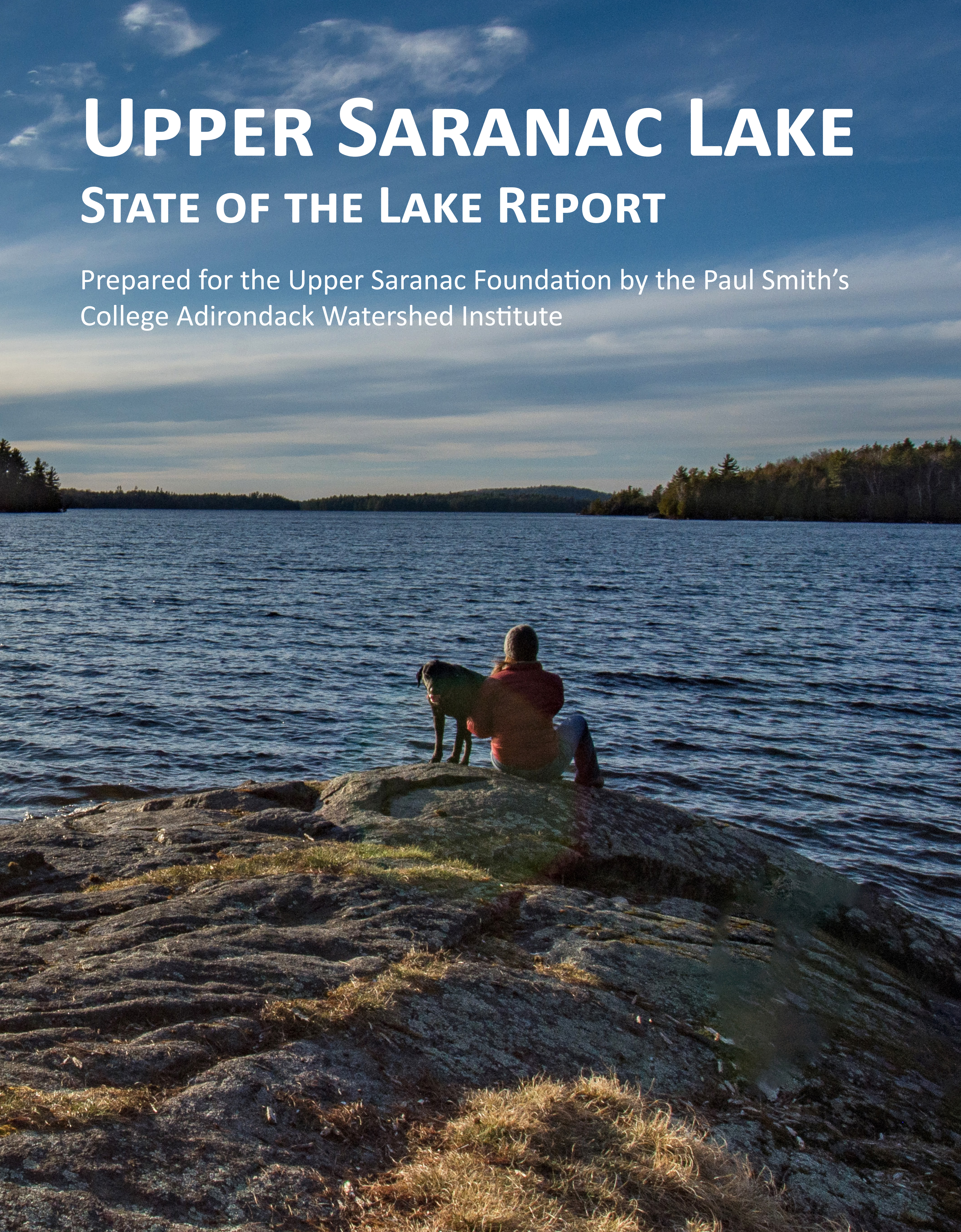
UPPER SARANAC LAKE

STATE OF THE LAKE REPORT

Prepared for the Upper Saranac Foundation by the Paul Smith's College Adirondack Watershed Institute



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State of the Lake Report

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Upper Saranac Foundation
It still is, and always will be, about water quality

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Photo 1. Paul Smith's College Adirondack Watershed Institute staff posing with the Upper Saranac Lake Environmental Monitoring Platform. Left to right: Corey Laxson, Elizabeth Yerger, and Dan Kelting.

Executive Summary

Upper Saranac Lake is one of the most intensively studied lakes in the Adirondacks. The lake has been the subject of numerous scientific research projects, a 28 year water quality monitoring initiative, and an invasive plant management program that has served as a model for lakes around the world. The goal of this report is to provide a synthesis of the historical and current monitoring data for Upper Saranac Lake and to provide interpretations of the findings where possible. The report can be summarized in the following key points:

1. 2017 was the inaugural year for the Upper Saranac Lake Environmental Monitoring Platform, an autonomous in-lake monitoring station that collects high frequency data on physio-chemical, biological, and meteorological characteristics of the lake. This station is a valuable tool that will enhance our understanding of the lake, foster collaboration, and engage citizen involvement in lake issues.

2. The phosphorus concentration of the surface water has exhibited a significant downward trend since the early 1990's in both the north and the south basins of the lake. Currently the total phosphorus concentration is below the target range identified in the Upper Saranac Lake Management Plan (12 µg/L). The phosphorus concentration in the bottom strata of the lake remains elevated, particularly in the late summer, when hypoxic conditions positively influence internal phosphorus loading to the lake.

3. Chlorophyll-a concentration (a surrogate measure of algal productivity) has exhibited a significant downward trend in the north basin and this may be related to efforts to reduce nutrient loading into the lake. Chlorophyll concentration has also exhibited a decline in the south basin, but this trend is not statistically significant.

4. Although substantial reductions in phosphorus and chlorophyll-a have been observed, the water clarity has exhibited a statistically significant reduction. The average transparency across the summer is nearly a meter less than it was in the early 1990's. Evidence from published research as well as our regional observations suggests that decreases in transparency may be related to recovery from acid deposition as well as shifts to our regional climate.

5. Historical analysis of nitrogen to phosphorus ratios confirms that Upper Saranac tends to be a phosphorus limited system; however, the TN:TP ratio is within the range where we should expect cyanobacteria dominance to occur from time to time.

6. Oxygen depletion occurs rapidly in the shallow north basin of the lake and this pattern has shown no signs of improvement. By early September of 2017, nearly half the water column was hypoxic at the deep hole of the north basin. Oxygen depletion in the deeper south basin has improved and the basin has experienced a reduction in overall oxygen depletion rate.

7. The chemistry of Upper Saranac Lake is influenced by the 27 km of salted roads in the watershed. The concentration of chloride in the lake (a surrogate for road salt impact) is approximately 40 times higher than baseline levels for least impacted Adirondack Lakes. This observation may not be entirely related to roads. Some of the chloride in the lake may be attributed to septic input and permitted discharge. For example, analysis of the EPA discharge monitoring report reveals that the hatchery has discharged an average of 1.3 million kilograms of chloride / year to the Little Clear Outlet over the last decade (1,400 tons/year). There is currently some debate over the validity of the chloride export data described in the EPA report.

8. The watershed monitoring program initiated in 2007 covers 75% of the Upper Saranac Watershed and captures 63% of the hydrologic budget of the lake. Continuous discharge observations at the lake outlet indicate that the water retention time of the lake was 0.7 years in 2017. Retention time calculated by the surface runoff model suggests a retention time of 0.9 years.

9. Phosphorus loading rates are within the range we would expect for low to moderately developed watersheds in the Adirondack Region. The tributary with the greatest phosphorus load in 2017 was Mill Brook, followed by Fish Creek and Black Swamp. Approximately 31% of the phosphorus content in Mill Brook can be attributed to the Little Clear Outlet, the receiving water for the permitted discharge of the Adirondack Fish Culture Station. The Hatchery continues to operate well below its permitted discharge rate.

10. Greatest nitrogen export was observed at Mill Brook (34 kg/day), which was double the next highest load found at Fish Creek. Our limited analysis suggests that approximately 21% of the nitrogen load of Mill Brook can be attributed to the Little Clear Outlet. The Adirondack Fish Culture Station is also permitted to discharge ammonium (an important nitrogen bearing molecule), and typically exports the nutrient at an average rate of 363 kg/year.

11. In general, the rates at which tributaries export chloride to Upper Saranac Lake are related to the density of salted roads within the sub watersheds. When normalized for watershed area, Cranberry Brook contributed the most amounts of sodium and chloride to the lake, with a median loading coefficient of 245 and 448 grams/ha/day respectively, followed by Mill Brook, and Indian Carry. In addition to salted state roads, Mill Brook also receives salt from the Little Clear Outlet, the receiving water for the hatcheries permitted discharge.

12. Eurasian water-milfoil was only detected at 5 of the 16 monitoring locations in 2017. The greatest encounter rate was at Fish Creek Pond, followed by Little Square Bay and Saginaw Bay. The average milfoil density across all Upper Saranac locations was 15 stems/acre, substantially lower than the 600 stems per acre observed in 2004. Eurasian water-milfoil would best be classified as a rare plant in Upper Saranac Lake.

13. The average Eurasian water-milfoil density at the Fish Creek Pond location in July was estimated at 474 stems/ acre. The density of the species has been relatively stable over the past three years.

14. Variable-leaf milfoil was first detected at the Fish Creek Pond location in 2009. In 2017, the species was encountered on 46% of the study segments, an increase of about 4%/year.

Photo 2. Goose Island Row. Photo by Travis Percival, Upper Saranac Lake Association webpage.

Introduction

Upper Saranac Lake is one of the more intensively studied lakes in the Adirondacks, with a diverse history of both scientific research and water quality monitoring. An impressive amount of peer reviewed science has been published from the lake, including studies on: degradation of water quality (Stager et al. 1997), environmental activism (Perry and Vanderklein 1996), impact of Eurasian water milfoil (Wilson and Ricciardi 2009), management of aquatic plants (Kelting and Laxson 2010), fate of septic tank effluent (Chen 1988), use of bioindicators (Benson 2008), spawning of lake trout (Royce 1951), accumulation of DDT in fish (Burdick et al 1964), and eutrophication recovery (Laxson et al. 2018). Thanks to the dedication of the Upper Saranac community and the foresight of the Upper Saranac Foundation, the water quality of the lake has been monitored for <u>28 consecutive years</u>. Long term data sets, such as this one for Upper Saranac Lake, are invaluable in their ability to provide us with a much broader view of lake ecology and watershed function. Analyzing a watershed in the context of time improves our capability to understand slow and highly variable ecological processes.

Historical Perspective

Human intrusion into the Upper Saranac Lake watershed in the form of residential development, logging, road construction, and nutrient discharge has been occurring for over 130 years. The cumulative result of our impacts were first noticed by observant residents in the 1970's, but exploded into visibility in 1989-1990 when dense surface blooms of cyanobacteria persisted on the lake for nine months (reviewed by Laxson et al 2018). The Upper Saranac Lake community rallied around the goal of improving water quality and initiated a comprehensive lake monitoring program with the PSCAWI (Paul Smith's College Adirondack Watershed Institute). The program still exists to this day and is the focus of this report.

By the mid 1990's the eutrophication issues in the lake were well understood, but another more costly problem was on the horizon. In 1996 the first large beds of Eurasian water-milfoil were documented in the head of Saginaw Bay. Limited control efforts in the form of hand harvesting and supplemental benthic matting began in 1999 and continued through 2003. The initial removal effort was successful at reducing milfoil cover within the managed areas, but the lakes 76 km of shoreline made lake wide control unattainable. Recognizing the partial success of the limited control effort and the documented expansion of Eurasian water milfoil in other parts of the lake, the Upper Saranac Foundation in partnership with the PSCAWI implemented a new management approach in 2004 (Kelting and Laxson 2010). The intensified approach to milfoil management called for the selective removal of the plant through hand harvesting of the entire littoral zone of the lake at least twice each summer for three years, supplemented by limited benthic matting of dense beds. The intensive management effort employed 32 divers during the period of 2004-2006. The effort was reduced by approximately 50% in 2007, and again in 2008 as the lake entered into the 'maintenance period' that it continues to operate in to this day. In an effort to monitor the success of the management strategy, the PSCAWI established 15 underwater monitoring sites across the lake in 2004, and one location in Fish Creek Pond in 2006.

In the summer of 2007, a watershed monitoring network was established with the goal of understanding long term watershed hydrology and chemical loading to the lake from its main tributaries. With support of the Upper Saranac Foundation the PSCAWI instrumented the five main tributaries of the lake, equating to 77% of the total watershed area. High resolution data on stream discharge, nutrient inputs, and road salt run off have been collected at intervals as short as 30 minutes over the last 10 years.

Photo 3. Milfoil removal on Upper Saranac Lake. Photo by Justin A. Levine, Adirondack Daily Enterprise.

Photo 4. The Upper Saranac Lake Environmental Monitoring Platform (EMP) moored at the deepest section of the south basin, May 26th 2017.

A significant advancement in our lake monitoring capabilities occurred in 2017 with the launch of the Upper Saranac Lake Environmental Monitoring Platform (EMP). The EMP is an autonomous in-lake monitoring station supported by funds from the National Fish and Wildlife Foundation and the Upper Saranac Foundation. The EMP collects information such as temperature, dissolved oxygen, pH, conductivity, turbidity, chlorophyll-a, and cyanobacterial pigment. Surface water data is collected every hour and a full profile from the surface to the bottom is collected every four hours. In addition to lake information, the EMP also contains a full meteorological station that gathers instantaneous data on air temperature, humidity, pressure, precipitation, wind speed, wind direction, and incoming solar radiation (Figure 1). Weather and lake data collected by the EMP are transmitted in near real time to Paul Smith's College and displayed on the AWI website

The EMP is an incredibly valuable tool for the Upper Saranac Lake community for the following reasons: (1) it provides high frequency data on the physical, chemical and biological characteristics of the lake as well as the meteorological drivers, thereby enhancing our understanding of the lake ecosystem in support of lake management; (2) it fosters collaboration with researchers and environmental professionals from around the world; and (3) it engages citizen involvement in lake management by providing real time information to the general public.

Although the EMP has only been collecting data for a short time, we have already increased our understanding of the lake system. High frequency meteorological observations have provided us with the site specific data needed to calculate essential hydrologic information. For example, from May 26th to November 9th 590 mm of precipitation fell onto the lake. A total of 364 mm (62%) of that precipitation was evaporated directly from the lake surface, with 204 mm (35%) evaporated through wind energy alone.

In this report we provide a synthesis of the historical and current water quality and aquatic plant monitoring data for Upper Saranac Lake and provide interpretations of the findings where possible. The report is designed to provide information for the informed lay audience as well as members of the scientific community.

