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Silver Lake Limnological Survey, 2004

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Silver Lake Limnological Survey, 2004

Prepared for the Silver Lake Association and the Silver Lake Watershed Commission

by

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Summary

1. During the spring, summer and fall of 2004, a limnological survey of Silver Lake was conducted. The purpose of the survey was to determine the environmental health of Silver Lake. Some of the questions being asked were as follows. Was the lake highly productive? Were the bottom layers of the lake devoid of oxygen? Was phosphorus being released from the sediments into the water column? Were there algal blooms? What might be the cause of them? Were there nuisance blue-green algae present? Were algal toxins present? When?
2. A mid-lake station on Silver Lake was sampled two times per month from June through September 2004. Field measurements included temperature, dissolved oxygen, pH and secchi disk transparency. Laboratory analyses on water samples collected from the surface to the bottom at two-meter intervals included total phosphorus, soluble reactive phosphorus, nitrate, chlorophyll *a*, and phycocyanin. Microcystin, total coliforms and *E. coli* were measured from the epilimnion on each date.
3. Additional microcystin samples were taken in September and October of 2004 in algae blooms located in the southwest corner of the lake in response to calls from lake residents to the Silver Lake Association and to SUNY Brockport.
4. Silver Lake was thermally stratified by 10 June 2004 with the thermocline at approximately 5 meters of depth. The thermocline lowered during the sampling period to around 8 meters of depth. The lake was nearly isothermal by 10 September 2004.
5. Epilimnetic oxygen concentrations stayed above 5 mg/L throughout the entire sampling period. Depletion of oxygen from the hypolimnion (lower stratum of the lake) was observed throughout the entire stratified period with anoxia occurring in the lower 2 meters of the lake. These anoxic conditions were similar to the observations from Silver Lake during the summers of 1990 and 1994 through 1997.
6. Soluble reactive phosphorus (SRP) and total phosphorus (TP) were relatively low (SRP < 15 µg P/L, TP < 50 µg P/L) in the epilimnion of Silver Lake during the stratified period in 2004. However, phosphorus levels in the hypolimnion near the bottom of the lake increased dramatically during this period. On 23 July 2004 for example, the epilimnetic SRP concentration was around 4 µg P/L and the hypolimnetic value was 508 µg P/L.

7. The hypolimnetic phosphorus levels observed in 2004 were much higher than in 1990 (maximum = 83 µg/L, 2004 maximum = 808 µg/L). This should not be interpreted as a major change since the F.X. Browne report contained only a few sampling dates. It is possible that in 1990 they simply did not sample on dates of high phosphorus levels.

8. Blooms of algae occurred at two different times of the year, late June and in September, in the middle of the lake. Both of them consisted of nuisance blue-green algae, especially *Microcystis aeruginosa*, and with higher levels of ambient phosphorus. The fall algae bloom coincided with the transfer of phosphorus from the phosphorus-rich hypolimnion. This result suggests that addition of alum to sediments would reduce the fall bloom of algae and would likely reduce bloom during other parts of the year. These algal blooms decrease water clarity.

9. Large masses of algae appeared on the shoreline, especially in the southwest sector of the lake in September. Shoreline blooms of Cyanobacteria (blue-green algae) coincided with the fall turnover of the lake in 2004. This result suggests that mixing of the nutrient rich hypolimnetic waters throughout the entire water column triggered the blooms of Cyanobacteria and other algae.

10. Microcystin is a hepatotoxin produced by several different species of cyanobacteria, most notably Microcystis aeruginosa. Microcystin concentrations ranged from 0.004 to 0.082 µg/L at the mid-lake site of Silver Lake during the 2004 field season. These levels are all well below the World Health Organization's (WHO) warning level of 1.0 µg/L.

11. However, microcystin concentrations (10.72 µg/L) well above the WHO standards in surface accumulations of Cyanobacteria blooms were observed in the southwest corner of the lake. Ingestion of this surface scum by humans or pets could be hazardous. Samples taken below that same surface scum were well below the WHO warning level and closer to the mid-lake concentrations observed throughout the summer.

12. The chlorophyll based Carlson trophic status index ranged from 43 to 63 with a mean of 55. Based on this index, Silver Lake would be considered to be eutrophic. Eutrophic bodies of water are productive and often contain blooms of blue-green algae and anoxic hypolimnion.

Introduction

During the spring, summer and fall of 2004, a limnological survey of Silver Lake was conducted. The purpose of the survey was to update the status of Silver Lake. Some of the questions being asked were as follows. Was the lake highly productive? Were the bottom layers of the lake devoid of oxygen? Was phosphorus being released from the sediments into the water column? Were there algal blooms? What might be the cause of them? Were there blue-green algae present? Were algal toxins present? When? Monitoring was designed to take samples only during the summer period with depth to minimize cost. We decided to sample an extra week in the fall because of the blue-green algae bloom that was observed during September of 2004.

Definitions

Total Phosphorus- A measure of all forms of the element phosphorus. Phosphorus is an element required for plant growth on land or in water. In lakes, phosphorus is often the limiting factor of phytoplankton growth and is the cause of eutrophication, or overproduction, of lakes. Phosphorus may enter a watershed in soluble or organic form from several sources including sewage, heavy-duty detergents, fertilizer and agricultural waste. Some forms of phosphorus are more available to, and cause more immediate activity in, plants.

Soluble Reactive Phosphorus- A measure of the most available and active form of phosphorus.

Nitrate + Nitrite- A measure of the soluble forms of nitrogen used readily by plants for growth. Sources of nitrates in the environment are many and include barnyard waste and fertilizer.

pH – pH is a measure of the concentration of hydrogen ions in the water. The pH scale is a measure of alkaline or acidic nature of the water. The scale is from 0-14 with 0 being the most acidic, 14 the most basic and 7 being neutral.

Secchi Disk - A disk with a 4 to 6-inch radius that is divided into 4 equal quadrates of alternating black and white colors. It is lowered into a section of shaded water until it can no longer be seen and then lifted back up until it can be seen once again.

Stratified lake - Where a lake is separated into distinct horizontal layers due to different characteristics such as density and/or temperature.

Epilimnion - The upper, wind-mixed layer of a thermally stratified lake. This layer can freely exchange dissolved gases with the atmosphere.

Metalimnion - The middle or transitional zone between the well-mixed epilimnion and the colder hypolimnion layers in a stratified lake. This layer contains the thermocline.

Hypolimnion - The bottom, and most dense layer of a stratified lake. It is typically the coldest layer in the summer and warmest in the winter. It is isolated from mixing by the wind and typically too dark for much plant photosynthesis to occur.

Chlorophyll *a* - Chlorophyll *a* is the molecule which makes photosynthesis possible. All plants, algae, and cyanobacteria which photosynthesize contain chlorophyll *a*. Chlorophyll is used as a limnological measurement of the amount of algae in the water.

Microcystin - A cyclic heptapeptide hepatotoxin produced by several different species of Cyanobacteria, most notably *Microcystis aeruginosa*.

Phycocyanin - Phycocyanin is a pigment that accounts for up to 20% of proteins in cyanobacteria or blue-green algae. It can be used as a measure of this nuisance group of algae. The pigment itself is nontoxic and is used commercially in many food dies and also in some cosmetics.

Sampling and Analytical Methods

Limnological sampling of Silver Lake was performed bimonthly from June to September 2004 at the deepest location in the basin (10.5 m, Figure 1). Field measurements included transparency with a secchi disk and temperature, dissolved oxygen and pH with a pre-calibrated Hydrolab (Model Quanta G) sonde. Water samples were collected with a horizontal Van Dorn bottle from the surface to the bottom at two-meter intervals and analyzed for total phosphorus, soluble reactive phosphorus, nitrate, chlorophyll *a*, and phycocyanin. Epilimnetic analyses for microcystin, total coliforms and *Escherichia coli (E. coli)* were also performed on each date. During algae blooms (Figure 2), additional microcystin samples were taken in the southwest corner during September and October of 2004 in response to resident telephone calls to the Silver Lake Association and to SUNY Brockport. Detailed analytical methodologies are presented below.

All sampling bottles were pre-coded so as to ensure exact identification of the particular sample. All sample bottles were routinely cleaned with phosphate free RBS between sampling dates. Containers were rinsed prior to sample collection with the water being collected. In general, all procedures followed Standard Methods for the Analysis of Water and Wastewater. Sample water for dissolved nutrient analyses (SRP, nitrate + nitrite) was filtered immediately with 0.45-µm MCI Magna Nylon 66 membrane and either frozen or analyzed within 48 hours of collection.

Nitrate+Nitrite: Dissolved nitrate+nitrite nitrogen were performed by the automated (Technicon autoanalyser) cadmium reduction method (APHA 1999).

Soluble Reactive Phosphorus: The filtrate was analyzed for orthophosphate using the automated (Technicon) colorimetric ascorbic acid method (APHA 1999). The formation of the phosphomolybdeum blue complex was read colorimetrically at 880nm.

Total Phosphorus: The persulfate digestion procedure was used prior to analysis by the automated (Technicon autoanalyser) colorimetric ascorbic acid method (APHA 1999).

Chlorophyll *a*: Chlorophyll *a* was measured fluorometrically following Wetzel and Likens (2000).

Phycocyanin: Phycocyanin was measured fluorometrically (Turner Designs Corporation, Aquafluor and TD 700 Models).

Microcystin: The protein phosphatase inhibition assay (PPIA) technique (Carmichael and An 1999) was used to measure microcystin concentrations on samples filtered from Silver Lake.

Coliform Bacteria: The membrane filter technique (EPA method 10029) using m-ColiBlue24 (® Millipore Corp) was used for total coliform and *Escherichia coli* (*E. coli*) (EPA 1994).

