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Phytoplankton in Mt. St. Helens Lakes, Washington

Cynthia Fay Baker
Portland State University

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THESIS APPROVAL

The abstract and thesis of Cynthia Fay Baker for the Master of Science in Biology were presented April 25, 1995, and accepted by the thesis committee and the department.

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ABSTRACT


Title: Phytoplankton in Mount St. Helens Lakes, Washington

Phytoplankton communities in fifteen lakes in the Mt. St. Helens area were surveyed to assess the abundance and species present. Eleven of the lakes were inside the blast zone of the 1980 eruption and four were located outside the blast zone as a comparison. The hypothesis is that lakes will cluster together based on the algal species present and that some algae will be correlated with certain environmental conditions.

A cluster analysis was performed to determine if the lakes would group together based on algal abundance. There did not appear to be any distinct clustering among the study lakes, but this analysis did help to sort out some similarities of algal species present between lakes. It demonstrated that the lakes outside the blast zone were not functional as control lakes because they were very different from the blast-zone lakes. They had different assemblages of algae and their origin was so different from the blast-zone lakes that there was little overlap between them.

The factor analysis was applied to determine the relationships between environmental variables and phytoplankton. The hypothesis is that certain algae are associated with each other and with identifiable environmental factors. Factor analysis should detect these patterns. The factors represent some condition in the environment but the analysis would be virtually meaningless unless these conditions can be recognized and the factors named. From the factor analysis alone, I could not name the factors but
returned to the task after the canonical correlation analysis was performed. The canonical correlation analysis gave some clues to identify the environmental conditions that exert control on these algae.

The most useful statistical technique used in this study was the canonical correlation analysis. This analysis is a useful tool in community ecology studies where species-environment relationships can be inferred from community composition and environmental data. The environmental data used was nutrient and light attenuation present at the time the phytoplankton samples were taken. From this analysis I summarized a list of algae and with what environmental conditions that they are associated.

Trophic state categories were assigned to the lakes from a trophic state index based on phytoplankton biovolume.
PHYTOPLANKTON IN MOUNT ST. HELENS LAKES, WASHINGTON

by

CYNTHIA FAY BAKER

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE
in
BIOLOGY

Portland State University
1995
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Many people contributed to this work for whom I would like to show my appreciation by mentioning. Dr. Richard Petersen, my graduate advisor, gave me the opportunity to do this work. Many students of his participated in collecting the samples. I am very grateful to Jim Sweet for helping me learn to identify the phytoplankton and for all of his reliable advice throughout this project. Dr. Bob Fountain and Damon Shepherd from the statistic counseling service provided the statistical analysis, advice on the interpretation of their analysis, and were patient with me as I tried to understand the techniques that they used. Nutrient data used in the canonical correlation analysis and my discussion of the ordination diagrams was provided by Kurt Carpenter. The map of the study area is due largely to Dr. Joe Porasky who helped me learn how to make the map and assisted with its editing. I thank my committee members: Dr. Richard Petersen, Dr. Mark Sytsma, Dr. John Reuter, and Dr. Bob Fountain for their advice and ideas. I would like to thank my family for their encouragement to continue my education, especially the unwavering support of my husband, Thomas.
TABLE OF CONTENTS

ACKNOWLEDGEMENTS i
LIST OF TABLES iv
LIST OF FIGURES v
INTRODUCTION 1
  Study Lakes 2
METHODS 6
  Sampling procedure 6
  Laboratory methods 7
  Identification and counting 7
  Data analysis 8
RESULTS AND DISCUSSION 13
  Patterns found clustering by biovolume 13
  Patterns found clustering by density 16
  Comparison of dominant phytoplankton 18
  Comparison with other studies 24
  The factor analysis 28
  The canonical correlation analysis 31
  Trophic state index among lake samples 62
  Quality assurance 63
CONCLUSION 70
LITERATURE CITED

APPENDICES

A PHYTOPLANKTON DATA SHEETS 74
B TAXONOMIC LIST OF PHYTOPLANKTON 240
C QUALITY ASSURANCE DATA SHEETS 257
| Table 1. Brief description of the study lakes | 4 |
| Table 2. Samples in which less than 100 algal units were counted | 8 |
| Table 3. Abundance of *Cyclotella Comta* in Coldwater, Fawn, and Hanaford lakes by average percent biovolume | 15 |
| Table 4. Comparison of *Chlamydomonas-like sp.* and *Glenodinium sp.* in Castle and Blue lakes by average percent biovolume | 15 |
| Table 5. Comparison of *Chromulina sp.* and *Rhodomonas minuta* in Merrill and Hanaford lakes by average percent biovolume | 17 |
| Table 6. Abundance of *Planktosphaeria gelatinosa* found in Coldwater Lake by average percent biovolume | 17 |
| Table 7. Comparison of phytoplankton in lakes analyzed by Aquatic Analysts and Portland State University | 20 |
| Table 8. Comparison of phytoplankton in Castle and Coldwater lakes analyzed by Aquatic Analysts and Portland State University | 23 |
| Table 9. Comparison of studies of lakes in the Mt. St. Helens area after the 1980 eruption | 26 |
| Table 10. Diatoms that loaded into the first four factor groups and their degree of correlation with that factor group | 29 |
| Table 11. Significance of canonical variable pairs | 32 |
| Table 12. Trophic state categories of lakes | 63 |
LIST OF FIGURES

Figure 1. Lakes in the Mt. St. Helens Study Area 3
Figure 2. Boot Lake canonical variables V1 vs. V2 36
Figure 3. Castle Lake - samples from 6/26/93 canonical variables V1 vs. V2 37
Figure 4. Castle Lake - samples from 9/17/93 canonical variables V1 vs. V2 38
Figure 5. Coldwater Lake canonical variables V1 vs. V2 40
Figure 6. Fawn Lake canonical variables V1 vs. V2 41
Figure 7. Hanaford Lake canonical variables V2 vs. V3 43
Figure 8. June Lake canonical variables V1 vs. V2 44
Figure 9. McBride Lake canonical variables V1 vs. V2 46
Figure 10. Merrill Lake - samples from 4/47/93 canonical variables V1 vs V2 47
Figure 11. Merrill Lake - September 1993 samples canonical variables V1 vs. V2 48
Figure 12. Merrill Lake - October 1993 samples canonical variables V1 vs. V2 50
Figure 13. Meta Lake - samples from June and August 1993 canonical variables V1 vs. V2 51
Figure 14. Meta Lake - samples from October 1993 canonical variables V1 vs. V3 52
Figure 15. Panhandle Lake canonical variables V1 vs. V2 54
Figure 16. Ryan Lake canonical variables V1 vs. V2 56
Figure 17. St. Helens Lake canonical variables V1 vs. V2 57
Figure 18. Venus Lake canonical variables V2 vs. V3
Introduction

Mount St. Helens has drawn interest from the scientific community since its eruption on May 18, 1980 as it has provided an opportunity to study an environment which has undergone a large-scale natural disturbance. Lakes inside the blast zone were chosen as study lakes and compared with lakes outside the blast zone. This paper covers the phytoplankton portion of the study. It is a mensurative experiment. The phytoplankton communities were surveyed and the relationships between the algae in these assemblages and the chemical and physical environment are described in this work. The hypothesis is that some algae will be correlated with certain environmental conditions. Samples (208 total, see Appendix A) from 15 lakes were collected during 1992 and 1993 on several sampling trips. Phytoplankton in the samples were identified and counted. A cluster analysis, factor analysis, and a canonical correlation analysis was performed with the help of the Statistic Counseling Service at Portland State University.

The cluster analysis is a procedure used to form groups of similar objects. The purpose of this cluster analysis is to determine if lakes are similar based on which algae were present in the samples and the quantity that were present. In a similar study, Allen and Koonce (1973) used an agglomerative cluster analysis to identify the functional place of algal species in a lake community. They identified persistent species with slow growth rates or rarer species with rapid growth rates.

Norusis (1993) defines the factor analysis as a statistical technique used to identify a small number of factors that can be used to represent relationships among sets of many interrelated variables; groups of variables constitute the factors. In this thesis, many algal
species were identified in the lakes and it was the goal to fit them into a much smaller number of factors. Phytoplankton species that are similar were put in the same factor, but some species appear in more than one factor. Algae can be positively or negatively correlated with a particular factor. A positive correlation reveals that particular alga belongs with the factor. Likewise, a negative correlation means that that species will probably not be present when the other species that positively correlate with that factor group are present. Canonical correlation analysis is a useful tool in community ecology studies where species-environment relationships can be inferred from community composition data and associated habitat measurements (ter Braak 1986). The data set included: 1) abundance of phytoplankton species at a series of sites (lake, depth, time); and 2) environmental variables including nutrients and light attenuation. The canonical correlation analysis summarizes the main variation in the species data by ordination and relates the ordination axes to the environmental variables by calculating coefficients. The result can be shown graphically (ter Braak 1986).

Trophic state indices were calculated from phytoplankton biovolume data and lakes are described by their trophic categories.

**Study Lakes:**

Fifteen lakes in the Mt. St. Helens area (Table 1) were sampled during 1992-93 to assess the biological, chemical, and physical characteristics of the lakes; eleven lakes were located within the blast zone of Mt. St. Helens and four were located out of this zone south of the volcano (Figure 1). Coldwater and Castle lakes were created as a result of the May 1980 eruption and are in the blast zone; other lakes within the blast zone are:
Fig. 1 Lakes in the Mt St Helens Study Area

- Blowdown
- Scorch
- Mudflow

Legend:
- Blowdown
- Scorch
- Mudflow
Boots, Fawn, Hanaford, Meta, Panhandle, Ryan, Spirit, St. Helens, and Venus. Lakes outside the blast zone include: Blue, June, McBride and Merrill which were sampled for comparison.

Table 1. Brief Description of the Study Lakes

<table>
<thead>
<tr>
<th>Lake</th>
<th>Elevation (meters)</th>
<th>Max. Depth (meters)</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>1200</td>
<td>23</td>
<td>cirque</td>
</tr>
<tr>
<td>Boot</td>
<td>1415</td>
<td>14.5</td>
<td>cirque</td>
</tr>
<tr>
<td>Castle</td>
<td>740</td>
<td>32</td>
<td>debris avalanche</td>
</tr>
<tr>
<td>Coldwater</td>
<td>740</td>
<td>62</td>
<td>debris avalanche</td>
</tr>
<tr>
<td>Fawn</td>
<td>1200</td>
<td>18</td>
<td>cirque</td>
</tr>
<tr>
<td>Hanaford</td>
<td>1260</td>
<td>16</td>
<td>cirque</td>
</tr>
<tr>
<td>June</td>
<td>985</td>
<td>1.5</td>
<td>landslide/basalt flow</td>
</tr>
<tr>
<td>McBride</td>
<td>862</td>
<td>2</td>
<td>landslide</td>
</tr>
<tr>
<td>Merrill</td>
<td>474</td>
<td>18</td>
<td>debris avalanche</td>
</tr>
<tr>
<td>Meta</td>
<td>1097</td>
<td>8</td>
<td>cirque</td>
</tr>
<tr>
<td>Panhandle</td>
<td>1415</td>
<td>18</td>
<td>cirque</td>
</tr>
<tr>
<td>Ryan</td>
<td>1018</td>
<td>7</td>
<td>cirque</td>
</tr>
<tr>
<td>Spirit</td>
<td>1330</td>
<td>34</td>
<td>debris avalanche</td>
</tr>
<tr>
<td>St. Helens</td>
<td>1405</td>
<td>&gt;90</td>
<td>maar</td>
</tr>
<tr>
<td>Venus</td>
<td>1415</td>
<td>39</td>
<td>cirque</td>
</tr>
</tbody>
</table>

Lakes in the blast zone were either: 1) newly formed or directly impacted by mudflow, debris avalanche, or pyroclastic deposits (Spirit, Castle and Coldwater lakes); or 2) in the area where timber was blown down or scorched by the blast of hot volcanic gases, and a thick layer of volcanic ash was deposited (Boot, Fawn, Hanaford, Meta, Panhandle, Ryan,
St. Helens, and Venus lakes) (McKnight, Klein, and Wissmar 1980). Mudflows and debris avalanches inundated the Toutle River Valley and formed new lakes by damming Castle and Coldwater creeks on the North Fork of the Toutle River (Wissmar, DeVol, Nevissi, Sedell 1982). Both Castle and Coldwater lakes started out as two smaller lakes, East Castle and West Castle lakes and North Coldwater and South Coldwater lakes. Over a period of time, snowmelt and rain filled them making one larger lake.

Prior to the eruption Spirit Lake was a relatively pristine, sub-alpine lake, but "massive debris and pyroclastic loadings to Spirit Lake raised the lake level ~40m and increased the surface area by ~30 percent" (Wissmar, Devol, Nevissi, Sedell 1982). The lake's natural outlet was blocked by a debris dam 150-180 meters thick (US Army Corps of Engineers 1987). Lake water elevation and volume steadily increased from inflow and the U.S. Army Corps of Engineers was concerned that the dam would be breached. Between June 1984 and April 1985 they constructed a 2592 meter-long tunnel from Spirit Lake to the North Fork Toutle River via South Coldwater Creek (US Army Corps of Engineers 1987). The tunnel is now the outlet for the lake.

Lake watersheds to the north of Coldwater Creek were characterized by denuded vegetation, snapped trees, heavy ashfall, and heat effects. These lakes include Boot, Fawn, Hanaford, Meta, Panhandle, Ryan, Spirit, St. Helens and Venus. Blue, June, McBride, and Merrill lakes received only ashfall (Baross, et al. 1982).
Methods

Sampling Procedure:

Phytoplankton samples were collected using a 2.5 liter Van Dorn bottle and were transferred to 250 ml HDPE Nalgene sample bottles. Pseudo-replicate samples (replicate sample bottles were filled from the same grab sample, but were treated as replicates from the lake) were taken at the deepest part of the lake from 1 meter below the surface, the thermocline (where temperature change was rapid relative to vertical distance), and 1 meter from the bottom. Samples are considered pseudo-replicates because sample bottles were filled from the same grab sample, but were treated as true replicates of the lake when the F-test was performed in the canonical correlation analysis. If the samples were true replicates of the lake, they would not have been filled from water of the same Van Dorn bottle. For the cluster analysis, factor analysis, and canonical correlation analysis, the purely data analysis portion of these routines are not affected by whether the samples were pseudo-replicates or true replicates. The canonical correlation analysis was functional as an analytic tool, but any hypothesis (such as the F-test determining which canonical pair were significant) drawn from it could be affected by pseudo-replication. In shallow lakes that do not stratify, like June and McBride lakes, only two samples were taken, one near the surface and one near the bottom. Only epilimnion samples were taken at Spirit lake and sample depths for Blue lake only included the surface and 10 meters.

In most lakes, samples were collected at the deepest part of the lake. In Coldwater, Castle, and Merrill Lakes samples were collected at two sites as the shapes of these lakes are long and narrow. Lugol's solution was used to preserve the samples; two
milliliters or more of Lugol's solution was put into the samples for approximately a 1% solution and the desired color was achieved. Samples were taken in the daytime from mid-morning to afternoon.

**Laboratory Methods:**

Preserved samples were permanently mounted onto slides. Aliquots of samples were filtered (using 10 cm Hg vacuum) onto Gelman 0.45 µm, 25 mm Metricel® membrane filters and allowed to dry overnight. The aliquots were 100 ml unless it appeared that the phytoplankton was too dense on the slide or there was too much debris. If so, the sample was refiltered with a smaller aliquot. Edges of the round filters were cut off so they would fit onto the slide. Drops of immersion oil were applied to the dried filter on the slide. When the filter cleared a cover slip was placed on top and clear fingernail polished was painted over the edges of the coverslip to seal it onto the slide.

**Identification and Counting:**

After the samples were permanently mounted onto slides they were ready for phytoplankton identification and counting. A Zeiss phase-contrast microscope at 1000X magnification was used. A transect on the slide was chosen and the distance that was scanned was recorded in order to calculate the area in which the phytoplankton were counted. At least 100 "algal units (defined as discrete particles - either cells, colonies, or filaments)" (Sweet 1986) or three transects were counted per sample. In low-density samples less than 100 algal units were counted due to time constraints. If fewer than 50 algal units were not counted in three transects I counted all algae in three complete transects (Table 2).
Biovolume estimates were calculated based on conversion factors developed by Sweet (1986). He obtained average biovolume estimates of each species from calculations of microscopical measurements of the dimensions of each alga. These measurements were used to define the three-dimensional shape of the alga giving biovolume in units of \( \mu m^3/ml \).

For quality assurance, 7.7% of the samples were recounted to measure precision. Jim Sweet of Aquatic Analysts recounted an additional 7.7% of the samples for a measure of accuracy.

Table 2. Samples in which less than 100 algal units were counted.

<table>
<thead>
<tr>
<th>Lake</th>
<th>Lab Code</th>
<th>Date</th>
<th>Depth</th>
<th>Units Counted</th>
<th>Density (#/ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coldwater</td>
<td>04-05</td>
<td>10/2/93</td>
<td>hypolimnion</td>
<td>52</td>
<td>11.8</td>
</tr>
<tr>
<td>Coldwater</td>
<td>04-06</td>
<td>10/2/93</td>
<td>hypolimnion</td>
<td>33</td>
<td>7.0</td>
</tr>
<tr>
<td>Coldwater</td>
<td>04-18</td>
<td>8/4/93</td>
<td>hypolimnion</td>
<td>11</td>
<td>5.9</td>
</tr>
<tr>
<td>Coldwater</td>
<td>04-24</td>
<td>8/4/93</td>
<td>hypolimnion</td>
<td>50</td>
<td>24.7</td>
</tr>
<tr>
<td>Coldwater</td>
<td>04-25</td>
<td>8/4/93</td>
<td>hypolimnion</td>
<td>50</td>
<td>25.8</td>
</tr>
<tr>
<td>Hanaford</td>
<td>06-05</td>
<td>8/5/93</td>
<td>epilimnion</td>
<td>43</td>
<td>25.7</td>
</tr>
<tr>
<td>St. Helens</td>
<td>14-03</td>
<td>9/92</td>
<td>hypolimnion</td>
<td>13</td>
<td>6.7</td>
</tr>
<tr>
<td>St. Helens</td>
<td>14-08</td>
<td>8/10/93</td>
<td>hypolimnion</td>
<td>12</td>
<td>6.0</td>
</tr>
<tr>
<td>Venus</td>
<td>15-04</td>
<td>8/10/93</td>
<td>epilimnion</td>
<td>19</td>
<td>9.8</td>
</tr>
<tr>
<td>Venus</td>
<td>15-05</td>
<td>8/10/93</td>
<td>epilimnion</td>
<td>26</td>
<td>12.9</td>
</tr>
</tbody>
</table>

Data Analysis:

Raw data were recorded onto a data sheet and later transferred to a spreadsheet ( Appendix A) and a taxonomic list of the algae in each lake can be found in Appendix B.
A trophic state index (TSI) based on phytoplankton biovolume was calculated based on Sweet (1986).

\[
TSI = (\log_{10} (B+1)) \times 20, \text{ where } B = \text{phytoplankton biovolume (µm}^3/\text{ml})/1000
\]

Lakes may be classified as ultraoligotrophic, oligotrophic, mesotrophic, eutrophic or hypereutrophic (from relatively non-productive to very productive).

A cluster analysis was performed on the phytoplankton data to determine if the lakes would cluster into distinct categories based on the presence of algal species. The hypothesis is that lakes will cluster together based on their similarities. The data were organized in two spreadsheets; one with the total biovolume (µm\(^3\)/ml) per algal species for each sample, and the other with the total density (# algal units/ml) per algal species for each sample. The spreadsheets were arranged so that each species of alga encountered in this study was recorded in a particular column. Each sample, identified by a unique lab code, was entered in a particular row. The spreadsheets were filled in such a way that if a species was identified in a particular sample the biovolume or density of that alga was recorded in the appropriate cell block. Of course, most of the cell blocks had a zero since only few of the algae were identified in any one sample. Dimensions of the spreadsheets were 106 species across and 208 samples long.

