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Heart Lake Monitoring Project 2018 Final Report

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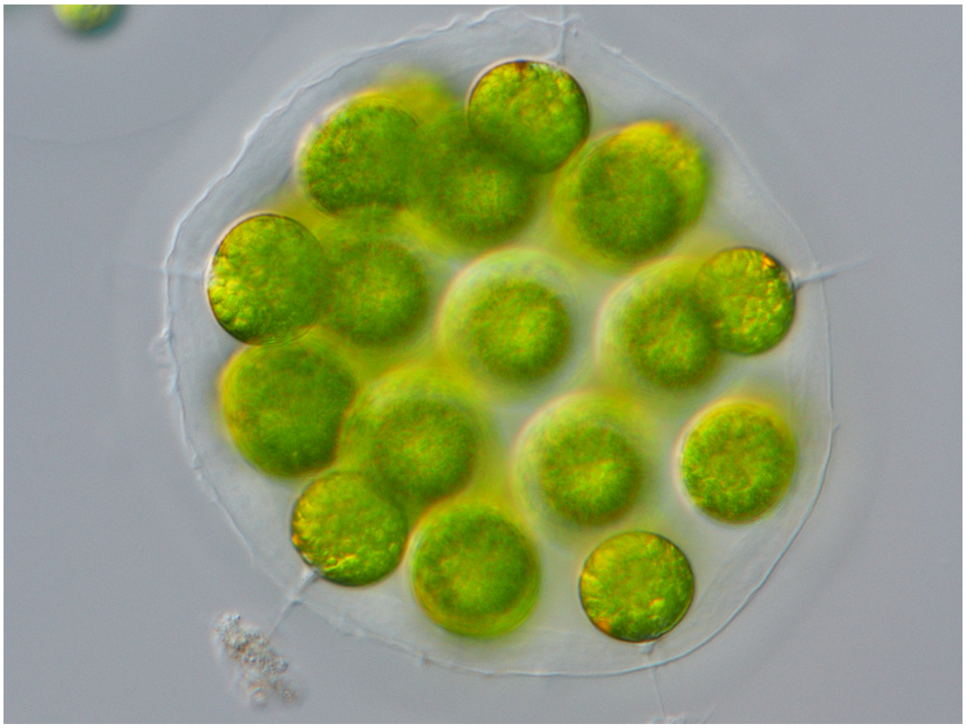

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Contents

1 Introduction

1.1 Background

Heart Lake is a 61.4 acre lake (0.248 km^2) located about 2 miles (3.2 km) south of Anacortes off of Heart Lake Road (Table 1; Figure 1). Heart Lake is separated into two basins and has a total shoreline length of 1.64 miles (2.645 km). The western basin is slightly larger and deeper that the eastern basin, but the maximum depth and average depth of the lake is only 5.8 and 2.7 meters, respectively. There are six seasonal sources of water flowing into the lake, including streams, wetlands, and runoff. The lake is situated at the headwaters for the Ace of Hearts Creek, which flows through Anacortes and empties into Fidalgo Bay.

Heart Lake is in the center of Fidalgo Island and is about 338 ft (103 m) above sea level. With the exception of Heart Lake Road, the gravel parking lot, and the trail network, the surrounding watershed is relatively intact. Most of the vegetation is native to the area, and there is a stand of old growth forest with the southwestern end dominated by old growth forest (City of Anacortes, 2012).

Heart Lake is part of the Anacortes Community Forest Lands and is a popular recreational destination. Activities on the lake include fishing for the biannually stocked rainbow trout (*Oncorhynchus mykiss*) as well as swimming, boating, birding, and picnicking (Washington Department of Fish & Wildlife, 2017). The watershed surrounding the lake contains an extensive recreation trail network that allows dog, horse, pedestrian, and mountain bike traffic (City of Anacortes, 2012). There is an active granite quarry just outside of the watershed boundary on the western end of the lake.

Historically, Heart Lake hosted a diverse aquatic plant community (City of Anacortes, 2012; Herrera, 2014) that included Hornwort (*Ceratophyllum demersum*), Slender water-nymph (*Najas flexilis*), Stonewort (*Nitella* spp.), Leafy pondweed (*Potamogeton foliosus*), Bladderwort (*Utricularia* sp.), Fragrant water lily (*Nymphea odorata*), Sago Pondweed (*Stuckenia pectinata*), Yellow water lily (*Nuphar polysepala*), Common elodea (*Elodea canadensis*), Floating leaf pondweed (*Potamogeton natans*) and Star duckweed (*Lemna trisulca*). In 1994 the native *Myriophyllum sibiricum* was discovered in Heart Lake, and in 1998 the non-native *Myriophyllum spicatum* was discovered in the lake (City of Anacortes, 2012). These two milfol species produced a highly invasive hybrid, which was found to be the dominant macrophyte species in Heart Lake in 2010 (City of Anacortes, 2012). In addition, Herrera (2014) found that many of the aquatic macrophytes previously reported from Heart Lake were no longer present, or were present in such low densities that they were not encountered during the 2010 plant survey. Heart Lake was treated with Sonar (fluridone) during the summer of 2017, with the goal of eradicating the milfoil hybrid. Aquatic vegetation surveys confirmed the absence of milfoil following the fluridone treatment (Herrera, 2018a). Fluridone is a broad-spectrum herbicide that is often toxic to other species of aquatic macrophytes, so most submerged vegetation in Heart Lake was eradicated by the treatment.

One challenging problem with controlling aquatic vegetation in lakes is that the removal of one type of plant may result in excessive growth of another type of plant. For example, successful eradication of milfoil may be followed by an algae bloom, especially if the lake contains large concentrations of phosphorus. In Heart Lake, dense growth of filamentous green algae were common on the surface of submerged macrophytes (City of Anacortes, 2012). Although the filamentous green algae may interfere with fishing, boating, and other recreational use of the lake, it is non-toxic and comparatively innocuous. But beginning in about 2012, there have been dense summer blooms of potentially toxic blue-green algae (Cyanobacteria) that caused the lake to be closed to fishing and recreational activities. While it is difficult to determine whether the frequency of blue-green algae blooms has increased, Heart Lake contains high concentrations of phosphorus and low concentrations of inorganic nitrogen (the type of nitrogen required by most plants), which favors the growth of blue-green algae.

1.2 Project Description

Heart Lake has had annual water quality and algae samples collected by the Institute for Watershed Studies (IWS) since 2006 as part of the Northwest Lakes Monitoring Project (www.wwu.edu/iws). The Northwest Lakes Monitoring Project is a public service project that samples approximately 60 lakes in Whatcom, Skagit, Snohomish, and Island Counties. In addition to the Northwest Lakes Project, there has been several assessments done by students from Western Washington University (WWU) and a number of studies conducted by environmental consulting companies.

Previous restoration work in Heart Lake focused on removal or control of the hybrid milfoil, which had become an increasing problem, as the plant now infests the entire lake. But the lake also develops dense blue-green algae blooms, including toxic blooms that occasionally closed the lake for fishing and other recreational activities. In April 2018 the lake was treated with alum to help reduce phosphorus concentrations, which is an important nutrient needed for growth by all algae (Herrera, 2018b).

To support the existing restoration efforts, and to help develop a more comprehensive lake management strategy to deal with the blue-green algae blooms, IWS was contracted by Herrera Environmental Consultants to provide assistance during the alum treatment process, followed by six months of water quality sampling, from May through October 2018, and provide a report of the current water quality condition in Heart Lake. In addition to the water quality sampling, algae samples were collected and analyzed by Dr. R. Matthews to document algal blooms and taxonomic diversity in the lake.

2 Methods

Water quality monitoring was conducted by the Institute for Watershed Studies using the methods summarized in Table 2, which followed the monitoring methods specified in Appendix B of the Heart Lake Alum Treatment Plan (Herrera, 2018b). All water quality data are included in Appendix A, starting on page 29. Monitoring efforts included short-term impact monitoring, which was designed to assess water quality prior to alum treatment, during the treatment process, and for the two weeks following alum treatment; and post-treatment monitoring, which was conducted for six months following alum treatment. Two sampling locations were identified for water quality monitoring (Figure 1) based on information from the 2016 Heart Lake Final Report (Wensloff, et al., 2017). One site ("deep site") was located in the deepest portion of the lake, which was approximately 5 meters deep. The second site ("shallow site") was located in the eastern basin, and was approximately 3 meters deep. Sampling sites were located using GPS, then an anchor was deployed to remain stationary during monitoring.

2.1 Short-term Monitoring

The short-term samples were collected 1 day prior to alum treatment (1x per day; deep site only); during the 2 days of treatment (2x per day; deep and shallow sites); and 2, 8, and 14 days following treatment (1x per day; deep site only). Additional randomly located Heart Lake sites (Figure 2) were sampled approximately one hour after alum application to measure water temperature, dissolved oxygen, conductivity, and pH. If pH values dropped below the lower bound of the pH criteria for alum application (6.5), an alkalinity sample was collected.

A YSI field meter was used to measure vertical profiles for water temperature, dissolved oxygen, percent oxygen saturation, pH, and conductivity from the surface (0.3 m) to the bottom. Water samples were collected 0.5 m below the surface and 0.5 m above the lake bottom using a horizontal Van Dorn sampler. All samples were placed on ice until lab analyses could be conducted. The Institute for Watershed Studies analyzed the samples for total alkalinity,[1] soluble phosphate (orthophosphate), total phosphorus, total nitrogen, nitrate/nitrite, and chlorophyll. Secchi depth was collected at the deep and shallow monitoring stations during all short-term sample collections; Secchi depth was not collected at the randomly located monitoring sites. Samples were also delivered to Edge Analytical Laboratories to be analyzed for total hardness, dissolved organic carbon, dissolved aluminum, and total recoverable aluminum.

Although not part of the original scope of work, a survey for rough-skinned newts (*Taricha granulosa*) was conducted during the short-term monitoring period. This survey was conducted by trolling the perimeter of the lake in search of egg masses, as well as dip netting for larvae and adults in the southwest lobe. The survey was conducted using a 650 μm dip net to sweep the lake bottom and aquatic vegetation for adult and larvae at depths of 0.2 to 1.5 m. Wildlife observations were also recorded, paying special attention to distressed behavior and mortalities.

2.2 Monthly Monitoring

The deep site was sampled monthly from May through October 2018. A YSI field meter was used to measure temperature, dissolved oxygen, conductivity, and pH profiles from 0.3 m to the bottom of the lake. Water samples were collected

[1] Alkalinity samples collected during alum treatment were analyzed in the field by Herrera.

0.5 m below the surface and 0.5 m above the bottom; the samples were analyzed by the Institute for Watershed Studies for total phosphorus, soluble phosphate (orthophosphate), total nitrogen, nitrate/nitrite, and chlorophyll.[2]

Phytoplankton samples were collected and preserved using Lugol's iodine solution for density calculation, and live phytoplankton samples were collected using a phytoplankton net (20 μm mesh) and transported to the laboratory for algal identification. Settling chambers were used to concentrate Heart Lake algae from raw water samples that were preserved using Lugol's iodine solution. The method was adapted from the procedure described by Hamilton, et al. (2001), and is described in detail in the 2016 Heart Lake Final Report (Wensloff, et al., 2017). All algae counts are included in Appendix B, beginning on page 43.

2.3 Quality Control

All water quality data described in this report were analyzed by the Institute for Watershed Studies at Western Washington University, which is accredited by the Washington State Department of Ecology (Laboratory ID #A543). The quality control results are discussed in Appendix C (page 47).

3 Results

3.1 Short-term Monitoring, Pre-treatment

Water quality measurements were collected on April 2, one day prior to the alum treatment (Tables A1-A2 in Appendix A). Water temperatures were cool, ranging from 8.5° C at 5 m to 9.4° C at the surface. The lake was well oxygenated at all depths, and exhibited super-saturated conditions in the upper portion of the water column. The lake was alkaline, with the pH ranging from 8.0 at 5 m, to 9.1 at the surface. The surface and bottom samples had similar alkalinities (65.8 mg/L and 65.3 mg/L, respectively). The water clarity was poor, with a Secchi depth of 1.6 m. The combination of poor water clarity, super-saturated dissolved oxygen concentrations, and elevated pH were likely the result of an observed algae bloom.

[2] The July chlorophyll data were excluded due to analysis error.

Rapid photosynthesis during algal blooms will cause super-saturated daytime oxygen concentrations because oxygen is a direct product of photosynthesis. The rapid photosynthetic rate also raises the daytime pH by reducing the availability of carbon dioxide, which would otherwise react with water to form carbonic acid. The surface and bottom samples contained high concentrations of chlorophyll (84.9 and 18.7 μg/L, respectively) and total phosphorus (129.8 and 68.2 μg-P/L, respectively).

Both the surface and bottom samples collected from Heart Lake on April 2 would be classified as eutrophic ($\text{TSI}_{chl} > 50$) based on Carlson's trophic state index (Carlson, 1977):

$$\begin{aligned}
\text{TSI}_{\text{chl}} &= 9.81 \times \ln(\text{Chl}, \mu\text{g/L}) + 30.6 \\
\text{Heart Lake surface TSI}_{\text{chl}} &= 9.81 \times \ln(84.9) + 30.6 = 74 \\
\text{Heart Lake bottom TSI}_{\text{chl}} &= 9.81 \times \ln(18.7) + 30.6 = 59
\end{aligned}$$

3.2 Short-term Monitoring, Treatment

The algae bloom mentioned above was still present on April 3, resulting in super-saturated oxygen concentrations (139%) and elevated pH (8.9) at the lake's surface (Table A1 in Appendix A). Alkalinity samples were collected by IWS staff and analyzed by Herrera personnel at 0.5 m below the surface and above the bottom of the lake at the deep and shallow sites. The samples were analyzed immediately; all were above the required 10 mg/L threshold required for alum treatment (personal communications, R. Zisette, Herrera Environmental Consultants, Inc.) Alum treatment was initiated on April 3. Prior to treatment, the early morning (~4 am) average pH in the water column was 8.4 and alkalinities were 56–60 mg/L. Jar tests were performed to select an alum-to-buffer ratio that would slightly lower the lake pH to be within the target range of 6.5–8.5 for protection of aquatic biota from potential aluminum toxicity (personal communications, R. Zisette, Herrera Environmental Consultants, Inc.).

