2014 Report:

Spitfire Lake

Adirondack Lake Assessment Program

Adirondack Watershed Institute

Paul Smith's College

P.O. Box 265

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Report No. PSCAWI 2015-10

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Acknowledgements

The Adirondack Lake Assessment Program (ALAP) is collaboration between the Paul Smith's College Adirondack Watershed Institute (AWI) (www.adkwatershed.org), Protect the Adirondacks (PROTECT) (www.protectadks.org), volunteer lakes monitors, and lake associations. The AWI is a program of Paul Smith's College that conducts research and service work broadly focused on conservation and protection of water resources. PROTECT is a non-profit organization dedicated to the protection and stewardship of the public and private lands of the Adirondack Park, and to building the health and diversity of its human communities and economies for the benefit of current and future generations. PROTECT recruits volunteers to participate in the program and provides administrative support, while AWI trains volunteers, conducts site visits, analyzes samples, and writes the reports. As such, this report and all results and interpretations contained herein were the sole responsibility of AWI. The narrative and results presented in this report were produced by Corey Laxson (Research Associate), Elizabeth Yerger (Research Assistant), and Daniel L Kelting (Executive Director), all with the AWI. Laboratory work on samples received from ALAP volunteers was conducted by Corey Laxson, Elizabeth Yerger, Sean Patton, Brandon Morey, and Dan Kelting. Sean Regalado produced watershed maps in GIS. Peter Bauer, Nancy Bernstein and Evelyn Greene from PROTECT provided administrative support. The lake sampling was conducted by the dedicated ALAP volunteers. John and Ellen Collins, Susan Murante and Marty Mozdzier provided locations for sample collection hubs. Paul Smith's College provided office and laboratory space. PROTECT is very grateful for the support provide to ALAP from the F.M. Kirby Foundation.

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Cover Photo: Lower Saranac Lake, an ALAP participating lake since 2001.

How to Use This Report

The ALAP reports are designed to provide lake information to the informed lay person, scientific community, lake managers, and other interested individuals. As such, it is written in a way to provide something for everyone. The report includes an overview of the water quality indicators, a detailed description of the methods, discussion of this year's results and historical trends, and characterization of the trophic status of the lake. Members of the scientific community will likely find the entire document useful, while readers who are interested in a simple summary of the lake may find the *Executive Summary* and the *Quick Facts* sections to be most helpful. The data and accompanying analysis provided in this report give insight into the water quality of the study lakes, more detailed limnological studies may be necessary to produce management recommendations or specific trend interpretations. Readers interested in additional information or accesses to the raw data are welcome to contact the corresponding author.

The data in this document are reported in metric units. Although this system has not been fully adopted in the United States, it is the standard system of measurement used by scientists and lake mangers throughout the world. Information on converting the metric units of measurements used in this report to English units is provided below. The amount of chemical elements dissolved in the lake samples are always described using metric concentration units. The most common ways chemical data is expressed is in milligrams per liter (mg/L) and micrograms per liter (µg/L). One milligram per liter is equal to one part analyte to one million parts water. One microgram per liter is equal to one part analyte to one billion parts water.

Metric Unit	Multiply by	English Unit
Liters (L)	1.05	Quart (qt)
Meters (m)	3.38	Feet (ft)
Kilometer (km)	0.62	Miles (mi)
Hectares (ha)	2.47	Acres (ac)
Cubic Meters (m^3)	1.31	Cubic Yards (yd^3)

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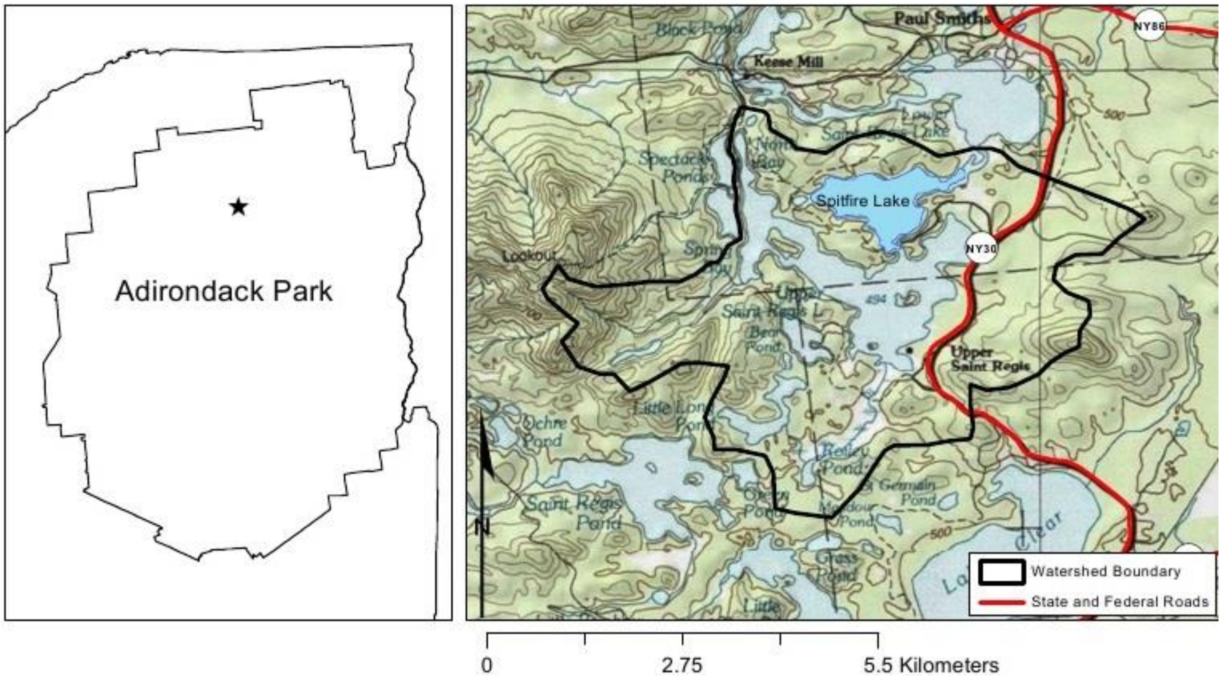

County:	Franklin
Town:	Brighton

Lake Area (ha):	105
Watershed Area (ha):	2,402

Trophic Status: Mesotrophic

Years in ALAP: 13

2014 Water Quality Indicators and Long-Term Trends*:

Indicator	Avg.	Trend
Transparency (m)	3.9	no trend
Total P (µg/L)	8.4	no trend
Chlorophyll-*a* (µg/L)	3.3	no trend
Laboratory pH	6.4	no trend
Conductance (µS/cm)	48.5	no trend
Color (Pt-Co)	17.9	no trend

Indicator	Avg.	Trend
Alkalinity (mg/L)	10.4	decreasing
Nitrate (µg/L)	9.2	na
Chloride (mg/L)	7.3	no trend
Calcium (mg/L)	3.3	na
Sodium (mg/L)	4.6	na

*Long term trends are only shown for indicators with more than five years of data.

