Management plan and state of the lake report for Paradox Lake, NY

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Continued inside back cover

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Executive summary

This document provides a management plan for Paradox Lake that can be adapted in the future by the Paradox Lake Association and regional management partners. Paradox Lake is a dual-basin lake in Essex County, NY and is within the Adirondack Park. The lake provides a popular destination for boating, swimming, fishing, and aesthetics for residents and non-resident visitors. The primary management concern of lake stakeholders in recent years is spread of Eurasian watermilfoil (*Myriophyllum spicatum*). Initially documented in the upper basin of the lake, the species has been actively managed since 2008. The management plan that follows was developed to include objectives and alternatives for ongoing Eurasian watermilfoil management, continued water quality monitoring, and public use and safety on the lake based on stakeholder surveys and feedback, characteristics of the lake and surrounding watershed, analysis of long-term water-quality monitoring data, compilation of available plant monitoring and management data, and evaluation of recreational fisheries. Each of these efforts is detailed in a "state of the lake" report that follows the management in the hopes that the compiled information will facilitate continued updates to the document.

According to long-term water quality monitoring, the upper basin was historically more productive (supporting more plant or algae growth) than the deeper, larger lower basin, but has become less so in the last decade. As a whole, the lake has low-to-moderate productivity based common indicators of productivity, including total phosphorus and nitrogen concentrations, Secchi depth (water transparency), and chlorophyll *a* concentration. This generally is perceived positively by lake users because low productivity confers clear water, reduced susceptibility to algae and plant over-growth, and increased ability of a lake to support popular cold-water fishes such as lake trout and salmon. The pH (lower values being more acidic) and alkalinity (ability to buffer changes in pH) have increased in recent decades. This is likely associated with recovery from acid rain deposition as observed elsewhere in New York and may be facilitated by limestone bedrock underlying much of the nearby watershed. Minimal change in ion concentrations have been observed despite increasing awareness of potential impacts of practices such as use of road salt in the region.

Plant surveys indicated that Eurasian watermilfoil has increased in distribution and relative abundance and now occurs in multiple locations in both basins, although plant density remains at manageable levels. Invasive species including Eurasian watermilfoil and curly leaf pondweed have been hand-harvested annually or semi-annually for the past several years. Despite extensive volunteer and contracted harvesting efforts, monitoring through the Adirondack Park Invasive Plant Program indicates that Eurasian watermilfoil continues to spread to new locations in the lake.

Fisheries surveys conducted periodically since 1985 suggest that warm water fisheries for species such as bass and sunfishes remain balanced between large and small fish, which can provide regular opportunities to catch quality size bass and sunfish while allowing for the occasional larger fish. The proportion of large lake trout collected in surveys has increased in recent years but it is unknown whether this is due to sampling methodologies, natural variability, or meaningful biological trends.

Table of Contents

Introduction

Background

Paradox Lake is located within the Adirondack Park in the Town of Schroon in Essex County, NY. The lake is so named because high spring discharge events can cause its outlet, the Schroon River, to increase in elevation to such an extent that flow reverses, and the Schroon River becomes a tributary to Paradox Lake. Before its incorporation, the Schroon area was largely French-dominated. Water, fish, game, and timber attracted people to the area, and flat, fertile land along the Schroon River provided suitable area for settlement. Old State Road, which later became part of the Adirondack Northway I-87, connected Schroon to Canada (Essex County Historical Society, personal communication).

The early economy was structured around timber. Logs that were not used locally were sent south down the Schroon River to Glens Falls, NY. In the mid-nineteenth century, the leather tanning industry reached its highest level of production due to the accessibility of hemlock trees that provided tannin for the process. However, other chemical processes quickly became less expensive, and the industry declined (Essex County Historical Society, personal communication). Today, the lake is home to a combination of full-time and seasonal residents, and is a popular destination for hiking, camping, fishing, and other outdoor activities.