Quality Control

The Water Chemistry Laboratory at SUNY Brockport is certified through the New York State Department of Health's Environmental Laboratory Approval Program (ELAP - # 11439). This program includes bi-annual proficiency audits, annual inspections and good laboratory practices documentation of all samples, reagents and equipment (Table 1).

Results

Temperature (Table 2, Figures 3 through 10):

Deeper lakes in temperate regions generally stratify during the summer. That is, they have a warm layer of water that sits over a cooler layer. Silver Lake is no exception as it was thermally stratified by the first sampling date on 10 June 2004 and remained stratified throughout the summer into September 2003. The depth of the transitional zone of temperature change, the metalimnion, varied from approximately 4 to 8 meters of depth throughout the study period. The maximum observed surface temperature was 23°C on 23 July 2004 (Figure 6). By 10 September 2004, the lake water was cooling and mixing, being nearly isothermal (Figure 10).

Dissolved Oxygen (Table 2, Figures 3 through 10):

In many ways Silver Lake is a typical productive temperate lake. During the summer, there is a continual "rain" of dead, decaying organic matter (phytoplankton, zooplankton, bacteria) that "use up" oxygen for respiration. Since the lake is stratified and does not mix, oxygen from the epilimnion is not transferred to the deeper waters of the hypolimnion. As a result, as the summer progresses the amount of oxygen in the hypolimnion decreases and eventually reaches zero. At this point, several things happen to phosphorus levels in the lake. This will be discussed under "Phosphorus". The lack of oxygen in the deeper waters preclude the existence of any cold water fisheries in Silver Lake.

Epilimnetic oxygen concentrations were generally in the 7 to 10 mg/L range for the entire summer: the exception being in September. When the entire lake mixed in September, deoxygenated hypolimnetic water mixed with the epilimnetic water causing oxygen conditions to be reduced in the upper layers to ~6 mg/L (Figures 9 and 10). Even though the epilimnion was oxygenated, a strong depletion of hypolimnetic oxygen was evident by the first sampling date (10 June 2004) (Figure 3). By the second sampling on 24 June 2004, oxygen concentrations were at zero at the 10 m depth (Figure 4). On 23 July 2004, the bottom three meters of Silver Lake were devoid of oxygen (Figure 6). In general, oxygen depletion of the hypolimnion (lower stratum of the lake) was observed until 10 September 2004. Similar anoxic conditions were observed in Silver Lake during the summers of 1990 (Browne 1991) and 1994 through 1997 (Wickham and McKurth 1998).

pH (Table 2 and Figure 11):

Epilimnetic pH increased on each sampling trip from 8.11 on 10 June to a high of 9.14 on 23 July, leveled off at ~8.4 through the month of August, and began to decrease in the epilimnion during September to a level of ~7.5. The large variability in pH levels observed is common to productive lakes and commonly reflects changes in hydrogen ion concentration due to uptake of carbon dioxide by blooms of algae.

Hypolimnetic pH increases were also quite variable ranging from a high of 9.90 on 23 July 2004 to a low of 7.15 on 30 September 2004. These changes in hydrogen ion concentration reflect reducing conditions that exist under anoxic conditions.

Nitrate (Table 2, Figures 3 through 10):

Nitrate concentrations were similar from the surface of the lake to the bottom ranging from 0.41 to 0.70 mg N/L on 10 June 2004 (Figure 3). Concentrations in the mixing layer generally decreased each subsequent week (~0.50 mg N/L, 24 June; ~0.25 mg N/L, 7 July; ~0.0 mg N/L, 23 July) until 23 July (Table 2, Figures 4-6). On 24 June, nitrate was undetectable at the 10-meter depth. Oxygen was also unavailable at this depth for production of nitrate from breakdown of nitrogen-bearing compounds. After 7 July and until the last sampling day on 30 September, concentrations remained below 0.10 mg N/L or were non-detectable with the exception of the 10 meter sample on 10 September which may have been influenced by some stirring of the bottom sediment (Table 2).

Total and soluble reactive phosphorus (Table 2, Figures 3 through 10):

Total phosphorus is a measure of all forms of the element phosphorous, including soluble reactive phosphorus. Soluble reactive phosphorus provides information on the amount of phosphate ion present in the water column. Phosphate is the form of phosphorus that is readily taken up by phytoplankton and macrophytes and is generally recognized as the limiting nutrient controlling algal growth in most freshwater systems (Wetzel 2001). Soluble phosphorus and total phosphorus were relatively low (SRP < 15 µg P/L, TP < 50 µg P/L) in the epilimnion compared to the hypolimnion of Silver Lake during the stratified period in 2004 (Table 2). However, phosphorus levels in the hypolimnion, especially near the bottom of the lake, increased dramatically during this period. A careful examination of Figures 3 to 8 demonstrates this point. From 10 June to 23 July 2004, SRP (phosphate) levels were low (~3- 6 µg/L) from the surface waters to 8m. At 10m, the concentration of SRP increased dramatically to a high of 508 µg P/L on 23 July 2004 (Figure 6). Note that there is an incremental increase every two weeks (26.1 on 10 June, 227.7 on 24 June, 341.6 on 7 July and 508 µg P/L on 23 July 2004 (Table 2). When the hypolimnion is devoid of oxygen, so-called reducing conditions exist, and phosphorus in the sediment readily moved from the sediment into the water column. During stratification, lakes with anoxic hypolimnia often accumulate phosphorus in the hypolimnion as phosphorus is released from the sediment via redox reactions (Nurnberg 1984, Mortimer 1941).

On 23 July 2004, as the area devoid of oxygen increased to 4 meters above the bottom of the lake, the area of elevated SRP expanded from the 10-meter depth to the 6-meter depth (Figure 6). The hypolimnetic phosphorus levels in 2004 (maximum = 808 µg P/L) appeared to be much higher than those observed in 1990 (maximum = 83 µg P/L, FX Browne 1991, Table 3). This result would suggest that the loss of phosphorous from the sediment of Silver Lake may be increasing. Previous results from 1991 suggest that the bottom sediment of Silver Lake is a large repository of phosphorus as the lake's sediment total phosphorus concentration was 984 mg/kg (FX Browne 1991).

By September when thermal mixing occurred and the bottom layers of the lake became oxygenated again, the movement of phosphorous from the sediment into the water column ended (Figures 9 and 10). However, some of the phosphorus that was in the hypolimnion clearly moved into the upper layers of the lake as concentrations of SRP jumped by a factor of 10 from ~ 3 to 6 µg P/L to 50 to 60 µg P/L. When hypolimnetic phosphorus is transported vertically to the upper layers of the lake where light is present, it may stimulate algal growth (Cooke *et al*. 1977). This will be discussed further under "Chlorophyll".

Chlorophyll and Phycocyanin (Table 2, Figures 3 through 10):

Chlorophyll *a* is a measure of the amount of pigment observed in all types of phytoplankton in a lake, while phycocyanin is a measure of the amount of pigment associated with nuisance-algae called the Cyanobacteria (often called blue-green algae). The higher the levels of chlorophyll and phycocyanin, the greater the amount of these algae in the lake. Epilimnetic chlorophyll *a* concentrations ranged from 3.6 µg/L in June to 27.6 µg/L in July (Table 2). The amount of phytoplankton present on 10 June was low (chlorophyll = ~3 µg/L). Transparency of the lake was fairly high at 4.2 meters (Table 4). By 24 June, transparency dropped by over 100% as transparency dropped to 2 meters as a bloom of algae occurred (chlorophyll = ~20 μg/L). Levels of phycocyanin reached as high as 54.8 μg/L indicating that it was a bloom of blue-green algae. Although chlorophyll levels generally dropped until 19 August, phycocyanin levels remained high (generally above 20 μg/L) indicating that the blue-green algae bloom continued while other types of algae decreased. Transparency remained low with secchi disk readings reaching a low of 1.3 meters on 23 July.

The lake showed evidence of mixing on 19 August (Figure 8) and as the phosphorus-rich hypolimnetic waters mixed with surface waters, another bloom was evident by 10 September when chlorophyll levels reached as high 23.9 μg/L in the upper layers of water – the highest observed all year (Figure 9). As in the late spring bloom, blue-green algae were prevalent as concentrations of phycocyanin reached 63.6 μg/L – also the highest observed all year. Despite the high phosphorus levels (~ 60 μg P/L) present in the water column on 30 September, the algae bloom appeared to be over (chlorophyll decreased to ~ 4 μg/L), although there were still blue-green algae present (phycocyanin = ~ 40 μg/L) (Figure 10). The end of the algae bloom was caused by the lake cooling off (drop in temperature of ~ 2^{o}C from 10 to 30 September).

The algae bloom that occurred in late summer-early fall clearly occurred during the mixing period when phosphorus released from the phosphorus-laden hypolimnion was transported by currents into the epilimnion. A management process, such addition of alum or addition of air to the bottom of Silver Lake, will likely reduce the algal blooms that occur in the late summer.

Generally in freshwater lakes, the most effective means of reducing productivity is usually obtained by decreasing algal growth through the reduction of phosphorus inputs (Wetzel 2001).

Microcystin (Table 5):

Microcystin is a toxin produced by several different species of Cyanobacteria or blue-green algae - the most common being *Microcystis aeruginosa*. This species was observed in Silver Lake in large quantities during the late summer of 2004 (Figure 2). Microcystin concentrations ranged from 0.004 to 0.082 µg/L at the mid-lake site of Silver Lake during the 2004 field season (Table 5). These levels are all well below the World Health Organization's (WHO) warning level of 1.0 µg/L. In response to inquiries made to the Silver Lake Association and directly to SUNY Brockport regarding a bloom occurring in the southwest corner of the lake, additional samples were taken from the surface of the wind and circulation driven accumulation of the algae bloom (Figure 2). Microcystin concentrations were as high as 10.72 µg/L on 21 September 2004, well above the WHO warning level (Table 5). In fact, the surface scum in the southwest corner of the lake was above the WHO warning level for nearly a month (14 September to 13 October 2004). This represents a worst case scenario as samples taken below that same surface scum were well below the WHO warning level and closer to the mid-lake concentrations observed throughout the summer (0.072 µg/L on 14 September and 0.078 µg/L of 21 September 2004) (Table 5). Nevertheless, the surface scum of the Cyanophyta blooms is toxic and pose a health hazard to humans and pets that ingest that water.

