J.C. Headwaters, Inc.

Water Quality Monitoring of Diamond Lake for 2003

Prepared for the
Umpqua National Forest
Roseburg, Oregon

By
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A. INTRODUCTION

Diamond Lake is being monitored as part of continuing effort to document current conditions and evaluate trends in water quality. The Umpqua National Forest began monitoring water quality in Diamond Lake starting in 1992 through a memorandum of understanding with Rogue Community College. In 2003, the contract to monitor the lake was awarded to MaxDepth Aquatics, Inc. (MaxDepth). This report summarizes the data collection activities related to water quality sampling. One exception is the cyanobacterial toxin analyses of the water conducted by Wright State University for the Umpqua National Forest. The toxin data are being compiled and interpreted through arrangements with other investigators. The data reported here have been incorporated into the Access® database for Diamond Lake which has been delivered to the Umpqua National Forest. Not all of the data reported here were collected by MaxDepth staff. Some of the data reported for Secchi disk transparency were collected by others, largely by ODFW staff. The DEQ collected water quality measurements and lake temperature continuously throughout the summer. These data are included here for completeness.

B. METHODS

The field and analytical methods employed in 2003 were similar to those used in 2002 by Rogue Community College, generally with minor exceptions. Diamond Lake was sampled in the north-central area of the lake; this area tends to be at or close to the deepest area of the lake and is in close proximity to the site of the DEQ monitoring buoy. Water samples were collected with an acrylic horizontal Van Dorn sampler, placed into a Wildco HDPE mixing bucket and distributed into the various aliquots. Except for phytoplankton samples, all water samples were placed in Nalgene® bottles that had been pre-rinsed with the sample water. Samples were placed in a cooler and transported to shore where the appropriate aliquots were filtered with a Whatman GF/C glass microfibre filters. Water samples were collected at depths of 1m, 13m (~1m above the bottom), and in the thermocline, which was generally about 7m. Samples collected for analysis of water were either frozen that evening or placed in a cooler depending on the nature of the analysis.

In-Situ measurements were collected on-site using an YSI 600XLS multi-parameter probe. The YSI unit was calibrated prior to deployment, according manufacturer's recommended procedures. pH was calibrated using a two-point calibration process employing Orion or Corning brand buffers at 7.00 and 10.01. Dissolved oxygen was equilibrated to percent saturation, which at the elevation of the lake was typically about 82% saturation. Dissolved oxygen was also checked against Winkler titrations using a Hach DO kit equipped with a digital titrater. Conductivity was calibrated using a NTIS traceable conductivity standard (VWR) with a conductivity of 1009 µS/cm. ORP was

calibrated with Ricca Zobell's solution with a value of +229 mV. The YSI was lowered vertically and allowed to remain at depth for a 90-second equilibration period. Values were recorded during the decent. Duplicate measurements were recorded at two depths during the retrieval process. Secchi disk transparency was measured on the sheltered side of the boat using a standard 20cm disk.

Zooplankton samples were collected using a 1.5m long 64-micron mesh net with the opening lowered to a depth of 12m. The net has a 20cm opening and a 30 cm reduction collar. The net is equipped with a modified Wisconsin bucket. Zooplankton samples were preserved in alcohol. Zooplankton samples were analyzed by Dr. Allan Vogel, with ZP Taxonomy.

Phytoplankton samples were collected as an aliquot from the water samples and were preserved in Lugol's solution. Chlorophyll *a* samples were also obtained from the water quality sample and were preserved with magnesium bicarbonate. Phytoplankton and chlorophyll samples were shipped overnight to James Sweet, Aquatic Analysts. A summary of the sample aliquots, analytical methods, and preservation are provided in Table 1.

The DEQ deployed a thermister string with thermisters set at 1m intervals. In addition, YSI and Greenspan water quality probes were deployed at a depth of 1.5 m. We attached an Onset Stowaway (LI) light intensity logger at this same depth to record changes in light penetration associated with algal blooms. MaxDepth deployed Onset Tidbit temperature loggers at the lake outlet and at both major inlets. In addition, we installed Solinst level loggers (pressure transducers) at both the outlet and in Silent Creek. A Solinst barologger was placed indoors at the ODFW housing to provide for barometric correction on the pressure transducers.

The Forest Service and MaxDepth staff installed a Hobo® Weather Station Logger on the jetty adjacent to the north boat ramp. The instrument package, which included temperature, solar radiation (PAR), wind speed, wind direction, precipitation, and barometric pressure, was installed approximately 3.5 m above the base of the jetty.

Table 1. Analytical methods used in the Diamond Lake study.

Parameter	Laboratory	Aliquot	Preservation	Detection Limit (mg/L)	Method
TP	CCAL[a]	A	ice	0.001	SM 424C,424F
TKN	CCAL	A	freezing	0.01	SM 4500
NO_3	CCAL	A	ice	0.001	SM 418F
NH_3	CCAL	A	ice	0.010	SM 417F
PO_4	CCAL	B	ice	0.001	SM 424F
Alkalinity	CCAL	E	ice	0.2	SM 403,4c
Silica	CCAL	E	ice	0.2	Technicon 105-71 W/B
Algae	AA[c]	F	Lugol's	na	Microscope
Chlorophyll	AA	G	$Mg(HCO_3)_2$	0.1	SM 10200.1
Major Ions	USFS[d]	H	Ice	< 1 ueq/L	Ion chromatography

[a] Central Analytical Laboratory, Corvallis; Standard Methods numbers refer to 15th edition
[c] Aquatic Analysts, White Salmon, WA
[d] USDA-FS Range and Experiment Station, Ft. Collins, CO

C. RESULTS

1. **Weather Station:** Data collected at the on-site weather station for the period May 14 to October 7, 2003 are summarized in Figures 1-4. Air temperature at Diamond Lake climbed rapidly in May, stabilized in June, increased again through July before cooling rapidly in August. Although temperatures recovered at the start of September, they declined rapidly in mid-September with the third rain event (over 1mm) of the season. Photosynthetically active radiation (PAR) exhibited moderately high values from May through August, with brief declines associated with rain and cloud cover. Average wind speed appeared to be lowest from the end of May through the early part of June. Wind speed reached a maximum at the end of June and the first of July, but declined through July. Wind speed increased through much of August and appeared to decline sharply in mid-September. One of the difficulties in interpreting the results of the wind speed sensor is associated with several periods where the instrument operation was hampered by entwined fishing line from errant casts. The sensor was checked periodically, but it is unclear if the anemometer was slightly interfered with as a result of the repeated disruptions. Wind speed generally increased starting at about 1030 hr and declined by about 1700 hr. The gentle sustained breezes were more commonly derived from the NE, whereas the stronger winds were primarily from the NW and secondarily from the south.

The rate of evaporation from Diamond Lake was calculated using the data from the Diamond Lake weather station and supplemented by relative humidity data from the nearby RAWS site at Cinnamon Butte. The calculated evaporation rate (using the Penman equation) was 402 mm (15.8 in) for the period May 15 to October 6. This estimate was generated using the PAR measurements for solar radiation. Substituting the solar radiation measurements from the RAWS site resulted in a calculated evaporation amount of 397 mm (15.6 in), which is only a 1.4 percent difference in estimates.

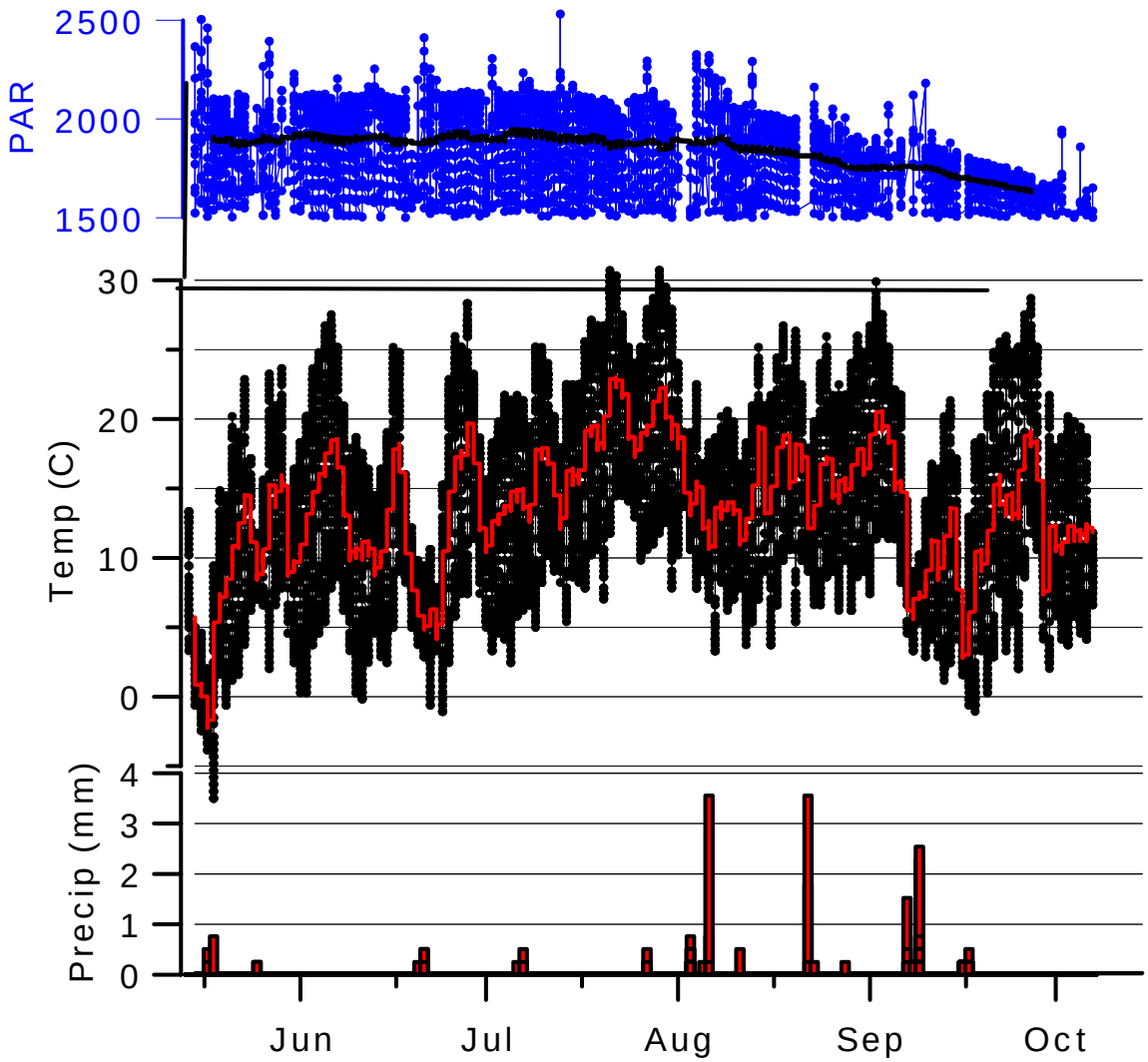


Figure 1. Precipitation, air temperature, and photosynthetically active radiation (PAR) for the weather station at Diamond Lake from June to October, 2003. The plots for PAR and temperature show the distribution of observations and the running average values superimposed over the data. The PAR plot has been truncated at 1500 umol/m^2/sec.

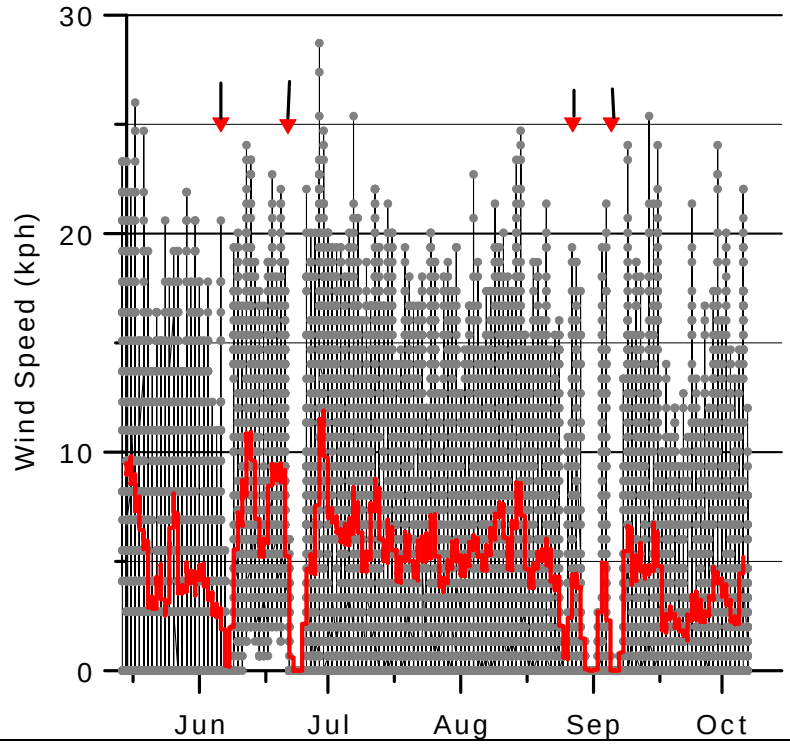


Figure 2. Average wind speed measured at Diamond Lake from May to October, 2003. The running average fit is superimposed over the observations. The arrows identify periods when operation of the wind speed sensor was impaired by fishing line from errant casts.

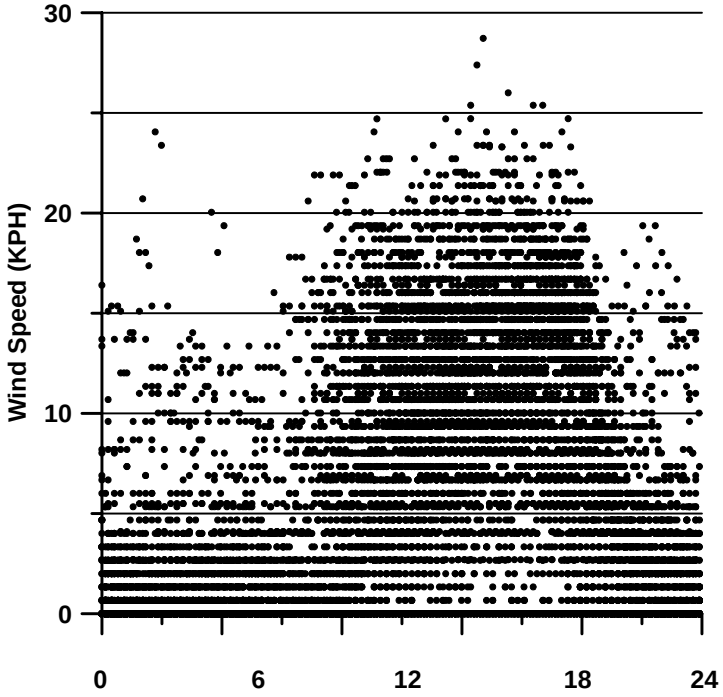


Figure 3. Average wind speed measured at Diamond Lake from May to October versus time (24 hr).

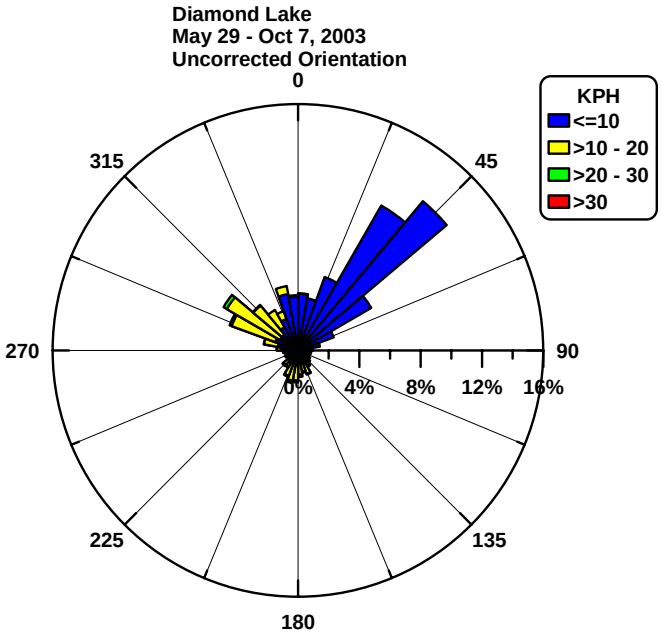


Figure 4. Wind rose data at Diamond Lake for the study period.

2. **<u>Water Temperature:</u>** Water temperatures for the two principle surface inlets and the outlet from Diamond Lake are shown in Figure 5. The temperature at the outlet is slightly warmer than the lake surface temperature, indicating some additional warming in the shallow north end of the lake as the water flows to the Lake Creek outlet. Silent Creek and Short Creek are very cold, spring-fed streams. Because of the greater length of Silent Creek, there is some opportunity for warming to occur before it discharges Diamond Lake. However, the travel time is so brief in Short Creek (several minutes) that the stream has little opportunity to warm prior to discharging into the lake. Lake temperatures had begun warming by the time the thermister string had been installed (Figure 6). June was relatively cool, but July showed steady heating through the month and a rapid onset of a thermocline (Figures 7 and 8). Despite the development of a thermocline, hypolimnetic temperatures continued to increase through July and August, illustrating the moderately high degree of mixing occurring in the lake. The thermocline generally occurred at a depth range of 6 to 8 m in July, although the thermocline formation was not as pronounced as other Oregon lakes at lower elevation or greater depth. By early August, the thermocline had deepened and this trend continued until the lake fully mixed in mid-September. By late on September 16, the temperature at all depths was 16.15 C (+/- 0.15 C, the error of the instrument). Some minor stratification developed about 10 days later with the return of warmer weather, but by early October, the lake was once again fully mixed.

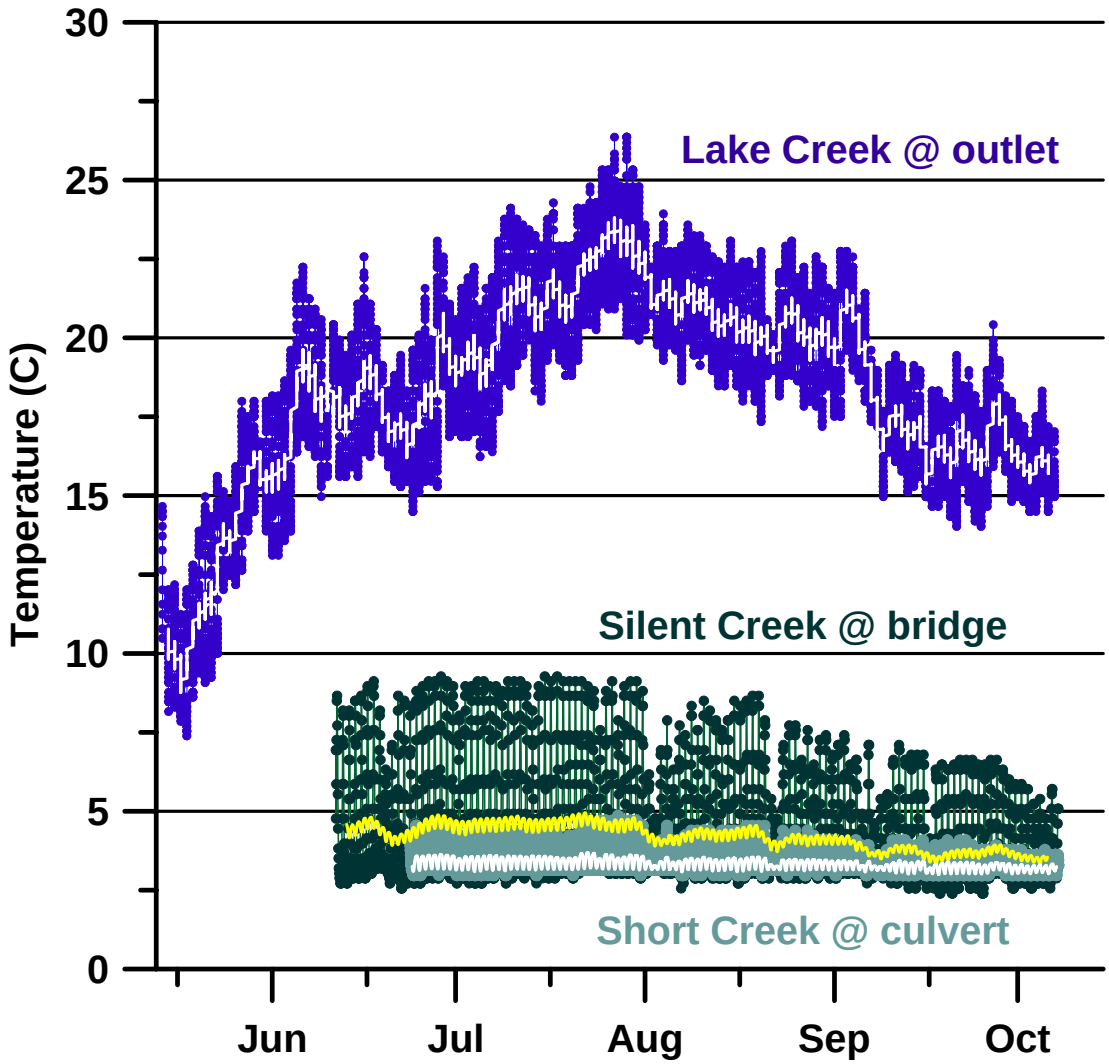


Figure 5. Stream temperatures measured at Lake Creek, Silent Creek, and Short Creek for the study period, 2003. The figures show the complete display of measured values (at 15 min-intervals) with the running average values superimposed over the observed data.

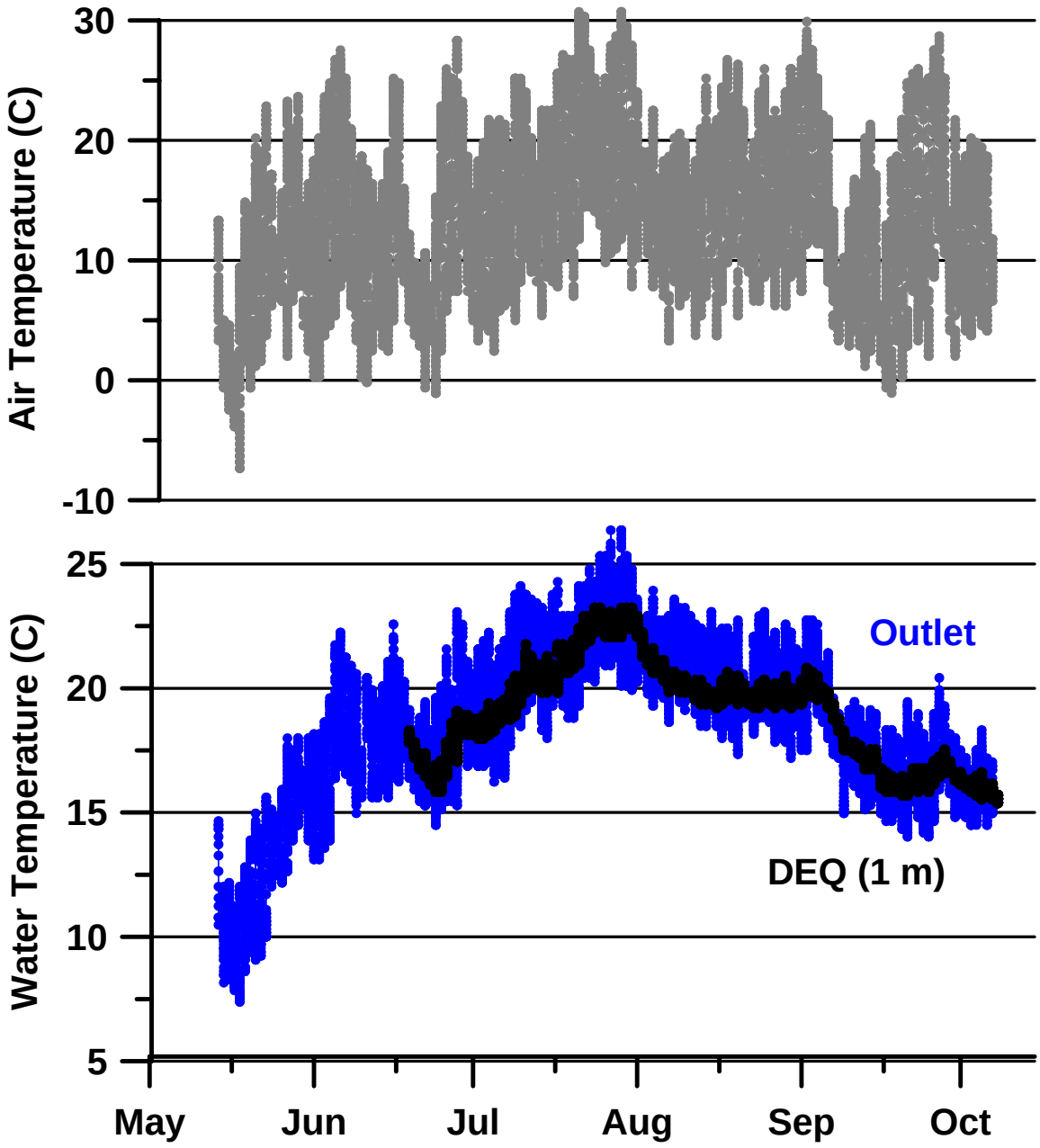
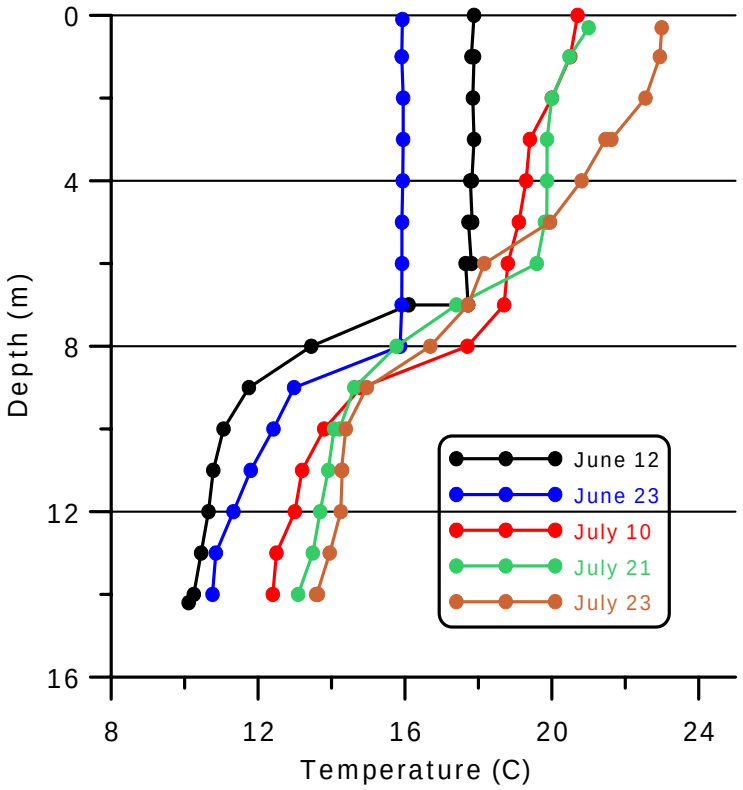


Figure 6. Water temperature at the Lake Creek outlet (blue) compared to Diamond lake temperature measured at 1 m depth (black) and air temperature (top).



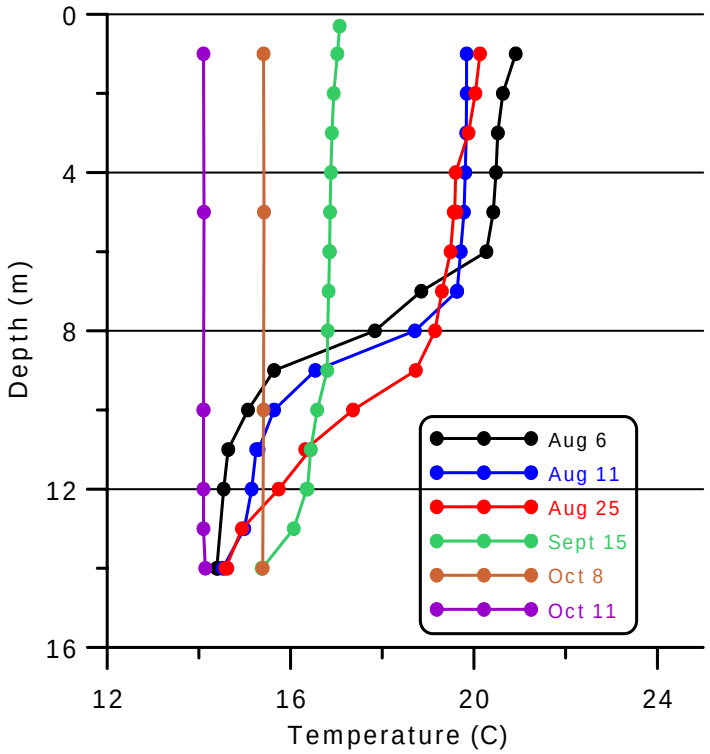


Figure 7. Temperature profiles measured in Diamond Lake from June and July (top) and August to October (bottom).