The program, SPSS for Windows 6.0, was used to generate:

- a hierarchical clustering of cases (samples)
- a k-means clustering of cases (samples)

SPSS makes a squared Euclidean dissimilarity coefficient matrix where cases are in the columns as well as rows and all pairs of cases have a value which is the distance between
the two cases. The squared Euclidean distance is a commonly used index which is the sum of the squared differences over all the variables. The method used to form clusters was an agglomerative hierarchical cluster analysis. The criterion for deciding which cases or clusters should be combined at each step was the nearest neighbor technique. The hierarchical cluster analysis procedure results in a series of solutions corresponding to different numbers of clusters.

The k-means cluster analysis procedure produces only one solution for the number of clusters requested, which must be specified by the user. Hierarchical cluster analysis is a useful start to determine the initial cluster centers for the k-means cluster analysis. In a hierarchical method a tree or icicle diagram represents a gradient of all the solutions; it starts out with every case in its own cluster, then it starts joining cases and clusters until, at the end, there is only one cluster. If five solutions are requested, the k-means method will cut the hierarchical diagram where there are five clusters.

Factor analysis was used to determine if there were any associations among the algal species identified in the samples. SAS was used to perform two factor analyses on algal data; one using biovolume data and one using density data. The same initial matrices for the cluster analysis were used in the factor analysis. Factor analysis identifies a small number of factors that can be used to represent relationships among sets of many interrelated variables. Each variable is expressed as a linear combination of factors that are not actually observed. A symmetric correlation matrix for all variables is computed. This matrix has the algal species in both the rows and the columns, and values represent linear combinations of these variables. From the matrix, the program finds Eigenvalues
and Eigenvectors which form the principal components. Principal components is the factor extraction method. It retains a subset of the principal components based on Kaiser's rule, where factors are kept if the Eigenvalue is greater or equal to one. After identifying the factors, an orthogonal rotation of the factors is done to transform the initial matrix into one that is easier to interpret. When the axes are maintained at right angles the rotation is called orthogonal. Rotation redistributes the explained variance for the individual factors. The algorithm used for orthogonal rotation to a simple structure is the varimax method, which minimizes the number or variables that have high loadings on a factor. Linear combinations which represent algae were put into factor groups if the correlation was greater than 0.5.

Canonical correlation analysis (CCA) explains the relationship between two sets of variables by finding a small number of linear combinations from each set of variables that have the highest possible between-set correlations. In this analysis data on algal abundance is used in the cluster and factor analysis with the addition of environmental variables (chemical variables) for the CCA. Two CCA were run for both the biovolume and density data; the first (CCA #1) included all of the lake samples plus PO₄, NO₃+NO₂, NH₄, and SiO₂ as environmental variables. For the second CCA (CCA #2) June Lake samples were removed and light attenuation (natural log of the extinction coefficient) was included in the environmental variables. There were no nutrient data available for Blue or Spirit Lakes, so they were not included in the CCA. Also, nutrient data was not available for fall 1992 samples or samples from Coldwater Lake on 3/24/93. The program SAS was used for the CCA and the CANCORR procedure was used to find a linear
combination from each set, called a canonical variable, such that the correlation between the two variables is maximized. The coefficients of the linear combinations are canonical weights. Only those canonical dimensions which the F-test shows to be significant are considered. The F-test is SAS's version of Bartlett's chi squared test. Both canonical weights and canonical variates are interpreted by considering the magnitude of each value in relation to the direction of their signs.
Results and Discussion

There did not appear to be any distinct clustering among the lakes studied based on algal abundance, but the cluster analysis did bring many similarities to light. The lakes were clustered by biovolume of the algae present in the samples and by the density of algae present in the samples. When samples were forced into five clusters by the k-means method, there was one sample in clusters one through four, with the rest of the samples appearing in cluster five. If the samples were forced into 30 and 40 clusters the large group of samples could be broken up. Several samples stood apart so far from the others that when five clusters were requested, four samples appeared in their own cluster. By forcing samples into a large number of clusters some similarities became apparent. Each method brought out different characteristics: Clustering by biovolume brought out the species that were large relative to the assemblage in the sample. For example, a rare species in the sample that was large could overshadow a common species with a small biovolume. Clustering by density highlighted the species that were common even though they may not have represented much of the biovolume.

Patterns found clustering by biovolume:

Clustering by biovolume showed that *Cyclotella comta* was a dominant diatom in Coldwater, Fawn, and Hanaford Lakes (Table 3). Boot and Panhandle Lakes grouped together fairly well according to the biovolume clustering. Samples taken in Boot Lake during the summer of 1993 at the surface were clustered with epilimnion samples from Panhandle Lake taken during the summer due to the biovolume of *Glenodinium sp.* and *Fragilaria crotonensis.* Summer metalimnion samples of Boot Lake clustered with
summer metalimnion samples of Panhandle Lake; there were large biovolumes of *Fragilaria crotonensis* with *Glenodinium sp.* or *Dinobryon sp.* as the sub-dominant species. Summer 1993 Castle Lake samples and samples from Blue Lake (7/11/93) are similar because of the dominance of a *Chlamydomonas*-like alga and *Glenodinium sp.* (Table 4). In some clusters there were only a pair of sample replicates which indicates that those replicates were similar. There was a "catch-all" cluster which seemed to have samples from many different lakes dominated by different species, but with similar biovolume. Two clusters had only a few samples from different lakes based on common algae, but with no discernable pattern.
Table 3. Abundance of *Cyclotella comta* in Coldwater, Fawn, and Hanaford lakes by average percent biovolume.

<table>
<thead>
<tr>
<th>Date</th>
<th>Depth (-limnion)</th>
<th>Coldwater (average % biovolume)</th>
<th>Fawn</th>
<th>Hanaford (average % biovolume)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/92</td>
<td>epi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10/92</td>
<td>meta</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10/92</td>
<td>hypo</td>
<td>57.7*</td>
<td></td>
<td>82.7*</td>
</tr>
<tr>
<td>3/24/93</td>
<td>epi</td>
<td></td>
<td>39.1</td>
<td></td>
</tr>
<tr>
<td>3/24/93</td>
<td>meta</td>
<td>52.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/24/93</td>
<td>hypo</td>
<td>28.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8/4/93</td>
<td>epi</td>
<td></td>
<td>33.3</td>
<td>53.3</td>
</tr>
<tr>
<td>8/4/93</td>
<td>meta</td>
<td>60.3</td>
<td></td>
<td>68.7</td>
</tr>
<tr>
<td>8/4/93</td>
<td>hypo</td>
<td></td>
<td>71.0</td>
<td>36.7</td>
</tr>
<tr>
<td>8/4/93</td>
<td>prod.</td>
<td></td>
<td>90.0* (15M)</td>
<td></td>
</tr>
<tr>
<td>10/2/93</td>
<td>epi</td>
<td></td>
<td>50.7</td>
<td>20.2</td>
</tr>
<tr>
<td>10/2/93</td>
<td>meta</td>
<td>62.0</td>
<td></td>
<td>34.8</td>
</tr>
<tr>
<td>10/2/93</td>
<td>hypo</td>
<td>67.4</td>
<td></td>
<td>77.6</td>
</tr>
<tr>
<td>10/2/93</td>
<td>prod.</td>
<td>54.1* (4M)</td>
<td></td>
<td>73.6*</td>
</tr>
</tbody>
</table>

*no replicates averaged

Table 4. Comparison of *Chlamydomonas-like sp.* (CHLK) and *Glenodinium sp.* (GDXX) in Castle and Blue lakes by average percent biovolume.

<table>
<thead>
<tr>
<th>Castle Lake (9/17/93)</th>
<th>Blue Lake (7/11/93)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>CHLK</td>
</tr>
<tr>
<td>epilimnion</td>
<td>43%</td>
</tr>
<tr>
<td>metalimnion</td>
<td>62.4%</td>
</tr>
</tbody>
</table>

*no replicates averaged

June and Spirit lakes stood out based on the species of algae present. June Lake was unusual because its phytoplankton assemblage consisted strictly of diatoms, many of
which were identified only in this lake. Spirit Lake samples (Summer 1993) clustered
together based on the presence of *Fragilaria crotonensis* and *Cyclotella comta*.

**Patterns found clustering by density:**

Clustering the samples by density of the algae revealed more groupings of the
samples due to similar algae. Fall 1993 samples from Merrill and Hanaford Lakes had
high densities of *Chromulina sp.* and *Rhodomonas minuta* (Table 5). *Kephyrion sp.* was a
dominant species in several lakes including: Coldwater (3/24/93) at all depths; Ryan
(8/24/93) epilimnion and hypolimnion, and (10/9/93) at all depths; Meta (10/9/93)
hypolimnion; all of the samples from Castle Lake. *Dinobryon sp.* was common in
Panhandle and Boot lakes, but was probably underestimated because the lorica
surrounding the chloroplast was not always visible. In a later analysis of prepared slides of
Boot Lake for *Dinobryon sp.* I found that epilimnion and metalimnion samples taken on
8/15/93 had many *Dinobryon sp.* and hypolimnion (8/15/93) and Fall 1992 metalimnion
and hypolimnion samples had fewer. *Ochromonas sp.* was dominant in Meta Lake
(10/9/93) in the epilimnion and metalimnion, and also in Boot Lake (8/15/93) in the
hypolimnion. *Fragilaria crotonensis* was the most common species in McBride Lake
(5/28/93) metalimnion and hypolimnion; Spirit Lake (Summer 1993) in the epilimnion;
Boot Lake (9/92) at all depths of the water column; and Panhandle Lake (8/14/93) in the
epilimnion and metalimnion. St. Helens Lake was dominated by *Ankistrodesmus falcatus*
during the sample period (9/92) metalimnion and (8/10/93) epilimnion and metalimnion
(average 74.3% algal units/ml) This taxon was also common (86.5% average density) in
Ryan lake during part of its yearly cycle; (6/17/93) at all depths.
Table 5. Comparison of *Chromulina* sp. (KMXX) and *Rhodomonas minuta* (RDMN) in Merrill and Hanaford lakes by average percent density.

<table>
<thead>
<tr>
<th>Depth</th>
<th>Merrill Lake (10/17/93)</th>
<th>Hanaford Lake (10/2/93)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>KMXX</td>
<td>RDMN</td>
</tr>
<tr>
<td>epilimnion</td>
<td>47.8</td>
<td>26.4</td>
</tr>
<tr>
<td>metalimnion</td>
<td>55.1</td>
<td>24.7</td>
</tr>
<tr>
<td>hypolimnion</td>
<td>50.4</td>
<td>27.1</td>
</tr>
</tbody>
</table>

Coldwater Lake grouped with Fawn and Hanaford lakes because of the similar biovolume of *Cyclotella comta*. However, the data from Coldwater Lake produced very different results because of the abundance of *Planktosphaeria gelatinosa* (Table 6).

Table 6. Abundance of *Planktosphaeria gelatinosa* found in Coldwater Lake by average percent density.

<table>
<thead>
<tr>
<th>Date</th>
<th>Depth</th>
<th>% PTGL</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/9/92</td>
<td>metalimnion</td>
<td>12.6*</td>
</tr>
<tr>
<td>3/24/93</td>
<td>epilimnion</td>
<td>7.8 (site 1 only)</td>
</tr>
<tr>
<td>3/24/93</td>
<td>metalimnion</td>
<td>21.8</td>
</tr>
<tr>
<td>3/24/93</td>
<td>hypolimnion</td>
<td>5.3</td>
</tr>
<tr>
<td>8/4/93</td>
<td>epilimnion</td>
<td>54.7</td>
</tr>
<tr>
<td>8/4/93</td>
<td>metalimnion</td>
<td>69.2</td>
</tr>
<tr>
<td>8/4/93</td>
<td>hypolimnion</td>
<td>16.0 (site 2 only)</td>
</tr>
<tr>
<td>8/4/93</td>
<td>productivity (4M)</td>
<td>75.3*</td>
</tr>
<tr>
<td>8/4/93</td>
<td>productivity (15M)</td>
<td>54.8*</td>
</tr>
<tr>
<td>10/2/93</td>
<td>epilimnion</td>
<td>85.0</td>
</tr>
<tr>
<td>10/2/93</td>
<td>metalimnion</td>
<td>41.4%</td>
</tr>
<tr>
<td>10/2/93</td>
<td>hypolimnion</td>
<td>73.5 (site 2 only)</td>
</tr>
</tbody>
</table>

*no replicates averaged
Venus Lake was dominated by species not found in other lakes. *Cyclotella stelligera* was found at all three depths sampled in 9/92 (average 86.9% of the density). *Crucigenia fenestrata* was 87.5% of the biovolume in the metalimnion samples from 8/10/93.

**Comparison of dominant phytoplankton:**

Phytoplankton data from 13 of the study lakes were compared to examine which algae dominate the communities at the depth of one meter in samples taken in the summer of 1991 and the summer of 1993. Unpublished data from 1991 were used in this comparison; students from Portland State University collected epilimnion samples in the manner described under *sampling procedure* and Aquatic Analysts (AA) counted and identified the phytoplankton. Data from 1993 are taken from this study (PSU). Two sample dates from 1993 and their respective data are presented for June, McBride, Meta, and Ryan Lakes as neither 1993 sample dates were very close to the 1991 sample date (Table 7). Dominant species in Boot, Fawn, June, McBride, Merrill and Meta Lakes present in 1991 were found in the same lakes in 1993, but not in the same proportion (Table 7). Hanaford, Panhandle, Ryan, St. Helens, and Venus Lakes did not have the same phytoplankton dominating the assemblage in 1993 as they did in 1991. All data tabled from 1993 had sample replicates and were averaged. Sample replicates from Hanaford Lake had a significant amount of variation; sample 06-04 had a density of 158.8 algal units/ml and sample 06-05 and only 25.7 algal units/ml and only 43 algal units were counted in this sample. Only data from sample 06-04 were reported in the table. It may be that these were true replicates (did not come from the same grab sample) or that they were not properly mixed before filtering. Sample replicates from Venus Lake also had a
high degree of variation, but they both had low densities of algae present and only 26 and 19 algal units were counted. In one sample (15-04) *Crucigenia quadrata* was the dominant alga, while in the replicate (15-05) *Crucigenia fenestrata* was the dominant taxon. Coldwater and Castle Lakes were compared on a different table (Table 8) because there were two samples per lake being compared and data in the PSU data were the average of sample replicates from both sites one and two. June samples of Castle Lake were dominated by *Cryptomonas erosa* in both years. September samples from this lake had different algae dominating the assemblage in the 1991 samples compared to the 1993 samples. Samples from Coldwater lake had a high density of *Planktosphaeria gelatinosa* in 1993, which differed from the algal species reported in 1991. *Cyclorella comta* dominated the phytoplankton biovolume in Coldwater Lake in both sample dates in 1991 and 1993.
<table>
<thead>
<tr>
<th>Lake</th>
<th>AA sample dates</th>
<th>PSU sample dates</th>
<th>AA % density</th>
<th>PSU % density*</th>
<th>AA % biovolume</th>
<th>PSU % biovolume*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boot</td>
<td>8/14/91</td>
<td>8/15/93</td>
<td>Glenodinium sp. 34.7; Kephyrion sp. 20.8</td>
<td>Glenodinium sp. 49.2; Fragilariacrotonensis 35.4</td>
<td>Glenodinium sp. 81.4</td>
<td>Glenodinium sp. 49.2; Fragilariacrotonensis 42.7</td>
</tr>
<tr>
<td>Fawn</td>
<td>7/25/91</td>
<td>8/5/93</td>
<td>Cyclotella comta 55.6; Rhodomonas minuta 22.2</td>
<td>Microcystis aeruginosa 23.5; Kephyrion spirale 27.9</td>
<td>Cyclorella comta 80.2; Ceratium hirundinella 16.0</td>
<td>Cyclorella comta 53.3; Cryptomonas erosa 11.5</td>
</tr>
<tr>
<td>Hanaford</td>
<td>7/24/91</td>
<td>8/5/93</td>
<td>Cyclotella stelligera 77.6; Kephyrion sp. 11.2</td>
<td>Kephyrion sp. 53.4; Cryptomonas erosa 12.6</td>
<td>Cyclorella stelligera 55.2; Cryptomonas erosa 17.4</td>
<td>Cryptomonas erosa 43.2; Kephyrion sp. 22.1</td>
</tr>
<tr>
<td>June</td>
<td>7/17/91</td>
<td>5/29/93</td>
<td>Achnanthes lanceolata 25.6; Fragilariaconstruens 15.6; Gomphonema angustatum 10.0</td>
<td>Nitzschia palea 18.7; Achnanthes lanceolata 17.8</td>
<td>Diatoma hiemale mesodon 26.5; Achnanthes lanceolata 18.7; Fragilariaconstruens 10.8</td>
<td>Diatoma vulgare 15.6; Diatoma hiemale mesodon 12.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9/9/93</td>
<td></td>
<td></td>
<td></td>
<td>Diatoma hiemale mesodon 41.3</td>
</tr>
</tbody>
</table>

*epilimnion sample replicates were averaged
<table>
<thead>
<tr>
<th>Lake</th>
<th>AA sample dates</th>
<th>PSU sample dates</th>
<th>AA % density</th>
<th>PSU % density*</th>
<th>AA % biovolume</th>
<th>PSU % biovolume*</th>
</tr>
</thead>
<tbody>
<tr>
<td>McBride</td>
<td>7/18/91</td>
<td>5/29/93</td>
<td>Fragilaria crotonensis 13.3; Anabaena sp. 13.3; Synedra radians 12.2</td>
<td>Fragilaria crotonensis 68.8</td>
<td>Fragilaria crotonensis 39.9; Anabaena sp. 16.3; Ceratium hirundinella 13.3</td>
<td>Fragilaria crotonensis 89.5</td>
</tr>
<tr>
<td></td>
<td>9/8/93</td>
<td></td>
<td></td>
<td>Microcystis aeruginosa 98.9</td>
<td></td>
<td>Microcystis aeruginosa 60.9; Cryptomonas erosa 25.7</td>
</tr>
<tr>
<td>Merrill</td>
<td>7/17/91</td>
<td>9/8/93</td>
<td>Cyclotella comta 68.3; Ankistrodesmus falcatus 12.9</td>
<td>Kephyrion spirale 28.1; Cyclotella comta 8.6</td>
<td>Cyclotella comta 96.8</td>
<td>Cyclotella comta 41.6</td>
</tr>
<tr>
<td>Meta</td>
<td>7/16/91</td>
<td>6/17/93</td>
<td>Rhodomonas minuta 35.1; Cryptomonas erosa 29.7</td>
<td>Dinobryon sp. 72.3; Syndra rumpens 24.4</td>
<td>Cryptomonas erosa 60.9</td>
<td>Dinobryon sp. 67.7; Syndra rumpens 25.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8/26/93</td>
<td></td>
<td>Oocystis pusilla 59.4; Asterionella formosa 20.2</td>
<td></td>
<td>Asterionella formosa 39.7; Oocystis pusilla 27.8; Cryptomonas erosa 25.2</td>
</tr>
<tr>
<td>Panhandle</td>
<td>8/14/91</td>
<td>8/14/93</td>
<td>Glenodinium sp. 71.8; Kephyrion sp. 9.7</td>
<td>Dinobryon sp. 52.8; Fragilaria crotonensis 40.1</td>
<td>Glenodinium sp. 93.8</td>
<td>Fragilaria crotonensis 78.6; Dinobryon sp. 15.7</td>
</tr>
</tbody>
</table>