It is important to note that the shoreline blooms of Cyanobacteria (blue-green algae) coincided with the fall turnover of the lake in 2004. The mixing of the nutrient rich hypolimnetic waters throughout the entire water column triggered the blooms of Cyanobacteria. Phytoplankton samples taken during the blooms showed that the dominant cyanobacteria species was *Microcyctis aeruginosa* (Figure 2).

Coliform bacteria (Table 4):

Total coliform bacteria ranged from 32 to 2084 CFU/100ml during the spring, summer and fall of 2004 in Silver Lake (Table 4). The maximum level for *Escherichia coli* (*E. coli*) (222 CFU/100ml) occurred on 7 July 2004. The *E. coli* levels observed were below the criteria deemed acceptable by the U.S. Environmental Protection Agency for a designated beach area or for moderate to full body contact recreation (Table 6).

Trophic Status:

The trophic status index (TSI) was developed by Carlson (1983) to categorize lakes in terms of the amount of biological material present or productivity. The TSI estimates algal biomass using the separate but relatively easily measured parameters: chlorophyll, secchi disk depth and total phosphorus concentration. Since all three parameters were measured during this study, the TSI was calculated based on each parameter (Table 7). Chlorophyll-based TSI is the preferred method as it is the best predictor of algal biomass. There is no advantage to averaging the TSI values based on each of the parameters (Carlson 1983). The TSI scale ranges from 1 to 100 with the categories explained in Table 8. There was relatively good agreement in the three parameter–based (chlorophyll, secchi disk depth and total phosphorus) TSI estimates (Table 7). The chlorophyll-based trophic status index ranged from 43 to 63 with a mean of 55; this classifies Silver Lake as a eutrophic body of water (Table 8). That is, it is a productive body of water. A lake with a value above 60 is described as having an anoxic hypolimnion, macrophyte problems, and blooms of nuisance blue-green algae. In fact, this is a good description of Silver Lake.

Acknowledgements

We would like to recognize individuals who helped make this project possible. Bill Soules and David Reckahn of the Silver Lake Association and Wyoming County SWCD, respectively, who initiated the idea of a limnological study of Silver Lake with us. Bill also provided a boat for some of the sampling while Dave assisted in the fieldwork on a number of occasions. Carol Brakenbury and Tom Oogjen also provided us with a vessel, often on short notice, from which to sample. Jane Bellamy, Bill Soules and Mary Kay Barton provided us with local information and photographs of algal blooms, which led to the important additional sampling for microcystin in the fall. Their genuine interest in the lake and its health is admirable. Silver Lake Marine provided us with a boat to sample algae blooms in October. We also wish to thank Dan White, Ben Moose, Sarah Wasson and Finessa Brandenburg of SUNY Brockport for their assistance with the laboratory work. Mary Arnold identified the algae and took the photomicrographs.

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Table 1. Results of proficiency audit samples of the Water Quality Laboratory at SUNY Brockport

WADSWORTH CENTER
NEW YORK STATE DEPARTMENT OF HEALTH
ENVIRONMENTAL LABORATORY APPROVAL PROGRAM
Proficiency Test Report

Lab 11439 SUNY BROCKPORT EPA Lab Code NY01449

WATER LAB LENNON HALL
BROCKPORT, NY 14420
USA

Shipment 275 Non Potable Water Chemistry
Shipment Date: 19-Jul-2004

Analyte	Sample ID	Result	Mean/Target	Warning Limits	Method	Score
Sample: **Water Residue**						
Solids, Total Suspended 260 passed out of 268 reported results. EPA Code: 0072	7502	82.9	89.0	73.6-91.6	SM 18-20 2540D	Satisfactory
Sample: **Organic Nutrients**						
Kjeldahl Nitrogen, Total 89 passed out of 98 reported results. EPA Code: 0034	7504	30.41	30.5	25.0-35.0	EPA 351.3	Satisfactory
Phosphorus, Total 115 passed out of 123 reported results. EPA Code: 0035	7504	4.37	4.38	3.63-4.84	SM18-20 4500-P E	Satisfactory
Sample: **Inorganic Nutrients**						
Nitrate (as N) 113 passed out of 121 reported results. EPA Code: 0032	7507	36.1	35.4	30.4-39.7	SM18-20 4500-NO3 F	Satisfactory
Orthophosphate (as P) 97 passed out of 101 reported results. EPA Code: 0033	7507	2.49	2.57	2.32-2.84	SM18-20 4500-P F	Satisfactory
Sample: **Minerals II**						
Sodium, Total 88 passed out of 102 reported results. EPA Code: NA	7537	67.32	63.9	59.7-68.1	SM 18-20 2450D	Satisfactory

Table 2. Silver Lake water chemistry and physical parameters: June through September 2004. Temp = temperature, DO = dissolved oxygen, SRP = soluble reactive phosphorus, TP = total phosphorus, Chl *a* = chlorophyll a, secchi = secchi disk depth, nd = non-detectable.

Sample	Date Collected	Temp (°C)	DO (mg/L)	pH	SRP (µg P/L)	TP (µg P/L)	Nitrate (mg N/L)	Chl a (µg/L)	Phycocyanin (µg/L)
Silver Lake 0m	6/10/2004	19.9	8.8	8.09	2.3	21.8	0.68	3.6	12.4
Silver Lake 2m	6/10/2004	19.9	8.7	8.11	2.0	30.5	0.68	3.6	6.7
Silver Lake 4m	6/10/2004	19.8	8.7	8.11	4.0	31.7	0.70	3.0	13.3
Silver Lake 6m	6/10/2004	17.7	6.7	7.71	3.0	28.2	0.66	2.9	8.3
Silver Lake 8m	6/10/2004	16.4	4.7	7.45	5.7	29.7	0.63	2.8	3.0
Silver Lake 10m	6/10/2004	12.9	0.5	9.22	26.1	106.4	0.41	2.1	17.0
Silver Lake 0m	6/24/2004	21.6	11.3	8.69	3.4	27.7	0.42	18.2	54.8
Silver Lake 2m	6/24/2004	21.5	10.9	8.69	12.4	37.9	0.42	25.3	50.4
Silver Lake 4m	6/24/2004	21.2	10.6	8.60	2.6	30.9	0.57	20.9	20.6
Silver Lake 6m	6/24/2004	21.1	10.1	8.62	4.8	34.1	0.44	21.9	33.2
Silver Lake 8m	6/24/2004	19.4	6.3	7.51	9.2	22.5	0.50	11.0	22.0
Silver Lake 10m	6/24/2004	13.1	0.3	9.10	227.7	304.6	< 0.02	5.5	6.4
Silver Lake 0m	7/7/2004	22.2	10.6	8.99	13.5	39.6	0.28	15.0	32.6
Silver Lake 2m	7/7/2004	22.1	10.6	9.05	2.8	33.5	0.24	18.7	27.5
Silver Lake 4m	7/7/2004	21.7	10.1	9.03	3.6	32.0	0.24	18.2	26.7
Silver Lake 6m	7/7/2004	21.5	9.4	8.98	2.8	31.1	0.26	20.0	1.9
Silver Lake 8m	7/7/2004	20.4	6.7	8.58	2.9	22.5	0.28	5.2	18.3
Silver Lake 10m	7/7/2004	14.4	0.5	7.87	341.6	380.7	0.07	6.5	24.2
Silver Lake 0m	7/23/2004	23.0	10.8	9.14	5.1	39.2	< 0.02	9.2	57.9
Silver Lake 2m	7/23/2004	22.7	10.7	9.05	3.5	39.5	nd	27.6	51.4
Silver Lake 4m	7/23/2004	22.3	10.0	8.96	<1.24	26.8	nd	6.5	24.6
Silver Lake 6m	7/23/2004	20.5	1.1	7.86	8.4	40.7	0.06	6.3	21.9
Silver Lake 8m	7/23/2004	19.1	0.4	8.09	3.5	29.2	0.05	7.7	17.2
Silver Lake 10m	7/23/2004	15.2	0.3	9.90	508.0	522.6	nd	0.5	30.1
Silver Lake 0m	8/5/2004	21.9	7.3	8.41	7.6	24.4	0.10	7.0	21.8
Silver Lake 2m	8/5/2004	21.8	7.0	8.34	5.6	21.8	nd	8.2	38.8
Silver Lake 4m	8/5/2004	21.5	6.1	8.12	2.5	22.0	nd	4.8	22.1
Silver Lake 6m	8/5/2004	21.3	4.4	7.87	23.0	31.6	0.07	3.5	20.8
Silver Lake 8m	8/5/2004	18.3	0.4	9.10	46.0	137.4	0.08	2.6	15.4
Silver Lake 10m	8/5/2004	15.4	0.2	9.42	496.4	808.1	nd	1.9	7.5
Silver Lake 0m	8/19/2004	21.3	10.7	8.43	3.8	48.8	nd	20.6	63.6
Silver Lake 2m	8/19/2004	21.2	10.2	8.60	4.1	44.6	nd	19.7	59.9
Silver Lake 4m	8/19/2004	21.2	10.2	8.71	16.0	42.0	nd	17.9	61.2
Silver Lake 6m	8/19/2004	21.2	9.7	9.37	2.5	40.3	nd	14.3	52.6
Silver Lake 8m	8/19/2004	19.4	4.1	8.51	19.3	39.2	nd	21.0	47.4
Silver Lake 10m	8/19/2004	18.3	0.6	9.00	232.9	327.3	nd	2.4	28.8
Silver Lake 0m	9/10/2004	20.6	6.2	8.02	69.2	93.1	0.02	23.9	17.6
Silver Lake 2m	9/10/2004	20.6	6.0	8.03	66.7	90.1	0.04	23.8	13.5
Silver Lake 4m	9/10/2004	20.6	5.9	8.05	46.6	89.8	0.02	23.0	29.6
Silver Lake 6m	9/10/2004	20.6	6.0	8.04	64.1	94.9	0.02	21.3	25.2
Silver Lake 8m	9/10/2004	20.5	5.8	8.01	66.8	86.3	0.02	23.1	33.1
Silver Lake 10m	9/10/2004	18.7	4.6	7.57	59.7	115.0	0.30	12.4	12.4
Silver Lake 0m	9/30/2004	19.0	5.7	7.59	72.8	109.7	0.08	4.5	31.4
Silver Lake 2m	9/30/2004	19.0	5.7	7.57	58.7	112.5	0.08	4.1	36.2
Silver Lake 4m	9/30/2004	19.0	5.6	7.55	59.4	117.8	0.07	4.0	40.4
Silver Lake 6m	9/30/2004	18.8	5.2	7.49	52.0	115.8	0.07	8.5	58.4
Silver Lake 8m	9/30/2004	18.3	4.0	7.15	68.5	120.8	0.07	3.6	29.7
Silver Lake 10m	9/30/2004	18.0	4.6	7.23	69.0	115.0	0.07	5.1	25.6