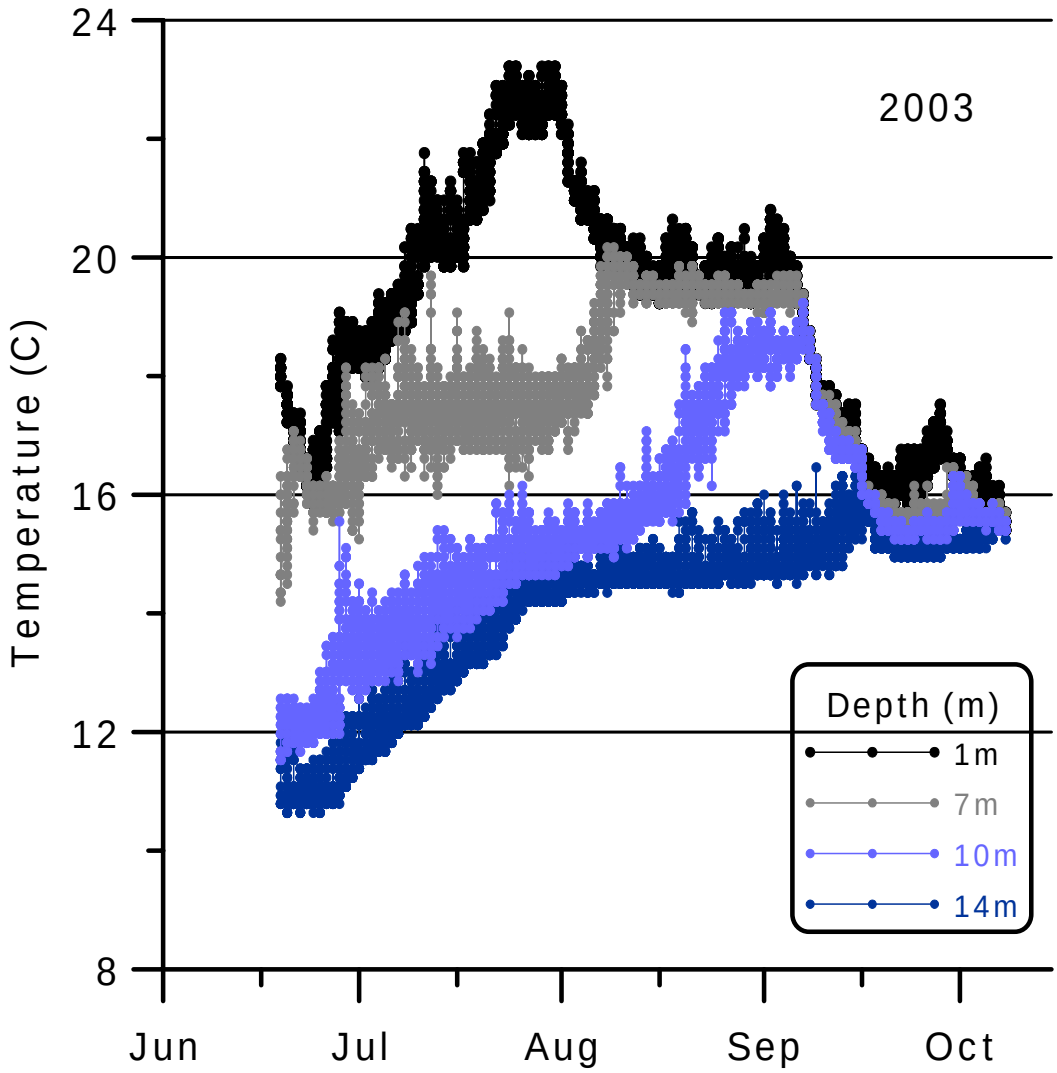


Figure 8. Diamond Lake water temperature displayed for selected depths (Source: DEQ).

3. **<u>Lake Transparency and Light Transmission</u>:** The Secchi disk transparency of the lake water was measured frequently during 2003 (Figure 9). The data show a steady decline in Secchi disk transparency from June through much of July. Minimum transparency was about 1m, which persisted for about two weeks in July. Transparency began increasing towards the end of July and reached a mid-summer maximum in early August. The Secchi disk transparency values corresponded closely with changes in light intensity measured at a depth of 1.5 m. Although light intensity measurements were altered slightly by diatom colonization on the plastic casing (as illustrated in the increase in measured light intensity after it was cleaned by DEQ staff on or around August 15), the results provide a continuous record of light transmission at this depth. The plot of PAR shows that Secchi disk transparency nor light intensity (@ 1.5 m) were altered greatly by variations in solar radiation. The relationship of these data to algal populations is described later in this report.

The temperature profiles conducted at the time of lake sampling shows the development of the thermocline through June and July and the deterioration of the thermocline from August to September (Figure 9).

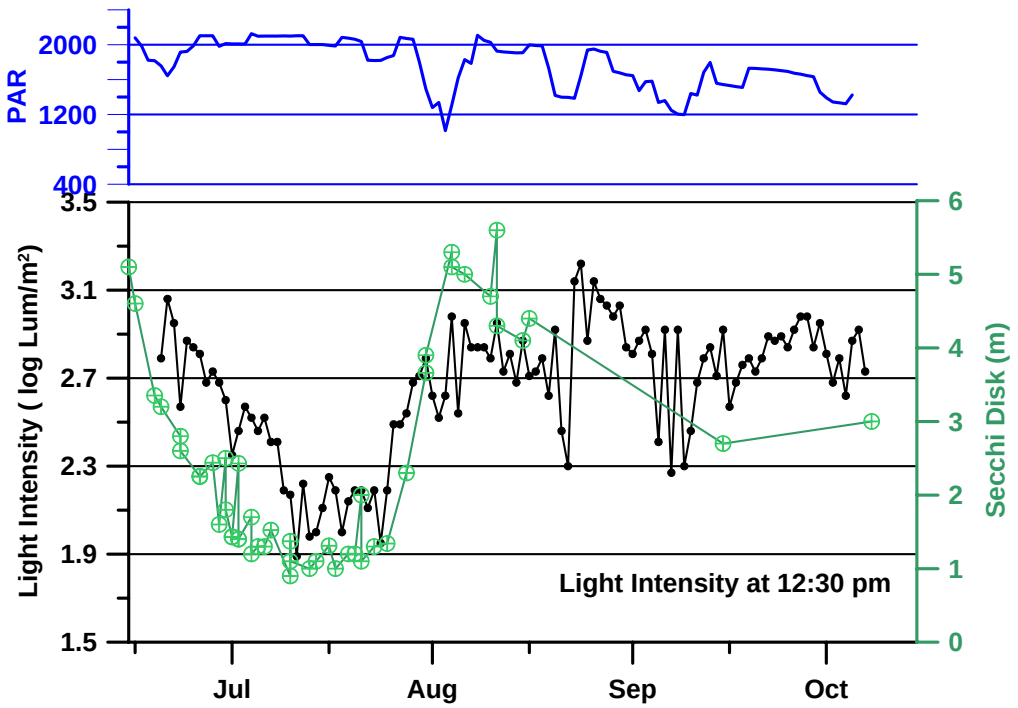
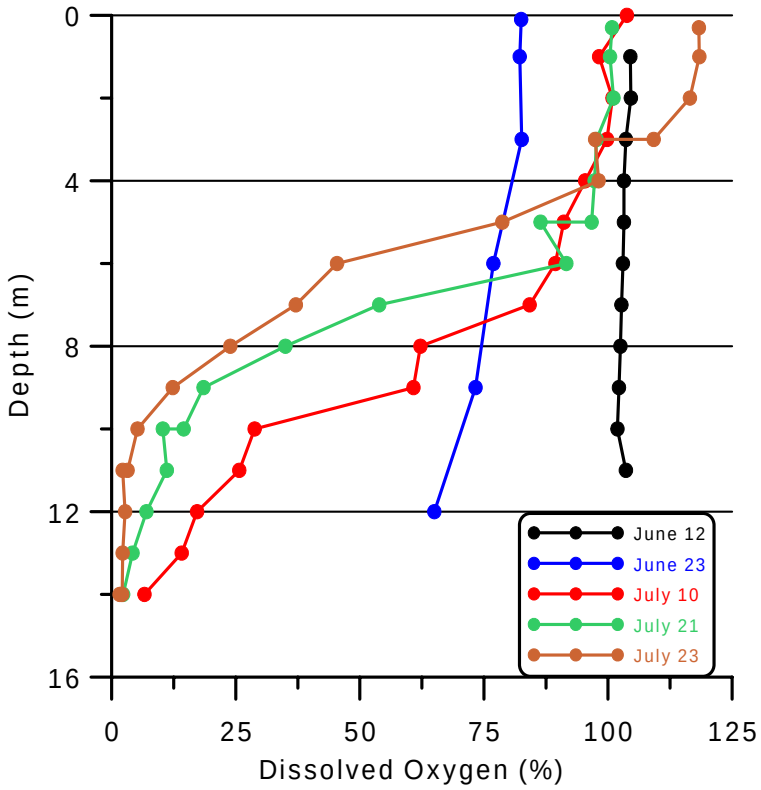


Figure 9. Measurement of Secchi Disk transparency (green) compared to light intensity (lumens/m^2) at 1.5 m depth (showing values recorded between 12:15 pm and 12:45 pm). Photosynthetically active radiation (PAR) recorded at the Diamond Lake weather station (umol/m^2/sec) is shown at the top (blue) for comparison.

4. In-Situ Chemistry:

The profile of dissolved oxygen, pH, and ORP are shown in Figures 10 to 12. Conductivity profiles are not shown because several of these did not meet quality assurance review. Dissolved oxygen (DO) profiles showed evidence of DO depletion in the hypolimnion by early July. The anoxia in the hypolimnion intensified through July and August and did not fully recover under the lake destratified after September 15. Supersaturation existed in the epilimnion during much of July and again at the end of August during a warming trend. pH values in the epilimnion were elevated above equilibrium (generally about 7.8 for Diamond Lake) from all of July and from the later part of August to mid-September (Figure 11). During these two periods, pH remained above the water quality standard of 8.5 fairly consistently. Hypolimnetic pH values during these same periods were well below the equilibrium value, indicating the presence of excess CO_2, which drove the pH down. ORP values were generally positive throughout the study period, although there was a trend towards decreasing ORP in the water column during July, which extended into August.

The results of the continuous water quality measurements conducted by DEQ are presented in Figure 13. The results are in reasonable agreement with the epilimnetic values from the profile data, which show the increase in surface water pH during June and July, a period of transition in August and a decline into October. The relatively large range of pH values measured in the first three weeks of August may reflect the high degree of change occurring during this cool period, although the abrupt transition in pH values on August 21 may be associated with re-calibration of the probe at this time. The measurements of DO in June and July did not meet quality assurance review (graded "D" by DEQ), but the DO data that were of acceptable quality show a strong correspondence between DO saturation and water temperature for September and October. The data available for August show a lower degree of supersaturation that was also observed with the profile data.



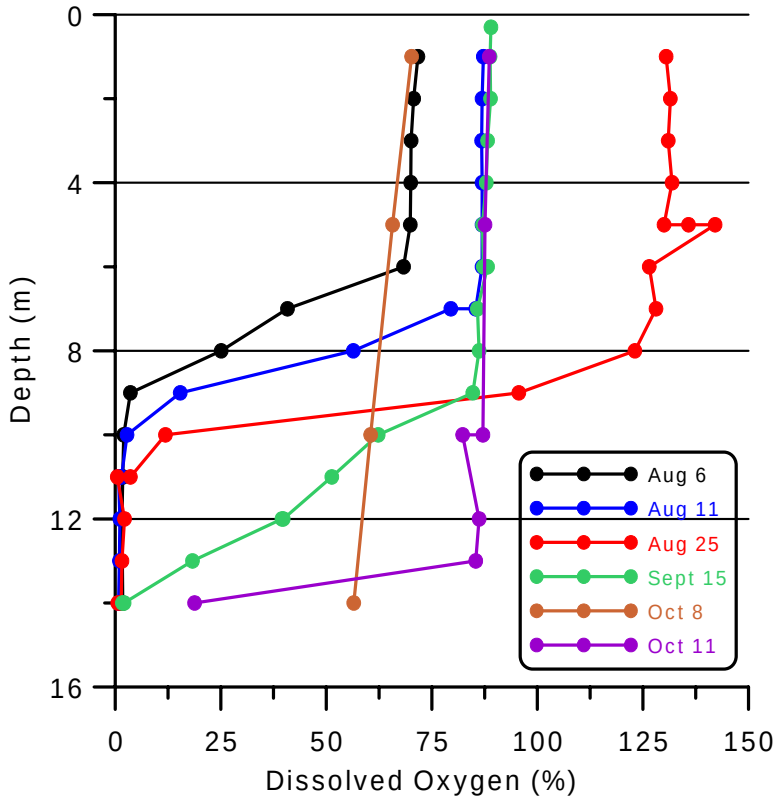


Figure 10. Dissolved oxygen (percent saturation) profiles for Diamond Lake from June and July (top) and August to October (bottom). DO saturation at this elevation is generally about 82 percent. Note the change in scales.

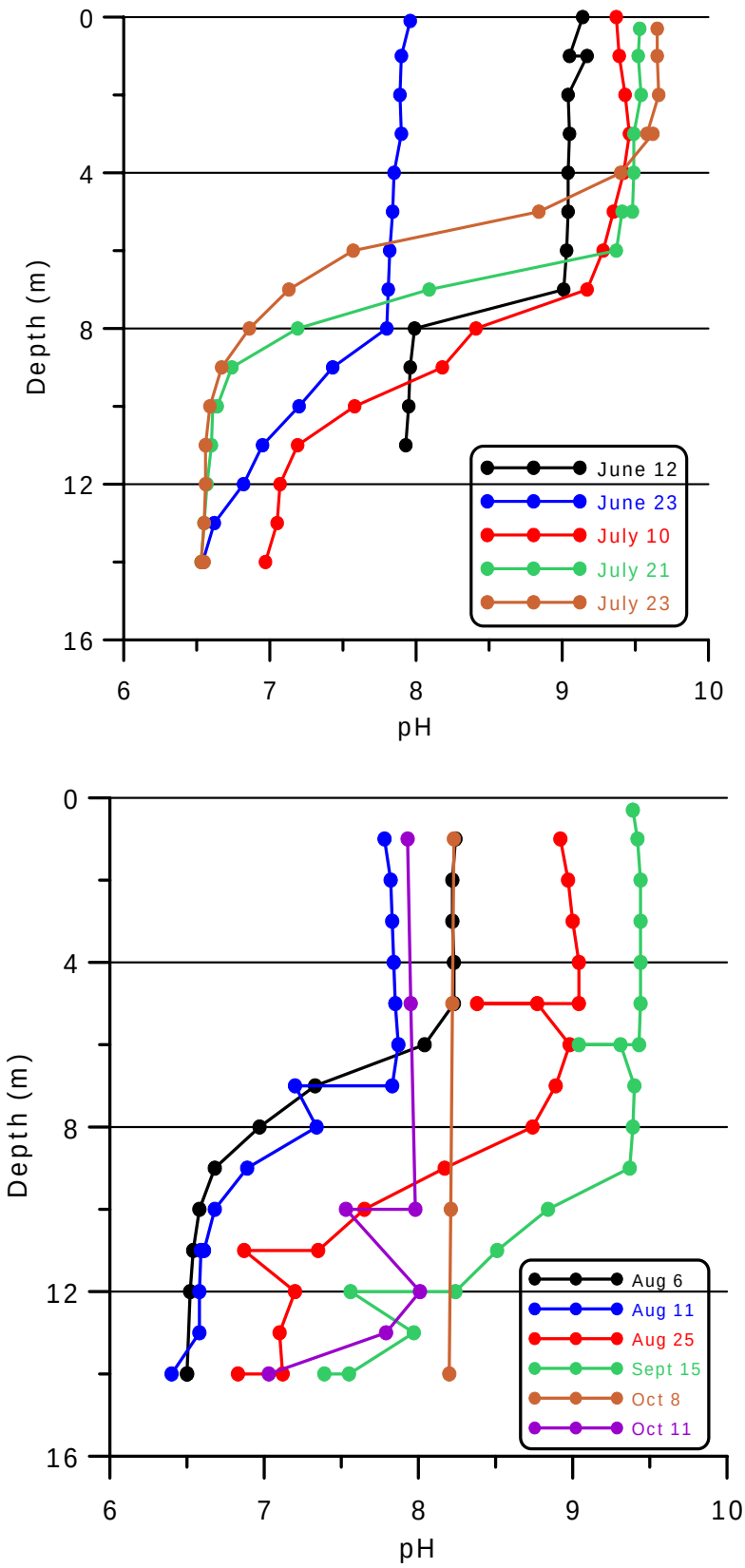


Figure 11. pH profiles for Diamond Lake from June and July (top) and August to October (bottom).

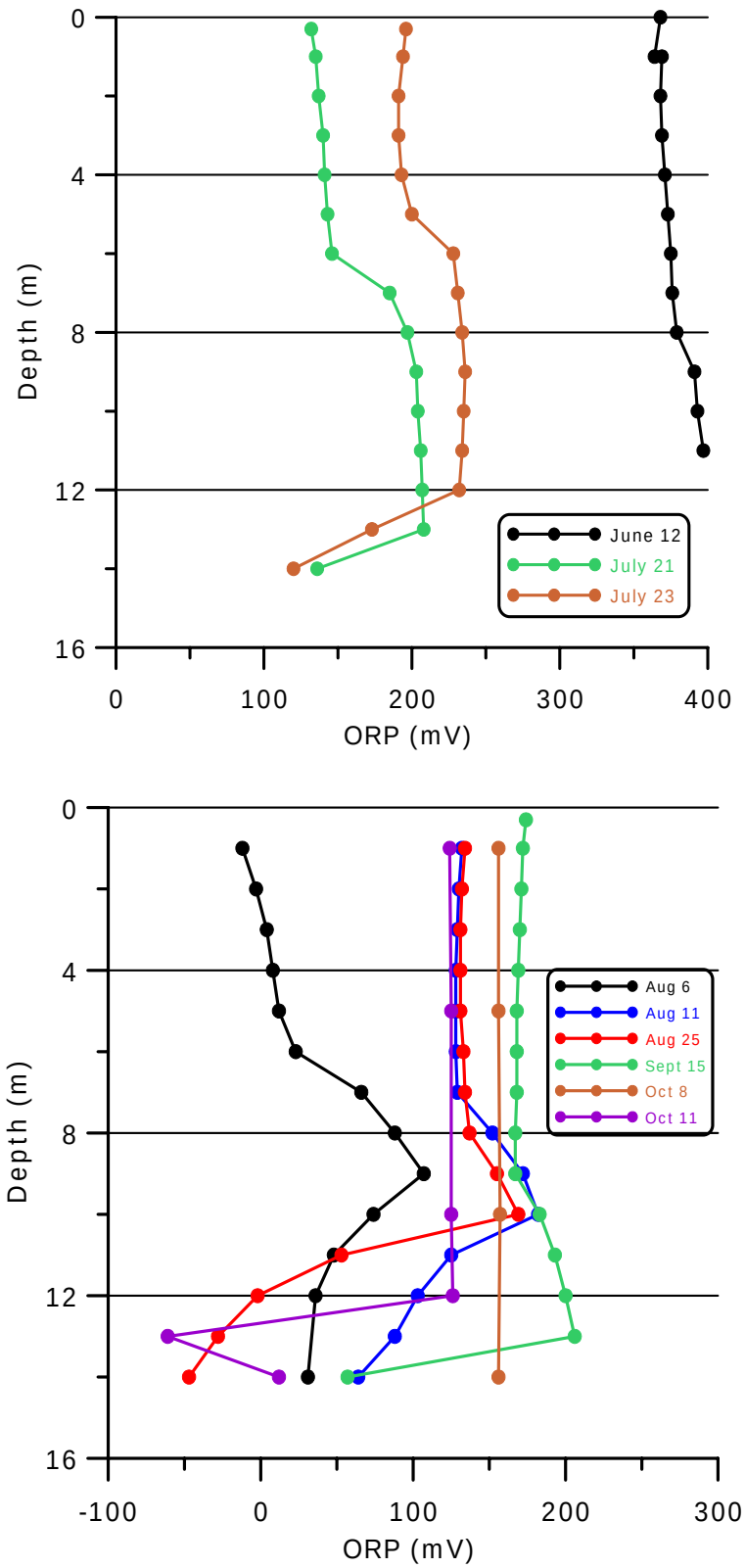


Figure 12. Oxidation-Reduction potential (ORP) profiles for Diamond Lake from June and July (top) and August to October (bottom). Note the change in scales.

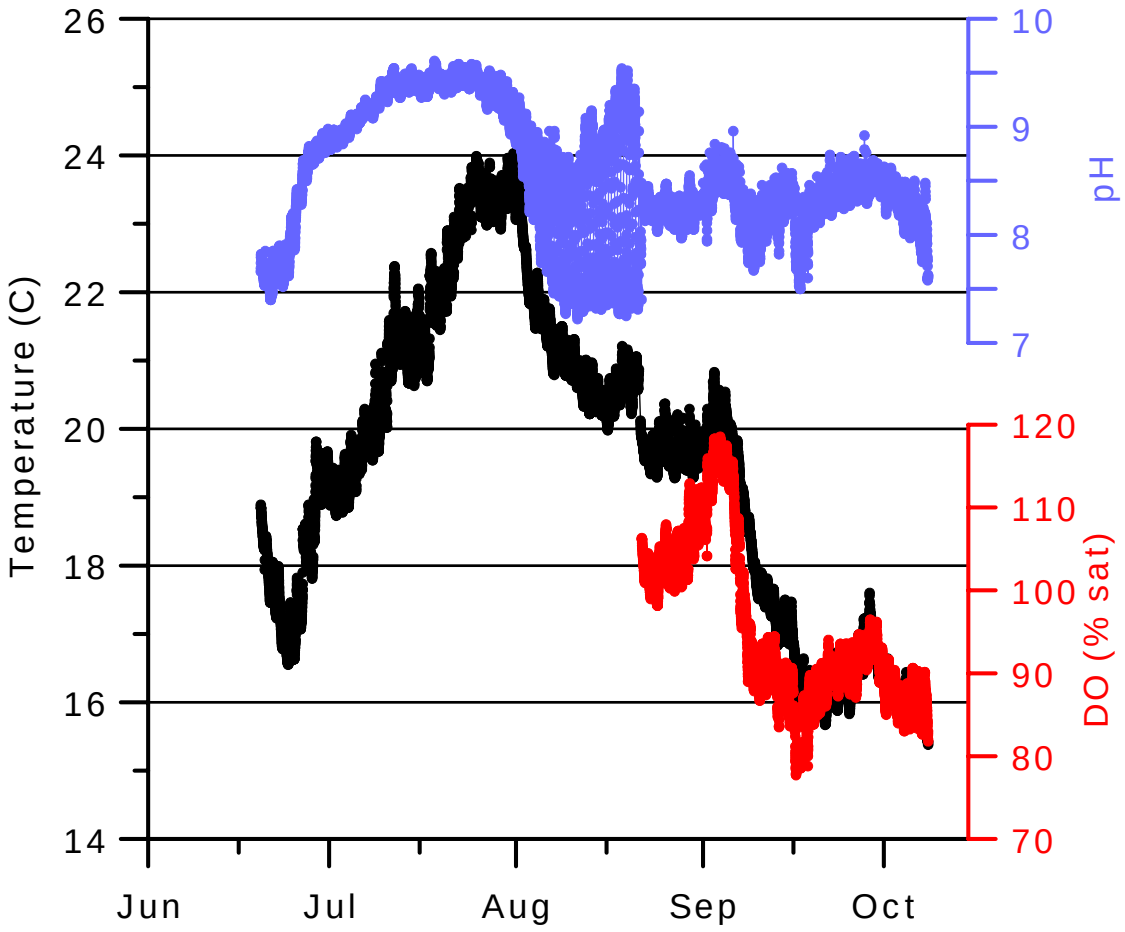


Figure 13. Continuous measurements of temperature, pH, and dissolved oxygen recorded at a depth of 1.5 m in Diamond Lake for 2003 (Source: DEQ).

5. **Analytical Chemistry:** Analytical chemistry measured in 2003 consisted of phosphorus, nitrogen, silica, pH, alkalinity, conductivity, and one sampling of major ions. From 1992-2001, what was reported as total phosphorus was actually a total phosphorus analysis of filtered samples (labeled as DTP here). Because of this, we elected to collect one season of total phosphorus on filtered (DTP) and unfiltered samples (UTP) in addition to the unchanged analysis of PO_4-P on filtered samples. From 1992-2001, only NO_3 and NH_3 were analyzed. In 2003, we also analyzed total Kjeldahl nitrogen (TKN). The results of the analyses are presented for three depths: epilimnion (1 m), metalimnion (generally 6 to 8 m), and hypolimnion (13 m).

a. pH

pH values for the three sets of lake samples and the two tributary stream sites are shown in Figures 14 and 15. Laboratory pH values for the surface lake samples have been at or above pH 9.0 for 2001-2003, whereas one two samples from the previous 10 years achieved this level. The pH values for the tributary streams are consistently in the vicinity of 7 to 7.7.

b. Alkalinity

Alkalinity values for the epilimnion and metalimnion exhibit an apparent decrease from 1994 to 1998 and a return to high values in 2001 (Figure 16). The pattern is not evident in the bottom waters of Diamond Lake. Alkalinity concentrations were stable in both tributary sites at about 5 to 6 mg/L (Figure 17).

c. Conductivity

Patterns in conductivity for Diamond Lake surface and metalimnetic water are very similar to those observed from alkalinity (Figures 18 and 19). The trends in conductivity mirror those for alkalinity since bicarbonate is the major anion in the lake (major ions are shown in section 5.l). Again, it is difficult to discern any trend in conductivity for the tributary sites.

d. Silicon

Silicon concentrations exhibit a strong, robust trend in Diamond Lake (Figure 20). Concentrations reach a minimum in 1992 and 1993 and increased by over 400 percent to 1998. The silicon concentrations in the lake have been declining since 2001. However, no trend in silicon is present in the tributaries (Figure 21). Silicon is a major requirement for growth of diatoms and chrysophytes. The possible relationship between variations in silicon and phytoplankton populations is currently being evaluated.

e. Total* Phosphorus (Dissolved)

From 1992 through 2001, total* phosphorus measurements for Diamond Lake were run on filtered samples (DTP). We continued this practice to compare with total phosphorus measurements run on unfiltered sampled (shown later). The DTP values reported for Diamond Lake and the tributary streams from 1992 to 1995 included sample results that were much greater than observed in recent years (Figures 22 and 23). We are unaware of any change in field and laboratory protocols that might have contributed to the observed variations.

f. Total Phosphorus (Unfiltered)

The analysis of total phosphorus on unfiltered lake samples showed that actual total phosphorus concentrations are about double the values observed for DTP, although the TP results for the tributary streams are nearly identical to the DTP results shown earlier (Figure 24 and 25). The high TP values for the lake samples show the influence on plankton and particulate organic matter entrained in the samples compared to the analyses on filtered samples. The lack of a significant difference in DTP and TP results for the tributary sites shows the absence of total suspended solids or organisms in these groundwater discharge systems.

g. Phosphorus (PO_4)

Reported ortho-phosphorus concentrations were elevated in the lake samples from 1992 to 1995 (Figure 26). After 1995, phosphorus concentrations have remained stable with values generally less than 5 ug/L. Again, the concentrations in the tributary streams have remained considerably high, generally in the range from 45 to 60 ug/L (Figure 27).

h. Total Kjeldahl Nitrogen

Total Kjeldahl nitrogen (TKN) has only been measured for the lake and tributaries since 2002. As expected, the concentrations of TKN are highly variable with space and time in the lake and consequently it is too early to assess any patterns in the lake data (Figure 28). The concentrations of TKN in the tributary sites are slightly above the detection limit for this analyte and are at least an order of magnitude below the values observed in the lake (Figure 29).

i. Nitrate

With the exception of a few observations, nitrate concentrations in Diamond Lake have remained at or near the analytical detection limit (Figure 30). Concentrations of nitrate are slightly greater in Silent Creek, however, the values in Short Creek are considerably greater than either those values in the

lake or in Silent Creek (Figure 31). The nitrate concentrations observed in Short Creek are seldom observed in high Cascade streams that lack input of nitrogen from alders. Anthropogenic inputs would be the likely source for input of nitrate from Short Creek.

j. Ammonia

Ammonia is the most abundant component of inorganic nitrogen measured in Diamond Lake (Figure 32). Concentrations of ammonia in surface waters reached nearly 0.2 mg/L (as N) in 2001 after the collapse of the cyanobacteria bloom. Concentrations of ammonia in the hypolimnion have reached 0.5 mg/L on several occasions and have been above 0.4 mg/L since 2001. Concentrations of ammonia in the tributaries have generally been near the analytical detection limit, with the exception of one high value reported at the beginning of the study (Figure 33). The value of 0.04 mg/L reported for Silent Creek in 1992 is not representative of over 40 subsequent samples that show almost no measurable ammonia in the creek.

k. Total Dissolved Solids

To some extent, the concentrations of total dissolved solids (TDS) follow the patterns observed for alkalinity and conductivity. The surface waters in Diamond Lake exhibit higher TDS values in the last five years compared to the period from 1992-1997 (Figure 34). This trend for the surface samples in Diamond Lake is highly significant ($P = 0.0003$). However, this pattern is not as definitive in the deeper waters of Diamond Lake. The pattern in TDS for Silent Creek appears to be just the opposite of what was observed in the surface waters of Diamond Lake (Figure 35).

l. Major Ions

Analysis of major ions has not been a routine set of analyses run on Diamond Lake samples in the past. We collected samples for analysis of major ions on Diamond Lake, the tributaries and the groundwater observation wells in August 2003. The results show strong similarity in the proportion of major ions for Diamond Lake and the tributaries (Figure 36). The dominant relative abundance of cations in Diamond Lake is Na > Ca > Mg > K and the order for anions is $HCO_3 >> Cl > SO_4 > NO_3$.