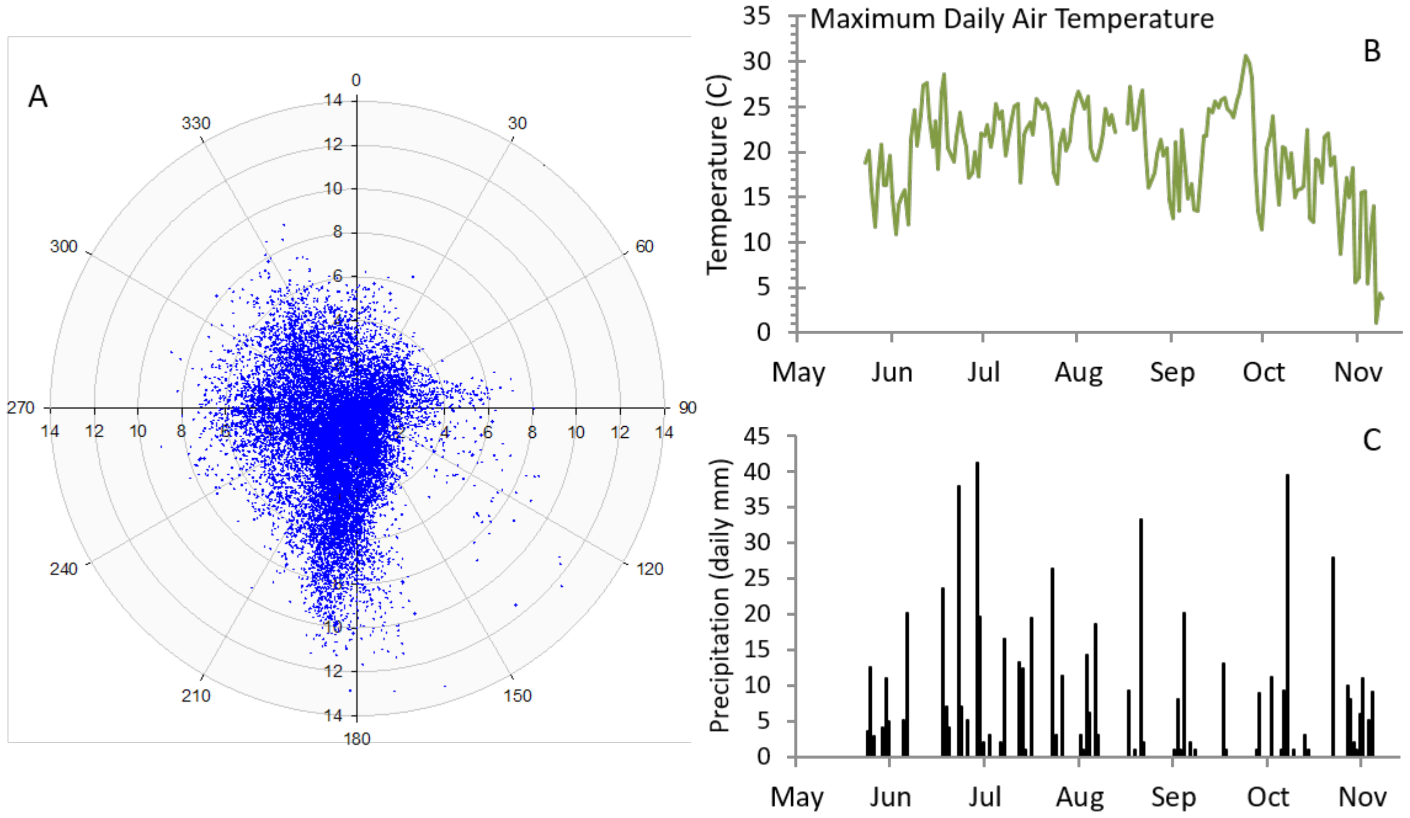

Figure 1. Meteorological data from the Upper Saranac Lake EMP, May 26th through November 9th 2017. (A) Wind rose depicting the wind speed (m/s) and direction (degrees) at 15 minute intervals. (B) Maximum daily air temperature. (C) Total daily precipitation.

Study Site

The lake and its watershed were described in detail in Martin et al. (1998). Upper Saranac Lake is a 1,912 hectare (4,725 ac) body of water located in Franklin County, NY at an elevation of 482 meters (1,581 ft) above sea level. The lake is 12.1 km (7.5 mi) long and 3.2 km (2.0 mi) wide at its widest point and has 76 km (47 mi) of shoreline The lake has three distinct basins (north, middle, and south) as a result of its depth characteristics and irregular shoreline (Figure 2). The maximum depth of the north basin is 17 meters (56 ft) and maximum depth of the south basin is 26 meters (85 ft) . The lake holds a total volume of approximately 150 million m^3 of water and has a flushing rate estimated at 0.9 times /year.

The total surface area of the Upper Saranac Lake watershed is 19,580 hectares (48,380 ac). The surficial geology of the watershed is dominated by glacial till (36%) and outwash (26%). An interesting feature of the Upper Saranac Lake watershed is that a major portion (21%) of the surface area consists of other lakes and ponds, particularly the Fish Creek watershed on the western side of the lake. Upper Saranac Lake has six inlet tributaries that run year round. Two of these tributaries, Mill Brook and Fish Creek are classified as major tributaries. Mill Brook is a second order stream that receives flow from the Lake Clear outlet and the Little Clear Pond before it empties into the north basin of the lake. Fish Creek drains a large part of the St. Regis Canoe Area, a region of dozens of waterways that are connected through surface and subsurface hydrology. Fish Creek enters into the middle basin of the lake, just north of the narrows. A number of other smaller tributaries flow into Upper Saranac, including Black Swamp, Brandy, Pork Bay, Cranberry and Indian Carry Brooks.

Limnology of Upper Saranac Lake

Objectives

This section of the report covers the limnological monitoring of Upper Saranac Lake, a program in its 28th consecutive year. The goal of this program is to provide reliable information to support lake management. The specific objectives are to assess the water quality and trophic indicators of the lake and assess the data for historical trends.

Methodology

Data collection

Field data for 2017 was collected from the R.V. *Clearwater* at the deepest sections of the north and south basins seven times starting on May 17th and ending on November 9th 2017. Transparency was observed using a 20 cm black and white Secchi disk from the shady side of the vessel. Temperature, dissolved oxygen (DO), conductivity, pH, chlorophyll-a and phycocyanin (cyanobacteria pigment) were determined every meter from the surface to the bottom with an YSI EXO 2 data logger. Surface water samples were collected using a 2 meter integrated tube sampler. The hypolimnetic water (bottom strata) was collected with a 1L Kemmerer bottle from approximately 1 meter off the bottom. 250 mL of the surface water was immediately passed through a 0.45µm cellulose membrane filter. The filter was collected, wrapped in foil and put on ice for chlorophyll-a analysis. All samples were kept on ice after collection and chemically preserved or stored at 4°C until analysis could be completed. Samples were analyzed for pH, conductivity, color, alkalinity, total phosphorus, nitrogen series, chlorophyll-a, DOC, CDOM, chloride, sodium, and calcium at the PSCAWI Environmental Research Lab following the analytical methods described in Table 1. All laboratory analyses included quality control (QC) measures such as check standards, blanks, matrix spikes, and duplicates that were assessed on an on-going basis.

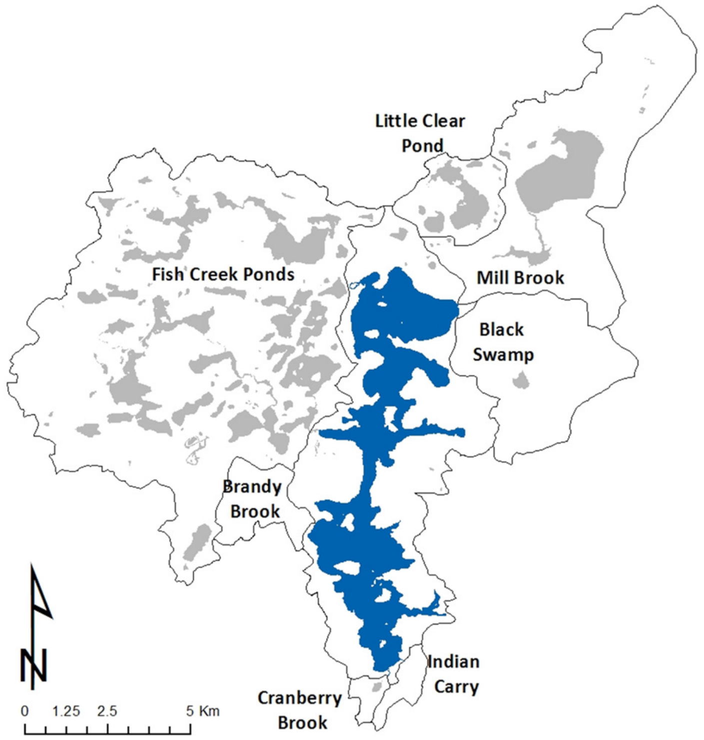

Figure 2. The Upper Saranac Lake watershed.

Data analysis

Field and laboratory data from 2017 were combined with historical limnological data from Upper Saranac Lake, which has been collected by various research groups in a similar manner since 1989 (reviewed by Kelting 2013). The majority of data was collected by the PSCAWI, followed by Cedar Eden Environmental and the NYS Citizen Science Lake Assessment Program. Historically, monitoring has occurred at the deepest portion of both the north and south basin, one to three times per month typically during the May to October interval.

Results for 2017 were tabulated and time series charts were constructed from the annual average value for each indicator. Trend analysis on the data from 1993 to present was conducted using Kendall's non-parametric rank correlation to test the hypothesis "there is no relationship between the indicator and time". Simple linear trend lines were fit to data with statistically significant ($P<0.05$) trends and displayed on the corresponding chart. Thus, absence of a line means there was no statistically significant trend in the indicator since 1993. Average annual values for secchi disk transparency, total phosphorus, and chlorophyll-a in the lake were used to calculate Carlson's Trophic Status Index, (TSI), a commonly used quantitative index for classifying lakes based on trophic status (Carlson 1977). Typically TSI values are between 0 and 100. Lakes with TSI values less than 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.

Table 1. Analytical methods used at the Paul Smith's College Adirondack Watershed Institute.

Analyte	Method Description	Reference
Laboratory pH	Mettler Toledo standard pH electrode	APHA
Spec. Conductivity	Conductance at 25°C via conductivity cell	APHA 2510 B
Apparent Color	Single wavelength method with PtCO standards	APHA 10200 H
Chlorophyll-a	In-vitro fluorescence, non-acidification optical kit	EPA 445
DOC	Oxidative infrared analysis	EPA 415.3
Total Phosphorus	Acid-persulfate digestion, ascorbic acid reduction	APHA 4500 - P H
Total Nitrogen	Oxidative combustion chemiluminescence	APHA 4500 - N
Nitrate + Nitrite - N	Automated cadmium reduction	APHA4500 - NO_3 I
Ammonium - N	Gas diffusion / pH indicator	Lachat: 10-107-06
Alkalinity	Automated methyl orange method	EPA 301.2
Chloride and Sulfate	Automated ion chromatography	EPA 300.0
Metals	Inductively coupled optical emission spectrophotometry	EPA 200.7

Results and Interpretation

Temperature and Thermal Stratification

Vertical mixing of a lake is driven by the relationship between the water density and temperature. Simply put, as the water warms it becomes less dense and floats on top of the colder and denser water. When the ice melts from the lake in the spring the water column is all the same temperature from top to bottom, a condition referred to as isothermal (Greek: *iso* = equal, *thermo* = heat). When a lake is isothermal it's also the same density throughout, allowing the water to vertically mix without impediment. Limnologists refer to this period of complete mixing as spring turnover.

As spring progresses, energy from the sun heats the surface water faster than the heat can be distributed through the water column. The thermal resistance to mixing increases between the warm surface water and the colder and denser bottom water. If the lake is deep enough, the water column will become separated into three distinct strata. The epilimnion is the upper stratum that is uniformly warm and freely mixes with itself. The hypolimnion is the bottom stratum that is uniformly cold and dense. 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 autumn, the epilimnion becomes cooler and deeper. Eventually the lake is once again isothermal and freely mixes, a period referred to as fall turnover (Figure 3).

Data from the EMP illustrates the heat budget of the lake during the ice-free period of 2017 (Figure 4). Cloudy skies and cool temperatures experienced in late May through Early June delayed the heating of the surface water. Maximum water temperature was observed on the afternoon of August 1st, at 24.5°C. Both basins of the lake were strongly stratified thorough the summer months, with a maximum epilimnion depth of 6.5 meters (Figure 5). A second period of surface warming was in autumn, when water temperature climbed to 23.2 °C. As autumn advanced, the low angle of the sun and shorter day length created in a heat negative budget to the lake; this resulted in steady cooling of the surface water through the month of October (Figures 4 and 5).

Dissolved Oxygen

Dissolved oxygen has been described as the most funda-

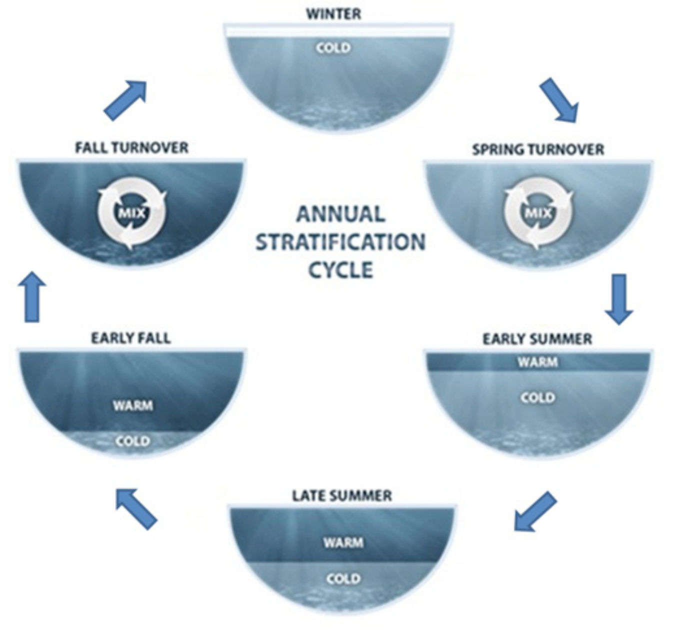

Figure 3. The typical stratification cycle of an Adirondack lake.

mental 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, 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). A second important impact of bottom water hypoxia is that it results in internal loading of phosphorus. Lack of oxygen in the hypolimnion influences the solubility of phosphorus and allows the release of dissolved reactive phosphorus from the lake sediments. During fall turnover the phosphorus can then get distributed through the entire water column (Wetzel 2001).

Dissolved oxygen data for Upper Saranac Lake is depicted in Figure 5. During the 2017 season the lake exhibited its typical clinograde oxygen profile, where the dissolved oxygen is elevated in the epilimnion and decreases with depth. In the north basin the bottom meter of water became anoxic (DO<0.5 mg/L) in late June. By September, the bottom 5 meters of water were essentially devoid of oxygen. The pattern was similar in the south basin, but the larger volume of the hypolimnion results in slower oxygen depletion. The bottom two meters of the south basin became hypoxic (DO < 2.0 mg/L) in mid-September and grew to include the bottom 9 meters of the deep hole in November. By the end of the sampling season the bottom three meters were devoid of oxygen (Figure 5). Data from the EMP provides us with a greater understanding of oxygen depletion in the south basin. We found that the oxygen content in the hypolimnion decreased in a linear fashion from May 23rd to October 29th, with an overall areal depletion rate of 0.25 g/m^2/day (Figure 6). This oxygen depletion rate is similar to the values estimated by Laxson et al. (2017) over the past 12 years (range 0.18 – 0.29 g/m^2/day).

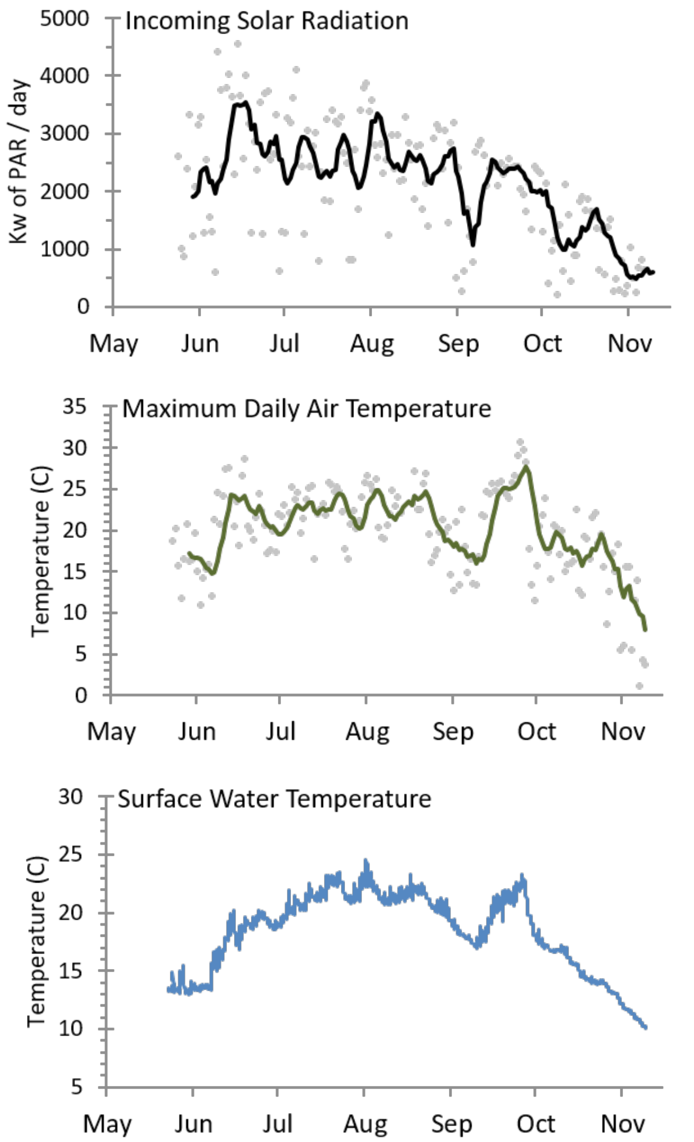

Figure 4. Incoming solar radiation, air temperature, and surface water temperature at the EMP on Upper Saranac Lake, May 26th through November 9th 2017. For solar radiation and air temperature, grey points represent daily values while lines denote 7-day moving average. Data for water temperature is taken hourly.

