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AN ENVIRONMENTAL HISTORY OF LOWER ST. REGIS: LAKE DEGRADATION AND THE PATH TO ECOLOGICAL REDEMPTION

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ABSTRACT

This paper examines the environmental history of Lower St. Regis Lake (Franklin County, NY), the historic location of the Paul Smith's Hotel and the present day site of Paul Smith's College. Using water quality and fiisheries data collected by students, faculty, and environmental professionals, this article examines ecological changes that have taken place in the lake during the last 50 years. An analysis of lake-bottom sediments also reaches farther back in time to show what Lower St. Regis might have been like long before Paul Smith arrived. The story illustrates the effects of massive loading of phosphorus on water quality, places the lake within the context of the environmental awakening of the late 1960s and early 1970s, and chronicles steps that have been taken move Lower St. Regis Lake from a state of degradation toward "ecological redemption.

Lower St. Regis Lake, located in the Town of Brighton, Franklin County, NY, is the third lake in the St. Regis chain that also includes Spitfire Lake and Upper St. Regis Lake (Figure 1). The 350-acre (142 ha) lake is a gateway to the St. Regis Canoe Area to the south and the St. Lawrence River to the north. Whether it's for visitors or residents in a canoe loaded for days in the backcountry, slowly cruising along the lake's shore at dusk casting for bass, or just skimming along its surface and through "the slough" into the upper lakes on a sunny summer afternoon, Lower St. Regis Lake is the point where many an Adirondack adventure begins. It has been that way since the first people moved to these uplands more than 10,000 years ago. It was that way in 1858 when Apollos A. ("Paul") Smith arrived on the lake's shore and started construction of the soon to be famous Paul Smith's Hotel. It still seemed to be that way up through the 1930s and 1940s as the hotel, with its extensive land holdings, morphed into the present-day Paul Smith's College of Arts and Sciences.

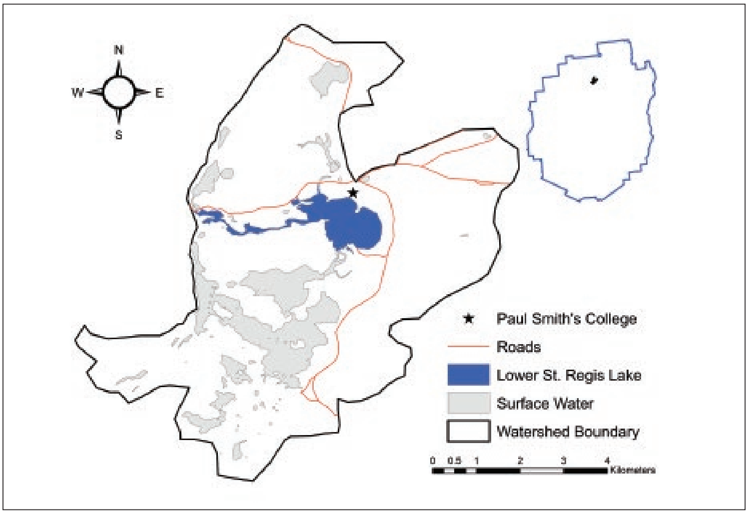

Figure 1: *The St. Regis chain of lakes and its watershed, including Lower St. Regis.*

However, by the 1960s something had noticeably changed. The change actually started much earlier, but, as with many environmental disturbances, went largely unnoticed until reaching a tipping point. Standing on the shores of Lower St Regis Lake in the early 1970s you might think twice about that canoe launch and you would certainly reconsider the fishing trip. Back then, thick blooms of cyanobacteria—commonly known as "blue-green algae"—developed during the summer months giving the lake a pea green color (Figure 2). The bloom could be parted with a paddle stoke, exposing dark, turbid waters below. At times, the transparency of the water was well below one meter. The cool bottom waters of the lake were devoid of oxygen, and the native "St. Regis strain" of brook trout had been replaced by a fish community dominated by white suckers. More likely than not, that boating trip to the upper lakes would have been replaced by a research excursion on a vessel bearing the symbol of a governmental agency—not trolling for bass or pike, but trolling for answers.

Figure 2: *Lower St. Regis Lake, August 5, 1971.*

This paper summarizes the environmental history of Lower St. Regis Lake as it is currently known. The story reaches far back in time to see what the lake might have looked like long before Paul Smith arrived on the scene. It places the lake within the context of the historic environmental awakening of the late 1960s and early 1970s, a time when much of our nation's environmental legislation, from the National Environmental Policy Act of 1969 to the Clean Water Act of 1972, was put into place. And finally, it looks at how the lake has changed since then, including the legacies of past abuse and the progress that has been made in moving from a state of degradation toward ecological redemption.

THE ARRIVAL OF PAUL SMITH

Paul Smith was already a well-known hunting guide in 1852 when he and his family operated Hunters Home a few miles south of present-day Loon Lake in Franklin County. Hunters Home was a primitive lodge that served as little more than a place to eat, sleep, and share stories of long days in the woods hunting and fishing (Tyler 1988). Some of Paul's wealthy clients encouraged him to construct a lodge with accommodations more appropriate for Victorian era women, thereby allowing the male guests to bring their wives with them on trips to the Adirondacks. In 1858, with financial backing from a regular client, Hezekiah Loomis, Paul Smith purchased 50 acres on the shore of Lower St. Regis Lake and constructed his new lodge (Surprenant 2009, Collins 1977) near a promontory where a Native American encampment had previously been located (Wardner 2010, Stager 2017). Over the next several decades, Paul and his wife, Lydia, grew the rustic hunting outpost, known as the St. Regis House, into a world-renowned wilderness resort: the Paul Smith's Hotel.

The growth and success of the Paul Smith's Hotel led some guests to seek their own piece of the Adirondack lifestyle. Shoreline property was purchased or leased from the Smiths on Spitfire and Upper St. Regis Lakes, where the new owners constructed their own "Adirondack great camps" and cottages. As the area developed, the St. Regis chain of lakes became an exclusive summer playground for some of the most affluent families in America (Hotaling 2016). Over time these camps, in addition to the hotel properties, started to have serious, but yet unseen, impacts on the lakes themselves.

