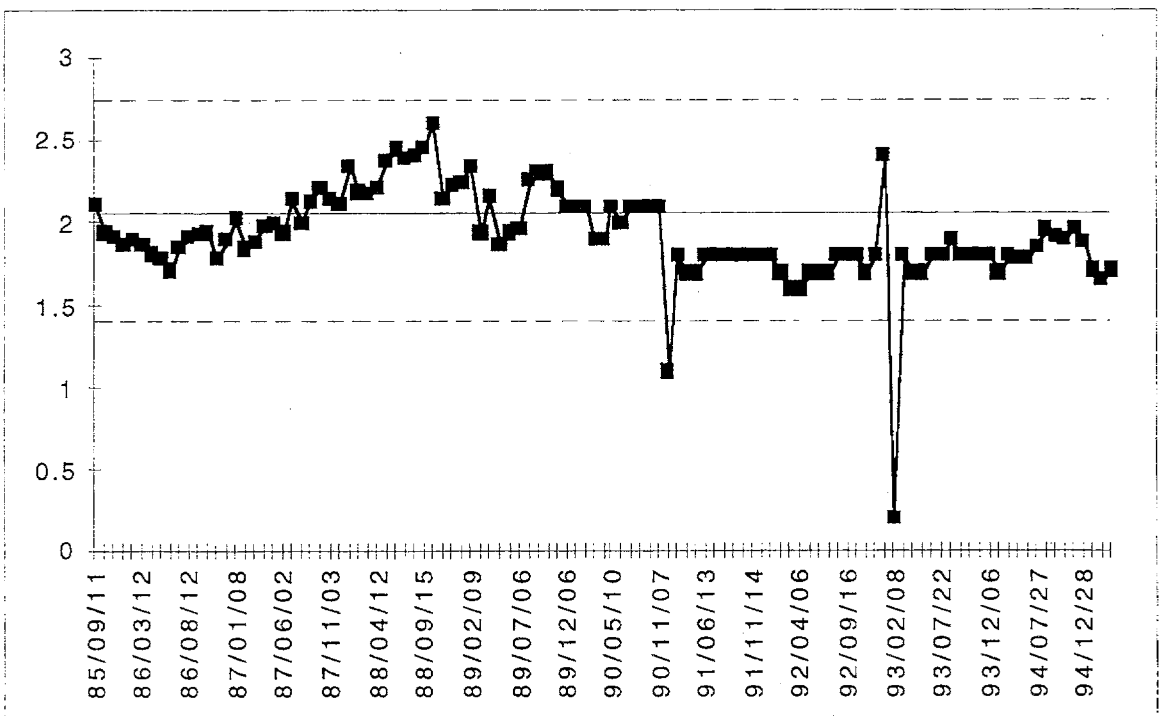


APPENDIX 3 (continued)

Old Wolf Lake: Sodium

There is a 99.4% chance that an downwards shift of 0.445 has occurred from the original mean of 2.06.