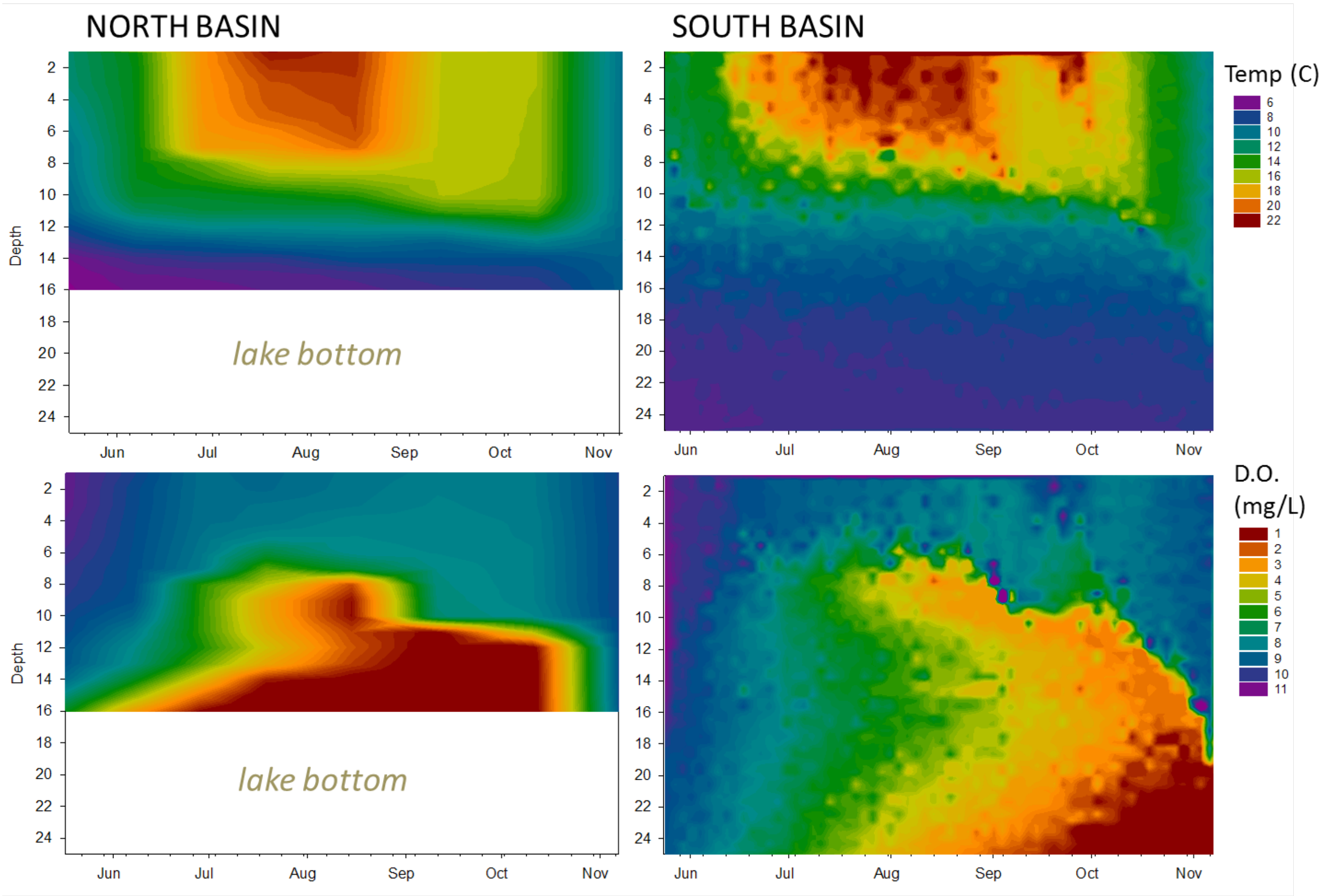

Figure 5. Temperature (top rows) and dissolved oxygen (bottom rows) of the north (left column) and south (right column) of Upper Saranac Lake during the 2017 field season. Data from the north basin is based on eight field visits while the data from the south basin is from the EMP and represents daily measurements taken at noon.

Annual lake monitoring has revealed that the oxygen depletion in the hypolimnion of the lake has shown encouraging signs of improvement. Historically, the zone of oxygen depletion was greatest in the early 1990's. In the summer of 1990 the greatest extent of the hypoxic zone covered a region of approximately 6.6 km^2. The size of this zone increased in 1991 to an area of approximately 10 km^2. After 1991 the hypoxic zone was substantially reduced, and typically ranged between 2 and 4 km^2. The vast majority of the reduction in hypoxic area has been observed in the south basin, were oxygen the depletion rate has slowed in a fairly progressive fashion. No apparent change has been observed in the anoxic pattern observed in the north basin (Laxson et al. 2017).

It is quite possible that hypolimnetic oxygen depletion is a natural occurrence in the north basin of Upper Saranac. During thermal stratification the thermocline serves as a barrier to vertical oxygen transport from the atmosphere; as a result the hypolimnion is a closed oxygen system, which means it only has as much oxygen as moved in during the spring turnover. When the volume of the hypolimnion is small relative to the sediment surface area, oxygen depletion will occur regardless of trophic condition. For example, Mathias and Barica (1980) examined oxygen depletion in 70 Canadian lakes under the ice and found that the ratio of the lakes sediment surface area to hypolimnion volume (SSA:HV) accounted for 72% of the variation in oxygen depletion rates in eutrophic lakes, and 78% of the variation in oligotrophic lakes. We believe that

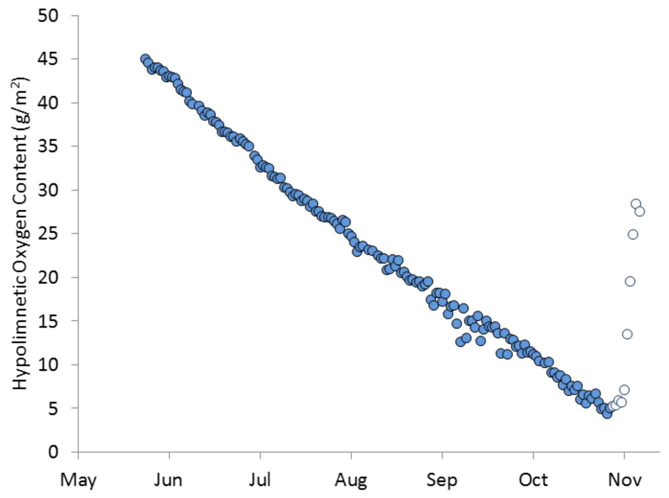

Figure 6. Oxygen content under each square meter of the hypolimnion during the 2017. Each point denotes the total content of oxygen during the noon hour of each day. Solid circles are from the period of thermal stratification, open circles are from the period of stratification break-down in autumn.

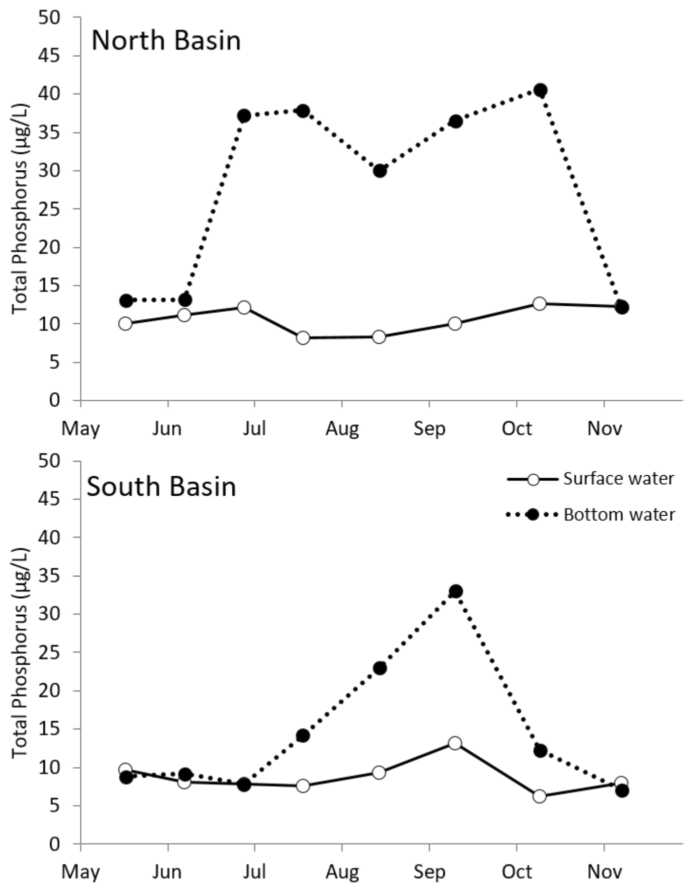

Figure 7. Total phosphorus concentration in the bottom water and surface water of Upper Saranac Lake during the 2017 field season.

the SA:HV plays the controlling role in oxygen depletion in the north basin of Upper Saranac; however, long term nutrient pollution would certainly exasperate the situation.

Phosphorus

Phosphorus is of major importance to the 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. Phosphorus is typically the limiting nutrient in aquatic systems and the addition of extra phosphorus allows production to increase greatly because all other essential elements are typically available in excess (Schindler 1974, Wetzel 2001); therefore, phosphorus is 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 concentration in the surface water of the north basin averaged 11 µg/L in 2017, with the highest concentration of 13 µg/L detected on May 20th. In the bottom water average total phosphorus concentration was much higher at 28 µg/L, with the greatest concentration of 41 µg/L observed on October 11th (Table 2). The elevated phosphorus concentration in the bottom water is correlated with the development of anoxic conditions. Depleted oxygen creates a reducing environment that essentially allows phosphate to freely move out of the lake sediments (Figure 7). Historically, the highest concentration of total phosphorus in the surface water occurred in 1990, with a summer average of 44 µg/L. Concentration was substantially lower in all other years, with a slight yet significant downward trend in the surface water concentration since 1993 (P = 0.004, tau = -0.43; Figure 8). The bottom water total phosphorus concentration has remained elevated throughout the monitoring period, and has not exhibited a significant positive or negative trend (P=0.230, Figure 9).

In the surface water of the south basin the total phosphorus concentration averaged 8.7 µg/L in 2017, with the highest concentration of 13.2 µg/L a detected on September

Table 2. Water quality indicators for the surface and bottom water of the north basin of Upper Saranac Lake during the 2017 field season. BDL denotes values below laboratory detection, ± denotes an estimated value.

North Basin	2017 Data								
Water Quality Indicator	5/17	6/7	6/28	7/19	8/15	9/11	10/11	11/9	Avg.
				Surface water (0-2 meter)					
Transparency (m)	2.2	2.6	3.5	2.5	3.0	2.5	2.7	2.1	2.6
Chlorophyll-a (µg/L)	9.5	7.8	8.7	5.5	5.4	1.2	6.8	5.4	6.3
Total Phosphorus (µg/L)	10	11	12	8	8	10	13	12	11
Total Nitrogen (mg/L)	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Ammonium-N (µg/L)	14.6	5.3	5.7	21.7	7.8	13.0	18.8	28.6	14.4
Nitrate-N (µg/L)	35.1	BDL	BDL	23.6	BDL	BDL	BDL	16.7	±9.4
Apparent Color (Pt-Co)	40.7	31.1	37.5	37.5	43.9	43.9	21.4	50.4	38.3
DOC (mg/L)	4.5	4.6	4.4		5.2		5.0	5.0	4.8
pH	6.8	7.8	7.1	7.7	7.1	7.1	7.4	7.3	7.3
Alkalinity (mg/L)	11.9	11.7	11.1	11.1	12.2	13.0	14.8	12.5	12.3
Conductivity (µS/cm@25°)	51.7	51.9	51.4	46.1	52.0	48.6	52.3	51.8	50.7
Chloride (mg/L)	7.9	8.2	8.0	7.4	7.7	8.3	8.3	8.5	8.1
Sodium (mg/L)	4.1	4.4	4.2	3.7	4.5	4.1	4.1	3.9	4.1
Ca (mg/L)	3.6	3.8	3.7	3.5	4.2	4.2	4.2	3.7	3.9
				Bottom water (~ 16 meter depth)					
Dissolved Oxygen (mg/L)	7.9	6.0	0.4	0.3	0.0	0.0	0.2	2.0	2.1
Total Phosphorus (µg/L)	13	13	37	38	30	37	41	12	28
Total Nitrogen (mg/L)	0.3	0.3	0.4	0.4	0.4	0.6	0.8	0.2	0.4
Ammonium-N (µg/L)	42.6	35.9	122.0	170.0	124.0	400.0	648.0	27.6	196.3
Nitrate-N (µg/L)	87.5	63.3	94.2	148.0	67.8	BDL	BDL	15.9	±60
Apparent Color (Pt-Co)	40.7	40.1	98.6	182.3	182.3	137.2	117.9	47.2	105.8
DOC (mg/L)	4.3	4.4	4.3		5.0		5.1	4.9	4.7
pH	6.6	6.7	6.3	6.4	6.4	6.6	7.0	7.2	6.6
Alkalinity (mg/L)	13.3	12.3	9.8	14.6	14.6	19.3	22.6	12.0	14.8
Conductivity (µS/cm@25°)	57.7	57.1	60.4	60.7	61.1	74.1	88.0	53.1	64.0
Chloride (mg/L)	8.8	8.6	11.4	9.0	9.0	8.8	9.4	8.5	9.2
Sodium (mg/L)	4.5	4.6	4.7	4.5	5.0	4.3	4.6	3.9	4.5
Ca (mg/L)	3.8	4.0	4.2	4.1	4.9	4.6	5.6	3.7	4.4

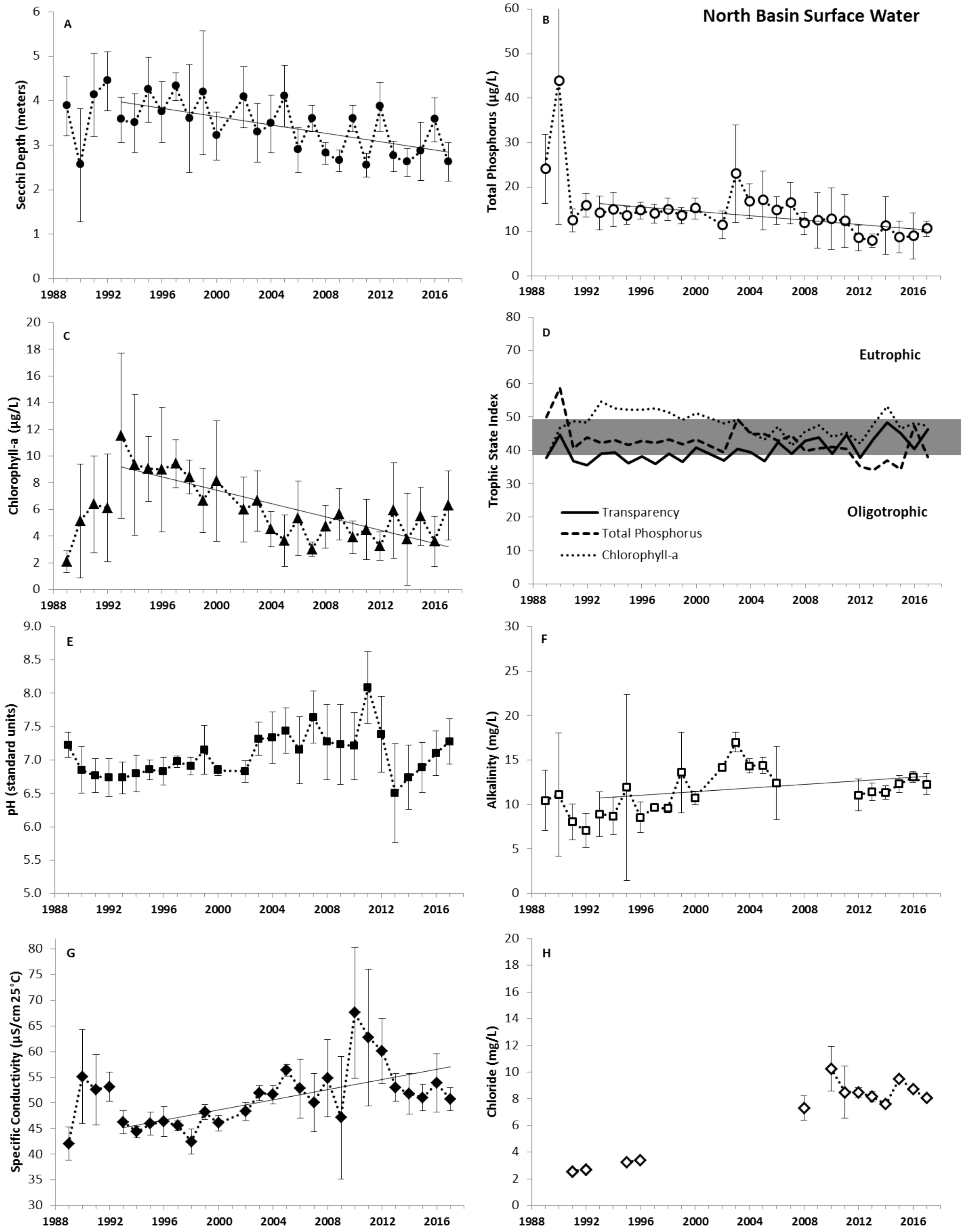

Figure 8. Time series of the average annual water quality and trophic indicators for the surface water of the north basin of Upper Saranac Lake 1989-2017. Vertical bars represent one standard deviation of the mean. Significant trends (P < 0.05) since 1993 are indicated with a trend line.