Table 3. Epilimnetic and hypolimnetic pH, nitrate and phosphorus results from the spring and summer of 1990 for two deep water stations in Silver Lake (Browne 1991). TP = total phosphorus, SRP = soluble reactive phosphorus, ND = no data.

Epilimnion		Depth (m)	pH	SRP (µg P/L)	TP (µg P/L)	Nitrate (mg N/L)
6/19/1990	Station 1	0.5	ND	15	21	1.20
6/19/1990	Station 2	0.5	ND	20	21	0.71
7/18/1990	Station 1	0.5	ND	ND	ND	ND
7/18/1990	Station 2	0.5	ND	ND	48	0.04
9/19/1990	Station 1	0.5	8.10	30	72	0.65
9/19/1990	Station 2	0.5	8.01	41	58	0.40
		Mean	8.06	27	44	0.60

Hypolimnion		Depth (m)	pH	SRP (µg P/L)	TP (µg P/L)	Nitrate (mg N/L)
6/19/1990	Station 1	10.5	ND	45	50	1.16
6/19/1990	Station 2	10.5	ND	49	31	0.55
7/18/1990	Station 1	10.5	ND	ND	37	0.01
7/18/1990	Station 2	10.5	ND	ND	83	0.03
9/19/1990	Station 1	10.5	7.92	34	63	0.24
9/19/1990	Station 2	10.5	8.01	33	81	0.23
		Mean	7.97	40	58	0.37

Table 4. Secchi disk depth, total coliform and *Escherichia coli* (*E. coli*) results for Silver Lake 2004. CFU = colony forming units which represents the amount of bacterial colonies per 100 milliliter of sample.

Date	Secchi (m)	Total Coliform CFU/100ml	*E. coli* CFU/100m
06/10/04	4.2	2,000	13
06/24/04	2.0	153	8
07/07/04	2.5	2,084	222
07/23/04	1.3	240	0
08/05/04	2.5	160	0
08/19/04	1.4	48	0
09/10/04	1.8	426	12
09/30/04	2.1	32	2

Table 5. Microcystin concentrations for mid-lake and shoreline bloom samples taken (surface and 1 meter below the surface) in the southwest corner of Silver Lake 2004 (see Figure 1 for locations). Mc = microcystin, NS = no sample.

Date	Mid-Lake Mc (µg/L)	Shoreline surface scum Mc (µg/L)	Below surface scum Mc (µg/L)
06/10/04	0.004	NS	NS
06/24/04	0.068	NS	NS
07/07/04	0.046	NS	NS
07/23/04	0.066	NS	NS
08/05/04	0.044	NS	NS
08/19/04	0.082	NS	NS
09/10/04	0.050	NS	NS
09/14/04	NS	2.55	0.072
09/21/04	NS	10.72	0.078
09/30/04	0.040	4.45	NS
10/13/04	NS	6.76	NS

Table 6. Ambient water quality criteria for bacteria (USEPA 1986). CFU = colony forming units which represents the amount of bacterial colonies per 100 milliliter of sample.

	E. coli (CFU/100 ml)
Designated Beach Area	235
Moderate to Full Body Contact Recreation	298
Lightly Used Fully Body Contact Recreation	409
Infrequent Used Full Body Contact Recreation	575
Drinking Water	0

Table 7. The Carlson Trophic status index calculated from epilimnetic samples taken from Silver Lake in 2004. The TSI index was calculated using total phosphorus (TP), chlorophyll *a* (CHL) and secchi disk depth (SD). Chlorophyll is the preferred estimate.

Sample	Date Collected	TP (µg P/L)	TSI (TP)	Chl *a* (µg/L)	TSI (CHL)	Secchi (m)	TSI (SD)
Silver Lake 0m	6/10/04	21.8	49	3.6	43	4.2	39
Silver Lake 2m	6/10/04	30.5	53	3.6	43		
Silver Lake 0m	6/24/04	27.7	52	18.2	59	2.0	50
Silver Lake 2m	6/24/04	37.9	57	25.3	62		
Silver Lake 0m	7/7/04	39.6	57	15.0	57	2.5	47
Silver Lake 2m	7/7/04	33.5	55	18.7	59		
Silver Lake 0m	7/23/04	39.2	57	9.2	52	1.3	56
Silver Lake 2m	7/23/04	39.5	57	27.6	63		
Silver Lake 0m	8/5/04	24.4	50	7.0	50	2.5	47
Silver Lake 2m	8/5/04	21.8	49	8.2	51		
Silver Lake 0m	8/19/04	48.8	60	20.6	60	1.4	55
Silver Lake 2m	8/19/04	44.6	59	19.7	60		
Silver Lake 0m	9/10/04	93.1	70	23.9	62	1.8	52
Silver Lake 2m	9/10/04	90.1	69	23.8	62		
Silver Lake 0m	9/30/04	109.7	72	4.5	45	2.1	49
Silver Lake 2m	9/30/04	112.5	72	4.1	45		
		Mean	59		55		49
		Minimum	49		43		39
		Maximum	72		63		56

Table 8. An explanation of the categories of the Carlson Trophic Status Index adapted from Carlson and Simpson, used with permission (1996).

A list of possible changes that might be expected in a north temperate lake as the amount of algae changes along the trophic state gradient.						
TSI	**Chl (ug/L)**	**SD (m)**	**TP (ug/L)**	**Attributes**	**Water Supply**	**Fisheries & Recreation**
<30	<0.95	>8	<6	**Oligotrophy:** Clear water, oxygen throughout the year in the hypolimnion	Water may be suitable for an unfiltered water supply.	Salmonid fisheries dominate
30-40	0.95-2.6	8-4	6-12	Hypolimnia of shallower lakes may become anoxic		Salmonid fisheries in deep lakes only
40-50	2.6-7.3	4-2	12-24	**Mesotrophy:** Water moderately clear; increasing probability of hypolimnetic anoxia during summer	Iron, manganese, taste, and odor problems worsen. Raw water turbidity requires filtration.	Hypolimnetic anoxia results in loss of salmonids. Walleye may predominate
50-60	7.3-20	2-1	24-48	**Eutrophy:** Anoxic hypolimnia, macrophyte problems possible		Warm-water fisheries only. Bass may dominate.
60-70	20-56	0.5-1	48-96	Blue-green algae dominate, algal scums and macrophyte problems	Episodes of severe taste and odor possible.	Nuisance macrophytes, algal scums, and low transparency may discourage swimming and boating.
70-80	56-155	0.25-0.5	96-192	**Hypereutrophy:** (light limited productivity). Dense algae and macrophytes		
>80	>155	<0.25	192-384	Algal scums, few macrophytes		Rough fish dominate; summer fish kills possible