Like many lake associations in New York State, the Paradox Lake Association (PLA) is involved with the management of their lake and the surrounding watershed. The presence of invasive macrophytes like Eurasian watermilfoil (*Myriophyllum spicatum*), more frequent algal blooms, and increasing boat traffic through the public boat launch are common concerns of residents and visitors to the lake. The PLA has worked with volunteers, private firms, municipalities and government agencies, and academic institutions to monitor and manage the lake in recent decades, with some monitoring records from as early as the 1930s (NYSDEC 1994).

Objectives

The objective of this document is to compile available monitoring and management information that can be used by the PLA to establish management objectives and determine appropriate strategies for achieving those objectives. To do this, we 1) characterized physical characteristics of the watershed based on available public data sources, 2) analyzed stakeholder concerns and priorities, 3) compiled and analyzed available water quality monitoring data, 4) conducted qualitative surveys of plant communities and compiled results of other surveys to date, 5) updated fishery information with a recent survey and compiled results of historical surveys, and 6) provided management alternatives to fit stakeholder objectives.

Management Plan for Paradox Lake

1 Overview and management goal

The goal of this section is to provide a long-term plan for the sustainable management of Paradox Lake by the Paradox Lake Association and other stakeholders. The identified purpose of the lake association is "*to preserve and protect Paradox Lake and its surroundings, to enhance the water quality, fishery, boating safety, and aesthetic values of Paradox Lake, as a public recreational facility for today and for future generations*." Informed by the 2017 stakeholder survey and subsequent discussion with board members, the plan will focus on in-lake and watershed alternatives that can be used or explored further to help achieve this goal.

2 Summary of results

Paradox Lake is a dual-basin, class AA lake in Essex County, NY in the Town of Schroon. It has historically been classified as chemically mesotrophic (moderately productive) when annual averages from both basins have been taken together. When looking at each basin individually, the lower basin has been classified as oligotrophic since the start of monitoring and the upper basin has become increasingly oligotrophic in recent years. According to 2020 data, the lower basin maintains an oligotrophic state and the upper basin is currently in a meso-oligotrophic state (Table 1). The historical differences in productivity between basins could be due to several factors, including basin depth and the direction of water flow (from the upper into the lower basin) among others.

Despite reduced productivity in the upper basin, Eurasian watermilfoil has continued to spread in the lake. While distribution of Eurasian watermilfoil has broadened, it is unclear whether the plant biomass has increased at this time. However, results of monitoring by APIP and SUNY Oneonta during recent years suggest Eurasian watermilfoil continues to spread and now constitutes a proportionally larger percentage of the plant community than it did when management for this species began in 2008.

Paradox Lake continues to support both warmwater and coldwater fisheries that serve both local residents and public visitors to the lake. The warmwater fishery appears to have maintained a state of balance in relative proportions of large and small fish, both within species and among predators and prey. It offers ample opportunity to angle for a variety of species including northern pike, black bass, sunfishes, and crappie. The coldwater fishery is composed primarily of stocked rainbow trout, lake trout, and landlocked Atlantic salmon. These fisheries are supplemented through annual spring stocking of about 5,000 yearling (9") rainbow trout, 1,500 yearling (6"-7") lake trout, and 500 yearling (6"-7") Atlantic salmon by NYSDEC.

Historical data from NYSDEC suggest that the representation of large lake trout has increased in recent years, but it is unknown whether this is the result of sampling methodologies or realized changes within the population.

Table 1. Classification of lake nutrient status (modified from NYSDEC 2013) compared to 5-year averages for upper and lower basins of Paradox Lake during 2016-2020. Numbers in parentheses are means of measurements from ALAP (2020).

Lake status	Total phosphorus (µg/L)	Chlorophyll *a* (µg/L)	Secchi depth (m)
Oligotrophic	< 10	< 2	> 5
Mesotrophic	10-20	2-8	2-5
Eutrophic	> 20	>8	< 2
Upper basin	8.1 (8.5)	2.6 (1.2)	3.96 (4.4)
Lower basin	6.1 (4.8)	1.7 (1.4)	5.1 (5.6)

3 Summary of stakeholder perceptions

According to the stakeholder survey conducted in 2017, the most common uses of Paradox Lake were swimming (28%), boating (canoe/kayak; 25%), and boating (motor; 22%). Invasive plants were the top concern of stakeholders (Figure 1). Eighty-eight percent of stakeholders responded that this was the issue about which they were "most concerned," and the remaining 12% responded "moderately concerned." The second and third most concerning issues were aesthetics (58% were "most concerned") and water clarity (55%). Most stakeholders were satisfied with current management practices, and there was some indication in the results that stakeholders were more commonly satisfied with management practices that included local (i.e., PLA) involvement and participation.