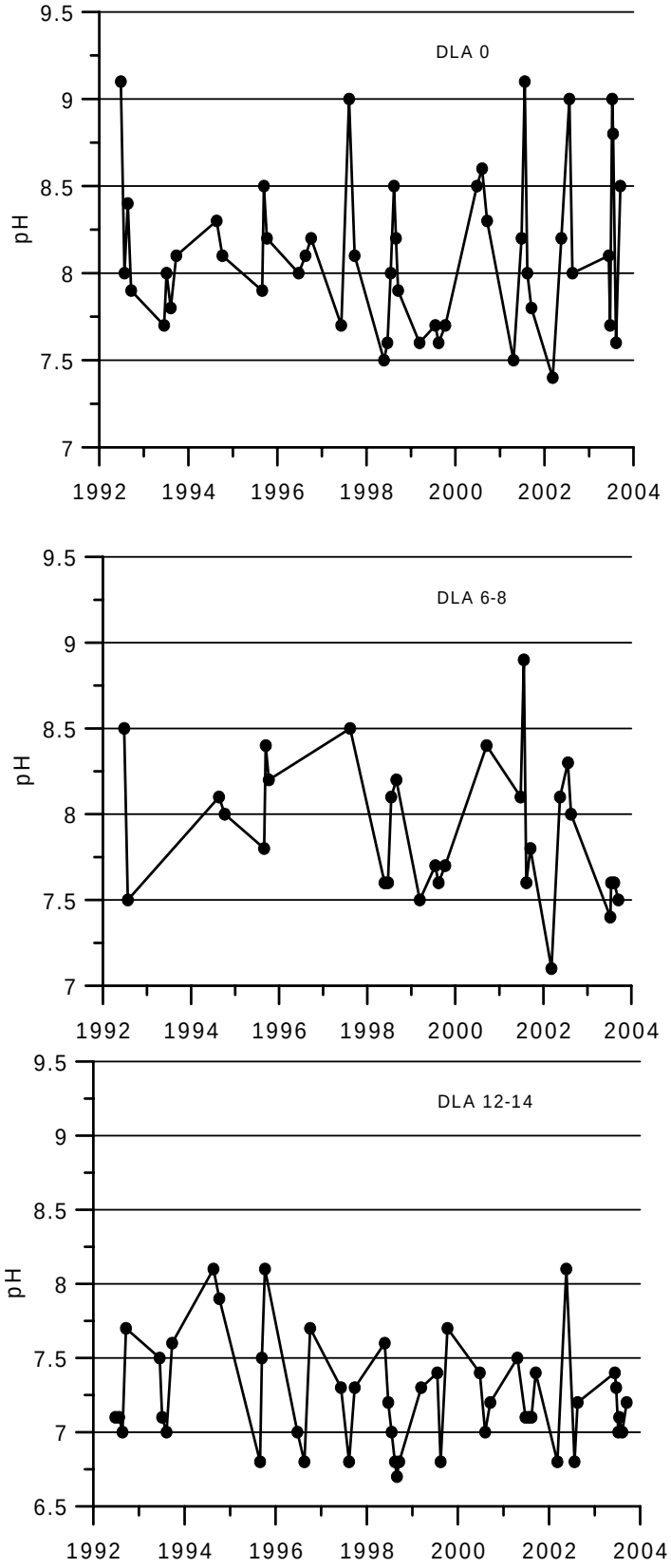


Figure 14. pH for the three different depth samples in Diamond Lake for 1992-2003.

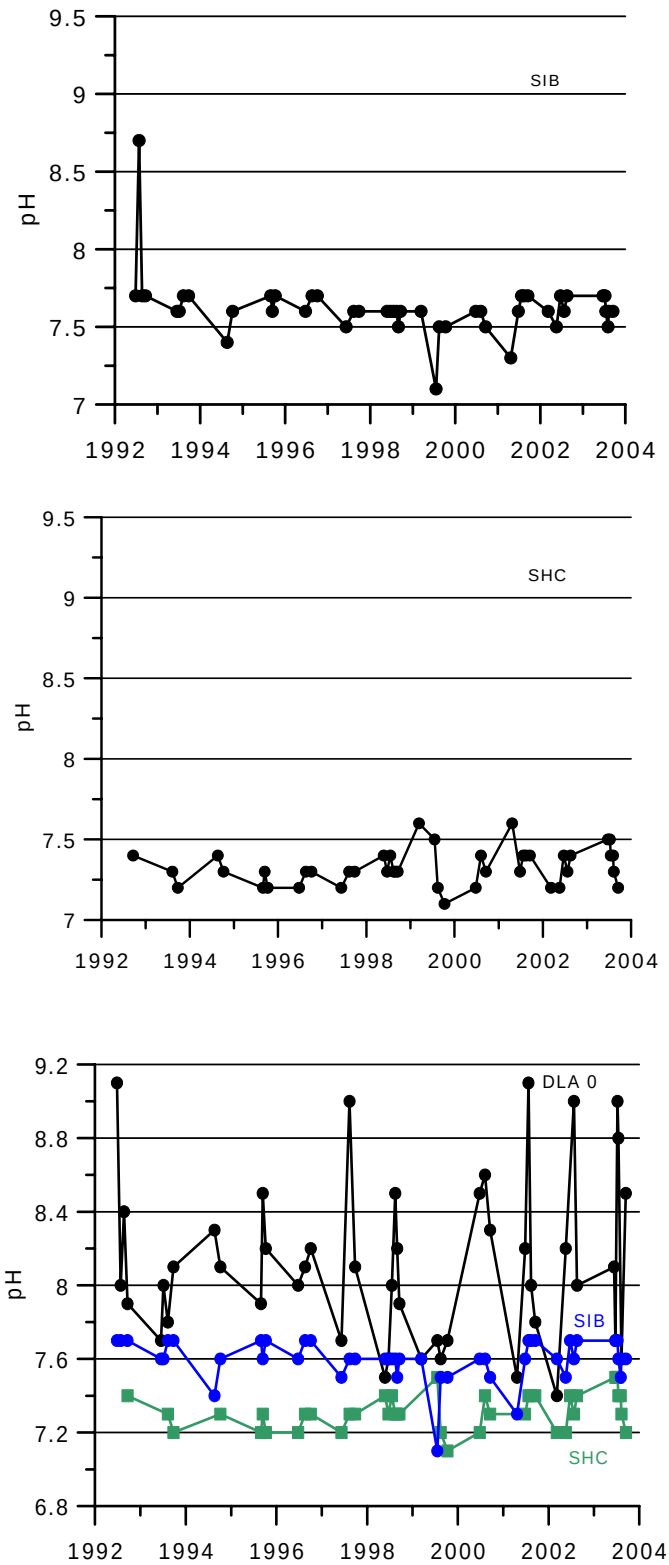


Figure 15. Laboratory pH measurements reported for Silent Creek (top) and Short Creek (middle) and stream values compared to the surface sample from Diamond Lake (bottom). Errant value for SIB has been clipped in the composite plot at the bottom.

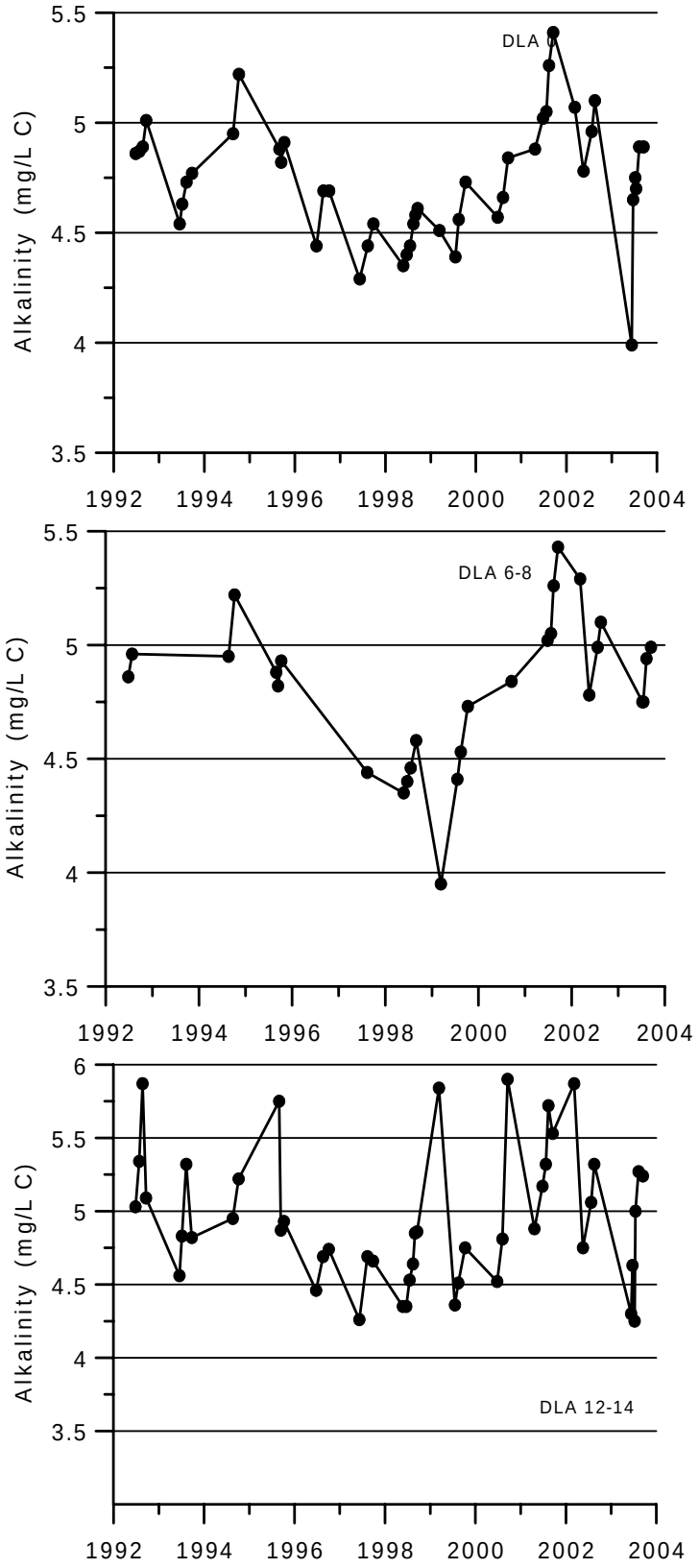


Figure 16. Alkalinity measurements for three different depths in Diamond Lake from 1992-2003.

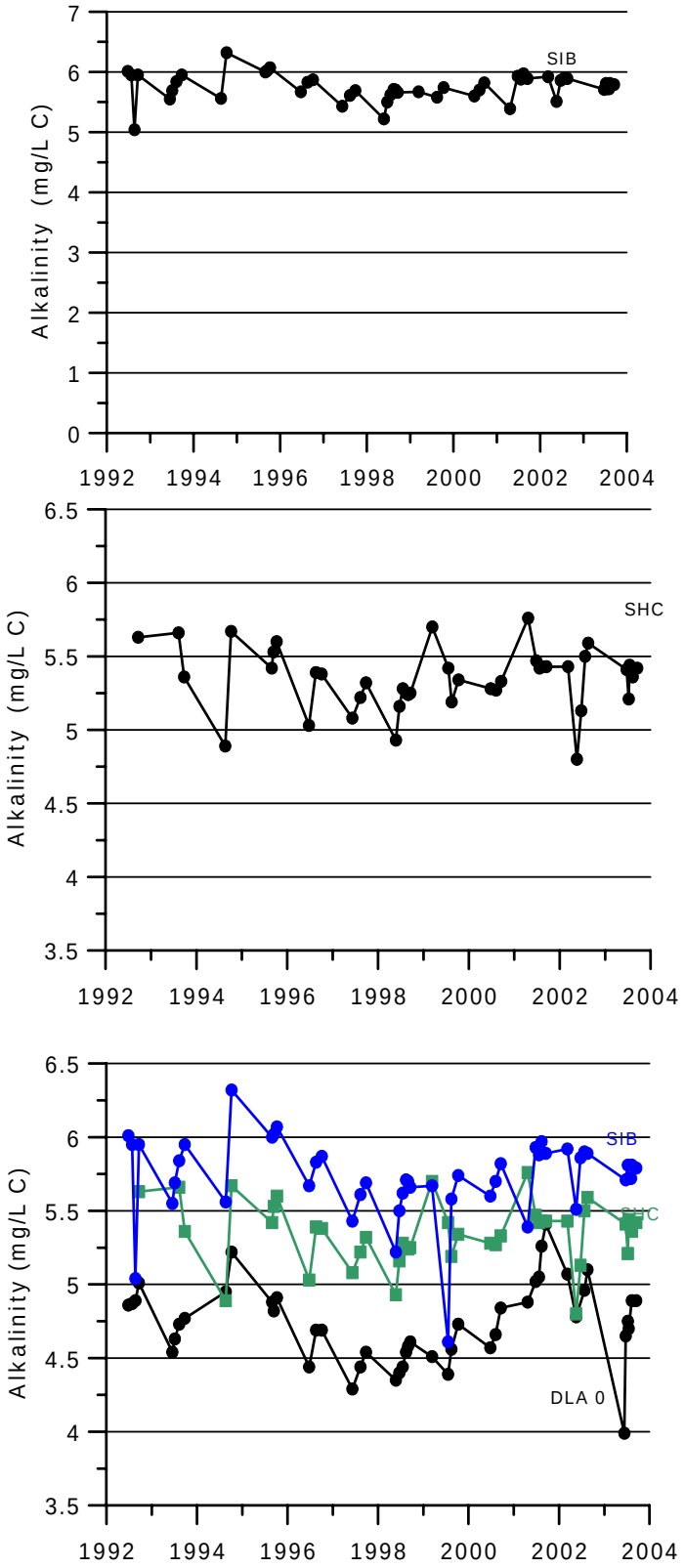


Figure 17. Alkalinity measurements reported for Silent Creek (top) and Short Creek (middle) and stream values compared to the surface sample from Diamond Lake (bottom).

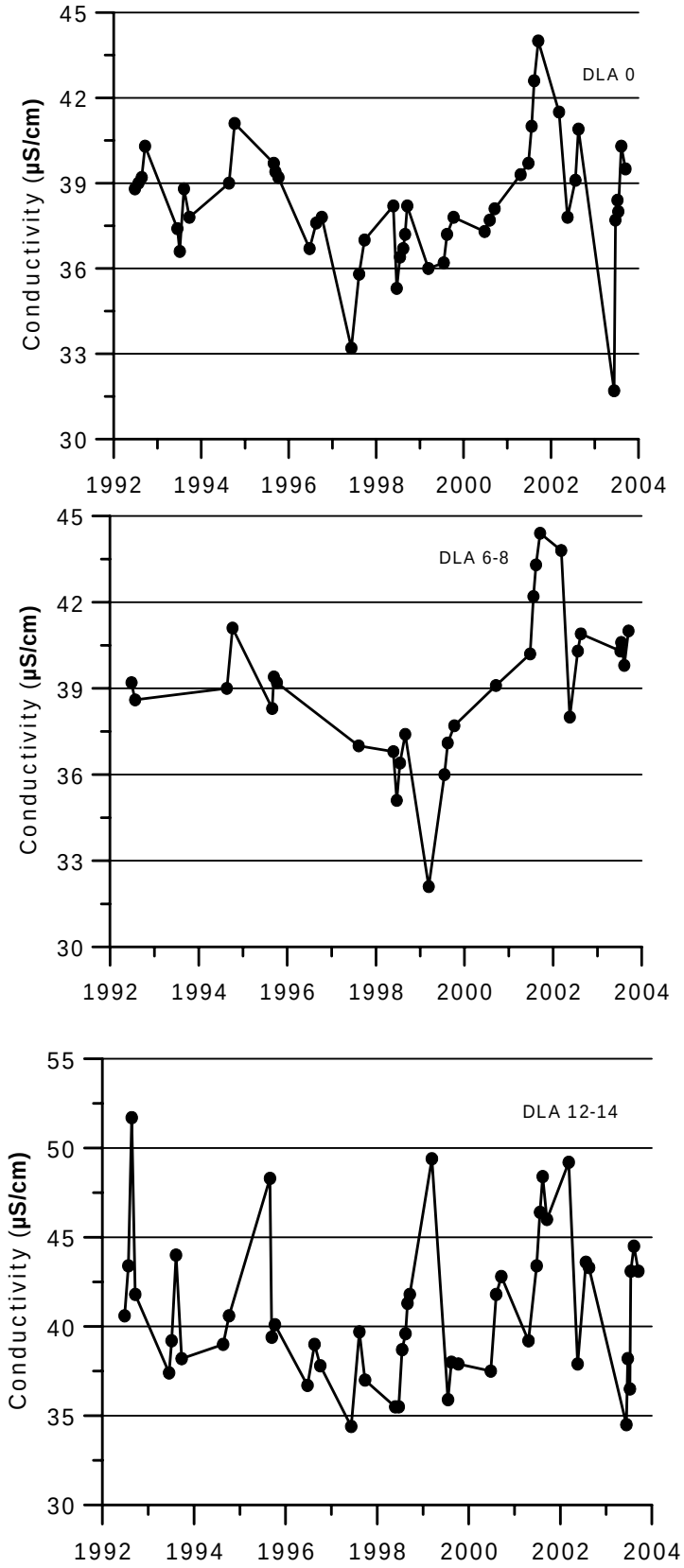


Figure 18. Laboratory conductivity measurements for thee different depths in Diamond Lake, 1992-2003.

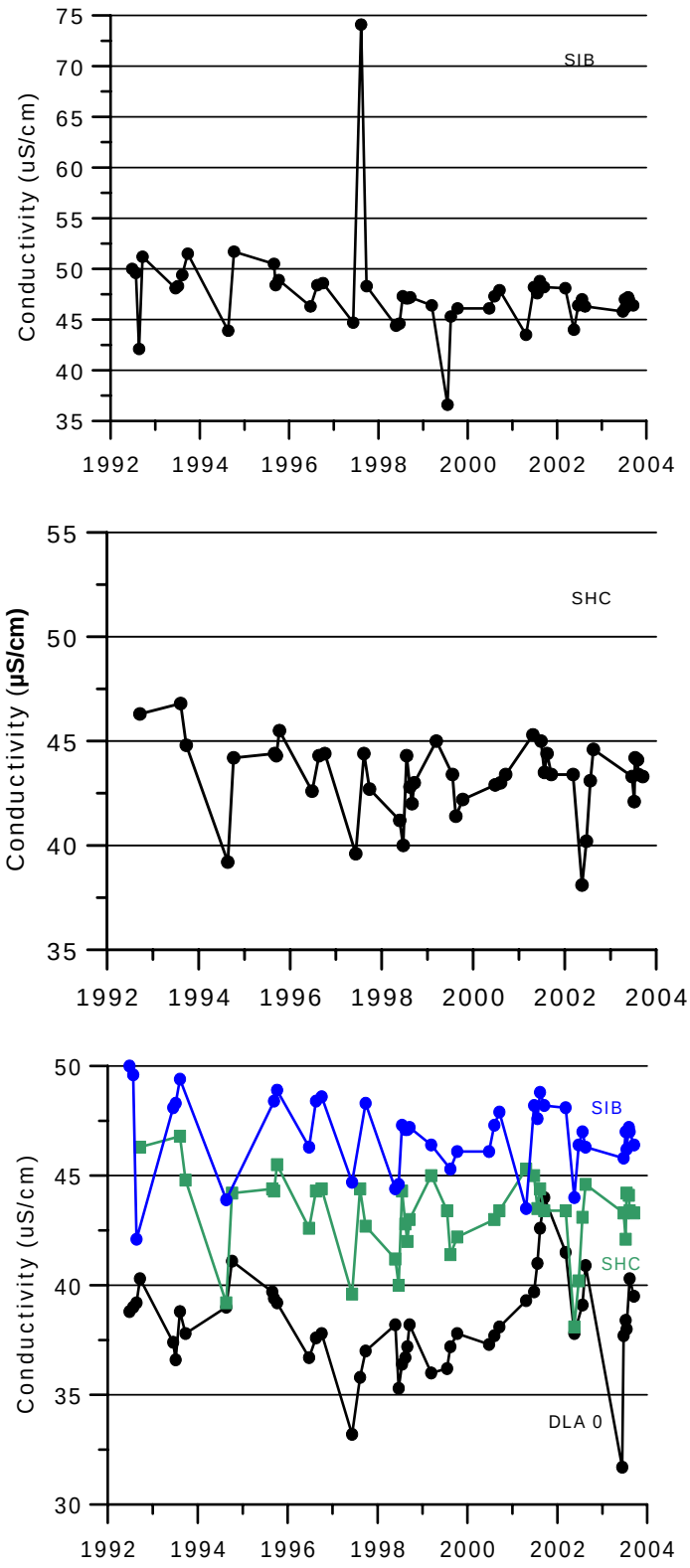


Figure 19. Laboratory conductivity measurements reported for Silent Creek (top) and Short Creek (middle) and stream values compared to the surface sample from Diamond Lake (bottom). Errant values for SIB have been removed from the bottom composite plot.

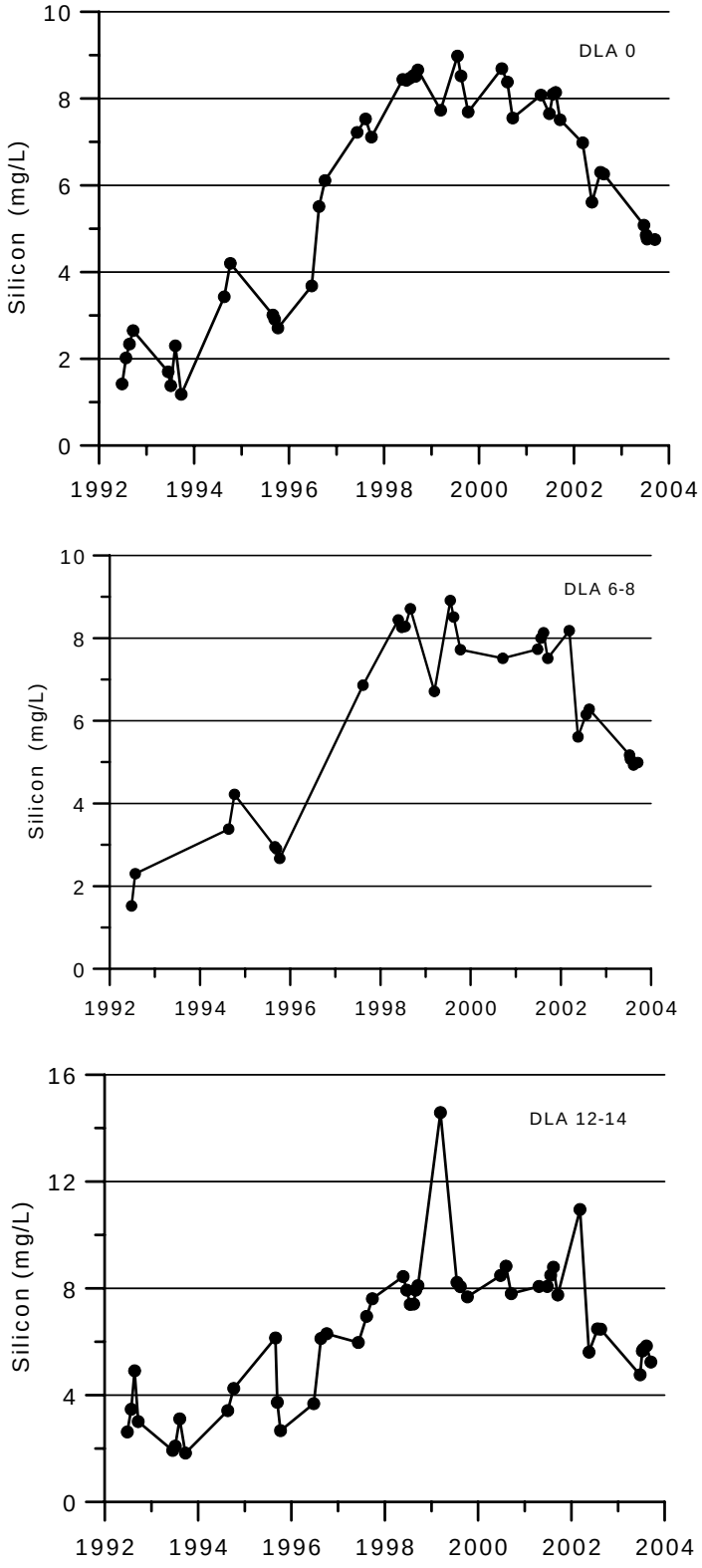


Figure 20. Silicon measurements for three different depths in Diamond Lake, 1992-2003.

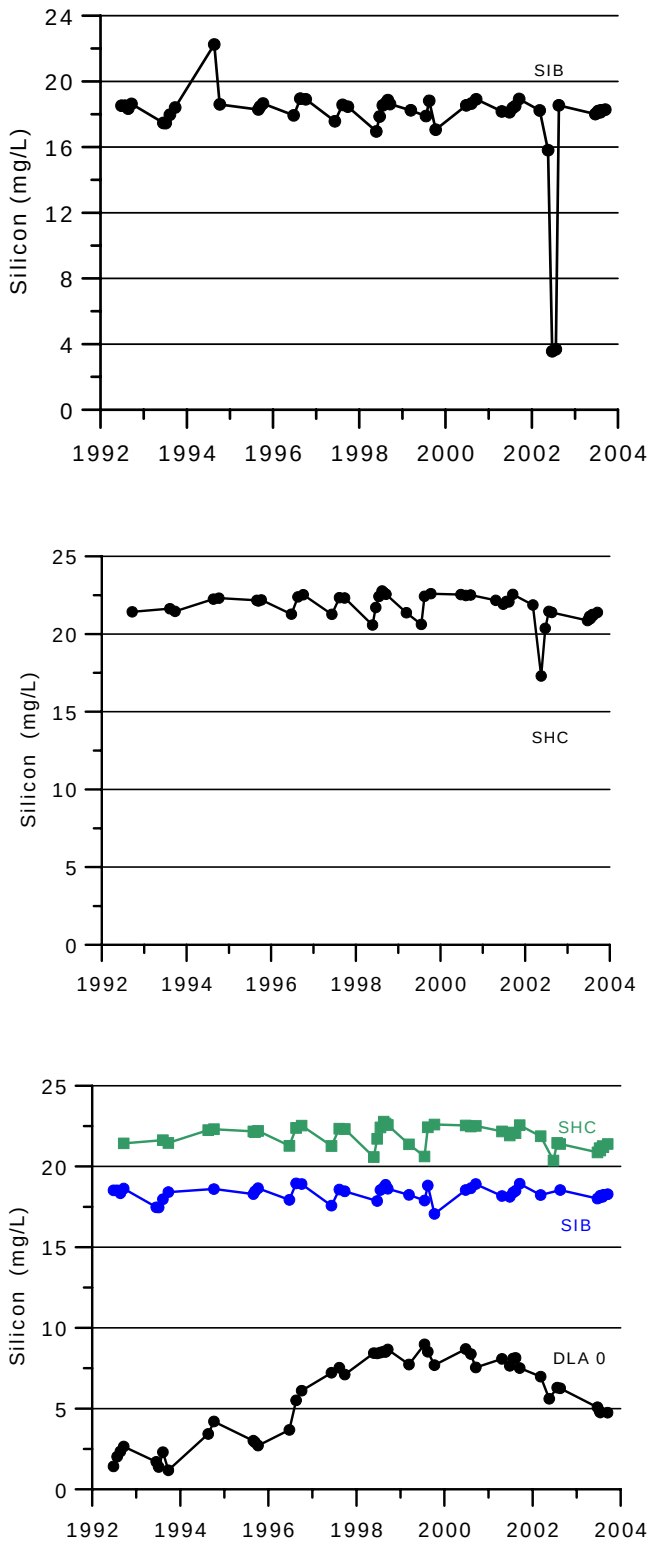


Figure 21. Silicon measurements reported for Silent Creek (top) and Short Creek (middle)and stream values compared to the surface sample from Diamond Lake (bottom). Errant values from SIB have been removed from the bottom composite plot.