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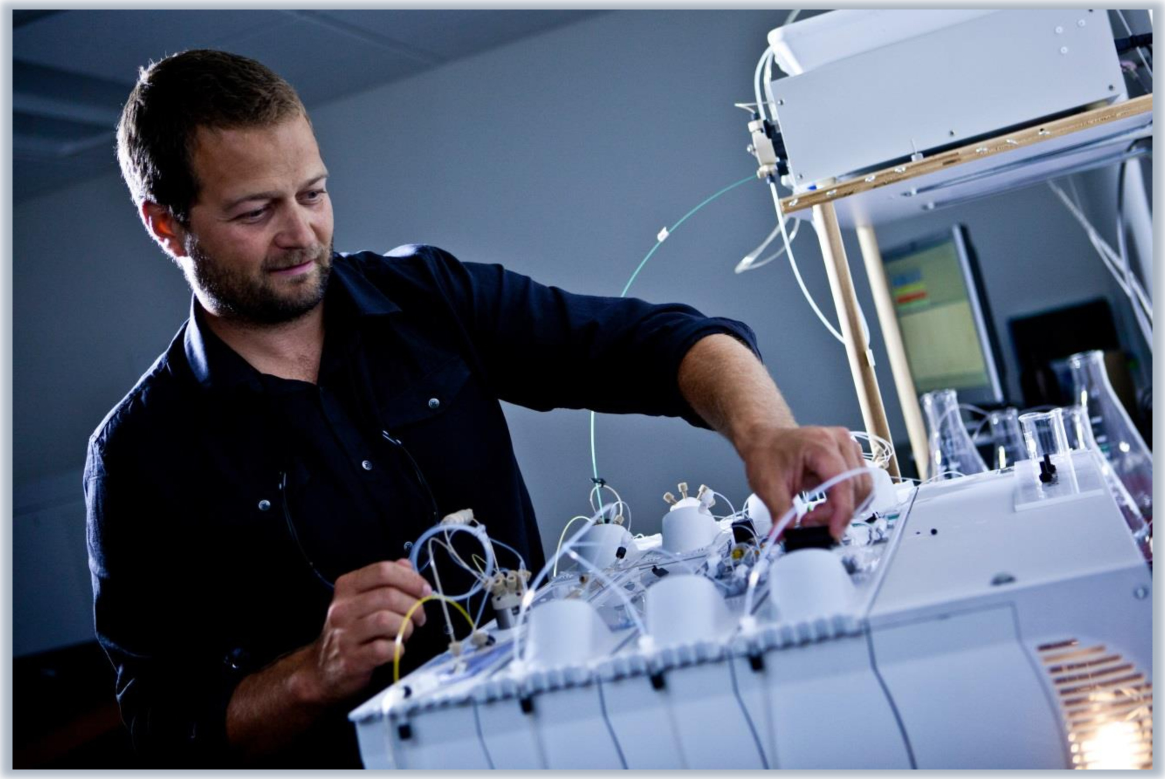

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Executive Summary

Spitfire Lake is a 580 ha lake located in Franklin County in the Town of Brighton. The lake is located within a 2,402 ha watershed dominated by forests. Spitfire Lake has been monitored by ALAP volunteers and the Adirondack Watershed Institute since 2002. Eight samples were analyzed in 2014 for transparency, chlorophyll-a, total phosphorus, nitrate, pH, color, alkalinity, conductivity, chloride, calcium and sodium. This report presents the 2014 data and describes long-term trends in water quality for analytes with sufficient data.

1. The bottom water of Spitfire Lake is essentially devoid of oxygen from mid-June until fall turnover. At its greatest extend, the anoxic strata occupies the bottom 1.5 meters of water in the deepest portion of the lake.

2. Secchi disk transparency has remained relatively constant over the length of the study, and exhibits no statistical trend over time. We found transparency on Spitfire Lake to be quite high in 2014, with depths nearing 6 meters in August. Transparencies of this depth are rare in the historical data, although this may be a function of increased sampling intensity in 2014 (eight observations instead of three).

3. Total phosphorus concentration in the epilimnion averaged 8.4 µg/L in 2014. Although no statistical trend has been detected in the data, this year marks the fourth consecutive year of phosphorus values less than 10 µg/L. TP concentrations in the bottom water were substantially higher, with a range between 43 and 108 µg/L during thermal stratification. The elevated concentration in the bottom water may be due to the anoxic conditions, whereby dissolved phosphorus was released from the lake sediments.

4. Chlorophyll concentrations have been variable over time, with no trend detected in the data. Surface water concentration of chlorophyll ranged from below detection to 8 µg/L in 2014. We observed the greatest algal abundance to be in the bottom water, where chlorophyll-a concentrations reached as high as 65.9 µg/L. The bottom water of Spitfire Lake supported a productive bloom of the cyanobacteria *Planktothrix* that persisted most of the summer. This species formed a surface bloom at least once, in the last few days of July.

5. The TSI Index for Spitfire Lake calculated from transparency (41) and chlorophyll-a (41) suggested a mesotrophic classification for the lake, while the TSI value for total phosphorus (34) indicated an oligotrophic classification for the lake. A disparity of this nature is common for lakes that experience phosphorus limitation in the surface water during the summer months. The lake has typically fluctuated within the mesotrophic condition since joining ALAP in 2002 (Figure 4).

6. Historically, Spitfire Lake has been a circumneutral water body with a typical pH in the 6.5 to 7.0 range. In 2014 the average pH was slightly lower, at 6.4 pH units. However, no statistical decrease in pH has been observed. The alkalinity of the lake (10.4 mg/L) is adequate enough to buffer the water from changes in acidity due to acid deposition (Alkalinity > 10 mg/L). However, the buffering ability of the lake is trending down at a rate of approximately 1.0 mg/L/year ($P = 0.03$).

7. Adirondack lakes in watersheds without paved roads typically have sodium and chloride concentrations less than 0.5 and 0.2 mg/L, respectively (Kelting et al 2012). The 2014 concentrations in Spitfire Lake averaged 4.6 mg/L for sodium and 7.3 mg/L for chloride, suggesting that the chemistry of the lake is influenced by shoreline development and the 4.4 km of salted roads in the watershed.

8. Calcium concentrations in Lower St Regis Lake (3.3 mg/L) are below the threshold required for the establishment of a viable zebra mussel population (8-20 mg/L).

Introduction

The Adirondack Lake Assessment Program (ALAP) is a cooperative citizen science lake monitoring program between Protect the Adirondacks (PROTECT), the Paul Smith's College Adirondack Watershed Institute (AWI), and numerous dedicated volunteers from across the Adirondack Park and beyond. The objectives of ALAP are to (1) develop a reliable water quality database for Adirondack lakes, (2) document historical trends in their limnological condition, and (3) engender lake stewardship by providing opportunities for citizens to participate in scientific monitoring. To accomplish these objectives participating lakes are sampled throughout the summer by trained volunteers and analyzed by the AWI for indicators of trophic productivity (total phosphorus, chlorophyll, transparency) and water quality (nutrients, pH, alkalinity, color, chloride, and metals). ALAP continues to be a highly successful program. Established in 1998 with 9 participating lakes, the program has grown to 72 lakes in 2014 (Figure 1 and Table 1). For many lakes the ALAP dataset represents the only available source of current water quality information.

Table 1. 2014 ALAP lakes organized by the number of years in the program.

Lake Name	Years	Lake Name	Years	Lake Name	Years
Blue Mnt. Lake	17	Pleasant Lake	14	Moss Lake	10
Eagle Lake	17	Rich Lake	14	Mountain View Lake	10
Loon Lake	17	Tripp Lake	14	Chazy Lake	8
Oven Mtn Pond	17	Twitchell Lake	14	Lower Chateaugay Lake	8
Silver Lake	17	Wolf Lake	14	Upper Chateaugay Lake	8
13th Lake	16	Balfour Lake	13	Chapel Pond	7
Brandreth Lake	16	Garnet Lake	13	Simon Pond	7
Eli Pond	16	Lens Lake	13	Lake Adirondack	6
Gull Pond	16	Lower Saranac Lake	13	Upper Cascade Lake	6
Little Long Lake	16	Lower St. Regis	**13**	Amber Lake	5
Stony Creek Ponds	16	Snowshoe Pond	13	Augur Lake	5
Austin Pond	15	Upper St. Regis	13	Otter Pond	5
Cranberry Lake	15	**Spitfire Lake**	**13**	Jordan Lake	5
Fern Lake	15	Canada Lake	12	Lake Titus	5
Middle Saranac Lake	15	Kiwassa Lake	12	Star Lake	5
Osgood Pond	15	Lake Colby	12	Lake Clear	4
Trout Lake	15	Raquette Lake	12	Lake Durant	4
White Lake	15	Sherman Lake	12	Lake Eaton (EC)	1
Arbutus Lake	14	Tupper Lake	12	Lake Placid	1
Catlin Lake	14	Indian Lake (HC)	11	Mill Pond	1
Deer Lake	14	Big Moose Lake	10	Mirror Lake	1
Hoel Pond	14	Dug Mnt. Pond	10	Paradox Lake	1
Lake of the Pines	14	Indian Lake (FC)	10	Schroon Lake	1
Long Pond	14	Lake Abanakee	10		