Those impacts on Lower St. Regis Lake increased when a dam at the outlet—originally constructed in 1851 by Oliver Keese and Thomas Tomlinson to power their sawmill—was purchased by Paul Smith, who then raised the lake level to store water for a power station at the outlet. Meanwhile, the last half of the 19th century saw widespread cutting of spruce and white pine throughout the St. Regis watershed, further impacting water quality in the lakes (Kudish 1981).

By the end of the 19th century, residential buildings at the hotel complex had been equipped with electricity and indoor plumbing. As was common during that day, sewage from the hotel and the associated camps and cottages was disposed of in cesspools. These were covered pits dug into the easily leached sandy soils and lined with brick or simply cribbed hemlock logs. Wastewater flowed through vitrified clay pipes to the pits, which retained the solids while nutrient-rich liquids percolated into the groundwater making its way into the nearby lake.

All this, in addition to the land clearance between 1896 and 1930 for three golf courses, began to take their toll on the ecology of Lower St Regis Lake. By August 1901, property owners on the St. Regis Lake chain, including Paul's son Phelps, E.L. Trudeau, and Walter B. James, were concerned enough about the degradation to sign a resolution promising that after June 1, 1902, they would not allow "sewage, kitchen or sanitary water, waste water, or any other refuse of any kind whatsoever to be thrown or drained into any of the waterbodies of the St. Regis Chain." The resolution also stated that property owners "will not build or continue to use any dry well or cesspool at a distance of less than 30 feet from the shore of these waters."

Despite the property owners' efforts to curb pollution, the water quality of the lake continued to decline. When the first scientific examination of the St. Regis lakes chain occurred in 1930 as part of the New York State Biological Survey (NYCD, 1931), it showed that Lower St. Regis lake supported a high density of cyanobacteria, including the potentially toxic genera *Anabaena* and *Microcystis*.

THE COLLEGE NAMED PAUL SMITH'S

The founding of Paul Smith's College on the hotel properties in 1946 further exacerbated the lake's problems. Whereas the hotel guests were primarily seasonal, the college brought a growing population of year-round residents, students and faculty, to the shores of Lower St. Regis Lake. This caused a dramatic increase in water usage without any change in wastewater treatment methods. It would soon become apparent that nutrient-rich sewage leachate was accelerating the eutrophication of the lake. Eutrophication is a process in which lakes accumulate nutrients and become more biologically-productive. When accelerated by artificial pollution (a process called cultural eutrophication), it can cause rapid declines in water quality accompanied by excessive growth of phytoplankton (algae and cyanobacteria) and depleted levels of dissolved oxygen.

By 1955, observations by local residents indicated that summer phytoplankton blooms had become common. By the early 1960s these blooms were developing earlier in the summer and persisting longer. Biologists from Cornell University, working at the nearby Brandon Park Fishery Laboratory, observed an unusually heavy cyanobacterial bloom in 1964. In their analysis they laid blame on the college, concluding that the problem was most likely caused by nutrient pollution from the college's sewage disposal system (Flick and Webster 1964). The outdated hotel-era cesspools and tile fields still being used by the college were failing, causing nutrient-rich subsurface leachate and surface overflows to reach the lake.

In response to its failing wastewater systems, in 1965 Paul Smith's College began construction of a centralized sewage collection system and state-of-the-art sewage treatment plant. In this system, solids were removed from the wastewater in a settling tank ("primary treatment"), and the liquid slurry was then moved to an aeration tank where a living bacterial sludge broke down the organic matter ("secondary treatment"). Although modern for its day, there was an unforeseen problem with the secondary treatment. When sewage or other organic matter breaks down it releases nutrients, such as nitrogen and phosphorus, into the water where they become available for phytoplankton growth. Unfortunately, the sewage treatment plant's nutrient-rich effluent was being discharged into Weller Brook, also known as Easy Street Creek, from which it flowed directly into Lower St. Regis Lake, just a few hundred meters downstream.

Although unknown at the time, this was the root of the problem. With the modernization of the college's sewage system, wastewater from over 1,000 campus residents was now being converted into a steady stream of biologically available nutrients and released into a tributary of the lake. Data collected by Allen (1970) illustrated that the total phosphorus concentration in the treatment plant effluent was over 600 times greater than background concentrations in Weller Brook. It has been estimated that between 1966 and 1972 the college's wastewater treatment plant discharged an average of 1,230 pounds of free reactive phosphorus per year into Lower St. Regis Lake. This accounted for 46 percent of the total phosphorus inputs to the lake during that time, a remarkable amount considering that the college campus represented only 0.4 percent of the total watershed area (Tofflemire 1975).

Lower St. Regis Lake quickly responded to this nutrient enrichment. One of the heaviest plankton blooms on record occurred in the summer of 1968, when the lake became so thick with cyanobacteria that discoloration from the bloom was observed 32 kilometers downstream in the St. Regis River. Total phosphorus concentrations in Lower St. Regis Lake during this event were as high as 144 μg/L, nearly six times greater than the total phosphorus values in Spitfire Lake just upstream in the St. Regis chain (Fuhs et al. 1977).

By the summer of 1970, the residents of the St. Regis chain had had enough. They filed a formal complaint to the New York State Department of Health (DOH) over the poor water quality of Lower St. Regis Lake. State agencies responded in August, 1971 by conducting an ecological survey of the lake. They couldn't have arrived at a better time as the lake was once again experiencing a heavy bloom of the cyanobacterium *Anabaena* (NYSDOH 1972; Figure 2).

Carl Schofield of Cornell University and G. W. Fuhs of the DOH recommended that phosphorus be removed from the college's wastewater effluent. They surmised that if the phosphorus loading from the wastewater treatment plant was stopped the lake could be restored to something resembling its previously un-impacted state. It is important to note that these researchers were on the front line of an emerging understanding of the role that phosphorus plays in the productivity of lakes. At that time, only a handful of scientific papers existed on the relationship between phosphorus and phytoplankton growth (Edmonson 1970, Maloney et al. 1972), and direct experimental studies of the importance of phosphorus to lake eutrophication had yet to be published (Schindler 1974, 1975). In other words, these early studies of Lower St. Regis Lake were part of a pioneering stage of foundational research that now supports our understanding of how nutrient enrichment affects lakes, rivers, and oceans worldwide.