*epilimnion sample replicates averaged
<table>
<thead>
<tr>
<th>Lake</th>
<th>AA sample dates</th>
<th>PSU sample dates</th>
<th>AA % density</th>
<th>PSU % density*</th>
<th>AA % biovolume</th>
<th>PSU % biovolume*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ryan</td>
<td>7/16/91</td>
<td>6/17/93</td>
<td>Unidentified flagellate 86.7;</td>
<td>Ankistrodesmus falcatus 85.6</td>
<td>Unidentified flagellate 41.3;</td>
<td>Ankistrodesmus falcatus 55.7;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dinobryon sertularia 9.3</td>
<td></td>
<td>Dinobryon sertularia 47.8</td>
<td>Cryptomonas erosa 11.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cryptomonas erosa 66.9</td>
</tr>
<tr>
<td>St. Helens</td>
<td>8/14/91</td>
<td>8/10/93</td>
<td>Tetraedron minimum 35.4;</td>
<td>Ankistrodesmus falcatus 94.5</td>
<td>Cryptomonas erosa 37.5;</td>
<td>Ankistrodesmus falcatus 86.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rhodomonas minuta 18.8;</td>
<td></td>
<td>Tetraedron minimum 31.5;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cryptomonas erosa 14.6</td>
<td></td>
<td>Chlamydomonas sp. 10.0</td>
<td></td>
</tr>
<tr>
<td>Venus</td>
<td>8/14/91</td>
<td>8/10/93</td>
<td>Cyclotella stelligera 81.6</td>
<td>Crucigenia fenestrata 32.7;</td>
<td>Cyclotella stelligera 62.2;</td>
<td>Crucigenia fenestrata 25.2;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Crucigenia quadrata 21.1</td>
<td>Sphaerocystis Schroeteri 27.8</td>
<td>Crucigenia quadrata 13.8</td>
</tr>
</tbody>
</table>

*epilimnion sample replicates averaged
<table>
<thead>
<tr>
<th>Lake</th>
<th>AA sample dates</th>
<th>PSU sample dates</th>
<th>AA % density</th>
<th>PSU % density*</th>
<th>AA % biovolume</th>
<th>PSU % biovolume*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Castle</td>
<td>6/13/91</td>
<td>6/26/93</td>
<td><em>Rhodomonas minuta 34.8; Acanthesthes minitamussa 15.2; Cryptomonas erosa 10.6</em></td>
<td><em>Cryptomonas erosa 54.2; Kephyrion sp. 33.1</em></td>
<td>Cryptomonas erosa 33.8; Synedra radians 13.4</td>
<td>Cryptomonas erosa 73.1; Glenodinium sp. 19.4</td>
</tr>
<tr>
<td>Castle</td>
<td>9/13/91</td>
<td>9/17/93</td>
<td><em>Gloeocystis-like sp. 45.4; Dinobryon sp. 21.3; Cryptomonas erosa 15.7</em></td>
<td><em>Kephyrion sp. 32.9; Chlamydamonas-like sp. 22.1; Quadrigula lacustris 13.6</em></td>
<td>Cryptomonas erosa 39.6; Gloeocystis-like sp. 31.3; Dinobryon sp. 15.7</td>
<td>Chlamydamonas-like sp. 42.9; Glenodinium sp. 19.9</td>
</tr>
<tr>
<td>Coldwater</td>
<td>7/27/91</td>
<td>8/4/93</td>
<td><em>Gloeocystis-like sp. 31.3; Rhodomonas sp. 13.3; Chrysochromulina sp. 10.8</em></td>
<td><em>Planktosphaeria gelatinosa 54.5; Kephyrion sp. 34.6</em></td>
<td>Cyclotella comta 64.0; Gloeocystis-like sp. 11.8; Cryptomonas erosa 11.0</td>
<td>Kephyrion sp. 42.0; Cyclotella comta 33.3</td>
</tr>
<tr>
<td>Coldwater</td>
<td>9/5/91</td>
<td>10/2/93</td>
<td><em>Kephyrion sp. 18.9; Cyclotella comta 18.9; Cryptomonas erosa 17.0</em></td>
<td><em>Planktosphaeria gelatinosa 84.9</em></td>
<td>Cyclotella comta 64.7; Ceratium hirundinella 14.0; Cryptomonas erosa 13.3</td>
<td>Cyclotella comta 50.6; Planktosphaeria gelatinosa 21.7</td>
</tr>
</tbody>
</table>

*epilimnion sample replicates from sites 1 and 2 were averaged*
Comparision with other Studies:

Results from previous studies in the Mt. St. Helens area involving phytoplankton demonstrate that these populations have been changing since the eruption. By comparing phytoplankton populations in given lakes at the same time period one can determine if these systems are relaxing back to their original regimen before the eruption. Reynolds (1984) explains that phytoplankton cycles in lakes are reproducible so that in a lake which is stable, a similar assemblage of phytoplankton should be present from summer to summer.

Larson and Geiger (1982) studied phytoplankton and water chemistry from Spirit Lake; samples were taken from the surface October 21, 1980. They report that 73% of the total phytoplankton counted were Cyclotella stelligera, Stephanodiscus astrea v. minuta, Fragilaria construens v. venter, and Melosira distans, which are all diatoms (Table 9). They concluded that the species composition was typical of other eutrophic lakes in the Oregon Cascade Range and that populations of highly tolerant phytoplankton were recolonizing the lake and that recovery was underway at that time.

Smith and White (1985) collected surface water samples from Castle, McBride, Meta, Coldwater, and Spirit lakes in mid-August 1982 and identified the algae which occurred at a 5% or greater relative frequency in these lakes (Table 9). Very few of the phytoplankton identified in this study were found in these lakes during the 1992 and 1993 sample period. The only species of phytoplankton identified in Smith and White's paper that was identified in the same lake during this study was Cryptomonas erosa in Spirit Lake, however in 1982 Smith and White found Cryptomonas erosa to occur at 57.9%
relative frequency and in 1993 it occurred less than 1% total density.

Kelly (1992) found that in Castle Lake from August 1989 samples Chromulina sp., Oocystis puscilla, Ochromonas sp., and Cryptomonas erosa were the dominant phytoplankton (Table 9). In Coldwater Lake from August 1989 samples, she found Rhodomonas minuta, Chlamydomons-like sp., Gloeocystis sp., and Cyclotella meneghiniana to be the taxa with the greatest abundance.

Table 9 illustrates the cyclic nature in some of the lakes that have stabilized to some degree. In Coldwater Lake, Gloeocystis sp. is present in 1989, 1991 and 1993; in 1993, I identified this species as Planktosphaeria gelatinosa whereas Mr. Sweet and Vallerie Kelly identified the alga as Gloeocystis sp. (see accuracy in identifying and counting the algae, Coldwater Lake). Cryptomonas erosa was present in Castle Lake in 1989 and 1991 and in Meta Lake in 1991 and 1993. In McBride Lake Fragilaria crotonensis is present in 1991 and 1993. Unfortunately there were no phytoplankton data available for Spirit Lake between 1982 and 1993; the available data for this lake suggests that the system is still in flux.
<table>
<thead>
<tr>
<th>Lake</th>
<th>Oct. 21, 1980 % density</th>
<th>mid-August 1982 % relative freq.</th>
<th>August 1989 % density</th>
<th>Summer 1991 % density</th>
<th>Summer 1993 % density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spirit</td>
<td><strong>Cryptomonas erosa</strong> 26.0; <strong>Stephanodiscus astrea minuta</strong> 22.0; <strong>Fragilaria construens venter</strong> 17.0; <strong>Melosira distans</strong> 8.0</td>
<td><em>C</em>. <em>erosa</em> 57.9; other flagellates 23.5; <em>Cyclotella meneghiniana</em> 8.9</td>
<td><em>C</em>. <em>erosa</em> 57.9; other flagellates 23.5; <em>Cyclotella meneghiniana</em> 8.9</td>
<td><em>(Summer '93)</em> <em>Fragilaria crotonensis</em> 37.5; <em>Cyclotella comta</em> 18.5; <em>Kephyrion sp.</em> 21.9</td>
<td></td>
</tr>
<tr>
<td>Coldwater</td>
<td><strong>Chrysophyte statocysts</strong> 28.4; fungal didymospires 44.7</td>
<td><em>(8/15/89)</em> <em>Rhodomonas minuta</em> 27; <em>Chlamydomonas-like sp.</em> 15; <em>Gloeocystis sp.</em> 14; <em>Cyclotella meneghiniana</em> 14</td>
<td><em>(7/27/91)</em> <em>Gloeocystis-like sp.</em> 31.3; <em>Rhodomonas minuta</em> 13.3; <em>Chrysochromulina sp.</em> 10.8</td>
<td><em>(8/4/93)</em> <em>Planktosphaeria gelatinosa</em> 54.5; <em>Kephyrion sp.</em> 34.6</td>
<td></td>
</tr>
<tr>
<td>Castle</td>
<td><strong>Chrysophyte statocysts</strong> 31.9; <em>Rhizosolenia sp.</em> 29.2; <em>Synedra delicatissima angustissima</em> 18.6; <em>Fragilaria crotonensis</em> 10.3</td>
<td><em>(8/8/89)</em> <em>Chromulina sp.</em> 49; <em>Oocystis puscilla</em> 29; <em>Ochromonas sp.</em> 14; <em>Cryptomonas erosa</em> 5</td>
<td><em>(9/13/91)</em> <em>Gloeocystis-like sp.</em> 45.4; <em>Dinobryon sp.</em> 21.3; <em>Cryptomonas erosa</em> 15.7</td>
<td><em>(9/17/93)</em> <em>Kephyrion sp.</em> 32.9; <em>Chlamydomonas-like sp.</em> 22.1; <em>Quadrigula lacustris</em> 13.6</td>
<td></td>
</tr>
</tbody>
</table>
Table 9 (cont.). Comparison of studies of lakes in the Mt. St. Helens area after the 1980 eruption.

<table>
<thead>
<tr>
<th>Lake</th>
<th>Oct. 21, 1980 % density</th>
<th>mid-August 1982 % relative freq.</th>
<th>August 1989 % density</th>
<th>Summer 1991 % density</th>
<th>Summer 1993 % density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meta</td>
<td></td>
<td><em>Dinobryon cylindricum pa/ustris</em> 90.5</td>
<td></td>
<td><em>(7/16/91) Rhodomonas minuta 35.1; Cryptomonas erosa 29.7</em></td>
<td><em>(8/26/93) Oocystis puscilla 59.4; Asterionella formosa 20.2; Cryptomonas erosa 8.8</em></td>
</tr>
<tr>
<td>McBride</td>
<td></td>
<td>Chrysophyte statocysts 48.5; <em>Nitzschia acucularis</em> 27.1; <em>Mallomonas crassisquama</em> 18.7</td>
<td></td>
<td><em>(7/18/91) Fragilaria crotonensis 13.3; Anabaena sp. 13.3; Synedra radians 12.2</em></td>
<td><em>(5/29/93) Fragilaria crotonensis 68.8</em></td>
</tr>
</tbody>
</table>
The Factor Analysis:

The purpose of this factor analysis was to determine if there were any associations between algal species based on their ability to coexist, or if any competitive exclusion between species. Data on density and biomass were analyzed separately. The results of the two factor analyses were similar; the analysis using biovolume data produced 38 factor groups, which explained 78.6% of the variance and the analysis using density data gave 41 factor groups, which explained about 80% of the variance. The strongest pattern found in the factor analysis was that many diatoms load together, perhaps due to their need for a high concentration of SiO$_2$ in their aquatic environment (Table 10). In the biovolume factor analysis, factors one through four explained 21.7% of the variance among the variables; factor one alone explained 9.7% of the variance with decreasing amount of variance explained by each successive factor. Many diatoms found in June Lake, which had the highest SiO$_2$ concentration during the sample period (averaging over 24 mg/l SiO$_2$), loaded together into factor groups. Many of these diatoms were found only in June Lake. June Lake also had a high concentration of PO$_4$ and NO$_3$+NO$_2$, averaging 46.3 µg/l and 48.4 µg/l, respectively. In Table 10, the percent variance explained by a variable can be calculated by squaring the correlation value and multiplying by 100. For example, *Acanthodes lanceolata*, which is in factor 1 of the biovolume group, had a degree of correlation of 0.72, therefore $(0.72)^2 \times 100 = 51.8\%$ of the variance for *Acanthodes lanceolata* is accounted for in factor 1. *Cymbella minuta* appears in factor groups one and two. A total of $(0.59)^2 \times (0.66)^2 \times 100 = 78.4\%$ of the variance for *Cymbella minuta* is explained in factors one and two. The factor analysis labels the factor groups so that
Table 10. Diatoms that loaded into the first four factor groups and their degree of correlation with that factor group.

<table>
<thead>
<tr>
<th>Species</th>
<th>June Lake Only</th>
<th>Biovolume Data Used</th>
<th>Density Data Used</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acnanthes lanceolata</strong></td>
<td></td>
<td>F1</td>
<td>.72</td>
</tr>
<tr>
<td><strong>Cymbella minuta</strong></td>
<td></td>
<td>F1,F2</td>
<td>.59,.66</td>
</tr>
<tr>
<td><strong>Diatoma vulgare</strong></td>
<td></td>
<td>* F1</td>
<td>.98</td>
</tr>
<tr>
<td><strong>Fragilaria brevistriata</strong></td>
<td></td>
<td>* F1</td>
<td>.73</td>
</tr>
<tr>
<td><strong>Hannaea arcus</strong></td>
<td></td>
<td>* F1</td>
<td>.98</td>
</tr>
<tr>
<td><strong>Navicula cincta</strong></td>
<td></td>
<td>* F1</td>
<td>.99</td>
</tr>
<tr>
<td><strong>Nitzschia fonticola</strong></td>
<td></td>
<td>* F1</td>
<td>.87</td>
</tr>
<tr>
<td><strong>Nitzschia palea</strong></td>
<td></td>
<td>F1</td>
<td>.82</td>
</tr>
<tr>
<td><strong>Rhoicosphenia curvata</strong></td>
<td></td>
<td>* F1,F2</td>
<td>.63,.60</td>
</tr>
<tr>
<td><strong>Cymbella mexicana</strong></td>
<td></td>
<td>F2</td>
<td>.98</td>
</tr>
<tr>
<td><strong>Cocconeis pediculus</strong></td>
<td></td>
<td>F2,F3</td>
<td>.58,.61</td>
</tr>
<tr>
<td><strong>Diatoma hiemale mesodon</strong></td>
<td></td>
<td>F2</td>
<td>.68</td>
</tr>
<tr>
<td><strong>Gomphonema olivaceum</strong></td>
<td></td>
<td>F2</td>
<td>.95</td>
</tr>
<tr>
<td><strong>Meridion circulare</strong></td>
<td></td>
<td>* F2</td>
<td>.98</td>
</tr>
<tr>
<td><strong>Navicula radiosa</strong></td>
<td></td>
<td>F2</td>
<td>.85</td>
</tr>
<tr>
<td><strong>Eunotia curvata</strong></td>
<td></td>
<td>F3</td>
<td>.92</td>
</tr>
<tr>
<td><strong>Nitzschia hungarica</strong></td>
<td></td>
<td>F3</td>
<td>.83</td>
</tr>
<tr>
<td><strong>Nitzschia linearis</strong></td>
<td></td>
<td>F3</td>
<td>.74</td>
</tr>
<tr>
<td><strong>Fragilaria crotonensis</strong></td>
<td></td>
<td>F4</td>
<td>.66</td>
</tr>
<tr>
<td><strong>Navicula cryptocephala</strong></td>
<td></td>
<td>F4</td>
<td>.52</td>
</tr>
<tr>
<td><strong>Navicula minima</strong></td>
<td></td>
<td>F4</td>
<td>.80</td>
</tr>
<tr>
<td><strong>Nitzschia sp.</strong></td>
<td></td>
<td>F4</td>
<td>.56</td>
</tr>
<tr>
<td><strong>Synedra sp.</strong></td>
<td></td>
<td>F4</td>
<td>.85</td>
</tr>
<tr>
<td><strong>Acnanthes minutissima</strong></td>
<td></td>
<td>F3</td>
<td>.68</td>
</tr>
<tr>
<td><strong>Navicula rhynchocephala</strong></td>
<td></td>
<td>F3</td>
<td>.99</td>
</tr>
</tbody>
</table>
species falling into the factor group can be correlated with a particular environmental variable and thus be predicted in the future if the environmental variables are known. For example, algae in factor group F1 may be labeled "algae that positively correlate with silica." In this factor analysis it was difficult to label the factor groups because it was not clear why species loaded into their factor groups. Canonical correlation analysis (CCA) provided additional information which made it possible to label the factor groups. The interpretation of Table 10 using the biovolume or density data is similar. For the biovolume data, most algae in group F1 strongly correlate with PO₄ and SiO₂. The species that do not correlate with PO₄ and SiO₂ do correlate with NH₄; these are *Diatoma vulgare*, *Hannaea arcus*, *Navicula cincta*, *Nitzschia fonticola*, and *Rhoicosphenia curvata*. Diatoms in group F2 correlate only with PO₄ and SiO₂. Species in group F3 have a weaker correlation with PO₄ and SiO₂ and algae in group F4 appear to have no correlation with any of the environmental variables examined in the first CCA. Based on factor analysis of the density data, diatoms in group F1 correlate positively with PO₄ and SiO₂. Diatoms in group F2 correlate either with PO₄ and SiO₂ or NH₄ as in group F1 of the biovolume data. Group F3 algae do not appear to load on any canonical variables. Other patterns found were that *Planktosphaeria gelatinosa* correlated negatively with *Cyclotella stelligera*. *Planktosphaeria gelatinosa*, which proliferated in Coldwater Lake during the summer and fall of 1993, grew well in conditions where nitrogen was plentiful. Carpenter (1995) reports that phytoplankton in Coldwater Lake were likely phosphorus limited as soluble reactive phosphorus and chlorophyll a concentrations decreased from March through August '93, but the nitrogen concentrations were consistently high.
Cyclotella stelligera were abundant in Venus and Panhandle Lakes in September of 1992. Unfortunately no nutrient data are available for this period to correlate the environmental conditions with the species present. *Ankistrodesmus falcatus* and *Crucigenia fenestrata* loaded together and were both found in Venus Lake where there were high concentrations of nitrate and nitrite in the summer 1993 samples (averaging 56.3 µg/l) while PO₄ concentration was very low (averaging 2.3 µg/l). Noticeably missing from the factor groups are *Cyclotella comta*, *Chromulina sp.*, *Rhodomonas minuta*, and *Cryptomonas eros*, which are common to many samples, but did not strongly correlate with any factor groups.

**The Canonical Correlation Analysis:**

In canonical correlation analysis (CCA), axes are put through each of the two clusters of variables (the two clusters being algae and environmental variables) so that they account for the maximum amount of variance within each set while simultaneously accounting for the maximum covariance between each set. So, the first pair of axes identifies the most important pattern that is common to the two data sets. SAS labeled the sets of linear combinations of algae data "V" and the sets of linear combinations of environmental variables "W." V₁ correlates with W₁ as they are a pair of axes or canonical variables. Therefore, the most important pattern would be the pair, V₁ and W₁. After the best positions are found for the first pair, further pairs of axes may be stuck through the vector clusters at right angles to the first set, and rotated until they account for the next best correlation between the sets. This occurs until there are as many pairs of axes as there are variables in the smaller data set. The first CCA (CCA #1), based on four
environmental variables (PO₄, NO₃ + NO₂, NH₄, and SiO₂) produced four pair of canonical variables. In order to determine if a pair of variables are significant the F-test was performed. A high F-value leads to a low P-value and if the P-value is less than or equal to 0.05, then that pair of canonical variables is significant. For CCA #1 based on biovolume, there were four pairs of canonical variables significant and based on the density data two pair were significant. For CCA #2 there were three significant pair for the biovolume data and only one pair of significance for the density data (Table 11).

Table 11. Significance of canonical variable pairs.