The pH values from the post-treatment vertical profiles remained above the threshold of 6.5 at both the deep and shallow sites during the two days of alum treatment. Similarly, the surface and bottom alkalinity samples remained above

10 mg/L on both treatment days (personal communications, R. Zisette, Herrera Environmental Consultants, Inc.). Water column monitoring at random locations confirmed that the pH did not drop below the lower limit (6.5) during either treatment day. No signs of distressed or deceased wildlife were observed during alum treatment; however, fish mortalities and distressed behavior were observed during the short-term post-treatment monitoring (see discussion of fish monitoring on page 10).

3.3 Short-term Monitoring, Post-treatment

Two days post-treatment: The vertical profile displayed a reduction in pH and dissolved oxygen, although the oxygen concentrations were still slightly supersaturated (Table A2 in Appendix A). These changes were most likely caused by the alum treatment, which greatly reduced the phytoplankton in the water column, resulting in a decrease in chlorophyll concentrations (Table A2). The alum treatment introduced dissolved substances into the lake, which resulted in an increase in conductivity. Water clarity improved, and the Secchi depth increased to 2.7 m. The alum treatment successfully reduced the nutrient concentrations (total phosphorus, total nitrogen, soluble phosphate, and nitrate) within the water column compared to pre-treatment concentrations.

Eight days post-treatment: Based on the chlorophyll concentrations, the algae bloom had subsided by April 12 (Table A2). The pH dropped from $\geq$8.5 prior to treatment to 7.6-7.7, and the dissolved oxygen concentrations dropped to slightly below saturation (Table A1). The water clarity greatly improved, with a Secchi depth of 5.2 m. The conductivities remained slightly elevated compared to pre-treatment conditions, and were similar to the 2 day post-treatment values.

Fourteen days post-treatment: The chlorophyll concentrations remained low (<2 μg/L) on April 18, and the dissolved oxygen was about 80-85% of saturation (Tables A1-A2 in Appendix A). The pH dropped to 7.4–7.5, and the water clarity remained good, with a Secchi depth of 5.2 m. The conductivities were similar to the previous post-treatment values.

3.4 Monthly Monitoring

The monthly water quality and algae data are summarized in Figures 3–13 and the raw data are listed in Appendices A–B.

Heart Lake was thermally stratified in May, but was destratified in June, with nearly uniform temperature, oxygen, pH, and conductivity values throughout the water column (Figures 3–7). This pattern is typical for shallow, polymictic lakes (Wetzel, 2001; Wilhelm and Adrian, 2008). Unstable stratification developed in July and August, accompanied by oxygen depletion near the bottom of the water column. The water column was destratified again in September and October. The 5 meter sample from September indicated a small residual area of oxygen depletion present near the lake bottom; by October the water column was completely mixed. Low oxygen concentrations were present near the bottom during May, July, August, and September, which is typical for shallow, polymictic lakes during periods of stratification.

The total phosphorus concentrations dropped abruptly following alum treatment, and remained relatively low throughout the monitoring period (Figure 8). Although the total phosphorus concentrations were slightly higher in the May-October bottom samples, the concentrations were not high enough to suggest any significant release of phosphorus. Phosphorus reduction is a major goal when using alum treatments in lakes, and the reduced phosphorus concentrations should help reduce Cyanobacteria blooms in Heart Lake.

The total nitrogen concentrations remained relatively high, and were usually higher in the bottom samples (Figure 9). High concentrations of nitrogen relative to phosphorus creates an environment that favors a more diverse algal community, so this too should help reduce Cyanobacteria blooms in Heart Lake.

A major goal in treating Heart Lake with alum was to reduce harmful algal blooms, especially blooms of potentially toxic Cyanobacteria, by reducing phosphorus concentrations in the water column. One of the best indicators of the effectiveness of alum treatment in Heart Lake is the drop in surface chlorophyll concentrations that occurred immediately following treatment (Figure 10). Lower chlorophyll concentrations were maintained throughout most of the post-treatment monitoring period. The chlorophyll concentrations increased slightly in September and October, but the algal community was dominated by green algae, cryptomonads, and diatoms rather than Cyanobacteria (Table C1 in

Appendix B). The reduced chlorophyll concentrations changed the lake's tropic state from eutrophic to mesotrophic (Figure 11) and resulted in an increase in water clarity (Figure 12). The median May-October water quality results met the chlorophyll, TSI, total phosphorus, and Secchi depth objectives listed in the Heart Lake Alum Treatment Plan (Herrera, 2018b):

Parameter	Treatment Goal	May-October, 2018 Shallow & Deep Water Quality Min	Median	Mean	Max
Chlorophyll (μg/L)	<7.2	2.1	5.0	8.8	18.4
Trophic index	<50†	38	46	49	59
Total phosphorus (μg-P/L)	<24	13.3	22.5	23.3	33.3
Secchi depth (m)	>2	2.0	4.3	3.8	5.2

†Mesotrophic

3.5 Wildlife Monitoring

Amphibian monitoring: Prior to the alum treatment the lake was surveyed for rough-skinned newts (*Taricha granulosa*). This survey was conducted by trolling the perimeter of the lake in search of egg masses, and using dip nets to search for larvae and adults in the southwest lobe of Heart Lake. The survey was conducted using a 650 μm dip net to sweep the lake bottom and aquatic vegetation for adult and larvae at depths of 0.2–1.5 m. No rough-skinned newt adults, larvae, or egg masses were captured or seen after more than 25 attempts. Their absence may be partly due to the behavior of the rough-skinned newts, as they conceal their eggs by laying them singly and attached to submerged vegetation. In addition, the reduction in submerged vegetation following the 2017 Sonar (fluridone) treatment may have reduced the substrates available for egg attachment.

Although rough-skinned newts were not found, there were three distinct types of amphibian egg masses identified along the shoreline. These egg masses belonged to the Northwestern salamander (*Ambystoma gracile*), the long-toed salamander (*Ambystoma macrodactylum*), and the Pacific chorus frog (*Pseudacris regilla*). Approximately 25 long-toed salamander embryos were found floating among the cattails, while at least 10 round, rigid, gelatinous egg clusters of the Northwestern salamander were found adhering to aquatic vegetation and woody debris. All embryos appeared to be alive and without deformities.

After the alum treatment, the Northwestern salamander egg sac abundance seemed to increase. This was likely due to both sampling variation and the deposition of additional Northwestern salamander egg masses between sampling dates. Immediately following the alum treatment, we were unable to locate any long-toed salamander embryos, possibly due to difficulty finding the small egg masses in the dense cattails. Due to their abundance, we continued to monitor the development of Northwestern salamander egg masses, which we used as an indicator of whether the alum treatment affected the amphibian populations of Heart Lake. The Northwestern salamander embryos increased noticeably in size increases between monitoring days. The embryos also developed front legs and gills. Emergence of larvae from egg clusters was observed during the final short-term monitoring visit on April 18. The Pacific chorus frog egg clusters were only observed during the post-treatment monitoring, but the larvae also exhibited growth and showed no signs of deformation.

Fish monitoring: The condition of the fish in Heart Lake was monitored by observing changes in behavior and mortality before, during, and after alum treatment. No abnormal behaviors or mortalities were observed before or during treatment. In the first five days following treatment (April 4–9, 2018), a total of 32 fish mortalities were observed. The mortalities included adult rainbow trout (*Oncorhynchus mykiss*), as well as adult and juvenile yellow perch (*Perca avescens*). The rainbow trout that were recovered ranged in size from 28–36 cm, while the one juvenile yellow perch measured 6 cm in length.

On April 5, two fish mortalities were reported (one rainbow trout and one yellow perch; personal communications, D. Oicles, City of Anacortes Parks and Recreation). On April 6, 23 fish mortalities were observed (22 rainbow trout and one yellow perch) and two adult rainbow trout were observed exhibiting signs of distress, which included gasping at the surface and delayed reaction times. Seven more fish mortalities were reported on April 9, (4 rainbow trout and 3 yellow perch; personal communications, D. Oicles, City of Anacortes Parks and Recreation).

The observed mortalities and distressed behavior were likely attributed to a combination of stressors that included both the alum treatment and the pre-existing algae bloom. The algae bloom that was present prior to alum treatment produced super-saturated dissolved oxygen concentrations that reached as high as 143.5% saturation. Such conditions can have deleterious effects on fish and have been linked to gas bubble disease and improper ination of the swim bladder (Weitkamp and Katz, 1980).

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5 Tables

Table 1: Heart Lake morphometric data (adapted from Horton, 2014).

Lake surface area	248,491 m^2 (0.248 km^2)	61.4 acre
Lake maximum depth	5.8 m	19.03 ft
Lake mean depth (m)	2.7 m	8.85 ft
Lake volume	681,660 m^3 (681×10^6 liter)	552.6 acre ft.
Shoreline length	2645 m (2.645 km)	1.64 miles
Watershed perimeter	5886 m (5.886 km)	3.68 miles
Watershed area	1,514,597 m^2 (1.515 km^2)	374.3 acre

Table 2: Summary of IWS analytical methods, abbreviations, and detection limits for analyses used in the Heart Lake monitoring project.

Abbrev.	Parameter	Method	Method Det. Limit	Sensitivity or Confidence limit
IWS field measurements:				
Cond	Conductivity	YSI (2010)	–	± 2 μS/cm
DO	Dissolved oxygen	YSI (2010)	–	± 0.1 mg/L
pH	pH	YSI (2010)	–	± 0.1 pH unit
Temp	Temperature	YSI (2010)	–	± 0.1° C
Secchi	Secchi depth	Lind (1985)	–	± 0.1 m
IWS laboratory analyses:				
Alk	Alkalinity	APHA (2017) #2320	–	± 0.4 mg/L
TN	T. nitrogen	APHA (2017) #4500-N C	20.7 μg-N/L	± 12.1 μg-N/L
NO3	Nitrate/nitrite	APHA (2017) #4500-NO3 I	12.6 μg-N/L	± 15.4 μg-N/L
TP	T. phosphorus	APHA (2017) #4500-P J	4.0 μg-P/L	± 2.3 μg-P/L
SRP	Orthophosphate	APHA (2017) #4500-P G	2.8 μg-P/L	± 2.0 μg-P/L
Chl	Chlorophyll	APHA (2017) #10200 H	–	± 0.1 μg/L

6 Annotated Figures

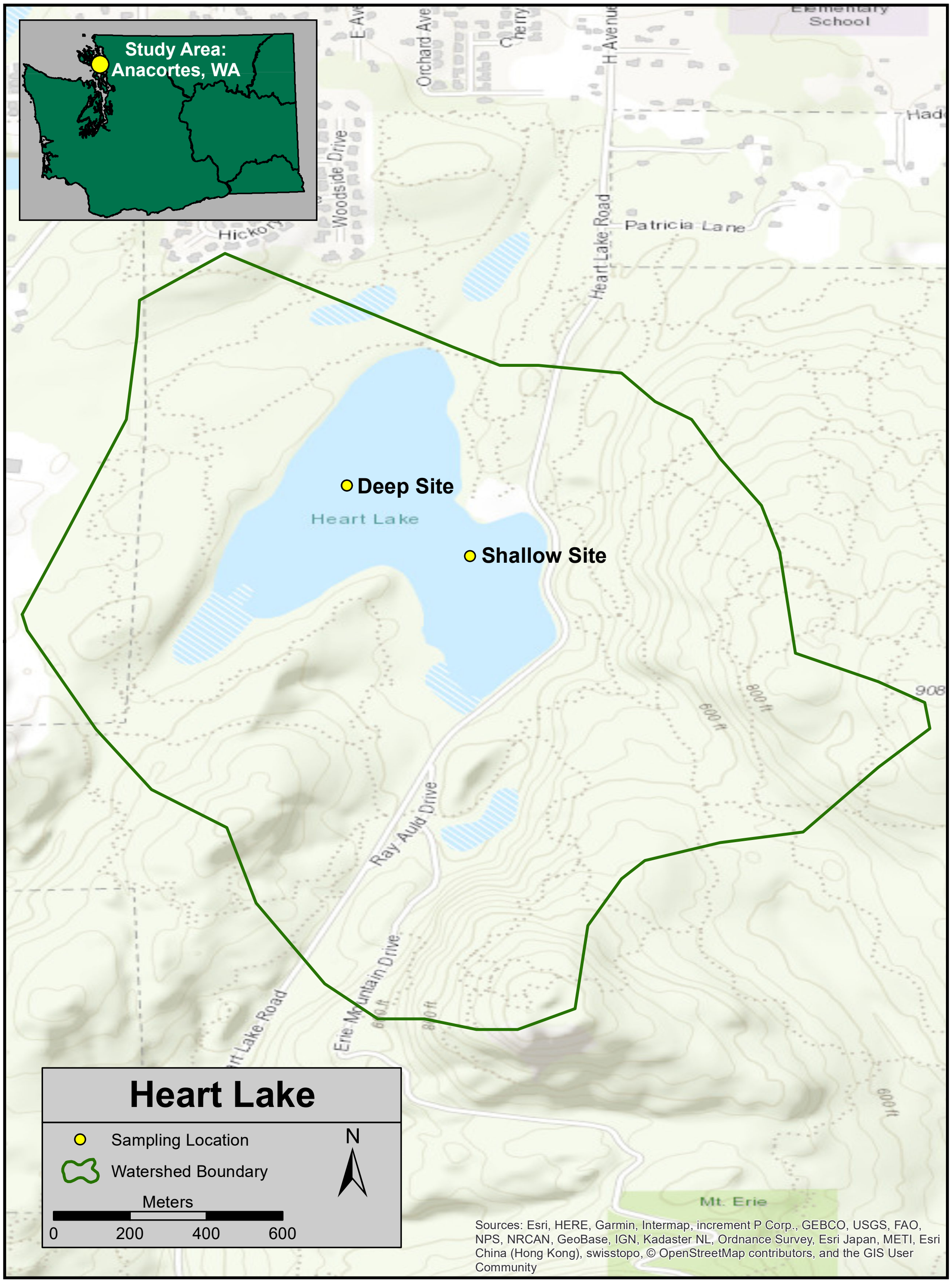

Figure 1: Heart Lake deep and shallow sampling sites, April-October 2018.