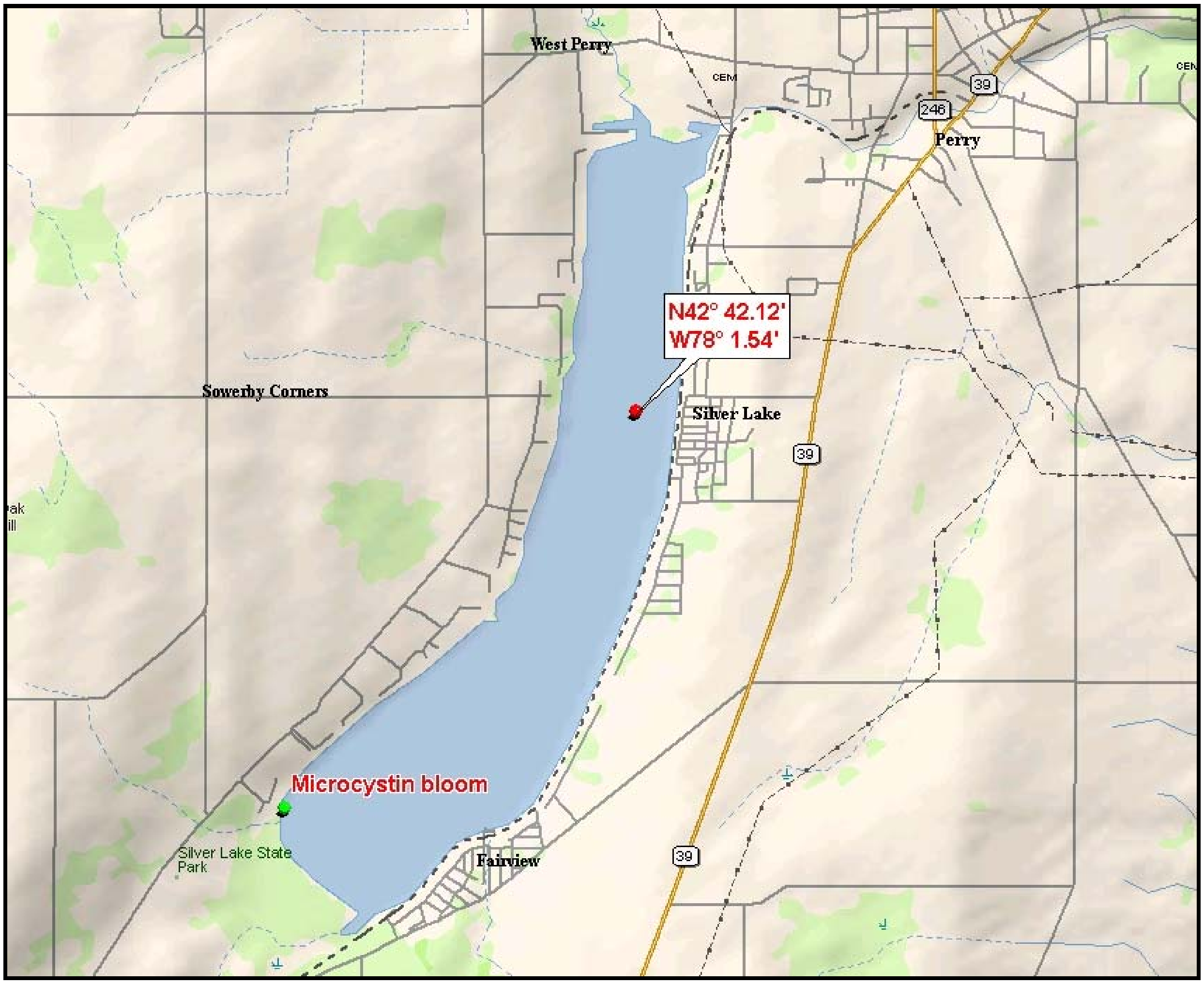

Figure 1. Map of Silver Lake, Wyoming County, NY with main mid-lake sampling station noted with a red dot. The area of additional samples taken for microcystin analysis is the green circle in the southwest corner of the lake.

Figure 2. Photographs of cyanobacteria (blue-green algae) blooms on Silver Lake in 2004. The top photo is in the southwest corner of the lake on 21 September (photo courtesy of Jane Bellamy). The middle photo is courtesy of Mary Kay Barton and was taken on 12 October. The bottom photomicrograph is of *Microcystin aeruginosa* in Silver Lake, the dominant Cyanobacteria in the 21 September bloom.

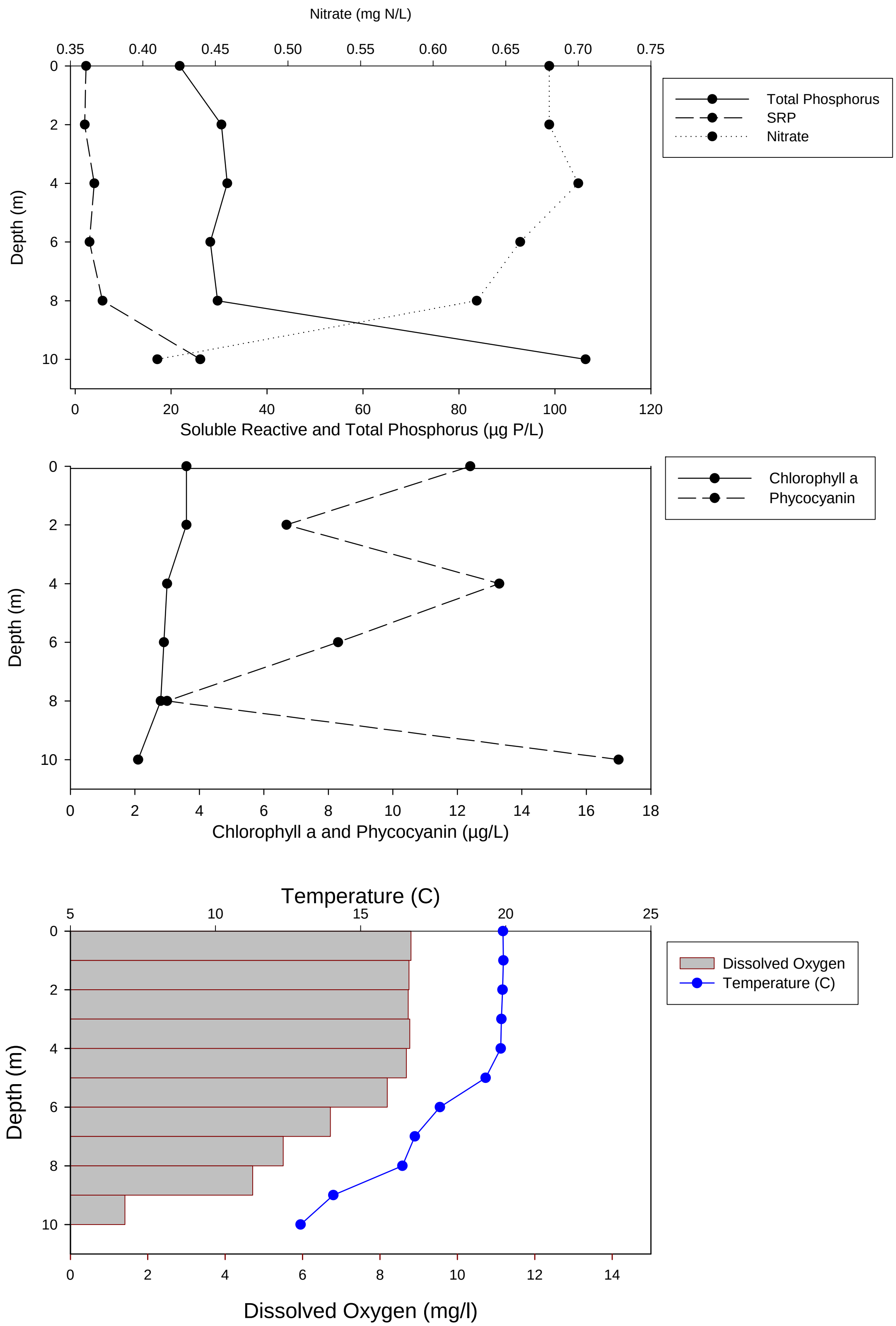

Figure 3. Nitrate, soluble reactive phosphorus, total phosphorus, chlorophyll *a*, phycocyanin temperature and dissolved oxygen profiles for Silver Lake, 10 June 2004.