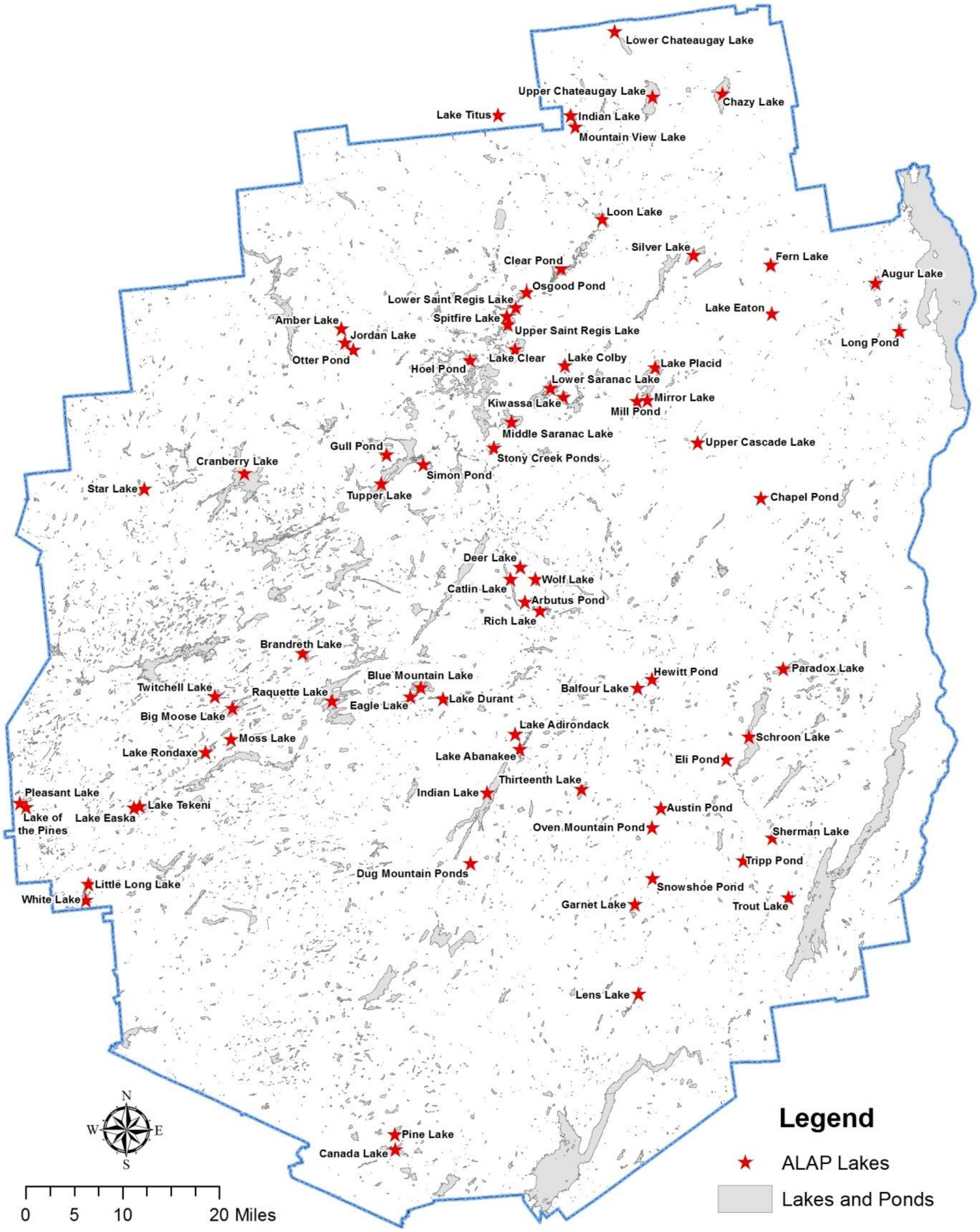

Figure 1. Locations and names of lakes that participated in the Adirondack Lake Assessment Program (ALAP) in 2014.

Table 2. Lake and watershed characteristics for Spitfire Lake.

Location	County: Town:	Franklin Brighton	Latitude: Longitude:	44.4164 -74.2738
Lake Characteristics	Lake Area (ha):	580	Z-max (m):	9.4
	Lake Perimeter (km):	8	Volume (m^3):	5,036,554
			Flushing Rate (T/Y):	2.7
Watershed Characteristics	Watershed Area (ha):	2,402	Residential (%):	0
	Surface Water (%):	21	Agriculture (%):	0
	Deciduous Forest (%):	53	Commercial (%):	0
	Evergreen Forest (%):	12	Local Roads (km):	1.0
	Mixed Forest (%):	10	State Roads (km):	4.4
	Wetlands (%):	5		

Methods

Spitfire Lake is located in the northern Adirondacks (Figure 2) in Franklin County in the Town of Brighton (Table 2). The lake is 580 ha in surface area and has 8 km of shoreline. The maximum depth is 9.4 m, total volume is 5,036,554 m^3, and the lake flushes about 2.7 times per year. The Spitfire Lake watershed is 2,402 ha, 6% of which is surface water. The watershed is dominated by forest cover, with 53% deciduous, 12% evergreen, and 10% mixed forests. The watershed contains 1.0 km of local roads (county, town, and local) and 4.4 km of state roads (state and US highways).

Data was collected from the deepest location of the lake, eight times during the ice free period in 2014. During each sampling event secchi transparency was observed by lowering a standard 20 cm black and white secchi disk to a depth where it could no longer be seen. This process was repeated and the average secchi depth for that day was recorded. Surface water samples were collected using a 2 meter integrated tube sampler. The hypolimnetic water was collected from approximately 0.5 meter off the bottom using a 1 liter Kemmerer bottle. The contents of the tube were poured into a 1 liter brown bottle and thoroughly mixed. A 250 mL aliquot of the integrated sample was collected for chemical analysis and a second 250 mL aliquot was filtered through a 0.45 µm cellulose membrane filter for chlorophyll-a analysis. The filter was retrieved and wrapped in foil. The water sample and chlorophyll filter were immediately delivered to the AWI Environmental Research Lab for analysis

Samples were analyzed for pH, conductivity, alkalinity, total phosphorus, nitrate, chlorophyll-a, chloride calcium and sodium at the AWI Environmental Research Lab following the analytical methods described in Appendix 1. Results for 2014 were tabulated and time series charts were constructed from the annual average value for each indicator. Trend analysis was conducted using Kendall's non-parametric regression to test the hypothesis "there is no relationship between the indicator and time". Simple linear trend lines were fit to data with significant trends ($P<0.05$) and displayed on the corresponding chart. Thus, absence of a line means there was no statistically significant trend in the indicator over time.

Average annual values for secchi disk transparency, total phosphorus, and chlorophyll-a were used to calculate Carlson's Trophic Status Index, (TSI), a commonly used quantitative index for classifying lakes based on trophic status (Carlson 1977). TSI values are calculated as follows:

- TSI (Secchi Disk) = 60 – 16.41xln[Secchi Disk (m)]
- TSI (Chlorophyll) = 30.6 + 9.81xln[Chlorophyll a(µg/L)]
- TSI (Total Phosphorus) = 4.15 + 14.42xln[Total Phosphorus (µg/L)]

Typically TSI values are between 0 and 100. Lakes with TSI values less 40 are classified as oligotrophic, TSI values between 40 and 50 are classified as mesotrophic, and TSI values greater than 50 are classified as eutrophic. A detailed description of TSI values and likely lake attributes is found in Table 3.

Table 3. Trophic classification of lakes based on Carlson's Trophic Status Index (TSI).

TSI Value	Trophic Classification*	Likely Attributes
<30	Oligotrophic	Clear water, high oxygen throughout hypolimnion during the entire year
30-40	Oligotrophic	Clear water, periods of hypolimnetic anoxia possible during the summer in relatively shallow lakes
40-50	Mesotrophic	Moderately clear, increasing probability of hypolimnetic anoxia during the summer
50-60	Eutrophic	Mildly eutrophic. Decreased transparency, hypolimnetic anoxia, and warm water fishery only. Supports all recreational / aesthetic uses but threatened.
60-70	Eutrophic	Dominance of blue-green algae, algal blooms likely, extensive macrophytes growth in shallow water
70-80	Eutrophic	Heavy algal blooms possible throughout summer, hyper eutrophic
>80	Eutrophic	Algal scum, summer fish kills, few macrophytes due to algal shading

Results and Discussion

The opening paragraph in each of the following sections provides basic background information for understanding the importance of each water quality indicator and interpreting data from the lake. The background paragraph is followed by a description of the results for the study lake as well as a comparison to the other lakes in the ALAP. The 2014 water quality results for Spitfire Lake are tabulated in Table 5, frequency histograms of the water quality indicators for all participating ALAP lakes are displayed in Figure 2, and the historical trends for Thirteen Lake are plotted in Figures 4 and 7.