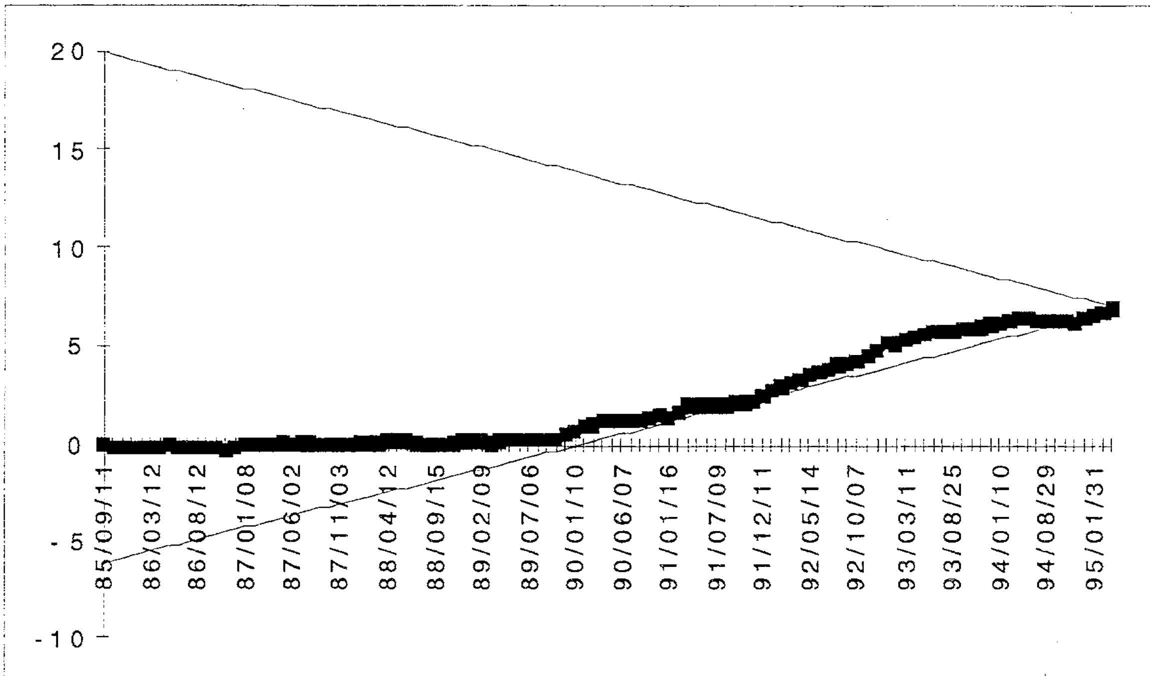


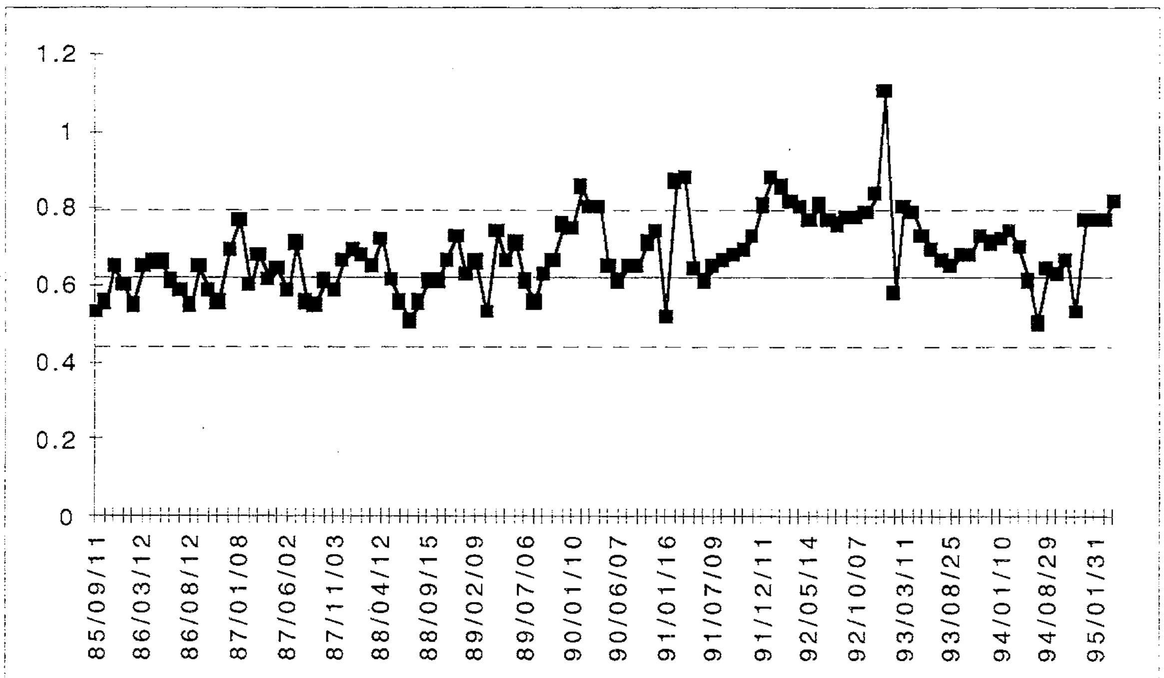


APPENDIX 3 (continued)

Old Wolf Lake: Sulphate

There is a 100% chance that an upwards shift of 0.2389 has occurred from the original mean of 0.619.