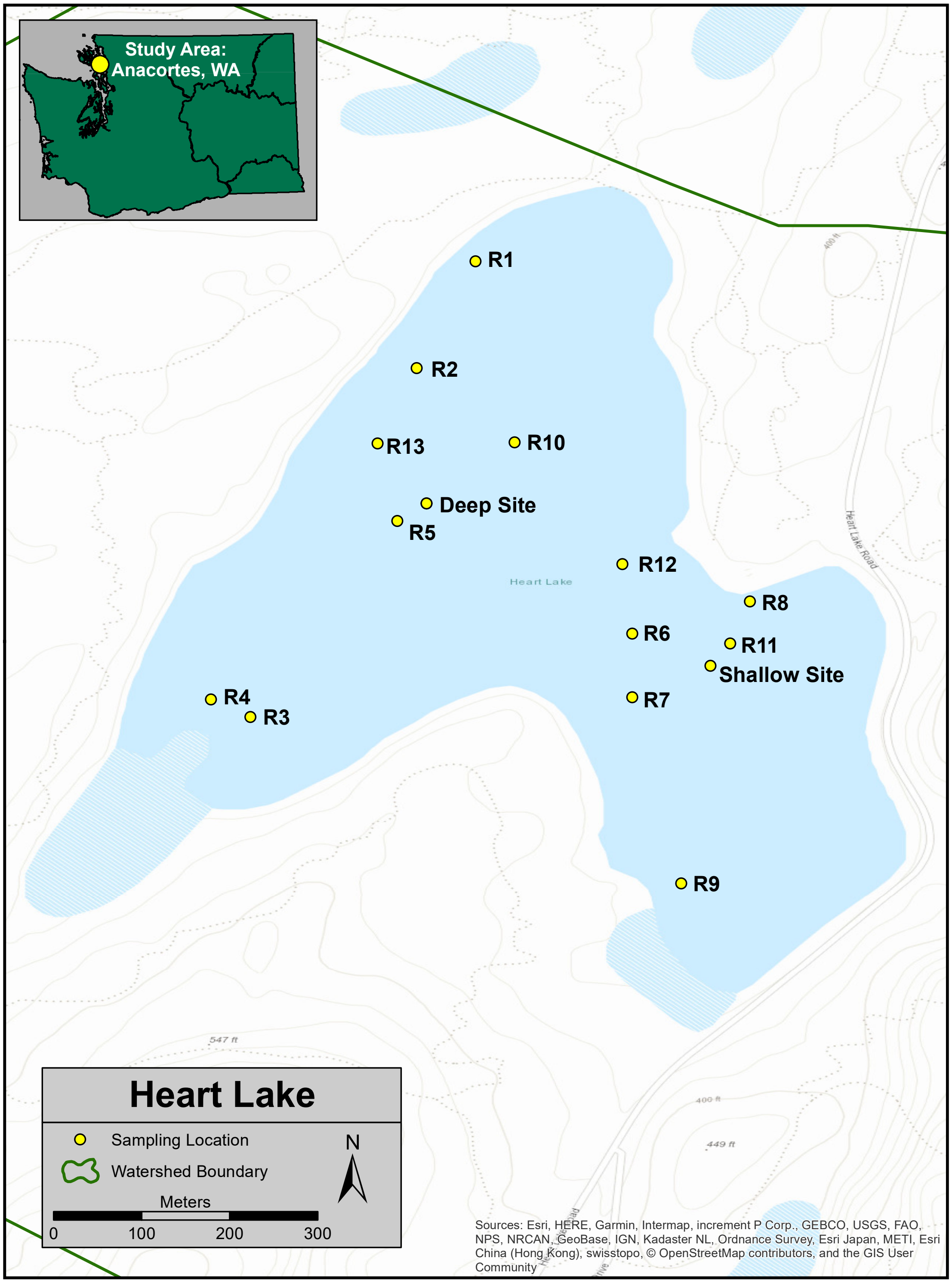

Figure 2: Heart Lake deep, shallow, and random sampling sites, April-October 2018.

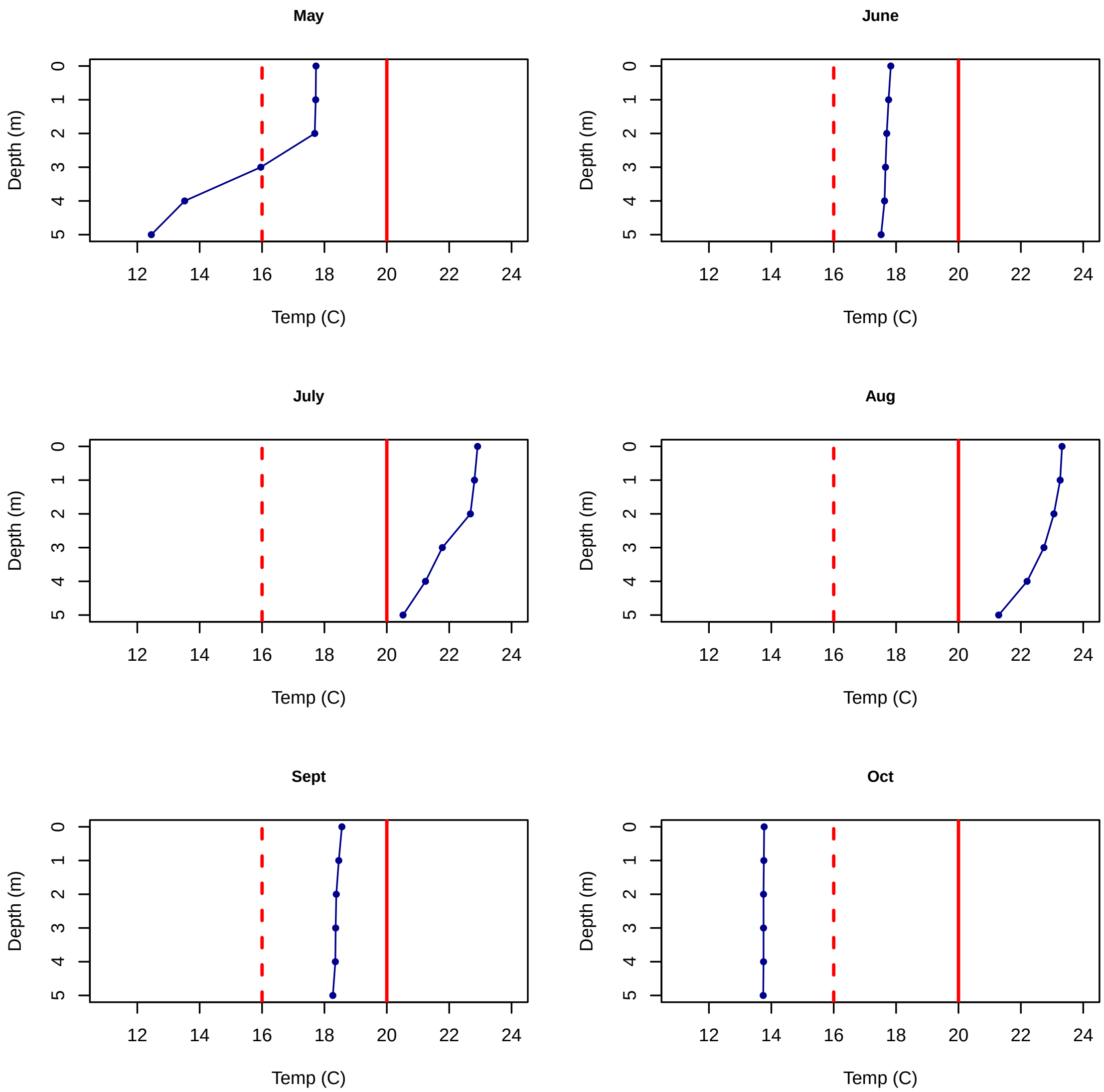

Figure 3: The Heart Lake water temperature data, May-October 2018. Heart Lake followed typical seasonal patterns, warming from May through August, then cooling in September and October. Thermal stratification was observed in May (ΔT = 5.3 °), but due to the shallow depth of the lake, stratification was lost in June, and was not fully restored for the remainder of the sampling period. This "polymictic" stratification pattern is very common in shallow lakes (Wetzel, 2001; Wilhelm and Adrian, 2008). Between June and September, the deep site in Heart Lake exceeded the temperature criteria for core summer salmonid habitat (- - -); in July and August the lake exceeded the temperature criteria for indigenous warm water species (—) based on the surface water standards in WAC 173-201A-200.

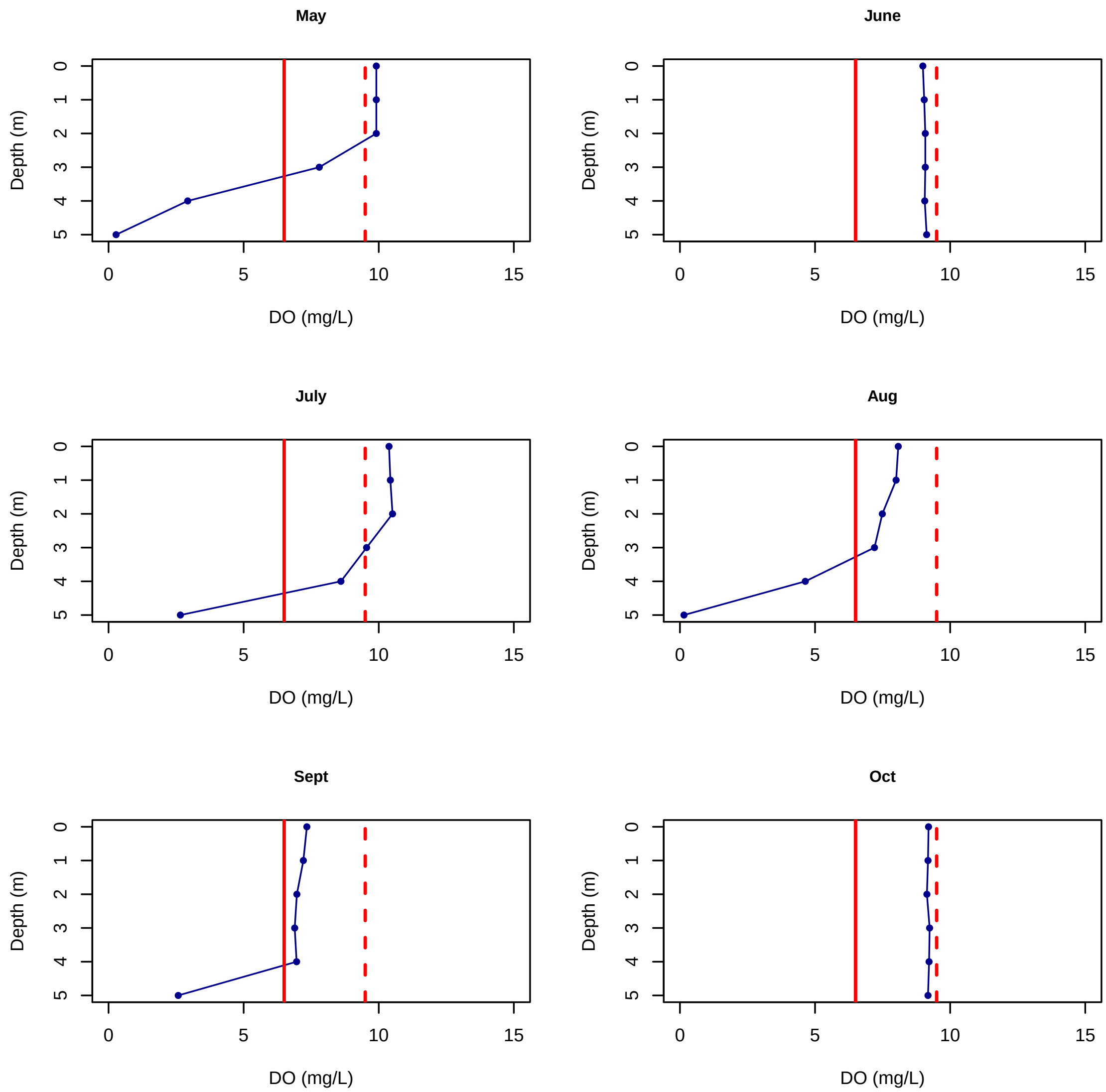

Figure 4: Heart Lake dissolved oxygen data, May-October 2018. The top three meters in Heart Lake were consistently well-mixed and oxygenated. When the water column was destratified, the oxygen concentrations were fairly uniform, but oxygen depletion was evident in samples near the bottom of the lake from July through September. Based on WAC 173-201A-200, the deep site in Heart Lake failed to meet the minimum dissolved oxygen concentration for providing summer habitat for salmonids (- - -) except near the surface in May and July. Heart Lake met the minimum dissolved oxygen concentration required for indigenous warm water species (—) except in the bottom samples during May, July, August, and September. This could be problematic if fish were seeking cooler bottom temperatures for survival, but as indicated in Figure 3, this site did not provide cool water habitat during the summer.