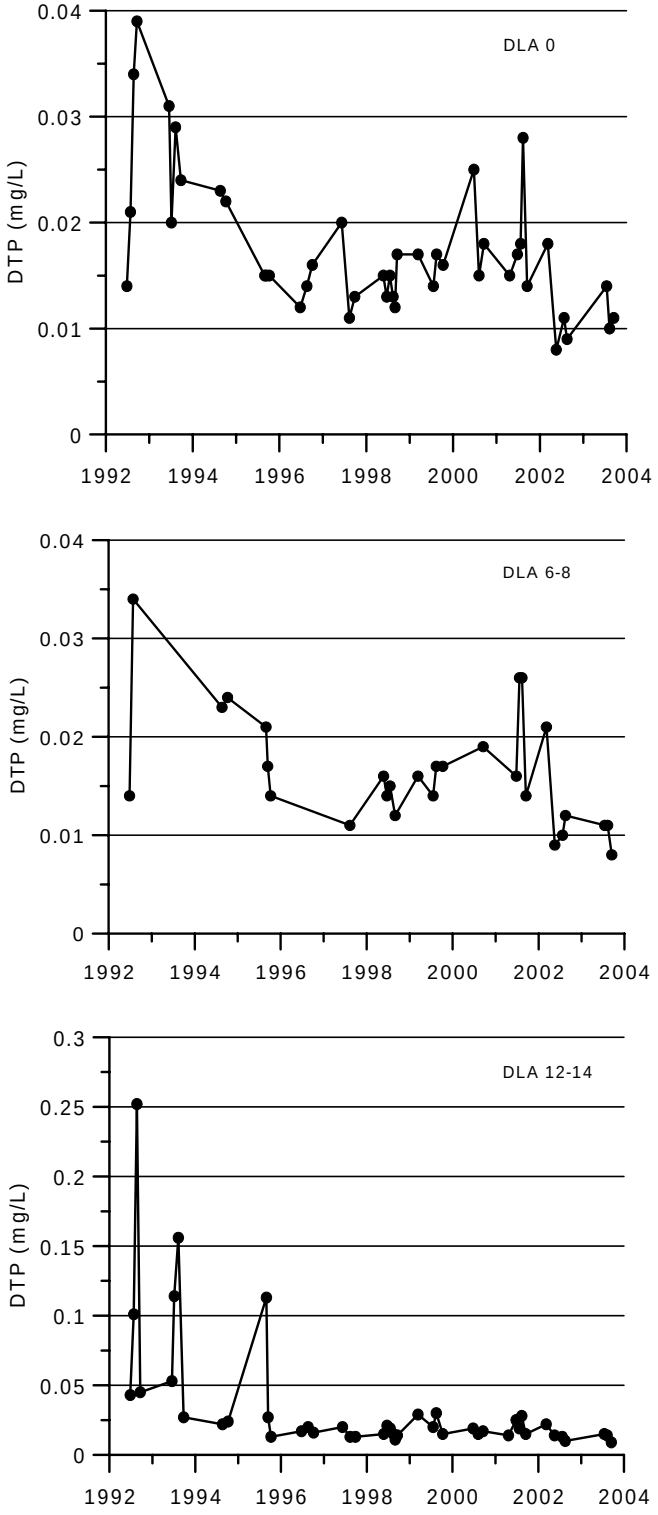


Figure 22. Total phosphorus analyses run on filtered samples (DTP) for three different depths in Diamond Lake from 1992-2003

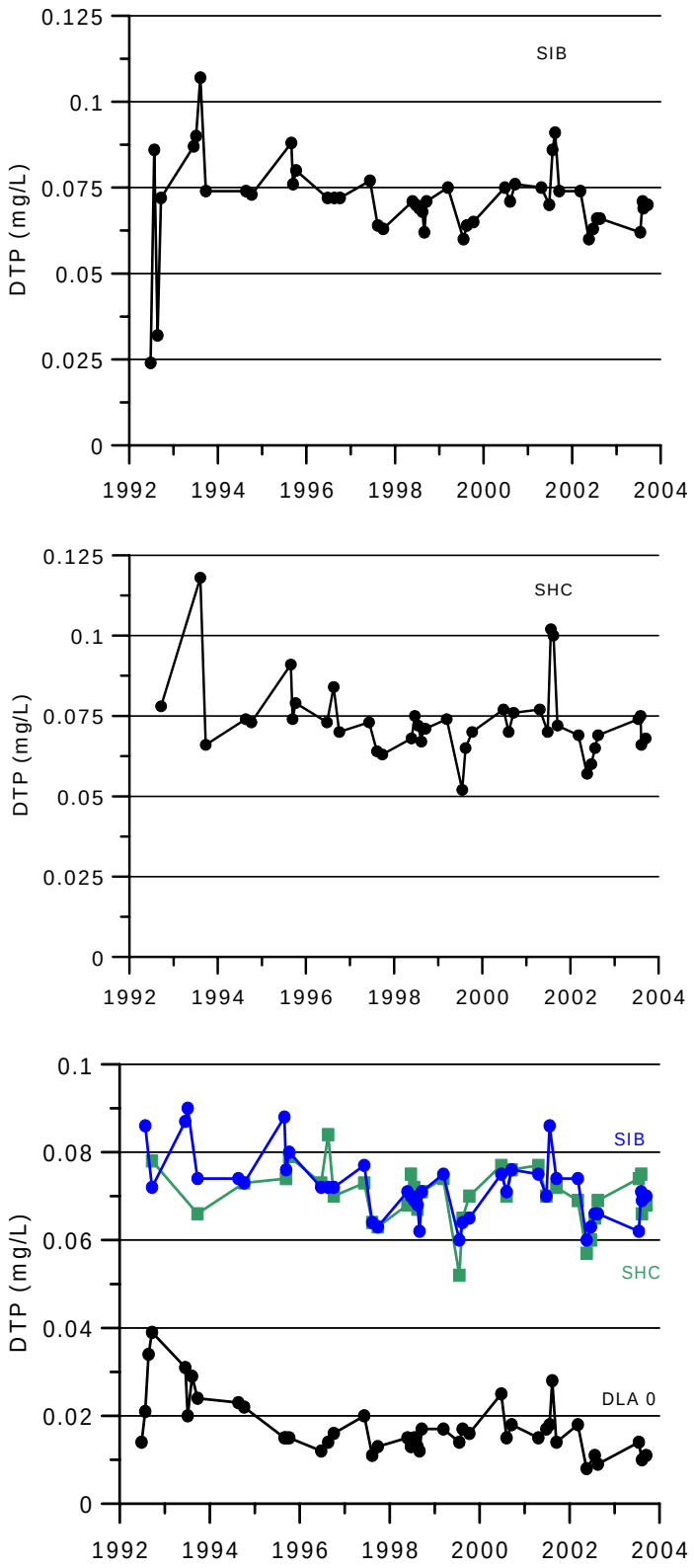


Figure 23. Total Phosphorus analyses run on filtered samples for Silent Creek (top) and Short Creek (middle)and stream values compared to the surface sample from Diamond Lake (bottom). Errant values from SIB and SHC from 1992-1994 have bee removed from the bottom composite plot.

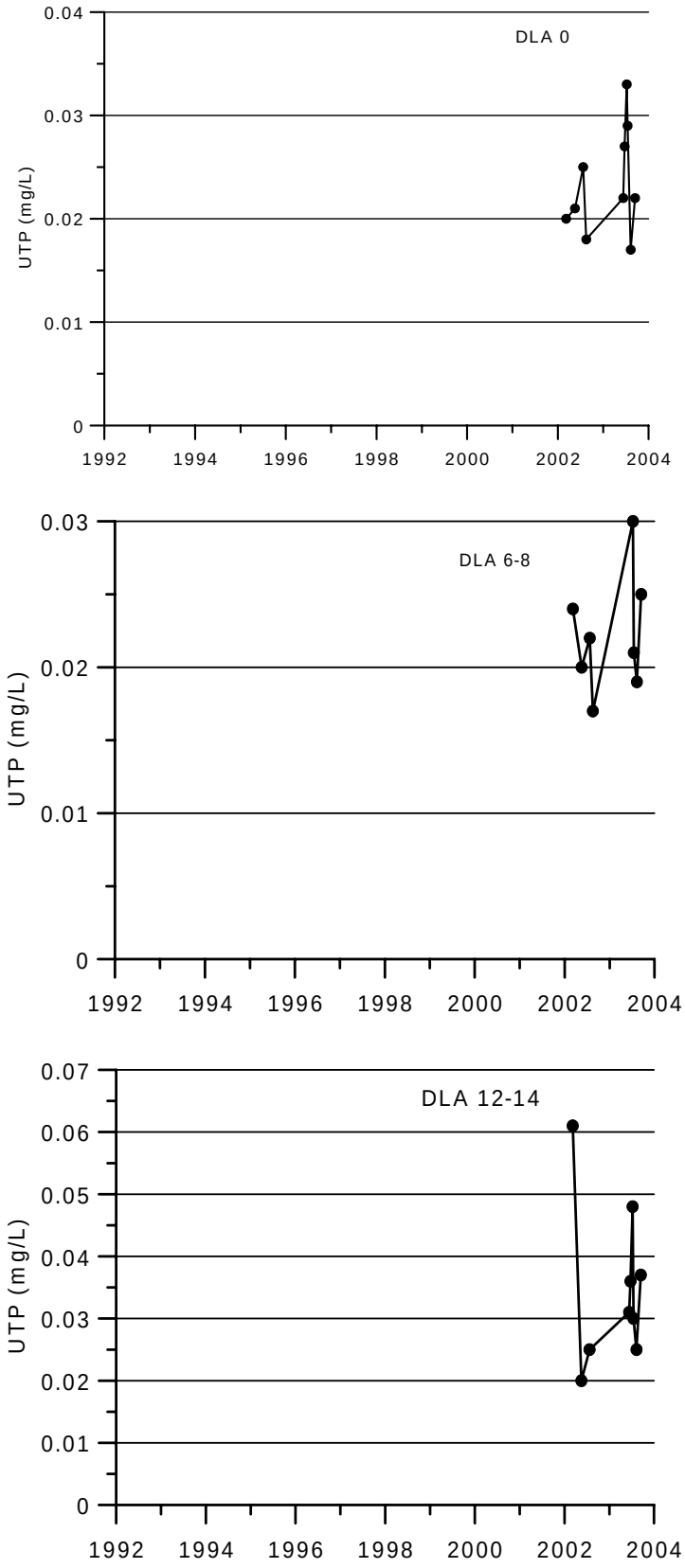


Figure 24. Total phosphorus (unfiltered sample) for three different depths in Diamond Lake from 2002 and 2003.

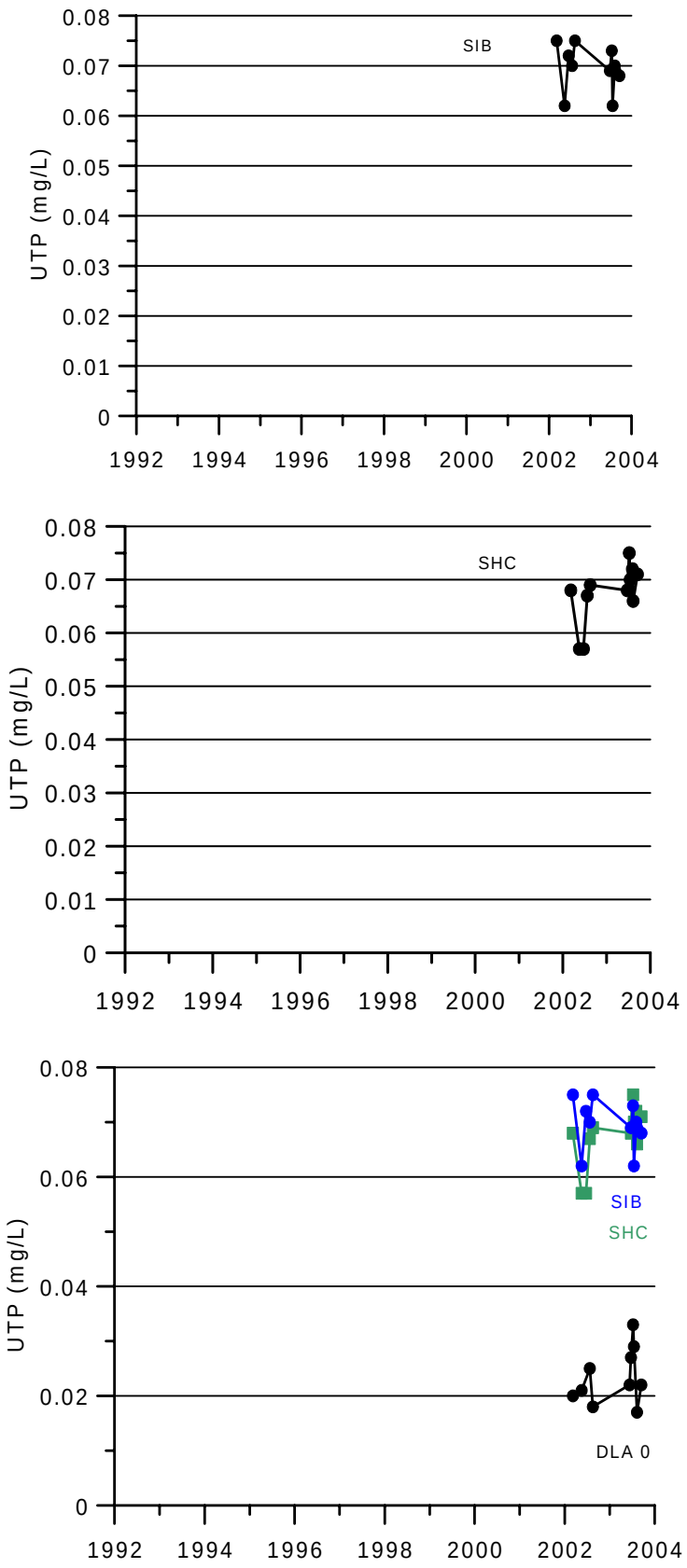


Figure 25. Total phosphorus (run on filtered samples) for Silent Creek (top) and Short Creek (middle) and stream values compared to the surface sample from Diamond Lake (bottom).

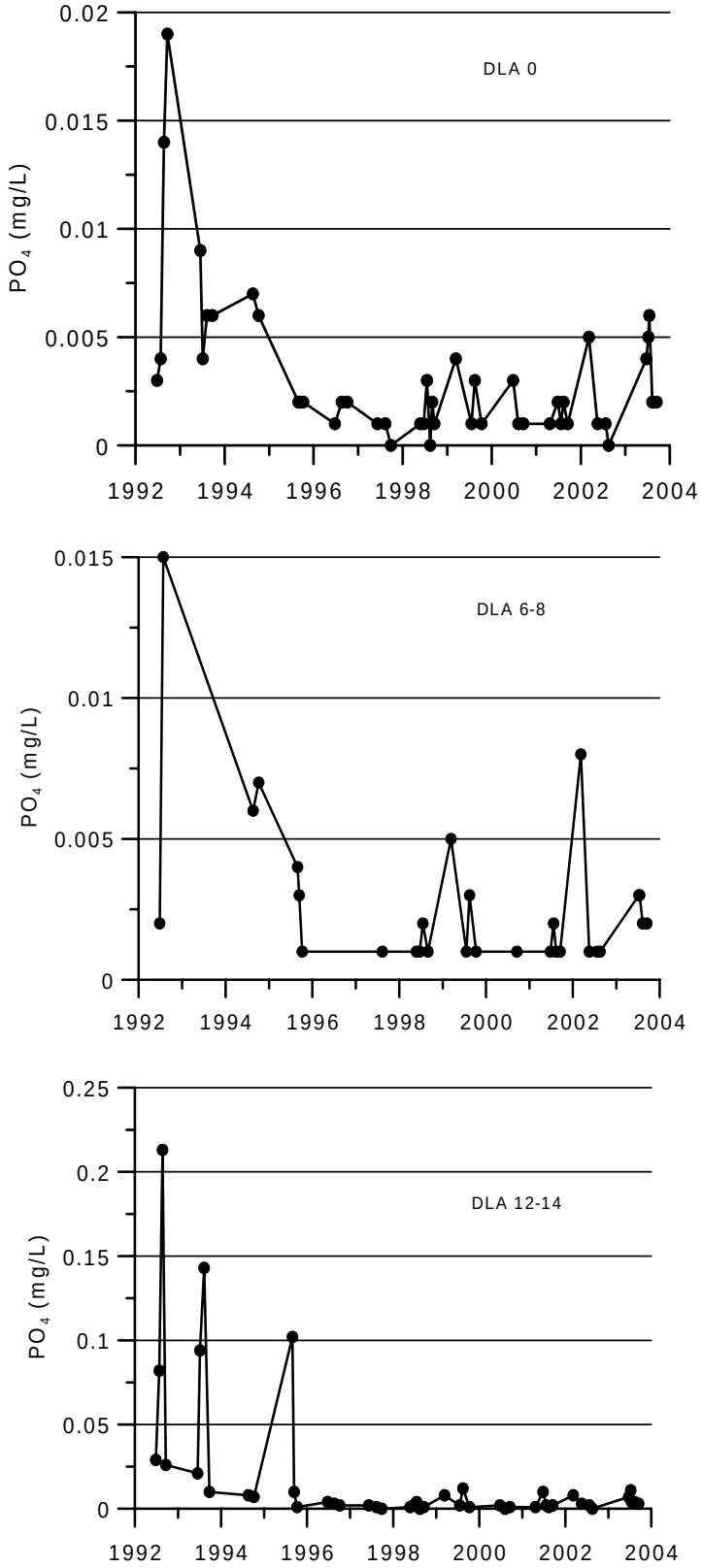


Figure 26. Phosphorus measurements for three different depths in Diamond Lake, 1992-233.

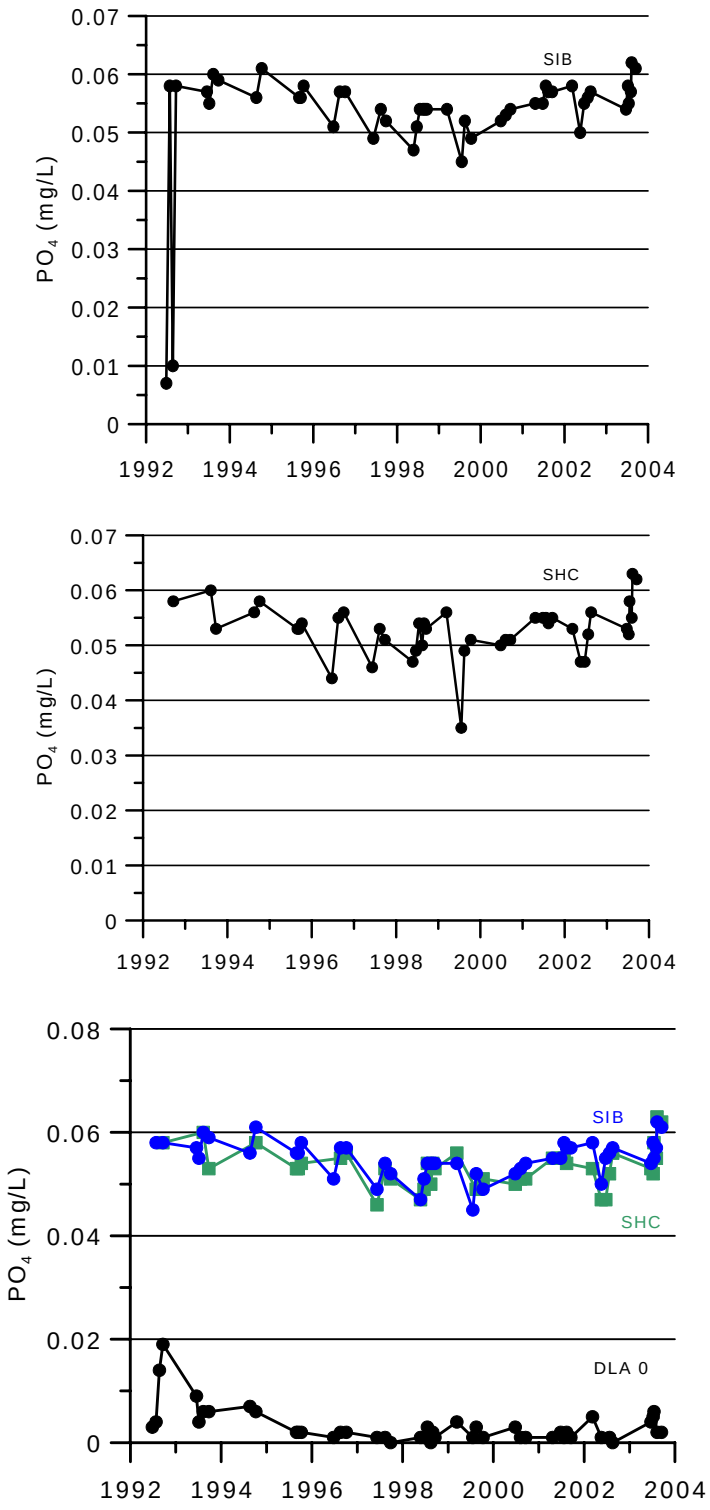


Figure 27. Phosphorus measurements reported for Silent Creek (top) and Short Creek (middle) and stream values compared to the surface sample from Diamond Lake (bottom). Errant PO_4 values from SIB and SHC have bee omitted from the composite bottom plot.

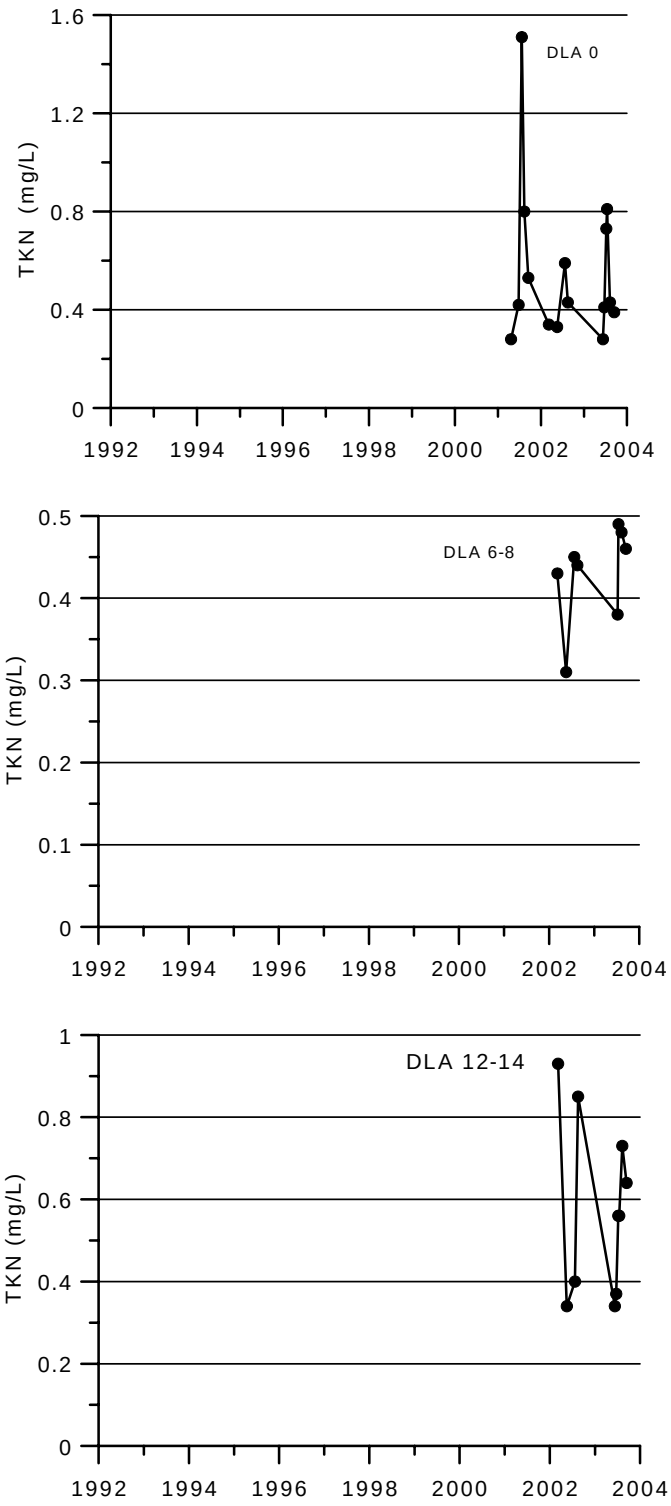


Figure 28. Total Kjeldahl nitrogen for three different depths in Diamond Lake from 2002 and 2003.

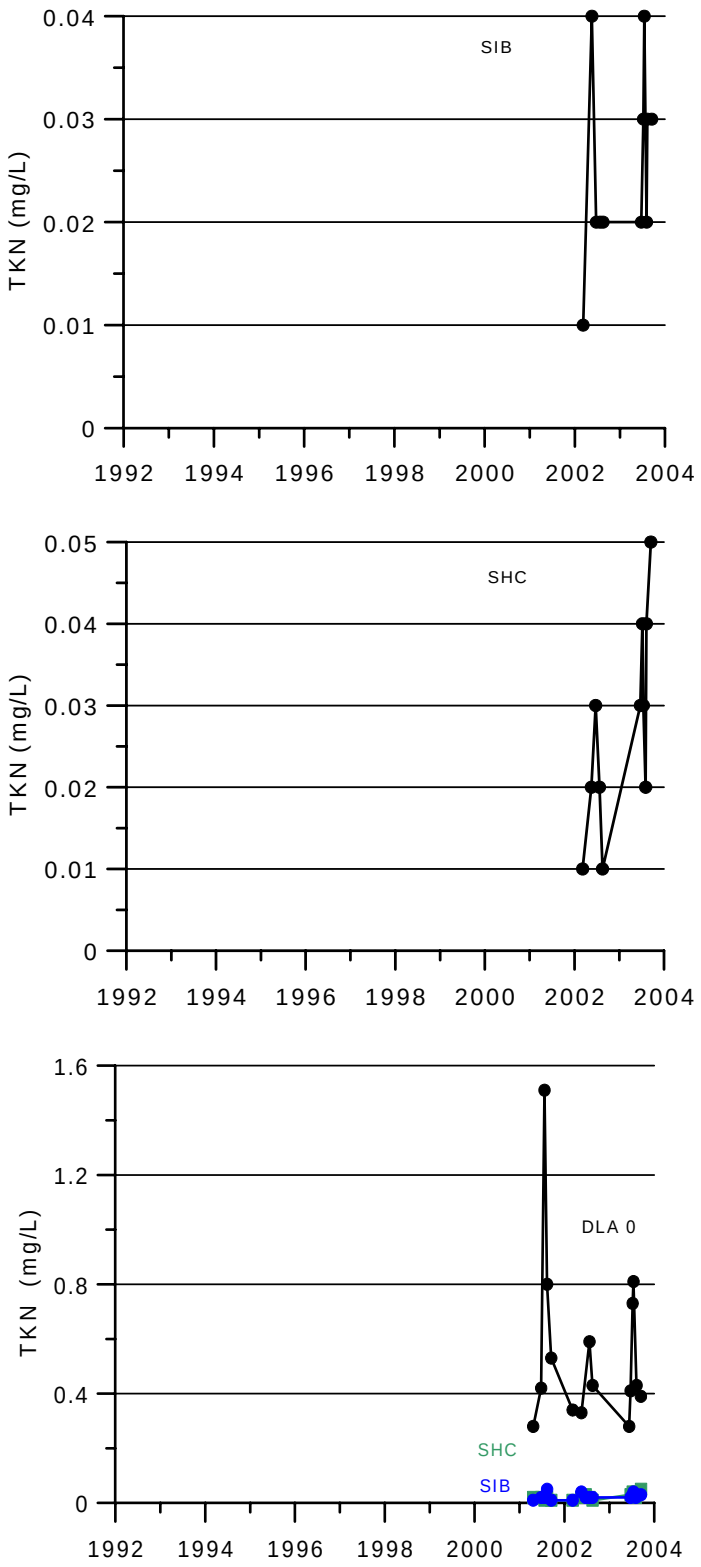


Figure 29. Total Kjeldahl nitrogen reported for Silent Creek (top) and Short Creek (middle)and stream values compared to the surface sample from Diamond Lake (bottom).