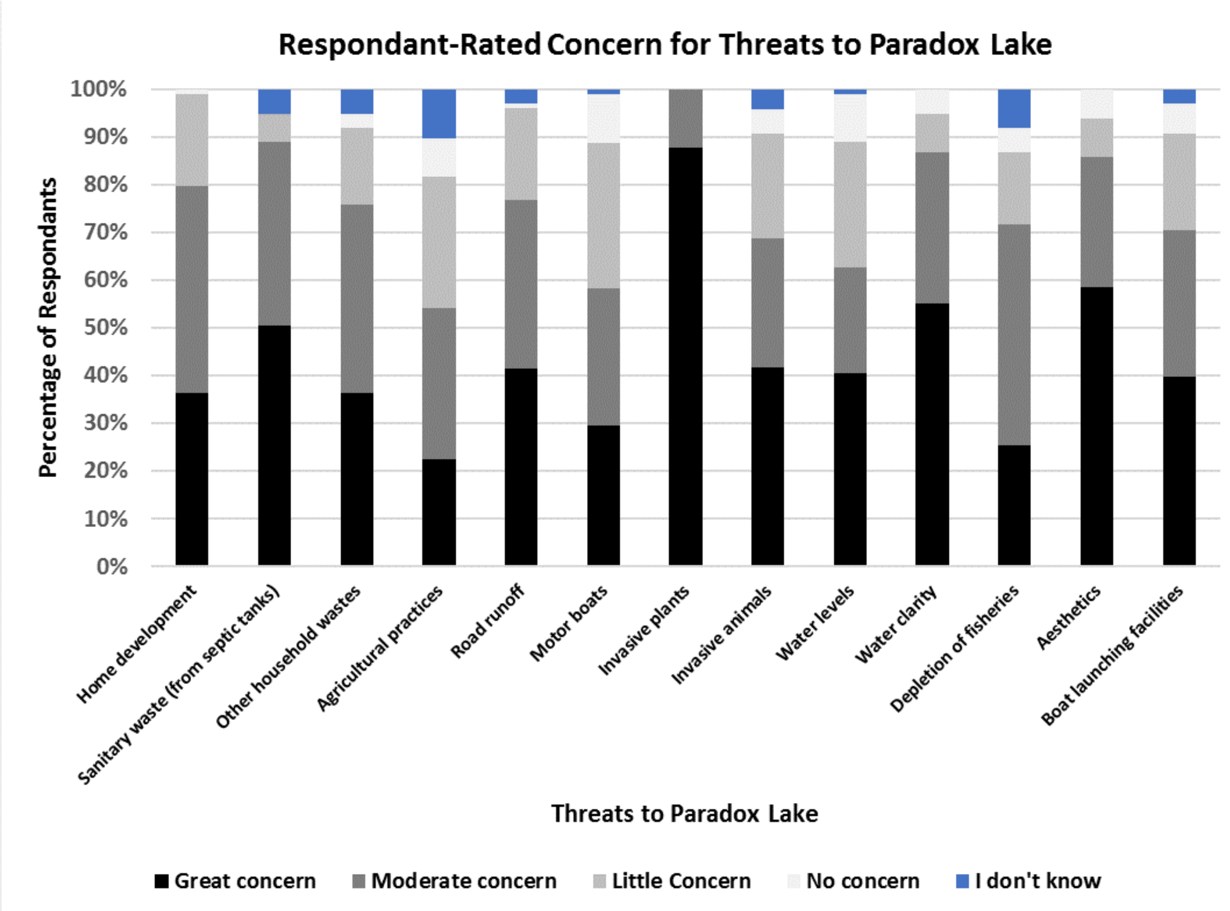


Figure 1. Paradox Lake stakeholder survey ratings of concern about various issues.