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Pair</th>
<th>Proportion (%)</th>
<th>Cumulative (%)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCA #1-biovolume</td>
<td>1</td>
<td>80.17</td>
<td>80.17</td>
<td>0.0001</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>9.14</td>
<td>89.31</td>
<td>0.0001</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>6.51</td>
<td>95.82</td>
<td>0.0001</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4.18</td>
<td>100</td>
<td>0.0065</td>
</tr>
<tr>
<td>CCA #1-density</td>
<td>1</td>
<td>83.42</td>
<td>83.42</td>
<td>0.0001</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>8.80</td>
<td>92.22</td>
<td>0.0001</td>
</tr>
<tr>
<td>CCA #2-biovolume</td>
<td>1</td>
<td>42.62</td>
<td>42.62</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>20.57</td>
<td>63.19</td>
<td>0.0001</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>18.97</td>
<td>82.16</td>
<td>0.0004</td>
</tr>
<tr>
<td>CCA #2-density</td>
<td>1</td>
<td>48.22</td>
<td>48.22</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

The data output for the CCA appear in a matrix of data; the algae matrix is above the environmental variables matrix. The variables make up the row headings and the canonical variables (V1, W1, etc.) make up the column headings. Canonical weights are the values in the matrix and represent coefficients of the linear combinations for each
species or environmental variable. A canonical weight is given for each variable across all the canonical variables. Ideally some species will have a large canonical weight in V1 which corresponds to a high value of a particular environmental variable W1 (e.g. PO4). If so, these algae are said to be loading highly on the canonical variable W1. Other species will associate with V2 and W2, and so on. Not all canonical weights are significant. Optimally, one would like to see either -1, 0, or +1 for values in the V and W columns. Zero's indicate that there is no correlation; -1 and +1 indicate either a strong negative or strong positive correlation. For example, if a canonical weight in V2 is -0.78 and a canonical weight in W2 is -0.84, then there is a high, positive correlation (they are large numbers and the same sign). Likewise if a canonical weight in V3 is +0.31 and a canonical weight in W3 is -0.24 then there is a weak, negative correlation.

In CCA #1, for both biovolume and density, the environmental variables PO4 and SiO2 in W1 had large canonical weights. Many algae in the V1 column were loading highly on W1. They were all diatoms, many of which were peculiar to June Lake. The first pair of canonical variables for both sets accounted for over 80% of the variance (Table 10). It was felt that June Lake was so different from the rest of the lakes that it may have been overshadowing the effects of the other lakes in the analysis. Therefore, data for June Lake were removed from the initial spreadsheet. In addition, light attenuation data were included as an environmental variable (in CCA #2).

In CCA #2, SiO2 was still the dominant variable in W1, but different algae were loading onto W1. Kephyrion sp. and Chroococcus dispersus have a positive correlation with SiO2 in W1 from the density data and Chromulina sp., Cyclotella glomerata,
Crucigenia quadrata, Crucigenia fenestrata, and Nitzschia amphibia correlate negatively with W1. From the biovolume data Chroococcus dispersus and Planktosphaeria gelatinosa are positively correlated with SiO₂ and Chromulina sp., Cyclotella glomerata, Crucigenia crucifera, Crucigenia fenestrata, Crucigenia quadrata, and Nitzschia amphibia are negatively correlated. In the second pair of canonical variables in the biovolume data set PO₄ and NO₃ + NO₂ are the principal environmental variables and are positively correlated with Ankistrodesmus falcatus, Cyclotella glomerata, and Crucigenia fenestrata. Asterionella formosa, Rhodomonas minuta, and Synedra rumpens are negatively correlated with these variables. By the time the third pair of axes is identified, relationships are not as clear, but the canonical variables are nevertheless significant in the biovolume data set. The dominance among the environmental variables is split between PO₄, SiO₂, and NO₃ + NO₂. Ankistrodesmus falcatus, Cyclotella stelligera, Chlamydomonas sp., and Glenodinium sp are positively correlated with NO₃ + NO₂, but negatively correlated with PO₄ and SiO₂. Nitzschia sp. and Quadrigula lacustris are negatively correlated with NO₃ + NO₂ but positively correlated with PO₄ and SiO₂. In either analysis, NH₄ and light attenuation did not appear to be a strong influence on the algae present relative to the other environmental factors.

The solution of the CCA can be displayed in an ordination diagram much like the diagrams shown in ter Braak (1986). Sites are represented by points and environmental variables are represented by arrows (Figures 2 - 18). The sites represent the dominant patterns in community composition to the extent they can be explained by the environmental variables and the arrows of the environmental variables reflect the species
distribution along each of the vectors. For example, the arrow which represents PO$_4$ points toward site 316. As can be seen in Appendix A, sample 03-16 is the third lake (Castle Lake) and the sixteenth sample from that lake. Accordingly, the algae found in that sample evidently require a relatively large amount of PO$_4$. If a site is directly behind the arrow representing PO$_4$, one can infer that at that site, the algae must not require as much PO$_4$. The arrows represent a gradient of a high to low requirement for the environmental variables that they represent. The length of an arrow is determined by the strength of the two vectors being graphed.

Samples from thirteen lakes were analyzed by the CCA and graphs were made for each lake, as discussed in the following section. All references to nutrient data were taken from Carpenter (1995).

**Boot Lake:** Samples from 8/15/93 were graphed with canonical variables V1 vs. V2 showing the best pattern (Figure 2). The SiO$_2$ vector points directly at the hypolimnion samples (208, 209), which are dominated by *Ochromonas sp.*, a Chrysophyte that requires SiO$_2$ for its lorica. The epilimnion samples (204, 205) were dominated by *Fragilaria crotonensis* and *Glenodinium sp.*, both of which have a positive correlation with W2, representing PO$_4$ and NO$_3$+NO$_2$. The presence of *Fragilaria crotonensis*, a pennate diatom, may pull these samples toward the SiO$_2$ vector. The metalimnion samples (206,207) are dominated by *Fragilaria crotonensis, Glenodinium sp* and *Kephyrion sp.*; *Kephyrion sp.* also has a positive correlation with W2. The metalimnion samples position on the graph is unclear.

**Castle Lake:** Samples from 6/26/93 are graphed in Figure 3 (V1 vs. V2). Most of
Fig. 2 Boot Lake
canonical variables V1 vs. V2

using biovolume data from CCA #2
Fig. 3 Castle Lake - samples from 6/26/93
canonical variables $V_1$ vs. $V_2$

using biovolume data from CCA #2
Fig. 4 Castle Lake - samples from 9/17/93

canonical variables V1 vs. V2

using biovolume data from CCA #1
the samples lie between PO$_4$ and NO$_3$+NO$_2$ vectors. In the epilimnion samples (301, 302, 307, 308), Cryptomonas erosa and Glenodinium sp. are the dominant algae. In the metalimnion samples (303, 304, 309, 310) Glenodinium sp. is dominant, followed by Cryptomonas erosa and Kephyrion sp. The hypolimnion samples (305, 306, 311, 312) are dominated by Cryptomonas erosa and Kephyrion sp. Cryptomonas erosa has a weak negative relationship with W2, which correlates with PO$_4$ and NO$_3$+NO$_2$. Glenodinium sp. and Kephyrion sp. have a stronger positive correlation with W2. Carpenter (1995) reports that nitrogen and phosphorus limit the growth of plankton in Castle Lake. He reported that phosphorus is the primary limiting nutrient, while nitrogen co-limits productivity. In Figure 4, epilimnion and metalimnion samples from 9/17/93 are graphed which correlates with SiO$_2$ and NO$_3$+NO$_2$ and Chlamydomonas-like sp. weakly loads on W2. In metalimnion site #2 samples, 321 and 322, Chlamydomonas-like sp. is dominant.

**Coldwater Lake:** Samples from 8/4/93 and 10/2/93 are graphed in Figure 5 (V1 vs. V2). Most of the samples are clustered between the NO$_3$+NO$_2$ and SiO$_2$ vectors and were dominated by Planktosphaeria gelatinosa. Planktosphaeria gelatinosa loads highly on W1, in which SiO$_2$ is the strongest environmental variable followed by NO$_3$+NO$_2$. Carpenter (1995) reports that during 1993, PO$_4$ remained low (averaging 4.2 µg/l) while NO$_3$+NO$_2$ concentrations were high (averaging 46.1 µg/l) and NH$_4$ concentrations averaged 9.7 µg/l. A small group of samples are scattered opposite the PO$_4$ vector. These do not have a great abundance of Planktosphaeria gelatinosa, but small flagellates (Cryptomonas erosa and Rhodomonas minuta) are the primary algae. Both of these
Fig. 5 Coldwater Lake
canonical variables V1 vs. V2

using biovolume data from CCA #2
Fig. 6 Fawn Lake
canonical variables V1 vs. V2

using biovolume data from CCA #2
flagellates load on W2 and have a negative correlation with \( \text{PO}_4 \) and \( \text{NO}_3+\text{NO}_2 \).

**Fawn Lake:** Samples from the fall and summer 1993 are plotted on Figure 6 (V1 vs. V2). Samples from the summer 1993 are clustered behind the \( \text{NO}_3+\text{NO}_2 \) vector. The alga with the greatest biovolume in the epilimnion and metalimnion samples was *Cyclotella comta* which has a negative correlation with \( \text{SiO}_2 \) and \( \text{NO}_3+\text{NO}_2 \) (W1).

*Cyclotella comta* and *Cryptomonas erosa* are dominant in the hypolimnion samples (508, 509). Sample 511 was also near this group of samples, but *Ochromonas sp.* was the dominant alga. The \( \text{NH}_4 \) and \( \text{NO}_3+\text{NO}_2 \) vector points toward the fall hypolimnion samples (514, 515) in which *Cyclotella comta* has the greatest biovolume, but with many *Chroococcus minima* present as well. During this period the hypolimnion was anoxic favoring reduced nitrogen (\( \text{NH}_4 \)) over oxidized nitrogen (\( \text{NO}_3+\text{NO}_2 \)), 41.4 g/l and 13.1 g/l respectively (Carpenter 1995). Cyanophytes require a large amount of nitrogen. Perhaps the *Chroococcus sp.* were present due to the \( \text{NH}_4 \) being released from the bottom sediments when the oxygen was depleted in the overlying water column.

**Hanaford Lake:** Summer and fall 1993 samples from Hanaford Lake were graphed in Figure 7 (V2 vs. V3). Summer epilimnion (604,605) and metalimnion (607,608) samples are in the path of the \( \text{NO}_3+\text{NO}_2 \) vector. In the epilimnion samples, *Cryptomonas erosa* is the alga with the greatest biovolume; in 604 some *Kephyrion sp.* are present which may explain the proximity to the \( \text{SiO}_2 \) vector. The dominant algae in the metalimnion samples are *Rhodomonas minuta* and *Cryptomonas erosa*. All of the fall samples are directly behind the \( \text{NO}_3+\text{NO}_2 \) vector. In the epilimnion samples (611,612) and metalimnion samples (613,614) *Cyclotella comta* contributed to the greatest biovolume.
Fig. 7 Hanaford Lake
canonical variables V2 vs. V3

using biovolume data from CCA #2
Fig. 8 June Lake
canonical variables V1 vs. V2

using biovolume data from CCA #1
followed by *Chromulina sp*. In the hypolimnion, *Cyclotella comta* is the dominant alga, then *Cryptomonas erosa* and *Chromulina sp*. *Cyclotella comta* (in V2) has a weak negative relationship with W2, which correlates with NO$_3$+NO$_2$.

**June Lake:** Samples from three sample dates were graphed in Figure 8, which shows canonical variables V1 vs. V2 from CCA #1. All points are between the SiO$_2$ and PO$_4$ vectors. Samples from 5/28/93 (701, 702) are closest to the SiO$_2$ vector and the entire assemblage consisted of diatoms. Nearly all of the diatoms load very highly on W1 where there is a strong correlation with PO$_4$ and SiO$_2$. These samples appear to be very diverse and there does not seem to be a dominant species. Samples from 9/9/93 (703, 704) and 10/17/93 (705, 706) are close together in between the two vectors and their assemblages consisted only of diatoms. Samples 703 and 704 are dominated by *Diatoma hiemale mesodon*, which loaded highly on W1 and correlates with PO$_4$ and SiO$_2$, and samples 705 and 706 were dominated by *Diatoma hiemale mesodon* and *Gomphonema olivaceum*; *Gomphonema olivaceum* also loaded highly on W1.

**McBride Lake:** Canonical variables V1 vs. V2 were graphed (Figure 9) for samples taken in May, September, and October 1993. All samples in May (801-804) clustered beyond the PO$_4$ vector. Carpenter (1995) states that phosphorus was not a limiting nutrient in this lake during 1993. *Fragilaria crotonensis* was by far the most abundant alga in the May samples and it loads on W2, where PO$_4$ is the strongest environmental variable followed by NO$_3$+NO$_2$. In September, samples (805,806) are dominated by *Microcystis aeruginosa*, a Cyanophyte. Carpenter (1995) indicated that nitrogen is clearly the limiting nutrient in McBride Lake, especially as the growing season
Fig. 9 McBride Lake
canonical variables V1 vs. V2

using biovolume data from CCA #2
Fig. 10 Merrill Lake - samples from 4/17/93
canonical variables V1 vs. V2

using biovolume data from CCA #2
Fig. 11 Merrill Lake - September 1993 samples
canonical variables V1 vs. V2

using bivolume data from CCA #2
progressed into the fall season. *Microcystis aeruginosa* may be fixing atmospheric nitrogen. In October, *Cryptomonas erosa* had the greatest biovolume in the samples (807,808). Sample 807 is near the origin, and 808 is along the SiO$_2$ vector, in which *Nitzschia palea* is the second most abundant alga; *Nitzschia palea* has a moderate correlation with W1, hence SiO$_2$.

**Merrill Lake:** Carpenter (1995) found that nitrogen and phosphorus concentrations were always low in Merrill Lake and this indicates a co-limitation by both nutrients; there appears to be a shift from phosphorus limited growth in the spring to limitation by nitrogen in the summer and fall. Most of the spring samples are clustered in the vicinity of the PO$_4$ path (Figure 10) and in the graph showing September samples (Figure 11) there is a linear gradient from NO$_3$+NO$_2$ to PO$_4$ and samples are scattered between the extremes. In the graph of October samples (Figure 12), the points are clustered behind the NO$_3$+NO$_2$ vector. In the spring (4/17/93) many *Cryptomonas erosa*, *Cyclorella comta*, and *Synedra rumpens* were present and loaded on W2. These species were thus negatively correlated with PO$_4$ suggesting that these algae can grow when PO$_4$ is limited. In the summer (9/9/93) *Cyclorella comta* was much more dominant that in the spring and *Anabaena sp.* was present in most of these samples. *Cyclorella comta* correlates negatively with NO$_3$+NO$_2$ as well as PO$_4$ on W2. NO$_3$+NO$_2$ concentrations were low (average 0.9 µg/l) during this period giving a competitive advantage to blue-green algae such as *Anabaena sp.*, with efficient capabilities for fixing molecular nitrogen (Wetzel 1983). Fall samples (Figure 12) from 10/17/93 are dominated by *Chromulina sp.* and *Rhodomonas minuta*. These algae may not have the greatest biovolume in the samples, but they are common to
Fig. 12 Merrill Lake - October 1993 samples
canonical variables V1 vs. V2

using biovolume data from CCA #2
Fig. 13 Meta Lake - samples from June and August 1993

canonical variables V1 vs. V2

using biovolume data from CCA #1
Fig. 14 Meta Lake - samples from October 1993
canonical variables V1 vs. V3

using biovolume data from CCA #2
Fig. 15 Panhandle Lake
canonical variables V1 vs. V2

using biovolume data from CCA #2
NO$_3$+NO$_2$ vector points toward the epilimnion samples, 1104 and 1105. The dominant algae are *Fragilaria crotonensis* and *Glenodinium sp*. Both algae load moderately onto W2, which correlates with PO$_4$ and NO$_3$+NO$_2$. Carpenter (1995) states that during this sample period phosphorus was the limiting nutrient. In the epilimnion there were 118.4 µg/l NO$_3$+NO$_2$, while only 0.2 µg/l PO$_4$. In the metalimnion (1106, 1107) *Fragilaria crotonensis* and *Dinobryon sp.* were dominant and *Cryptomonas erosa* and *Dinobryon sp.* were dominant in the hypolimnion (1108, 1109). Metalimnion and hypolimnion samples appeared behind the PO$_4$ vector and possibly a little toward the SiO$_2$ vector; *Fragilaria crotonensis* is a pennate diatom and *Dinobryon sp.* is a Chrysophyte (Appendix B). Both require silica for their frustules or lorigas. In the metalimnion and hypolimnion, there was still plenty of NO$_3$+NO$_2$ (average 38.9 µg/l), but PO$_4$ was again in short supply 0.5 µg/l (Carpenter 1995).

**Ryan Lake:** Three sample dates are represented in Figure 16 (V1 vs. V2); 6/17/93, 8/24/93, and 10/9/93. *Ankistrodesmus falcatus* was the dominant alga in the lake during the sample period, 6/17/93, followed by *Cryptomonas erosa* (1201-1203). *Ankistrodesmus falcatus* loads on W2, which correlates with PO$_4$ and NO$_3$+NO$_2$. Samples from 8/24/93 and 10/9/93 are scattered below the PO$_4$ and NO$_3$+NO$_2$ vectors. The epilimnion and metalimnion samples from 8/24/93 (1204-1207) are dominated by *Cryptomonas erosa* followed by *Kephyrion sp.*. Hypolimnion samples (1208,1209) have *Cryptomonas erosa* and *Cryptomonas ovata* as the dominant algae. *Cryptomonas erosa* and *Cryptomonas ovata* have a weak negative relationship with W2 and correlated negatively with PO$_4$ and NO$_3$+NO$_2$. Epilimnion and metalimnion samples (1210-1213) are
Fig. 16 Ryan Lake
canonical variables V1 vs. V2

using biovolume data from CCA #2
Fig. 17 St. Helens Lake
canonical variables V1 vs. V2

using biovolume data from CCA #2
Fig. 18 Venus Lake
canonical variables V2 vs. V3

using biovolume data from CCA #2
dominated by *Cryptomonas erosa* and *Cryptomonas ovata*, followed by *Kephyrion spirale* and/or *Kephyrion sp.* The hypolimnion samples (1214, 215) from this data are dominated by *Cryptomonas erosa* followed by *Kephyrion spirale* or *Kephyrion sp.* Carpenter found that both nitrogen and phosphorus limit phytoplankton growth in Ryan Lake.

**St. Helens Lake:** Summer 1993 samples are graphed in Figure 17 (V1 vs. V2). Epilimnion and metalimnion samples (1404-1407) were dominated by *Ankistrodesmus falcatus*, although in 1406 there were about 26% more *Cryptomonas erosa* than *Ankistrodesmus falcatus*. These samples were in the path of the NO$_3$+NO$_2$ vector. *Ankistrodesmus falcatus* is positively correlated with NO$_3$+NO$_2$ as it loads on W2. There was only one hypolimnion sample (1408), that was dominated by *Cryptomonas erosa*. This sample was very sparse with algal units (only 6 units/ml), and was located below the PO$_4$ and NO$_3$+NO$_2$ vectors. *Cryptomonas erosa*, loads on W2 and is negatively correlated with PO$_4$ and NO$_3$+NO$_2$. Carpenter reports abundant NO$_3$+NO$_2$ concentrations during this sample period (average 143.8 µg/l). Phosphorus appeared to be the limiting nutrient. The concentration of PO$_4$ decreased with depth from 3.7 µg/l in the epilimnion to 0.1 µg/l in the hypolimnion.

**Venus Lake:** Samples from 8/10/93 are graphed in Figure 18 (V2 vs. V3). There was a low density of algae in the epilimnion samples, 9.7 and 12.9 algal units/ml respectively. Fewer than 100 algal units were counted from each sample. Sweet (1986) has demonstrated that results from counting less than 100 algal units in a sample are significantly different than if 100 or more algal units are counted, so one should not have
great confidence in what these samples represent. The metalimnion samples (1506, 1507) are dominated by *Crucigenia fenestrata*, which loads highly on W2 and positively correlates with $\text{PO}_4$ and $\text{NO}_2+\text{NO}_2$. The metalimnion samples lie between the $\text{PO}_4$ and $\text{NO}_3+\text{NO}_2$ vectors. The alga with the greatest biovolume in the hypolimnion samples is *Cryptomonas erosa*. There is a weak, negative correlation between *Cryptomonas erosa* and W2, which may explain the location of these samples on the graph; they are far from the $\text{PO}_4$ and $\text{NO}_3+\text{NO}_2$ vectors.