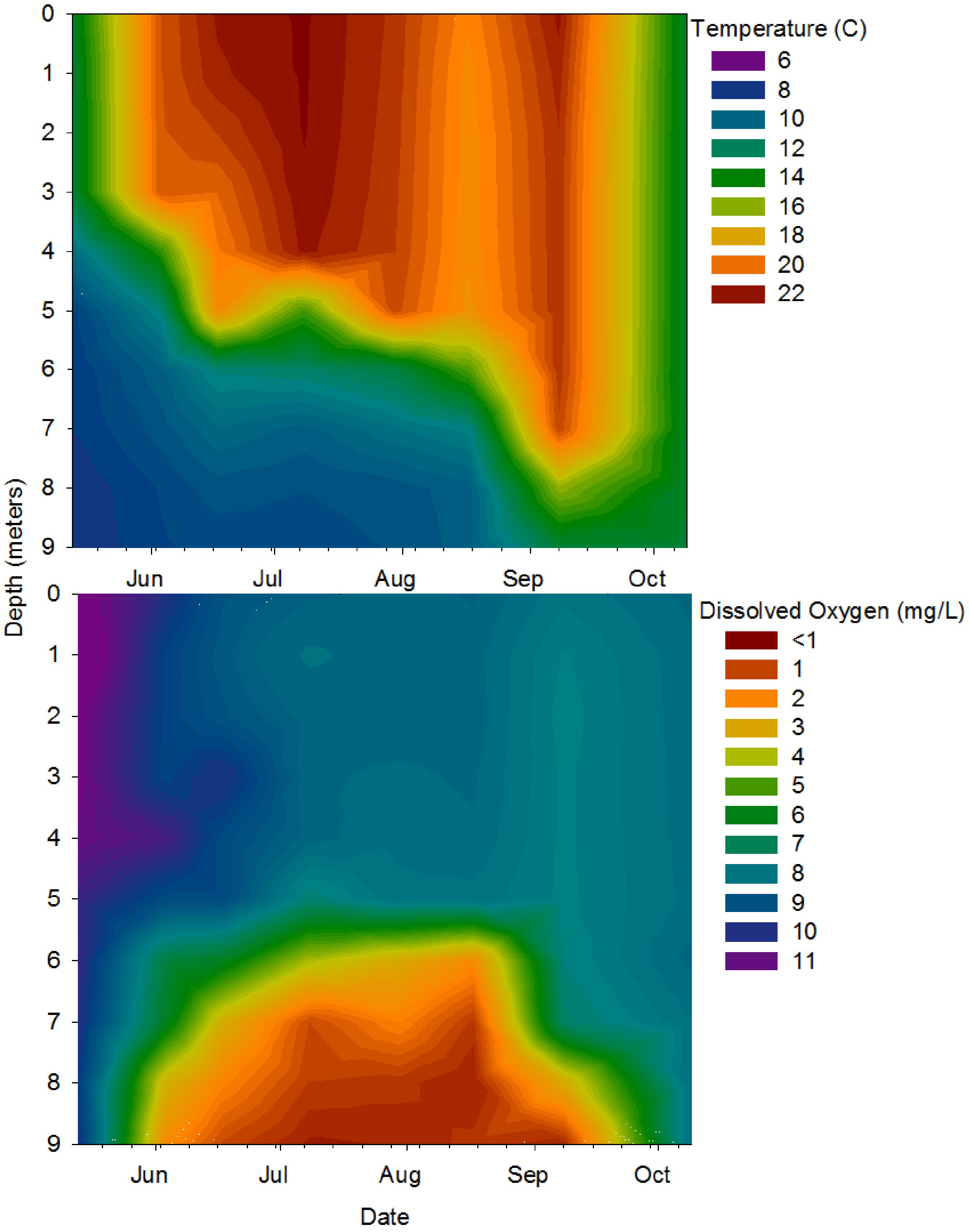

Figure 2. Isopleth diagrams depicting the temperature (upper panel) and dissolved oxygen (lower panel) of Spitfire Lake during the 2014 season.

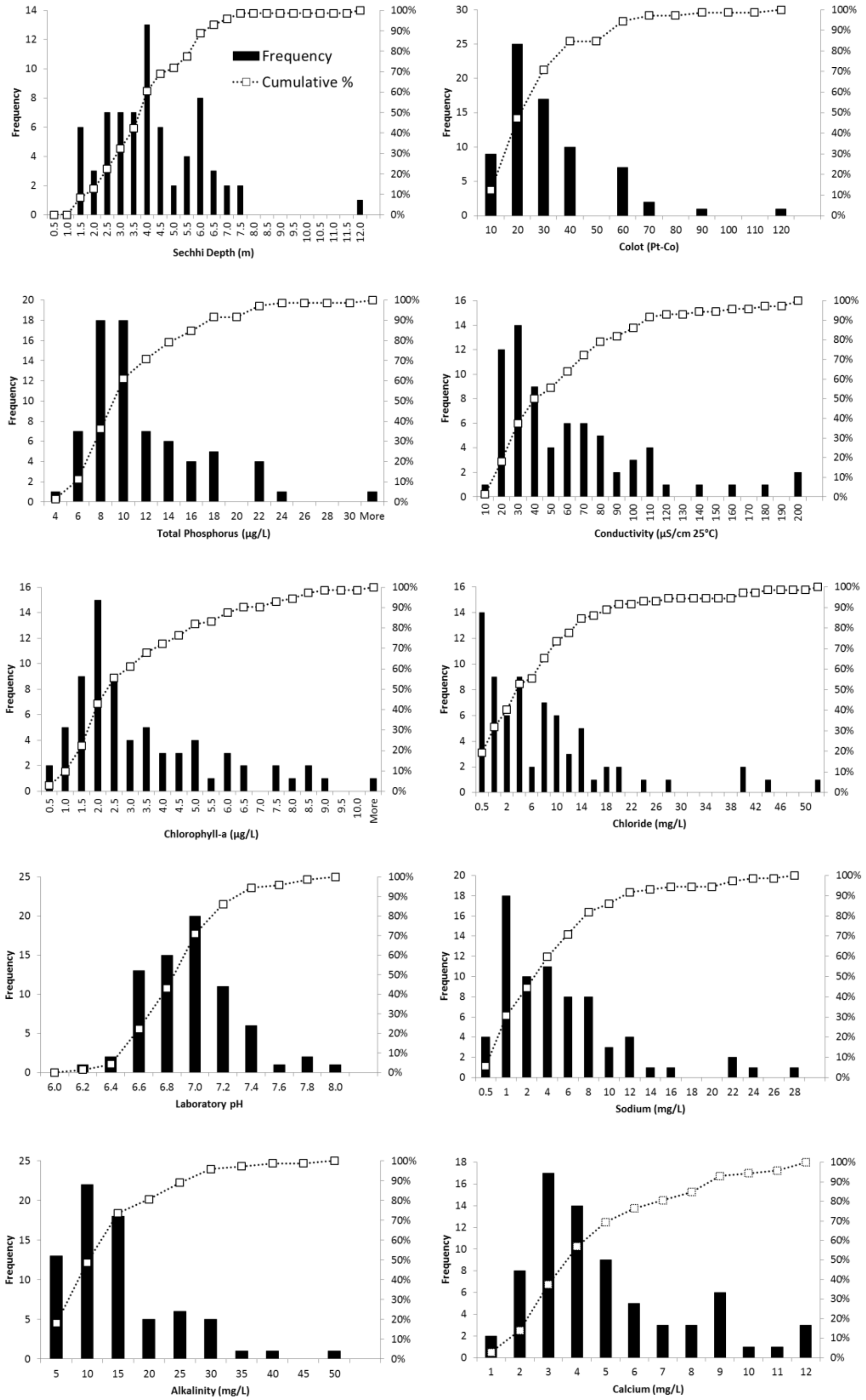

Figure 3. Frequency histogram (bars) and cumulative percentage (plots) of 2014 water quality indicators for the 72 participating lakes. Figure is constructed with each lakes 2014 average.