THE EPA AND THE SEARCH FOR ANSWERS

Lower St. Regis Lake was not alone. By the late 1960s the nation was developing a greater awareness of environmental issues in general. Aldo Leopold's writings (*A Sand County Almanac* and *The Land Ethic*) were helping to make "ecology" a household term, and Rachel Carson's *Silent Spring* was a best seller. In 1969, *Time Magazine* described Lake Erie as *"*a giant cesspool*"* and warned that it *"*was in danger of dying by suffocating.*"* That summer, only three of Lake Erie's 63 beaches were rated as suitable for swimming (*Time Magazine* 1969). By the late 1960s close to 10,000 lakes around the country showed signs of excessive algae growth (Ashworth 1987). The probable cause? Nutrient enrichment. The suspected culprit? Dissolved reactive phosphorus.

Dissolved reactive phosphorus (PO_4^{-3}) is a phosphorus-based molecule that is readily taken up by plants or phytoplankton and used as nutrition for their growth. By the late 1960s, a hypothesis was developing that free reactive phosphorus was acting as a fertilizer, causing excessive growth of algae and cyanobacteria in lakes, rivers, and oceans just as it stimulates plant growth in lawns, gardens, and farm fields. It was further thought that when the plankton eventually died and decayed, especially in the lowermost waters of a lake known as the "hypolimnion," that bacterial decomposition of the organic debris consumed oxygen. The result was plankton-choked lakes, fish kills due to the lack of oxygen, and stench.

Dissolved reactive phosphorus, most often in the form of phosphate, comes from many sources, but at that time the largest single source of phosphorus pollution in the nation's waterways was from detergents. After World War II, cleaning agents were reformulated to produce more sophisticated products to meet the needs of evolving household technology, such as automatic washing machines and dishwashers. In some cases, phosphates comprised up to 60 percent of the mass of the detergent. By chemically enhancing a detergent's cleaning abilities, phosphates helped to give clothes, according to one 1960s era commercial, *"whiter whites and brighter brights."*

Fearing for their water supplies and beaches, communities took action against the newly identified pollutant. In 1971, Dade County, Florida, banned high-phosphate detergents, and Erie County, NY, enacted Local Law No. 8, which prohibited the sale of phosphorus-rich detergents. The detergent industry cried foul, "not us," and brought suit (Soap & Detergent Association v. Clark) to overturn the local bans.

As this debate raged, in 1972 the recently formed United States Environmental Protection Agency (EPA) sought to bring more science to the controversy with the initiation of a National Eutrophication Survey (USEPA 1972). Of the 812 lakes chosen for this survey, 26 were in the state of New York, and one, Lower St. Regis Lake, was in the heart of the Adirondack State Park.

What could Lower St. Regis Lake tell those early investigators about nutrient enrichment and phytoplankton blooms? In the early 1970s, the lake was experiencing both. And, unlike many of the other lakes in the national survey with more complicated stories, it was already known that most of the dissolved reactive phosphorus flowing into Lower St Regis Lake could be traced to a single source, the Paul Smith's College sewage treatment effluent.

In the spring of 1972, with the phosphorus controversy raging and the National Eutrophication Study gearing up, Paul Smith's College and the DOH began to cut off the flow of phosphorus in its discharge stream. The college added "tertiary treatment," a form of nutrient removal, to its wastewater treatment process. First, phosphorus was bound chemically and made to precipitate out of solution through the addition of ferric chloride (July 1972 to May 1974). Later, the effluent was passed through sand filtration beds, and in 1974 the old discharge pipe to Weller Brook was shut off permanently.

These efforts put Lower St Regis Lake and the college's academic programs on a positive trajectory that continues to this day. As part of the National Eutrophication Survey, Paul Smith's College students in the Ecology and Environmental Technology (EET) program began working with water quality professionals from the New York State Department of Environmental Conservation (DEC) on a water quality-monitoring program that has collected data from Lower St Regis Lake for more than four decades. It also initiated academic programs to train environmental professionals who would soon make their marks in newly emerging environmental professions. The pioneering research that was conducted on Lower St. Regis and other lakes during the 1970s added to the scientific consensus that phosphorus was the problematic "limiting nutrient" in thousands of lakes that were undergoing cultural eutrophication. The college's mitigation efforts also began to alter the water quality, fisheries, and resulting recreational opportunities on Lower St. Regis Lake.

"WATER, WATER EVERYWHERE." ANYONE CARE FOR A DRINK?

Since the 1970s, the water quality of Lower St. Regis Lake has noticeably improved. But exactly what does that statement mean, and how do we know? During the half century since the initial concern about water quality on the lake, measurements of various water quality indicators have been made by the DEC, DOH, and Paul Smith's College students and faculty, among others. Three of those water quality indicators—phosphorus, chlorophyll-a, and transparency—have been particularly informative in that research. Although each parameter measures a different aspect of water quality, they are ecologically interrelated.

Free reactive phosphorus released into the water is quickly incorporated into the food web through algal and cyanobacterial growth. This can increase the concentration of green chlorophyll-a, which in turn lowers the transparency of the water. Phosphorus is of major importance to the metabolism and nutrition of all organisms. In lakes, however, it is normally present in relatively small amounts in its free reactive state. Adding extra phosphorus to a lake can stimulate plankton productivity because the other essential elements of life are typically available in excess. Lakes of low biological productivity ("oligotrophic") have total phosphorus concentrations of less than 10 µg/L, while highly productive lakes ("eutrophic") routinely have concentrations greater than 20 µg/L. During the early restoration efforts of 1970-1975, the total phosphorus concentrations of Lower St. Regis Lake averaged 45 µg/L, and observations of over 70 µg/L were common. More recently, the phosphorus concentrations in the lake have been much lower, averaging 12 µg/L between 2011 and 2017 (Figure 3). This large reduction in phosphorus availability is a direct result of the effluent diversion causing changes in the other two parameters of interest.