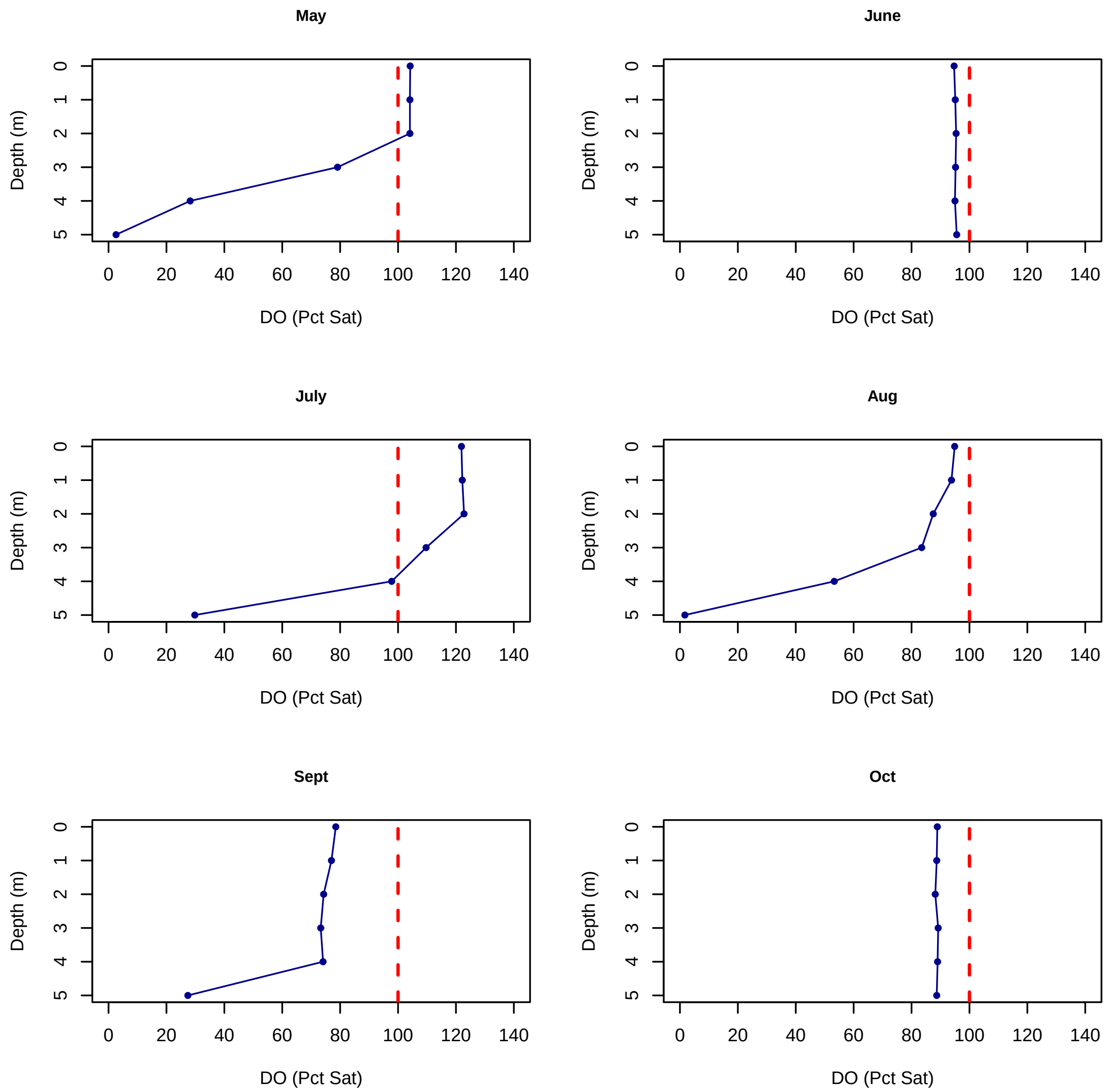

Figure 5: Heart Lake oxygen percent saturation data, May-October 2018. The Heart Lake dissolved oxygen concentrations were at or below saturation (- - -) during most months. Low saturation occurred near the bottom during periods of stratification (Figure 3). Super-saturation occurred in near-surface samples during July. Super-saturation is caused by algae or aquatic plants releasing oxygen faster than the oxygen can diffuse out of the water column. Unfortunately, the chlorophyll sample from July was lost due to analytical error, but the algal counts (Figure 13) showed a small increase in density, mostly due to blooms of green algae. Despite the relatively low cell densities, the oxygen data suggest that the algae were very actively photosynthesizing.

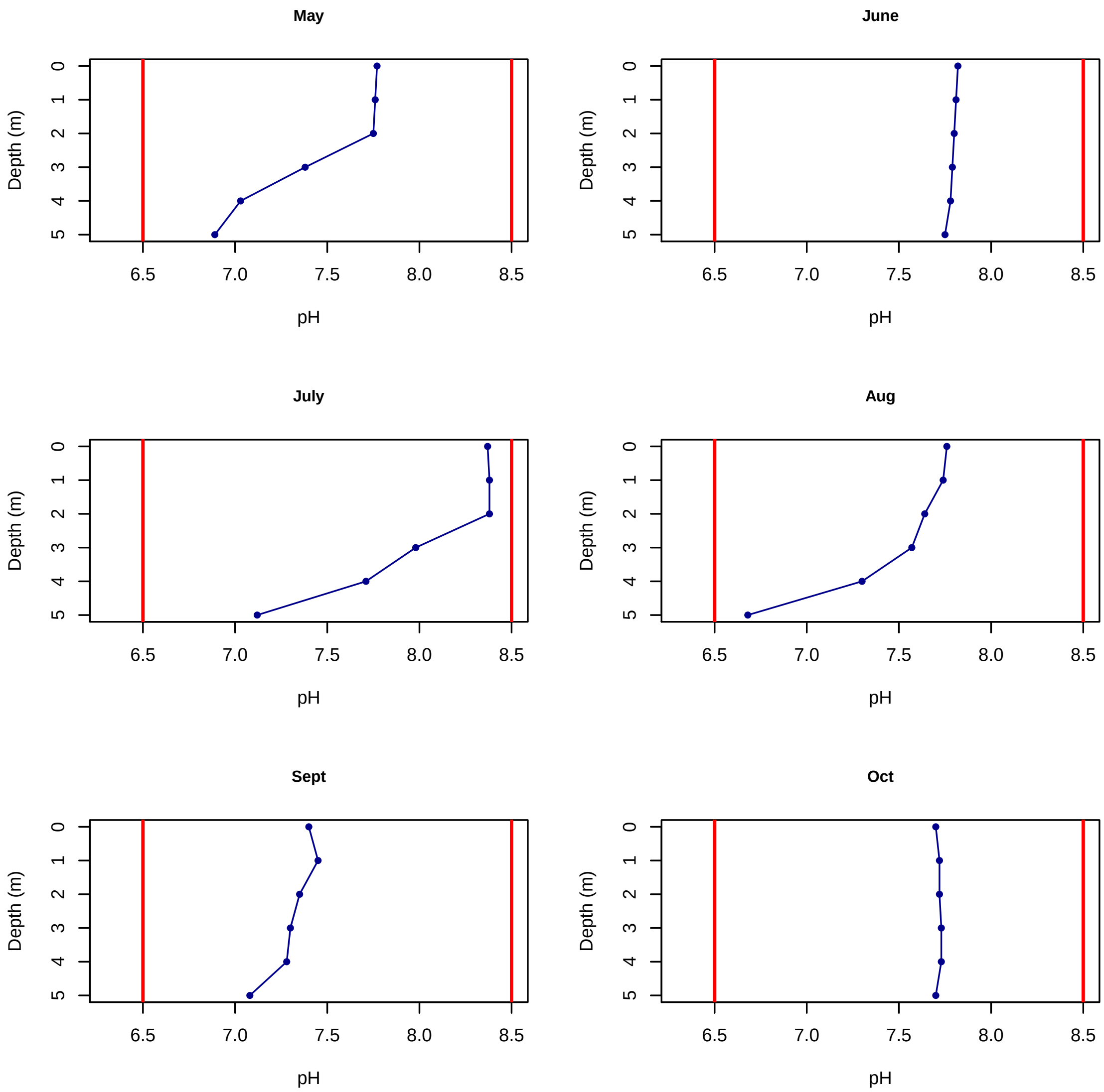

Figure 6: Heart Lake pH data, May-October 2018. The pH values were slightly elevated in the near surface water, especially during stratification, but all values fell within the WAC 173-201A-200 range needed to sustain salmonid and indigenous warm-water fished (—). The slightly elevated pH could be due to photosynthesis. During photosynthesis, algae or aquatic plants remove dissolved CO_2, which in turn reduces the amount of dissolved carbonic acid that forms when CO_2 reacts with water. The pH was lower in bottom samples especially when the lake was stratified and the oxygen concentrations were low. This is usually caused by accumulation of slightly acidic compounds released by the sediments or from bacterial decomposition. The alum floc, which can be slightly acidic, may also have contributed to the slightly lower pH in the bottom samples.

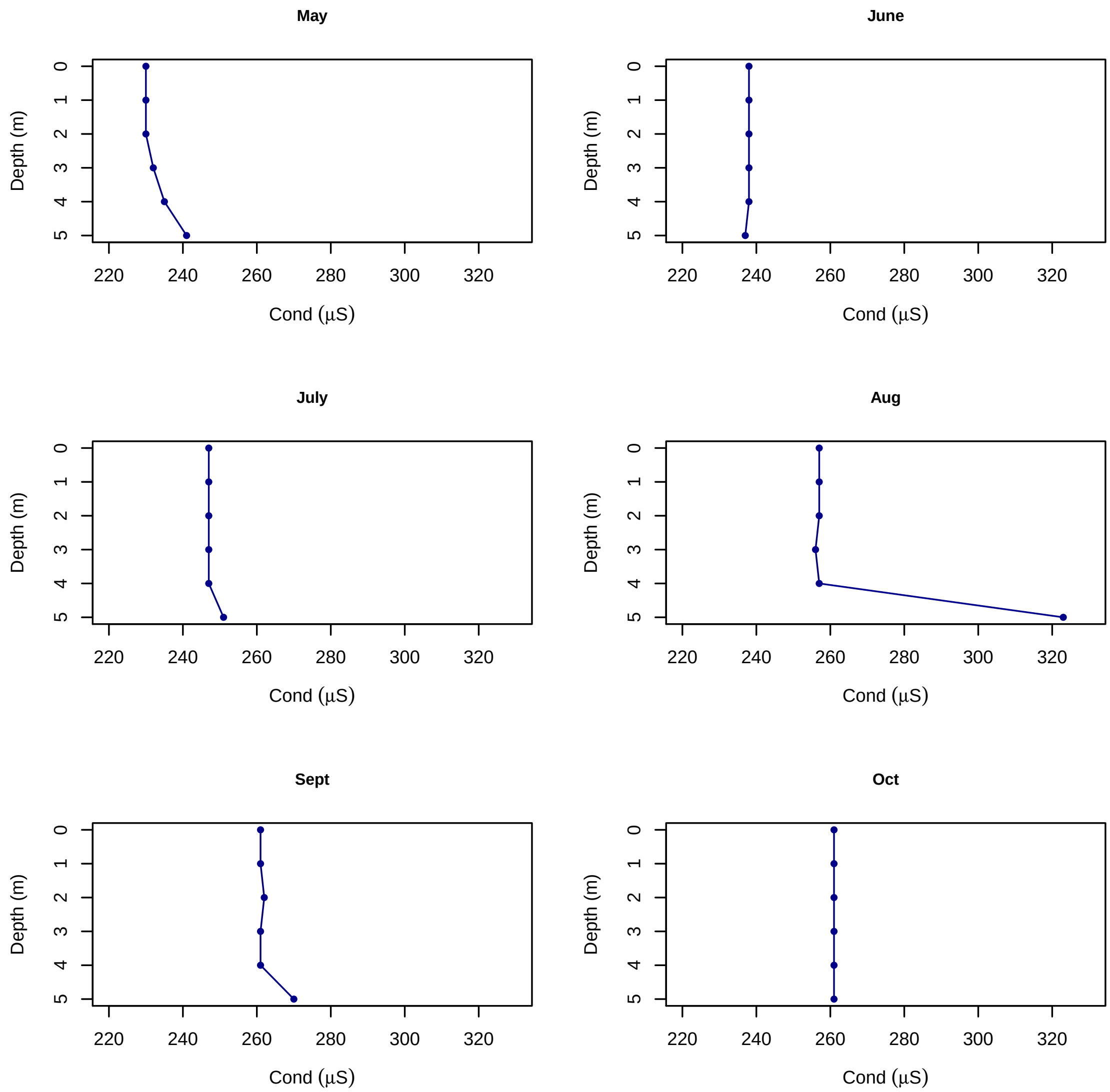

Figure 7: Heart Lake conductivity data, May-October 2018. Conductivity was fairly uniform throughout the water column except in the bottom samples. Conductivity is influenced by the type and amount of dissolved ions in the water. The soil type and land use in the watershed influence the amount of dissolved ions entering the lake via surface runoff and groundwater. Biological activity and chemical interactions determine whether dissolved ions remain in the water column. Conductivity can be influenced by in-lake factors such as decomposition, which often increases conductivity. This is the most likely reason for the slightly higher conductivities in most of the bottom samples.

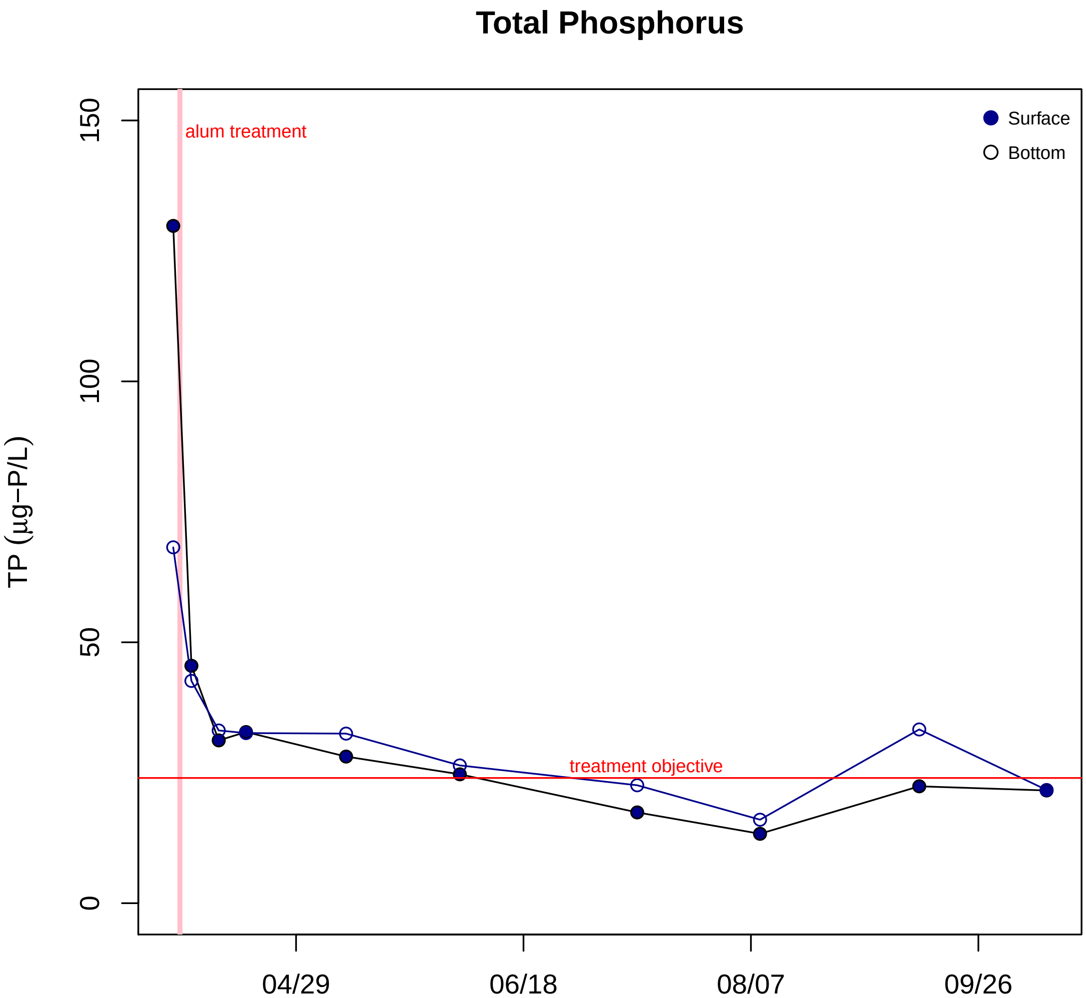

Figure 8: Heart Lake total phosphorus data, April-October 2018. The total phosphorus in Heart Lake is comprised of phosphorus associated with organic matter (algae, aquatic plants, and other microbiota) plus dissolved or soluble phosphate. Phosphorus is usually the nutrient that limits the amount of algae or aquatic plants in a lake. Prior to alum treatment the Heart Lake total phosphorus concentrations were ranged from 68.2–129.8 μg-P/L (Table A2). The phosphorus concentrations dropped abruptly immediately following treatment. The average May-October phosphorus concentration was 23.3 μg-P/L, and 58% of the samples were below the alum treatment objective of $<$24 μg-P/L (Herrera, 2018b).