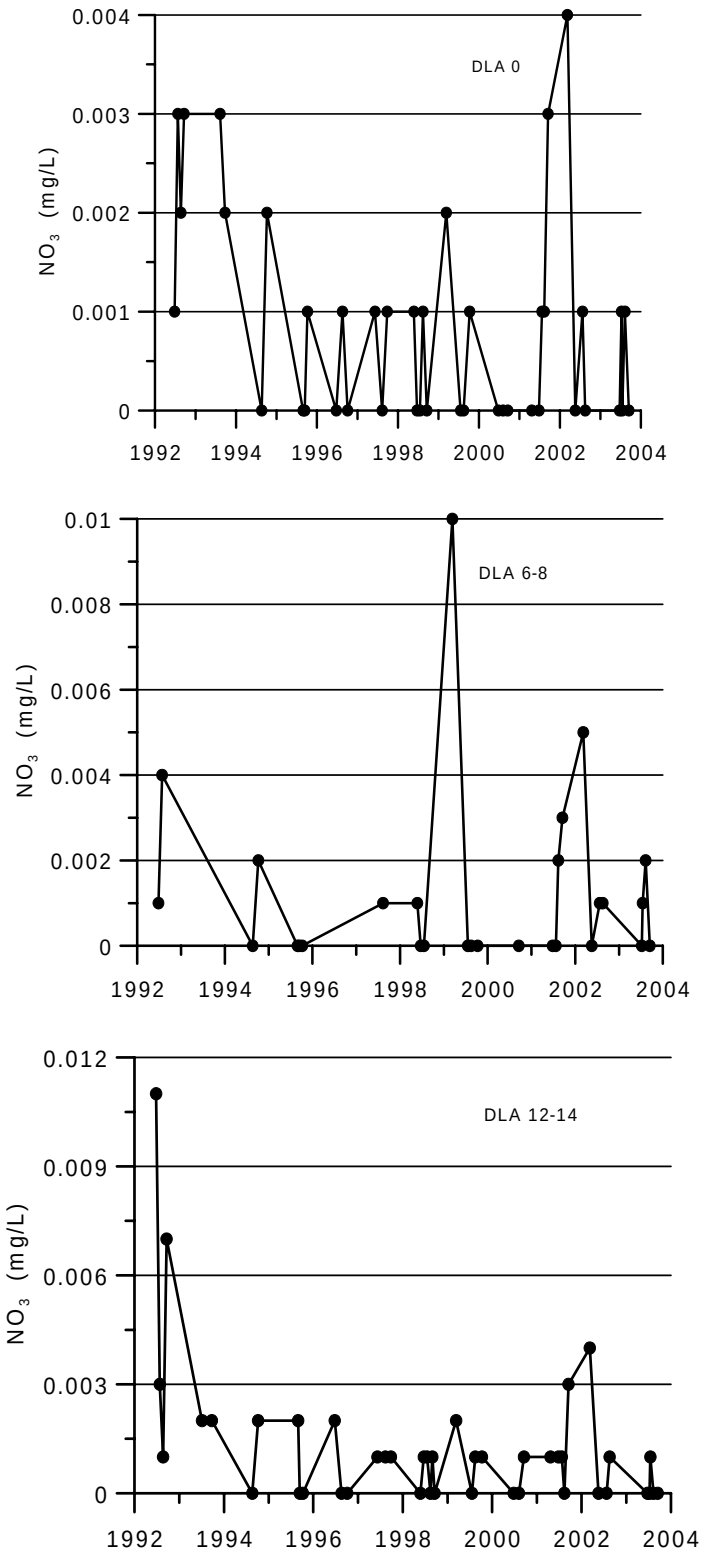


Figure 30. Nitrate-nitrogen reported for three different depths in Diamond Lake from 1992-2003.

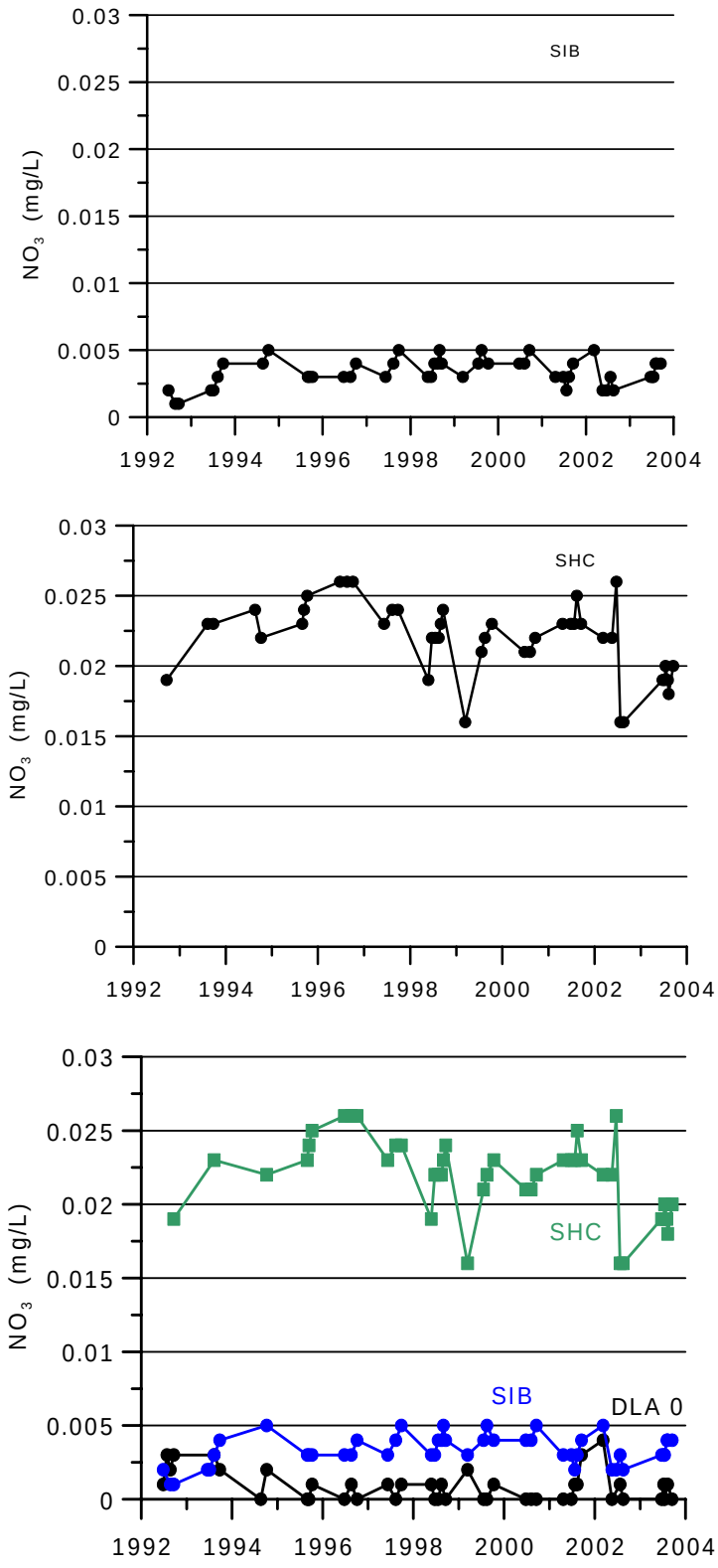


Figure 31. Nitrate measurements reported for Silent Creek (top) and Short Creek (middle) and stream values compared to the surface sample from Diamond Lake (bottom). Errant values from SIB and SHC have been removed from the composite plot at the bottom.

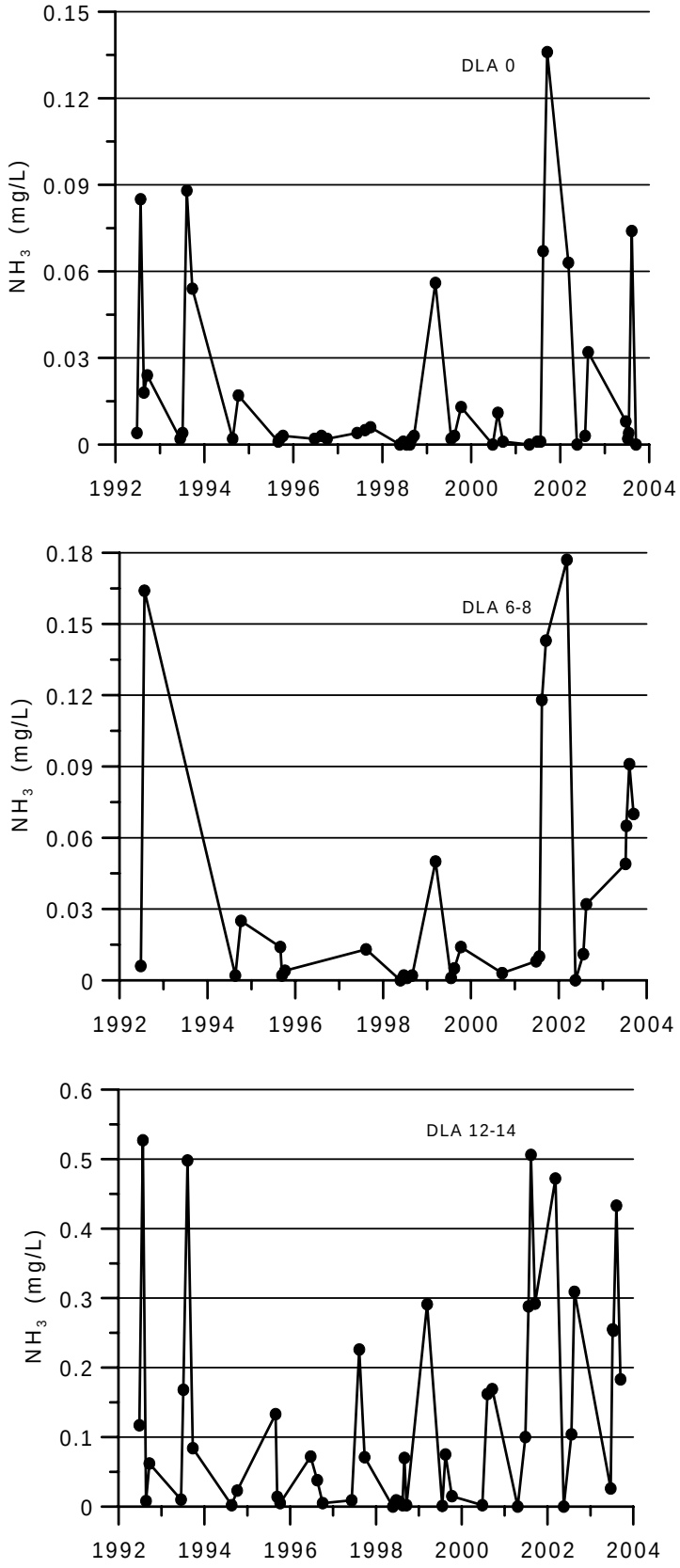


Figure 32. Ammonia-nitrogen measurements reported for three different depths in Diamond Lake from 1992-2003.

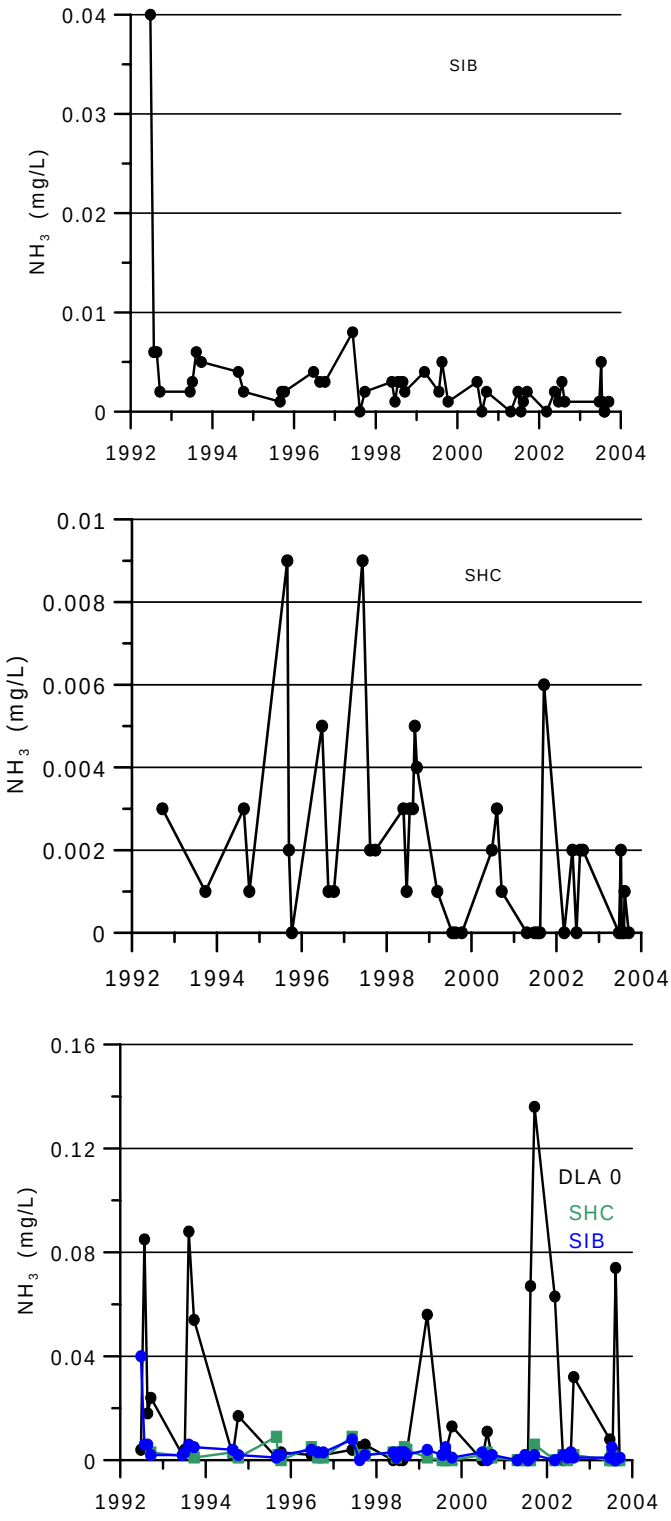


Figure 33. Ammonia-nitrogen measurements reported for Silent Creek (top) and Short Creek (middle)and stream values compared to the surface sample from Diamond Lake (bottom).

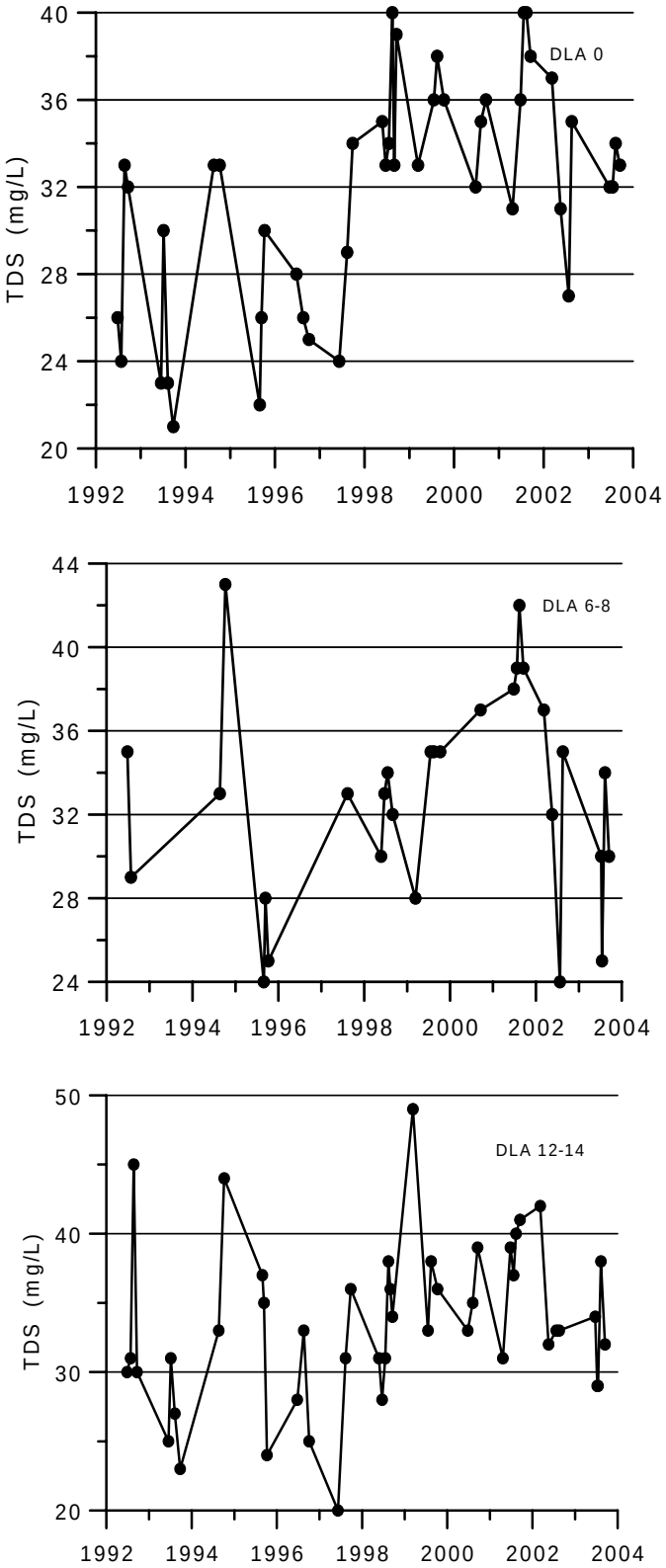


Figure 34. Total dissolved solids reported for three different depths in Diamond Lake, 1992-2003.

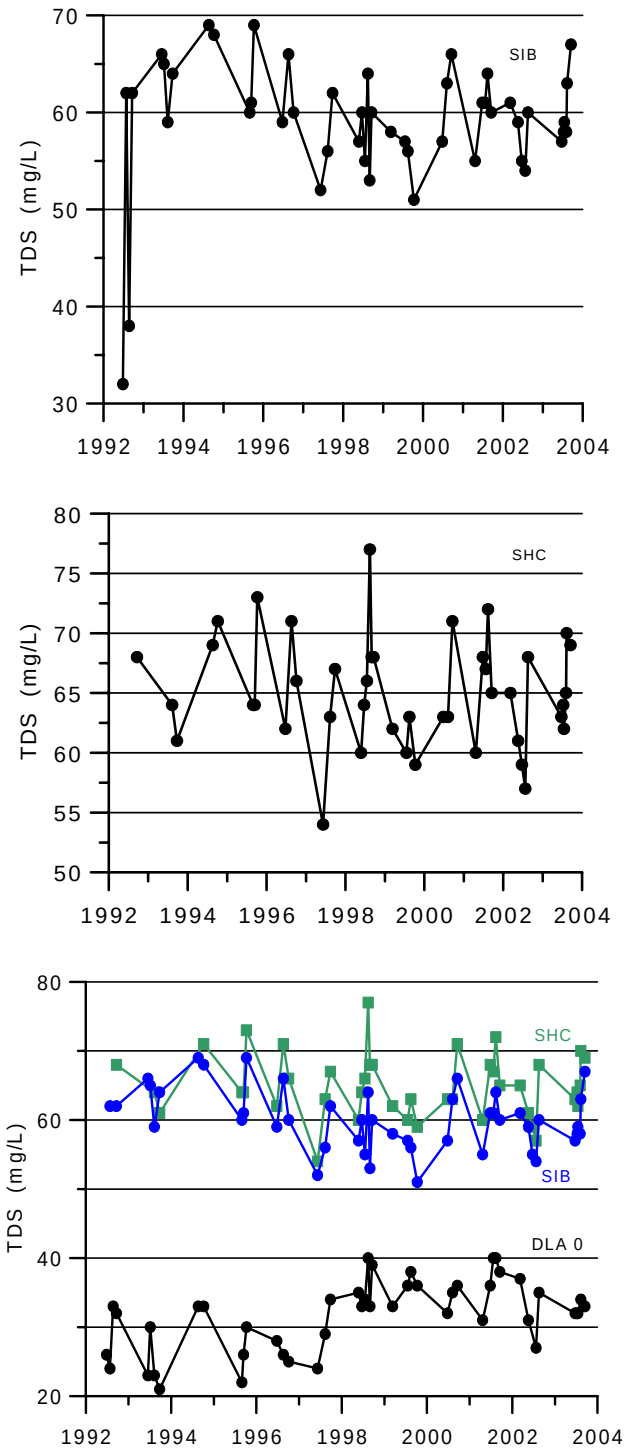


Figure 35. Total dissolved solids reported for Silent Creek (top) and Short Creek (middle)and stream values compared to the surface sample from Diamond Lake (bottom).

Major ions were analyzed in August 2003 for the primary sampling sites and the groundwater observation wells installed in July 2003. The proportion of major ions for Diamond Lake and the stream sites are very similar (Figure 36). The ground water samples show considerably greater variation in major ions, which presumably reflect differences in contact with various deposits and dissolution rates of the lithography.

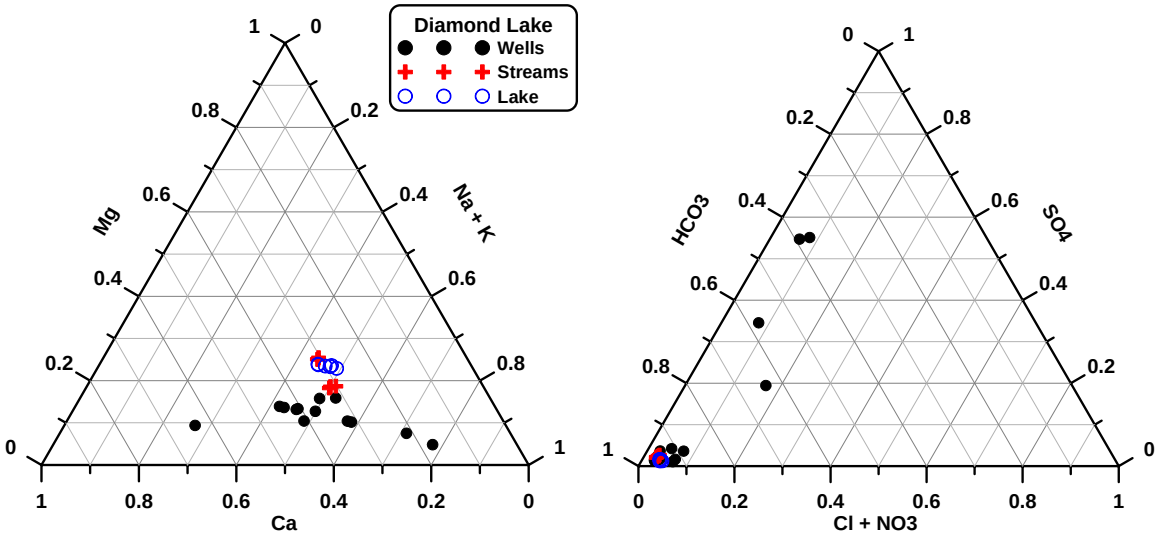


Figure 36. Proportions of major ions for Diamond Lake (O), tributary streams (+), and groundwater samples (●) from samples collected in august 2003.

6. Zooplankton:

a. Overview

Zooplankton density in Diamond Lake has remained high, but largely because of the high abundance of rotifers. As a consequence, the percent of organisms that are considered viable food targets for fish has dropped dramatically from the early 1990's (Figure 37). There were minor recoveries of percent edible zooplankton in fall 1998 and spring 2000, but on the whole, the lake has experienced a substantial loss in food-source zooplankton. Many of these larger "food-grade" zooplankton are also the most effective phytoplankton grazers and consequently, the loss of the larger zooplankton not only reduces the available food for planktivorous fish, but also reduces the grazing pressure on the phytoplankton.

Not only has the food-quality of the zooplankton community been altered, but also the absolute density of zooplankton has fluctuated greatly (Figure 38). In 1999 and 2003, the density of rotifers increased dramatically. Because the density of rotifers is so much greater than the other groups of zooplankton, it is necessary to remove the rotifers to examine the changes in copepods and cladocerans separately (Figure 39). The cladocerans also showed increases in 1999 and 2003, coinciding with the major peaks in the rotifers.

Part of the difficulty in interpreting a change in abundance of zooplankton is that the sampling through the study period has not been consistent in terms of when the samples were collected. Since there is a seasonal dynamic with respect to zooplankton abundance where populations generally increase in the summer, it is necessary to evaluate changes in zooplankton abundance with respect to seasonal variation.

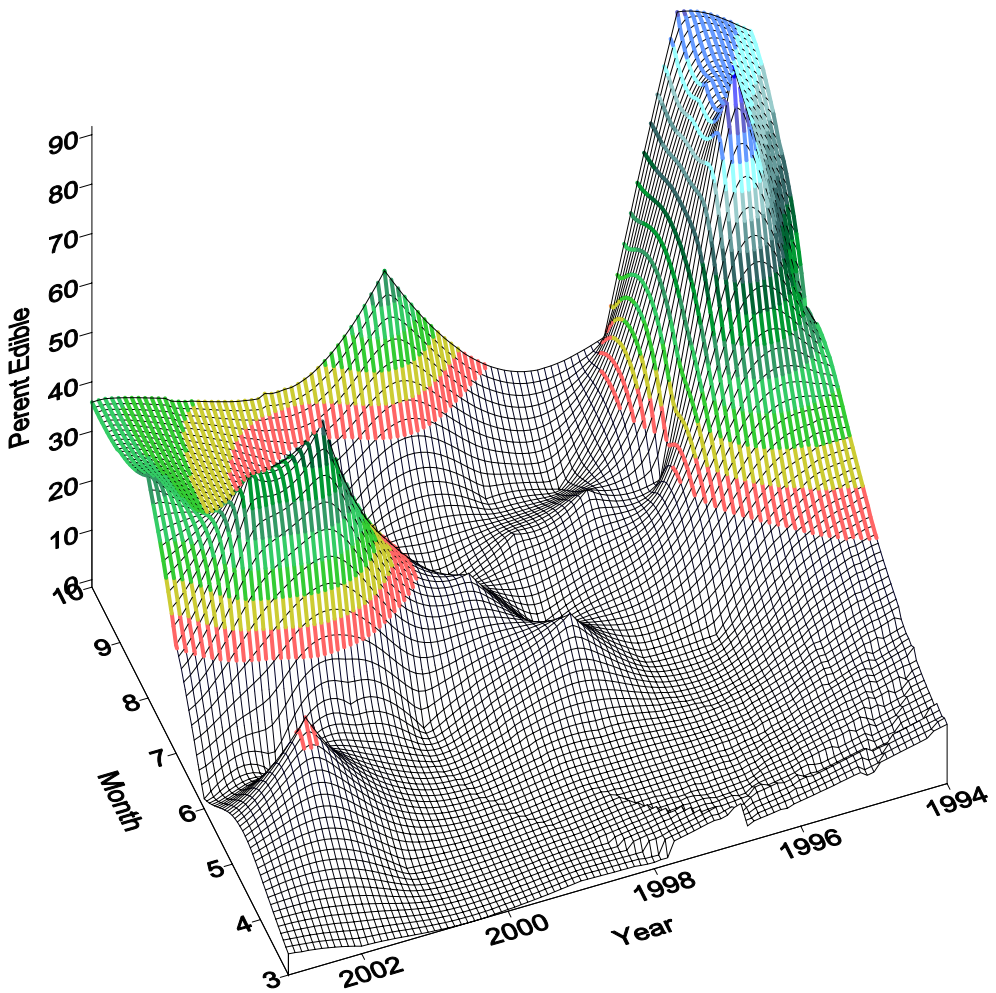


Figure 37. Percentage of "edible" zooplankton by year and month, using the classification of A. Vogel (unpublished).

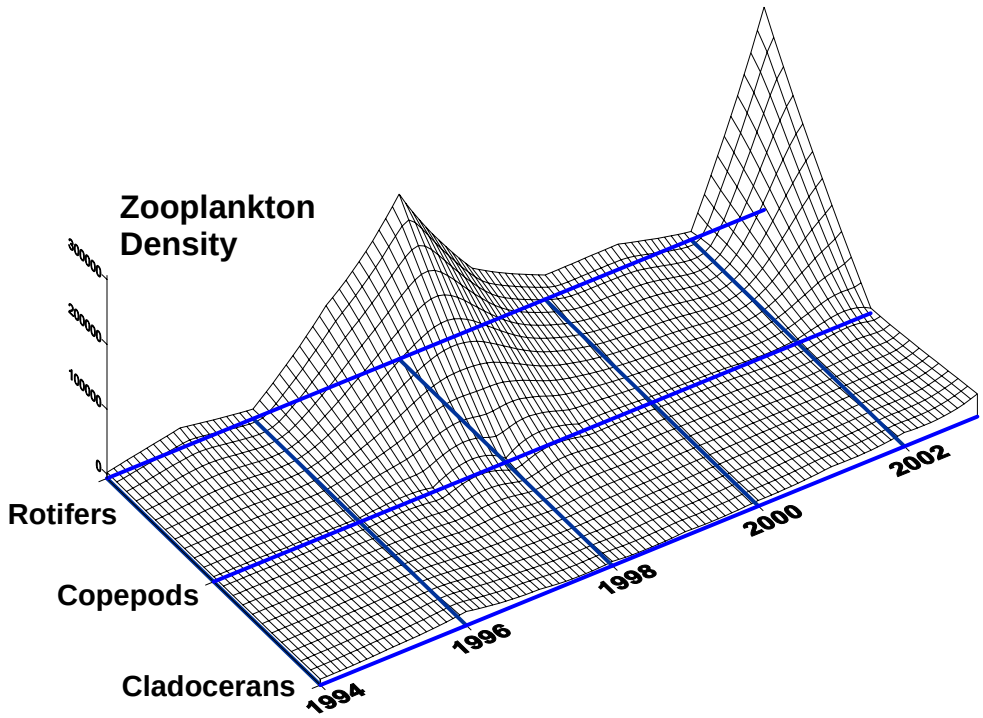


Figure 38. Zooplankton density (number per cubic meter) from 1994 to 2003.