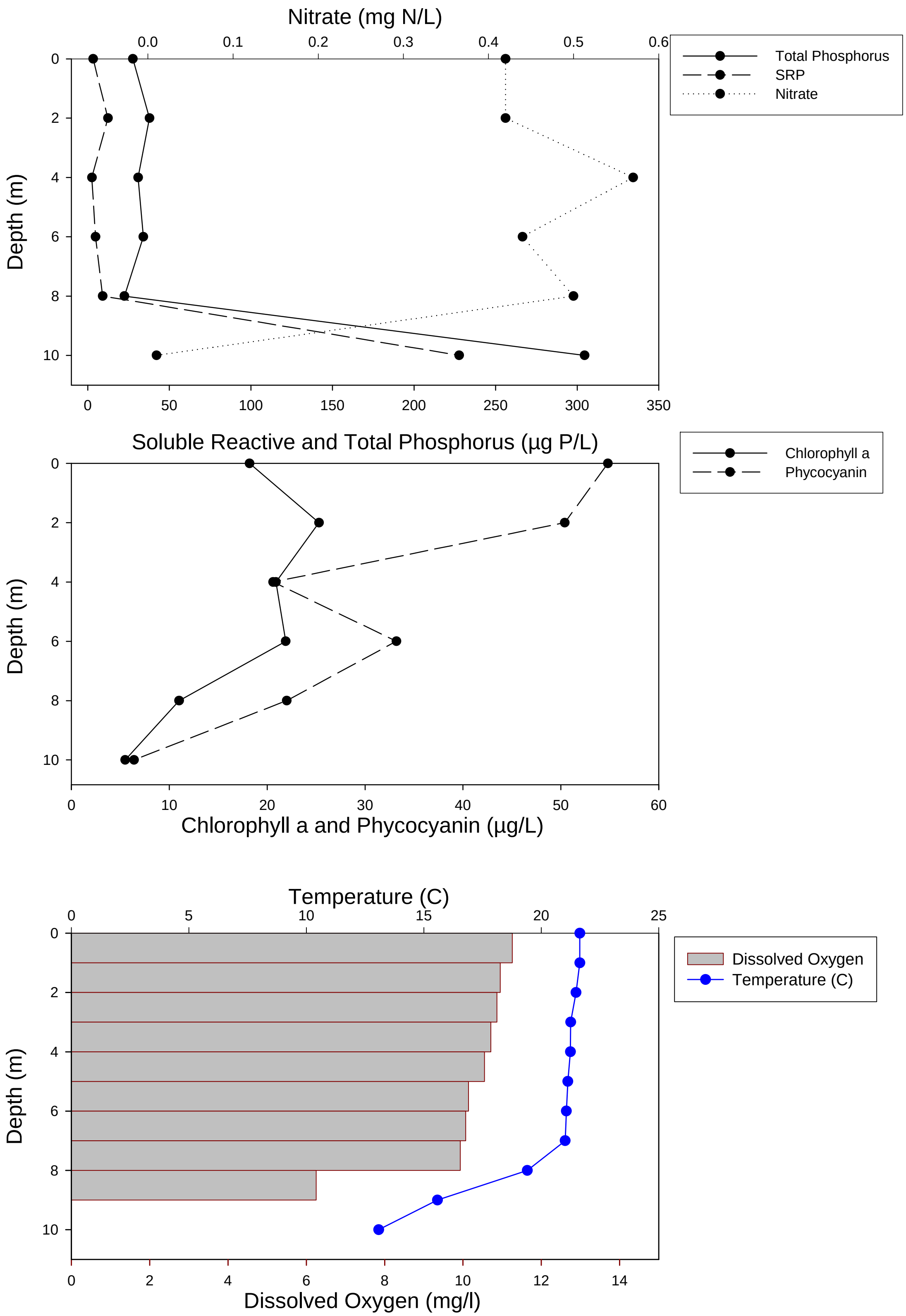

Figure 4. Nitrate, soluble reactive phosphorus, total phosphorus, chlorophyll *a*, phycocyanin temperature and dissolved oxygen profiles for Silver Lake, 24 June 2004.

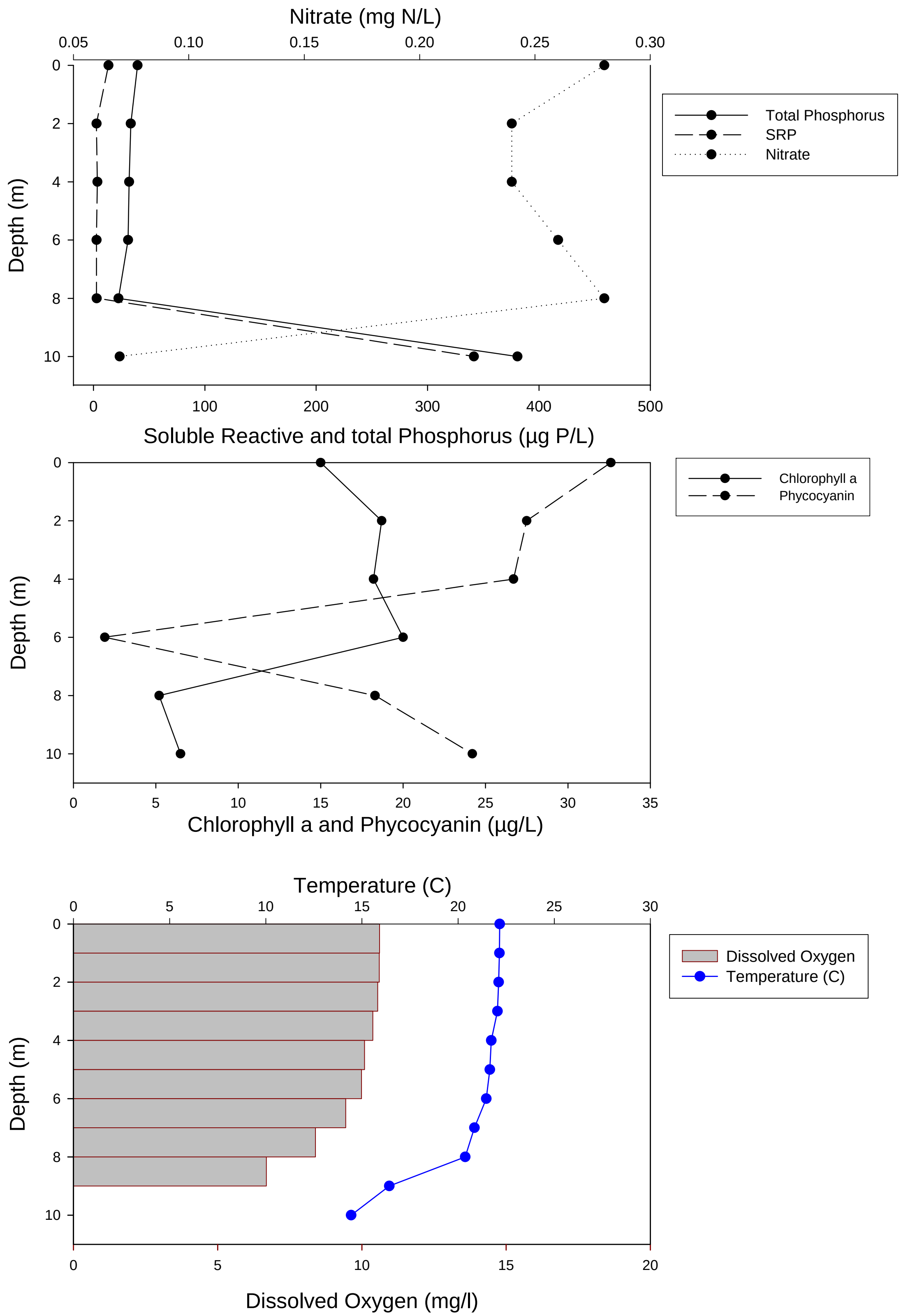

Figure 5. Nitrate, soluble reactive phosphorus, total phosphorus, chlorophyll *a*, phycocyanin temperature and dissolved oxygen profiles for Silver Lake, 7 July 2004.

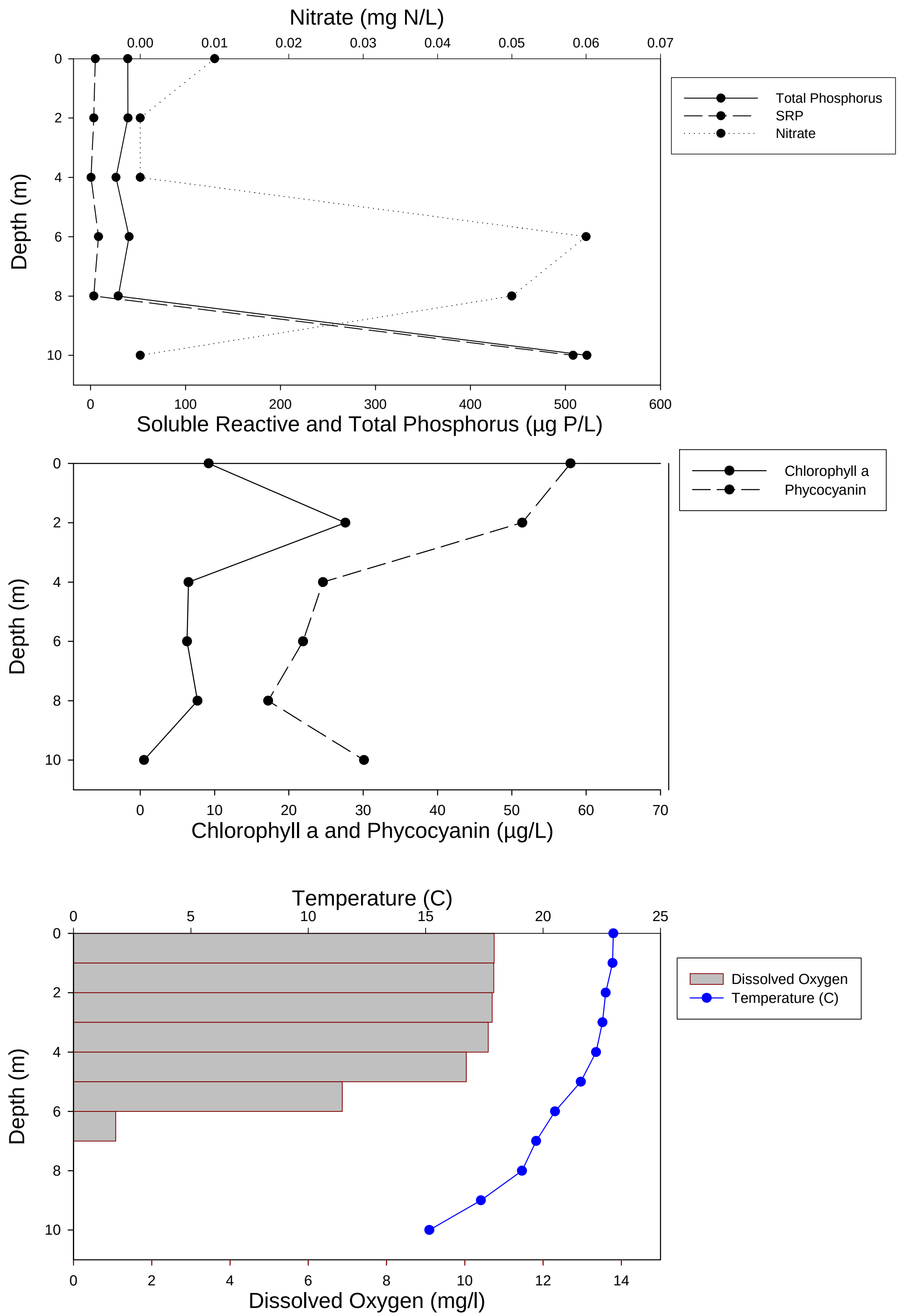

Figure 6. Nitrate, soluble reactive phosphorus, total phosphorus, chlorophyll *a*, phycocyanin temperature and dissolved oxygen profiles for Silver Lake, 23 July 2004.