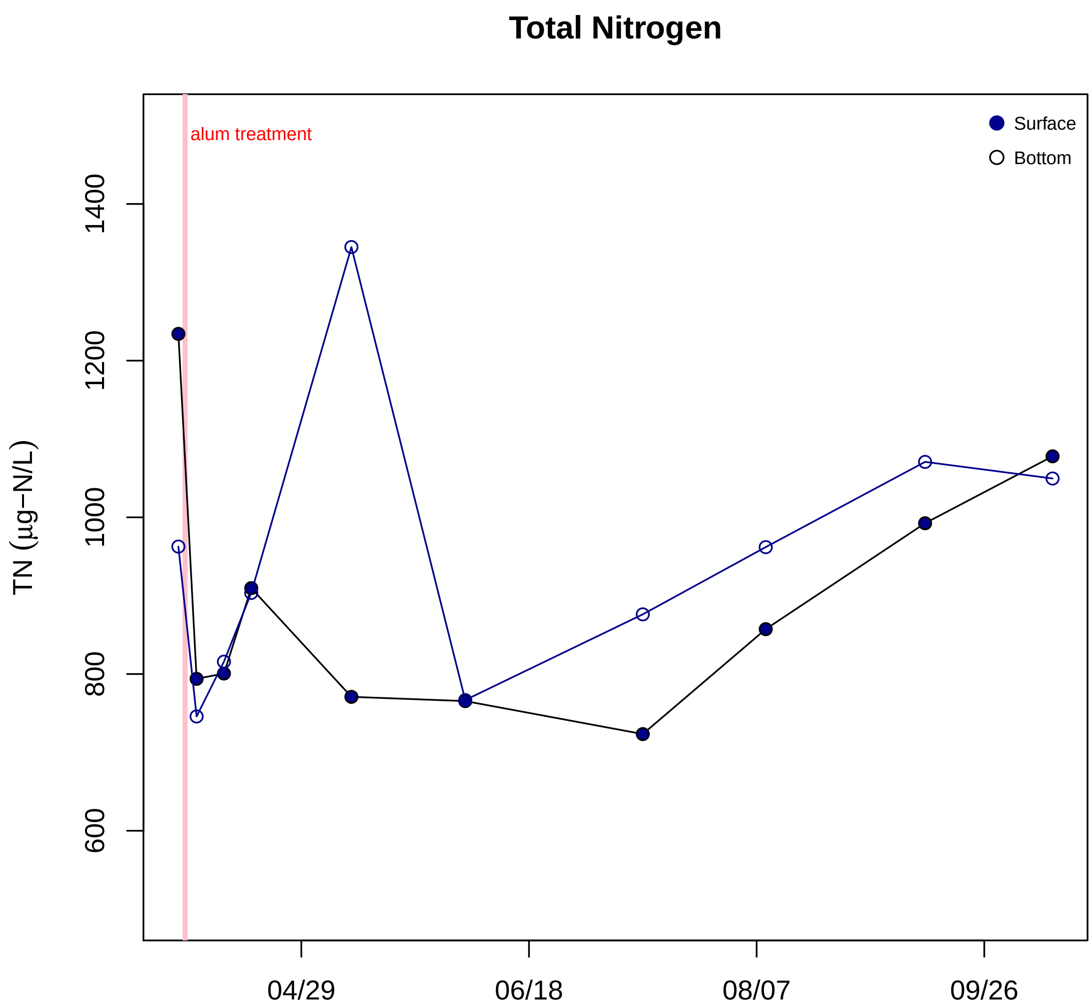

Figure 9: Heart Lake total nitrogen data, April-October 2018. Total nitrogen includes nitrogen bound in organic matter (algae, aquatic plants, and other microbiota) and dissolved inorganic nitrogen (DIN = nitrate, nitrite, and ammonium). There were higher concentrations of total nitrogen in the bottom samples, except for October. The lower surface nitrogen concentrations may be due to photosynthetic uptake by algae. Low nitrogen to phosphorus ratios (<15:1) favor Cyanobacteria blooms because many Cyanobacteria can use dissolved N_2 gas as a nitrogen source. The average May-Oct ratio of TN:TP was 42:1, which favors the growth of a diverse algal community rather than Cyanobacteria.

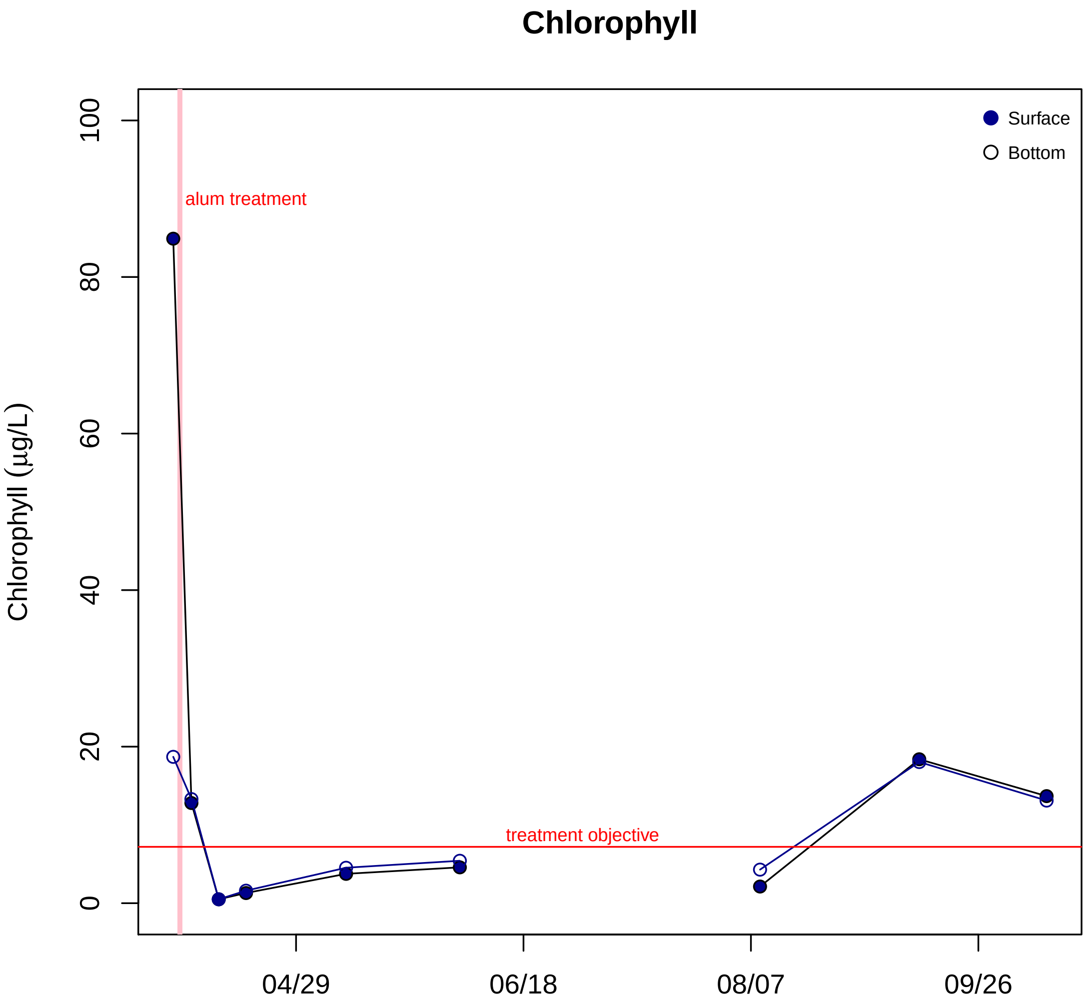

Figure 10: Heart Lake chlorophyll data, April-October 2018 (July results omitted due to analysis error). Chlorophyll is the primary photosynthetic pigment in algae and is the best single indicator of the amount of algae present. Prior to alum treatment the chlorophyll concentrations were 18.7–84.9 μg/L. Following treatment the chlorophyll concentrations dropped abruptly, which was consistent with the phosphorus results. The average May-October chlorophyll concentration was 5.0 μg-P/L, and 60% of the samples were below the alum treatment objective of $<$7.2 μg-P/L (Herrera, 2018b). The chlorophyll concentrations in September and October were slightly elevated (13.1–18.4 μg.L), so it is not yet clear whether algal blooms will continue to be a problem for Heart Lake.

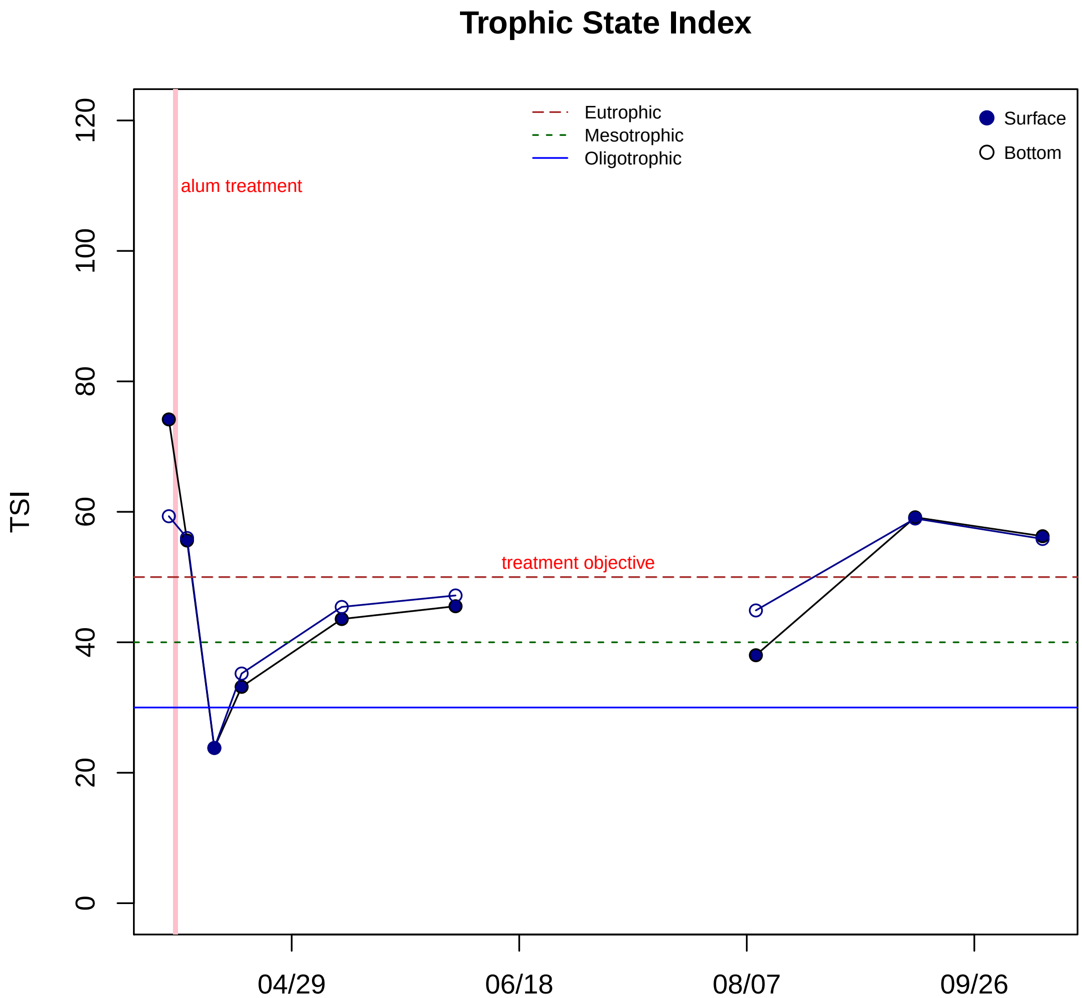

Figure 11: Heart Lake TSI data, April-October 2018 (July results omitted due to chlorophyll analysis error). Chlorophyll can be used to classify lakes using Carlson's Trophic State Index (see page 5). Lakes with low concentrations of chlorophyll are biologically unproductive or oligotrophic (TSI_{chl} <30); lakes that have high chlorophyll concentrations are biologically productive or eutrophic (TSI_{chl} >50); lakes that fall between these concentrations are moderately productive or mesotrophic (TSI_{chl} 30–50). Heart Lake was eutrophic prior to alum treatment, then dropped to oligotrophic or mesotrophic until September and October. The average May-October TSI was 46, and 60% of the samples were below the treatment objective of <50 (Herrera, 2018b).