4 Management history

The first record of monitoring on Paradox Lake is from the 1932 Upper Hudson River Biological Survey conducted by the Conservation Department (predecessor to the DEC). The results from that survey indicated higher water transparency than contemporary surveys. It also showed low dissolved oxygen in the hypolimnion (as low as 4 parts per million) that can impact cold-water fish species such as lake trout. A series of surveys and stocking evaluations were conducted during the mid-1900s (NYSDEC 1994) before detailed recorded keeping allowed inclusion in what is now the NYSDEC state-wide fisheries database (NYSDEC 2022).

Paradox Lake was next surveyed in 1982 as part of the Lake Classification and Inventory survey by the NYSDEC. Water transparency was still slightly higher than contemporary results, but phosphorus and chlorophyll *a* were higher.

The PLA participated in CSLAP in 2003, 2005, 2007-2011, and 2013. Since 2014, the PLA has been participating in a similar program, the Adirondack Lake Assessment Program (ALAP). Annual summaries for CSLAP surveys can be found at http://www.dec.ny.gov/lands/77872.html, and annual reports for ALAP can be found at https://www.adkwatershed.org/adirondack-lake-assessment-program.

From 2000 to 2015, the PLA also worked with Adirondack Ecologists, LLC (AE). The initial goal was to establish a baseline for limnological data from which future research could be compared. They completed shoreline surveys of macrophyte (plant) communities (AE 2014a), in addition to water-quality monitoring (AE 2014b). Water quality monitoring data and trends in these reports were similar to those from CSLAP monitoring that covered the same time period.

In 2008, Eurasian watermilfoil was discovered near the public boat launch by AE personnel. Since the discovery, Eurasian watermilfoil management has constituted the main priority for monitoring and management within the lake. From 2008 through 2013 the PLA contracted Adirondack Ecologists LLC to hand-harvest. Volunteer divers have hand-harvested plants annually since 2012 to minimize the spread of the plant and provided critical coverage during years 2014-2016. Additional harvesting was contracted as needed. Since 2016, the PLA has worked with Aqualogic, Inc. to harvest the densest plant beds, relying primarily on hand harvesting. The lake association began working with the Adirondack Park Invasive Plant Program (APIPP) in 2015 and participated in the Lake Tracker Management Program in 2019 and 2021 (Schwartzberg et al. 2021) to implement a repeatable monitoring program.

5 Management Alternatives

Management alternatives were compiled based on historical priorities of the PLA and most concerning management issues identified through the 2017 stakeholder survey, and tailored to fit within the regulatory and management frameworks of the Adirondack Park. The management alternatives presented in this plan are in line with the overarching goals outlined above and:

1) are standard practice in the field of lake management,
2) are minimally invasive regarding human health or ecosystem impacts, and
3) can be modified easily to adapt to changes in regional management circumstances or in-lake conditions

5.1 Eurasian watermilfoil

Invasive plant growth was the most common concern of stakeholders according to the 2017 stakeholder survey and based on conversations with PLA board members continues to constitute the highest priority for management within the lake. Invasive plants, in this case, are plants that are not native to the New York Adirondack region and have potential to affect human uses or local ecology in undesirable ways.

Eurasian watermilfoil and curly-leaf pondweed are the most abundant invasive plants that have been observed in Paradox Lake to date. Management options for the control of these aquatic invasive species are based on currently available management options within New York with the understanding that local (i.e., Adirondack Park) regulations may or may not currently support their widespread use. However, recent developments in lake management products and techniques have prompted test cases for select applications of previously unsupported management alternatives. As laws or policies are updated, new management options become available, so we include alternatives that may be uncommon now but more common in the future.