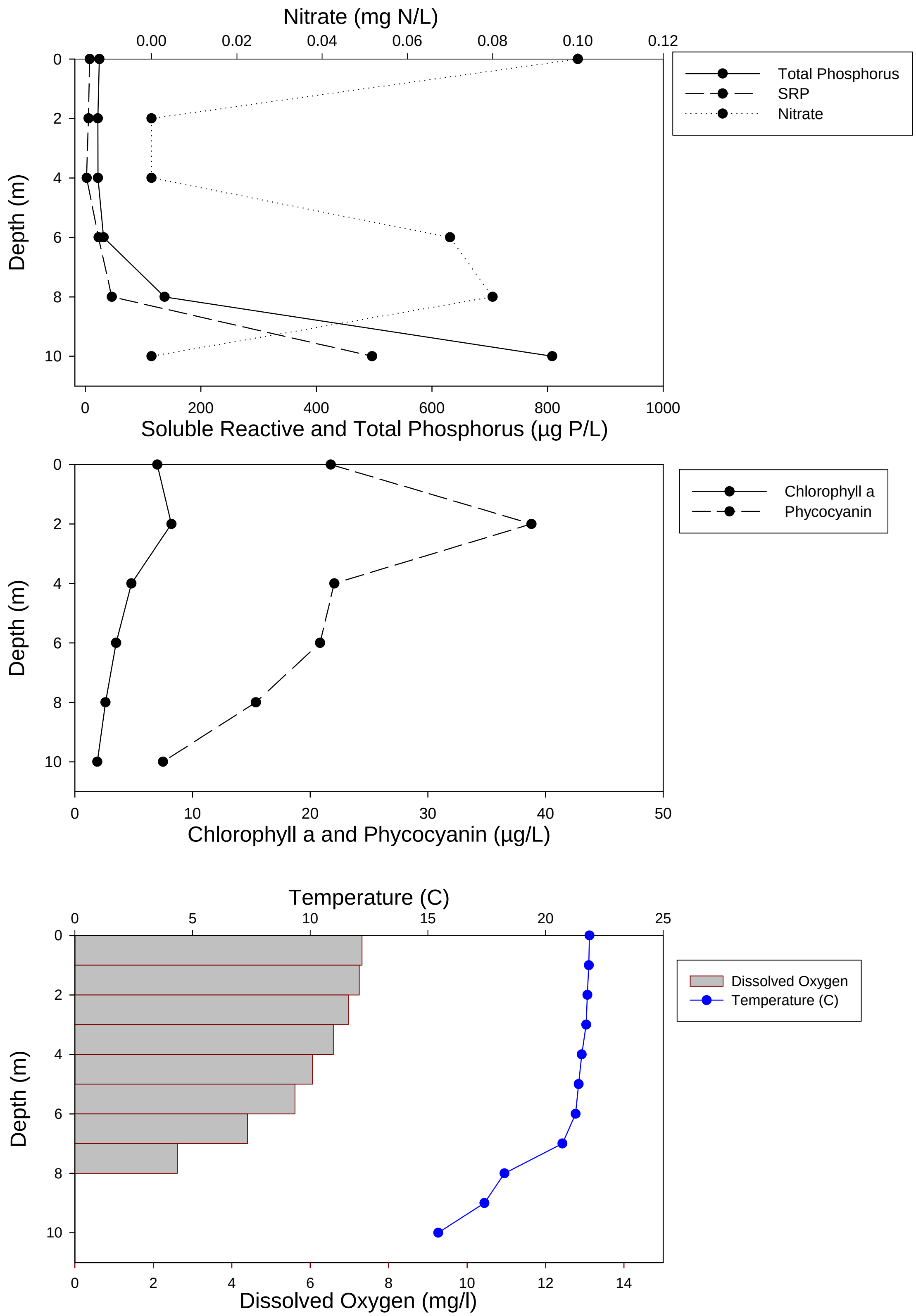

Figure 7. Nitrate, soluble reactive phosphorus, total phosphorus, chlorophyll *a*, phycocyanin temperature and dissolved oxygen profiles for Silver Lake, 5 August 2004.

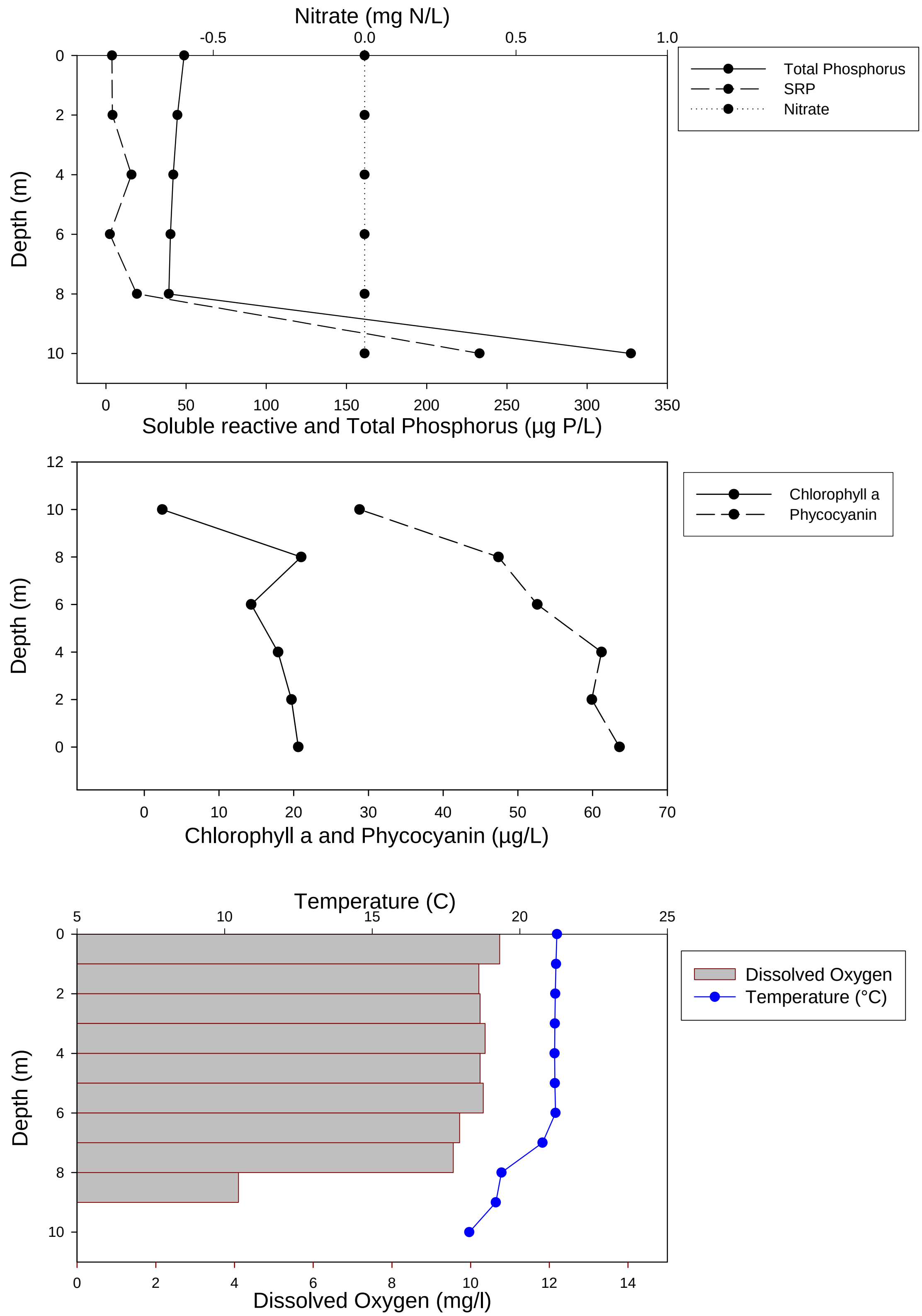

Figure 8. Nitrate, soluble reactive phosphorus, total phosphorus, chlorophyll *a*, phycocyanin temperature and dissolved oxygen profiles for Silver Lake, 19 August 2004.