Measuring phytoplankton productivity in a lake can be difficult. However, measuring the amount of chlorophyll in the water is a relatively simple and inexpensive surrogate measure of productivity because chlorophyll-a is the main photosynthetic pigment found in algae and cyanobacteria. As a lake becomes more productive the concentration of chlorophyll increases. A typical oligotrophic lake has chlorophyll-a concentrations of less than 2 µg/L, while eutrophic lakes often have concentrations of 8 µg/L or greater. During the early 1970s the chlorophyll concentrations in Lower St. Regis Lake averaged 9 µg/L, with values occasionally as high as 18 µg/L. In contrast, chlorophyll concentrations averaged only 6 µg/L between 2011 and 2017 (Figure 3).

Transparency is a measure of water clarity and light penetration, and as phytoplankton productivity increases the transparency of the water decreases. Transparency is usually estimated by lowering a black and white Secchi disk to a depth at which it is no longer visible from the surface. During the early 1970s, the transparency of Lower St. Regis Lake averaged 1.6 meters, with several observations of less than one meter. During the 2011-2017 monitoring period the transparency averaged 2.2 meters, indicating a major increase in water clarity and/or light penetration that was largely the result of reduced phytoplankton productivity (Figure 3).

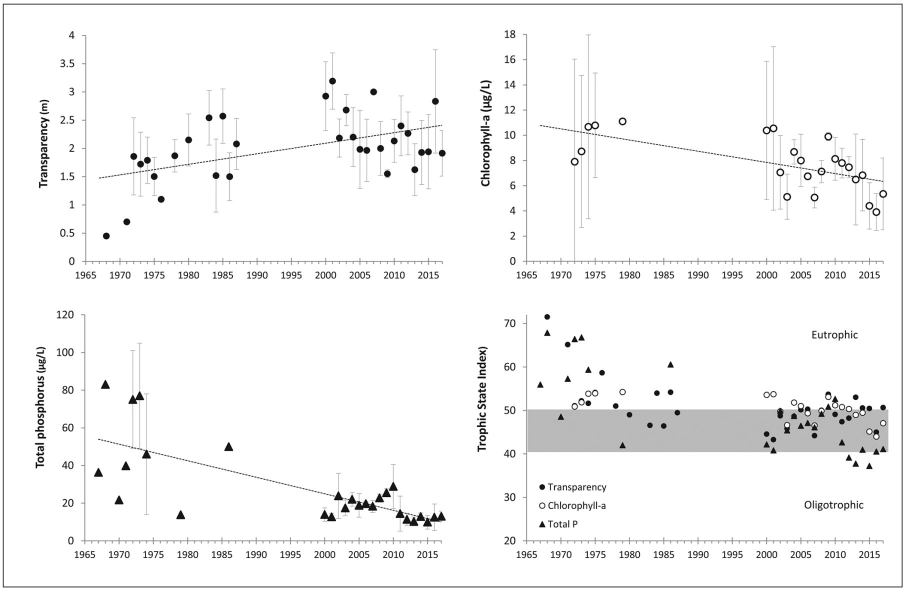

Figure 3. *Time series of annual average trophic indicators in the surface water of Lower St. Regis Lake, 1967-2017. Error bars represent one standard deviation of the mean. Dashed line indicates a significant historical trend based on the Kendall's Tau, a rank correlation coefficient (transparency: p value = 0.03, tau = 0.27; chlorophyll-a: p value = <0.001, tau = -0.51; total phosphorus: p value = 0.003, tau = -0.43).*

FISH ALSO HAVE A TALE TO TELL ABOUT LOWER ST. REGIS LAKE

Not many people would pour a glass of water and exclaim, "Wow, only 6 µg/l of chlorophyll-a, and 12 µg/l of total phosphorus. I'll bet the transparency is greater than 2 meters. Now *that* is good-quality water!" However, they might instead look at a lake and ask, "How's the fishing?"

HISTORICAL ACCOUNTS

The answer to this question in 1860 would be very different from the answer today. When Paul Smith arrived on the shores of Lower St. Regis Lake it was known as a brook trout lake. In his book *I Go A-Fishing*, William Prime provided two early accounts of fishing on the lake. In 1860, he recounted: "From him [an old guide] I learned that brook trout were abundant in one part of the pond, close by the house." As he described his experience, "…the fish rose at every cast; and when I had half a dozen of the same sort [a little less than 2 pounds], and one that lacked only an ounce of being four pounds, we pulled up the killeek and paddled homeward…" In 1872, Prime also wrote "I looked out across the lake to Peter's Rock and wondered whether trout would rise to a fly over there as in other years."

Historical accounts such as these are useful, but to better understand how and why the lake has changed, we need to dig deeper. We might ask, "What was the native fish community composition?" or "What can altered fish communities tell us about environmental changes" or even "Can the fish community be restored to its pre-impact state?"

To answer these questions, we need to look at stocking records and fish population surveys conducted over many years. In the case of Lower St. Regis Lake, sampling protocols were not standardized until 2004 when students in the Paul Smith's College Fisheries and Wildlife Science program began working on the lake, but the studies that are available provide important insights into the history of the fish community and ecological conditions in the lake during the last century.

FISH STOCKING IN LOWER ST. REGIS LAKE

As we have seen in Prime's accounts, brook trout were readily caught in 1860 and in 1872. Brook trout are highly susceptible to fishing pressure, and with the development of the hotel complex the local brook trout population would have likely declined. As a result, Paul Smith started stocking brook trout in the lake as early as 1885 and the stocking program continued through 1937 (Table 1). Lake trout stocking, which began a few years later, continued through 1955. Non-native brown trout and rainbow trout were occasionally stocked as well, with the last stocking of cold-water species, a brook trout x lake trout hybrid known as "splake," occurring in 1974.