Temperature and Dissolved Oxygen

Vertical mixing within the water column of a lake is a function of the waters temperature dependent density gradient (as water warms, it becomes less dense). When the ice comes off the lake in the spring the water column is isothermal, meaning it's all the same temperature, and thus all the same density. During isothermal conditions in the spring the lake can completely mix from top to bottom, this is referred to as "spring turnover". As spring progresses the surface waters are heated more rapidly than heat can be distributed by mixing. The thermal resistance to mixing increases between warm surface water and cooler and denser bottom water. If the lake is deep enough the water column will becomes stratified into three distinct strata. The epilimnion is the upper strata that is uniformly warm and freely mixes with itself. The hypolimnion is the bottom stratum that is uniformly cold and dense. In between the two strata is the metalimnion, a zone of sharp thermal change that prevents mixing between the surface and the bottom (Wetzel 2001). As the lake loses heat in the fall, the epilimnion becomes cooler and deeper. Eventually the lake is once again isothermal and freely mixes. This is referred to as "fall turnover"

Dissolved oxygen has been described as the most fundamental parameter of a lake, aside from the water itself (Wetzel 2001). Available oxygen is essential for aerobic metabolism and non-biotic chemical reactions. In addition the presence or absence of oxygen directly affects the solubility of a number of important inorganic nutrients such as phosphorus. The primary source of oxygen in a lake is the atmosphere, thus the in lakes that are thermally stratified the hypolimnion is isolated from the oxygen source. When lake sediments contain high amounts of organic material, bacterial decomposition consumes all of the dissolved oxygen resulting in hypolimnetic hypoxia (very low O_2 in hypolimnion). In some lakes a certain amount of hypolimnetic hypoxia may be natural; however nutrient enrichment resulting from human activities stimulates algal productivity and subsequent algal settlement, decomposition, and oxygen loss (i.e. Bertram 1993). Several ecological processes are influenced by hypolimnetic hypoxia. The most obvious impact is loss to the fishery. Hypoxia has the potential to negatively affect individual fish growth, survival, reproduction, and ultimately population growth (Wu 2009). For example many game fish such as bass, pike and perch require oxygen concentrations above 4 mg/L, and native salmonid species such as brook trout and lake trout require oxygen concentrations greater than 5 mg/L (Spoor 1990). Many Adirondack lakes, including Spitfire, have seen the extirpation of native trout due to hypolimnetic hypoxia (among other factors). Hypoxia also results in internal phosphorus loading to the lake. Lack of oxygen in the hypolimnion allows the release of dissolved phosphorus from the lake sediments. During fall turnover the phosphorus gets distributed through the entire water column (Wetzel 2001).

Temperature and dissolved oxygen data for Spitfire is depicted as a depth time isopleth in Figure 2. In this type of graph, color represents the temperature or concentration of oxygen over time on the X-axis. The lake was stratified during the entire 2014 sampling period. The epilimnion (strata of uniform temperature) ranged from in size from 4 meters deep in May to over 9 meters deep in October. The maximum surface temperature of 22 °C was observed in early July, with a second warming period observed in early September. Loss of thermal stratification had initiated by late September, and can be observed in Figure 2 as a cooling and thickening of the epilimnion.

During stratification the lake exhibited it's typical a clinograde oxygen profile, where the oxygen concentration in the bottom strata was much lower than the surface water. The bottom water of the lake contained between 4 and 10 mg/L of oxygen in May, but became hypoxic by June, with the water becoming essentially anoxic (D.O. < 1.0 mg/L) from mid-June until fall turnover was achieved in late September. The anoxic strata occupied up to 1.5 meters of the bottom water by late August. The anoxic condition of Spitfire drastically affects the concentrations of other chemical parameters, which will be discussed later in this report.

Table 4. Water quality and trophic indicators for Spitfire Lake, 2014. BDL = below laboratory detection level, ND = no data, ± represents an estimate as the concentration is below the practical quantitation limit.

Water Quality Indicator	**Sampling Date**								**Average**
	5/14	**6/4**	**6/19**	**7/8**	**7/30**	**8/18**	**9/8**	**10/10**	
	Surface water (0-2 meter integrated)								
Transparency (m)	2.4	4.1	4.0	2.7	4.3	5.0	5.9	2.7	3.9
Total Phosphorus (µg/L)	15.5	7.7	6.5	7.3	6.3	8.0	6.3	9.9	8.4
Chlorophyll-*a* (µg/L)	BDL	5.2	4.4	1.5	8.4	1.4	0.9	5.3	3.3
Laboratory pH	5.4	6.2	7.1	5.8	6.7	6.8	6.5	6.9	6.4
Sp. Conductance (µS/cm)	48.1	47.5	46.1	49.8	50.8	50.1	49.6	45.6	48.5
Color (Pt-Co)	32.0	10.2	16.4	25.8	13.3	19.5	ND	26.0	17.9
Alkalinity (mg/L)	10.4	10.5	10.0	10.0	9.9	10.0	10.9	11.6	10.4
Nitrate-Nitrogen (µg/L)	57.5	12.4	BDL	5.6	BDL	1.5	BDL	±4.7	9.2
Chloride (mg/L)	6.1	6.4	6.4	7.3	7.1	8.1	8.7	8.4	7.3
Calcium (mg/L)	3.4	3.2	3.5	2.9	3.3	3.7	3.3	3.5	3.3
Sodium (mg/L)	4.4	4.5	5.0	4.1	4.5	5.2	4.5	4.6	4.6
	Bottom Water (~8 meters)								
Total Phosphorus (µg/L)	21.4	24.6	43.7	41.2	108.0	58.1	53.1	10.2	45.0
Chlorophyll-*a* (µg/L)	ND	ND	ND	ND	65.9	38.8	23.7	5.3	33.4
Laboratory pH	5.4	6.4	6.8	5.6	6.8	6.7	6.4	6.9	6.4
Sp. Conductance (µS/cm)	46.8	51.6	50.3	60.6	54.0	78.1	53.8	46.0	55.2
Color (Pt-Co)	41.4	72.6	153.6	371.9	265.9	312.6	159.9	32.0	176.2
Alkalinity (mg/L)	10.8	13.1	12.8	16.7	13.0	16.2	16.1	12.1	13.8
Nitrate-Nitrogen (µg/L)	92.3	36.0	16.9	10.3	BDL	BDL	BDL	6.5	19.2
Chloride (mg/L)	5.9	6.1	6.0	6.5	6.7	7.8	8.1	8.4	6.9
Calcium (mg/L)	3.4	3.4	3.9	4.2	4.3	5.1	4.0	3.5	4.0
Sodium (mg/L)	4.3	4.3	4.7	4.4	4.4	5.0	4.4	4.7	4.5

Transparency

Transparency is a measure of water clarity in lakes. It is measured by lowering a 20 cm black and white disk (Secchi disk) to the depth where it is no longer visible from the surface. The transparency of a lake is influenced by many factors, including algal abundance, turbidity, suspended sediments, and dissolved organic matter (Hutchinson 1957). Transparency can serve as an important indicator of overall trophic condition of a lake as well as influencing human perception of water quality. In general, lakes that have low productivity and low algal abundance have greater secchi transparencies. As algal productivity increases secchi depths become much shallower.

Transparency of Spitfire Lake ranged from 2.4 meters to as high as 5.9 meters meters , with a seasonal average of 3.9 meters in 2014 (Table 4). The majority of lakes in the ALAP data set (60%) had a transparency less than that of Spitfire Lake (Figure 3). Over the 13 years of participation in ALAP, average annual transparency has ranged from 2.7 to 4.5 meters with no significant trend detected in the data (Figure 4). None of the participating ALAP lakes showed a positive trend in transparency over time, 11% showed a decreasing trend and 89% showed no trend in the data.

Phosphorus

Phosphorus is of major importance to structure and metabolism of all organisms. However, it exists in relatively small amounts in freshwater systems compared to other essential nutrients such as carbon, hydrogen, oxygen, and sulfur. The addition of extra phosphorus to an aquatic system allows production to increase greatly because all other essential elements are usually available in excess. Thus phosphorus is typically the limiting nutrient in aquatic systems (Schindler 1974, Wetzel 2001), and widely considered as the most important contributor to reduced water quality in lakes (Søndergaard et al. 2003). Natural weathering releases phosphorus from rocks and soils, and it also enters our watersheds in fertilizers, human waste, and atmospheric deposition. Phosphorus exists in a number of forms in aquatic systems, including readily available dissolved phosphorus, and organically and inorganically bound phosphorus. Total phosphorus is all of the forms of phosphorus combined and serves as an important indicator of overall trophic status of a lake. Generally speaking, lakes of low productivity (oligotrophic) have total phosphorus concentrations less than 10 µg/L, while highly productive lakes (eutrophic) have total phosphorus concentrations greater than 20 µg/L (NYS DEC assessment criteria).