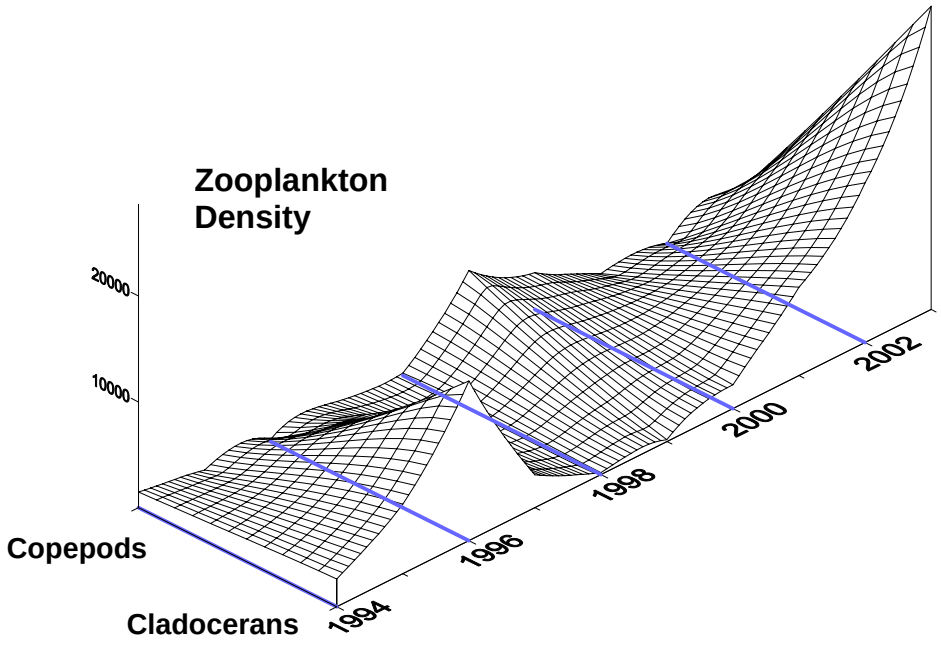


Figure 39. Density of copepods and cladocerans by year.

b. Copepods

Copepods currently comprise a relatively small percentage of the zooplankton community in Diamond Lake (Figures 38 and 39). As a group, the copepods appear to exhibit less temporal variation in population density than other groups of zooplankton in Diamond Lake (Figure 40). Furthermore, a large portion of the copepods is now comprised of smaller cyclopoid copepods. Examples of population variation for two copepods representative of the community in Diamond Lake are shown in Figures 41 and 42).

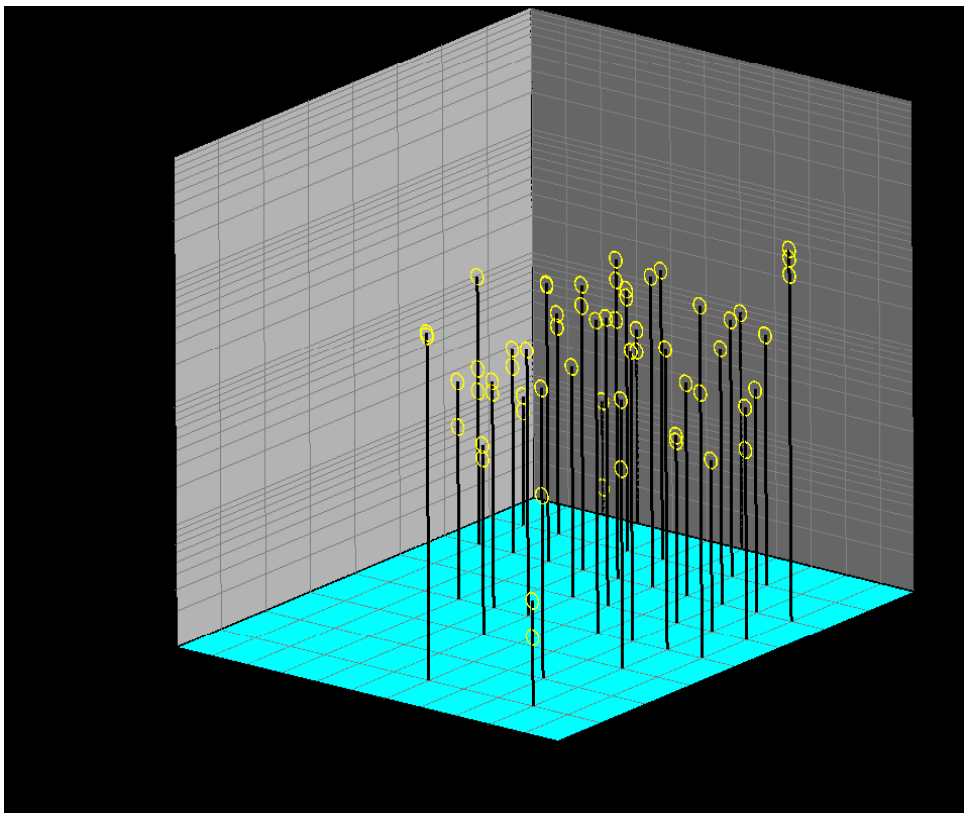


Figure 40. Copepod density (Number per m^3) in Diamond Lake plotted by year and month.

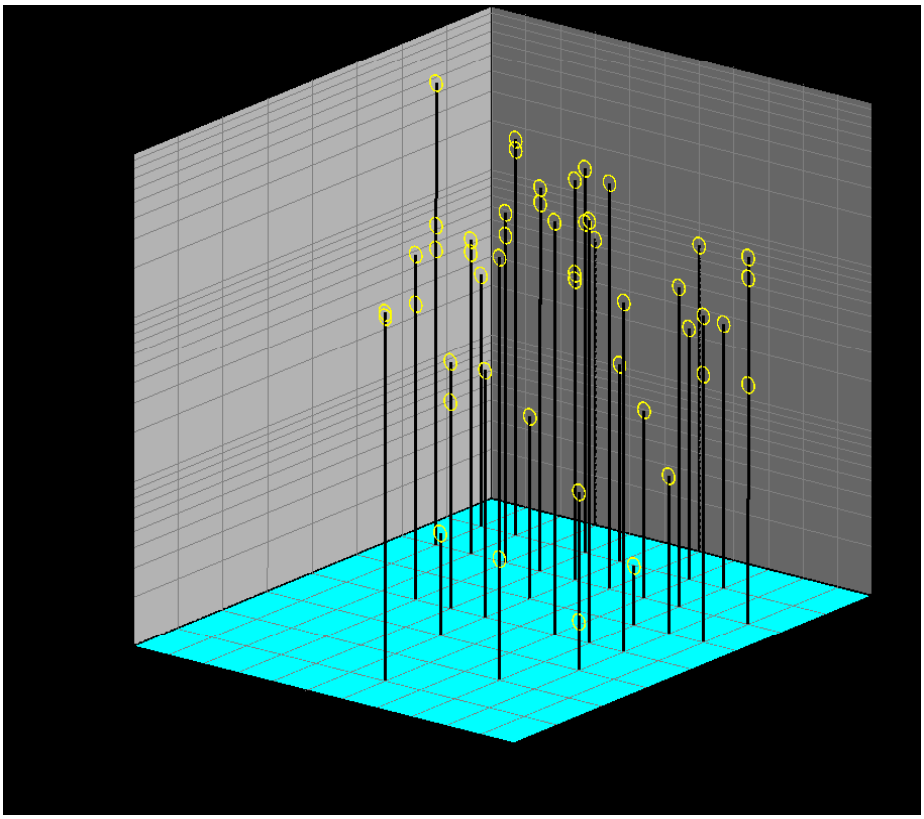


Figure 41. Density of *Orthocyclops modestus* by year and month.

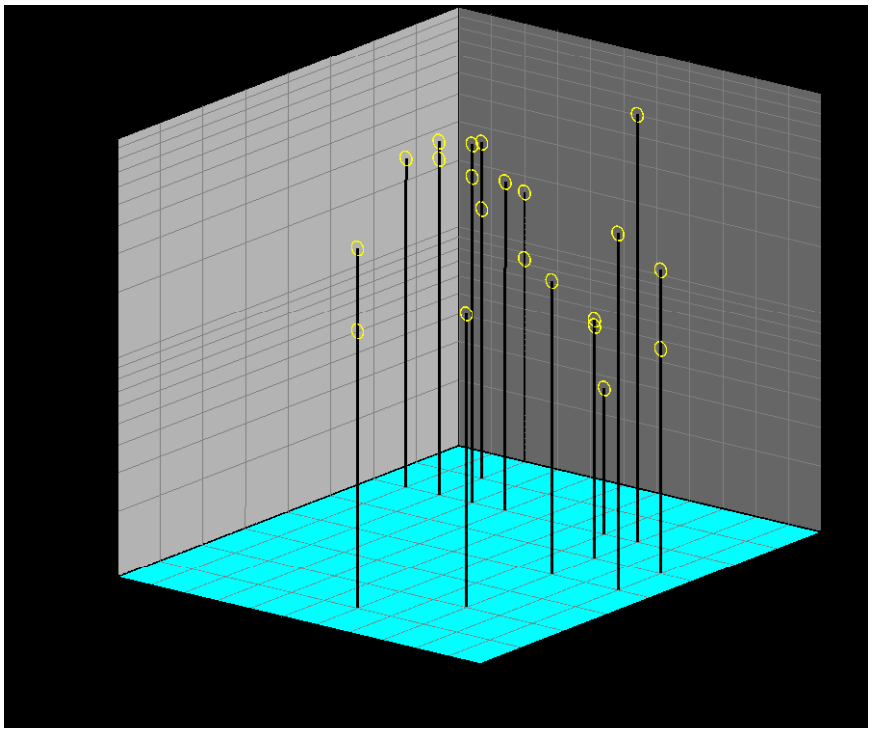


Figure 42. Density of *Macrocyclops albidus* by year and month.

c. Cladocerans

The overall density of cladocerans has fluctuated considerably in the period from 1994-2003 (Figures 38,39 and 43). Examples of population fluctuation for selected taxa of cladocerans are shown in Figures 44-51). The large increases in the cladocerans in 1999 and 2003 were dominated by the smaller cladocerans such as *Bosmina longirostris* (Figure 45). The single largest zooplankton taxon to be sampled in Diamond Lake occurred in June of 2003 when *Bosmina longirostris* densities reached almost 300,000 individuals per m^3. Larger daphnids such as *Daphnia pulicaria* (Figure 50) have all but been eliminated from the lake and have been replaced by smaller species such as *D. galeatae mendotae* (Figure 49).

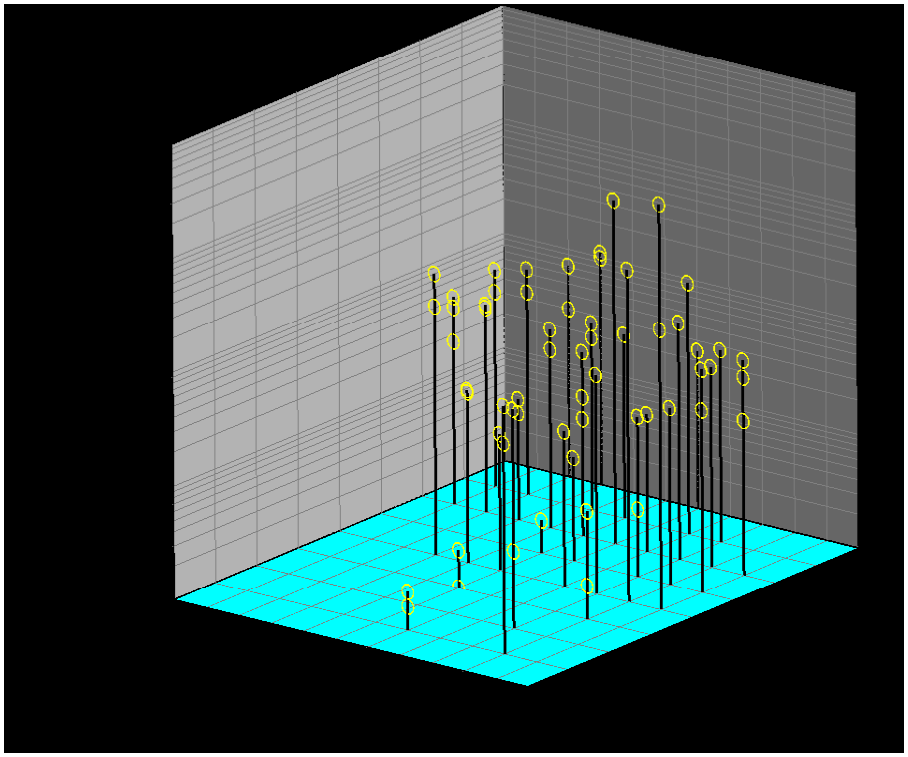


Figure 43. Density of cladocerans (number per m^3) in Diamond Lake plotted by year and month.

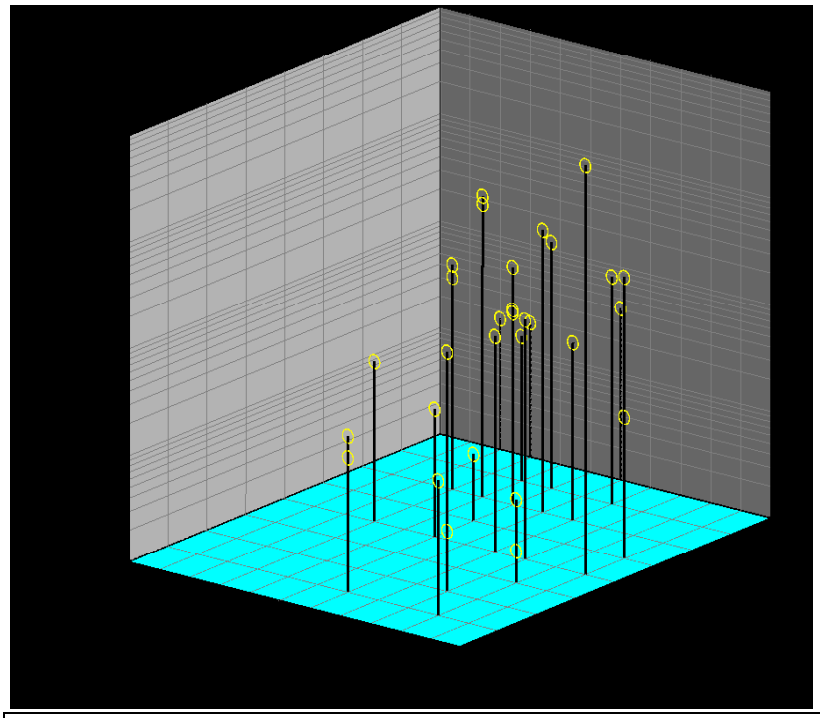


Figure 44. Density of *Alona costata* (#/m^3) by year and month

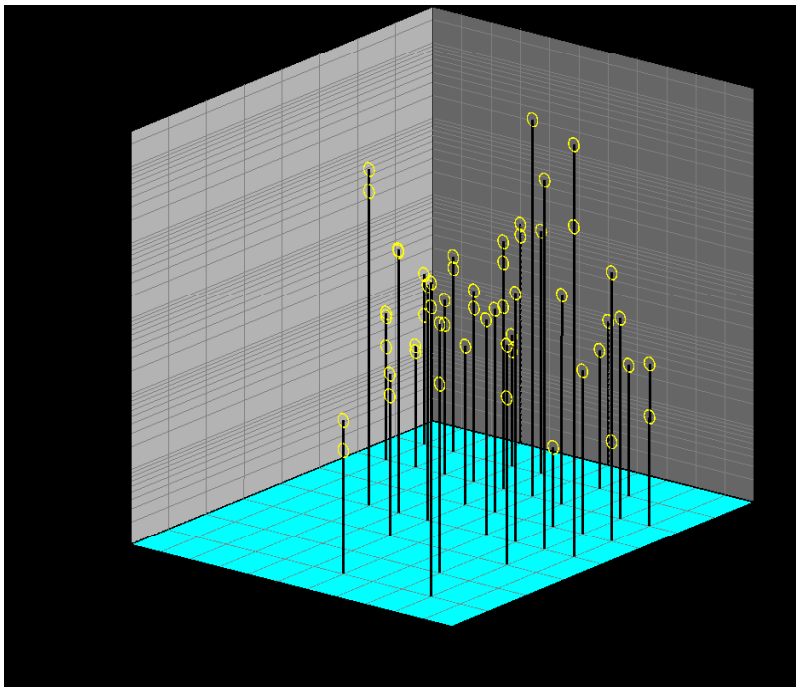


Figure 45. Density of *Bosmina longirostris* by year and month.

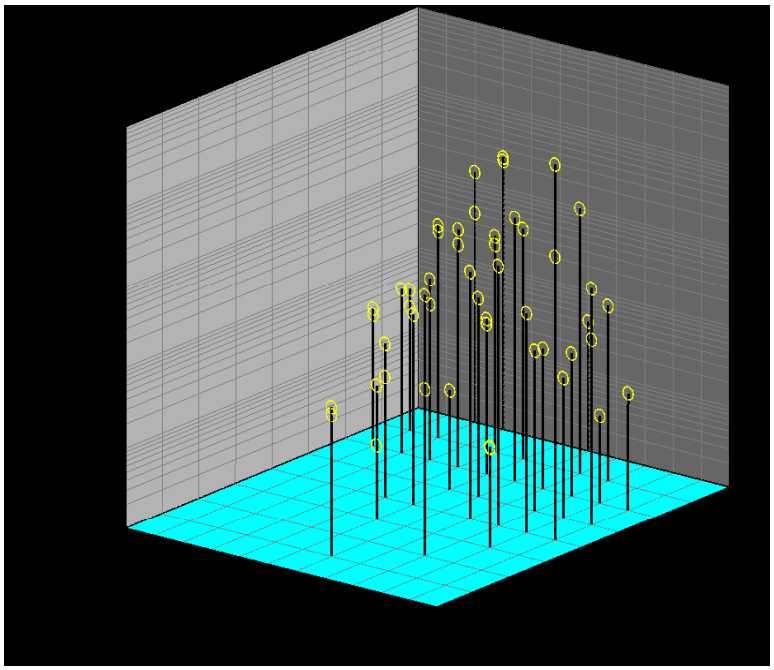


Figure 46. Density of *Chydorus sphaericus* (#/m^3) by year and month.

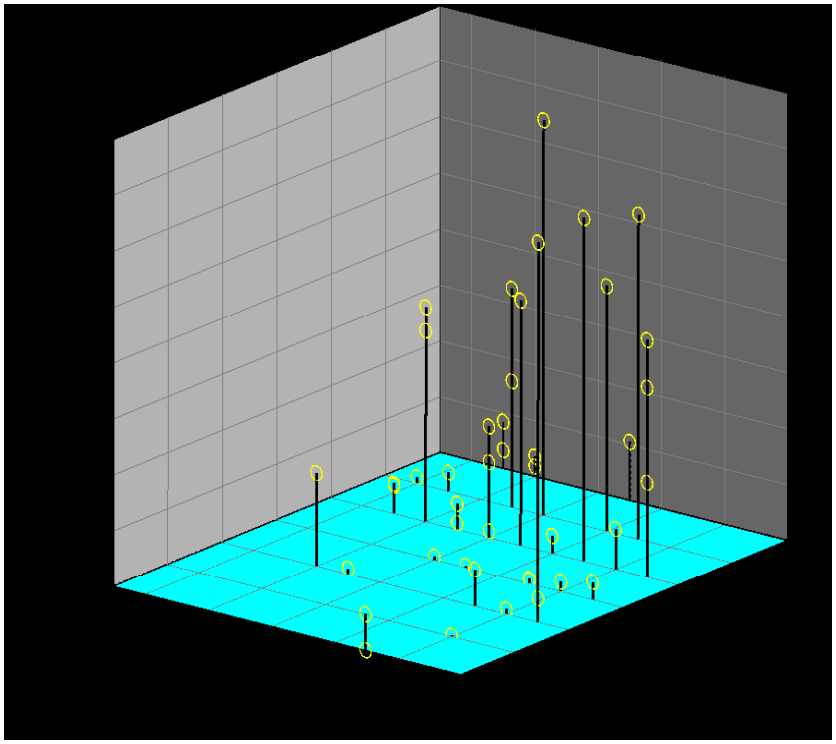


Figure 47. Density of *Ceriodaphnia pulchella* (#/m^3) by year and month.

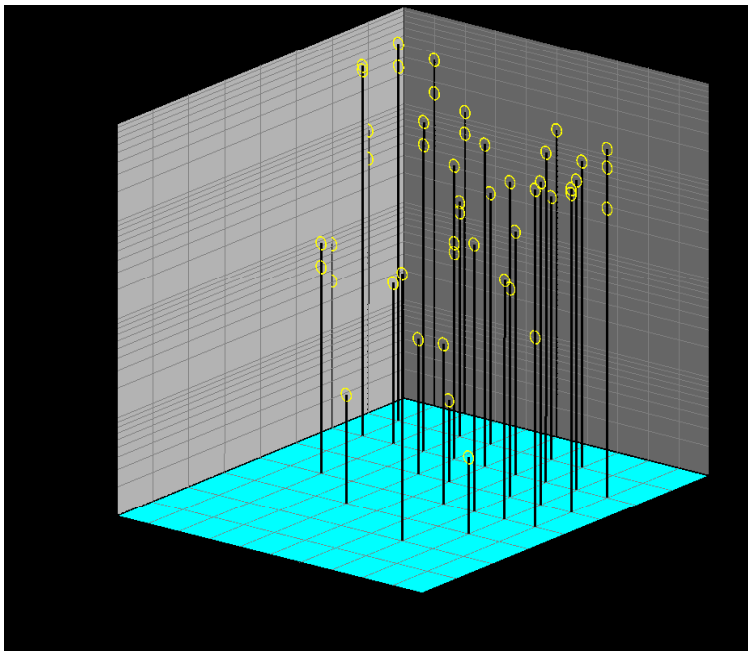


Figure 48. Density of *Diaphanosoma brachyuran* (#/m^3) by year and month.

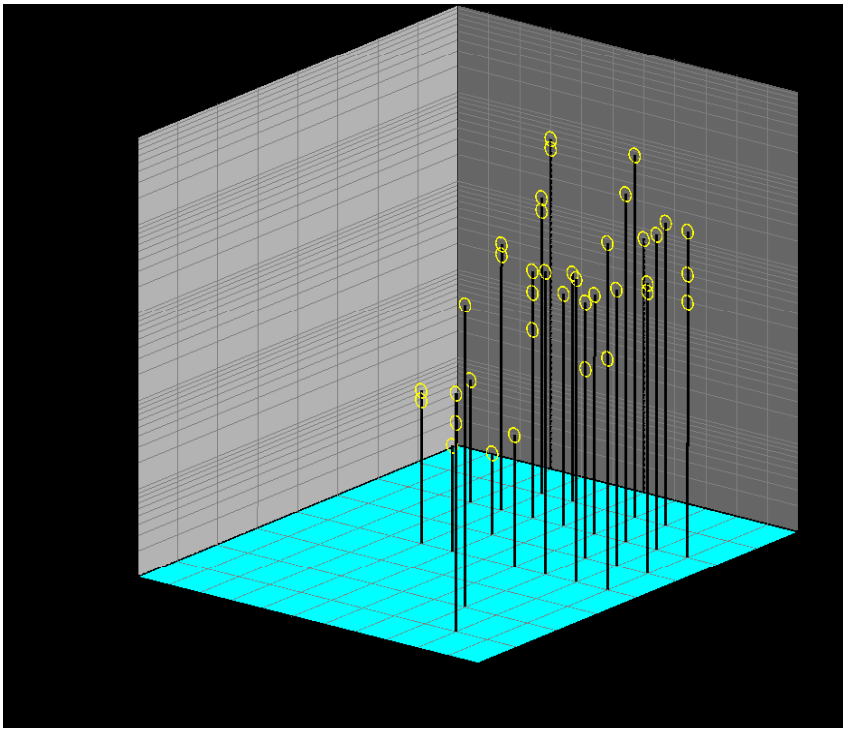


Figure 49. Density of *Daphnia galeata mendotae* (#/m^3) by year and month

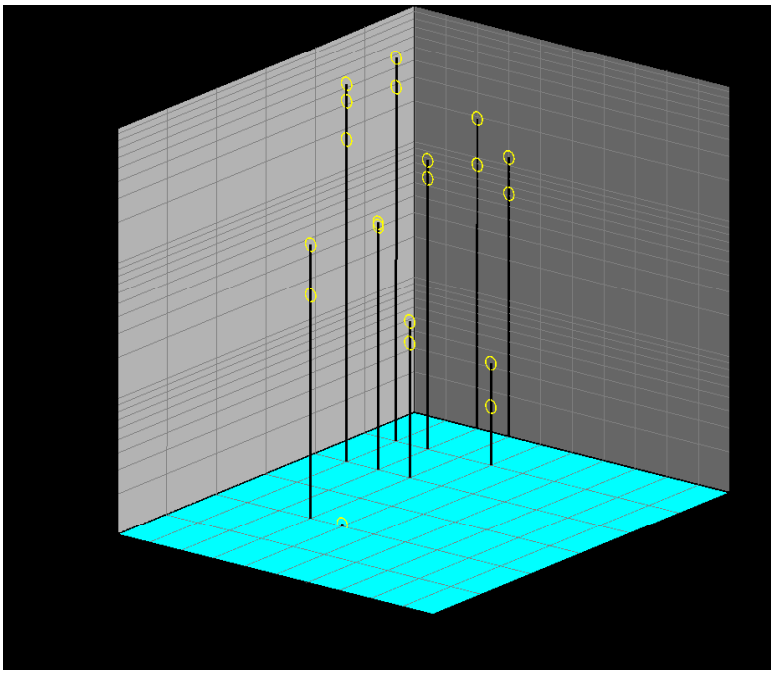


Figure 50. Density of *Daphnia pulicaria* (#/m^3) by year and month.

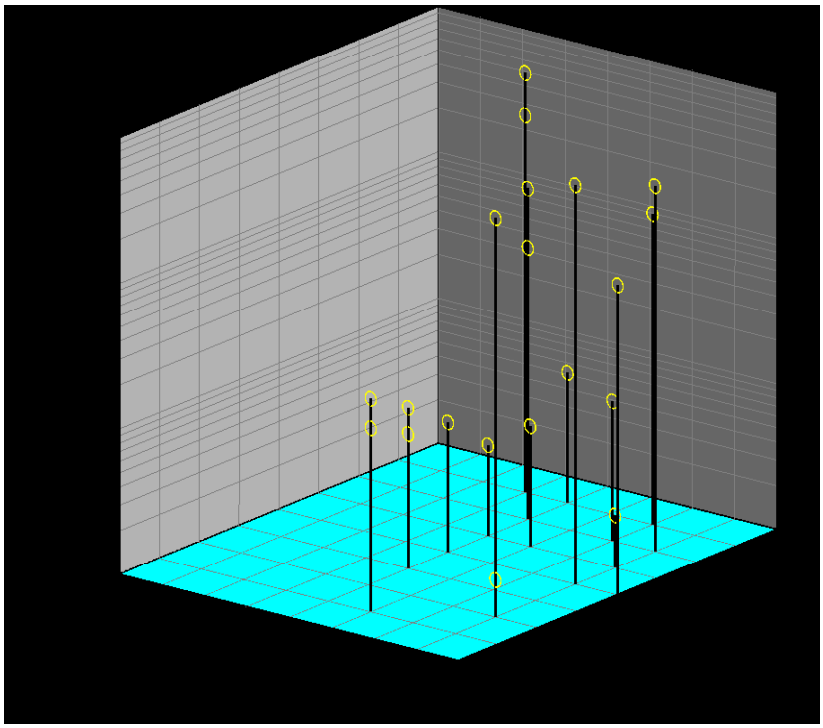


Figure 51. Density of *Daphnia rosea X laevis* (#/m^3) by year and month

d. Rotifers

The rotifers are the smallest of the zooplankton and there abundance in high numbers is often associated with eutrophic lakes. Rotifers are generally the most abundant zooplankton group in Diamond Lake (Figure 38). Although *Bosmina* reached the greatest density recorded in Diamond Lake in Jun 2003, all other densities of zooplankton taxa in excess of 100,000 per m^3 (n = 13) have been achieved by rotifers. The rotifers show a pronounced increase from spring to fall (Figure 52). Examples of temporal variations among dominant taxa of rotifers are shown in Figures 53 to 60. The most abundant rotifer genera are *Keratella, Kellicottia, Polyarthra*, and *Filnia*.