Aside from the splake, most of the stocking of cold-water fishes was over by 1955, and the last official stocking, this time of a warm-water species, largemouth bass, was in 1974. This suggests that an ecological change in the lake, specifically oxygen depletion in the hypolimnion, made further stocking of trout species futile.

Table 1. *Fish stocking records for Lower St. Regis Lake.*

SPECIES	YEAR
SAM Brown	1884, 1887
Unknown species	1887, 1896
Brook Trout	1885, 1889, 1893, 1896, 1897, 1899, 1930, 1931, 1935, 1937
Lake Trout	1889, 1897, 1932, 1938, 1940, 1942-1947, 1950-1955
Rainbow Trout	1947-1949
Splake	1974
Largemouth Bass	1974

THE NATIVE FISH COMMUNITY OF LOWER ST. REGIS LAKE

The earliest detailed analysis of the fish community was a statewide biological survey conducted by the State of New York in 1930. This study provides clues to the composition of the native fish assemblage on the basis of how the lake itself was likely classified. In that survey, deep lakes were assumed to support oxygen-demanding cold-water fish species such as trout. Shallow lakes were split into two categories; shallow warm water lakes supporting only warm-water fish species, and shallow cold-water lakes with some cold-water species persisting during the warm summer months, most often in spring-fed refuges.

Lower St. Regis Lake itself was not classified in the 1930 survey, but the adjacent Spitfire Lake was classified as a shallow cold-water lake. Because they have similar maximum depths (10 meters for Lower St. Regis and 8 meters for Spitfire), we can presume that Lower St. Regis Lake would have been classified a shallow cold-water lake, as well, and that the hydrological connection between the two lakes allowed fish to move between them. Assuming Lower St. Regis Lake had been classified a shallow cold-water lake, the expectation is that Lower St. Regis Lake would have supported three general fish assemblages: (1) a cold-water assemblage including brook trout, (2) a cool-water assemblage comprised of a diversity of minnows, and (3) a few warm-water species (Table 2).

Table 2: *Generalized native fish assemblages in Lower St. Regis Lake based on temperature preferences. This table includes only fishes that were actually collected in the 1930 survey.*

COLD-WATER ASSEMBLAGE	COOL-WATER ASSEMBLAGE	WARM-WATER ASSEMBLAGE
Whitefish	Creek Chub	Pumpkinseed
Lake Trout	Pearl Dace	Brown Bullhead
Brook Trout	Finescale Dace	White Sucker
Longnose Sucker	Common Shiner	
Slimy Sculpin	Brassy Minnow	
Lake Chub	Northern Redbelly Dace	

SCIENTIFIC POPULATION SURVEYS

The 1930 survey (Table 3) documented 15 fish species in Lower St. Regis Lake; three cold-water salmonid species and 9 other species from the cool-water and warm-water assemblages. Lake trout were stocked in previous years, and whitefish were said to have been stocked to provide a food source for the lake trout, so these two species could have been introduced rather than being part of the native community. The genetic strain of hatchery-reared brook trout stocked into the lake is uncertain, so their effect on the population decline or the degree to which any native strains may have declined as a result is unknown.

The fish community was surveyed again during the early 1970s, and by then the changes were dramatic. The cold-water and cool-water fish assemblages no longer existed. Fish in the warm-water category thrived, specifically brown bullhead, white suckers, and pumpkinseeds which are more tolerant of eutrophication conditions. As seen in the previous analysis of water chemistry, phosphorus pollution caused high phytoplankton productivity followed by decomposition and anoxic conditions in the deep water. In addition, the introduction of non-native golden shiners, largemouth bass, and perhaps northern pike would have changed competitive relationships within the fish community. Golden shiners are large minnows with a high reproductive capacity and the ability to out-compete native minnow species, and largemouth bass and northern pike prey upon native minnows. By the time of this survey, four of the six native minnow species were extirpated from the lake, but they can still be found in adjacent tributaries and wetlands connected to the lake where their non-native predators and competitors are rare or absent.

Table 3: *Fish species documented in fisheries surveys of Lower St. Regis Lake.*

COMMON NAME	SCIENTIFIC NAME	1930	1971	1972	1973	1986	2004	2016	2017
Family: Salmonidae									
Whitefish (C)	Coregonus sp.	X							
Lake Trout (C)	Salvelinus namaycush	X							
Brook Trout (C)	Salvelinus fontinalis	X		X					
Family: Esocidae									
Northern Pike	Esox lucius		*			X	X	X	X
Family: Catostomatidae									
White Sucker	Catostomus commersoni	X	X	X	X	X	X	X	X
Longnose Sucker (C)	Catostomus catostomus	X							
Family: Cyprinidae									
Lake Chub (C)	Couesius plumbeus	X							
Creek Chub	Semotilus atromaculatus	X							
Pearl Dace	Margariscus margarita	X							
Finescale Dace	Chrosomus neogaeus	X							
Common Shiner	Luxilus cornutus	X							
Brassy Minnow	Hybognathus hankinsoni	X							
Northern Redbelly Dace	Chrosomus eos	X							
Golden Shiner	Notemigonus crysoleucas		X	X	X	X	X	X	X
Family: Ictaluridae									
Brown Bullhead	Ameiurus nebulosus	X	X	X	X	X	X	X	X

COMMON NAME	SCIENTIFIC NAME	1930	1971	1972	1973	1986	2004	2016	2017
Family:Osmeridae									
Rainbow Smelt	Osmerus mordax					X			
Family: Centrachidae									
Pumpkinseed	Lepomis gibbosus	X	X	X	X	X	X	X	X
Rock Bass	Ambloplites ruprestris						X	X	X
Black Crappie	Pomoxis nigromaculatus							X	X
Largemouth Bass	Micropterus salmoides		X			X	X	X	X
Smallmouth Bass	Micropterus dolomieui						X	X	X
Family: Percidae									
Yellow Perch	Perca flavescens		X	X	X	X	X	X	X
Family: Gasterosteidae									
Brook Stickleback	Culaea inconstans							X	
Family: Cottidae									
Slimy Sculpin (C)	Cottus cognatus	X							
Species Richness=		15	6	6	5	8	9	11	10