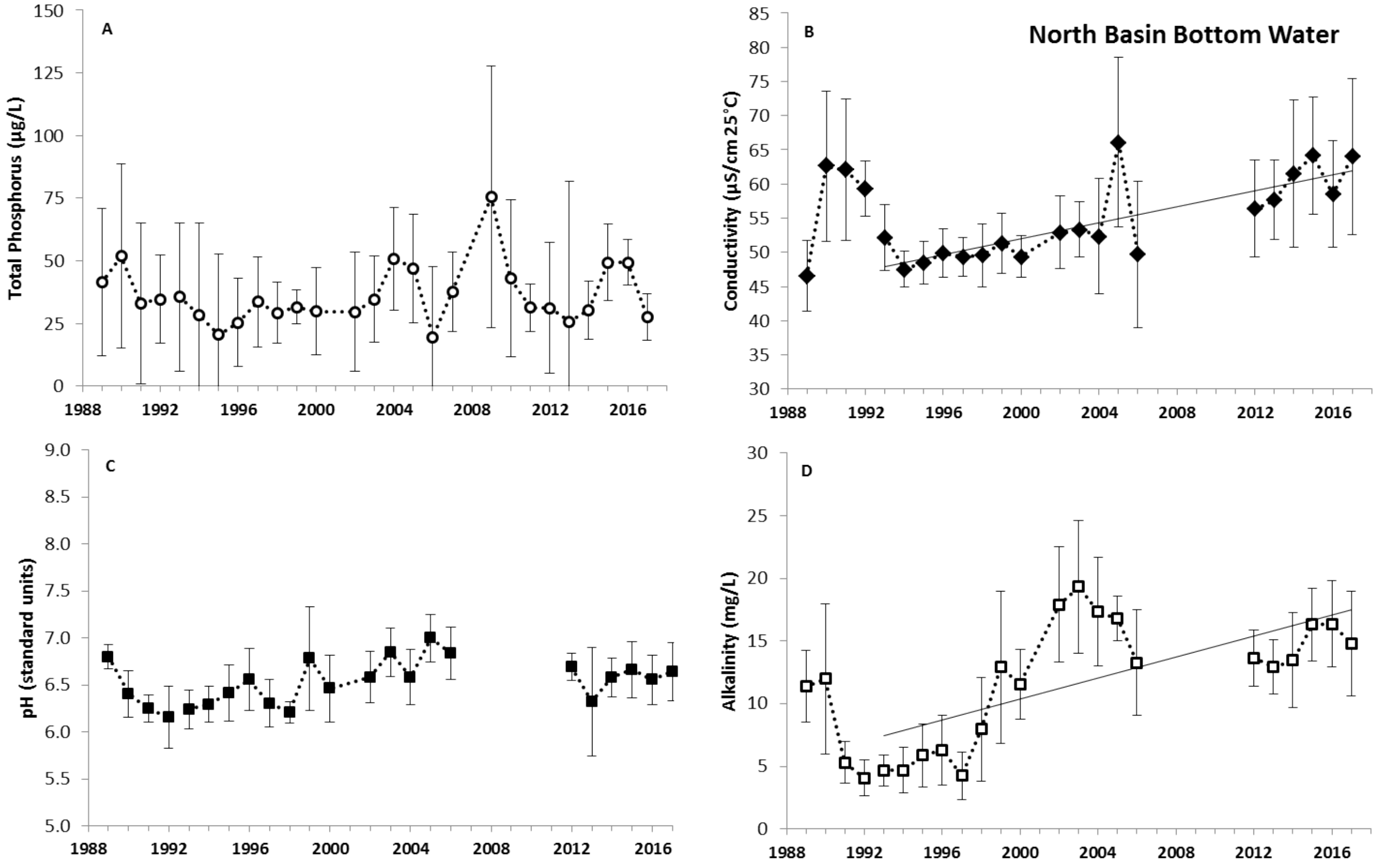

Figure 9. Time series of the average annual water quality and trophic indicators for the bottom water of the north basin of Upper Saranac Lake 1989-2017 Vertical bars represent one standard deviation of the mean. Significant trends (P < 0.05) since 1993 are indicated with a trend line.

Table 3. Water quality indicators for the surface and bottom water of the south basin of Upper Saranac Lake during the 2017 field season. BDL denotes values below laboratory detection, ± denotes an estimated value.

South Basin Water Quality Indicator	2017 Data								
	5/17	6/7	6/28	7/19	8/15	9/11	10/11	11/9	Avg.
				Surface water (0-2 meter)					
Transparency (m)	3.0	3.5	3.7	2.9	3.2	2.9	3.0	2.6	3.1
Chlorophyll-a (µg/L)	7.0	4.0	8.4	4.0	7.6	7.8	5.9	4.0	6.1
Total Phosphorus (µg/L)	9.7	8.1	7.9	7.6	9.3	13.2	6.2	7.9	8.7
Total Nitrogen (mg/L)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Ammonium-N (µg/L)	BDL	BDL	18.8	18.9	7.7	10.5	4.3	14.7	9.4
Nitrate-N (µg/L)	6.0	BDL	BDL	22.7	BDL	BDL	BDL	31.2	±7.5
Apparent Color (Pt-Co)	24.6	24.7	24.6	31.1	37.5	37.5	15.0	43.9	29.9
DOC (mg/L)	3.9	4.0	4.0		4.6		4.5	4.1	4.2
pH	6.7	7.0	7.1	7.3	6.9	6.9	7.2	7.2	7.0
Alkalinity (mg/L)	11.9	11.8	11.2	11.4	0.5	12.2	14.1	11.1	10.5
Conductivity (µS/cm@25°)	50.8	51.0	50.6	48.6	48.6	51.1	52.0	52.9	50.7
Chloride (mg/L)	7.8	7.9	8.0	7.6	8.2	7.9	8.2	8.0	7.9
Sodium (mg/L)	4.0	4.1	4.1	3.9	4.8	4.1	3.8	3.9	4.1
Ca (mg/L)	3.6	3.7	3.6	3.5	4.5	4.1	3.7	3.6	3.8
				Bottom water (~ 25 meter depth)					
Dissolved Oxygen (mg/L)	9.0	8.0	6.8	4.8	2.9	1.7	0.4	0.4	4.3
Total Phosphorus (µg/L)	8.8	9.2	7.8	14.2	23.0	33.0	12.3	7.1	14.4
Total Nitrogen (mg/L)	0.3	0.3	0.2	0.3	0.3	0.4	0.4	0.4	0.3
Ammonium-N (µg/L)	15.3	16.1	26.9	26.2	18.1	71.7	86.2	54.4	39.4
Nitrate-N (µg/L)	34.1	63.0	84.3	190.0	154.0	185.0	210.0	211.0	141.4
Apparent Color (Pt-Co)	24.6	24.6	21.4	24.6	47.2	43.9	24.6	43.9	31.9
DOC (mg/L)	3.5	3.6	3.5		3.5		4.1	3.5	3.6
pH	6.7	6.9	6.9	6.5	6.4	6.6	6.9	6.4	6.7
Alkalinity (mg/L)	13.0	12.3	12.2	13.2	14.8	18.0	15.8	14.7	14.2
Conductivity (µS/cm@25°)	56.1	56.0	56.1	54.3	53.3	62.2	65.2	57.5	57.6
Chloride (mg/L)	8.1	8.2	8.3	8.3	8.4	8.1	8.4	7.9	8.2
Sodium (mg/L)	4.2	4.3	4.0	4.1	4.9	4.3	4.0	3.8	4.2
Ca (mg/L)	3.6	3.8	3.6	3.8	4.8	4.5	4.2	4.0	4.0

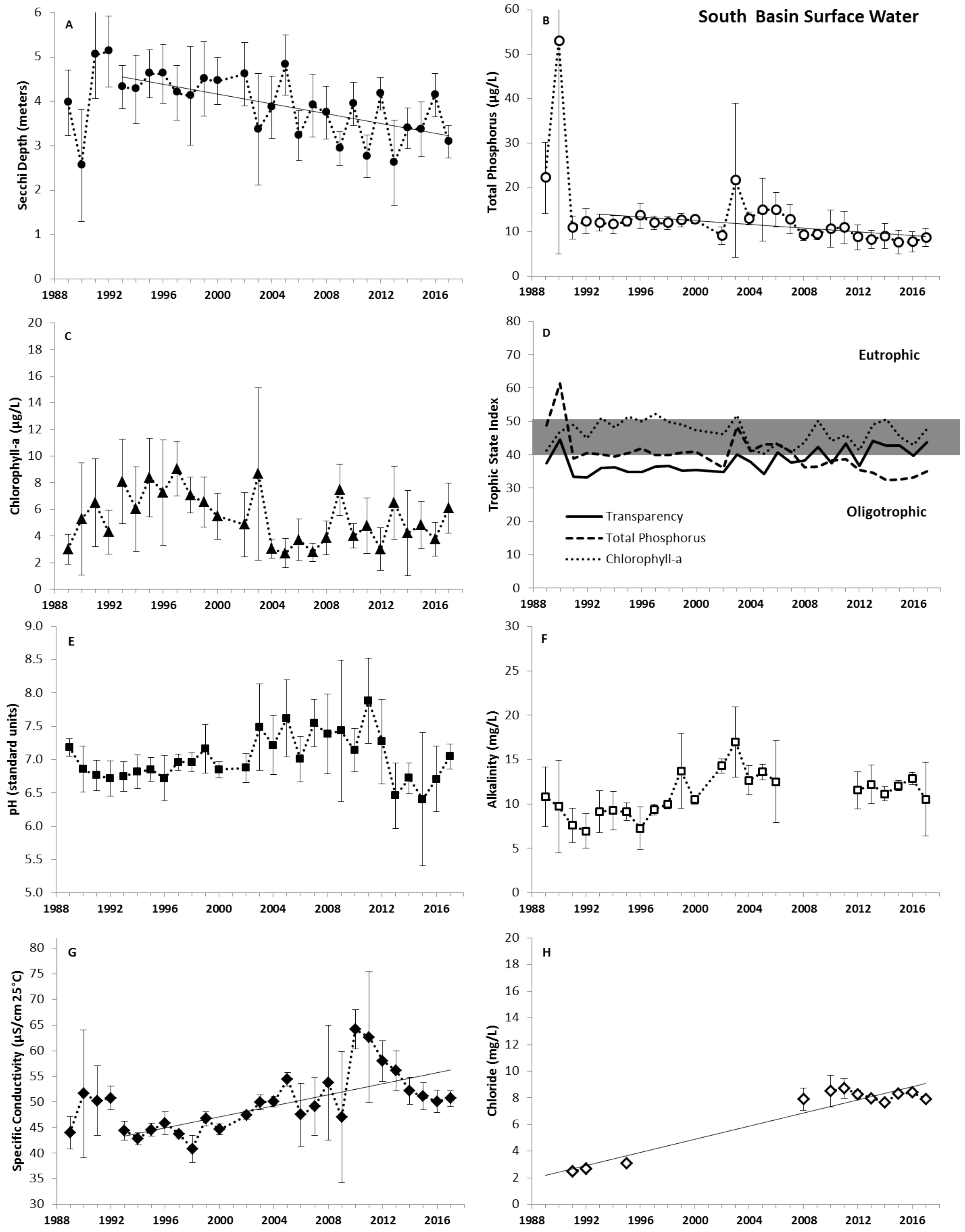

Figure 10. Time series of the average annual water quality and trophic indicators for the bottom water of the south basin of Upper Saranac Lake 1989-2017 Vertical bars represent one standard deviation of the mean. Significant trends (P < 0.05) since 1993 are indicated with a trend line.

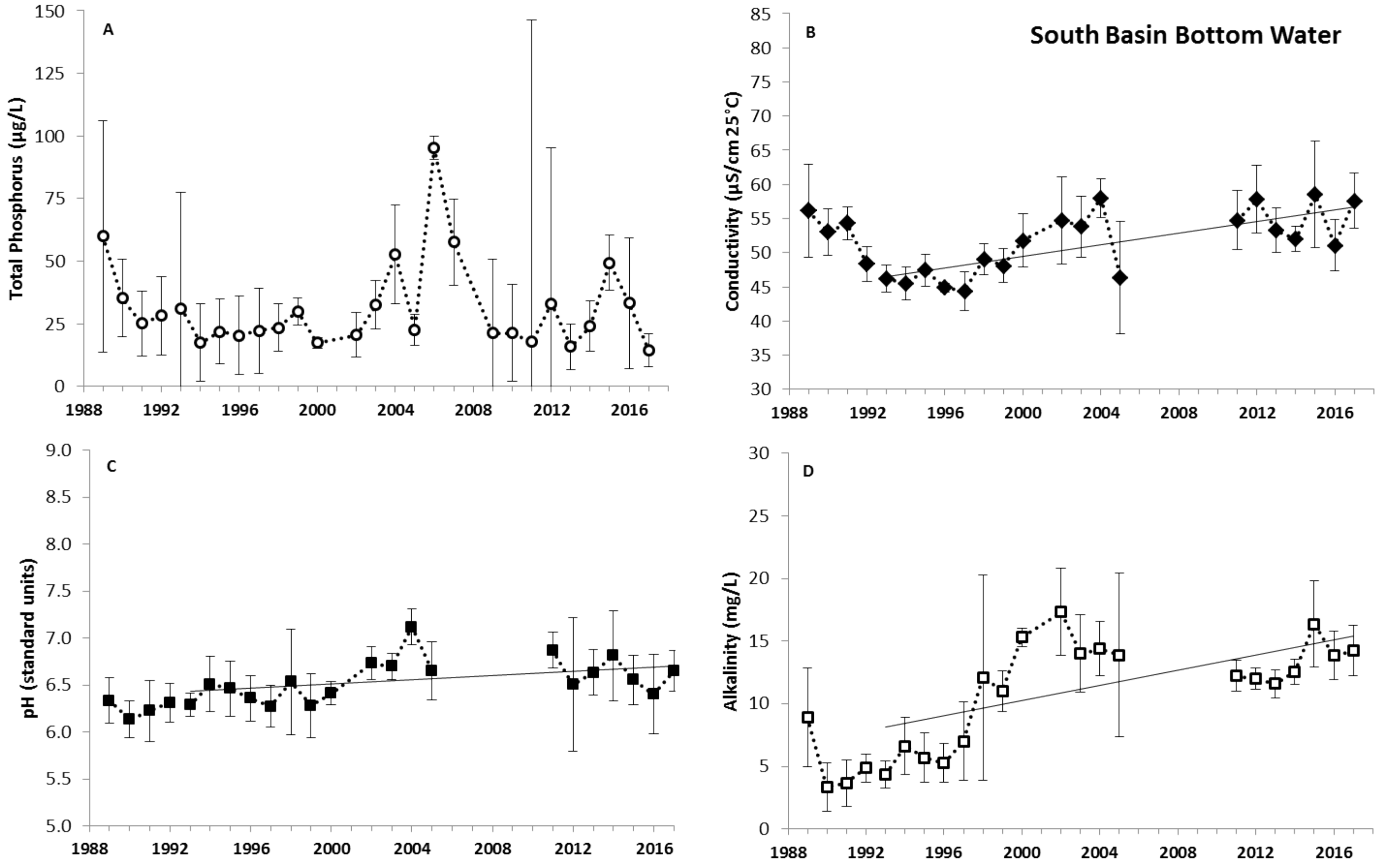

Figure 11. Time series of the average annual water quality and trophic indicators for the bottom water of the south basin of Upper Saranac Lake 1989-2017 Vertical bars represent one standard deviation of the mean. Significant trends (P < 0.05) since 1993 are indicated with a trend line.