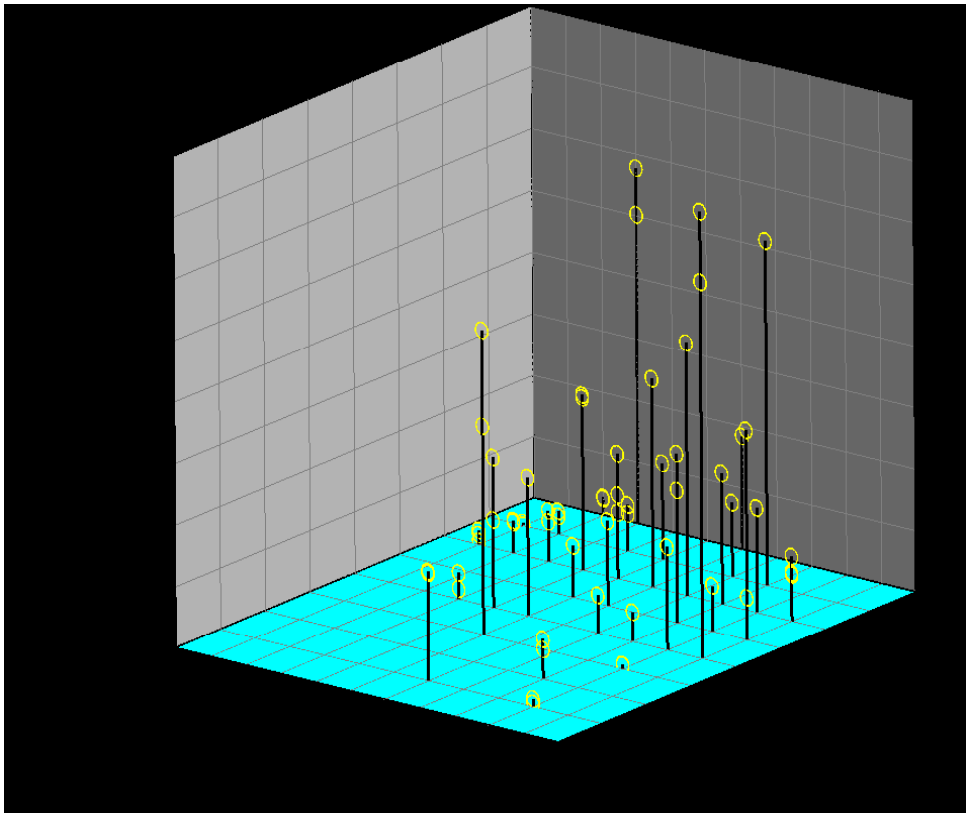


Figure 52. Density of total rotifers (#/m^3) in Diamond Lake by year and month.

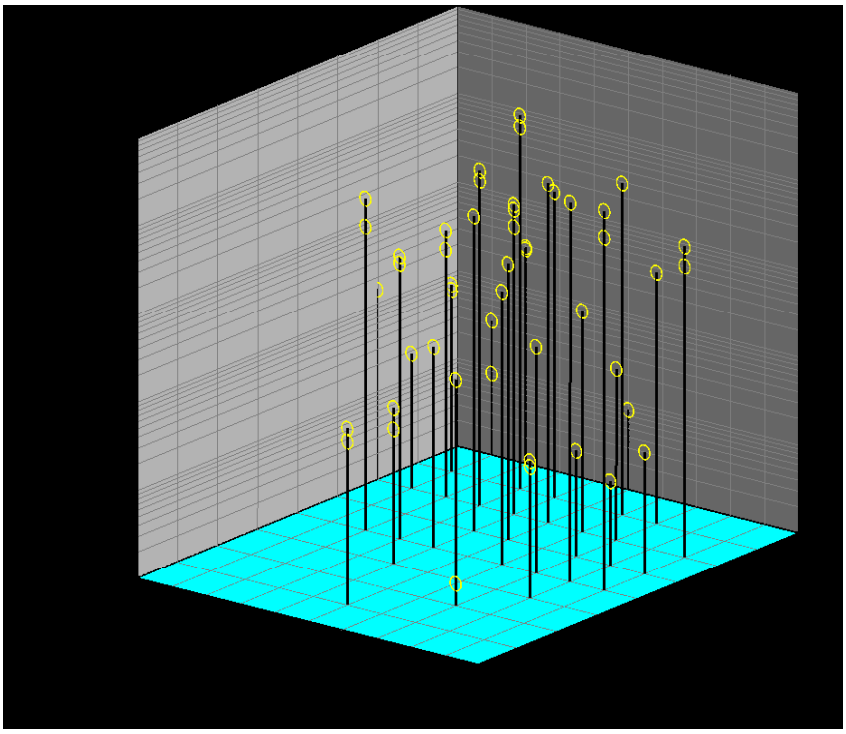


Figure 53. Density of *Asplanchna priodonta* (#/m^3) by year and month

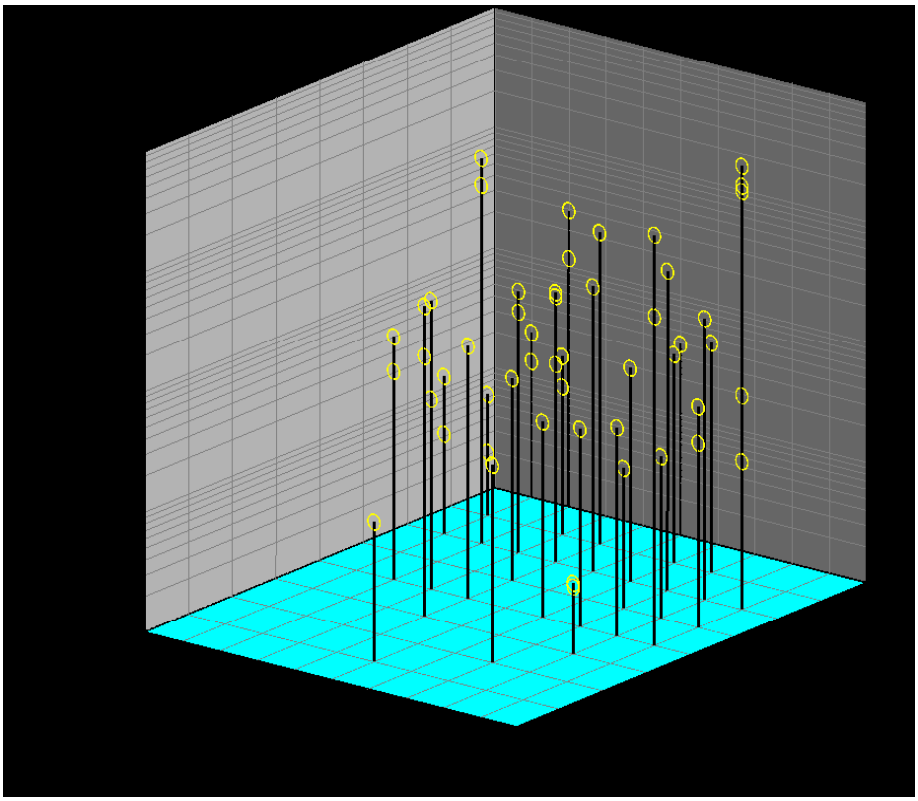


Figure 54. Density of *Conchilus sp.* (#/m^3) by year and month

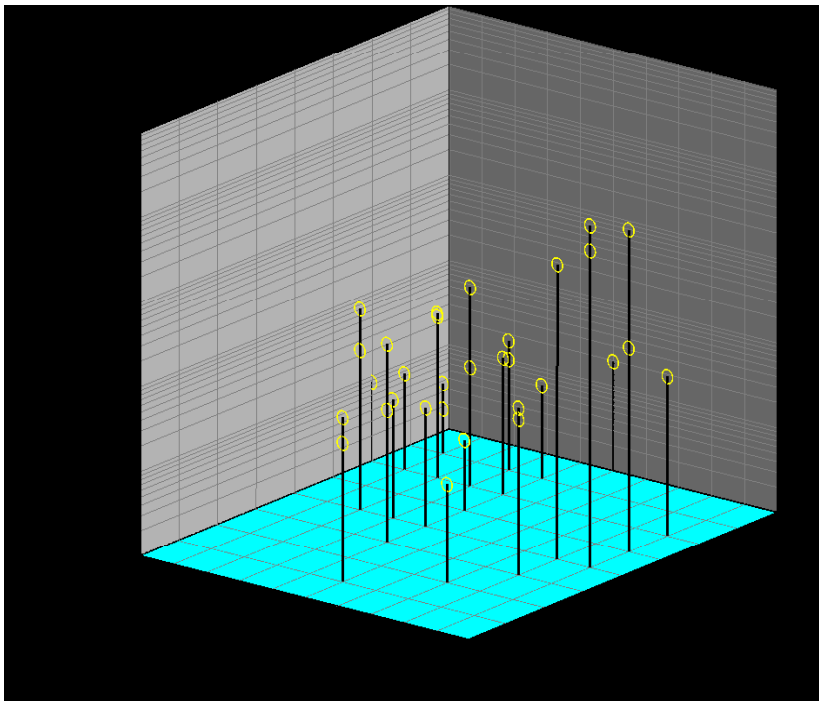


Figure 55. Density of *Filnia terminalis* (#/m^3) by year and month

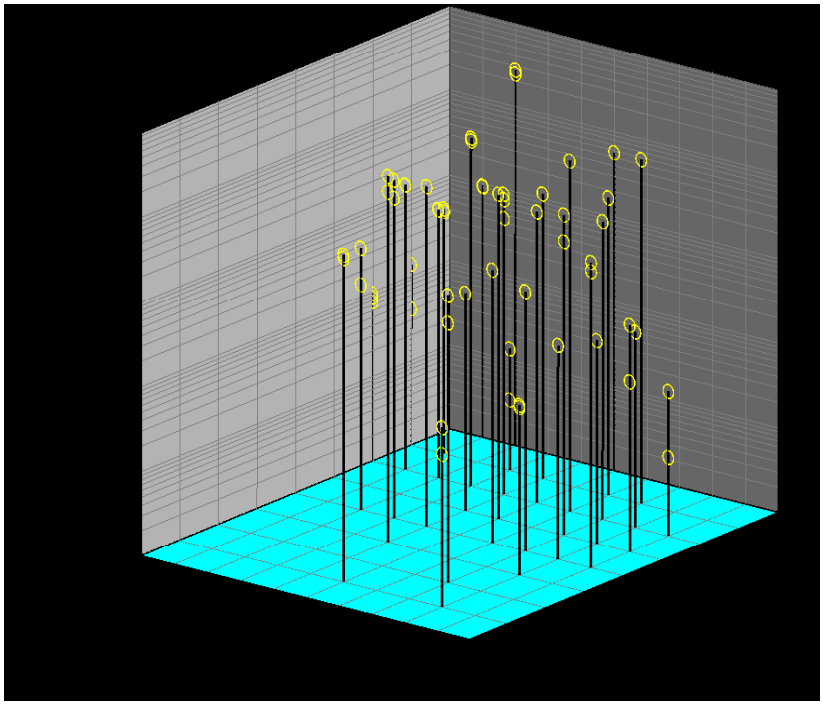


Figure 56. Density of *Keratella cochlearis* (#/m^3) by year and month

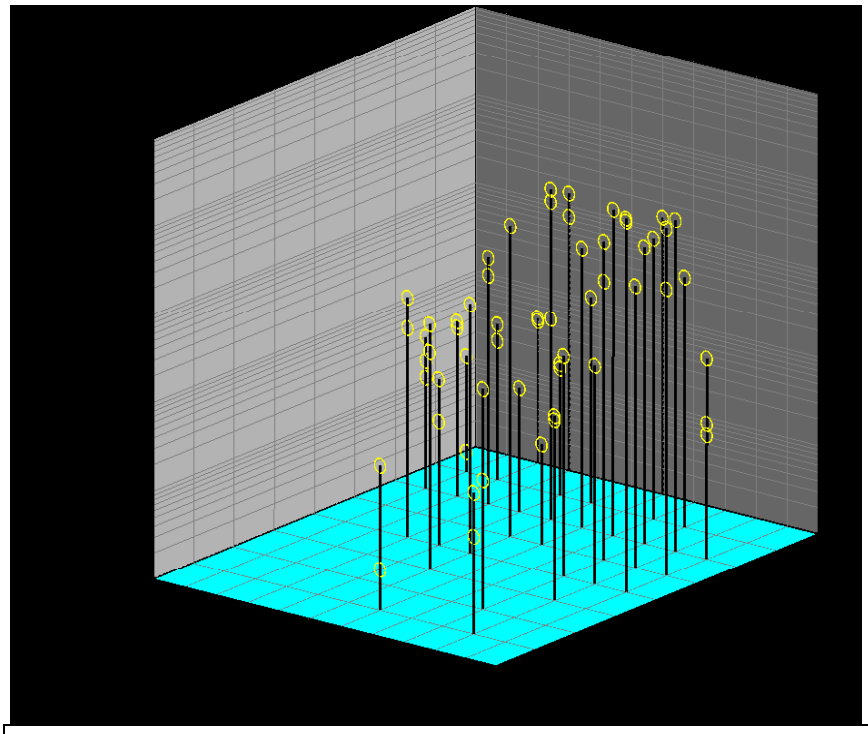


Figure 57. Density of *Keratella longispina* (#/m^3) by year and month

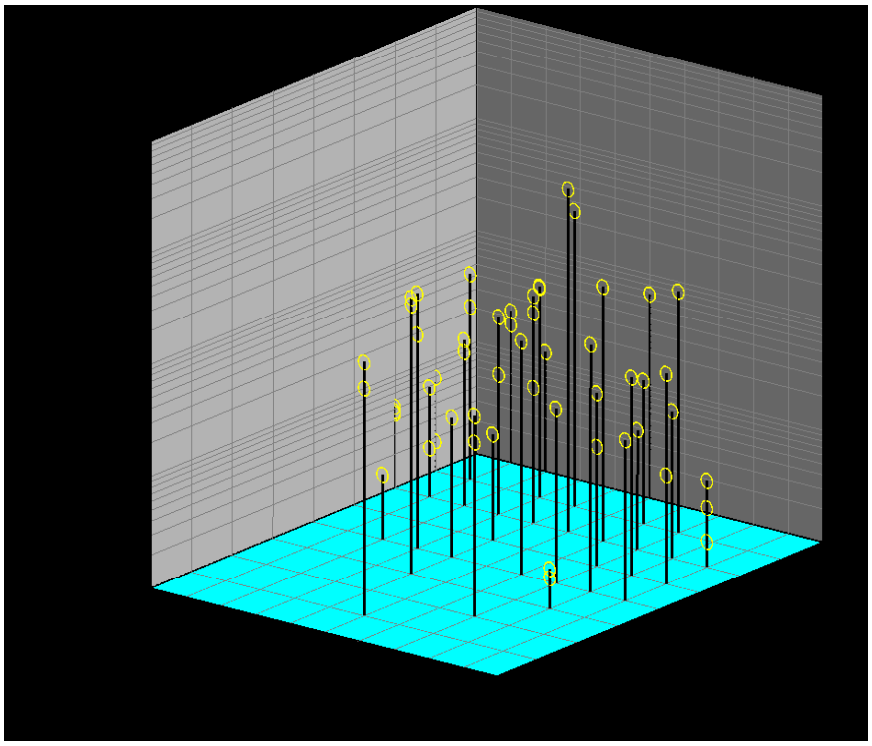


Figure 58. Density of *Polyarthra doliochoptera* (#/m^3) by year and month

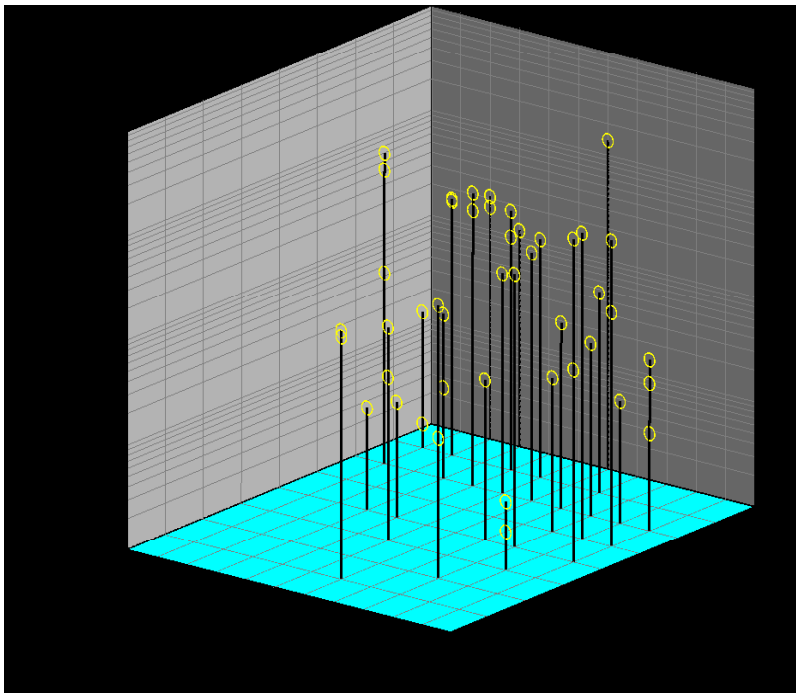


Figure 59. Density of *Synchaeta sp.* (#/m^3) by year and month

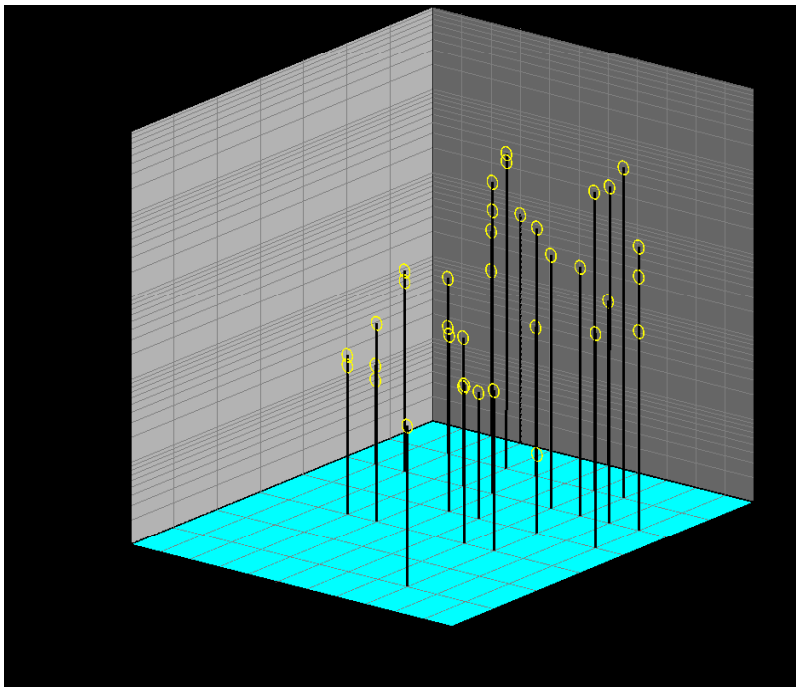


Figure 60. Density of *Trichocerca longiseta* (#/m^3) by year and month

7. Phytoplankton: High phytoplankton abundance is one of the most distinctive features of eutrophic lakes. The phytoplankton abundance can be measured directly through cell density or indirectly by concentration of chlorophyll *a*, Secchi disk transparency or light extinction. Chlorophyll concentrations above 10 ug/L are often associated with eutrophic lakes. Maximum chlorophyll values in 2003 were slightly less that the peak values observed in 2001 (Figure 61). However, the values in 2003 were well above threshold values commonly associated with eutrophic lakes.

Changes in total biovolume (Figure 62) closely mirrored the pattern observed for chlorophyll. A trophic state index based on a summation of assigned rankings applied to individual taxa illustrates a similar pattern as well (Figure 63).

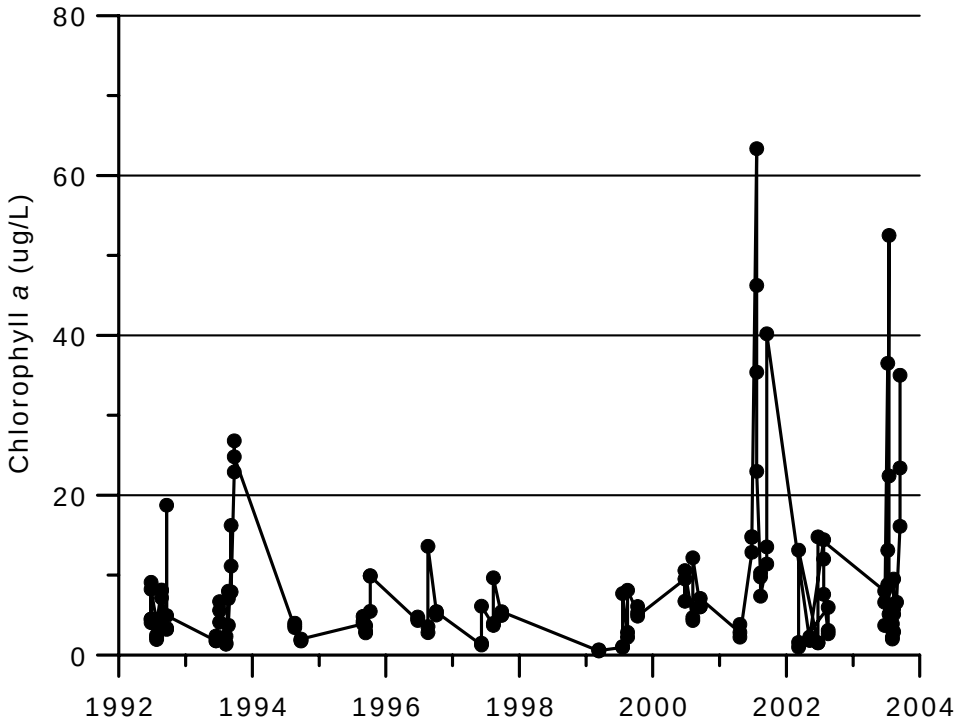


Figure 61. Concentrations of chlorophyll *a* in Diamond Lake from 1992 to 2003.

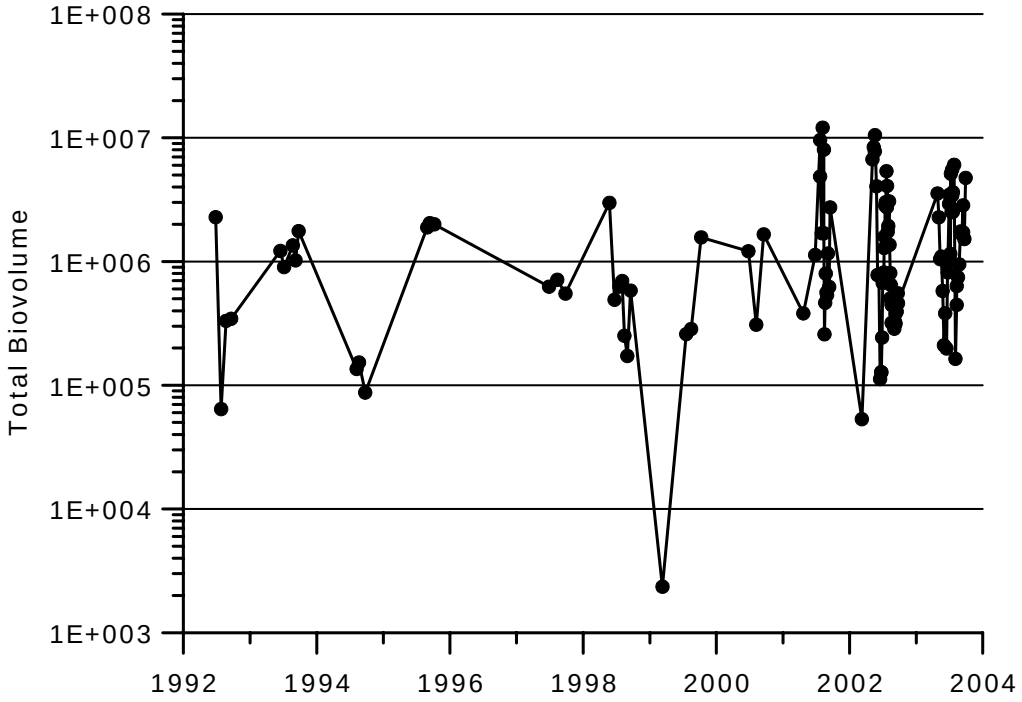


Figure 62. Total phytoplankton biovolume for Diamond Lake from 1992-2003.

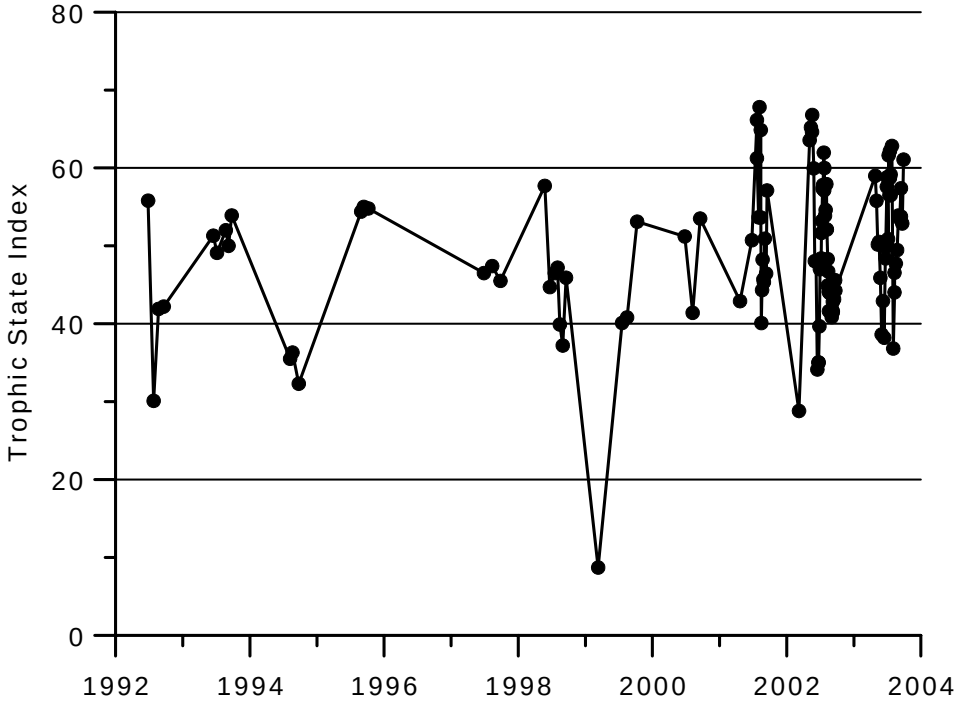


Figure 63. Trophic state index for Diamond Lake based on trophic rankings of phytoplankton taxa (from J. Sweet, unpublished).

b. Chrysophytes

The most numerically abundant phytoplankton group in Diamond Lake is the chrysophytes. These small-celled phytoplankton, although abundant, are so small that they often account for only a small portion of the phytoplankton biovolume (Figure 64). However, since 1999, these phytoplankton taxa have become much more important in the lake, particularly in the spring and fall. Two representative chrysophytes in Diamond Lake are *Chromulina* and *Chrysochromulina*, which are shown in Figures 65 and 66.

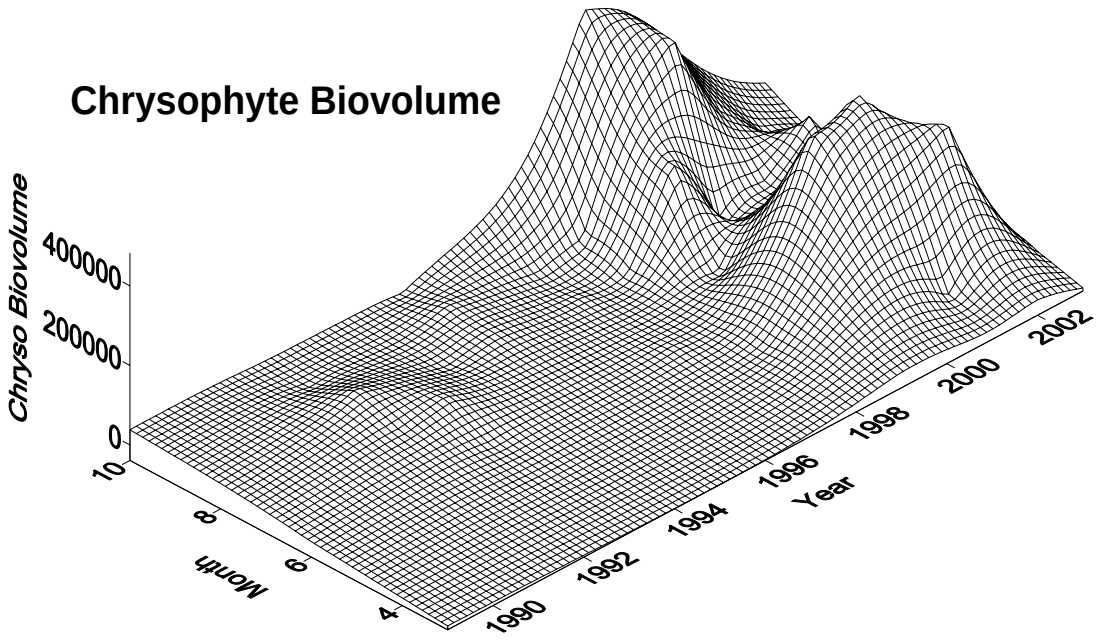


Figure 64. Biovolume of chrysophytes in Diamond Lake by year and month.