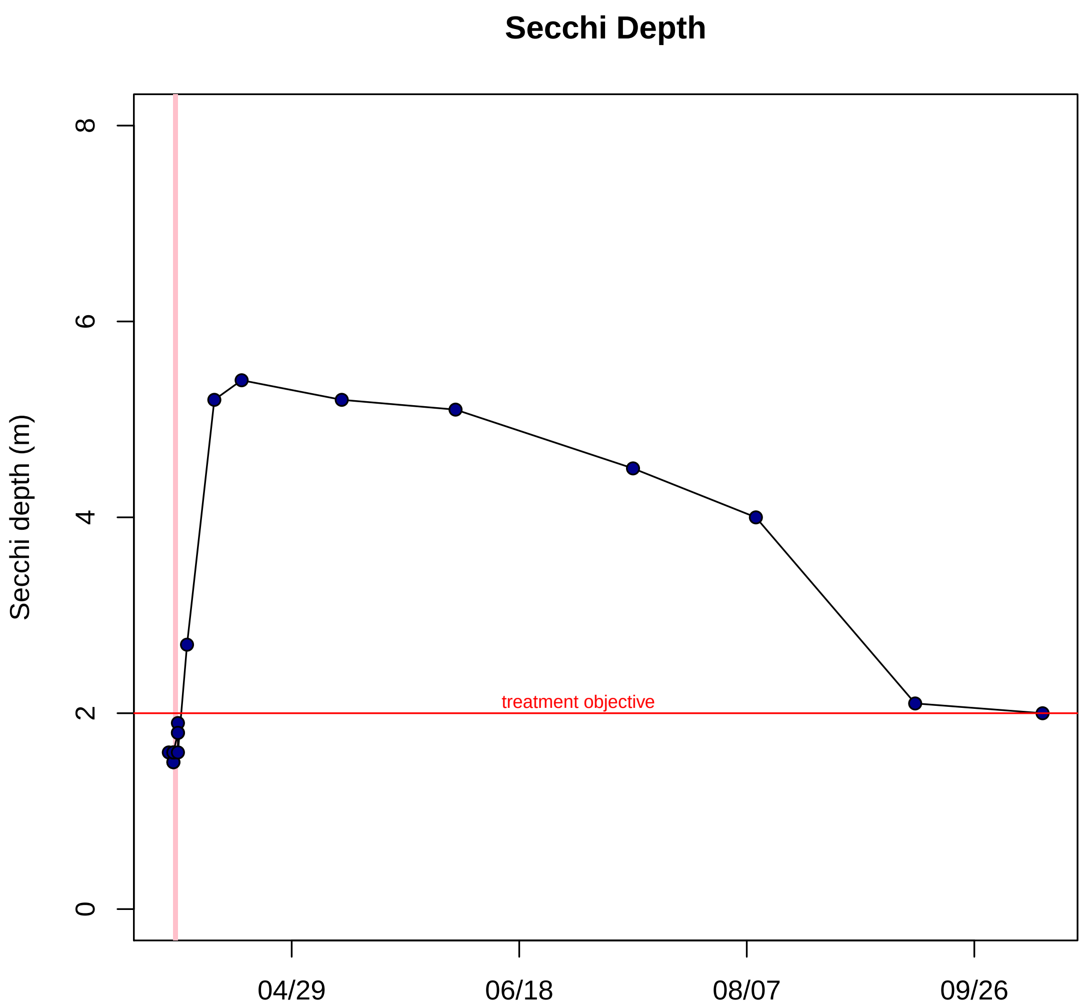

Figure 12: Heart Lake Secchi depth data, April-October 2018. Secchi depths are measured by lowering a black and white disk into the water column, marking the depth at which the disk is no longer visible, which is a simple way to assess water clarity. Water clarity is influenced by suspended particulates from algae and other organic matter like leaf fragments, as well as inorganic particles like silt. In Heart Lake, the water clarity matched the chlorophyll results, with limited water clarity prior to alum treatment (<2 m), and better clarity following treatment until September and October. The average May-October Secchi depth was 3.8, and 83% of the samples were below the treatment objective of >2 (Herrera, 2018b).

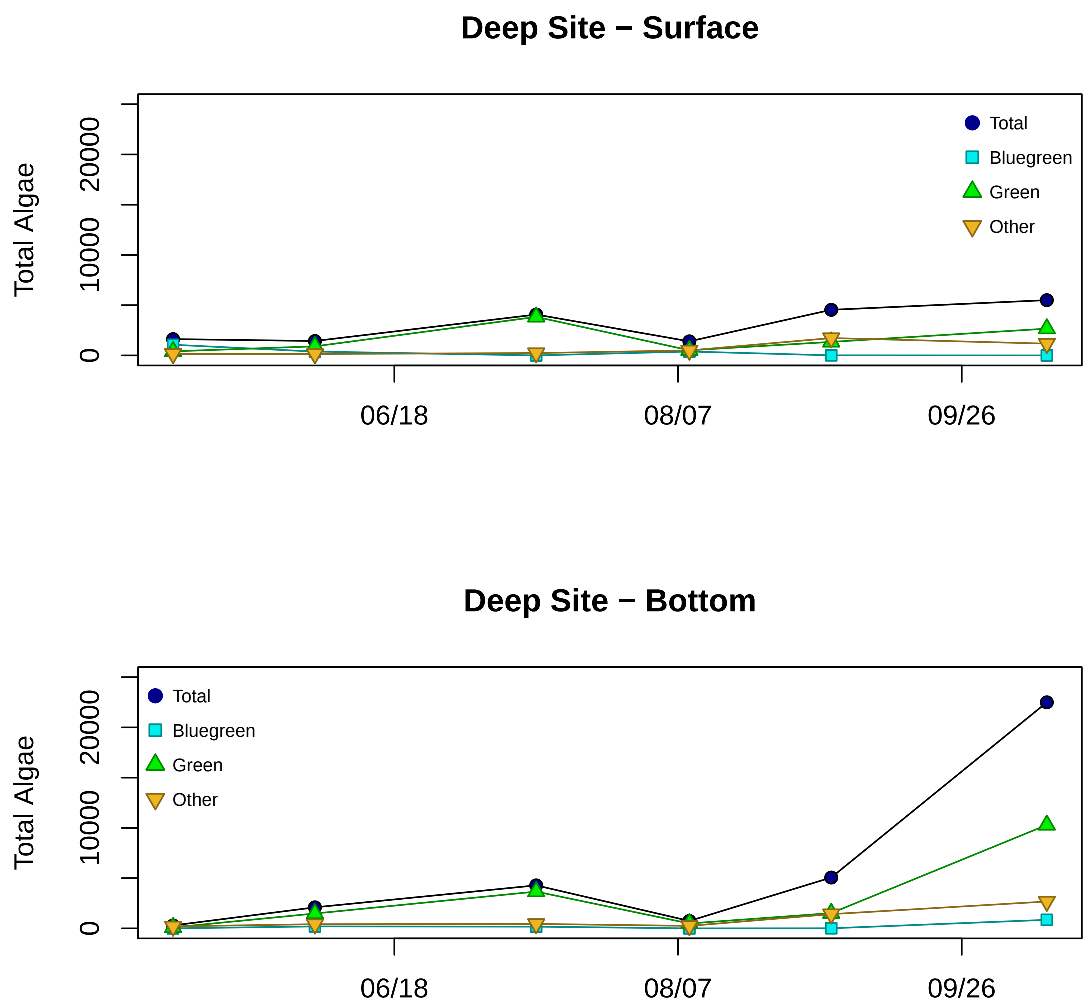

Figure 13: Heart Lake algae counts, May-October 2018. The Heart Lake algae counts indicated that the algal community was no longer dominated by Cyanobacteria, as it had been in 2016. The algal density was very low in May, but increased over the summer and fall (see Table C1). By October, the deep samples contained relatively high densities of green algae. The high counts in the bottom samples reflect the increased water clarity, which allowed photosynthesis to be maintained near the sediments.

A Water Quality Data

Table A1: Heart Lake 2018 field data. See Figures 1–2 for site locations; see Table 2 for analytical methods, abbreviations, and detection limits.

Site	Depth (m)	Date	Time	Temp (C))	DO (pct)	DO (mg/L)	Cond (μS)	pH	Secchi (m)
Pre-treatment									
deep	0.3	Apr 2, 2018	12:23:24	9.4	136.4	15.6	197.4	9.1	1.6
deep	1.0	Apr 2, 2018	12:29:00	9.2	136.2	15.7	197.5	9.1	-
deep	2.0	Apr 2, 2018	12:35:15	9.2	133.7	15.4	197.6	9.1	-
deep	3.0	Apr 2, 2018	12:39:04	9.1	132.2	15.2	197.8	9.0	-
deep	4.0	Apr 2, 2018	12:44:02	8.7	109.0	12.7	200.0	8.3	-
deep	5.0	Apr 2, 2018	12:48:55	8.5	101.3	11.9	200.8	8.0	-
			Minimum	8.5	101.3	11.9	197.4	8.0	-
			Mean	9.0	124.8	14.4	198.5	8.8	-
			Median	9.2	133.0	15.3	197.7	9.1	-
			Maximum	9.4	136.4	15.7	200.8	9.1	-

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Table A1: Heart Lake field data, continued

Site	Depth (m)	Date	Time	Temp (C))	DO (pct)	DO (mg/L)	Cond (μS)	pH	Secchi (m)
Treatment - day 1									
deep	0.3	Apr 3, 2018	4:07:05	9.9	139.2	15.8	209.9	8.9	1.5
deep	1.0	Apr 3, 2018	4:07:56	9.6	136.7	15.6	214.0	8.7	-
deep	2.0	Apr 3, 2018	4:08:43	9.5	132.4	15.1	227.2	8.4	-
deep	3.0	Apr 3, 2018	4:10:59	9.2	121.0	13.9	215.5	8.5	-
deep	4.0	Apr 3, 2018	4:12:00	8.6	101.9	11.9	200.8	8.1	-
deep	5.0	Apr 3, 2018	4:13:32	8.4	92.6	10.8	202.3	7.9	-
deep	0.3	Apr 3, 2018	8:39:42	9.5	136.4	15.6	197.1	9.1	1.6
deep	1.0	Apr 3, 2018	8:42:08	9.5	136.4	15.6	197.2	9.1	-
deep	2.0	Apr 3, 2018	8:43:49	9.5	136.1	15.5	197.2	9.1	-
deep	3.0	Apr 3, 2018	8:46:57	9.3	129.0	14.8	197.8	8.9	-
deep	4.0	Apr 3, 2018	8:49:37	9.2	125.0	14.4	198.1	8.9	-
deep	5.0	Apr 3, 2018	8:51:26	8.5	101.1	11.8	200.5	8.0	-
deep	6.0	Apr 3, 2018	8:53:05	8.3	82.8	9.7	203.7	7.6	-
shallow	0.3	Apr 3, 2018	4:32:23	9.9	143.5	16.2	200.8	9.2	1.5
shallow	1.0	Apr 3, 2018	4:33:14	9.8	142.6	16.2	199.4	9.2	-
shallow	2.0	Apr 3, 2018	4:35:35	9.4	132.3	15.1	217.3	8.6	-
shallow	3.0	Apr 3, 2018	4:36:17	9.3	128.1	14.7	247.6	8.5	-
shallow	0.3	Apr 3, 2018	9:18:53	9.3	130.7	15.0	197.7	9.1	1.6
shallow	1.0	Apr 3, 2018	9:20:03	9.2	128.7	14.8	198.0	9.0	-
shallow	2.0	Apr 3, 2018	9:21:06	9.2	127.3	14.6	197.9	9.0	-
shallow	3.0	Apr 3, 2018	9:22:49	9.0	100.3	11.6	199.6	8.7	-
random1	0.3	Apr 3, 2018	11:26:10	9.7	136.1	15.5	200.4	9.1	-
random1	1.0	Apr 3, 2018	11:27:27	9.7	136.4	15.5	200.0	9.1	-
random1	2.0	Apr 3, 2018	11:28:31	9.6	136.0	15.5	201.1	9.1	-
random1	3.0	Apr 3, 2018	11:29:51	9.6	135.3	15.4	204.0	9.0	-
random2	0.3	Apr 3, 2018	11:38:55	9.7	137.7	15.7	201.0	9.1	-
random2	1.0	Apr 3, 2018	11:39:44	9.6	137.9	15.7	200.5	9.1	-

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Table A1: Heart Lake field data, continued

Site	Depth (m)	Date	Time	Temp (C))	DO (pct)	DO (mg/L)	Cond (μS)	pH	Secchi (m)
random2	2.0	Apr 3, 2018	11:40:40	9.6	138.0	15.7	199.5	9.1	-
random2	3.0	Apr 3, 2018	11:41:36	9.6	137.9	15.7	200.7	9.1	-
random2	4.0	Apr 3, 2018	11:44:46	9.4	130.1	14.9	222.1	8.5	-
random2	4.4	Apr 3, 2018	11:47:35	8.8	7.7	0.9	230.5	7.3	-
random3	0.3	Apr 3, 2018	12:02:43	9.5	135.6	15.5	203.5	9.0	-
random3	1.0	Apr 3, 2018	12:04:04	9.5	135.7	15.5	206.2	8.9	-
random3	2.0	Apr 3, 2018	12:05:45	9.5	135.0	15.4	238.3	8.1	-
random3	3.0	Apr 3, 2018	12:07:22	9.5	134.7	15.4	248.4	8.4	-
random4	0.3	Apr 3, 2018	2:10:39	9.8	143.0	16.2	198.8	9.2	-
random4	1.0	Apr 3, 2018	2:11:53	9.5	138.4	15.8	208.0	8.9	-
random4	2.0	Apr 3, 2018	2:12:45	9.5	136.6	15.6	242.0	8.5	-
random4	3.0	Apr 3, 2018	2:14:03	9.5	115.1	13.1	259.0	8.2	-
random4	0.3	Apr 3, 2018	12:22:11	9.6	137.4	15.7	206.3	8.9	-
random4	1.0	Apr 3, 2018	12:24:36	9.6	137.6	15.7	206.9	8.9	-
random4	2.0	Apr 3, 2018	12:25:36	9.6	137.2	15.7	213.2	8.8	-
random4	3.0	Apr 3, 2018	12:27:55	9.5	130.8	14.9	244.1	7.9	-
random5	0.3	Apr 3, 2018	2:33:34	9.6	133.5	15.2	205.6	9.0	-
random5	1.0	Apr 3, 2018	2:34:34	9.6	133.7	15.2	209.7	8.9	-
random5	2.0	Apr 3, 2018	2:35:39	9.6	134.2	15.3	224.2	8.8	-
random5	3.0	Apr 3, 2018	2:37:09	9.5	132.8	15.2	232.0	8.5	-
random5	4.0	Apr 3, 2018	2:38:24	9.1	116.6	13.5	229.2	8.3	-
random5	5.0	Apr 3, 2018	2:39:44	8.5	94.4	11.0	208.6	7.9	-
random5	6.0	Apr 3, 2018	2:42:00	8.3	34.1	4.0	238.4	7.2	-
random5	0.3	Apr 3, 2018	3:11:33	9.7	136.4	15.5	212.2	8.9	-
random5	1.0	Apr 3, 2018	3:13:44	9.6	136.5	15.5	215.4	8.8	-
random5	2.0	Apr 3, 2018	3:14:44	9.6	134.4	15.3	218.3	8.8	-
random5	3.0	Apr 3, 2018	3:16:12	9.5	132.0	15.1	229.1	8.7	-
random5	4.0	Apr 3, 2018	3:17:27	9.0	109.1	12.6	219.5	8.2	-