11th. Concentration was also elevated in the bottom water of the south basin, reaching a maximum of 33 µg/L (Table 3). Similar to the north basin, the highest average phosphorus concentration observed over the monitoring period occurred in 1990, with a summer average of 53 µg/L. Concentration was reduced in subsequent years, with a significant downward trend in the surface water concentration since 1993 (P = 0.007, tau = -0.45; Figure 10). Despite the downward trend in surface water phosphorus, hypolimnetic phosphorus concentrations in the south basin have been elevated and highly variable, with no significant positive or negative trend (Figure 11; P = 0.95).

Overall, the amount of phosphorus in the surface water has decreased in both basins over the last 24 years, and is currently within the target concentration of 12 mg/L outlined in the Upper Saranac Lake Management Plan (Martin 1998). The observed decrease in phosphorus concentration is due to numerous improvements made on both point and non-point pollution sources. Perhaps the most important of these improvements was the permit modification and implementation of best management practices at the Adirondack Fish Culture Station in the 1990's. Phosphorus discharge from the hatchery has been greatly reduced over time, and the facility currently operates well below its permitted discharge rate of 0.45 lbs/day. Despite the reduced loading from the watershed, the phosphorus loading from the sediments of the lake continue to be an important component of the nutrients dynamics in the lake.

Nitrogen

Nitrogen is an essential element that can be the limiting nutrient for algal productivity in lakes, but it is generally the second most limiting nutrient after phosphorus. Nitrogen does not typically receive the attention that phosphorus does because it is more abundant and has a variety of sources in the watershed. Nitrogen exists in many forms in a lake, including inorganic and organic molecules. The inorganic forms include nitrogen gas (N_2), nitrate (NO_3), nitrite (NO_2), and ammonium (NH^{+4}). Nitrogen gas is the most abundant form of nitrogen; it makes up 78% of the earth's atmosphere and readily dissolves into water. This gaseous form of nitrogen is unusable by the vast majority of organisms, only some species of cyanobacteria can "fix" this form of nitrogen into a form they can utilize, giving cyanobacteria a competitive edge in environments with limited useable nitrogen. Plants and algae can assimilate the other forms of inorganic nitrogen. Nitrate, nitrite, and ammonium enter the lake though precipitation, surface runoff, and ground water sources and are continually cycled through bacterial decomposition of organic matter. Inorganic nitrogen concentration in the surface water of lakes is typically quite low, as it is rapidly assimilated by phytoplankton. Concentrations may become elevated due to anthropogenic sources such as waste water discharge, agricultural runoff, and urban development. Organic nitrogen represents the stores of nitrogen that are locked up in organic molecules, such as proteins, amino acids, urea, and living and decomposing organisms. Organic nitrogen is not readily available for algal productivity until bacteria decompose the organic material and excrete useable forms of inorganic nitrogen. Total nitrogen is a measure of all of the non-gaseous inorganic and organic forms of nitrogen in the water.

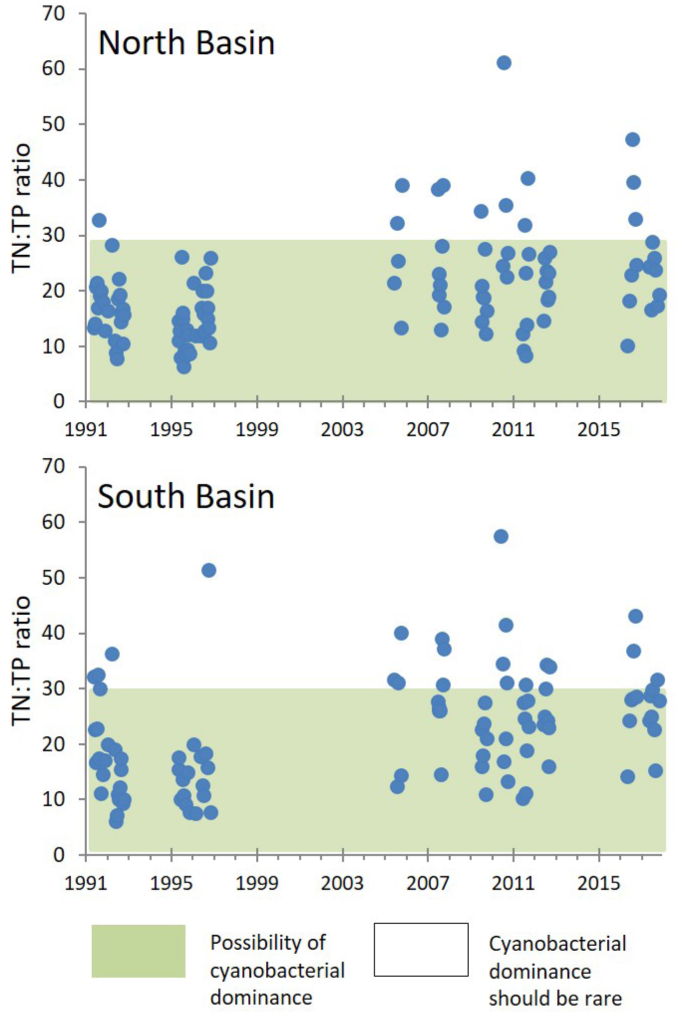

Figure 12 Mass ratio of total nitrogen to total phosphorus in the surface water of Upper Saranac Lake during the sampling events of 1990-2017. The green boxes represents the TN:TP ratio where cyanobacteria presence can be expected (Smith 1983).

As the two elements most likely to limit productivity in lakes, the mass ratio of total nitrogen to total phosphorus (TN:TP) is frequently used as a metric to determine which element limits productivity and which algal groups are likely to dominate. It is generally believed that TN:TP greater than 50 indicates that phosphorus is the limiting nutrient for productivity, while a TN:TP less than 20 indicate nitrogen limitation.

TN:TP between 20 and 50 represent a gray area, where either element may be limiting productivity (Guildford and Hecky 2000). Because many species of cyanobacteria can utilize atmospheric nitrogen, these species tend to dominate in nitrogen limited systems. The critical TN:TP ratio at which cyanobacteria tend to dominate is open to debate, with research suggesting ratios as low as 5 to as high as 40 (Schindler 1977; Bulgakov and Levich 1999). For example, Smith (1983) found that cyanobacteria tended to be rare in the water column when the TN: TP mass ratio exceeded 29:1 and have the potential to dominate the planktonic biomass at ratios below 22:1. It is important to recognize that cyanobacteria occurrence is not simply dependent on TN:TP ratios, several other variables such as temperature, light, and availability of inorganic carbon and trace elements are all important factors (Dokulil and Teubner 2000).

The mass ratio of total nitrogen to total phosphorus in the surface water of Upper Saranac Lake ranged from 16.6 to 28.9 in the north basin and 15.2 – 31.7 in the south basin, indicating that the lake is often nitrogen limited. Between 1990 and 2017, the mass ratio of TN:TP was above the threshold of 29 on only 12% of the 109 observation in the north basin and 23% of the 97 observations made in the south basin. These results indicate that we should not expect cyanobacteria to be rare in the lake; rather, we should expect them to occasionally dominate the plankton (Figure 12). Heavy lake wide cyanobacteria blooms have been rare since the early 1990's, but small blooms are fairly common in the spring and early fall.

Algal Pigments: Chlorophyll-a and Phycocyanin

Chlorophyll-a is the primary photosynthetic pigment found in all freshwater species of algae and cyanobacteria. Studying actual algal productivity in a lake is a difficult and expensive undertaking. A measurement of chlorophyll-a is relatively simple and inexpensive, and can provide 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 the interaction of nutrient availability, light, water temperature, and grazing so there can be considerable variation in chlorophyll concentrations throughout the year depending on which of these factors is limiting growth at a particular time. Typically, 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). Chlorophyll-a concentration is analyzed on water samples in the lab, while relative distribution is analyzed in the field with the YSI EXO 2 sonde.

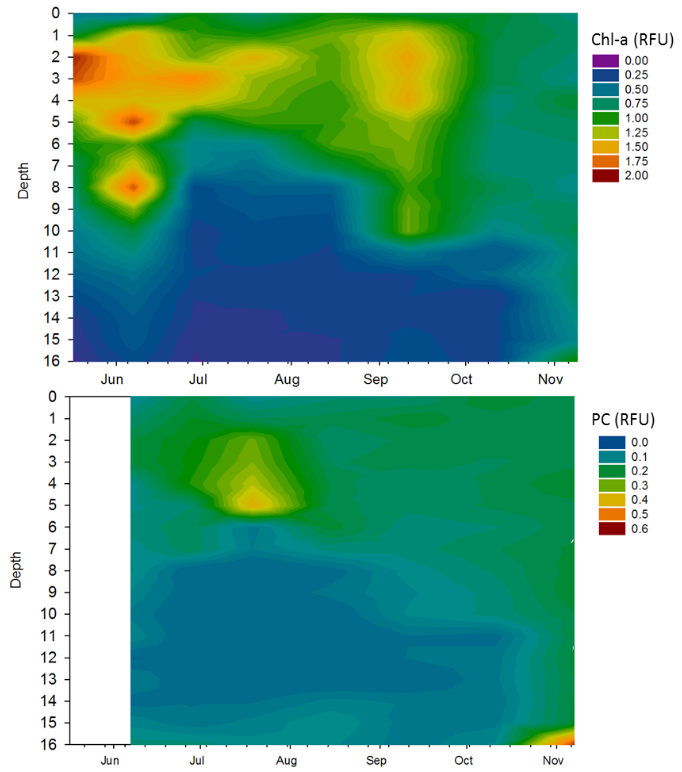

Figure 13. Profiles of the concentration of chlorophyll-a (top panel) and the cyanobacterial pigment phycocyanin (bottom panel) in the north basin of Upper Saranac Lake during the 2017 field season. Concentrations are displayed as relative fluorescence units (RFU).

Phycocyanin is an accessory photosynthetic pigment found only in cyanobacteria, thus its presence serves as a marker for cyanobacteria presence. Research over the past decade has demonstrated a strong correlation between phycocyanin concentration and cyanobacterial biomass.

Chlorophyll-a concentration in the surface water of the north basin averaged 6.3 μg/L in 2017, and ranged from 1.2 to 9.5 μg/L (Table 2). We detected a significant downward trend in the annual average chlorophyll-a concentration since 1993, decreasing at a rate of approximately 0.25 μg/L/year (Figure 8; $P < 0.001$, tau = -0.6). Profile measurements of chlorophyll-a taken in the field reveal that the phytoplankton population of the north basin was typically centered between the depths of one and four meters, and was most abundant from mid-May to early July (Figure 13). We detected phycocyanin throughout the water of the north basin, but at relatively low concentrations. The greatest density of cyanobacterial pigment was encountered directly below the epilimnion, at a depth of 5 meters on July 19th. (Figure 13). Many species of cyanobacteria are adapted to photosynthesis in very low light condition, so it is not uncommon to find the populations centered deeper than common eukaryotic algae. An elevated reading was recorded right off the bottom on November 9th, however, we believe this is bottom interference.

Chlorophyll-a concentration was similar in the south basin where it averaged 6.1 μg/L and ranged from 4.0 to 7.8 μg/L (Table 3). Historically, chlorophyll concentration in the south basin have generally decreased since the early 1990's, but there is no statistical trend in this observation (Figure 10; $P = 0.19$). Profile measurements taken by the EMP provide fine scale resolution of the spatial and temporal distribution of algal pigments in the south basin. Maximum planktonic abundance was typically encountered between a depth of three and 6 meters, and was most prevalent in late May, and again in the beginning of July. Phycocyanin was also detected at low levels throughout most of the water column in the south basin, with the greatest concentration encountered in late June and early July at depths of four and six meters respectively (Figure 14).

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 can also be influenced by the amount of dissolved organic material in the water. Dissolved organic matter rapidly attenuates light, resulting in lower transparencies.

Secchi disk transparency in the north basin ranged from 2.2 to 3.5 meters and averaged 2.6 meters in 2017 (Table 2). In the south basin transparency was slightly higher and ranged from 2.6 to 3.7 meters with an average of 3.1 meters (Table 3) The transparency of the lake has exhibited a significant downward trend since 1993 in both the north basin (Figure 8; $P = 0.004$, tau = -0.42) and the south basin (Figure 10; $P = 0.005$, tau = -0.38).

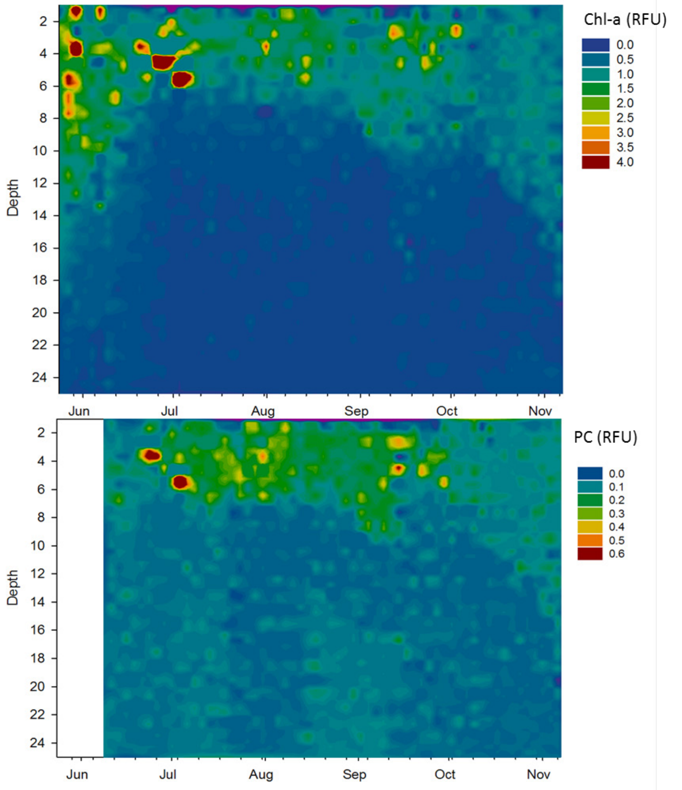

Figure 14. Profiles of the concentration of chlorophyll-a (top panel) and the cyanobacterial pigment phycocyanin (bottom panel) in the south basin of Upper Saranac Lake during the 2017 field season. Data is from the EMP and represents daily measurments at noon. Concentrations are displayed as relative fluorescence units (RFU).

With a decrease in phosphorus and algal biomass in the lake surface, we would expect to see an overall increase in water transparency; however, this has not been the case in Upper Saranac Lake. Both lake basins have seen a significant reduction in water transparency since the early 1990's, as a rate of approximately 4-6 cm/year. Reductions in water transparency appear to be a regional phenomenon. A recent analysis of historical transparency data from 125 Adirondack lakes reveals that 22% of the lakes have exhibited a statistical reduction in transparency (Kelting and Laxson 2015). Current research supports that decreasing transparencies in lakes is related to increased concentrations of dissolved organic carbon (DOC) (Williamson et al 2014. Montieth et al 2007). DOC has a strong ability to absorb light, thus when a lake becomes enriched with DOC, the transparency of the lake decreases. The primary source of DOC is decomposition in the terrestrial landscape. Warmer and wetter climatic patterns may be increasing the decomposition rate and flushing a greater pool of DOC to receiving lakes (Tranvik et al. 2009, Curtis and Schindler 1997). Increased DOC may also be a signal of recovery from acid deposition. As lakes acidify they tend to exhibit an increase in transparency due to a decrease in DOC (Yan 1983; Schindler et al. 1996), so it is possible that acidification recovery may result in an opposite effect. Unfortunately long term data on DOC does not exist for Upper

Saranac Lake, and is scarce for many lakes in the region.

Trophic State

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 and development within a watershed have the potential to increase the rate of nutrient supply into the lake and thereby accelerate lake productivity, a process known as cultural eutrophication. Most lakes in the Adirondacks can be assigned into one of three trophic classes; oligotrophic, mesotrophic, or eutrophic based on their overall level of biological productivity.

Oligotrophic - From the Greek words *oligo*, meaning few and *trophi*, meaning nourishment; oligotrophic lakes have low biological productivity due to relatively low nutrient content. 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 (trout and salmon).

Eutrophic - From the Greek words *Eu*, meaning good. Eutrophic lakes have high biological productivity due to 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 (the 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

Mesotrophic - From the Greek words *Meso*, is an intermediate trophic classification on the continuum of biological productivity between oligotrophy and eutrophy.

The most commonly used tropic state index is Carlson's TSI (Carlson 1977). This index uses algal biomass as determined by the three variables of transparency, total phosphorus, and chlorophyll as the basis for the trophic state classification. The range of the index is from approximately zero to 100, although technically there are no upper or lower bounds. Each major TSI division (10, 20, 30, etc.) represents a doubling in algal biomass. The Traditional trophic classification scheme can be overlaid on the index as follows: TSI: < 40 = oligotrophic, TSI: 40-50 = mesotrophic, TSI: > 50 = eutrophic.