THE EMERGENCE OF A NEW FISH COMMUNITY

Since the 1970s, the fish community of Lower St. Regis Lake has continued to change with the addition of new species. By 1971, brook trout were absent and white suckers, brown bullheads, and pumpkinseeds accounted for 857 of the 1068 fish caught in the survey. Another species recorded for the first time in 1971 was yellow perch. Fisheries biologists have long assumed that yellow perch are not native to the Adirondack uplands, based largely upon their absence in earlier surveys. However, Paul Smith's College faculty and students recently challenged that assumption and triggered a professional debate. They found yellow perch DNA in two sediment cores from Lower St. Regis Lake that dated as far back as 2000 years (Stager et al. 2015). Contrary to popular belief, this suggests that yellow perch might be native to the region. However, even if perch were present in the original community in low enough numbers to be overlooked in the 1930 survey, it is clear that they only became abundant in Lower Saint Regis Lake during the 20^{th} century in response to ecological changes taking place in the Lake.

A 1986 survey showed that the fish community had not changed substantially since 1971. However, surveys with standardized sampling procedures only began 2004. These surveys carried out in 2004, 2016 and 2017, show that the community composition has become dominated by fishes in the family Centrarchidae; pumpkinseeds, black crappies, rock bass, largemouth bass and smallmouth bass (Table 3).

Today, the fish community in Lower St. Regis is very different from its native composition, being comprised of a mix of cool-water species (e.g., northern pike and yellow perch), warm-water species from the bass and sunfish family, and one non-native minnow species, golden shiner. Although this mix is largely the result of informal introductions, improved water quality in the lake may also benefit some species more than others, influencing community dynamics.

THE PATH TO RECOVERY LEADS WHERE?

Recovery can be defined as a return to a normal state of health and vigor. Ecological restoration is a field that works to "renew and restore degraded, damaged, or destroyed ecosystems and habitats in the environment…" If we wish to return somewhere, though, we might start by getting a better idea of where we came from.

To look at the earliest history of the lake we need to study the fossilized remains of its earliest inhabitants. Paleoecology is the study of past environments, and in the case of lakes it typically involves studies of the remains of organisms that once lived within and around the lake. In the case of Lower St. Regis Lake, the silica-rich remains of diatoms (a common kind of alga in the phytoplankton) found in layers of ancient sediment that have accumulated on the lake bed are particularly useful in determining past environmental conditions.

By carbon-14 dating the sediments it was determined that Lower St. Regis Lake is approximately 14,000 years old. It formed shortly after the continental ice sheets retreated from the Adirondack uplands at the end of the last ice age, and it has been accumulating diatom-rich sediments ever since (Paleoecology 2017). Figure 4 equates the depth of bottom sediments to the approximate time they were deposited and show that the lake began filling in with organic matter about 14,000 years ago.

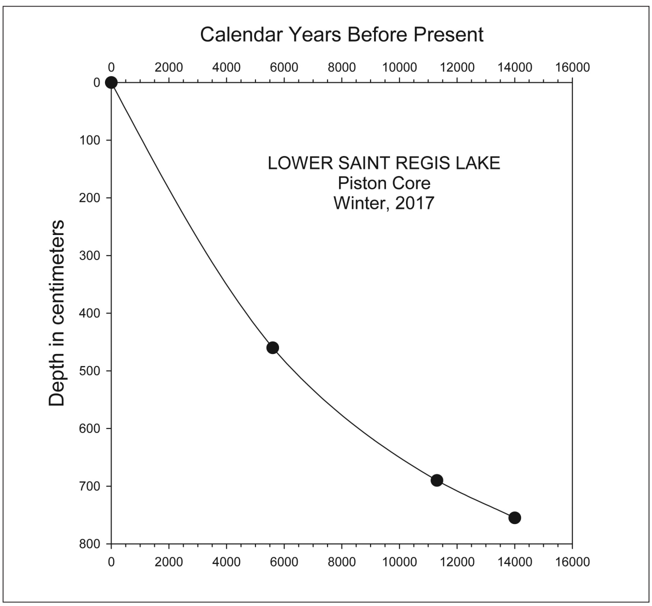

Figure 4: *Carbon-14 dating of a sediment profile from Lower St. Regis Lake. The lower three black circles on the age-depth curve indicate calibrated radiocarbon dates. The uppermost black circle indicates the sediment surface, which is presumed to have been deposited in 2016-2017.*

Fourteen thousand years ago the landscape around Lower St. Regis Lake was probably a tundra-parkland ecosystem with scattered spruce and birch thickets. The lake itself could have been a watering hole for caribou and musk oxen as well as a home to people who hunted those animals. A flint projectile point found on the shore of Tupper Lake has been traced to Paleo-Indian hunters who inhabited the region between 13,000 and 10,000 years ago, and a flint point found on the PSC campus might be of similar age (Stager 2017).

Native North Americans continued to live in the area right up to the time when Paul Smith arrived. Bits of ancient pottery, flint flakes, and projectile points dating back thousands of years have been found on Picnic Point and Peter's Rock (named after the Native American guide and veteran of the War of 1812, Peter Sabattis), and a broken pot was found in a rock shelter near the base of St. Regis Mountain (Stager 2017). Accounts in the diary of James Wardner from Rainbow Lake (Wardner 2010) maintain that an indigenous encampment was located on the site upon which Paul Smith built his hotel, and that Paul evicted those people after he became the owner of the property. During the late 1800s, Abenaki guide Mitchell Sabattis reported that his father Peter Sabattis told him that Lower St. Regis Lake used to be called "Akwesasne Lake," after the ancient settlement of Akwesasne which was located where the St. Regis River meets the St. Lawrence. This makes sense because Lower St. Regis would have been the first lake that native travelers from Awkesasne would have encountered on their journeys into the uplands.