5.1.1 Outreach

Outreach regarding invasive plant control can happen on two fronts: with public lake users and with regulatory, municipal, and management bodies. The goal of outreach with lake users most commonly is to promote knowledge and education about invasive species but can also include ongoing efforts to recruit volunteers for monitoring or management. The PLA has a strong history of communicating plans and results with public stakeholders through semi-regular PLA and public meetings, social events, and signage. Designation of volunteer recruitment under the duties of current board members in the PLA bylaws promotes continuation of these efforts (PLA 2019). Posting of board meeting minutes, events, and results of monitoring or management activities on the PLA website (https://paradox-lake.com/) promotes dissemination of information and transparency of science and decision making. These are practices that generally are high impact and low cost and should be continued into the foreseeable future.

With many public and private institutions invested in monitoring and management of Paradox Lake, the PLA may also consider assigning one or more liaisons or representatives to streamline communications with partners and cooperators. These could include communications with local municipalities (e.g., town boards), regulatory or management agencies (e.g., APA, NYSDEC, Essex County Soil and Water Conservation District) if this not already formalized. Continued collaboration with regional academic institutions (e.g., Paul Smiths AWI) and collaboratives such as APIPP will ensure that PLA Board and members can stay informed about emerging opportunities for monitoring and management. Finally, regular communication with lake management companies or other contractors could be included within this objective. Each of these components of outreach are activities that the PLA has successfully carried out in the past. Formalization of these roles within the duties of Board members or their appointees will promote continuation of these activities in the future.

5.1.2 Control objectives

The PLA should establish formal short-term and long-term objectives for the management of Eurasian watermilfoil in Paradox Lake in collaboration with partners identified through ongoing or newly initiated outreach activities. While permanent eradication of Eurasian watermilfoil from Paradox Lake is unlikely, informed management can provide control and minimize negative impacts on native plant communities while remediating issues related to human uses and activities within the lake. As an over-arching goal, the PLA might consider "minimizing the negative impacts of Eurasian watermilfoil on native plant communities and human activities within Paradox Lake". Objectives that would contribute to this goal might be associated with reducing surface acreage, biomass, number of sites where present, or percent relative abundance within sites where present. Control options can then be focused to achieve those specific objectives and monitoring can be used to determine whether those goals are being met on an annual or otherwise regular interval. This approach can also be used to evaluate alternatives needed for Eurasian watermilfoil control to adapt management depending on whether control was successful.

5.1.3 Control options

Alternative 1: Hand harvesting

Hand harvesting is one of the most common management techniques for controlling unwanted plant grown in New York State (NYSFOLA 2009). It is inexpensive, highly selective, and rarely requires special permitting. It is better suited to sporadic or sparsely populated Eurasian watermilfoil (e.g., when mixed with native plants) than to dense beds. In the Adirondack Park, there are several examples of hand-harvesting as a successful method, or as part of integrated plant management efforts, to control Eurasian watermilfoil including Upper Saranac Lake, Lake George, and Brant Lake. A guide to hand harvesting can be found on page 124 of Diet for a Small Lake (NYSFOLA 2009).

For hand harvesting in Paradox Lake, efforts could be focused seasonally to optimize effects: for example, harvesting once at the beginning of the growing season and again later in summer. Harvesting can occur early in the season before shoots are visible from the surface to prevent early season growth. Because it is difficult to mark plants if they are not visible, harvesting can be focused on known milfoil bed locations at this time. Secondly, plants can be marked and harvested as they appear during summer. Plants could be harvested with diver assisted suction harvesting or treated with herbicides in the case of dense beds.

The Adirondack Park Agency regulates hand harvesting and benthic barriers collectively under General Permit 2015G-1 (APA 2015). Project applications under the permit must be submitted to the APA for prior approval even under the general permit. The permit proposal includes requirements such oversight by a qualified entity, treatment areas and objectives, target species, and other information. General Permit 2015G-1 permits treatment of up to 0.5 acres in aggregate within a given waterbody. Projects may require additional permits at discretion of the APA if:

- conducted on public waterway (more than 1000 ft from the shoreline) or without the landowner's permission (within 1000 ft of the shoreline)
- aided by suction harvesting
- leaving less than 200 square feet of contiguous, native plant vegetation within the immediate vicinity of the owner's shoreline
- involving more than 100 square feet of freshwater wetland plants
- rare or endangered species are present
- conducted in combination with other chemical or physical controls, including suction harvesting and benthic barriers
- conducted concurrently with dredging or any other removal of benthic substrate
- part of a lake-wide harvesting program by a group or individual

Alternative 2: Diver-assisted suction harvesting

Diver-assisted suction harvesting is an extension of hand harvesting that involves the use of suction to remove plants from the substrate. Divers control a suction-powered hose that pulls the plants to a barge on the surface and can be used in combination with hand harvesting. Waste plant material is later disposed of or composted.