**Summary of Factor Analysis and Canonical Correlation Analysis Results:**

The most conspicuous associations between algal species and environmental variables found in the ordination diagrams can be summarized as follows:

**For Canonical Correlate #1:**

- *Asterionella formosa* in Meta Lake negatively correlates with $\text{NO}_3+\text{NO}_2$ and $\text{SiO}_2$.
- *Cryptomonas erosa* in Castle Lake positively correlates with $\text{SiO}_2$ and $\text{NO}_3+\text{NO}_2$.
- *Cryptomonas erosa* in Meta Lake negatively correlates with $\text{PO}_4$ and $\text{SiO}_2$.

There appears to be a discrepancy between the relationship of *Cryptomonas erosa* and silica. In both instances, the correlation is fairly weak and $\text{SiO}_2$ may not be significant in the physiology of this alga.

**For Canonical Correlate #2:**

- *Kephyrion sp.*, *Fragilaria crotonensis*, and *Glenodinium sp.* in Boot, McBride, and Panhandle lakes correlate positively with $\text{PO}_4$ and $\text{NO}_3+\text{NO}_2$.
- *Cryptomonas erosa* in Merrill, Ryan, St. Helens, and Venus lakes and *Cryptomonas ovata* in Ryan Lake have a weak, negative correlation with $\text{PO}_4$ and $\text{NO}_3+\text{NO}_2$. 
· *Rhodomonas minuta* in Coldwater Lake negatively correlates with PO$_4$ and NO$_3$+NO$_2$.

· *Ankistrodesmus falcatus* in Ryan and St. Helens lakes positively correlate with PO$_4$ and NO$_3$+NO$_2$.

· *Crucigenia fenestrata* in Venus Lake positively correlates with PO$_4$ and NO$_3$+NO$_2$.

· *Planktosphaeria gelatinosa* in Coldwater Lake is positively correlated with SiO$_2$ and NO$_3$+NO$_2$.

· *Cyclotella comta* in Fawn and Hanaford lakes negatively correlate with SiO$_2$ and NO$_3$+NO$_2$.

· *Diatoma hiatum mesodon* and *Gomphonema olivaceum* in June Lake strongly correlate with SiO$_2$ and PO$_4$.

· *Nitzschia palea* moderately correlates with silica in June Lake.

· *Ochromonas sp.* in Boot Lake was found to have a positive correlation with silica.

· *Cryptomonas erosa, Cyclotella comta, and Synedra rumpens* negatively correlate with PO$_4$ in Merrill Lake.

· *Chromulina sp.* and *Rhodomonas minuta* negatively correlate with NO$_3$+NO$_2$ in Merrill Lake.

Corel Chart 3.0 was used to construct these diagrams using coordinates for the environmental variables produced by the CCA procedure in SAS. There is an assumption that the dominant algae in the samples, on the basis of their canonical weights with respect to the canonical weights of the environmental variables, explain the position of the sample on the ordination diagram with reference to the vectors. ter Braak (1986) describes a multivariate analysis technique, detrended canonical correspondence analysis, in which
points represent species and sites, and vectors represent environmental variables. Therefore, his ordination diagrams not only show the sites, but also plot the species.

**Trophic State Indices among Lake Samples:**

The trophic state indices (TSI) of the lake samples were compared against a list of TSI values from *Atlas of Oregon Lakes* (1985). The authors define an ultraoligotrophic lake to have a TSI value less than 20, oligotrophic lakes have TSI values between 20 and 35, and mesotrophic lakes have values between 35 and 50 (based on Carlson 1977). Table 12 summarizes classification of the 13 St. Helens lakes in this thesis according to a TSI based on algal biomass. Lake samples in the ultraoligotrophic range are: all the samples from St. Helens Lake; most of the Merrill Lake samples from 10/16/93, except for the epilimnion site 1 samples, which are oligotrophic; Ryan Lake samples from 6/17/93; Venus (8/10/93) epilimnion and metalimnion; epilimnion samples from Coldwater Lake on 8/4/93 and 10/2/93; and epilimnion samples from McBride Lake (9/8/93). Hanaford Lake samples from 8/5/93 are on the boarder of ultraoligotrophic and oligotrophic. Lake samples in the oligotrophic category are: all samples from Castle, Blue, Meta, and June lakes; most of the Coldwater Lake samples; Boot Lake metalimnion and hypolimnion samples from 8/15/93; Ryan Lake samples from 8/24/93 and 10/9/93; Fawn Lake, except for the metalimnion samples from 8/5/93; fall '93 samples from Hanaford and McBride Lakes; most Merrill Lake samples from 4/17/93 and 9/8/93; and hypolimnion samples from Venus Lake (8/10/93). The mesotrophic category includes: samples from Spirit Lake; Boot Lake samples from 9/92 and epilimnion samples from 8/15/93; epilimnion (8/14/93) samples from Panhandle Lake; surface and bottom sample from McBride Lake
on (5/29/93); and metalimnion samples from Fawn Lake (8/5/93).

Table 12. Trophic State Categories of Mt. St. Helens Lakes assigned from phytoplankton biovolume.

<table>
<thead>
<tr>
<th>Lake</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>oligotrophic</td>
</tr>
<tr>
<td>Boot</td>
<td>oligotrophic-mesotrophic</td>
</tr>
<tr>
<td>Castle</td>
<td>oligotrophic</td>
</tr>
<tr>
<td>Coldwater</td>
<td>ultraoligotrophic-oligotrophic</td>
</tr>
<tr>
<td>Fawn</td>
<td>oligotrophic-mesotrophic</td>
</tr>
<tr>
<td>Hanaford</td>
<td>ultraoligotrophic-oligotrophic</td>
</tr>
<tr>
<td>June</td>
<td>oligotrophic</td>
</tr>
<tr>
<td>McBride</td>
<td>ultraoligotrophic-oligotrophic-mesotrophic</td>
</tr>
<tr>
<td>Merrill</td>
<td>ultraoligotrophic-oligotrophic</td>
</tr>
<tr>
<td>Meta</td>
<td>oligotrophic</td>
</tr>
<tr>
<td>Panhandle</td>
<td>mesotrophic</td>
</tr>
<tr>
<td>Ryan</td>
<td>ultraoligotrophic-oligotrophic</td>
</tr>
<tr>
<td>Spirit</td>
<td>mesotrophic</td>
</tr>
<tr>
<td>St. Helens</td>
<td>ultraoligotrophic</td>
</tr>
<tr>
<td>Venus</td>
<td>ultraoligotrophic-oligotrophic</td>
</tr>
</tbody>
</table>

Quality Assurance:

In order to check the precision and accuracy of the principle investigator, 7.7% of the samples initially counted were recounted: 1) by the principle investigator to check for precision, and 2) by Jim Sweet of Aquatic Analysts to check for accuracy. Sample replicates were also compared; these are actually pseudo-replicates as explained in the *sampling procedure* section, but they measure how homogenous the algae were in the...
grab sample and error can be introduced by the experimenter when preparing the slides, identifying and counting the algae, or in data management.

**Comparison of sample replicates:**

There are 83 pairs of phytoplankton sample replicates in this study. The TSI value (Sweet 1986) was used to compare the replicates because it is based on the total biovolume of phytoplankton found in the samples. The sum of squares of the differences between replicates was divided by the 83 observations and the square root of this value was taken, giving an estimate of standard deviation from one replicate to the next. This estimate of standard deviation is 3.8 and the TSI values range from 10.8 to 43.0. The data has a chi squared distribution because the sum of squares is used to construct the statistic. Accordingly, a 95% confidence interval was calculated to be 3.3 to 4.4. The coefficient of variation (CV) was calculated by taking the estimate of the standard deviation, multiplying it by 100 and dividing by the average TSI value (both replicate columns had an average TSI value and these two averages were averaged). The CV is about 13.9%, which means that the standard deviation of the replicates is about 13.9% of the actual size of the measurements.

**Precision of the algal identification and enumeration:**

Sixteen slides (7.7% of the total slides counted) were recounted to check for precision in identifying and enumerating the algae. Slides were selected from different lakes, times of year, and sample depth. An estimate of standard deviation and CV was calculated for this data set in the same fashion as for the comparison of sample replicates. The estimate of standard deviation is 5.0, 95% confidence interval is 3.7 to 7.6, and the
TSI values range from 12.1 to 40.5. The CV is 21.3%, which is larger than the replicate comparison (13.9%). This difference is due to the increasing skill in identifying and counting the algae over time plus the intrinsic variability in patchy distribution of the algae on the slides. The recounts were fairly precise, but there were a few discrepancies identified in the following section.

Blue Lake (01-02): *Rhodomonas minuta* is the dominant species in the quality assurance (QA) count and in the original count, but *Chlamydomonas-like sp.* was ignored in the QA. In the original count *Chlamydomonas-like sp.* appeared grey/brown with a red spot in the middle, like a pyrenoid, and were about 2 µm in diameter. Other than not counting the *Chlamydomonas-like sp.*, the counts were similar.

Boot Lake (02-02 and 02-06): Quality assurance counts were similar to original counts except that *Dinobryon sp.* were not recognized in the original count but, they turned out to be a significant alga in this lake.

Castle Lake: The recount of 03-13 was close to the original count; *Kephyrion sp.* was the dominant alga, *Rhodomonas minuta* was also abundant. Again *Chlamydomonas-like sp.* was not identified in the QA, but was found in the original sample. This was also the case with the recount of 03-21, where *Chlamydomonas-like sp.* was not counted in the QA transect. *Dinobryon sp.* were identified in the QA count, but not in the original count.

Coldwater Lake (04-22): The QA and original counts were similar, *Planktosphaeria gelatinosa* dominated the sample and *Rhodomonas minuta* was also significant. The larger TSI value in the QA was due to finding more *Cyclorella comta*, which was a large biovolume.
Fawn Lake (05-11 and 05-16): Original and QA counts were similar.

Hanaford Lake (06-10): Original and QA counts were similar, but in the original count three groups of 20 *Planktosphaeria gelatinosa* were counted and no *Planktosphaeria gelatinosa* were identified in the QA transect for this slide; this is probably due to patchy distribution of the colonies of *Planktosphaeria gelatinosa*.

McBride Lake (08-04): Original and QA counts were similar. *Fragilaria crotonensis* was the dominant alga in both transects. Some of the *Microcystis aeruginosa* identified in the summer and fall 1993 samples (08-05 through 08-08) may have been protozoans. When these protozoans lyse they look much like *Microcystis aeruginosa*.

Merrill Lake (09-07): Inadvertently slide 09-07 was counted two times as a QA count, but different transects were used. This data was included as it may demonstrate the patchy distribution of algae on a slide. The transect from 09-07 (count #2) and the original count were very close, 13.2 and 13.7 TSI respectively, but the 19-07 (count #1) had a slightly higher TSI value, 18.3. This higher TSI value is due to two *Cyclotella comta* found in this transect, representing 63% of the biovolume in the sample. In all three counts, *Chromulina sp.* was identified as the dominant species with *Rhodomonas minuta* as the second most abundant species.

Meta Lake (10-02): The original and QA counts were similar; *Dinobryon sp.* is the dominant species in both counts.

Ryan Lake (12-03): The original and QA counts were similar; *Ankistrodesmus falcatus* was the dominant species in both. There were a few more *Cryptomonas erosa* in the QA count than the original, 65.2% *Cryptomonas erosa* biovolume and 44.3% *Cryptomonas*
erosa biovolume, respectively. The protozoans mentioned in McBride Lake were also present in Ryan Lake in the summer and fall 1993 samples at all depths; none were present in samples taken 6/17/93.

St. Helens Lake: The original and QA counts for slide 14-04 were similar; *Ankistrodesmus falcatus* is the dominant alga. The TSI value in the QA count for 14-06 is larger than the original, 23.3 and 16.2 respectively. *Ankistrodesmus falcatus* is still the dominant species and similar assemblages were found in each count. In the QA transect there were a few large diatoms identified that brought the total biovolume up considerably; two *Synedra ulna* accounted for 29.1% of the biovolume and 7 *Tabellaria flocculosa* contributed to another 30.2% of the biovolume.

Accuracy in identifying and counting the algae:

Sixteen slides (7.7% of the total slides counted) were selected to have Jim Sweet of Aquatic Analysts recount and check for accuracy. A slide was selected from each lake at various depths and time of year. An estimate of standard deviation and CV was calculated for this data set in the same fashion as for the comparison of sample replicates and precision of the algal identification and enumeration. The estimate of standard deviation is 10.6, 95% confidence interval is 7.9 to 16.2 and the TSI values range from 8.3 to 48.4. The CV is 37.0%. As expected, the CV is larger in this comparison because another factor (a different person identifying and counting the algae) is added to the variables that can affect the results. The intrinsic variability from phytoplankton patchiness and subsampling are included in this variation. The comparison between the slides will be discussed in the following section. The number in parenthesis identifies the lab code and
Mr. Sweet's results are in Appendix C.

Blue Lake (01-01): I identified *Chlamydomonas-like sp.* and *Glenodinium sp.* as the dominant algae in this sample and Mr. Sweet did not identify these species in the sample.

Boot Lake (02-05): As stated earlier in the precision of the algal identification and enumeration section, I underestimated *Dinobryon sp.* in the original counts. Mr. Sweet confirms this, as he has found *Dinobryon sertula*ria to be the dominant species. Also, it appears what I had called *Fragilaria crotonensis* he has identified as *Synedra rumpens*. He found some *Glenodinium sp.* but not to the degree that I had estimated, 13.2% and 38.5% biovolume, respectively.

Castle Lake (03-15): Mr. Sweet identified *Dinobryon sertularia* as the dominant alga in this sample and I identified *Chlamydomonas-like sp.* as the dominant alga. Also, I counted a number of *Quadrigula lacustris*, which he did not identify in this sample, but otherwise the rest of the count is similar.

Coldwater Lake (04-08): There is a great difference in the biovolume TSI value between my count and Mr. Sweets count of this sample, 16.7 and 38.5 respectively. Actually, the counts were similar except that I identified *Planktosphaeria gelatinosa* as the dominant alga and Mr. Sweet called the dominant alga *Gloeocystis sp.*; I believe we were referring to the same alga. The biovolume of the *Gloeocystis sp.* algal unit is much larger than the biovolume of the *Planktosphaeria gelatinosa* algal unit, which may explain the difference in biovolume TSI values.

Fawn Lake (05-09): Our counts were very similar in this sample, we had no discrepancies over the identification of species. We both identified *Cryptomonas erosa* as the dominant
species, although I estimated that it represented a greater amount of the biovolume in the sample than Mr. Sweet, 24440 µm³/ml and 11604 µm³/ml, respectively.

**Hanaford Lake (06-12):** Mr. Sweet identified *Chlamydomonas-like sp.* as the dominant alga in this sample and I called this alga *Chromulina sp.* Other than this, our counts were similar; *Cyclorella comta* is the next most abundant species in both counts.

**June Lake (07-03):** Our counts were similar in this sample; *Diatoma hiemale mesodon* is the dominant alga in both counts.

**McBride Lake (08-03):** In this sample I identified the dominant alga as *Fragilaria crotonensis* and Mr. Sweet identified this species as *Fragilaria radians.* He does identify some *Fragilaria crotonensis,* but not to the degree that I did, 28.7% and 91.2%, respectively. Also, he identified *Chrysococcus rufescens,* which I did not find in the sample.

**Merrill Lake (09-15):** These counts were very similar; we both identified *Rhodomonas minuta* and *Chromulina sp.* as the most abundant species by density and *Cyclorella comta* as the alga with the greatest biovolume.

**Merrill Lake (09-16):** Again, these counts were similar, *Cyclorella comta* is the dominant alga.

**Meta Lake (10-10):** I identified the dominant alga to be *Ochromonas sp.* and Mr. Sweet identified it as *Ochromonas-like sp.*

**Panhandle Lake (11-04):** Mr. Sweet identified the dominant algae to be *Synedra rumpens* and *Glenodinium sp.* and I identified *Glenodinium sp.* and *Fragilaria crotonensis* to be dominant. Also, Mr. Sweet identified *Dinobryon sertularia* to be 9.4% of the algal
biovolume and I did not identify this species in my count.

**Ryan Lake** (12-09): Mr. Sweet and I both agree that *Cryptomonas erosa* is the dominant alga in this sample. I called some of the Cryptomonads *Cryptomonas ovata* because they were much larger than the *Cryptomonas erosa* and their gullets appeared to extend nearly three-quarters the length of the cells (Prescott 1970).

**Spirit Lake** (13-02): *Cyclotella comta* was the dominant alga in both counts followed by *Fragilaria crotonensis*, although I thought that *Fragilaria crotonensis* was more significant than Mr. Sweet, 41.1% and 7.3% biovolume, respectively. The discrepancy may be because I counted cells that no longer had a chloroplast in them, which means that they were dead at the time the samples were taken.

**St. Helens Lake** (14-04): Our counts were similar; in both counts *Ankistrodesmus falcatus* was identified as the dominant alga.

**Venus Lake** (15-06): The results of these counts are similar; Mr. Sweet identified *Crucigenia sp.* and *Ankistrodesmus falcatus* to be the dominant species in terms of density. I called the *Crucigenia sp.*, *Crucigenia fenestrata* and also identified *Ankistrodesmus falcatus* to be the second most abundant species. Mr. Sweet identified *Sphaerocystis schroeteri* as the species with the greatest biovolume and I did not identify this alga in my count.

**Conclusion**

In this study I have attempted to answer the questions 1) What phytoplankton are present in the study lakes? and 2) What is the relationship between the chemical and physical variables and the biologic community that have developed utilizing these
resources? Phytoplankton populations in the study lakes were described and compared with other post-eruption studies involving phytoplankton in Mt. St. Helens lakes. These algal communities appear to be recovering from the eruption as they show signs of stabilization. The cyclic nature of phytoplankton populations gaged from summer populations from year-to-year can be seen in some of the lakes (Coldwater, Castle, Meta, and McBride lakes).

Environmental variables were related to the presence of phytoplankton species in lakes. \( \text{PO}_4, \text{SiO}_2, \text{and NO}_3+\text{NO}_2 \) are the nutrients driving the system and exerting bottom-up control over the phytoplankton.

The lakes outside of the blast zone were not useful as control lakes. They are too different from the blast-zone lakes and do not overlap in important characteristics. They are located on the south side of the mountain as opposed to the blast-zone lakes being located on the north side. The origin of the control lakes are from landslides or debris avalanches and most of the blast-zone lakes exist as a result of glacial activity (cirque lakes).