Those first Adirondackers probably had little impact on the lake that most of us now know as Lower St. Regis. In 2018, however, the Paul Smith's College Paleoecology class used sediment records to date the recent onset of cultural eutrophication in the lake, in order to help identify its original cause as well as the more recent changes that followed. Under faculty direction, students cored the bottom sediments, dated selected depths with a lead isotope method, and analyzed changes in the diatom species preserved in the sediment layers. Diatoms typical of eutrophic lakes, such as *Fragilaria crotonensis,* are common in today's lake, but they were rare at the bases of the cores (Figure 5). Their abundances began to increase in sediments that were deposited during the mid-1800s. This means that the first signs of cultural eutrophication began about when Paul Smith built his hotel. That is not surprising because the hotel brought logging to the St. Regis watershed, which would have introduced nutrients from floating logs and land clearance. It also added sewage from guests and livestock, fertilizers from the hotel grounds and gardens, and soils from increased shoreline erosion after the level of the lake was raised, all of which added nutrients to the food web and bottom sediments.

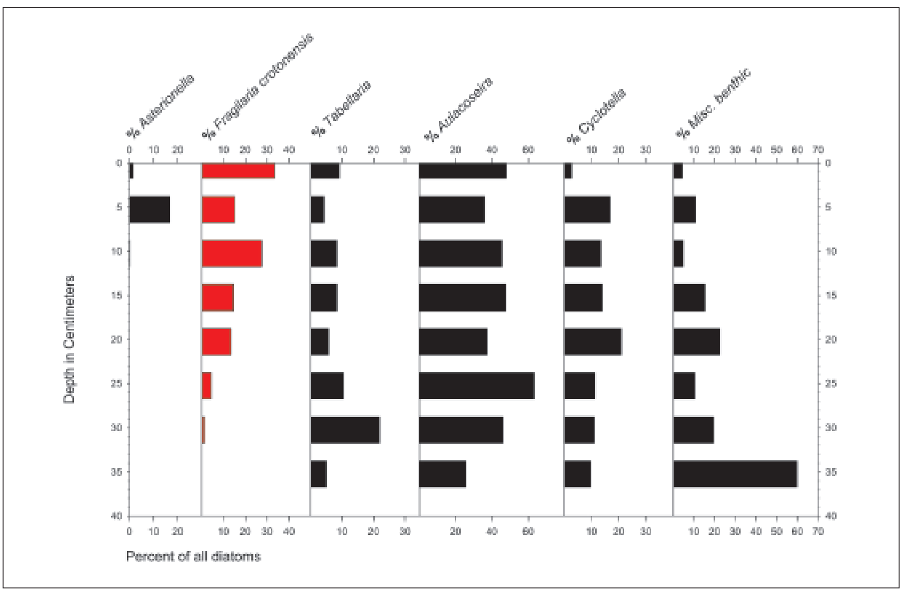

Figure 5: *Diatom assemblages in a sediment core from Lower St. Regis Lake, representing the last two centuries or so. Percentages of Fragilaria crotonensis, an indicator of eutrophication, are shown in red. Sediments that were deposited when Paul Smith's Hotel was established lie at approximately 25 cm depth on this chart.*

All of this raises another question; "what condition do we want to restore the lake to? Assuming that a post-glacial tundra with caribou and musk oxen is out of the question, do we want to go back to the Akwesasne Lake of the early Adirondackers, to the lightly impacted book trout lake of Paul Smith's days, or are we happy with the less culturally eutrophic pike and bass waters of today? Once we decide where we want to go, the next question becomes, "can we get there?"

An ecological legacy can be defined as "the influence of past events on the structure and behavior of extant ecosystems" (Little et al. 1997, Vogt et al. 1997). The enduring legacy of phosphorus enrichment in Lower St. Regis Lake is found in the bottom sediments and in the reduced dissolved oxygen levels in the hypolimnion of the thermally stratified lake in summer.

As we have seen (Figure 3, and accompanying discussion of water chemistry) lots of free reactive phosphorus was flowing into Lower St. Regis Lake during the 1960s and early 1970s, causing algae blooms and reducing water clarity. Plankton thriving in the well-lit upper layers of the lake were dying, raining down, and settling on the bottom as a brown or black flocculent sediment. As this organic material slowly decayed, it used up the hypolimnion's oxygen supply and helped buried nutrients from years past to escape from the bottom sediments. In the fall and spring turnover periods, when the lake lost its thermal stratification, the hypolimnion re-oxygenated and the nutrients dispersed throughout the water column, stimulating more plankton growth.

Figure 6 shows snapshots of oxygen profiles of Lower St Regis Lake in its summer stratified state as well as the extent of the anoxic region from 1974 to 2017. What is striking about these profiles is that although the surface water quality has been improving, oxygen depletion in the bottom waters has not, and that legacy of past pollution is a problem for the future as well as the present.

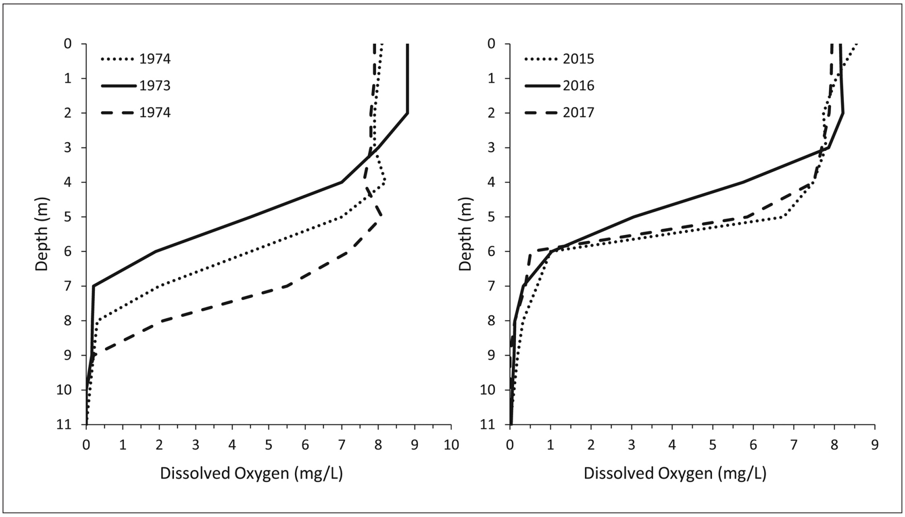

Figure 6: *Late summer dissolved oxygen profiles from Lower St. Regis Lake. Data from the early restoration period of 1972-1974 are on the left, and most recent data from 2015-2017 are on the right.*