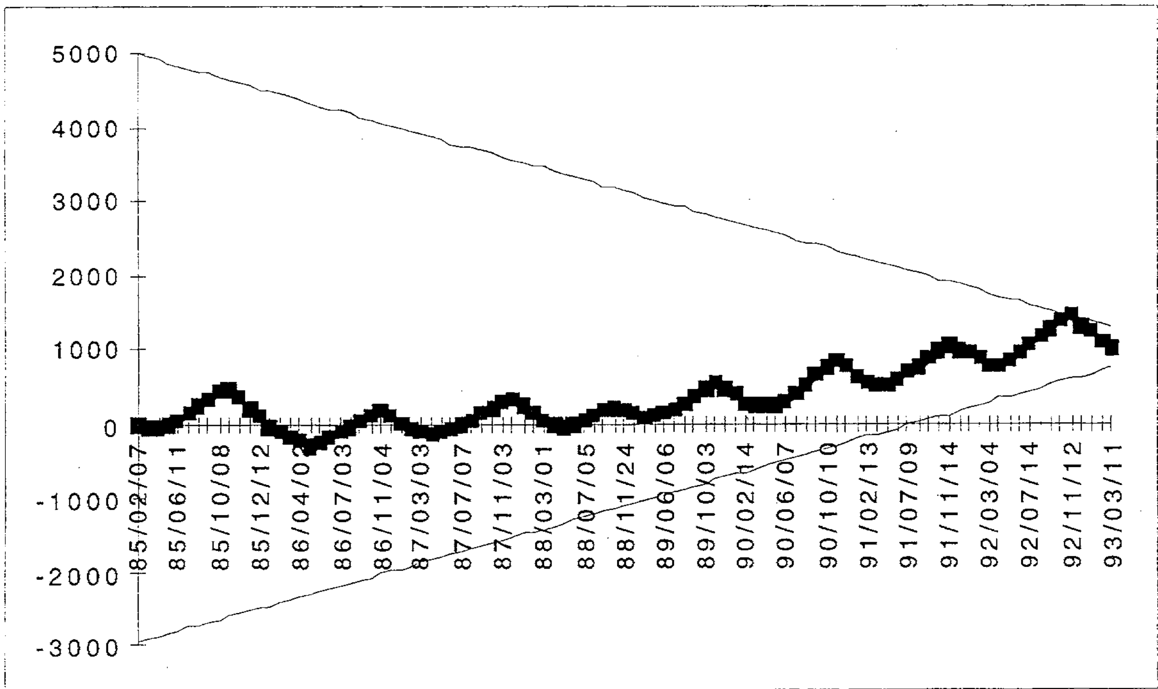


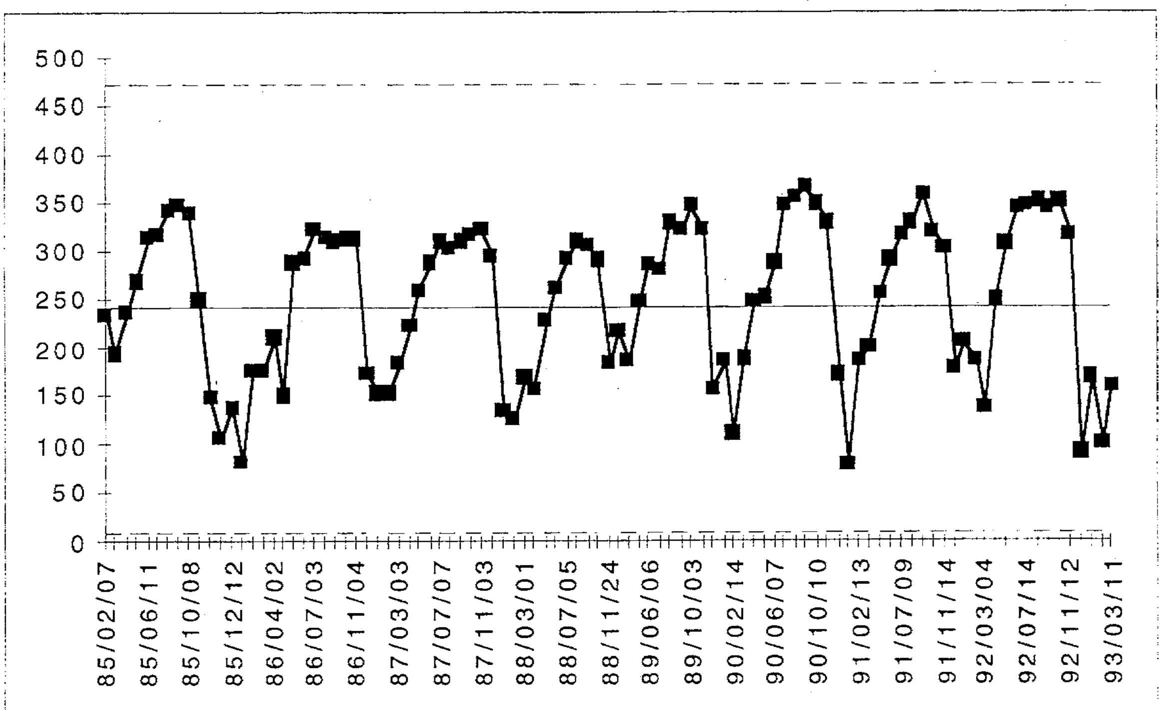


APPENDIX 3 (continued)

Spectacle Lake: Alkalinity

There is a 97.1% chance that an downwards shift of 76.9 has occurred from the original mean of 241.