Total phosphorus in the surface water of Spitfire ranged from 6.3 to 15.5 µg/L , with a seasonal average of 8.4 µg/L in 2014 (Table 4). The majority of ALAP lakes (64%) had an average concentration of total phosphorus less than that of Spitfire (Figure 3). Historically, average total phosphorus concentrations have ranged from 7.6 to 48.4 µg/L with no statistical trend detected in the data set (Figure 4). None of the participating ALAP lakes showed a positive trend in total phosphorus in the surface water over time, 33 % showed a decreasing trend, and 67% showed no trend in the data. The total phosphorus in the bottom water of the lake was substantially higher, with concentrations in the range of 41 to 108 µg/L during thermal stratification. (Table 4). The increase in phosphorus in the bottom water may be the result of the anoxic conditions in the hypolimnion, where reducing conditions convert insoluble forms of phosphorus to soluble ones and allow stored reactive phosphate to essentially leak out of the sediment.

Chlorophyll-a

Chlorophyll-a is the primary photosynthetic pigment found in all species of algae, as well as cyanobacteria. A measurement of chlorophyll in a lake provides a surrogate measure of algal productivity (Wetzel 2001). Chlorophyll-a is not a direct measure of algal biomass as the concentration of chlorophyll varies somewhat by species and environmental conditions. This said, increases in chlorophyll are generally associated with increased algal production, and the concentration of chlorophyll is widely considered as the most direct measure of the trophic state of lakes. Algal biomass is affected by nutrient availability, water temperature, and light, so there can be considerable variation in chlorophyll concentrations throughout the year depending on which of these three factors is limiting growth at a particular time. Though, major changes in algal biomass (e.g. an algae bloom), and thus chlorophyll, are usually related to changes in the availability of phosphorus, nitrogen, silica or inorganic carbon (Wetzel 2001; Klemer 1990).

Chlorophyll concentration in the surface water of Spitfire Lake ranged from below detection to 8.4µg/L, and averaged 3.3 µg/L (Table 4). The majority of ALAP lakes (63%) had annual average chlorophyll-a concentrations lower than Spitfire Lake (Figure 3). Historically, the annual average concentration of chlorophyll-a has ranged from 2.5 to 6.4 µg/L with no apparent trend detected in the data (Figure 4). Two percent of the participating ALAP lakes showed a positive trend in chlorophyll over time, 11 % showed a decreasing trend, and 86% showed no trend in the data.

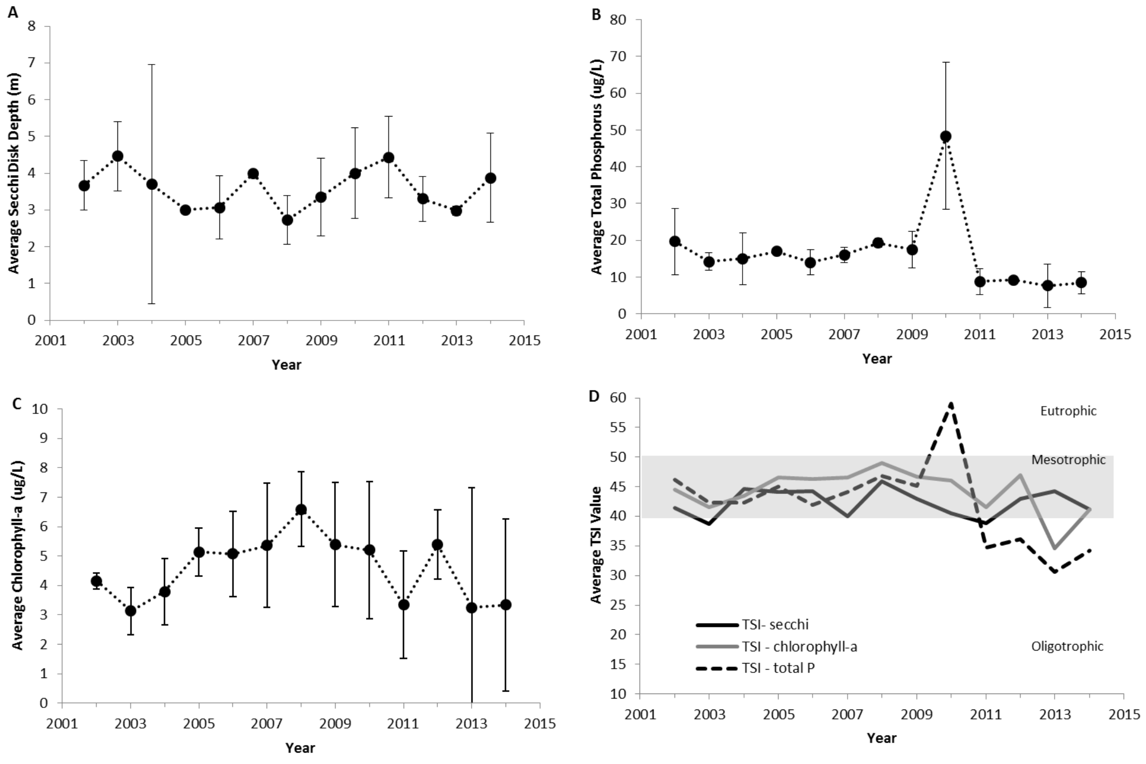

Figure 4. The annual average values of epilimnetic trophic indicators of Spitfire Lake, 2000-2014. (A) Secchi disk transparency, (B) total phosphorus concentration, (C) chlorophyll-a concentration, and (D) Carlson's Trophic Status Index. Vertical bars represent one standard deviation of the mean. Significant trends (*P*≤0.05) are noted with a trend line.

We found the greatest amount of chlorophyll-a in Spitfire to be just of the bottom, where concentrations ranged from 23.7 to 65.9 during thermal stratification (Table 4). A profile of chlorophyll-a concentration with depth performed on July 30the 2014 further demonstrated the presence of a deep-water bloom consisting primarily of the cyanobacteria *Plantothrix species* (Figure 5 and 6). Subsequent evaluation revealed that the bloom persisted at least through fall turnover.

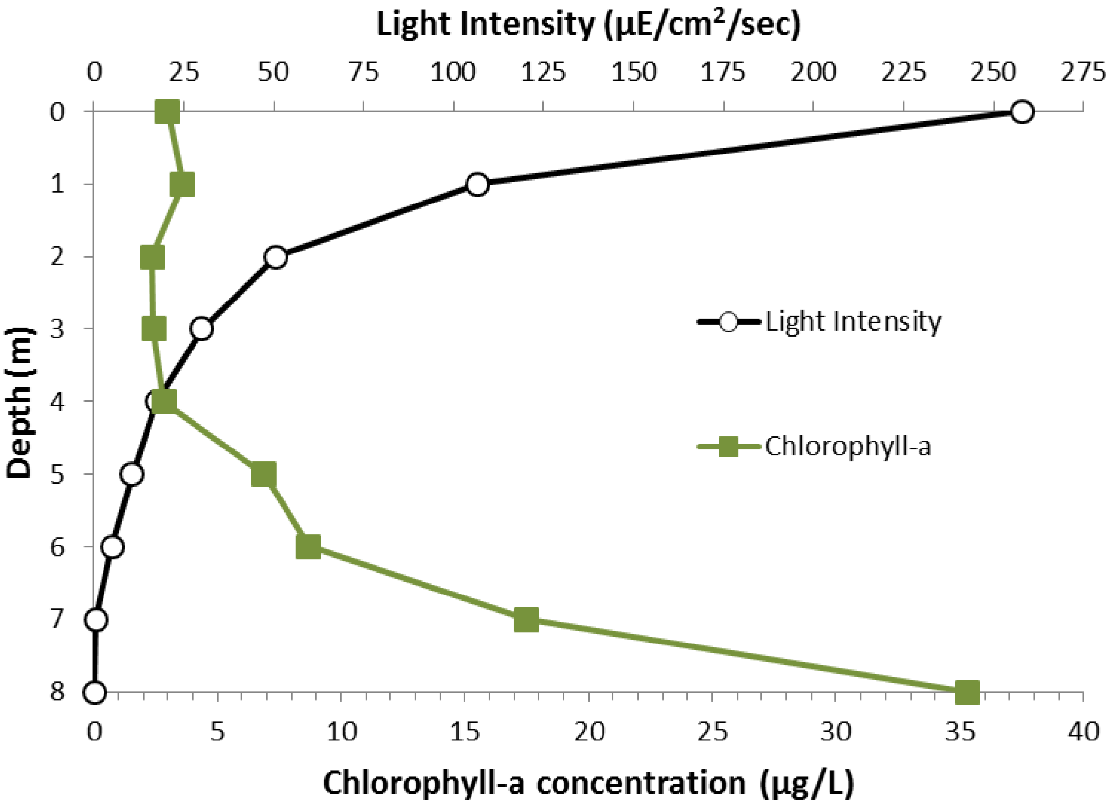

Figure 5. Profile of light intensity and chlorophyll-a concentration in Spitfire Lake, performed mid-day on July 31st 2014.