The north basin of Upper Saranac Lake is best classified as a mesotrophic water body, with average TSI values for transparency, chlorophyll, and total phosphorus all scored between 40 and 50 in 2017 (Figure 8). According to Carlson (1977) lakes with TSI values in the 40's are moderately clear with an increased probability of hypolimnetic anoxia in the summer; therefore our trophic assessment fits the characteristics of the north basin well. The south basin of the lake is best classified on the border of oligotrophic and mesotrophic (Figure 0. The TSI value for chlorophyll (47) and transparency (44) indicates a mesotrophic condition, while the TSI for total phosphorus (35) both indicate an oligotrophic status. A disparity of this nature is common in Adirondack lakes (Laxson et al. 2016), and typically related to phosphorus limitation (Carlson and Simpson 1996). Both basins of the lake have shown improvement in the trophic state since the early 1990's when eutrophic values in the 50's and 60's were commonly observed.

Regardless of the lakes trophic state, or the method used to classify it, it's important to remember that "trophic state" is just an organizing concept limnologists use to locate a particular waterbody on a continuum of productivity, thereby connecting the lake to previous information and knowledge from other lakes. An oligotrophic lake and its biota do not possess a distinct identity or wholeness that separates it from a mesotrophic lake. The physical variables of a lake system are dynamic and exist across a wide gradient and the biological components of a lake change continuously as well (Carlson and Simpson 1996).

pH and Alkalinity

In chemistry, pH is used to communicate the acidity of a solution. Technically pH is a surrogate measure of the concentration of hydrogen ions in water. Hydrogen ions are very active, and their interaction with other molecules determines the solubility and biological activity of gasses, nutrients, and heavy metals; thus pH is considered a master variable for its influence on chemical processes and aquatic life. pH exists on a logarithmic scale from 0-14, with 7 being neutral. pH values less than 7 indicate increasing acidity, whereas pH values greater than 7 indicate increasingly alkaline conditions. Because pH exists on a logarithmic scale a decrease in 1 pH unit represents a 10 fold increase in hydrogen ion activity. Lakes can become acidified when they are influenced by organic acids from wetlands and bogs or when acidic precipitation falls on a poorly buffered watershed (Driscoll et al. 2003, Wetzel 2001). In the Adirondacks acidification status can be assed from pH values based on the guidelines outlined in Table 4.

Table 4. Assessment of lake acidification based on pH.

Lake acidity	Status
pH less than 5	Acidic: Critically Impaired
pH 5.0 – 6.0	Acidic: Threatened
pH 6 – 6.5	Acidic: Acceptable
pH 6.5 – 7.5	Circumneutral: non-impacted
pH >7.5	Alkaline: non-impacted

Alkalinity (or acid neutralizing ability) is the capacity of water body to neutralize acids and thereby resist changes in pH. The alkalinity of a lake plays a major role in whether or not a lake is impacted by acid deposition. Alkalinity is largely a function of the amount of calcium carbonate in the water which is derived mainly from the watershed. Most Adirondack lakes exist on slowly weathering granitic bedrock that has a slow rate of calcium carbonate generation, and therefore lower acid neutralizing ability. The opposite is true for lakes that exist on bedrock derived from ancient ocean deposits, such as limestone or dolomite. Soil depth also plays a role in acid neutralizing capacity, with deeper soils offering more buffering ability than shallower soils. Alkalinity is quantified by analyzing the amount of dilute acid that is required to lower the pH of a lake sample to 4.3 pH units, the point at which all of the carbonate and bicarbonate alkalinity is consumed. The acid neutralizing ability of a lake can be generally assessed following the parameters presented in Table 5.

Upper Saranac Lake is a circumneutral water body and is not degraded by acid deposition. The surface water pH is similar between the two study basins and averaged 7.3 in the north basin and 7.1 in the south basin. Acidity of the bottom water was slightly higher, and averaged 6.6 in the north and 6.7 in the south. Acidity is typically lower in the surface water, where photosynthesis removes CO_2 causing an increase in pH. In the bottom water decomposition of organic material liberates CO_2 resulting in an increase in acidity (Tables 2 and 3). The annual average pH of the lake has been relatively stable since monitoring began with no significant trend detected in the surface or bottom water of either of the basins (Figures 11-13).

Upper Saranac Lake has adequate buffering ability and low sensitivity to acid deposition. The alkalinity concentration averaged 12.3 mg/L in the north basin and 10.5 in the south basin. Values were slightly elevated in the bottom water of the lake. This in-lake alkalinity generation is common in the deep portions of lakes; it can be caused by bacteria mediated reduction of sulfate and nitrate as well as redox reactions involving iron and manganese (Hutchinson 1957, Wetzel 2001).

Table 5. Assessment of sensitivity to acid deposition based on alkalinity.

Alkalinity (mg/L)	Buffering Ability	Acidification status
< 0	none	acidified
0 - 2	low	extremely sensitive
2 - 10	moderate	moderately sensitive
10 - 25	adequate	low sensitivity
> 25	high	not sensitive

Conductivity

Conductivity is a measurement of the ability of a water sample to conduct electricity. Pure H_2O 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. Electrical conductance increases with water temperature so conductivity is typically expressed at the specific temperature of 25°C, a water quality variable referred to as specific conductance. The conductivity of an undeveloped lake in the Adirondacks is usually in the range of 15-25 µS/cm (Laxson et al 2016). 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 and lakes (Daley et al. 2009).

The specific conductivity of the surface water of Upper Saranac Lake was very similar between basins, and averaged 50.7 µS/cm. Conductance was slightly higher in the bottom strata, particularly in the north basin. This is most likely due to decomposition near the bottom liberating dissolved ions (Tables 2 and 3). We detected a significant increase in the surface water conductance by approximately 0.5 µS/cm/year in both the north and south basins of the lake (Figures 8 and 10; north: $P < 0.001$, tau = -0.43; south: P=0.002, tau = -0.45). Similar trends were also detected in the bottm strata of both basins (Figure 9 and 11). The conductance of Upper Saranac Lake is approximately two to three times greater than the value of least impacted Adirondack lakes (15-25 µS/cm). The elevated conductance is due to a number of sources including road salt, development run off, septic input, and permitted discharge. The earliest surface conductivity measurement of the lake was reported by the NYS Department of Health in 1971 as 38µS/cm, suggesting that the lake was already noticeably impacted by dissolved ions 45 years ago.

Sodium and Chloride

Lakes in the Adirondack region have naturally low concentrations of chloride and sodium, with average background concentrations of 0.2 mg/L and 0.5 mg/L respectively (Kelting et al. 2012). However, wide spread use of road deicers

Photo 5. Wide spread use of road deicers is the largest contributor of chloride to Upper Saranac Lake.

(primarily sodium chloride) have significantly increased the concentration of these chemicals in the environment. The New York State Department of Transportation applies an average of 23 tons of road salt per lane kilometer of State and Federal roads annually (personal communication. NYSDOT, 2012). Given that there are 54 km of state roads within the Upper Saranac Lake watershed, we can estimate an annual salt load of approximately 1,242 tons of NaCl. Recent research by Kelting et al. (2012) highlighted that concentrations of sodium and chloride in Adirondack Lakes are directly proportional to the density of state roads within the watershed. Upper Saranac Lake also receives a large amount of chloride from the Adirondack Fish Culture Station, which discharges and average of 1.3 million kilograms of chloride/year to Little Clear Outlet and is permitted to discharge substantially more.

Sodium and chloride concentration in Upper Saranac Lake did not significantly differ between the surface and bottom water. Concentration of sodium and chloride were very similar between basins, averaging 4.1 and 8.1 mg/L respectively in the north, and 4.1 and 7.9 mg/L respectively in the south (Tables 2 and 3). Although these values are fairly low, they are substantially higher than concentrations in Adirondack lakes without paved roads (10X higher for sodium, 35X higher for chloride), and nearly 4X greater than they were in 1991 (Figures 8 and 10). For example, using the 2016 average lake wide chloride concentration (8.5 mg/L) and the volume of the lake (150 million m^3), we can estimate that there was approximately 1,370 tons of chloride in the lake in 2016. In 1991, there was approximately 410 tons of chloride in the lake. If Upper Saranac Lake was undeveloped, and had no maintained roads in its watershed, we would predict the chloride content of the lake to be approximately 40 tons.

Road salt can have direct and indirect effects on aquatic ecosystems. It is clear that the direct impact of road deicers on organisms is not well understood, and is highly variable across taxa. Based on laboratory studies the lethal concentration for most aquatic organisms is much higher than concentrations encountered in a lake environment. However, at times lethal concentrations can be encountered in near-road environments that receive direct run-off such as road side streams or vernal pools (reviewed by Kelting and Laxson 2010).

Indirect effects to aquatic systems have also been documented. For example sodium actively displaces base cations (Ca, K, and Mg) as well as heavy metals from the soil, potentially elevating their concentration in surface waters. In some extreme cases excessive road salt pollution can interfere with lake stratification due to salts effect on water density (Bubeck et al. 1971; Kjensmo 1997). Sodium and chloride impart an undesirable taste to drinking water. The US EPA has a guideline of 250 mg/L for chloride and 20 mg/L for sodium, but these are for drinking water only and are not enforceable standards.

Watershed Inputs to Upper Saranac Lake

Objectives

This section of the report covers the tributary monitoring project on Upper Saranac Lake, a program in its 10th consecutive year. The specific objectives are to develop an understanding of the hydrology and chemical loading to the lake from its main tributaries.

Methodology

Sample collection and analysis

We began a monitoring program in 2007 to estimate stream discharge and nutrient loadings (primarily phosphorus) in the Upper Saranac Lake Watershed. The streams monitored in this program represent approximately 75% of the total watershed area and include: Black Swamp Brook, Brandy Brook, Fish Creek, Indian Carry Brook, Mill Brook, and Cranberry Brook (Figure 1). Monitoring also occurs at the Little Clear Pond Outlet, a sub watershed of Mill Brook, because this is the discharge point for the Adirondack Fish Culture Station (SPEDES NY0035335). Each of the study watersheds, with the exception of Cranberry Brook, was instrumented with a differential pressure transducer stage recorder to measure the height of the stream at 30 minute intervals (Levelogger Gold, Solinist Canada Ltd). Study streams were visited 8-10 times per year, roughly two weeks apart between April and October. During each visit a stream discharge measurement was made and a water sample was collected for chemical analysis.

Photo 6. PSCAWI technician, Hunter Favreau measuring the discharge entering Upper Saranac Lake from Brandy Brook.

Stream discharge was measured using standard procedures developed by the US Geological Survey (Turnipseed and Sauer 2010). Cross sectional area and stream velocity were measured at ten segments across the width of each stream using an acoustic Doppler velocity meter (SonTek, Flow Tracker ADV), these measurements were then integrated into total stream discharge (m^3/second). Rating curves for each of the study streams were developed by plotting the stream discharge against the corresponding stream height recorded by the Levelogger, this relationship was then used to calculate the discharge for the study streams at 30 minute intervals. Stream water samples were collected, preserved, and analyzed using standard methodologies. Samples were analyzed at the Adirondack Watershed Institute's Environmental Research Lab for total phosphorus, nitrogen, chloride, and sodium using the same methods described for the lake samples.

Loading calculations

Loading is the amount of a substance (chemical, nutrient, or soil) that is lost from the watershed and imported to the lake expressed as weight/time (typically weight/day). Loading for each of the study streams was calculated by converting the instantaneous discharge (m^3/sec) to daily discharge (m^3/day), multiplied by that day's analyte concentration. For analytes that were below laboratory detection, a zero was entered into the calculation. Areal loading, also known as the loading coefficient (g/ha/day), was calculated by dividing the total daily loading by the surface area of the sub-watersheds. Areal loading provides a better comparison of chemical flux between watersheds because the factor of watershed size is normalized. The median loading values (± 95% confidence interval) were calculated using Minitab and tabulated for comparison.

Results and Interpretation

Stream Discharge

Correlation between the stream height recorded by the Levelogger and discharge for the study streams was generally very good, with coefficient of determination values (R^2) exceeding 0.87 for all but one inlet (range 0.87-0.98: Figure 15). This indicates that for most of the study streams 87 to 98% of the variability in discharge is explained by water height on the instream recorders. The one exception is Fish Creek, where the stage height was much less predictive (R^2 = 0.42). A combination of aquatic vegetation interference,

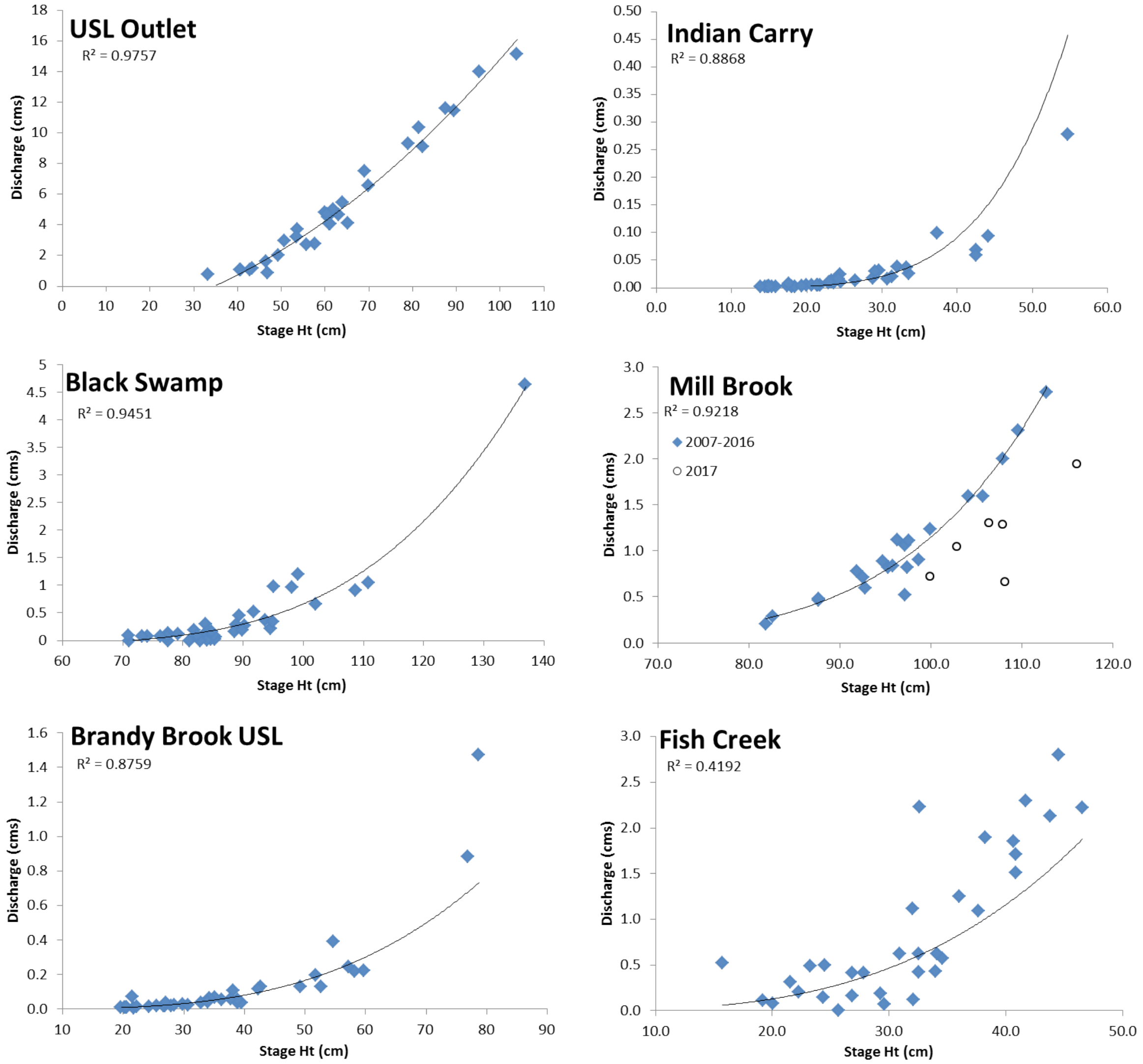

Figure 15. Stage discharge curves for the main tributaries of Upper Saranac Lake.

low water level, and wind induced flow reversal has made rating curve development at Fish Creek an ongoing difficulty. Similar problems were encountered by Martin et al. (1998).