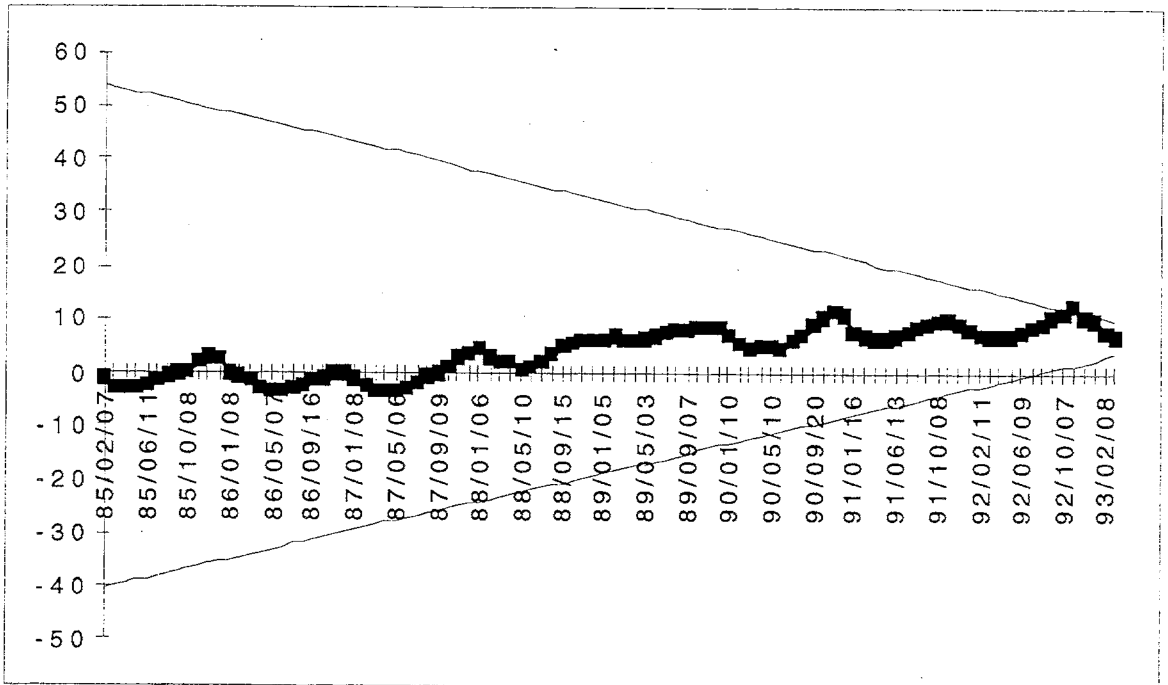


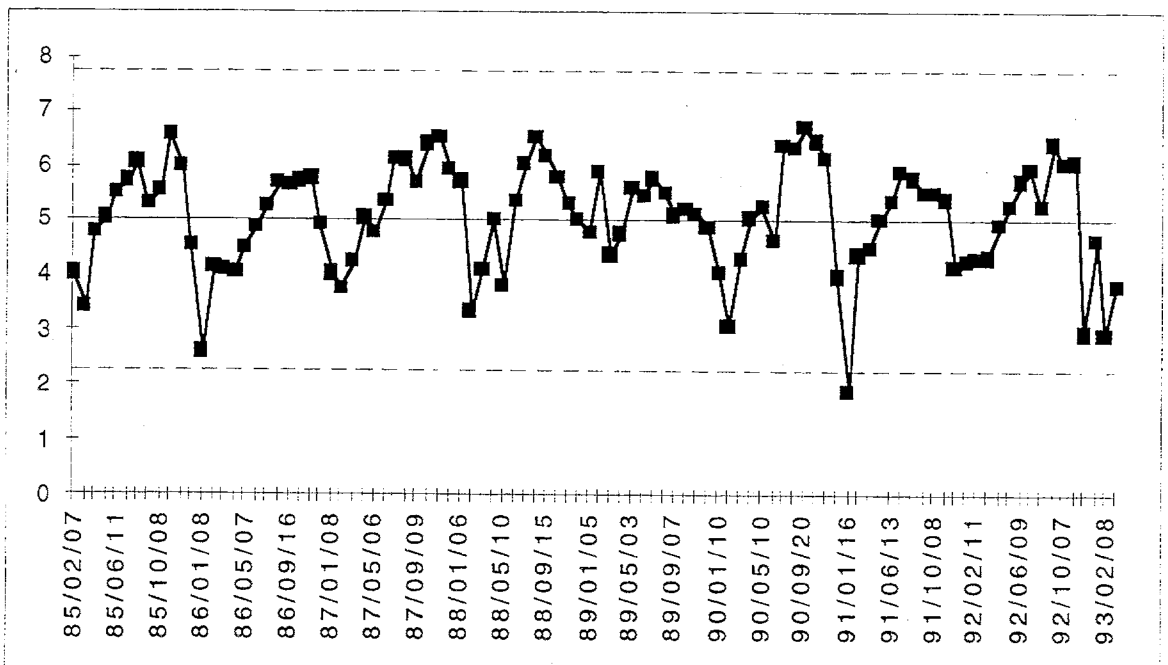


APPENDIX 3 (continued)

Spectacle Lake: Calcium

There is a 97.1% chance that an downwards shift of 0.906 has occurred from the original mean of 5.