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Table A1: Heart Lake field data, continued

Site	Depth (m)	Date	Time	Temp (C))	DO (pct)	DO (mg/L)	Cond (μS)	pH	Secchi (m)
random5	5.0	Apr 3, 2018	3:19:12	8.5	100.0	11.7	205.0	8.0	-
random5	6.0	Apr 3, 2018	3:21:00	8.3	39.1	4.6	209.1	7.6	-
random6	0.3	Apr 3, 2018	2:53:15	9.8	139.4	15.8	210.1	8.9	-
random6	1.0	Apr 3, 2018	2:55:22	9.6	138.3	15.8	207.5	8.9	-
random6	2.0	Apr 3, 2018	2:57:12	9.5	134.9	15.4	254.6	8.3	-
random6	3.0	Apr 3, 2018	3:00:39	9.4	130.8	15.0	250.8	8.2	-
random6	3.5	Apr 3, 2018	3:01:40	9.4	130.1	14.9	251.4	8.2	-
			Minimum	8.3	7.7	0.9	197.1	7.2	-
			Mean	9.4	124.1	14.2	214.3	8.6	-
			Median	9.5	134.3	15.3	207.8	8.8	-
			Maximum	9.9	143.5	16.2	259.0	9.2	-

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Table A1: Heart Lake field data, continued

Site	Depth (m)	Date	Time	Temp (C))	DO (pct)	DO (mg/L)	Cond (μS)	pH	Secchi (m)
Treatment - day 2									
deep	0.3	Apr 4, 2018	1:07:48	9.6	134.8	15.4	215.1	8.7	1.8
deep	1.0	Apr 4, 2018	1:09:25	9.5	133.9	15.3	222.7	8.3	-
deep	2.0	Apr 4, 2018	1:10:20	9.5	133.0	15.2	229.8	8.1	-
deep	3.0	Apr 4, 2018	1:11:11	9.3	126.3	14.5	233.5	8.0	-
deep	4.0	Apr 4, 2018	1:12:46	9.4	128.6	14.7	259.8	7.7	-
deep	5.0	Apr 4, 2018	1:14:01	9.3	127.9	14.7	264.5	7.7	-
deep	5.5	Apr 4, 2018	1:16:32	9.1	110.4	12.7	264.9	7.9	-
deep	0.3	Apr 4, 2018	7:53:35	9.3	130.2	14.9	211.5	8.6	1.9
deep	1.0	Apr 4, 2018	7:56:16	9.3	130.8	15.0	211.1	8.6	-
deep	2.0	Apr 4, 2018	7:57:31	9.3	130.1	14.9	212.8	8.6	-
deep	3.0	Apr 4, 2018	7:58:52	9.3	125.1	14.4	224.0	8.2	-
deep	4.0	Apr 4, 2018	8:00:38	9.3	122.1	14.0	239.8	8.0	-
deep	5.0	Apr 4, 2018	8:02:01	8.7	102.4	11.9	211.6	7.9	-
deep	5.5	Apr 4, 2018	8:03:22	8.5	96.2	11.2	207.4	7.8	-
shallow	0.3	Apr 4, 2018	8:20:55	9.4	130.6	15.0	208.9	8.9	1.8
shallow	1.0	Apr 4, 2018	8:22:36	9.4	132.6	15.2	210.1	8.8	-
shallow	2.0	Apr 4, 2018	8:24:16	9.4	130.8	15.0	215.1	8.7	-
shallow	3.0	Apr 4, 2018	8:25:14	9.1	104.0	12.0	230.6	8.1	-
shallow	0.3	Apr 4, 2018	12:47:26	9.5	133.3	15.2	225.8	8.2	1.6
shallow	1.0	Apr 4, 2018	12:49:01	9.5	133.4	15.2	228.6	8.0	-
shallow	2.0	Apr 4, 2018	12:50:50	9.4	127.2	14.6	262.7	7.5	-
shallow	3.0	Apr 4, 2018	12:51:33	9.3	110.7	12.7	306.8	7.4	-
random7	0.3	Apr 4, 2018	9:13:36	9.3	131.1	15.0	214.1	8.6	-
random7	1.0	Apr 4, 2018	9:14:14	9.3	130.2	14.9	223.7	8.4	-
random7	2.0	Apr 4, 2018	9:15:04	9.4	130.7	15.0	234.9	8.3	-
random7	3.0	Apr 4, 2018	9:16:01	9.4	130.5	15.0	253.5	8.3	-

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Table A1: Heart Lake field data, continued

Site	Depth (m)	Date	Time	Temp (C))	DO (pct)	DO (mg/L)	Cond (μS)	pH	Secchi (m)
random7	0.3	Apr 4, 2018	9:53:54	9.4	134.8	15.4	208.9	8.9	-
random7	0.5	Apr 4, 2018	9:54:51	9.4	134.8	15.4	209.2	8.9	-
random7	1.0	Apr 4, 2018	9:56:32	9.4	134.8	15.4	212.8	8.8	-
random8	0.3	Apr 4, 2018	9:59:15	9.4	135.1	15.5	209.6	8.9	-
random8	0.5	Apr 4, 2018	10:00:16	9.4	135.0	15.4	211.0	8.8	-
random8	1.0	Apr 4, 2018	10:01:15	9.4	134.9	15.4	213.5	8.8	-
random9	0.3	Apr 4, 2018	10:21:51	9.4	129.0	14.8	217.2	8.3	-
random9	0.5	Apr 4, 2018	10:25:07	9.3	128.9	14.8	213.8	8.4	-
random9	1.0	Apr 4, 2018	10:25:49	9.3	128.0	14.7	223.5	8.1	-
random9	1.5	Apr 4, 2018	10:26:28	9.3	122.2	14.0	280.4	7.9	-
random10	0.3	Apr 4, 2018	11:49:16	9.7	137.1	15.6	215.1	8.9	-
random10	1.0	Apr 4, 2018	11:51:20	9.5	134.9	15.4	215.2	8.8	-
random10	2.0	Apr 4, 2018	11:52:56	9.5	133.1	15.2	221.9	8.7	-
random10	3.0	Apr 4, 2018	11:54:08	9.4	132.1	15.1	223.0	8.5	-
random10	4.0	Apr 4, 2018	11:55:03	9.3	128.6	14.7	233.8	8.0	-
random10	5.0	Apr 4, 2018	11:56:13	9.1	120.5	13.9	236.1	8.2	-
random11	0.3	Apr 4, 2018	12:07:05	9.5	134.3	15.3	225.0	8.1	-
random11	1.0	Apr 4, 2018	12:10:50	9.5	135.2	15.4	226.9	8.1	-
random11	2.0	Apr 4, 2018	12:11:50	9.4	133.5	15.3	255.7	7.7	-
random11	2.5	Apr 4, 2018	12:14:06	9.4	131.1	15.0	311.0	7.6	-
random12	0.3	Apr 4, 2018	1:38:53	9.5	134.0	15.3	221.6	8.4	-
random12	1.0	Apr 4, 2018	1:40:58	9.5	133.2	15.2	228.5	8.0	-
random12	2.0	Apr 4, 2018	1:42:41	9.4	132.6	15.2	242.1	7.9	-
random12	3.0	Apr 4, 2018	1:43:38	9.4	132.8	15.2	263.0	7.7	-
random12	3.9	Apr 4, 2018	1:44:41	9.1	63.8	7.4	273.0	7.4	-
random13	0.3	Apr 4, 2018	1:52:27	9.7	138.4	15.7	213.6	8.9	-
random13	1.0	Apr 4, 2018	1:53:57	9.7	138.8	15.8	215.6	8.9	-

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Table A1: Heart Lake field data, continued

Site	Depth (m)	Date	Time	Temp (C))	DO (pct)	DO (mg/L)	Cond (μS)	pH	Secchi (m)
random13	2.0	Apr 4, 2018	1:54:29	9.5	135.4	15.5	220.7	8.6	-
random13	3.0	Apr 4, 2018	1:56:12	9.3	127.2	14.6	235.6	8.2	-
random13	4.0	Apr 4, 2018	1:57:56	9.2	119.2	13.7	246.4	8.2	-
random13	5.0	Apr 4, 2018	2:00:01	8.8	100.7	11.7	215.4	7.9	-
random13	6.0	Apr 4, 2018	2:01:15	8.5	87.0	10.2	210.6	7.8	-
			Minimum	8.5	63.8	7.4	207.4	7.4	-
			Mean	9.3	126.5	14.5	230.6	8.3	-
			Median	9.4	130.8	15.0	223.3	8.2	-
			Maximum	9.7	138.8	15.8	311.0	8.9	-

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Table A1: Heart Lake field data, continued

Site	Depth (m)	Date	Time	Temp (C))	DO (pct)	DO (mg/L)	Cond (μS)	pH	Secchi (m)
Post-treatment - day 2									
deep	0.3	Apr 6, 2018	1:23:32	9.7	122.2	13.9	225.3	8.3	2.7
deep	1.0	Apr 6, 2018	1:26:17	9.6	122.5	13.9	225.4	8.3	-
deep	2.0	Apr 6, 2018	1:27:13	9.5	120.3	13.7	226.6	8.2	-
deep	3.0	Apr 6, 2018	1:28:40	9.3	120.1	13.8	229.5	8.2	-
deep	4.0	Apr 6, 2018	1:29:55	9.3	120.1	13.8	244.4	8.0	-
deep	5.0	Apr 6, 2018	1:31:25	9.1	113.6	13.1	255.5	7.8	-
			Minimum	9.1	113.6	13.1	225.3	7.8	-
			Mean	9.4	119.8	13.7	234.5	8.1	-
			Median	9.4	120.2	13.8	228.1	8.2	-
			Maximum	9.7	122.5	13.9	255.5	8.3	-

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Table A1: Heart Lake field data, continued

Site	Depth (m)	Date	Time	Temp (C))	DO (pct)	DO (mg/L)	Cond (μS)	pH	Secchi (m)
Post-treatment - day 8									
deep	0.3	Apr 12, 2018	9:32:54	10.3	93.7	10.5	231.5	7.7	5.2
deep	1.0	Apr 12, 2018	9:34:35	10.3	93.6	10.5	231.5	7.7	-
deep	2.0	Apr 12, 2018	9:37:16	10.3	93.6	10.5	231.5	7.7	-
deep	3.0	Apr 12, 2018	9:39:43	10.3	93.6	10.5	231.6	7.7	-
deep	4.0	Apr 12, 2018	9:40:51	10.3	93.2	10.5	231.5	7.6	-
deep	5.0	Apr 12, 2018	9:41:44	10.2	92.2	10.4	232.1	7.6	-
			Minimum	10.2	92.2	10.4	231.5	7.6	-
			Mean	10.3	93.3	10.5	231.6	7.6	-
			Median	10.3	93.6	10.5	231.5	7.7	-
			Maximum	10.3	93.7	10.5	232.1	7.7	-

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Table A1: Heart Lake field data, continued

Site	Depth (m)	Date	Time	Temp (C))	DO (pct)	DO (mg/L)	Cond (μS)	pH	Secchi (m)
Post-treatment - day 14									
deep	0.3	Apr 18, 2018	9:26:22	10.5	84.3	9.4	228.4	7.5	5.4
deep	1.0	Apr 18, 2018	9:29:09	10.4	84.5	9.4	228.3	7.5	-
deep	2.0	Apr 18, 2018	9:30:42	10.4	84.7	9.5	228.1	7.5	-
deep	3.0	Apr 18, 2018	9:35:28	10.4	83.6	9.4	228.1	7.5	-
deep	4.0	Apr 18, 2018	9:38:18	10.2	82.1	9.2	228.4	7.5	-
deep	5.0	Apr 18, 2018	9:41:00	10.1	79.7	9.0	228.4	7.4	-
			Minimum	10.1	79.7	9.0	228.1	7.4	-
			Mean	10.3	83.2	9.3	228.3	7.5	-
			Median	10.4	84.0	9.4	228.4	7.5	-
			Maximum	10.5	84.7	9.5	228.4	7.5	-

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Table A1: Heart Lake field data, continued