The phytoplankton data were analyzed using the canonical correlation procedure. The results are plotted as ordination diagrams, I have shown some of the associations between specific alga and environmental variables.
LITERATURE CITED


Appendix A

Phytoplankton Data Sheets
Phytoplankton Data Sheets for

Blue Lake
<table>
<thead>
<tr>
<th>Species</th>
<th>count</th>
<th>Biovol</th>
<th>T Biovol (um3/ml)</th>
<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achnanthes minutissima</td>
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<td>50</td>
<td>0.15</td>
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<tr>
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<td>325</td>
<td>14300</td>
<td>43.13</td>
<td>32.2</td>
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<tr>
<td>Chroococcus dispersus</td>
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<td>22</td>
<td>88</td>
<td>0.27</td>
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<tr>
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<td>170</td>
<td>0.51</td>
<td>1.5</td>
<td>1.85</td>
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<td>500</td>
<td>1.51</td>
<td>0.7</td>
<td>0.93</td>
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<tr>
<td>Glenodinium sp.</td>
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<td>42.23</td>
<td>14.6</td>
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<td>78.9</td>
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TSI= 30.7
Lake: Blue  Date: 7/11/93  Depth: 10M
sample: 01-02  width (mm): 0.182  area (mm2): 2.5
transect (mm): 13.8
vol. filtered: (ml) 100

<table>
<thead>
<tr>
<th>Species</th>
<th>count</th>
<th>Biovolume</th>
<th>T Biovol(um3/ml)</th>
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141 23269  275.6

TSI= 27.7
Phytoplankton Data Sheets for

Boot Lake
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TSI = 38.2
### Lake: Boot Date: 8/15/93 Depth: meta (7m)

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<th>% Biovol</th>
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<td>Cymbella minuta</td>
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TSI = 33.4

### Lake: Boot Date: 8/15/93 Depth: meta (7m)

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<th>% Biovol</th>
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<th>Percent</th>
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Phytoplankton Data Sheets for

Castle Lake
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<th>Date: 6/26/93</th>
<th>Depth: epi (1m)</th>
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<tr>
<td>sample: 03-01</td>
<td>transect (mm): 42.1</td>
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<th>T Biovol (um3/ml)</th>
<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eunotia pectinalis minor</td>
<td>2</td>
<td>375</td>
<td>750.0</td>
<td>2.1</td>
<td>1.3</td>
<td>1.8</td>
</tr>
<tr>
<td>Glenodinium sp.</td>
<td>17</td>
<td>700</td>
<td>11900.0</td>
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<td>10.9</td>
<td>15.0</td>
</tr>
<tr>
<td>Cryptomonas erosa</td>
<td>38</td>
<td>520</td>
<td>19760.0</td>
<td>55.0</td>
<td>24.3</td>
<td>33.6</td>
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<td>Kephyrion sp.</td>
<td>56</td>
<td>63</td>
<td>3528.0</td>
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TSI= 31.3

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<th>% Biovol</th>
<th>#/ml</th>
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<td>0.5</td>
<td>0.9</td>
</tr>
<tr>
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<td>1.8</td>
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<td>Glenodinium sp.</td>
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<tr>
<td>Kephyrion spirale</td>
<td>4</td>
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<td>252</td>
<td>0.8</td>
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<td>8.1</td>
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<td>700</td>
<td>23100</td>
<td>71.7</td>
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<tr>
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<td>63</td>
<td>4851</td>
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<td>62.1</td>
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<td></td>
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TSI = 30.4

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<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
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<td>63</td>
<td>378</td>
<td>1.8</td>
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<td>700</td>
<td>7000</td>
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</tr>
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<tbody>
<tr>
<td>Cymbella minuta</td>
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<td>370</td>
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<td>1.6</td>
<td>0.8</td>
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<td>Diatoma tenue</td>
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<td>290</td>
<td>290</td>
<td>2.1</td>
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<td>0.8</td>
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<td>Glenodinium sp.</td>
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<td>1400</td>
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<td>Cryptomonas erosa</td>
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<td>5200</td>
<td>37.6</td>
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<td>Kephyrion sp.</td>
<td>118</td>
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<td>6552</td>
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TSI = 23.4

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<th>% Biovol</th>
<th>#/ml</th>
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<tbody>
<tr>
<td>Kephyrion spirale</td>
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<td>14040</td>
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<td>7245</td>
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<td>Navicula radiosa</td>
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<tr>
<td>Navicula sp.</td>
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<td>150</td>
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<td>Glenodinium sp.</td>
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<td>Kephyrion sp.</td>
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<td>63</td>
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<td>Cryptomonas erosa</td>
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<td>520</td>
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<tr>
<td>Navicula rhynchoce</td>
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<td>Achnanthes minutis</td>
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<td>Glenodinium sp.</td>
<td>5</td>
<td>700</td>
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<tr>
<td>Kephyrion sp.</td>
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<td>63</td>
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<tr>
<td>Cryptomonas erosa</td>
<td>70</td>
<td>520</td>
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</tr>
<tr>
<td>sample:</td>
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</table>

**Species** | **count** | **Biovolume (um3/ml)** | **% Biovol** | **#/ml** | **percent** |
<table>
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<tr>
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<td>325</td>
<td>1.3</td>
<td>0.7</td>
<td>0.9</td>
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<tr>
<td>Navicula rhynchocephala</td>
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<td>295</td>
<td>1.2</td>
<td>0.7</td>
<td>0.9</td>
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<tr>
<td>Fragilaria crotonensis</td>
<td>2</td>
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<td>6.8</td>
<td>1.3</td>
<td>1.9</td>
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<tr>
<td>Rhodomonas minuta</td>
<td>2</td>
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<td>0.2</td>
<td>1.3</td>
<td>1.9</td>
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<td>13</td>
<td>700</td>
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<tr>
<td>Cryptomonas erosa</td>
<td>16</td>
<td>520</td>
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<td>15.0</td>
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**TSI=** 28.2

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</table>

**Species** | **count** | **Biovolume (um3/ml)** | **% Biovol** | **#/ml** | **percent** |
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<td>Cryptomonas erosa</td>
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<td>520</td>
<td>65.6</td>
<td>18.4</td>
<td>27.9</td>
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<td>Kephyrion sp.</td>
<td>77</td>
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**TSI=** 29.2
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<tr>
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<th>T Biovol (um3/ml)</th>
<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
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<tbody>
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<td>0.3</td>
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<td>0.7</td>
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TSI= 25.4

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<table>
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<th>Biovolume</th>
<th>T Biovol (um3/ml)</th>
<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kephyrion spirale</td>
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<td>840</td>
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<td>7.3</td>
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<td>Cryptomonas erosa</td>
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TSI= 27.8
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Date: 9/17/93  
Depth: epi (1m)  
Site: 1  
Sample: 03-13  
Transect (mm): 17.5  
Width (mm): 0.182  
Area (mm2): 3.2  
Vol. filtered: (ml) 100

<table>
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<th>Biovol (um3/ml)</th>
<th>% Biovol</th>
<th>#/ml</th>
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**TSI=** 27.7
Phytoplankton Data Sheets for

Coldwater Lake
**Lake:** Coldwater  
**sample:** 04-01  
**transect (mm):** 8.7  
**vol. filtered: (ml)** 50  
**Date:** 10/02/93  
**Depth:** epi (1m)

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**TSI= 19.3**

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**Date:** 10/02/93  
**Depth:** epi (1m)

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</table>

**Sample: 04-09**

- **Transect (mm):** 21.8
- **Vol. Filtered (ml):** 100

<table>
<thead>
<tr>
<th>Species</th>
<th>Count</th>
<th>Biovolume</th>
<th>T Biovol.</th>
<th>% Biovol.</th>
<th>#/ml</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glenodinium sp.</td>
<td>1</td>
<td>700</td>
<td>700</td>
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<td>1.0</td>
</tr>
<tr>
<td>Kephyrion sp.</td>
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<td>63</td>
<td>63</td>
<td>0.3</td>
<td>1.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Cyclotella comta</td>
<td>6</td>
<td>2270</td>
<td>13620</td>
<td>63.4</td>
<td>7.4</td>
<td>6.1</td>
</tr>
<tr>
<td>Cryptomonas erosa</td>
<td>11</td>
<td>520</td>
<td>5720</td>
<td>26.6</td>
<td>13.6</td>
<td>11.1</td>
</tr>
<tr>
<td>Chroococcus dispersus</td>
<td>16</td>
<td>22</td>
<td>352</td>
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<td>19.8</td>
<td>16.2</td>
</tr>
<tr>
<td>Rhodomonas minuta</td>
<td>17</td>
<td>20</td>
<td>340</td>
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<td>17.2</td>
</tr>
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<td>48</td>
<td>14</td>
<td>672</td>
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</tbody>
</table>

Total Biovolume: 21467 ml

**Date: 10/02/93**

- **Width (mm):** 0.182

**Sample: 04-10**

- **Transect (mm):** 18.5
- **Vol. Filtered (ml):** 100

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<th>Species</th>
<th>Count</th>
<th>Biovolume</th>
<th>T Biovol.</th>
<th>% Biovol.</th>
<th>#/ml</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kephyrion sp.</td>
<td>1</td>
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<td>63</td>
<td>0.4</td>
<td>1.5</td>
<td>0.9</td>
</tr>
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<td>63</td>
<td>0.4</td>
<td>1.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Cyclotella comta</td>
<td>3</td>
<td>2270</td>
<td>6810</td>
<td>46.7</td>
<td>4.4</td>
<td>2.6</td>
</tr>
<tr>
<td>Cryptomonas erosa</td>
<td>11</td>
<td>520</td>
<td>5720</td>
<td>39.2</td>
<td>16.0</td>
<td>9.5</td>
</tr>
<tr>
<td>Rhodomonas minuta</td>
<td>23</td>
<td>20</td>
<td>460</td>
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<td>33.5</td>
<td>19.8</td>
</tr>
<tr>
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<td>30</td>
<td>14</td>
<td>420</td>
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<td>43.7</td>
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<td>22</td>
<td>1056</td>
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</table>

Total Biovolume: 14592 ml

**TSI= 27.0**

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<th>Date: 10/02/93</th>
<th>Depth: meta (20m)</th>
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**Sample: 04-10**

- **Transect (mm):** 18.5
- **Vol. Filtered (ml):** 100

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<th>T Biovol.</th>
<th>% Biovol.</th>
<th>#/ml</th>
<th>Percent</th>
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</thead>
<tbody>
<tr>
<td>Kephyrion sp.</td>
<td>1</td>
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<td>63</td>
<td>0.4</td>
<td>1.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Kephyrion spirale</td>
<td>1</td>
<td>63</td>
<td>63</td>
<td>0.4</td>
<td>1.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Cyclotella comta</td>
<td>3</td>
<td>2270</td>
<td>6810</td>
<td>46.7</td>
<td>4.4</td>
<td>2.6</td>
</tr>
<tr>
<td>Cryptomonas erosa</td>
<td>11</td>
<td>520</td>
<td>5720</td>
<td>39.2</td>
<td>16.0</td>
<td>9.5</td>
</tr>
<tr>
<td>Rhodomonas minuta</td>
<td>23</td>
<td>20</td>
<td>460</td>
<td>3.2</td>
<td>33.5</td>
<td>19.8</td>
</tr>
<tr>
<td>Planktosphaeria gelatinosa</td>
<td>30</td>
<td>14</td>
<td>420</td>
<td>2.9</td>
<td>43.7</td>
<td>25.9</td>
</tr>
<tr>
<td>Chroococcus dispersus</td>
<td>48</td>
<td>22</td>
<td>1056</td>
<td>7.2</td>
<td>70.0</td>
<td>41.4</td>
</tr>
</tbody>
</table>

Total Biovolume: 14592 ml

**TSI= 23.9**
### Lake: Coldwater
- **Date:** 10/02/93
- **Depth:** hypo (40m)

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<thead>
<tr>
<th>Sample</th>
<th>Transect (mm)</th>
<th>Width (mm)</th>
<th>Area (mm²)</th>
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</thead>
<tbody>
<tr>
<td>04-11</td>
<td>90.7</td>
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</tr>
<tr>
<td>04-12</td>
<td>127.9</td>
<td>0.182</td>
<td>23.3</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Species</th>
<th>Count</th>
<th>Biovolume</th>
<th>T Biovol.</th>
<th>% Biovol.</th>
<th>#/ml</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achnanthes minutissima</td>
<td>1</td>
<td>50</td>
<td>50</td>
<td>0.2</td>
<td>0.3</td>
<td>1.1</td>
</tr>
<tr>
<td>Cymbella minuta</td>
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<td>370</td>
<td>370</td>
<td>1.4</td>
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<td>1.1</td>
</tr>
<tr>
<td>Kephyrion sp.</td>
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<td>63</td>
<td>63</td>
<td>0.2</td>
<td>0.3</td>
<td>1.1</td>
</tr>
<tr>
<td>Tabellaria flocculosa</td>
<td>1</td>
<td>590</td>
<td>590</td>
<td>2.2</td>
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<td>1.1</td>
</tr>
<tr>
<td>Chroococcus dispersus</td>
<td>8</td>
<td>22</td>
<td>176</td>
<td>0.7</td>
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<td>8.9</td>
</tr>
<tr>
<td>Cryptomonas erosa</td>
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<td>520</td>
<td>4160</td>
<td>15.5</td>
<td>2.4</td>
<td>8.9</td>
</tr>
<tr>
<td>Cyclotella comta</td>
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<td>20430</td>
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<td>77.8</td>
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<tr>
<td></td>
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<td>26819</td>
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</table>

**TSI= 28.9**

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### Lake: Coldwater
- **Date:** 10/02/93
- **Depth:** hypo (40m)

<table>
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<tr>
<th>Sample</th>
<th>Transect (mm)</th>
<th>Width (mm)</th>
<th>Area (mm²)</th>
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</thead>
<tbody>
<tr>
<td>04-12</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Species</th>
<th>Count</th>
<th>Biovolume</th>
<th>T Biovol.</th>
<th>% Biovol.</th>
<th>#/ml</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
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<td>63</td>
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<td>0.2</td>
<td>1.0</td>
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<td>0.4</td>
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<tr>
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<td>22</td>
<td>176</td>
<td>0.6</td>
<td>1.7</td>
<td>8.2</td>
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<tr>
<td>Cyclotella comta</td>
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<td>2270</td>
<td>18160</td>
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</tr>
<tr>
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**TSI= 29.9**
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<th>T Biovol</th>
<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
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<td>441</td>
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<td>53.9</td>
<td>4.1</td>
</tr>
<tr>
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<td>1386</td>
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</tr>
<tr>
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<td>1932</td>
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</table>

TSI = 19.5
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<th>#/ml</th>
<th>percent</th>
</tr>
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<tbody>
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<td>85</td>
<td>4.5</td>
<td>0.8</td>
</tr>
<tr>
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<td>520</td>
<td>4.5</td>
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</tr>
<tr>
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<td>1</td>
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<td>2270</td>
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<tr>
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Lake: Coldwater  
Date: 8/4/93  
Depth: epi (1m)  
Site1

<table>
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<th>% Biovol.</th>
<th>#/ml</th>
<th>percent</th>
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<tbody>
<tr>
<td>Kephyrion spirale</td>
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<td>63</td>
<td>5.2</td>
<td>0.5</td>
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<tr>
<td>Cryptomonas erosa</td>
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<td>520</td>
<td>1040</td>
<td>10.4</td>
<td>0.9</td>
</tr>
<tr>
<td>Crucigenia quadrata</td>
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<td>85</td>
<td>340</td>
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<tr>
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<td>Depth: meta (9m)</td>
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<tr>
<td>-----------------</td>
<td>--------------</td>
<td>------------------</td>
<td></td>
<td></td>
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</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>transect (mm): 4.3</td>
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</tr>
<tr>
<td>vol. filtered: (ml) 100</td>
<td></td>
<td>area (mm2): 0.8</td>
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<table>
<thead>
<tr>
<th>Species</th>
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<th>Biovolume</th>
<th>T Biovol.</th>
<th>% Biovol.</th>
<th>#/ml</th>
<th>percent</th>
</tr>
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<tbody>
<tr>
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<td>50</td>
<td>0.7</td>
<td>6.3</td>
<td>0.7</td>
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<tr>
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<td>1990</td>
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<td>0.7</td>
</tr>
<tr>
<td>Kephyrion spirale</td>
<td>4</td>
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<td>252</td>
<td>3.6</td>
<td>25.1</td>
<td>2.6</td>
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<tr>
<td>Dinobryon sp.</td>
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TSI = 18.0

<table>
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<tr>
<th>Lake: Coldwater</th>
<th>Date: 8/4/93</th>
<th>Depth: meta (9m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>sample: 04-17</td>
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<td>Site1</td>
</tr>
<tr>
<td>transect (mm): 6.5</td>
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<tr>
<td>vol. filtered: (ml) 100</td>
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<td>area (mm2): 1.2</td>
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<table>
<thead>
<tr>
<th>Species</th>
<th>count</th>
<th>Biovolume</th>
<th>T Biovol.</th>
<th>% Biovol.</th>
<th>#/ml</th>
<th>percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kephyrion sp.</td>
<td>4</td>
<td>63</td>
<td>252</td>
<td>1.1</td>
<td>16.6</td>
<td>2.4</td>
</tr>
<tr>
<td>Dinobryon sp.</td>
<td>6</td>
<td>125</td>
<td>750</td>
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<td>24.9</td>
<td>3.6</td>
</tr>
<tr>
<td>Cyclotella comta</td>
<td>9</td>
<td>2270</td>
<td>20430</td>
<td>85.7</td>
<td>37.3</td>
<td>5.4</td>
</tr>
<tr>
<td>Chroococcus dispersus</td>
<td>22</td>
<td>22</td>
<td>484</td>
<td>2.0</td>
<td>91.3</td>
<td>13.1</td>
</tr>
<tr>
<td>Rhodomonas minuta</td>
<td>25</td>
<td>20</td>
<td>500</td>
<td>2.1</td>
<td>103.7</td>
<td>14.9</td>
</tr>
<tr>
<td>Planktosphaeria gelatinosa</td>
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<td>14</td>
<td>1428</td>
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<th>% Biovol.</th>
<th>#/ml</th>
<th>percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryptomonas erosa</td>
<td>3</td>
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<td>1.6</td>
<td>27.3</td>
</tr>
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<td>Rhodomonas minuta</td>
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<td>20</td>
<td>60</td>
<td>0.5</td>
<td>1.6</td>
<td>27.3</td>
</tr>
<tr>
<td>Cyclotella comta</td>
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<td>2270</td>
<td>11350</td>
<td>87.5</td>
<td>2.7</td>
<td>45.5</td>
</tr>
<tr>
<td></td>
<td>11</td>
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</tr>
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TSI = 22.9
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<th>T Biovol.</th>
<th>% Biovol.</th>
<th>#/ml</th>
<th>percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achnanthes minutissima</td>
<td>1</td>
<td>50</td>
<td>50</td>
<td>0.5</td>
<td>5.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Cryptomonas erosa</td>
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<td>520</td>
<td>5.4</td>
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<td>0.6</td>
</tr>
<tr>
<td>Cyclotella comta</td>
<td>1</td>
<td>2270</td>
<td>2270</td>
<td>23.7</td>
<td>5.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Dinobryon sp.</td>
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<td>125</td>
<td>1.3</td>
<td>5.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Kephyrion spirale</td>
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<td>63</td>
<td>0.7</td>
<td>5.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Planktosphaeria gelatinosa</td>
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<td>14</td>
<td>924</td>
<td>9.7</td>
<td>378.8</td>
<td>41.3</td>
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<td>Kephyrion sp.</td>
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<td>9559</td>
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TSI= 20.5

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<th>#/ml</th>
<th>percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryptomonas erosa</td>
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<td>5.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Kephyrion spirale</td>
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<td>63</td>
<td>63</td>
<td>0.9</td>
<td>5.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Chroococcus dispersus</td>
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<td>22</td>
<td>176</td>
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<td>40.0</td>
<td>3.8</td>
</tr>
<tr>
<td>Kephyrion sp.</td>
<td>67</td>
<td>63</td>
<td>4221</td>
<td>61.8</td>
<td>334.7</td>
<td>32.1</td>
</tr>
<tr>
<td>Planktosphaeria gelatinosa</td>
<td>132</td>
<td>14</td>
<td>1848</td>
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<td>659.3</td>
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<tr>
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TSI= 17.9
Lake: Coldwater  
Sample: 04-22  
Transect (mm): 5.6  
Vol. filtered: (ml) 100  