Dissolved oxygen is essential for metabolism in most organisms and it also plays an important role in non-biotic chemical reactions in the water and sediments (Wetzel 2001). The primary source of oxygen in a lake is usually the atmosphere, but when a lake becomes thermally stratified the hypolimnion is seasonally isolated from this oxygen source. When lake sediments contain high amounts of organic material, bacterial decomposition consumes dissolved oxygen and can cause hypoxia (dissolved oxygen < 2.0 mg/L) or anoxia (dissolved oxygen < 0.5 mg/L). A certain amount of hypoxia may be normal in some lakes, but nutrient enrichment resulting from human activities stimulates phytoplankton productivity and subsequent decomposition and oxygen loss.

How long will this legacy of the past influence Lower St. Regis Lake in the future? Only time will tell, but in all likelihood its effects will last a very long time.

Lower St. Regis Lake is also being influenced by global environmental changes. Figure 7 shows changes in the date of ice-out on Lower St. Regis Lake and on Mirror Lake in nearby Lake Placid, NY. The left side of the graph, representing ice-out dates from 1900 to the 1940s, shows the natural variability that occurred in the arrival of open water conditions each spring. The right side shows a statistically significant trend towards earlier ice-out dates starting in the 1970s and continuing to the present. Warmer temperatures that cause earlier ice-out can also cause longer periods of lake stratification and seasonal oxygen depletion during longer, warmer summers. As the world continues to warm, in the future it will require lake managers to make even greater efforts to maintain the stabilized or improved water quality conditions that lakes such as Lower St. Regis Lake have now begun to display (Jeppesen et al. 2017).

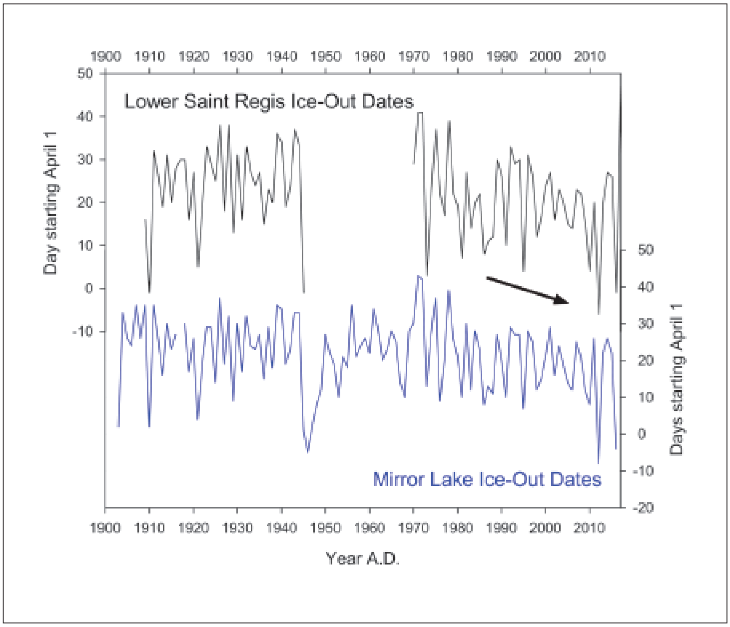

Figure 7: *Ice-out dates on Lower St. Regis and Mirror Lake, showing a trend toward earlier dates beginning in the 1970s.*

THE ECOLOGICAL REDEMPTION OF LOWER ST. REGIS LAKE

Ecological redemption, a concept developed by Burch, Machlis and Force (2014, 2017) is not restoration. For many years to come, Lower St. Regis Lake will be different from what it once was, all because of what human activities did to it during the last century and a half. As long as the phosphorus-laden organic matter remains to decay on the lake bottom it is available to reduce hypolimnetic oxygen levels and periodically enrich the surface waters, resulting in sporadic reprises of those unwelcome phytoplankton blooms of the 1970s. Such events will become more likely to occur during the longer, hotter summers expected of the future (Stager and Thill 2010). With an oxygen-depleted hypolimnion there is no longer a suitable habitat for the cold-water fish species that occupied Lower St. Regis Lake in the past.

Does this mean that our pollution control efforts have failed? Not at all. We have seen in this paper how the water quality of Lower St. Regis Lake has improved in recent decades. You may need to trade your lake trout fly for a pike lure, but fishing is still good. Is it the same lake it was when Paul Smith and the first Adirondackers knew it? No. Will it ever be the same as it was? No. But the lake is still beautiful and enjoyable for those of us who know it today. Our efforts to clean up Lower St. Regis have, in this sense, redeemed its aesthetic and recreational qualities. But ecological redemption comes at a cost, and that cost is vigilance. Hidden below the surface is a legacy in the form of oxygen depleting, phosphorus-rich bottom sediments from our environmentally "sinful" past. Without continued monitoring and action to protect the lake and its watershed, Lower St. Regis Lake could once again be said to "fall from grace" by returning to the former days of intense cultural eutrophication.

The environmental history of Lower St. Regis Lake, from degradation to ecological redemption, has left another enduring legacy on the Adirondack landscape. That is the legacy of the environmental work that was done here to identify a globally significant environmental problem and set a path for well-informed and effective action. The lake monitoring, the college's field and lab studies, and a growing environmental consciousness among the general public resulted in a commitment to change practices that impact water quality, and they also changed Paul Smith's College profoundly. "By the shores of fair Saint Regis" [the first line of the college's alma mater song], research efforts and academic programs that were originally developed to monitor and track water quality changes in this historically important lake have had, and are still having, personal and professional impacts far beyond the shores of this exceptional lake, the Adirondack Park, and the nation.

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To the Paul Smith's College students who over the years worked on the water and in the lab to better understand the ecology of Lower St. Regis Lake.

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