Trophic Status

Trophic status is a term derived from the Greek word *trophi*, meaning food or nourishment, and is used by limnologists to explain the overall productivity of a lake. Lake productivity is naturally influenced by the rate of nutrient supply from the watershed, climatic condition, and lake and watershed morphology. Human activities within a watershed have the potential to increase the rate of nutrient supply into the lake, and thereby accelerate algal productivity (cultural eutrophication).

Lakes are typically assigned into one of three trophic or productivity classes (oligotrophic, mesotrophic, eutrophic) based on total phosphorus, chlorophyll *a*, and Secchi transparency.

- Oligotrophic - From the Greek words *oligo*, meaning few and *trophi*, meaning nourishment; oligotrophic lakes have low levels of available nutrients. As a result of low nutrients, oligotrophic lakes have high transparency, low algal abundance, low organic matter in the sediments, sparse aquatic plant growth, and abundant dissolved oxygen throughout the water column the entire year. Oligotrophic lakes are most likely to support a cold water fishery (Wetzel 2001).

- Eutrophic - From the Greek words *Eu*, meaning good. Eutrophic lakes have abundant levels of nutrients. As a result of high nutrient availability eutrophic lakes are typified by high algal productivity, low transparency, high organic matter in the sediments, and periods of anoxia in the bottom of the water column (hypolimnion). Eutrophic lakes tend to support dense aquatic plant growth in the littoral zone. Eutrophic lakes are unlikely to support a viable cold water fishery (Wetzel 2001).

- Mesotrophic - from the Greek words *Meso*, meaning the middle. Mesotrophic lakes and an intermediate trophic classification on the continuum between oligotrophy and eutrophy.

The Carlson Trophic Status Index (TSI Index) is a common and valuable metric for evaluating the productivity of a lake (Carlson 1977). The index is calculated by logarithmically converting the values of Secchi transparency, chlorophyll-a concentration, and total phosphorus to a scale of relative trophic state ranging from 0-100. TSI values less than 40 are considered oligotrophic, values between 40 and 50 are considered mesotrophic, and values grater that 50 are eutrophic (Table 3). Calculating the TSI scores from three trophic indicators allows further interpretation of productivity status of the lake.

The TSI Index for Spitfire Lake calculated from transparency (41) and chlorophyll-a (41) suggested a mesotrophic classification for the lake, while the TSI value for total phosphorus (34) indicated an oligotrophic classification for the lake. A disparity of this nature is common for lakes that experience phosphorus limitation in the surface water during the summer months. The lake has typically fluctuated within the mesotrophic condition since joining ALAP in 2002 (Figure 4).

Figure 6. Water sample (right) and membrane filter (left) used for chlorophyll-a analysis. Sample was taken from a depth of 8 meters in Spitfire Lake, July 31st, 2014.

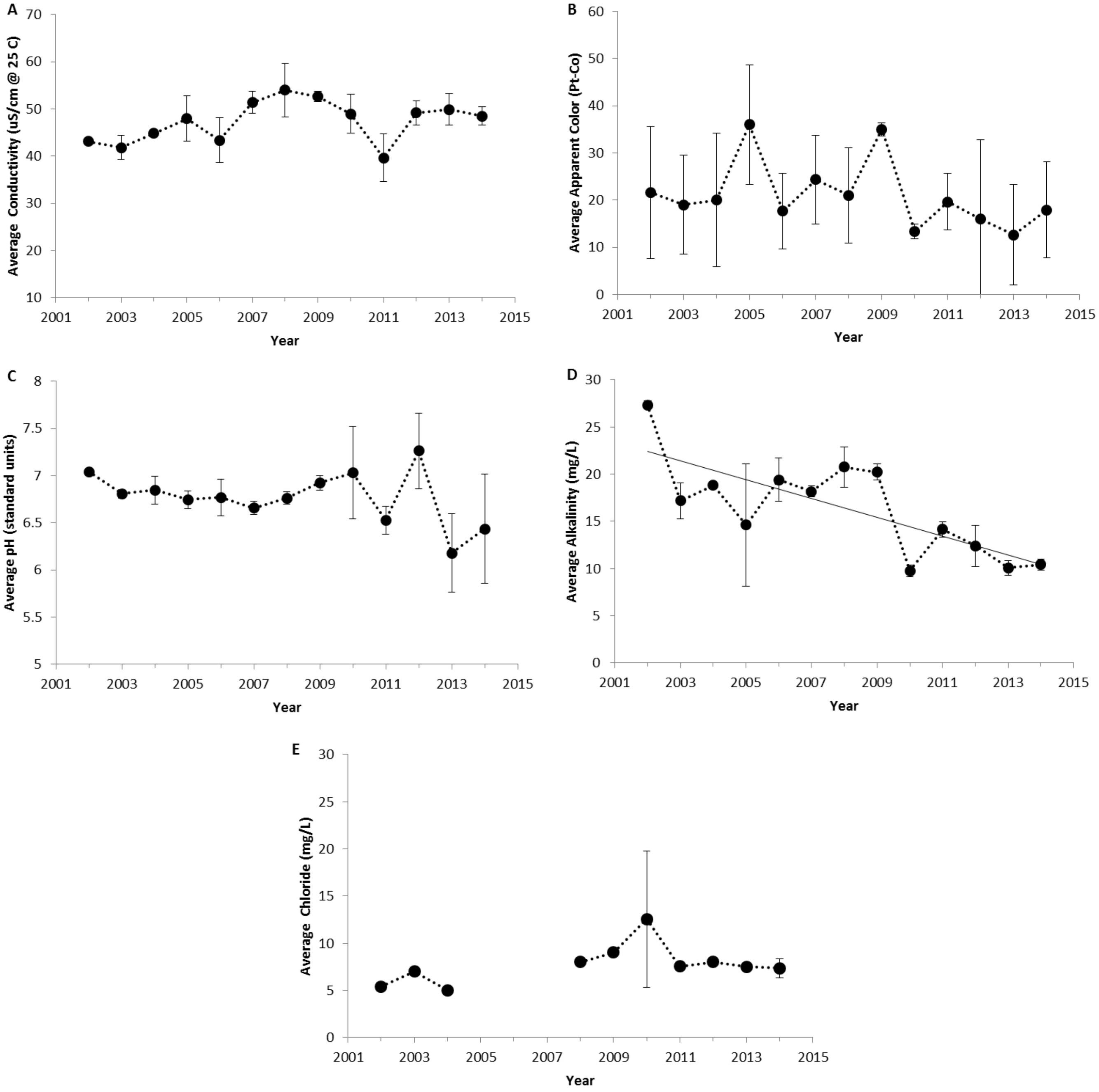

Figure 7. The annual average values of water quality indicators of Spitfire Lake, 2000-2014. (A) Specific lab conductivity @ 25 C, (B) apparent color, (C) pH, (D) total alkalinity, and (E) chloride. Vertical bars represent one standard deviation of the mean. Significant trends (*P*≤0.05) are noted with a trend line.

pH

pH is a measurement of the concentration of hydrogen ions in water (acidity). Hydrogen ions are very active, and their interaction with other molecules affects the behavior of gasses, nutrients, and heavy metals and biological activity; thus pH is considered a master variable for its influence on chemical processes and aquatic life. pH exists on a logarithmic scale between 0 and 14. Because pH is logarithmic a decrease in 1 pH unit represents a 10 fold increase in hydrogen ion activity. Lakes are considered circumneutral when they have a pH between 6.5 and 7.5, while lakes with pH values less than 6.5 are considered acidic and those with pH values greater than 7.5 are considered basic. Lakes can become acidified when they are influenced by organic acids from soils, wetlands and bogs or when acidic precipitation falls on a poorly buffered watershed (Dodson 2005, Wetzel 2001). Acidity is also influenced by the time of day. For example, water samples taken during a bright sunny afternoon will often have elevated pH levels due to algal photosynthesis and the subsequent removal of carbon dioxide from the water (Dodson 2005). This natural process along with release of carbon dioxide by respiration means lake pH can fluctuate throughout the day.