Daily discharge for the six instrumented tributaries of Upper Saranac Lake over the last two study years are depicted in Figure 16. Overall, discharge was greatest in the largest sub watersheds, and lowest in the smallest. As expected, discharge for each tributary was highest in the spring and early summer and lowest during the base flow conditions of late summer and early autumn. Water year 2016-2017 was much wetter than 2015-2016, with substantially more water moving through the study watersheds. For example, we estimated a 40% increase in discharge between the study years for Indian Carry, Brandy Brook, and Black Swamp. The six instrumented streams in our study account for approximately 63% of the total hydrologic budget for Upper Saranac Lake on an annual basis. The two largest sub watersheds, Fish Creek and Mill Brook together accounted for 55% of the water leaving the lake at the outlet (Table 6).

Based on the total volume of water leaving the lake at the outlet, we calculated the retention time of the lake to be 0.7 years in water year 2017, 1.1 years in 2016, and 0.9 in 2015. These values were in close agreement with the retention time of 0.9 years calculated using the surface runoff model (Martin et al. 1998).

Total phosphorus

The greatest concentration of phosphorus was found in Brandy Brook, with a median value of 27 µg/L during the last three study years. The second highest concentration was found in Indian Carry Brook (25µg/L), followed by Black Swamp (22 µg/L), Mill Brook (14 µg/L) Cranberry Brook (11 µg/L), and Fish Creek (8 µg/L). Little Clear Outlet, a sub watershed of Mill Brook that sup-

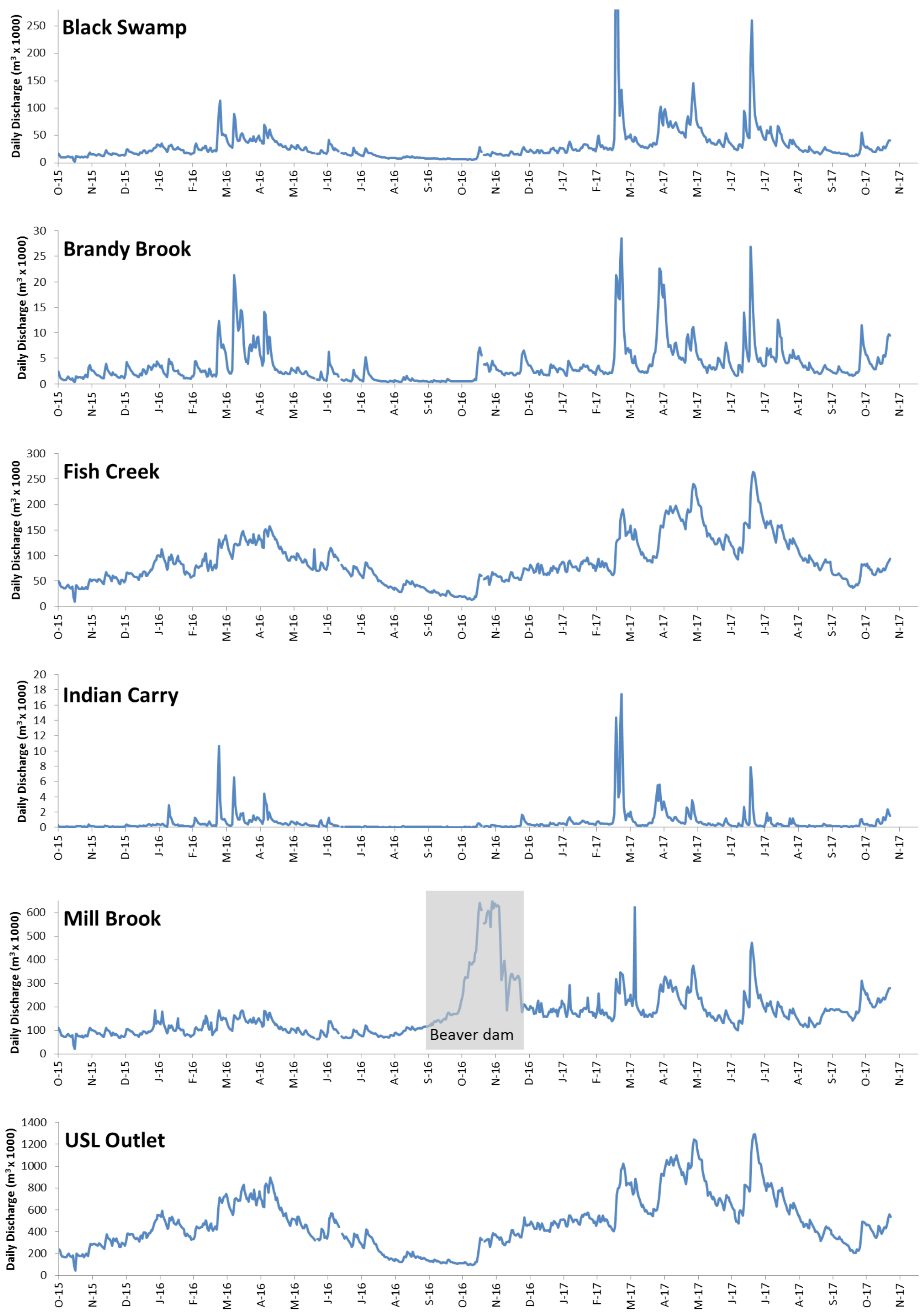

Figure 16. Daily discharge from the major sub-watersheds of Upper Saranac Lake from October, 2015 to November 2017

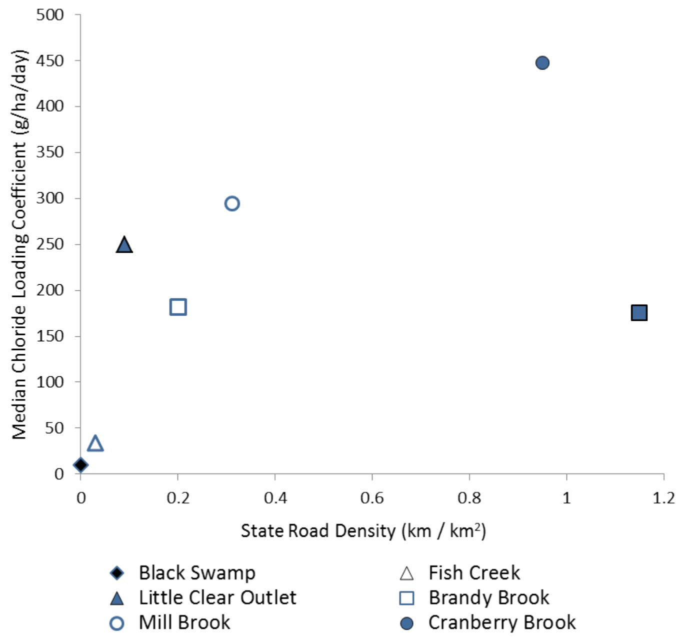

Figure 17 Relationship between state road density and chloride loading for the main sub-watersheds of Upper Saranac.

ports the Adirondack Fish Culture Station, had a median total phosphorus concentration of 19.7 μg/L. The mass of phosphorus loaded to the lake each day was greatest at Mill Brook at a median value of 1.34 kilograms per day, and lowest at Cranberry and Indian Carry Brooks, at 0.01 and 0.003 kilograms/day respectively. Comparison of nutrient export between watersheds is best performed by standardizing the export for watershed surface area (known as the loading coefficient). The median phosphorus loading coefficients ranged from a low 0.02 at Indian Carry to as high as 0.3 grams/ha/day at Mill Brook (Table 7).

It is well known that nutrient loading to a lake varies greatly between watersheds depending on watershed size, soil characteristics, topography, land cover, and of course human activities. Overall, we feel that the phosphorus export from the sub watersheds to Upper Saranac Lake range from low to moderate. For comparison purposes, median annual phosphorus export from undeveloped watersheds in the St. Regis, Raquette, and Ausable River watersheds ranged from 0.01 to 0.21 g/ha/day in 2015 (AWI unpublished data), which is similar to the range for the Upper Saranac lake loading coefficients (0.02 - 0.3 g/ha/day). There are a few sub-watersheds that stand out as having elevated phosphorus, particularly Mill Brook and Black Swamp. Our analysis suggests that approximately 31% of the phosphorus discharged from Mill Brook into the lake on a daily basis (1.3 kg/day) can be partitioned to the Little Clear Outlet (0.4 kg/day), the location of the permitted discharge from the Adirondack Fish Culture Station. The hatchery releases a fair amount of phosphorus to the lake, but it has accomplished a 6-fold reduction in phosphorus export since 1992 and the facility currently operates well below its permitted discharge rate of 164 lbs per year (Figure 12; reviewed by Laxson et al. 2015, Martin 1998). The elevated loading coefficient at Black Swamp may be related to the large wetland in the watershed. Martin et al (1998) observed similarly high loads from Black Swamp and suggested it was related to elevated levels of humic and fluvic acids in the wetlands. Recent work by Gehrels and Mulamootil (1989) demonstrated that wetlands may increase export of certain forms of phosphorus.

Nitrogen

The greatest concentration of total nitrogen was found in Black Swamp, with a median value of 505 μg/L over the last three years. The second highest concentration was found in Brandy Brook (399 μg/L), followed by Indian Carry (365 μg/L), Mill Brook (339 μg/L), Cranberry Brook (327 μg/L), and Fish Creek (254g/L). Little Clear Outlet had a median total nitrogen concentration of 373 μg/L. The median daily mass of total nitrogen loaded to the lake was greatest at Mill Brook at 34 kilograms per day, and lowest at Cranberry and Indian Carry Brooks, at 0.3 and 0.1 kilograms/day respectively. When standardized for watershed area, the greatest nitrogen loading coefficient was found at Mill Brook where 8.6 g/ha/day of nitrogen were exported and the lowest was at Indian Carry where 0.7 g/ha/day was exported (Table 7).

Table 6. Hydrologic description of the tributaries of Upper Saranac. Discharge is expressed as the median between Oct 2014 and Nov 2017.

	Upper Saranac Outlet	Black Swamp	Brandy Brook	Fish Creek	Indian Carry Brook	Mill Brook
Watershed Area (ha)	19,580	1,754	487	8,336	405	4003
Daily discharge (m³/day)	427,380	22,600	2,168	74,219	178	116,080
Areal discharge (m³/ha/day)	21.8	12.9	4.5	8.9	0.4	29.0
% of total lake discharge	100%	6.5%	1%	19%	0.14%	36%

Table 7. Loading data for the main sub-watersheds of Upper Saranac. Values represent the median between Oct 2014 and Nov 2017.

	Black Swamp	Brandy Brook	Fish Creek	Indian Carry	Mill Brook	Cranberry Brook
Median Stream Concentration (95% Confidence Interval)						
Total Phosphorus (μg/L)	22 (17-27)	27 (19-33)	8 (8-10)	25 (19-28)	14 (13-16)	11 (10-13)
Total Nitrogen (μg/L)	505 (462-579)	399 (321-447)	254 (222-281)	365 (334-402)	339 (296-376)	327(317-361)
Chloride (mg/L)	1.1 (0.9-1.3)	23 (20-26)	3.7 (3.5-3.8)	129 (110-221)	14 (13.6-14.6)	77 (73-82)
Sodium (mg/L)	1.5 (1.2-1.9)	11 (10-14)	2.6 (2.4-2.9)	65 (44-129)	8 (7.3-8.3)	38 (36-41)
Median Daily Loading Rate (95% Confidence Interval)						
Total Phosphorus (Kg/day)	0.4 (0.3-0.6)	0.1 (0.04-0.17)	0.6 (0.3-1.2)	0.003 (2E^{-4}-0.01)	1.3 (0.2 –2.2)	0.01 (5E^{-3}-0.01)
Total Nitrogen (Kg/day)	7 (3-26)	2.0 (0.5-3.5)	17 (4-47)	0.1 (0.2-0.3)	34 (20-67)	0.3 (0.1-0.5)
Chloride (Kg/day)	10 (8-15)	88 (29-148)	287 (188-405)	30 (14-42)	1183 (900-1880)	49 (35-79)
Sodium (Kg/day)	26 (18-37)	47 (22-95)	197 (126-72)	15 (8-31)	677 (499-1129)	26 (18-41)
Median Loading Coefficient (95% Confidence Interval)						
Total Phosphorus (g/ha/day)	0.2 (0.1-0.4)	0.2 (0.08-0.34)	0.08 (0.04-0.14)	0.02 (0.01-0.06)	0.3 (0.2-0.5)	0.08 (0.05-0.1)
Total Nitrogen (g/ha/day)	3.9 (2-15)	4 (1-7)	2.1 (0.4-5.7)	0.7 (0.1-2.0)	8.6 (5-17)	2.8 (1.3-4.8)
Chloride (g/ha/day)	10 (8-15)	182 (59-303)	34 (23-49)	176 (87-256)	295 (225-470)	448 (323-729)
Sodium (g/ha/day)	15 (11-21)	97 (45-195)	24 (15-33)	89 (47-184)	169 (124-422)	245 (167-384)

Sodium and Chloride

Sodium and chloride concentrations over the last three years were greatest at Indian Carry where median concentrations were observed to be 65 and 129 mg/L respectively. Lowest concentrations of sodium and chloride were observed at Black Swamp, where median concentrations were 1.5 and 1.1 mg/L respectively. The total daily mass of sodium and chloride loaded to the lake was greatest at Mill Brook with median values of 677 and 1183 and kilograms / day respectively. The lowest daily loads were observed at Indian Carry and Black Swamp. When normalized for watershed area, Cranberry Brook contributed the most amounts of sodium and chloride to the lake per unit of watershed area, with a median loading coefficient of 245 and 448 grams/ha/day respectively, followed by Mill Brook, and Indian Carry (Table 7). In addition to salted state roads, Mill Brook also receives salt from the Little Clear Outlet, the receiving water for the hatcheries permitted discharge. The Environmental Protection Agency reported that the Adirondack Fish Culture Station has exported an average of 1.3 million kilograms of chloride per year to Little Clear Outlet since 2007, although this value seems unusually high (EPA Discharge Monitoring Report 2018). Our limited analysis suggests that approximately 14% of the sodium and chloride loaded to the lake from Mill Brook load can be partitioned to Little Clear Outlet (166 of 1183 kilograms/day).

We anticipated that the amount of chloride moving through the Upper Saranac Lake tributaries would be strongly related to the density of salted roads in the watershed (Kelting et al. 2012; Regalado and Kelting 2015). Although this was generally the case, road density only explained 30% of the variability in median loading coefficients (Figure 17). The greatest road density occurs in the Indian Carry watershed, yet we found the export of chloride in our study to be disproportionally low. We can only speculate on the reason for this, but it's likely due to the flashy behavior of this small watershed. Most of our export measurements are made in the summer when the discharge is very low. The stream responds quickly to rain events and we typically do not capture them in our sampling regime. Indian Carry is part of our more comprehensive road salt study; however, the data analysis for that project is not included in this report.

Milfoil Monitoring Program

Objectives

This section of the report covers the milfoil monitoring efforts on Upper Saranac Lake, a program in its 14th consecutive year. The specific objectives are to assess the efficacy of hand harvesting Eurasian water-milfoil by analyzing current and historical milfoil abundance across 16 underwater study locations.

Methodology

Detailed descriptions of the methods are presented in previous annual reports, as well as Kelting and Laxson (2010). In general, fifteen sites on Upper Saranac and one on Fish Creek Pond with historically high Eurasian water milfoil densities were selected (Figure 18). At each site a transect line method was used to monitor the presence and abundance of Eurasian water milfoil. At each site four permanent underwater transect lines (nylon rope) were installed, with the exception of the Gull Bay sites and Deer Island which had two and three transects respectively. The transects ran from approximately 3 feet of depth to 15 feet of depth. At several locations the lake bottom had very little slope, in which case 150 foot long transects were established. Once a month during the summer (June-Sep) a SCUBA diver swam each transect at the 16 locations and enumerated the number of milfoil stems in 6 feet wide by 10 feet long segments for the entire length of each transects line. Presence or absence of native aquatic species was recorded for each segment during the month of August. There are a total of 588 segments in Upper Saranac and 36 in Fish Creek Pond.