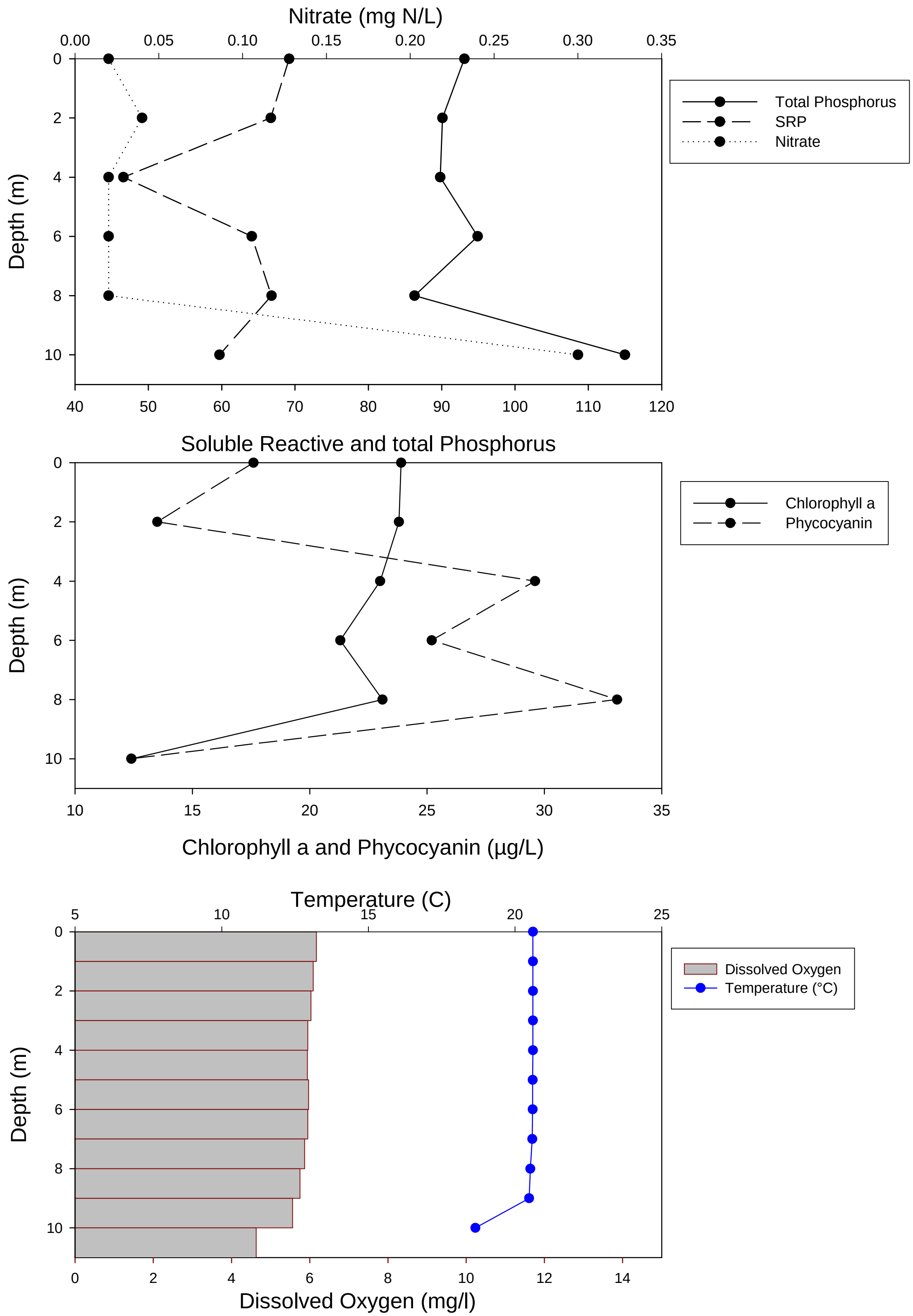

Figure 9. Nitrate, soluble reactive phosphorus, total phosphorus, chlorophyll *a*, phycocyanin temperature and dissolved oxygen profiles for Silver Lake, 10 September 2004.

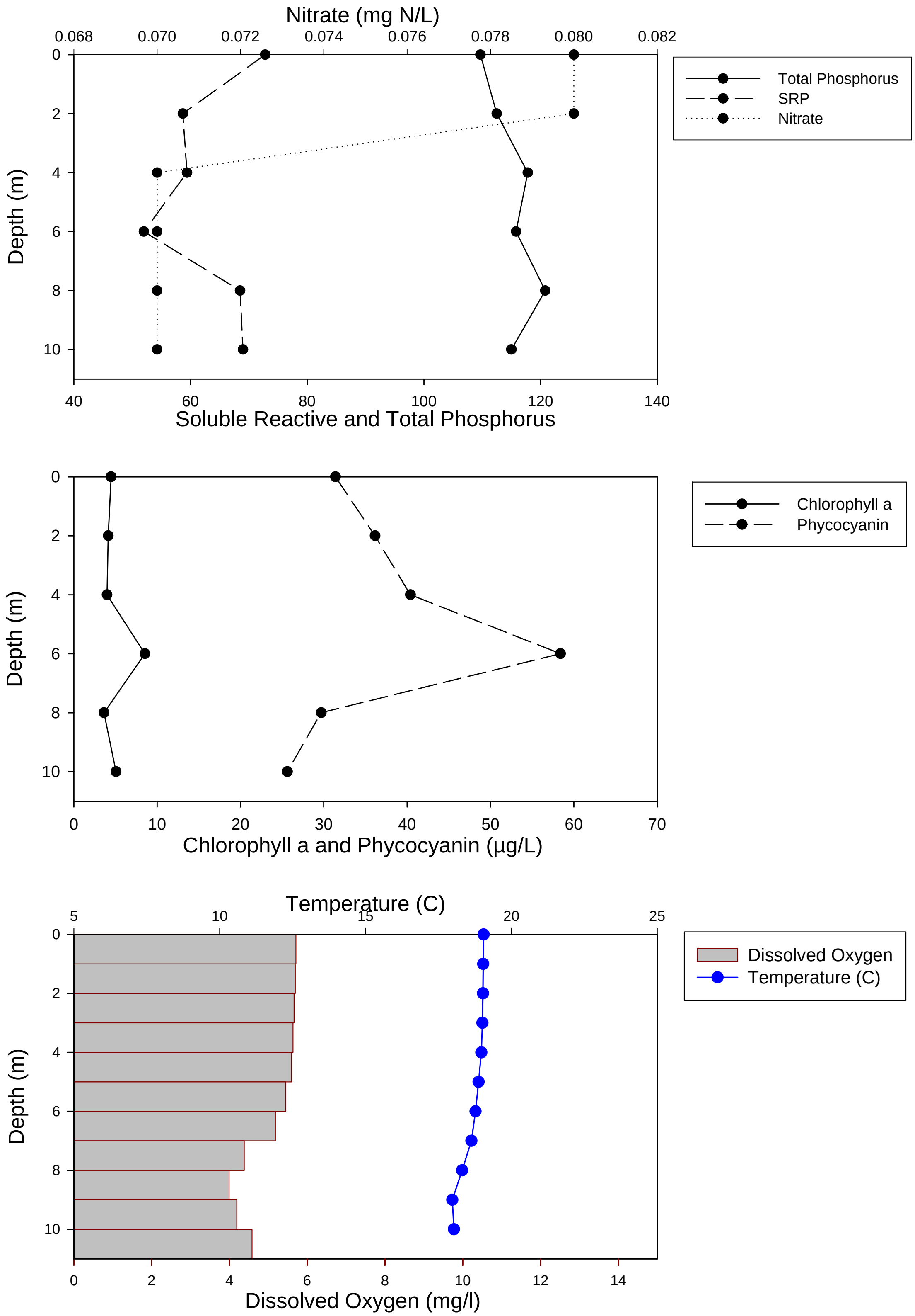

Figure 10. Nitrate, soluble reactive phosphorus, total phosphorus, chlorophyll *a*, phycocyanin temperature and dissolved oxygen profiles for Silver Lake, 30 September 2004.

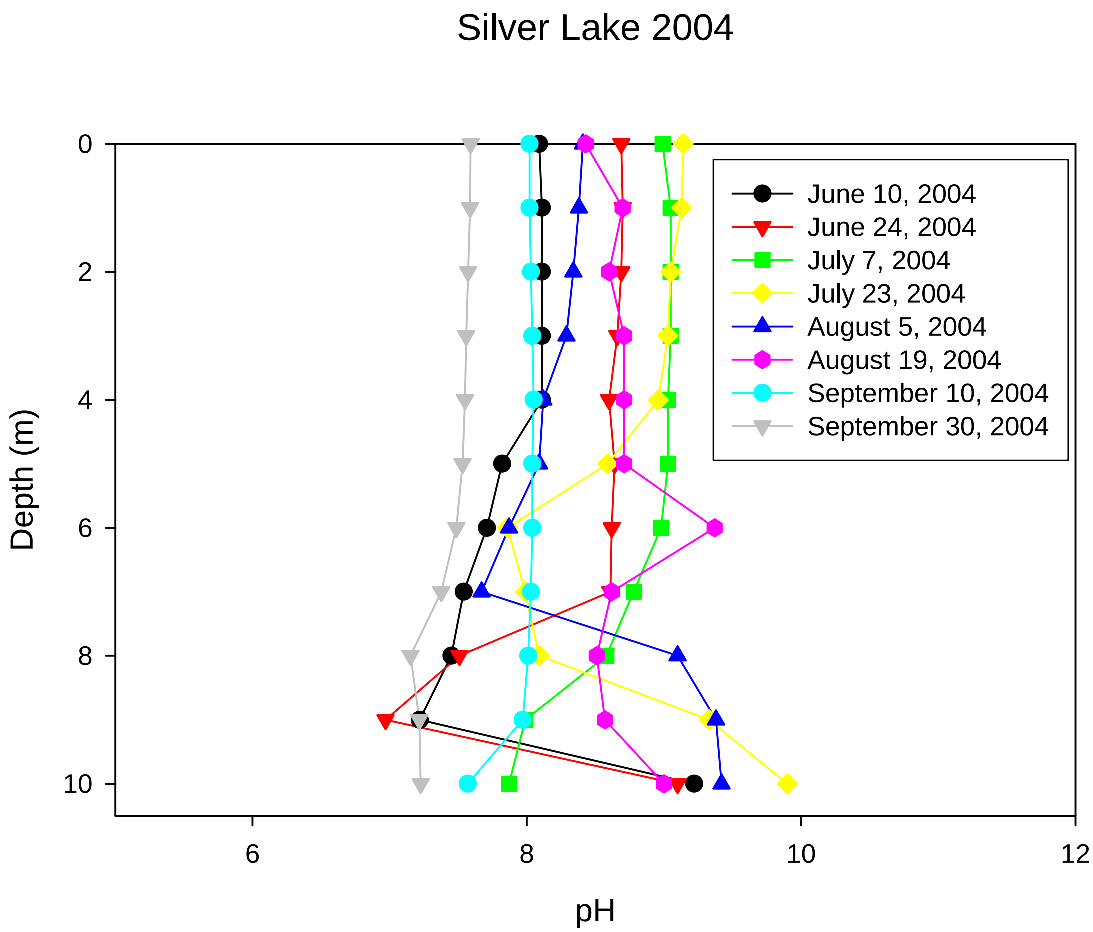

Figure 11. pH profiles for Silver Lake, 2004