Site	Depth (m)	Date	Time	Temp (C))	DO (pct)	DO (mg/L)	Cond (μS)	pH	Secchi (m)
Monthly									
deep	0.3	May 10, 2018	10:33:53	17.7	104.2	9.9	230.3	7.8	5.2
deep	1.0	May 10, 2018	10:35:18	17.7	104.1	9.9	230.3	7.8	-
deep	2.0	May 10, 2018	10:37:49	17.7	104.1	9.9	230.4	7.8	-
deep	3.0	May 10, 2018	10:39:28	16.0	79.1	7.8	232.3	7.4	-
deep	4.0	May 10, 2018	10:41:51	13.5	28.2	2.9	234.8	7.0	-
deep	5.0	May 10, 2018	10:44:13	12.4	2.6	0.3	240.6	6.9	-
			Minimum	12.4	2.6	0.3	230.3	6.9	-
			Mean	15.8	70.4	6.8	233.1	7.4	-
			Median	16.8	91.6	8.9	231.4	7.6	-
			Maximum	17.7	104.2	9.9	240.6	7.8	-
deep	0.3	Jun 4, 2018	10:23:36	17.8	94.7	9.0	237.8	7.8	5.1
deep	1.0	Jun 4, 2018	10:24:11	17.8	95.1	9.0	237.7	7.8	-
deep	2.0	Jun 4, 2018	10:25:11	17.7	95.4	9.1	237.7	7.8	-
deep	3.0	Jun 4, 2018	10:25:56	17.7	95.2	9.1	237.7	7.8	-
deep	4.0	Jun 4, 2018	10:26:53	17.6	95.0	9.1	237.6	7.8	-
deep	5.0	Jun 4, 2018	10:28:33	17.5	95.6	9.1	237.4	7.8	-
			Minimum	17.5	94.7	9.0	237.4	7.8	-
			Mean	17.7	95.2	9.1	237.7	7.8	-
			Median	17.7	95.2	9.1	237.7	7.8	-
			Maximum	17.8	95.6	9.1	237.8	7.8	-
deep	0.3	Jul 13, 2018	10:21:18	22.9	121.9	10.4	247.2	8.4	4.5
deep	1.0	Jul 13, 2018	10:24:09	22.8	122.2	10.4	247.2	8.4	-
deep	2.0	Jul 13, 2018	10:25:43	22.7	122.8	10.5	247.0	8.4	-
deep	3.0	Jul 13, 2018	10:27:04	21.8	109.7	9.6	247.2	8.0	-
deep	4.0	Jul 13, 2018	10:32:29	21.2	97.8	8.6	247.2	7.7	-
deep	5.0	Jul 13, 2018	10:35:27	20.5	29.8	2.7	251.2	7.1	-
			Minimum	20.5	29.8	2.7	247.0	7.1	-
			Mean	22.0	100.7	8.7	247.8	8.0	-
			Median	22.2	115.8	10.0	247.2	8.2	-
			Maximum	22.9	122.8	10.5	251.2	8.4	-

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Table A1: Heart Lake field data, continued

Site	Depth (m)	Date	Time	Temp (C))	DO (pct)	DO (mg/L)	Cond (μS)	pH	Secchi (m)
deep	0.3	Aug 9, 2018	11:09:59	23.3	94.9	8.1	257.1	7.8	4.0
deep	1.0	Aug 9, 2018	11:11:34	23.3	93.8	8.0	256.8	7.7	-
deep	2.0	Aug 9, 2018	11:12:52	23.1	87.5	7.5	256.8	7.6	-
deep	3.0	Aug 9, 2018	11:16:03	22.7	83.5	7.2	256.4	7.6	-
deep	4.0	Aug 9, 2018	11:19:22	22.2	53.3	4.6	256.8	7.3	-
deep	5.0	Aug 9, 2018	11:22:13	21.3	1.7	0.2	322.8	6.7	-
			Minimum	21.3	1.7	0.2	256.4	6.7	-
			Mean	22.6	69.1	5.9	267.8	7.4	-
			Median	22.9	85.5	7.3	256.8	7.6	-
			Maximum	23.3	94.9	8.1	322.8	7.8	-
deep	0.3	Sep 13, 2018	10:39:53	18.6	78.5	7.3	261.2	7.4	2.1
deep	1.0	Sep 13, 2018	10:42:26	18.5	77.0	7.2	261.4	7.5	-
deep	2.0	Sep 13, 2018	10:43:07	18.4	74.3	7.0	261.5	7.4	-
deep	3.0	Sep 13, 2018	10:44:01	18.4	73.3	6.9	261.4	7.3	-
deep	4.0	Sep 13, 2018	10:44:51	18.4	74.1	7.0	261.3	7.3	-
deep	5.0	Sep 13, 2018	10:46:23	18.3	27.4	2.6	269.6	7.1	-
			Minimum	18.3	27.4	2.6	261.2	7.1	-
			Mean	18.4	67.4	6.3	262.7	7.3	-
			Median	18.4	74.2	7.0	261.4	7.3	-
			Maximum	18.6	78.5	7.3	269.6	7.5	-
deep	0.3	Oct 11, 2018	10:15:12	13.8	88.9	9.2	260.5	7.7	2.0
deep	1.0	Oct 11, 2018	10:18:22	13.8	88.7	9.2	260.5	7.7	-
deep	2.0	Oct 11, 2018	10:20:06	13.7	88.2	9.1	260.6	7.7	-
deep	3.0	Oct 11, 2018	10:23:01	13.7	89.2	9.2	260.6	7.7	-
deep	4.0	Oct 11, 2018	10:24:40	13.7	89.0	9.2	260.6	7.7	-
deep	5.0	Oct 11, 2018	10:25:25	13.7	88.7	9.2	260.5	7.7	-
			Minimum	13.7	88.2	9.1	260.5	7.7	-
			Mean	13.8	88.8	9.2	260.6	7.7	-
			Median	13.7	88.8	9.2	260.6	7.7	-
			Maximum	13.8	89.2	9.2	260.6	7.7	-

Table A2: Heart Lake 2018 laboratory data. See Figures 1–2 for site locations; see Table 2 for analytical methods, abbreviations, and detection limits.

Site	Depth (m)	Date	Chl μg/L	Alk mg/L	TN μg-N/L	NO3 μg-N/L	TP μg-P/L	SRP μg-P/L
Pre-treatment								
Deep	Surface	Apr 2, 2018	84.9	65.8	1234	49.2	129.8	4.4
Deep	Bottom	Apr 2, 2018	18.7	65.3	963	131.4	68.2	6.5
Post-treatment - day 2								
Deep	Surface	Apr 6, 2018	12.8	61.6	794	41.0	45.5	3.8
Deep	Bottom	Apr 6, 2018	13.3	59.8	746	52.6	42.6	3.1
Post-treatment - day 8								
Deep	Surface	Apr 12, 2018	0.5	61.2	801	44.5	31.2	3.7
Deep	Bottom	Apr 12, 2018	0.5	61.3	816	44.0	33.1	3.5
Post-treatment - day 14								
Deep	Surface	Apr 18, 2018	1.3	61.3	910	65.4	32.8	2.5
Deep	Bottom	Apr 18, 2018	1.6	61.4	904	63.7	32.6	2.3
Monthly								
Deep	Surface	May 10, 2018	3.75	NA	771	NA	28.1	NA
Deep	Bottom	May 10, 2018	4.53	NA	1345	NA	32.5	NA
Deep	Surface	Jun 4, 2018	4.58	NA	766	NA	24.7	NA
Deep	Bottom	Jun 4, 2018	5.42	NA	767	NA	26.4	NA
Deep	Surface	Jul 13, 2018	NA	NA	723	NA	17.4	NA
Deep	Bottom	Jul 13, 2018	NA	NA	876	NA	22.6	NA
Deep	Surface	Aug 9, 2018	2.13	NA	857	NA	13.3	NA
Deep	Bottom	Aug 9, 2018	4.29	NA	962	NA	16.0	NA
Deep	Surface	Sep 13, 2018	18.39	NA	992	NA	22.4	NA
Deep	Bottom	Sep 13, 2018	18.04	NA	1071	NA	33.3	NA

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Table A2: Heart Lake field data, continued

Site	Depth (m)	Date	Chl μg/L	Alk mg/L	TN μg-N/L	NO3 μg-N/L	TP μg-P/L	SRP μg-P/L
Deep	Surface	Oct 11, 2018	13.68	NA	1078	NA	21.6	NA
Deep	Bottom	Oct 11, 2018	13.11	NA	1050	NA	21.7	NA

B Heart Lake Algae

Table C1: Heart Lake settled algae counts (cells/mL) from preserved, whole-water samples collected May-October 2018. See Table 2 for a summary of the settling methods and Wensloff, et al. (2017) for digital images of algae collected in Heart Lake.

Deep Site - Surface	May 10	Jun 4	Jul 14	Aug 9	Sept 3	Oct 11
***Cyanobacteria* (blue-green algae)**						
Aphanizomenon flosaquae	1062	290	0	0	0	0
Aphanocapsa/Aphanothece	0	0	0	387	0	0
Dolichospermum	0	0	0	0	9	0
Merismopedia	0	0	0	0	0	0
Phormidium	0	97	0	0	0	0
Pseudanabaena	0	0	0	0	0	0
Total Cyanobacteria	**1062**	**386**	**0**	**387**	**9**	**0**
***Chlorophyta* (green algae)**						
Ankyra	13	196	175	43	0	0
Botryococcus	0	0	0	0	0	0
Coelastrum	0	0	0	4	4	0
Cosmarium	0	0	0	4	47	0
Desmodesmus/Scenedesmus	0	0	0	0	34	671
Elakatothrix gelatinosa	9	0	0	0	0	21
Oocystis	0	36	2225	0	64	158
Planktosphaeria gelatinosa	173	671	1435	316	585	696
Sphaerocystis schroeteri	0	0	0	137	269	982
Staurastrum	0	0	0	0	0	0
Tetraëdron minimum	0	0	0	9	342	137
Tetraspora lacustris	21	0	0	0	0	0
Volvox	193	0	0	0	0	0
Total Chlorophyta	**409**	**903**	**3835**	**513**	**1345**	**2665**
Other Algae - *Bacilliariophyta* (diatoms)						
Asterionella formosa	0	0	0	0	1414	1661
Fragilaria crotonensis	0	0	0	0	43	0
Synedra	0	0	0	4	0	0
misc diatoms	0	2	0	0	0	0

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Table C1: Heart Lake settled algae counts, continued

Deep Site - Surface	May 10	Jun 4	Jul 14	Aug 9	Sept 3	Oct 11
Other Algae - *Cryptophyta* (cryptomonads)						
Cryptomonas (large)	120	13	17	9	9	68
Cryptomonas (small or med)	34	117	188	167	1661	978
Other Algae - *Dinophyta* (dinoflagellates)						
Ceratium hirundinella	0	0	9	9	30	0
Peridinium/Gymnodinium	0	0	0	0	4	0
Other Algae - *Euglenophyta* (euglenoids)						
Trachelomonas	0	2	0	0	0	0
Other Algae - *Ochrophyta* (golden algae)						
Dinobryon	0	11	21	316	4	128
Mallomonas	0	2	0	0	21	0
Synura	0	0	0	0	0	0
Total Other Algae	**154**	**147**	**234**	**504**	**3186**	**2836**
Total Algae (all groups)	**1624**	**1436**	**4070**	**1403**	**4540**	**5501**

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Table C1: Heart Lake settled algae counts, continued

Deep Site - Bottom	May 10	Jun 4	Jul 14	Aug 9	Sept 3	Oct 11
***Cyanobacteria* (blue-green algae)**						
Aphanizomenon flosaquae	0	193	0	0	0	0
Aphanocapsa/Aphanothece	0	0	0	0	0	0
Dolichospermum	0	0	0	0	9	271
Merismopedia	0	0	34	0	0	578
Phormidium	0	0	0	0	0	0
Pseudanabaena	0	0	137	0	0	0
Total Cyanobacteria	**0**	**193**	**171**	**0**	**9**	**849**
***Chlorophyta* (green algae)**						
Ankyra	0	203	141	64	0	0
Botryococcus	0	0	0	4	0	0
Coelastrum	0	0	4	4	0	0
Cosmarium	0	0	0	0	26	0
Desmodesmus/Scenedesmus	0	0	0	0	85	1282
Elakatothrix gelatinosa	47	0	0	30	0	36
Oocystis	0	38	1960	17	60	1878
Planktosphaeria gelatinosa	32	741	1555	367	457	1444
Sphaerocystis schroeteri	0	495	0	0	436	5489
Staurastrum	0	0	0	0	4	0
Tetraëdron minimum	0	0	0	0	448	163
Tetraspora lacustris	17	0	0	0	0	0
Volvox	0	0	0	0	0	0
Total Chlorophyta	**96**	**1478**	**3660**	**487**	**1516**	**10291**
Other Algae - *Bacilliariophyta* (diatoms)						
Asterionella formosa	0	0	0	0	2118	8648
Fragilaria crotonensis	0	0	0	0	0	36
Synedra	0	2	0	0	0	0
misc diatoms	0	6	4	4	0	0
Other Algae - *Cryptophyta* (cryptomonads)						
Cryptomonas (large)	184	17	94	26	9	163
Cryptomonas (small or med)	11	199	346	209	1358	1950

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Table C1: Heart Lake settled algae counts, continued

Deep Site - Bottom	May 10	Jun 4	Jul 14	Aug 9	Sept 3	Oct 11
Other Algae - *Dinophyta* (dinoflagellates)						
Ceratium hirundinella	0	0	0	4	0	0
Peridinium/Gymnodinium	0	0	0	0	0	18
Other Algae - *Euglenophyta* (euglenoids)						
Trachelomonas	0	0	0	0	0	0
Other Algae - *Ochrophyta* (golden algae)						
Dinobryon	0	192	4	9	51	506
Mallomonas	2	6	0	0	0	18
Synura	0	0	0	0	0	18
Total Other Algae	**196**	**423**	**449**	**252**	**3536**	**11357**
Total Algae (all groups)	**290**	**2094**	**4279**	**739**	**5061**	**22496**

C Quality Control

Blanks, laboratory duplicates, check standards, and matrix spiked samples were used to monitor the quality of the data. Acceptance limits for laboratory duplicates, check standards, and matrix spiked samples were established by building control charts using the previous two years of data. Blank results must be less than the detection limits. All of the 16 spiked samples, 14 check standards, and 20 laboratory duplicates analyzed for this project were within the control limits. All blanks were below the analytical detection limits.

Although field duplicates were not specified in the contract, one field duplicate was collected on May 9 from the bottom of the deep site. The results are summarized below.

Parameter	Sample Conc.	Field Dup. Conc.
Alkalinity	59.8 mg/L as $CaCO_3$	60.1 mg/L as $CaCO_3$
Chlorophyll	13.2 μg/L	13.7μg/L
Total nitrogen	745.9 μg-N/L	781.5 μg-N/L
Nitrate/nitrite	52.6 μg-N/L	59.1 μg-N/L
Total phosphorus	42.6 μg-P/L	46.0 μg-P/L
Orthophosphate	3.1 μg-P/L	2.9 μg-P/L