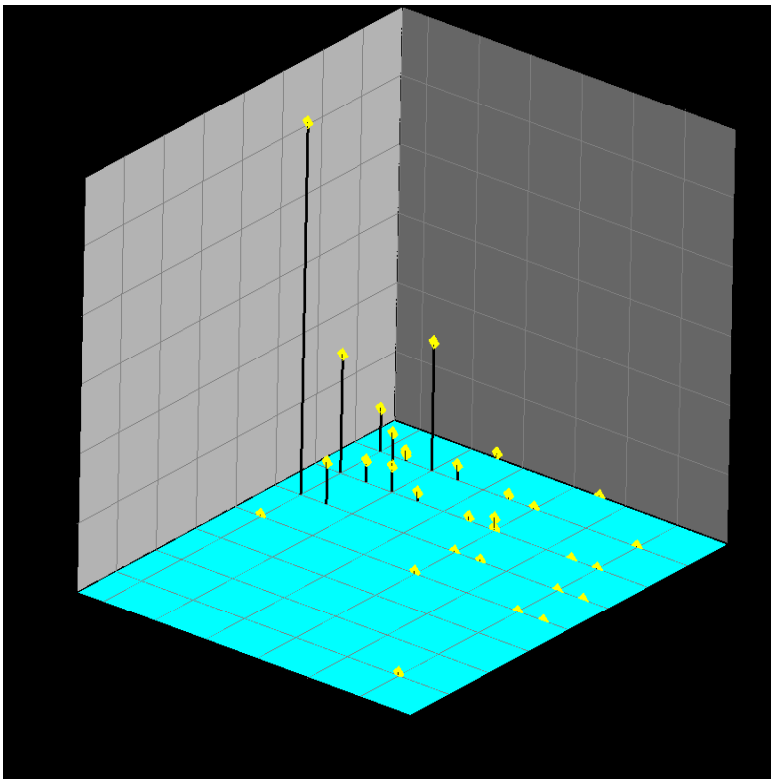


Figure 65. Abundance of *Chromulina sp*. In Diamond Lake as a percent of biovolume plotted by year and month.

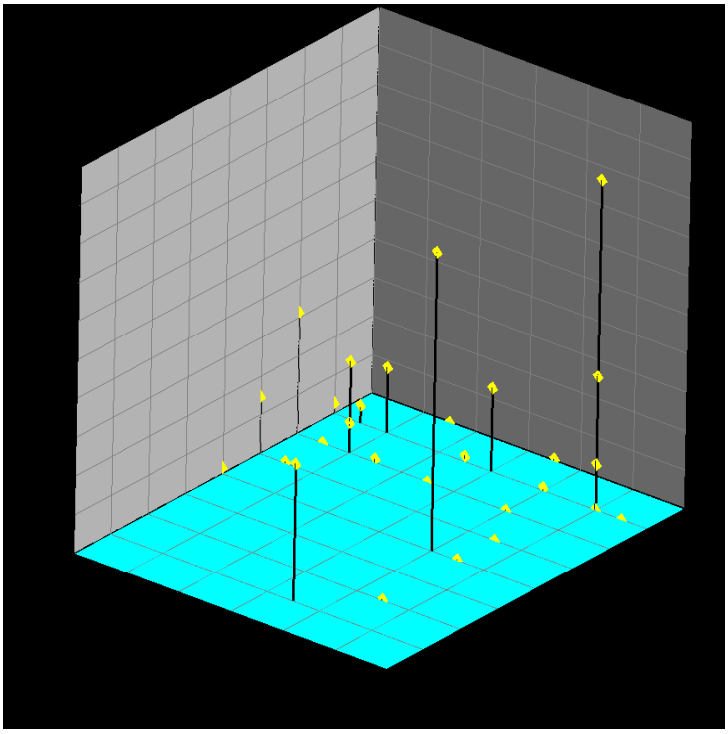


Figure 66. Abundance of *Chrysochromulina* in Diamond Lake as a percent of biovolume plotted by year and month

c. Diatoms

The diatoms are an important component of the phytoplankton assemblage in Diamond Lake. The living diatoms provide a major food source for herbivorous grazing zooplankton and the silicon remains of diatoms (and chrysophytes) provide one of the major elements to the lake sediments. Diatom abundance has varied considerable during the study period, reaching a peak in May 2002 with a bloom of *Synedra parasitica* and *Synedra radians* that dominated the phytoplankton assemblage for the entire month (Figure 67). The greatest diatom biovolumes to occur at other times were all associated with *Fragilaria crotonensis,* which reached peak values in April, July, and September 2003. Whereas the *Synedra* and *Fragilaria* have shown dramatic increases in Diamond Lake, other taxa such as *Asterionella formosa* have shown substantial decreases in percent biovolume. Examples of temporal variation among representative diatom taxa are shown in Figures 68-71. Again, it is difficult to determine if these observations are related to trends because so few samples have been collected from Diamond Lake in the non-summer period.

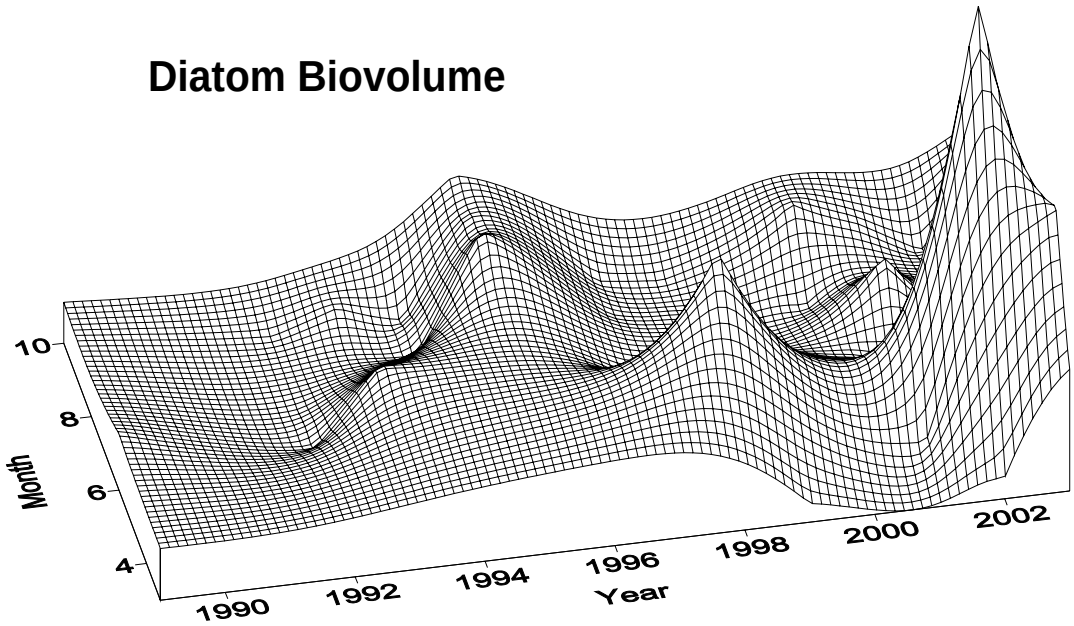


Figure 67. Relative concentration of diatom biovolume in Diamond Lake from 1992-2003 by month.

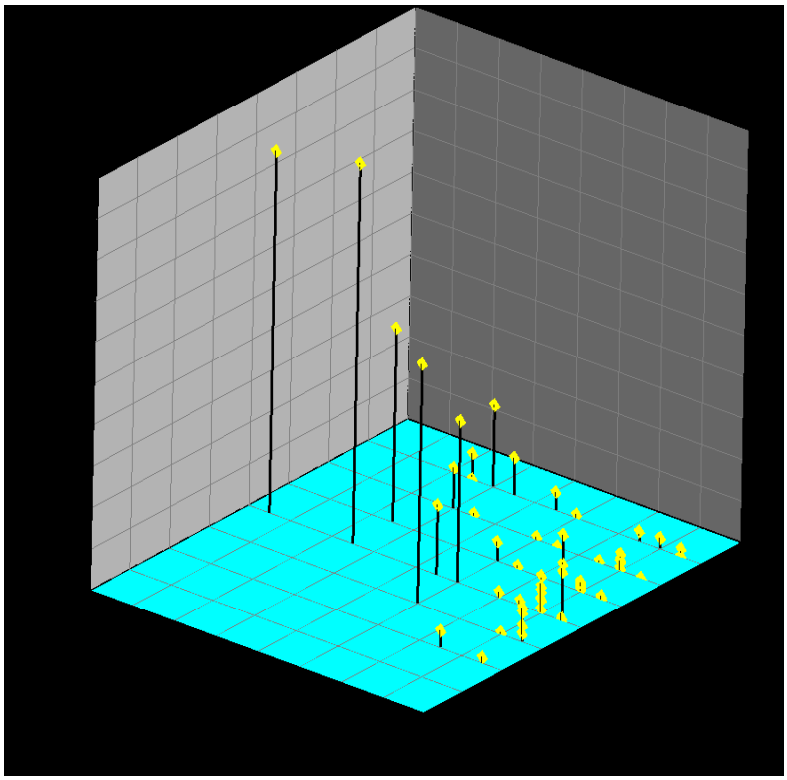


Figure 68. Percent biovolume of *Asterionella formosa.*

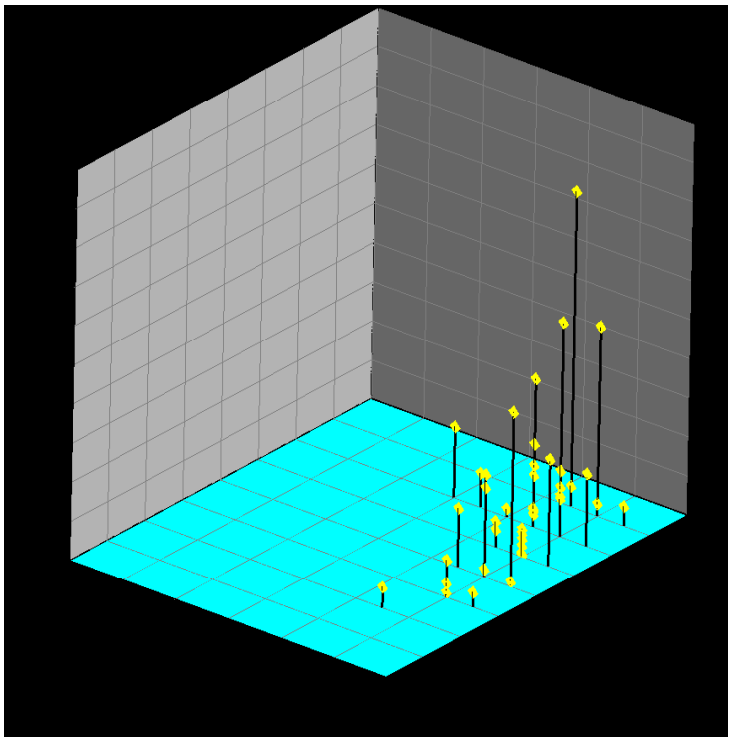


Figure 69. Percent biovolume of *Fragilaria construens.*

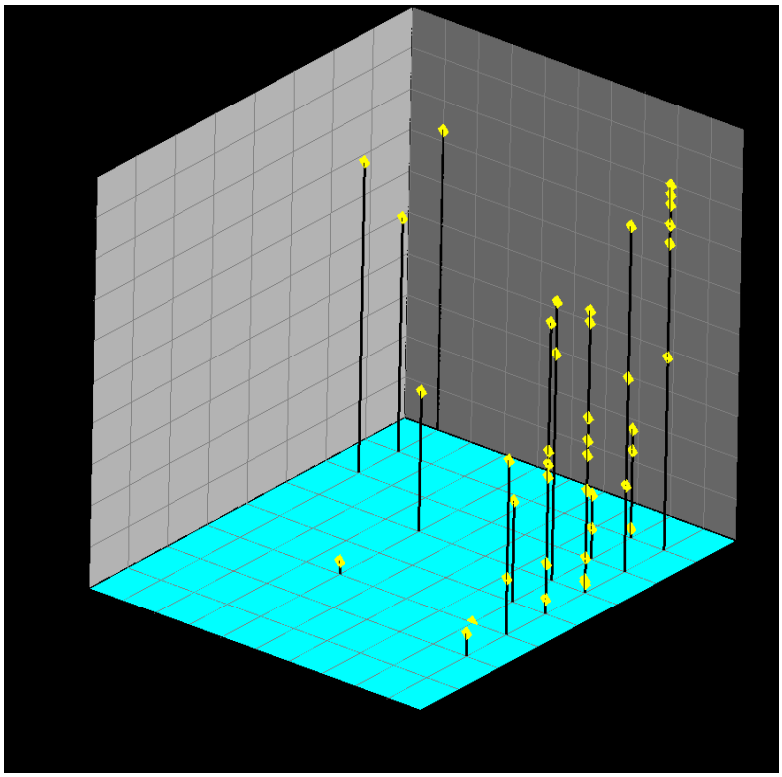


Figure 70. Percent biovolume of *Fragilaria crotonensis.*

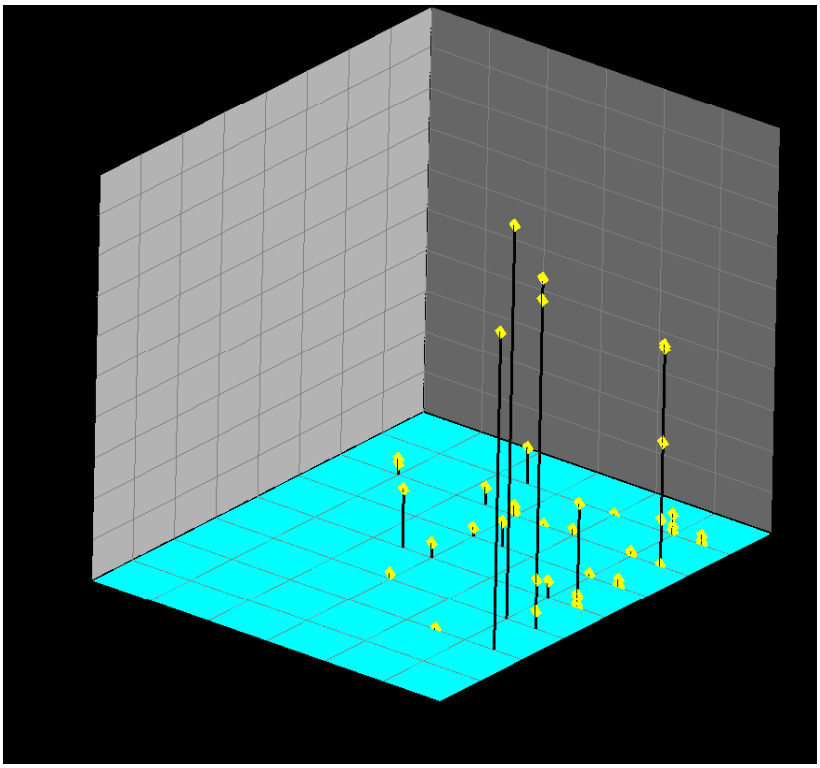


Figure 71. Percent biovolume of *Synedra radians.*

d. Cyanobacteria

The cyanobacteria have become the dominant phytoplankton group in Diamond Lake in recent years (Figure 72). The cyanobacteria peaked in 2001, although populations measured in 2002 and 2003 still exceeded cyanobacteria biovolumes in previous years. By far the most dominant genera in Diamond Lake is Anabaena, which is represented here by three species: *A. flos-aquae* (Figure 73), *A. planktonica* (Figure 74), and *A. circinalis* (Figure 75). Although *A. planktonica* was the dominant cyanobacteria in the early 1990's, the dominant species is now *A. flos-aquae* and to a lesser extent, *A. circinalis*. A new species to be reported for Diamond Lake starting in 2002 is *Microcystis aeruginosa* (Figure 75). Although the percent biovolume of this species has remained less than five percent of the total biovolume, it is still present in significant quantities.

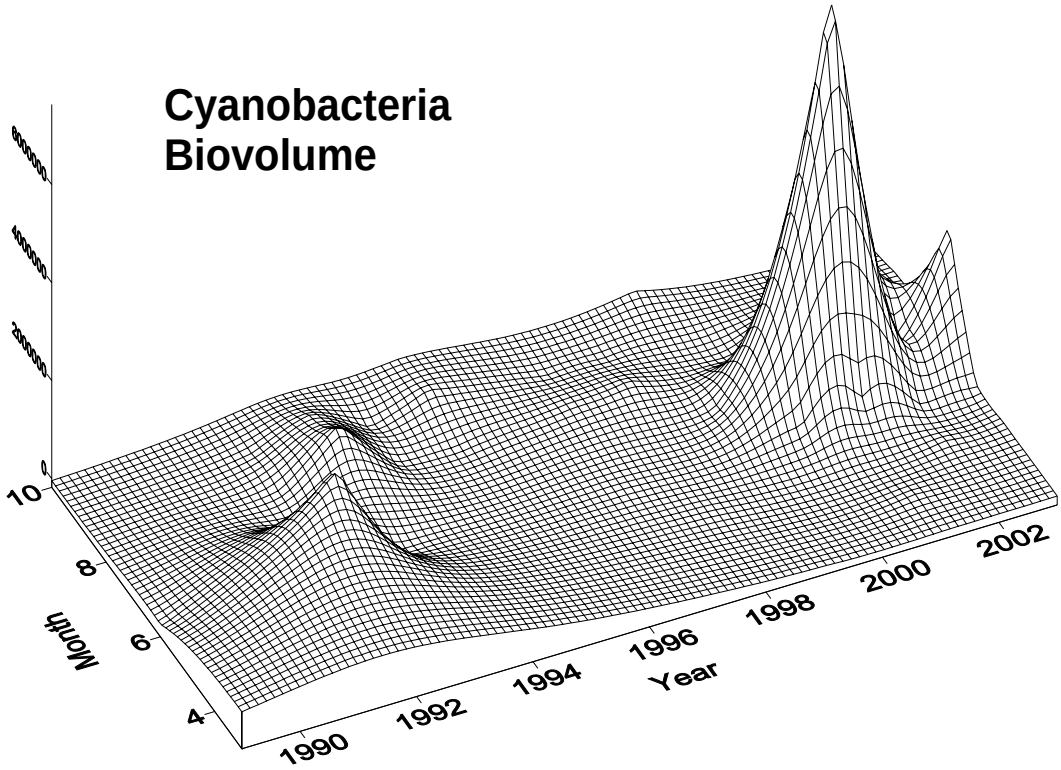


Figure 72. Biovolume of cyanobacteria in Diamond Lake from 1992 to 2003, by month.

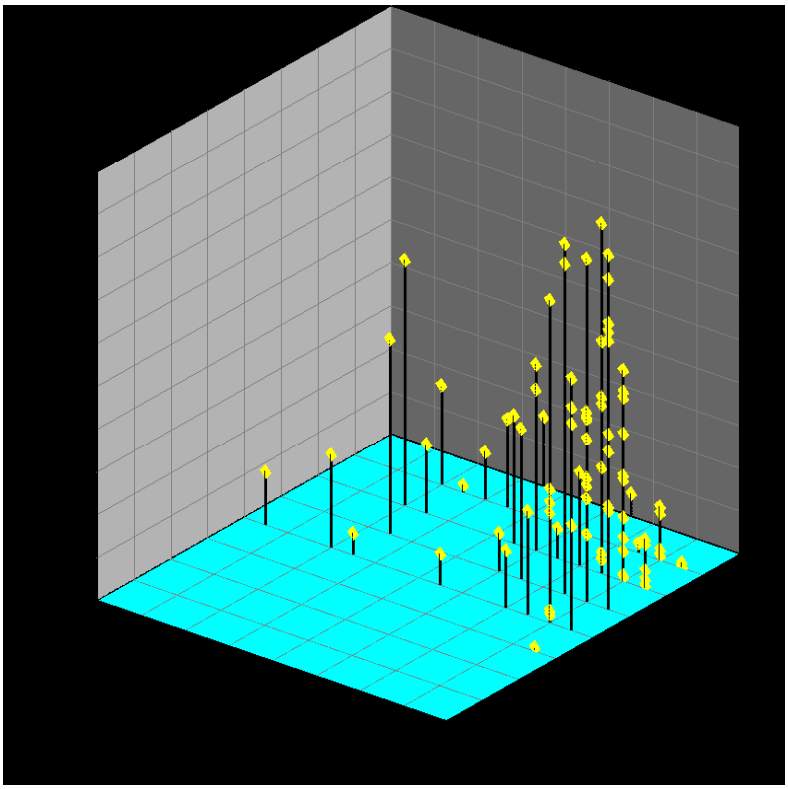


Figure 73. Percent biovolume of *Anabaena flos-aquae.*

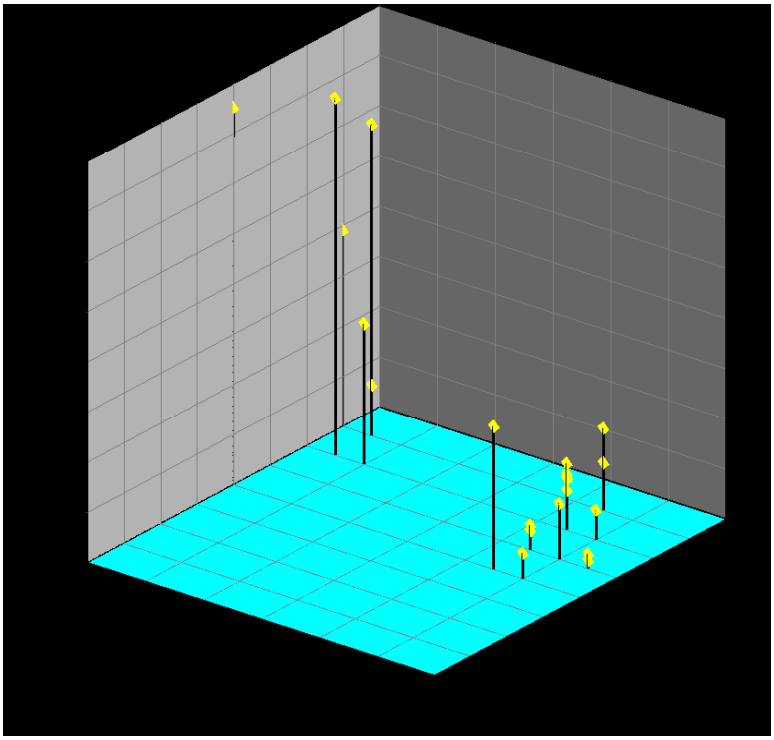


Figure 74. Percent biovolume of *Anabaena planktonica.*

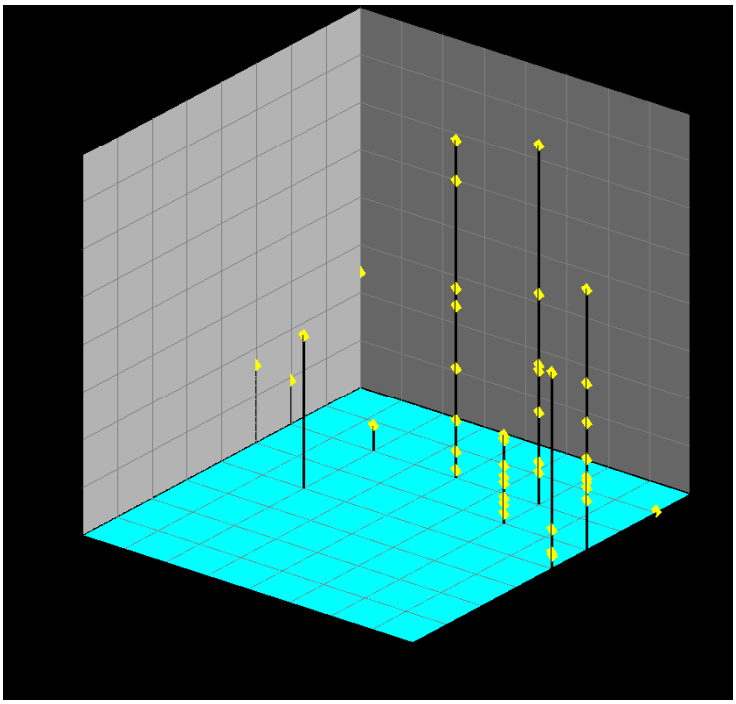


Figure 75. Percent biovolume of *Anabaena circinalis*.

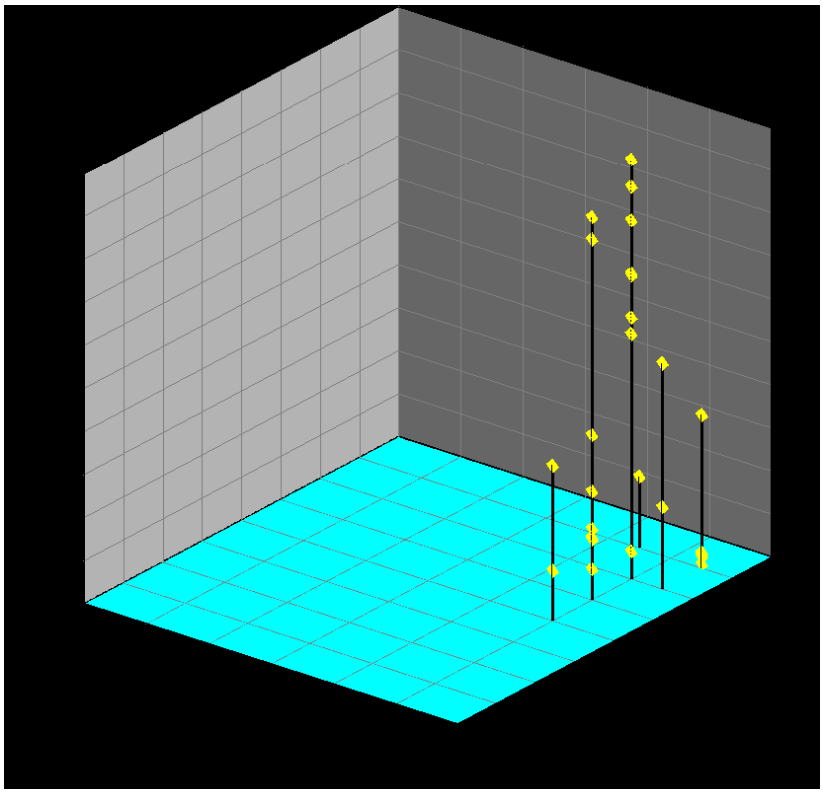


Figure 76. Percent biovolume of *Microcystis aeruginosa*.

D. DISCUSSION

The data for 2003 continues to indicate that water quality in Diamond Lake is poor. pH values remained above 8.5 for much of June and July and portions of August and September. The unusually cold period beginning in August appeared to have played a major role in driving down the cyanobacteria populations. Dissolved oxygen concentrations in the hypolimnion continued to approach anoxia for most of July and the DO concentrations in the epilimnion were high with values of 30 to 40 percent over saturation.

Few of the sampled analytes exhibit any demonstrable trends in Diamond Lake. One exception is silica, which showed an increase in the lake from 1992 to 2000 and has since continued to decline. The changes in concentrations of silica in the lake are unrelated to concentrations in the tributaries, which have remained steady over the period of measurement. The decline in lake silica may be related to changes in populations of chrysophytes and diatoms during the fall, winter, and spring during which few phytoplankton samples have been collected. We observe only slight changes in silica concentrations during the summer, which would also point towards substantial changes during other times of the year.

A number of cases of highly atypical values for a number of parameters were observed for Diamond Lake and the tributaries. Most of these aberrant values were generated in 1992-1994.

Although the cyanobacteria bloom did not reach the levels experienced in 2001, a greater proportion of the cyanobacteria in 2003 were *Anabaena flos-aquae.* In addition, *Microcystis aeruginosa* continues to be present in the lake after first being reported in 2002. Whereas the diatom, *Synedra*, was the dominant genera in Diamond Lake in May 2002, *Fragilaria crotonensis* was the dominant diatom in the lake in 2003. In the absence of the cyanobacteria, the abundance of the *Fragilaria* was sufficient to have been recognized as a bloom on its own. The biovolume of chrysophytes has also become elevated in the lake, particularly in spring and fall. The abundance of cyanobacteria, diatoms, and chrysophytes indicates a lack of sufficient grazing pressure on the phytoplankton and an adequate supply of nutrients to support their prolific growth.

The zooplankton population continues to exhibit a critical loss of large cladocerans and an excessive proportion of rotifers. The dominance of small zooplankton taxa provides low quantities of high-quality food for planktivorous fish and low grazing pressure on the phytoplankton.

Some of the problems in trying to detect changes in Diamond Lake based on the extant data are related to the design and frequency of sampling from 1992-2000. Samples were collected at various times in the open-water period with the vast majority concentrated in the summer months. There were almost no samples collected during the winter and few in the spring. The spring months may hold an important key to better understanding the cyanobacteria blooms in the summer. If diatom blooms are occurring under the ice and

during the spring, it may establish favorable conditions for cyanobacteria to become dominant in the summer. However, because of the focus on the summer conditions during peak recreational use of the lake there is little information to assess how changes during other times of the year may be facilitating changes during the summer. I recommend the implementation of a more systematic lake sampling design that would provide for sample collection throughout the year (Table 2).

Table 2. Suggested monitoring frequency for Diamond Lake.

Month	Frequency
January	1
March	1
April	1
May	2
June	2
July	2
August	2
September	1
November	1

E. ACKNOWLEDGEMENTS

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