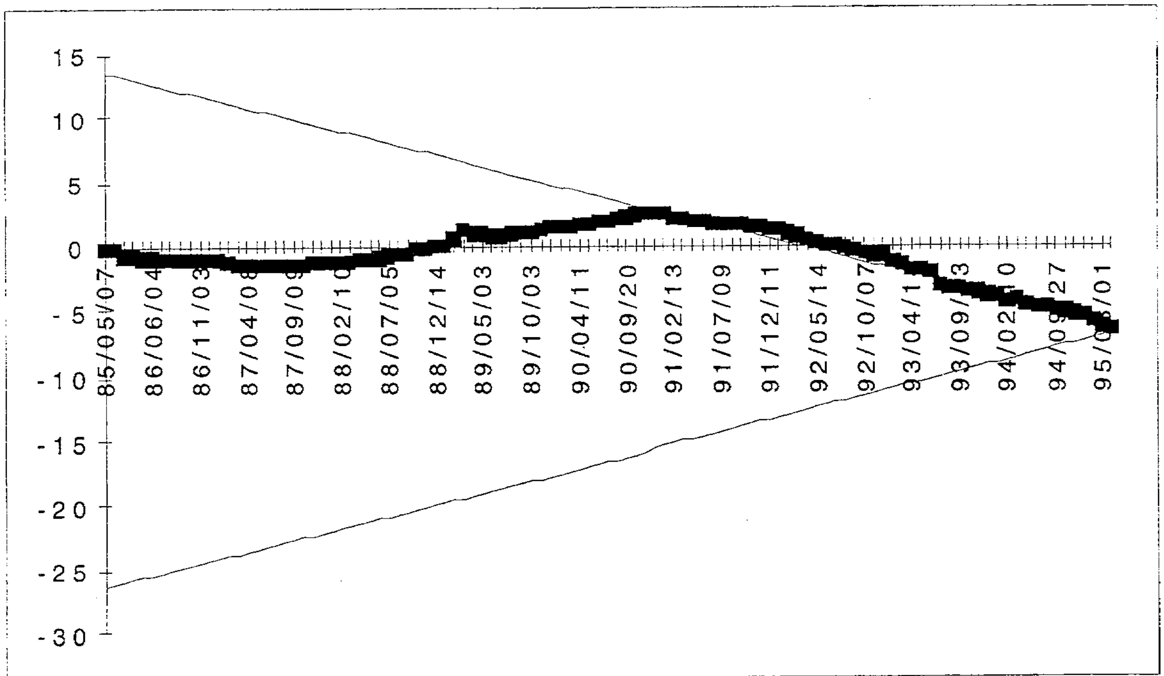


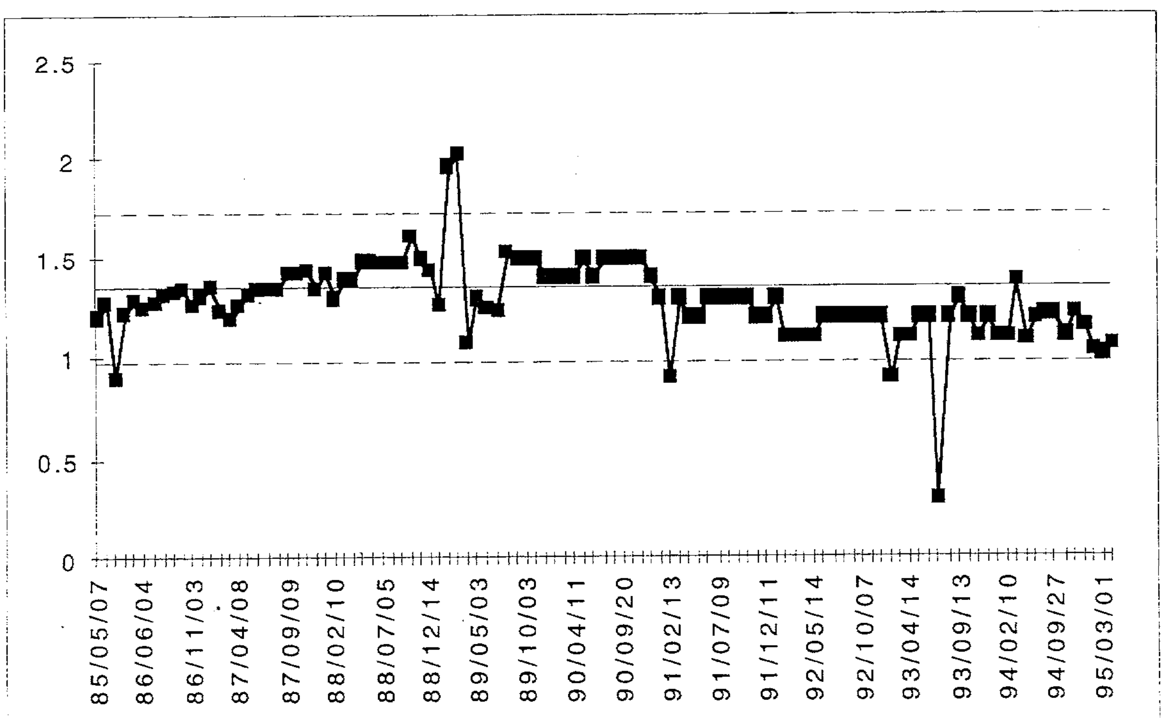


APPENDIX 3 (continued)

Stocking Lake: Sodium

There is a 99.9% chance that an downwards shift of 0.371 has occurred from the original mean of 1.35.





APPENDIX 3 (continued)

Stocking Lake: Sulphate

There is a 99.4% chance that an downwards shift of 0.224 has occurred from the original mean of 1.87.