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<tr>
<th>Species</th>
<th>Count</th>
<th>Biovolume</th>
<th>T Biovol.</th>
<th>% Biovol.</th>
<th>#/ml</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryptomonas erosa</td>
<td>2</td>
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<td>9.6</td>
<td>1.5</td>
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<td>375</td>
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<td>14.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Kephyrion sp.</td>
<td>3</td>
<td>63</td>
<td>189</td>
<td>1.3</td>
<td>14.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Cyclotella comta</td>
<td>4</td>
<td>2270</td>
<td>9080</td>
<td>62.8</td>
<td>19.3</td>
<td>3.1</td>
</tr>
<tr>
<td>Quadrugula lacustris</td>
<td>4</td>
<td>30</td>
<td>120</td>
<td>0.8</td>
<td>19.3</td>
<td>3.1</td>
</tr>
<tr>
<td>Gloecystis sp.</td>
<td>8</td>
<td>260</td>
<td>2080</td>
<td>14.4</td>
<td>38.5</td>
<td>6.2</td>
</tr>
<tr>
<td>Rhodomonas minuta</td>
<td>14</td>
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<td>280</td>
<td>1.9</td>
<td>67.4</td>
<td>10.8</td>
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<td>Planktosphaeria gelatinosa</td>
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<td>1288</td>
<td>14452</td>
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<td>70.8</td>
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</table>

TSI = 23.8

Lake: Coldwater  
Sample: 04-23  
Transect (mm): 6.5  
Vol. filtered: (ml) 100  

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<tr>
<th>Species</th>
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<th>T Biovol.</th>
<th>% Biovol.</th>
<th>#/ml</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achnanthes minutissima</td>
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<td>4.8</td>
<td>8.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Kephyrion sp.</td>
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<td>63</td>
<td>315</td>
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<td>20.7</td>
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</tr>
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<td>2270</td>
<td>29510</td>
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<td>20</td>
<td>380</td>
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<td>78.8</td>
<td>11.9</td>
</tr>
<tr>
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TSI = 30.4
### Lake: Coldwater

#### Date: 8/4/93

**Depth:** hypo (35m)

**Site:** 2

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<th>T Biovol.</th>
<th>% Biovol.</th>
<th>#/ml</th>
<th>percent</th>
</tr>
</thead>
<tbody>
<tr>
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<td>300</td>
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<td>2.0</td>
</tr>
<tr>
<td>Cyclotella comta</td>
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<td>2270</td>
<td>4540</td>
<td>41.8</td>
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<td>4.0</td>
</tr>
<tr>
<td>Kephyrion sp.</td>
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<td>63</td>
<td>189</td>
<td>1.7</td>
<td>1.5</td>
<td>6.0</td>
</tr>
<tr>
<td>Planktosphaeria gelatinosa</td>
<td>7</td>
<td>14</td>
<td>98</td>
<td>0.9</td>
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<td>14.0</td>
</tr>
<tr>
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<td>520</td>
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<td>20.0</td>
</tr>
<tr>
<td>Rhodomonas minuta</td>
<td>27</td>
<td>20</td>
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<td>5.0</td>
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<tr>
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TSI = 21.5

**Lake: Coldwater**

#### Date: 8/4/93

**Depth:** hypo (35m)

**Site:** 2

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<th>T Biovol.</th>
<th>% Biovol.</th>
<th>#/ml</th>
<th>percent</th>
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<tr>
<td>Navicula sp.</td>
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<tr>
<td>Kephyrion sp.</td>
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</tr>
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<td>11350</td>
<td>67.1</td>
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<td>10.0</td>
</tr>
<tr>
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<td>4680</td>
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<td>18.0</td>
</tr>
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<td>14</td>
<td>126</td>
<td>0.7</td>
<td>4.7</td>
<td>18.0</td>
</tr>
<tr>
<td>Rhodomonas minuta</td>
<td>24</td>
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TSI = 25.1
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<th>Depth: 4M</th>
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<td>vol. filtered: (ml):</td>
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</tbody>
</table>

<table>
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<tr>
<th>Species</th>
<th>count</th>
<th>Biovolume</th>
<th>T Biovol</th>
<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navicula sp.</td>
<td>1</td>
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<td>4.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Kephyrion sp.</td>
<td>22</td>
<td>63</td>
<td>1386</td>
<td>21.2</td>
<td>91.3</td>
<td>11.6</td>
</tr>
<tr>
<td>Dinobryon sp.</td>
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<td>45.9</td>
<td>99.6</td>
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TSI= 17.5

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<th>Depth: 15M</th>
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<td>vol. filtered: (ml):</td>
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</tr>
</tbody>
</table>

<table>
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<tr>
<th>Species</th>
<th>count</th>
<th>Biovolume</th>
<th>T Biovol</th>
<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
</tr>
</thead>
<tbody>
<tr>
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<td>63</td>
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<td>1.5</td>
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<tr>
<td>Kephyrion sp.</td>
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<td>63</td>
<td>189</td>
<td>0.5</td>
<td>4.8</td>
<td>3.6</td>
</tr>
<tr>
<td>Cryptomonas erosa</td>
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<td>7.7</td>
<td>6.0</td>
</tr>
<tr>
<td>Rhodomonas minuta</td>
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<td>280</td>
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<td>21.6</td>
<td>16.7</td>
</tr>
<tr>
<td>Cyclotella corna</td>
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<td>2270</td>
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<td>17.9</td>
</tr>
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<td>14</td>
<td>644</td>
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TSI= 31.8
Lake: Coldwater  Date: 10/9/92  Depth: 1M
sample: 04-28  transect (mm): 17.5  width (mm): 0.182  area (mm²): 3.2
vol. filtered: (ml) 100

<table>
<thead>
<tr>
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<th>Biovolume</th>
<th>T Biovol</th>
<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
</tr>
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<tbody>
<tr>
<td>Achnanthes linearis</td>
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<td>132</td>
<td>0.4</td>
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<td>0.9</td>
</tr>
<tr>
<td>Navicula sp.</td>
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<td>150</td>
<td>150</td>
<td>0.4</td>
<td>1.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Kephyrion spirale</td>
<td>2</td>
<td>63</td>
<td>126</td>
<td>0.3</td>
<td>3.1</td>
<td>1.9</td>
</tr>
<tr>
<td>Navicula rhynchocephala</td>
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<td>295</td>
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<td>3.1</td>
<td>1.9</td>
</tr>
<tr>
<td>Quadrigula lacustris</td>
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<td>30</td>
<td>90</td>
<td>0.2</td>
<td>4.6</td>
<td>2.8</td>
</tr>
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<td>Fragilarias sp.</td>
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<td>12.3</td>
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<td>63</td>
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<td>11.3</td>
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</tr>
<tr>
<td>Rhodomonas minuta</td>
<td>19</td>
<td>20</td>
<td>380</td>
<td>1.0</td>
<td>29.3</td>
<td>17.9</td>
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Depth: epi (1m)  
Sample: 04-31  
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Width (mm): 0.182  
Area (mm2): 4.1  
Vol. filtered: (ml) 100

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Date: 3/24/93  
Depth: epi (1m)  
Site2

Sample: 04-34  
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Width (mm): 0.182  
Area (mm2): 2.6  
Volume filtered: 100 ml

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sample: 04-36  Site2
transect (mm): 12.6  width (mm): 0.182  area (mm2): 2.3
vol. filtered: (ml) 100

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Phytoplankton Data Sheets for

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Date: 10/11/92  
Depth: 1M  
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transect (mm): 27.9  
vol. filtered: (ml) 100  

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Depth: epi (1m)

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vol. filtered: (ml) 100  
width (mm): 0.182  
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Date: 8/5/93

width (mm): 0.182

Biovol. % Biovol. #/ml percent

Depth: meta (10m)

area (mm²): 3.2

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Depth: productivity  

sample: 05-16  
transect (mm): 3.8  
vol. filtered: (ml) 100  

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TSI= 24.1
Phytoplankton Data Sheets for

Hanaford Lake
Lake: Hanaford
Sample: 06-01
Transect (mm): 31.5
Vol. filtered: (ml) 100

Species count

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Lake: Hanaford  
Date: 10/11/92  
Depth: meta (8m)

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Sample: 06-03  
Transect (mm): 9.8  
Vol. Filtered (ml): 100

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Depth: epi (1m)

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width (mm): 0.182
area (mm2): 3.2

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Date: 8/5/93
Depth: hypo (14m)

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Phytoplankton Data Sheets for

June Lake
Lake: June  
sample: 07-01  
transect (mm): 24.5  
vol. filtered: (ml) 100

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Date: 9/9/93
width (mm): 0.182
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Vol. filtered: (ml) 100

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Phytoplankton Data Sheets for

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Date: 10/17/93

Depth: epi (1m)

Species count

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Sample: 09-09  Transect (mm): 7.9  Vol. filtered: (ml) 100

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Sample: 09-10  Transect (mm): 7.4  Vol. filtered: (ml) 100

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Biovolume #/ml percent

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TSI= 33.0

Date: 9/8/93

width (mm): 0.182

area (mm²) 2.5
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<th>% Biovol</th>
<th>#/ml</th>
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TSI = 35.5
Lake: Menill  
Sample: 09-20  
Transect (mm): 16.1  
Vol. filtered: (ml) 100

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<th>% Biovol</th>
<th>#/ml</th>
<th>Percent</th>
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25 50 0.1 3.4 1.8
54 108 0.2 3.4 1.8
125 375 0.8 5.0 2.7
30 120 0.2 6.7 3.5
180 1080 2.2 10.1 5.3
20 160 0.3 13.4 7.1
20 180 0.4 15.1 8.0
1000 10000 20.6 16.8 8.8
2270 29510 60.8 21.8 11.5
308 4312 8.9 23.5 12.4
63 2646 5.5 70.4 37.2
113 48541 189.3  

TSI= 33.9
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TSI= 38.0
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Lake: Merrill
sample: 09-34
transect (mm): 13.3
vol. filtered: (ml) 100

Species count Biovolume T Biovol % Biovol #/ml percent

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Phytoplankton Data Sheets for

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TSI= 19.6

Lake: Meta Date: 10/9/93 Depth: epi (1m)
sample: 10-11
transect (mm): 2
vol. filtered: (ml) 100

<table>
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<th>% Biovol</th>
<th>#/ml</th>
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<tbody>
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TSI= 24.7
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Phytoplankton Data Sheets for

Panhandle Lake
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<th>T Biovol</th>
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TSI= 37.1

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<th>T Biovol</th>
<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
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TSI= 37.8
### Lake: Panhandle
#### sample: 11-06
- transect (mm): 22.5
- vol. filtered: (ml) 100

#### Species count
- **Cryptomonas erosa**: 1
- **Kephyrion sp.**: 1
- **Cyclotella stelligera**: 6
- **Glenodinium sp.**: 6
- **Fragilaria crotonensis**: 49
- **Dinobryon sp.**: 113

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<tr>
<th>Species</th>
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<th>T Biovol</th>
<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
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<tr>
<td>Cryptomonas erosa</td>
<td>1</td>
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Date: 8/14/93

#### Biovolume T Biovol % Biovol #/ml percent
- 520 520 1.0 1.2 0.9
- 63 63 0.1 1.2 0.9
- 55 330 0.6 7.2 5.3
- 700 4200 8.0 7.2 5.3
- 840 41160 78.4 58.7 43.4
- 125 6250 11.9 59.9 44.2

**TSI = 34.6**

#### Lake: Panhandle
#### sample: 11-07
- transect (mm): 23.7
- vol. filtered: (ml) 100

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<th>#/ml</th>
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<td>55</td>
<td>0.1</td>
<td>1.1</td>
<td>0.9</td>
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<td>700</td>
<td>700</td>
<td>1.7</td>
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<td>0.9</td>
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<td>840</td>
<td>32760</td>
<td>78.7</td>
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<td>36.8</td>
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<tr>
<td>Dinobryon sp.</td>
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Date: 8/14/93

#### Biovolume T Biovol % Biovol #/ml percent
- 55 55 0.1 1.1 0.9
- 700 700 1.7 1.1 0.9
- 840 32760 78.7 44.4 36.8
- 125 8125 19.5 74.0 61.3

**TSI = 32.6**

Date: 8/14/93

#### Depth: meta (10m)
- area (mm2): 4.1

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<th>#/ml</th>
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**TSI = 32.6**
### Lake: Panhandle

**Sample**: 11-08  
**Transsect (mm)**: 2  
**Vol. Filtered (ml)**: 50

<table>
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<tr>
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<th>Count</th>
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<th>T Biovol</th>
<th>% Biovol</th>
<th>#/ml</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fragilaria crotonensis</td>
<td>19</td>
<td>840</td>
<td>15980</td>
<td>38.5</td>
<td>512.5</td>
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</tr>
<tr>
<td>Cryptomonas erosa</td>
<td>31</td>
<td>520</td>
<td>16120</td>
<td>38.9</td>
<td>836.1</td>
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<tr>
<td>Dinobryon sp.</td>
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**TSI**: 32.6

### Lake: Panhandle

**Sample**: 11-09  
**Transsect (mm)**: 1.8  
**Vol. Filtered (ml)**: 50

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<th>% Biovol</th>
<th>#/ml</th>
<th>Percent</th>
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<tbody>
<tr>
<td>Synedra rumpens</td>
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<td>1120</td>
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<td>Cryptomonas erosa</td>
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**TSI**: 29.0
Phytoplankton Data Sheets for

Ryan Lake
### Lake: Ryan

**Date:** 6/17/93

**Depth:** epi (1m)

**transect (mm):** 4.8

**vol. filtered: (ml)** 100

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<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
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<tbody>
<tr>
<td>Cryptomonas erosa</td>
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<tr>
<td>Cymbella minuta</td>
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<tr>
<td>Navicula cryptcephala</td>
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<td>0.8</td>
</tr>
<tr>
<td>Achnanthes minutissima</td>
<td>3</td>
<td>50</td>
<td>150</td>
<td>3.3</td>
<td>16.9</td>
<td>2.5</td>
</tr>
<tr>
<td>Crucigenia quadrata</td>
<td>4</td>
<td>85</td>
<td>340</td>
<td>7.5</td>
<td>22.5</td>
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<tr>
<td>Kephyrion sp.</td>
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<td>5.9</td>
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**TSI=** 14.9

### Lake: Ryan

**Date:** 6/17/93

**Depth:** meta (4m)

**transect (mm):** 2.9

**vol. filtered: (ml)** 100

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<td>150</td>
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<td>27.9</td>
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<tr>
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**TSI=** 18.2
Lake: Ryan  
Date: 6/17/93  
Depth: hypo (6m)

sample: 12-03  
transect (mm): 2  
vol. filtered: (ml) 50

width (mm): 0.182  
area (mm2) 0.4

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<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
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<tbody>
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<td>Crucigenia fenestrata</td>
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TSI= 15.1

N-0
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<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
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<td>0.4</td>
<td>5.6</td>
<td>4.0</td>
</tr>
<tr>
<td>Cryptomonas erosa</td>
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<td>520</td>
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**TSI= 29.0**

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<th>#/ml</th>
<th>percent</th>
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<td>325</td>
<td>1.2</td>
<td>1.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Achnanthes minutissima</td>
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<td>50</td>
<td>150</td>
<td>0.6</td>
<td>3.6</td>
<td>2.9</td>
</tr>
<tr>
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<td>100</td>
<td>0.4</td>
<td>4.8</td>
<td>3.8</td>
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<tr>
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**TSI= 28.7**
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<td>1.9</td>
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<td>Dinobryon sp.</td>
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<td>2.1</td>
<td>1.9</td>
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<tr>
<td>Cryptomonas erosa</td>
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<td>20800</td>
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TSI = 33.2

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<td>2.0</td>
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<tr>
<td>Cryptomonas erosa</td>
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<td>23920</td>
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TSI = 29.1
Lake: Ryan  
Date: 8/24/93  
Depth: hypo (6m)  

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<table>
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<table>
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<th>Species</th>
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<th>Biovolume</th>
<th>T Biovol</th>
<th>% Biovol</th>
<th>#/ml</th>
<th>Percent</th>
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<tbody>
<tr>
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<td>Cymbella minuta</td>
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<td>0.9</td>
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<tr>
<td>Navicula rhychocephala</td>
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<td>0.9</td>
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<td>180</td>
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<td>175</td>
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<td>1.6</td>
<td>0.9</td>
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<td>Navicula radiosa</td>
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<td>325</td>
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<td>1.8</td>
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<td>Achnanthes minutissima</td>
<td>5</td>
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<td>4.5</td>
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| Total Biovolume: | 61854 | TSI= | 36.0 |

Lake: Ryan  
Date: 8/24/93  
Depth: hypo (6m)  

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<tr>
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<th>Width (mm):</th>
<th>Area (mm²):</th>
<th>Vol. Filtered (ml):</th>
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<tbody>
<tr>
<td>34.1</td>
<td>0.182</td>
<td>6.2</td>
<td>50</td>
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<th>Area (mm²):</th>
<th>Vol. Filtered (ml):</th>
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<th>T Biovol</th>
<th>% Biovol</th>
<th>#/ml</th>
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| Total Biovolume: | 72018 | TSI= | 37.3 |

213
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<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
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<td>Achnanthes minutissima</td>
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| Total                   | 91    | 16247     | 206.3    |          |      |         |

TSI= 24.7

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<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
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<td>0.1</td>
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<td>11960</td>
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| Total                   | 115   | 22237     | 202.7    |          |      |         |

TSI= 27.3
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<th>#/ml</th>
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<td>0.9</td>
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<td>11960</td>
<td>50.1</td>
<td>48.1</td>
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<td>63</td>
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<th>Depth: hypo (6m)</th>
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<td>vol. filtered: (ml)</td>
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<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
</tr>
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<td>1.0</td>
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<td>185</td>
<td>1.3</td>
<td>3.2</td>
<td>1.0</td>
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<th>T Biovol</th>
<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
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<tr>
<td>Nitzschia palea</td>
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<td>180</td>
<td>0.9</td>
<td>2.6</td>
<td>0.9</td>
</tr>
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<td>50</td>
<td>0.2</td>
<td>5.2</td>
<td>1.8</td>
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<td>1.8</td>
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<td>1700</td>
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TSI= 26.8
Phytoplankton Data Sheets for

Spirit Lake
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<th>#/ml</th>
<th>percent</th>
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<td>0.6</td>
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<tr>
<td>Kephyrion spirale</td>
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<td>63</td>
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<td>96</td>
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<tr>
<td>Nitzschia palea</td>
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<td>180</td>
<td>0.1</td>
<td>0.9</td>
<td>0.6</td>
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<td>0.6</td>
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<td>Asterionella formosa</td>
<td>220</td>
<td>440</td>
<td>0.3</td>
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<td>1.2</td>
</tr>
<tr>
<td>Gomphonema olivaceium</td>
<td>225</td>
<td>450</td>
<td>0.3</td>
<td>1.8</td>
<td>1.2</td>
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<tr>
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<td>27</td>
<td>54</td>
<td>0.0</td>
<td>1.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Navicula minima</td>
<td>44</td>
<td>132</td>
<td>0.1</td>
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<td>1.8</td>
</tr>
<tr>
<td>Achnanthes minutissima</td>
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TSI = 43.0
Lake: Spirit  
Date: Sum '93  
Depth: epi (1m)  

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<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
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<td>295</td>
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<td>0.6</td>
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<tr>
<td>Nitzschia palea</td>
<td>1</td>
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<td>180</td>
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<td>0.8</td>
<td>0.6</td>
</tr>
<tr>
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<td>520</td>
<td>1040</td>
<td>0.9</td>
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<td>1.3</td>
</tr>
<tr>
<td>Achnanthes minutissima</td>
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<td>1.9</td>
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<td>Asterionella formosa</td>
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<td>660</td>
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<td>1.9</td>
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<td>44</td>
<td>132</td>
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<td>1.9</td>
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TSI= 41.2
Phytoplankton Data Sheets for

St. Helens Lake
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<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryptomonas erosa</td>
<td>2</td>
<td>520</td>
<td>1040</td>
<td>13.7</td>
<td>3.1</td>
<td>1.8</td>
</tr>
<tr>
<td>Crucigenia quadrata</td>
<td>3</td>
<td>85</td>
<td>255</td>
<td>3.4</td>
<td>4.7</td>
<td>2.8</td>
</tr>
<tr>
<td>Rhodomonas minuta</td>
<td>3</td>
<td>20</td>
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TSI= 18.7

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Lake: St. Helens
Date: 9/92
Depth: hypo