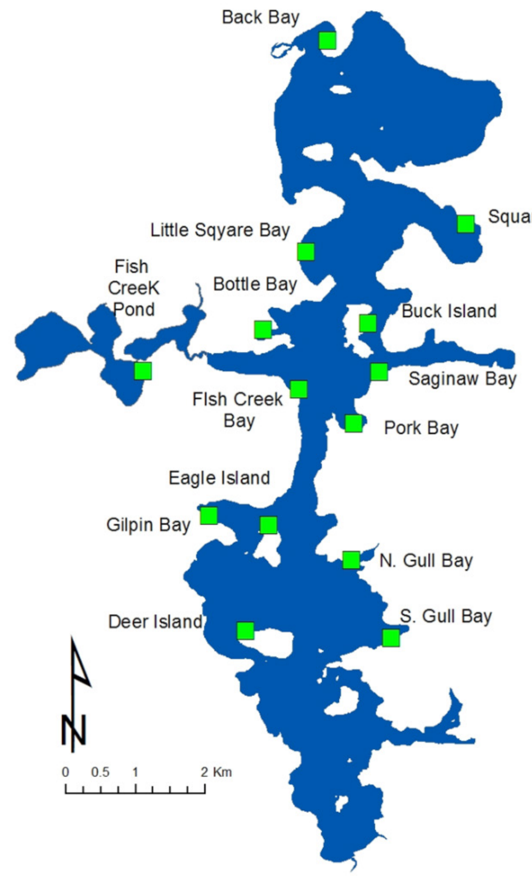

Figure 18. Location of the underwater monitoring sites on Upper Saranac Lake and Fish Creek Pond.

Results and Interpretation

Fish Creek Pond

The milfoil stem count at the unmanaged Fish Creek Pond location ranged from a high of 22 in July to as low as 11 in September of 2017. We estimated a stem density of 474 stems / acre during the month of July. Milfoil density had been on the rise at this location since 2007; however we have observed relativly stable stem densities at the study site during the past three summers (Figure 19). This type of variation is not uncommon, as aquatic plant growth is affected by numerous environmental variables.

The aquatic plant species found to occur most frequently at the Fish Creek location was Robbin's pondweed (*Potamogeton robbinsii*), which occurred on roughly 71% of the segments (Figure 20). Other common plants were stonewort (*Nitella species*), small pondweed (*Potamogeton pusillus*), and eel grass (*Vallisneria americana*). Eurasian water milfoil was ranked number 10 in terms of frequency of occurrence, and was found to occur on 15% of the study segments in August of 2017. Interestingly, a different species of invasive milfoil, variable-leaf milfoil (*Myriophyllum heterophyllum*), as become common in Fish Creek Pond than Eurasian water-milfoil.

First detected in 2009, variable-leaf milfoil now occurs on 46% of the study segments and is exhibiting an increase in its encounter rate by about 4% per year ($P < 0.001$, $R^2 = 0.71$). Surface water observations confirm that the species can be found throughout Fish Creek Pond, and it has also been encountered sporadically in Upper Saranac Lake. Although its native status is unclear, variable-leaf milfoil is a species of concern throughout the northeast. Like Eurasian water milfoil, variable-leaf milfoil is capable of forming dense beds, congesting waterways, and reducing plant species richness.

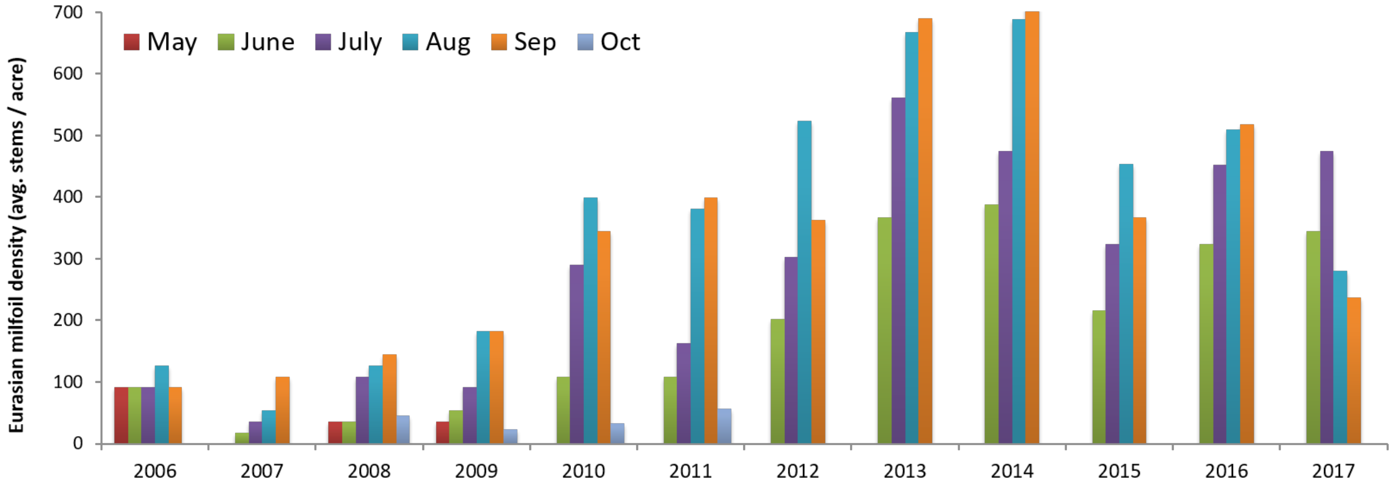

Figure 19. Average density of Eurasian water-milfoil at the Fish Creek location, 2006-2016 (n=4)

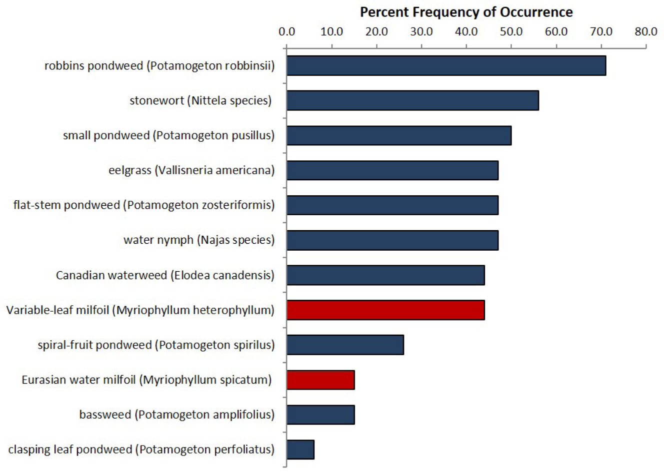

Figure 20. Percent frequency of occurrence of plant species on the transects of the Fish Creek location during August, 2017. Species in red are non-native or species of concern.

Upper Saranac Lake

During the summer of 2017 we encountered very few Eurasian water milfoil stems, and the plant was only detected in 5 of the 16 monitoring locations. In Upper Saranac Lake the greatest amount of milfoil occurred at the Little Square Bay location during June and August, where we encountered seven and five stems, respectively. We detected between 1 and 7 milfoil stems at other locations on Upper Saranac Lake, including Saginaw, Gilpin, and South Gull Bay.

The 14 years of management effort on Upper Saranac have been incredibly successful at reducing the lake wide abundance of Eurasian water milfoil. Overall, stem density (stems/acre) has remained low through the entire maintenance period and has been particularly low during the last five years (Figure 21). For example, average August stem density across all locations in 2017 was 15 stems/acre, which is approximately 44 times lower than the densities encountered in 2004, the first year of intensive harvesting. Milfoil density in Upper Saranac is substantially lower than other lakes in the Adirondacks with established milfoil populations. For example, in Chateaugay Lakes the average August milfoil density across similar underwater transects has ranged from 5,200 to 11,000 stems/acre over the last 7 years (Laxson and Kelting 2017). Similarly, milfoil density at the unmanaged Fish Creek Pond location was approximately 30 times greater than the average density at the Upper Saranac locations in 2017.

The aquatic plants found to occur most frequently in Upper Saranac Lake was Robbins pondweed, which occurred on 74% of the study segments (Figure 22). Other common species encountered were water nymph (Najas species), eelgrass (*Vallisneria americana*), spiral fruit pondweed (*Potamogeton spirillus*), stonewort, (*Nitella species*), and Canada water weed (*Elodea canadensis*). The management effort has also been successful at reducing the frequency at which milfoil beds are encountered on Upper Saranac. At this time we consider Eurasian water milfoil to be a rare plant in Upper Saranac Lake as it occurred on only 1% of the 588 study segments during August, the month of greatest aquatic plant cover; we were 10 times more likely to encounter milfoil on the study segments in 2005.

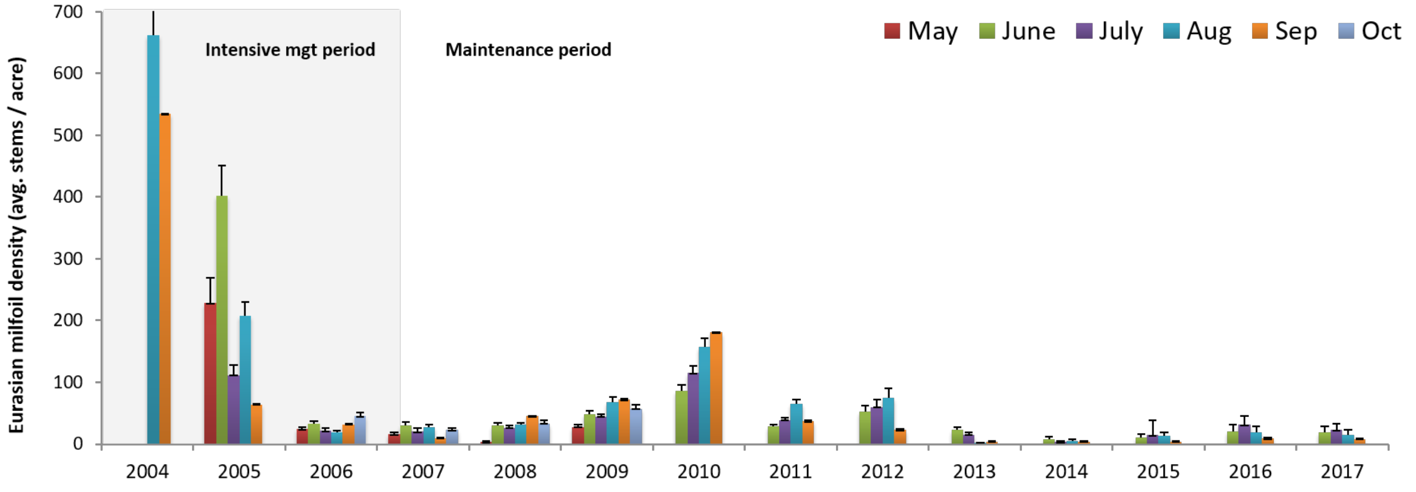

Figure 21 Average density of Eurasian water-milfoil at the Upper Saranac Lake sites from 2004 to 2017. Vertical bars represent the standard error of the mean (n=15).

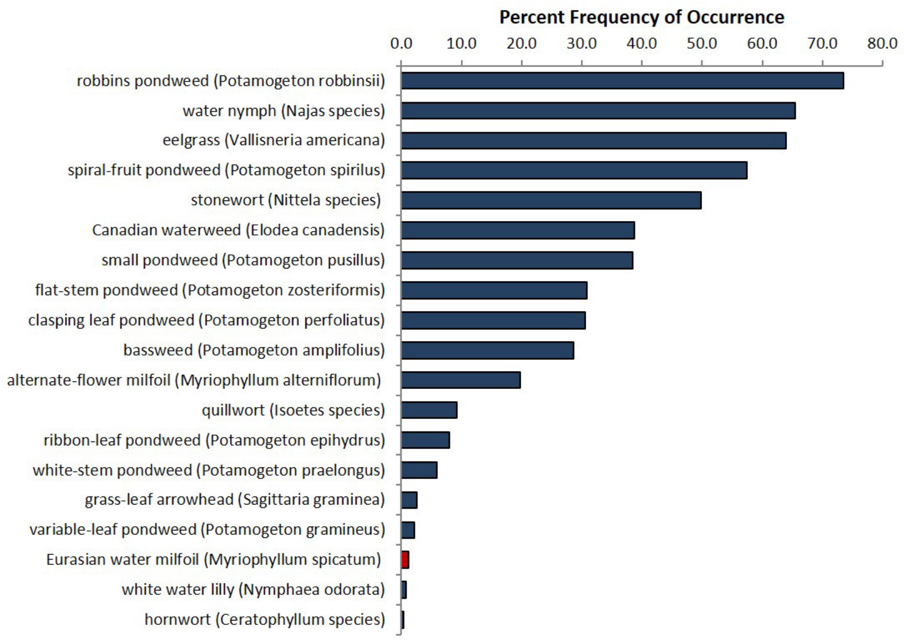

Figure 22. Percent frequency of occurrence of plant species on the transects of tUpper Saranac Lake during August, 2017. Species in red are non-native or species of concern.

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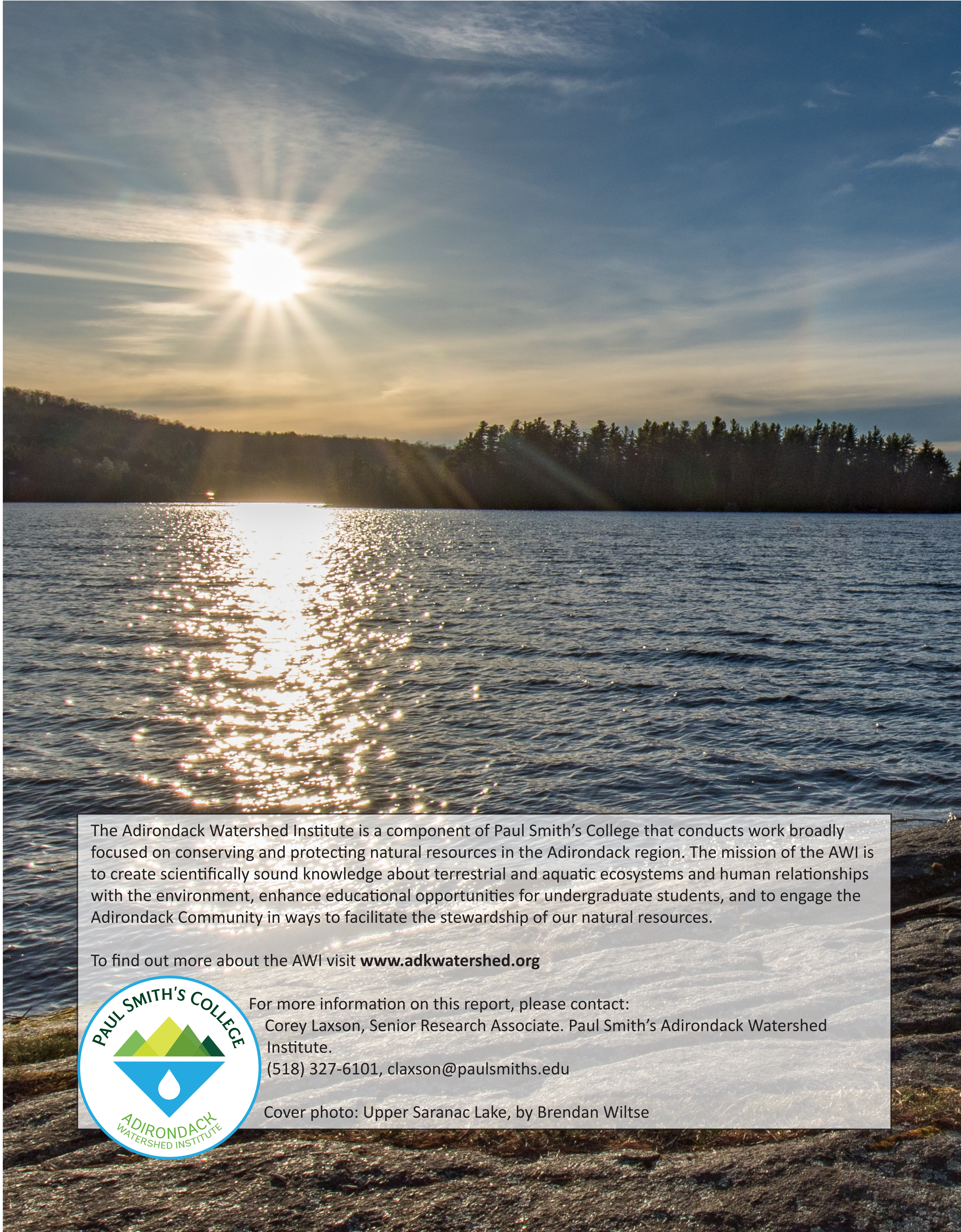

The Adirondack Watershed Institute is a component of Paul Smith's College that conducts work broadly focused on conserving and protecting natural resources in the Adirondack region. The mission of the AWI is to create scientifically sound knowledge about terrestrial and aquatic ecosystems and human relationships with the environment, enhance educational opportunities for undergraduate students, and to engage the Adirondack Community in ways to facilitate the stewardship of our natural resources.

To find out more about the AWI visit **www.adkwatershed.org**

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Cover photo: Upper Saranac Lake, by Brendan Wiltse