Spitfire Lake is a slightly acidic water body. In 2014 the pH of the surface and bottom water samples averaged 6.4 pH units, with the lowest value of 5.4 pH units occurring in the spring. (Table 4). The majority of lakes in the ALAP data set (96%) had a pH higher than that of Spitfire Lake (Figure 3). Over the past 13 years of monitoring, the pH of Spitfire Lake has been circumneutral, and ranged from 6.4 to 7.2 with no trend apparent in the data (Figure 7). Three percent of the participating ALAP lakes showed a positive trend in pH over time, none of the lakes showed a decreasing trend, and 97% showed no trend in the data.

Alkalinity

Alkalinity (or acid neutralizing ability) measures the buffering capacity of a lake, which is the ability of the lake to resist a change in pH. High alkalinity lakes are well buffered against changes in pH, while low alkalinity lakes are poorly buffered against changes in pH. Thus, a high alkalinity lake would have a more stable pH compared to a low alkalinity lake, and a more stable pH is less stressful to aquatic life. The carbonate system provides acid buffering through two alkaline compounds: bicarbonate (HCO_3^-) and carbonate ($CO_3^{=}$). These two compounds are typically found in association with calcium or magnesium. Lakes with less than 10 mg/L calcium carbonate are sensitive to acidification, while lakes with greater than 20 mg/L calcium carbonate are not sensitive to acidification (Godfrey et al. 1996).

Spitfire Lake has low to moderate acid neutralizing ability. In 2014 the alkalinity averaged 10.4 mg/L as calcium carbonate (Table 4). Lakes with alkalinity values less than 10 mg/L are considered vulnerable to acid deposition. The alkalinity of the upper lake represents approximately the median concentration within the ALAP program (Figure 3). Historically the alkalinity of the lake has ranged between 10 and 27.3 mg/L with a significant downward trend at a rate of approximately 1.0 mg/L/year ($P = 0.03$, Figure 7). None of the participating ALAP lakes showed a positive trend in alkalinity over time, 29% of the lakes showed a decreasing trend, and 70% showed no trend in the data.

Color

The observed color of a lake is an optical property that results from light being scattered upwards after selective absorption by water molecules as well as dissolved (metallic ions, organic acids) and suspended (silt, plant pigments) materials . For example, alkaline lakes with high concentrations of calcium carbonate scatter light in the green and blue wavelength and thus appear turquoise in color. Lakes rich in dissolved organic matter and humic compounds absorb shorter wavelengths of light such as green and blue and scatter the longer wavelengths of red and yellow, thus these lakes appear to be brown in color (Wetzel 2001). Thus analysis of color can provide us with information about the quantity of dissolved organic material in the water. For objective quantification of apparent color we compare water samples to standards of platinum-cobalt solution. (Pt-Co units).

Apparent color values from the surface water of Spitfire Lake ranged from 10 to 26 Pt-Co units in 2014. The color of the bottom water was much greater, ranging from 32 to 312 Pt-Co units (Table 4). The elevated color in the bottom strata is likely the result of the dense cyanobacterial bloom, but also may be evidence of the high rate of decomposition occurring near the substrate. The majority of ALAP lakes (60%) had less color to the water than Spitfire Lake (Figure 3). Over the period of ALAP participation the annual average color value of the surface water have been highly variable, with a range between 7 and 30 Pt-Co units with no statistical trend detected in the data (Figure 7). Eleven percent of the participating ALAP lakes showed a positive trend in color over time, none of the lakes showed a decreasing trend, and 89% showed no trend in the data.

Conductivity

Pure water is a poor conductor of electricity. The ability of water to conduct electricity increases as the concentration of dissolved ions in the water increases. Thus, conductivity is considered a strong indicator of the amount of dissolved ions in water. Typically the conductivity of a clean undeveloped lake in the Adirondacks is in the range of 10-25 µS/cm. Elevated conductance may be indicative of road salt pollution, faulty septic systems or the influence of bogs and wetlands in the watershed. Conductivity is a very useful surrogate when the relationships between ion concentrations and conductivity are known. For example, conductivity can be used to estimate sodium and chloride concentrations in streams (Daley et al. 2009).

Conductance values of the surface water of Spitfire Lake exhibited little variation around the average value of 48.5 µS/cm . Conductivity of the bottom water was elevated, particularly during stratification, when conductance values reached 78 µS/cm (Table 4). The conductivity of Spitfire represents approximately the median value for all the participating lakes (Figure 3). Historically the conductivity of the lake has ranged from 39 and 54 µS/cm no significant positive or negative trend in the data (Figure 7). Three percent of the participating ALAP lakes showed a positive trend in conductivity over time, 22% of the lakes showed a decreasing trend, and 75% showed no trend in the data.

Sodium and Chloride

Non-impacted Lakes in the Adirondack region have naturally low concentrations of sodium and chloride, with average background concentrations of 0.5 mg/L and 0.24 mg/L respectively. However, wide spread use of road deicers (primarily sodium chloride) has significantly increased the concentration of these chemicals in lakes that have salted roads in their watersheds (Kelting et al 2012). Sodium and chloride can have negative effects on aquatic life when at high concentrations (Corsi et al. 2010), and can impart an undesirable taste to drinking water. The US EPA has a drinking water guideline of 250 mg/L for chloride and 20 mg/L for sodium, but these are not enforceable standards.

Average concentrations in the surface water Spitfire Lake during 2014 were 4.6 mg/L for sodium and 7.3 mg/L for chloride. Concentrations were similar in the bottom water samples (Table 4). The elevated concentrations of these chemicals are within the range we would expect for a watershed containing shoreline development and 4.4 km of salted roads. The majority of ALAP lakes had lower concentration of sodium and chloride than Spitfire Lake (~ 65% of lakes for both, Figure 3). Historic chloride concentrations generally ranged between 5.5 and 13 mg/L in Spitfire Lake with no apparent trend detected in the historical data (Figure 7). Historical trend analysis of sodium was not performed.

Calcium

Calcium is an essential element for plant growth, but is generally considered a micronutrient in freshwater systems (needed by organisms in tiny amounts, Wetzel 2001). Some organisms, such as shell producing mollusks, require larger amounts of calcium to establish a population. Calcium is derived from the weathering of calcium bearing bedrock, such as limestone and dolomite. The majority of the bedrock in the Adirondack region is comprised of granite, and thus offers little in the way of calcium to the watershed. Calcium concentration is a good indicator of the overall habitat suitability for the zebra mussel, a non-indigenous species from Eurasia that has been spreading through North America and transforming food webs and biochemical cycles in freshwater systems since 1988 (Strayer 2009). Researchers have reported minimum calcium concentrations ranging from 8-20 mg/L to support a viable zebra mussel population (Cohen 2004).

Calcium concentration in Spitfire Lake exhibited little variation around the seasonal average of 3.3 mg/L, well below the reported threshold ranges for the zebra mussel. The calcium concentration of the upper lake represents approximately the median value for the participating ALAP lakes (Figure 3). Historical trend analysis was not performed for calcium.

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Appendix 1. Analytical methods performed on ALAP samples at the AWI Environmental Research Lab.

Analyte	Method Description	Reference
Lab pH	Mettler Toledo standard pH electrode	APHA
Conductivity	Conductivity at 25° C via Mettler Toledo conductivity cell	APHA 2510 B
Apparent Color	Single wavelength method with PtCO standards	APHA 2120 C
Chlorophyll-a	Trichromatic method uncorrected for phaeophyton	APHA 10200 H
Total Phosphorus	Acid-persulfate digestion, automated ascorbic acid reduction	APHA 4500-P H
Nitrate + Nitrite	Automated cadmium reduction	APHA 4500-NO_3 I
Alkalinity	Automated methyl orange method	EPA 301.2
Chloride	Automated ion chromatography	EPA 300.0
Calcium and Sodium	Inductively coupled plasma optical emission spectroscopy	EPA 200.7