Sample: 14-03
Transect (mm): 52.2
Vol. Filtered: (ml) 100
Width (mm): 0.182
Area (mm2): 9.5

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Lake: St. Helens  
Sample: 14-04  
Transect (mm): 12.5  
Vol. filtered: (ml) 100  

Date: 8/10/93  
Depth: epi (1m)  
Width (mm): 0.182  
Area (mm2): 2.3

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TSI: 12.1

Lake: St. Helens  
Sample: 14-05  
Transect (mm): 7  
Vol. filtered: (ml) 100  

Date: 8/10/93  
Depth: epi (1m)  
Width (mm): 0.182  
Area (mm2): 1.3

TSI: 10.9
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TSI= 16.2

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TSI= 14.2
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sample: 14-03
transect (mm): 54.1
vol. filtered: (ml) 100

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TSI = 16.1
Phytoplankton Data Sheets for

Venus Lake
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TSI= 16.9
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**TSI= 10.8**

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sample: 15-06
transect (mm): 28.8
vol. filtered: (ml) 100

Species count Biovolume T Biovol % Biovol #/ml percent
Cyclotella stelligera 1 55 55 0.6 0.9 0.9
Oocystis pusilla 2 54 108 1.2 1.9 1.8
Crucigenia quadrata 4 85 340 3.8 3.7 3.6
Ankistrodesmus falcatus 8 25 200 2.3 7.5 7.2
Crucigenia fenestrata 96 85 8160 92.1 89.9 86.5
111 8863 103.9

Date: 8/10/93

Biovolume T Biovol % Biovol #/ml percent
55 55 0.6 0.9 0.9
54 108 1.2 1.9 1.8
85 340 3.8 3.7 3.6
25 200 2.3 7.5 7.2
85 8160 92.1 89.9 86.5
8863 103.9

TSI= 19.9

Lake: Venus
sample: 15-07
transect (mm): 22.9
vol. filtered: (ml) 100

Species count Biovolume T Biovol % Biovol #/ml percent
Ankistrodesmus falcatus 45 25 1125 17.1 53.0 41.3
Crucigenia fenestrata 64 85 5440 82.9 75.4 58.7
109 6565 128.4

Date: 8/10/93

TSI= 17.6

Depth: meta (12m)

Area (mm2): 5.2

Biovolume T Biovol % Biovol #/ml percent
25 1125 17.1 53.0 41.3
85 5440 82.9 75.4 58.7
109 6565 128.4

TSI= 17.6

Date: 8/10/93

Width (mm): 0.182

Area (mm2): 4.2

Biovolume T Biovol % Biovol #/ml percent
25 1125 17.1 53.0 41.3
85 5440 82.9 75.4 58.7
109 6565 128.4

TSI= 17.6
### Lake: Venus

**Sample:** 15-08  
**Transsect (mm):** 14.3  
**Vol. Filtered (ml):** 100

#### Species Count and Biovolume

<table>
<thead>
<tr>
<th>Species</th>
<th>Count</th>
<th>Biovolume</th>
<th>T Biovol</th>
<th>% Biovol</th>
<th>#/ml</th>
<th>Percent</th>
</tr>
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<tbody>
<tr>
<td><em>Fragilariopsis crotonensis</em></td>
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<td>840</td>
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<td><em>Unident. pennate diatom</em></td>
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<td>0.7</td>
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<td>660</td>
<td>1.8</td>
<td>15.1</td>
<td>6.0</td>
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<td><em>Cryptomonas erosa</em></td>
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<td>520</td>
<td>33280</td>
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**Biovolume:**

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<th>#/ml</th>
<th>Percent</th>
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<tr>
<td>85</td>
<td>170</td>
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<tr>
<td>25</td>
<td>125</td>
<td>0.3</td>
<td>13.9</td>
<td>4.1</td>
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<tr>
<td>63</td>
<td>504</td>
<td>1.3</td>
<td>22.2</td>
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<tr>
<td>125</td>
<td>2000</td>
<td>5.1</td>
<td>44.5</td>
<td>13.1</td>
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<tr>
<td>55</td>
<td>1320</td>
<td>3.4</td>
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**Biovolume (ml):**

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<th>Biovolume</th>
<th>T Biovol</th>
<th>% Biovol</th>
<th>#/ml</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>520</td>
<td>34640</td>
<td>89.4</td>
<td>188.3</td>
<td>54.9</td>
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**TSI=** 31.9

### Lake: Venus

**Sample:** 15-09  
**Transsect (mm):** 9.7  
**Vol. Filtered (ml):** 100

#### Species Count and Biovolume

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<th>Count</th>
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<th>T Biovol</th>
<th>% Biovol</th>
<th>#/ml</th>
<th>Percent</th>
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</thead>
<tbody>
<tr>
<td><em>Crucigenia fenestrata</em></td>
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<td>0.4</td>
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<td>1.6</td>
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<tr>
<td><em>Ankistrodesmus falcatus</em></td>
<td>5</td>
<td>25</td>
<td>125</td>
<td>0.3</td>
<td>13.9</td>
<td>4.1</td>
</tr>
<tr>
<td><em>Kephyrion sp.</em></td>
<td>8</td>
<td>63</td>
<td>504</td>
<td>1.3</td>
<td>22.2</td>
<td>6.6</td>
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<tr>
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<td>125</td>
<td>2000</td>
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<td>44.5</td>
<td>13.1</td>
</tr>
<tr>
<td><em>Cyclotella stelligera</em></td>
<td>24</td>
<td>55</td>
<td>1320</td>
<td>3.4</td>
<td>66.7</td>
<td>19.7</td>
</tr>
<tr>
<td><em>Cryptomonas erosa</em></td>
<td>67</td>
<td>520</td>
<td>34640</td>
<td>89.4</td>
<td>188.3</td>
<td>54.9</td>
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**Biovolume:**

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<th>T Biovol</th>
<th>% Biovol</th>
<th>#/ml</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>125</td>
<td>0.3</td>
<td>13.9</td>
<td>4.1</td>
<td></td>
</tr>
<tr>
<td>63</td>
<td>504</td>
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<td>22.2</td>
<td>6.6</td>
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<td>1320</td>
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**Biovolume (ml):**

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<th>T Biovol</th>
<th>% Biovol</th>
<th>#/ml</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>520</td>
<td>34640</td>
<td>89.4</td>
<td>188.3</td>
<td>54.9</td>
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**TSI=** 32.0
Phytoplankton Data Sheets for

Quality Assurance
(Precision of the Algal Identification and Enumeration)
<table>
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<tr>
<th>Species</th>
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<th>T Biovol</th>
<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
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</thead>
<tbody>
<tr>
<td>Dinobryon sp.</td>
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<td>125</td>
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<td>Synedra rumpens</td>
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<td>140</td>
<td>140</td>
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<td>3.0</td>
<td>1.0</td>
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<td>Cryptomonas erosa</td>
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<td>520</td>
<td>1040</td>
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<td>5.9</td>
<td>1.9</td>
</tr>
<tr>
<td>Glenodinium sp.</td>
<td>6</td>
<td>700</td>
<td>4200</td>
<td>57.0</td>
<td>17.8</td>
<td>5.8</td>
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<tr>
<td>Rhodomonas minuta</td>
<td>93</td>
<td>20</td>
<td>1860</td>
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<td>275.7</td>
<td>90.3</td>
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<td></td>
<td>103</td>
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**TSI= 18.4**

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<th>T Biovol</th>
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<th>#/ml</th>
<th>percent</th>
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</thead>
<tbody>
<tr>
<td>Cryptomonas erosa</td>
<td>2</td>
<td>520</td>
<td>1040</td>
<td>2.2</td>
<td>11.2</td>
<td>1.8</td>
</tr>
<tr>
<td>Kephyrion spirale</td>
<td>6</td>
<td>63</td>
<td>378</td>
<td>0.8</td>
<td>33.7</td>
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<tr>
<td>Kephyrion sp.</td>
<td>14</td>
<td>63</td>
<td>882</td>
<td>1.9</td>
<td>78.7</td>
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<td>Dinobryon sp.</td>
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<td>125</td>
<td>5625</td>
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<tr>
<td>Fragilaria crotonensis</td>
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**TSI= 33.5**
Lake: Boot  
Sample: 02-06QA  
Transect (mm): 3.4  
Vol. filtered: (ml) 100  
Species count  Biovolume  T Biovol  % Biovol  #/ml  percent
Cryptomonas erosa 1 520 520 2.0 7.9 0.8
Synedra rumpens 1 140 140 0.5 7.9 0.8
Fragilaria crotonensis 15 640 12600 48.5 119.0 11.9
Kephyrion sp. 15 63 945 3.6 119.0 11.9
Dinobryon sp. 94 125 11750 45.3 745.7 74.6

Lake: Castle  
Sample: 03-13QA  
Transect (mm): 24.3  
Vol. filtered: (ml) 100  
Species count  Biovolume  T Biovol  % Biovol  #/ml  percent
Ochromonas sp. 1 85 85 0.9 1.1 0.8
Cryptomonas erosa 8 520 4160 43.4 8.9 6.6
Ankistrodesmus falcatus 9 25 225 2.3 10.0 7.4
Dinobryon sp. 10 125 1250 13.0 11.1 8.3
Kephyrion spirale 12 63 756 7.9 13.3 9.8
Planktosphaeria gelatin 18 14 252 2.6 20.0 14.9
Rhodomonas minuta 26 20 520 5.4 28.9 21.5
Kephyrion sp. 37 63 2331 24.3 41.1 30.6

TSI = 26.6

Date: 8/15/93  

Depth: meta (7m)  
Area (mm2) 0.6  

Lake: Castle  
Sample: 03-13QA  
Transect (mm): 24.3  
Vol. filtered: (ml) 100  
Species count  Biovolume  T Biovol  % Biovol  #/ml  percent
Ochromonas sp. 1 85 85 0.9 1.1 0.8
Cryptomonas erosa 8 520 4160 43.4 8.9 6.6
Ankistrodesmus falcatus 9 25 225 2.3 10.0 7.4
Dinobryon sp. 10 125 1250 13.0 11.1 8.3
Kephyrion spirale 12 63 756 7.9 13.3 9.8
Planktosphaeria gelatin 18 14 252 2.6 20.0 14.9
Rhodomonas minuta 26 20 520 5.4 28.9 21.5
Kephyrion sp. 37 63 2331 24.3 41.1 30.6

TSI = 20.5

Date: 9/17/93  

Depth: epi (1m)  
Area (mm2) 4.4  

Date: 8/15/93  

Depth: meta (7m)  
Area (mm2) 0.6
<table>
<thead>
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<th>Date: 9/17/93</th>
<th>Depth: meta (10m)</th>
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<tr>
<td>Species</td>
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<td>Biovolume</td>
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<tr>
<td>Kephyrion sp.</td>
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<tr>
<td>Kephyrion spirale</td>
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<tr>
<td>Ankistrodesmus falcatus</td>
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<td>Rhodomonas minuta</td>
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<td>Lake: Fawn</td>
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<td>--------------</td>
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<td>Kephyrion sp.</td>
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Lake: Fawn | Date: 10/2/93 | Depth: productivity |
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<td>Chroococcus minutus</td>
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<td>85</td>
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sample: 06-10QA
transect (mm): 26
vol. filtered: (ml) 100

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<th>T Biovol</th>
<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
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\[TSI = 18.6\]

Lake: McBride
sample: 08-04QA
transect (mm): 17.8
vol. filtered: (ml) 100

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\[TSI = 40.5\]
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TSI= 18.3

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<th>% Biovol</th>
<th>#/ml</th>
<th>percent</th>
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TSI= 13.2
Lake: Meta  
Sample: 10-02QA  
Transect (mm): 3.2  
Vol. filtered (ml): 50  

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TSI = 26.0

Lake: Ryan  
Sample: 12-03QA  
Transect (mm): 1.8  
Vol. filtered (ml): 50  

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<th>#/ml</th>
<th>Percent</th>
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<tr>
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TSI = 18.3

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Width (mm): 0.182  
Depth: meta (4m)  
Area (mm²): 0.6

Date: 6/17/93  
Width (mm): 0.182  
Depth: hypo (6m)  
Area (mm²): 0.3
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Lake: St. Helens
Date: 8/10/93
Depth: epi (1m)

Lake: St. Helens
Date: 8/10/93
Depth: meta (5m)
Appendix B

Taxonomic List of Phytoplankton for Lakes in the Mt. St. Helens Study Area
<table>
<thead>
<tr>
<th>Phylum (division)</th>
<th>Sub-phylum</th>
<th>Order</th>
<th>Family</th>
<th>Genus and species</th>
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<td>Chlorophyceae</td>
<td>Chlorococcales</td>
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<td><strong>Family</strong></td>
<td><strong>Genus and species</strong></td>
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<tr>
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<tr>
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<td></td>
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<tr>
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<td>Dinokontaes</td>
<td>Glenodiniaceae</td>
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- Quadrigula lacustris
- Chlamydomonas-like
- Melosira distans
- Achnanthes minitissima
- Achnanthes sp.
- Eunotia pectinalis minor
- Diatoma tenue
- Fragilaria crotonensis
- Navicula minima
- Navicula pectinalis minor
- Navicula radiosa
- Navicula rhynchocephala
- Navicula sp.
- Nitzschia palea
- Nitzschia sp.
- Kephyrion sp.
- Kephyrion spirale
- Dinobryon sp.
- Rhodomonas minuta
- Cryptomonas erosa
- Anabaena sp.
- Glenodinium sp.
Appendix C

Phytoplankton Data Sheets for Quality Assurance from Aquatic Analysts
## PHYTOPLANKTON SAMPLE ANALYSIS

**SAMPLE: 01-01**

**SAMPLE DATE:**

**TOTAL DENSITY (#/ml): 9**

**TOTAL BIOVOLUME (cu.μm/ml): 2168**

**TROPHIC STATE INDEX: 8.3**

**DIVERSITY INDEX: 3.41**

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*Note: ZZ01 appears at the end of the document.*
PHYTOPLANKTON SAMPLE ANALYSIS

SAMPLE: 02-05
SAMPLE DATE:
TOTAL DENSITY (#/ml): 325
TOTAL BIOVOLUME (cu.uM/ml): 63609
TROPHIC STATE INDEX: 30.1
DIVERSITY INDEX: 1.73

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PHYTOPLANKTON SAMPLE ANALYSIS

SAMPLE: 03-15

SAMPLE DATE:

TOTAL DENSITY (#/ml): 78

TOTAL BIOVOLUME (cu. um/ml): 16478

TROPHIC STATE INDEX: 20.6

DIVERSITY INDEX: 2.38

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AQUATIC ANALYSTS ZZ03
PHYTOPLANKTON SAMPLE ANALYSIS

SAMPLE: 04-08

SAMPLE DATE:

TOTAL DENSITY (#/ml): 182

TOTAL BIOVOLUME (cu. um/ml): 207522

TROPHIC STATE INDEX: 38.5

DIVERSITY INDEX: 1.77

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AQUATIC ANALYSTS ZZ04
# Phytoplankton Sample Analysis

**Sample:** 05-09  
**Sample Date:**  
**Total Density (#/ml):** 141  
**Total Biovolume (cu.um/ml):** 24840  
**Trophic State Index:** 23.5  
**Diversity Index:** 1.28

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<th>Pct</th>
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**PHYTOPLANKTON SAMPLE ANALYSIS**

**SAMPLE:** 06-12  
**SAMPLE DATE:**  
**TOTAL DENSITY (#/ml):** 441  
**TOTAL BIOVOLUME (cu.um/ml):** 133819  
**TROPHIC STATE INDEX:** 35.4  
**DIVERSITY INDEX:** 1.06

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**AQUATIC ANALYSTS**

ZZ06
**PHYTOPLANKTON SAMPLE ANALYSIS**

**SAMPLE: 07-03**

**SAMPLE DATE:**

**TOTAL DENSITY (#/ml):** 71

**TOTAL BIOVOLUME (cu.um/ml):** 22986

**TROPHIC STATE INDEX:** 22.9

**DIVERSITY INDEX:** 4.53

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**PHYTOPLANKTON SAMPLE ANALYSIS**

**SAMPLE: 08-03**

**SAMPLE DATE:**

**TOTAL DENSITY (#/ml):** 188

**TOTAL BIOVOLUME (cu.um/ml):** 65411

**TROPHIC STATE INDEX:** 30.3

**DIVERSITY INDEX:** 2.63

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### PHYTOPLANKTON SAMPLE ANALYSIS

**SAMPLE: 09-15**

**SAMPLE DATE:**

**TOTAL DENSITY (#/ml): 220**

**TOTAL BIOVOLUME (cu.uH/ml): 66059**

**TROPHIC STATE INDEX: 30.3**

**DIVERSITY INDEX: 2.37**

<table>
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<th>PCT</th>
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**AQUATIC ANALYSTS**

ZZ09
PHYTOPLANKTON SAMPLE ANALYSIS

SAMPLE: 09-16

SAMPLE DATE:

TOTAL DENSITY (#/ml): 230

TOTAL BIOVOLUME (cu.mm/ml): 76558

TROPHIC STATE INDEX: 31.4

DIVERSITY INDEX: 2.21

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PHYTOPLANKTON SAMPLE ANALYSIS

SAMPLE: 10-10
SAMPLE DATE:

TOTAL DENSITY (#/ml): 677
TOTAL BIOVOLUME (cu.um/ml): 32545
TROPHIC STATE INDEX: 25.3
DIVERSITY INDEX: 0.58

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AQUATIC ANALYSTS

ZZ11
PHYTOPLANKTON SAMPLE ANALYSIS

SAMPLE: 11-04

SAMPLE DATE:

TOTAL DENSITY (#/ml): 169
TOTAL BIOVOLUME (cu.um/ml): 53392
TROPHIC STATE INDEX: 28.8
DIVERSITY INDEX: 2.09

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<td>Cymbella minuta</td>
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<td>1346</td>
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</tr>
<tr>
<td>Hemidinium sp.</td>
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AQUATIC ANALYSTS ZZ12
PHYTOPLANKTON SAMPLE ANALYSIS

SAMPLE: 12-09

SAMPLE DATE:

TOTAL DENSITY (#/ml): 1641

TOTAL BIOVOLUME (cu.um/ml): 820388

TROPHIC STATE INDEX: 48.4

DIVERSITY INDEX: 0.45

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<tr>
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AQUATIC ANALYSTS ZZ13
### PHYTOPLANKTON SAMPLE ANALYSIS

**SAMPLE: 13-02**

**SAMPLE DATE:**

**TOTAL DENSITY ($#/ml$): 85**

**TOTAL BIOVOLUME (cu.uM/ml): 71147**

**TROPHIC STATE INDEX: 30.9**

**DIVERSITY INDEX: 2.04**

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<th>PCT</th>
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<td>1145</td>
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<td>5  Cryptomonas erosa</td>
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<td>8  Nitzschia frustulum</td>
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**PHYTOPLANKTON SAMPLE ANALYSIS**

**SAMPLE:** 14-04

**SAMPLE DATE:**

**TOTAL DENSITY (#/ml):** 157

**TOTAL BIOVOLUME (cu.um/ml):** 12441

**TROPHIC STATE INDEX:** 18.7

**DIVERSITY INDEX:** 1.97

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<td>Crucigenia quadrata</td>
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<tr>
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**AQUATIC ANALYSTS**

ZZ15
# Phytoplankton Sample Analysis

**Sample:** 15-06  
**Sample Date:**  
**Total Density (#/ml):** 113  
**Total Biovolume (cu. um/ml):** 13220  
**Trophic State Index:** 19.2  
**Diversity Index:** 3.04

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<th>PCT</th>
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<td>3 Crucigenia quadrata</td>
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<tr>
<td>9 Crucigenia crucifera</td>
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<td>1.8</td>
<td>174</td>
<td>1.3</td>
</tr>
<tr>
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<td>443</td>
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</tr>
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<td>11 Synedra rumpens</td>
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<tr>
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Aquatic Analysts: ZZ16