Diver-assisted suction harvesting maintains the selectivity of hand harvesting with the benefit of speed and full removal of the plant. Because the diver still controls the plant removal, it is less like than other mechanical removal methods to also harvest native, rare, or endangered plants. Additionally, divers can still harvest in shallow water or between obstacles (like docks) where other forms of mechanical harvesting or cutting are not feasible. While still highly selective, diver-assisted suction harvesting can be costly for large areas with sparse vegetation, and as such should be focused on moderate-to-large milfoil beds or mixed plant beds with a large proportion of milfoil (e.g. > 50%) to maximize cost-effectiveness. Suction harvesting is currently covered under the APA General Permit 2015G-1 along with hand harvesting. The same stipulations apply.

Alternative 3: Benthic barriers

Benthic barriers are mats (like tarps) that can be spread out on the bottom (benthos) of a lake to impede plant growth. They can be an effective solution for localized control of Eurasian watermilfoil around docks and in areas used for swimming and wading. They prevent all plant growth beneath them by blocking light. Cost is variable depending on size and material but can become prohibitively expensive for large areas. Options include non-toxic synthetic and natural materials. They can be removed and stored seasonally if synthetic or left in to deteriorate if biodegradable. Benthic barriers may require maintenance to release gas bubbles during the growing season. Installation and maintenance can be time consuming or expensive if contracted. Benthic barriers are currently approved for use in New York State under APA General Permit 2015G-1 along with hand harvesting and suction harvesting with the same stipulations (APA 2015).

Alternative 4: Herbicides

Herbicides can provide a cost-effective solution for control of invasive and nuisance aquatic vegetation compared to mechanical and biological controls, providing highly effective control and costing anywhere from a few hundred to several thousand dollars or more depending on the size of treatment area. It can, however, have unintended effects on native plant communities that fulfill essential ecological functions such as providing habitat and food, or sensitive areas such as wetlands that provide valuable ecological services through nutrient and toxin filtration. Toxicity of herbicides to non-target plants and animals (including humans) is increasingly regulated in efforts to reduce non-target environmental impacts and most modern dosing levels are orders of magnitude (100 or 1,000 fold) lower than toxicity levels due to advancements in response to negative impacts of early pesticides. Because no herbicides target Eurasian watermilfoil exclusively, there is a chance herbicide use will kill non-target plants during application. Herbicides used for control of Eurasian watermilfoil in New York State and the Adirondack Park therefore require consideration of lake-specific circumstances.

Regulation and permitting of herbicides for use is more restrictive in the Adirondack Park than at the state-wide level because of greater potential for impact to native biological communities. As of 2015 no herbicides were approved for control of aquatic invasive species within the Adirondack Park (APA 2014). Currently, the APA provides guidance related to herbicide permitting, best practices, and recommended uses of herbicides on a case-by-case basis (e.g., APA 2014). In recent years, permits have been issued for applications of triclopyr and ProcellaCOR (APA 2020). Adherence of aquatic plant management plans and activities to the guidelines provided, while potentially daunting, can greatly facilitate the likelihood that project proposals or tests cases will be approved. Guidance on specific herbicides from APA (2014) are therefore integrated below where applicable in this document, but stakeholders and decision makers are encouraged to review these guidelines and other available information sources regularly. This is especially true given developments in herbicide technology and application that have allowed for regulated use of herbicides in recent years. The permitting process currently requires long-term planning and documentation on the part of associations. The PLA does have long-term information about alternative Eurasian watermilfoil control efforts and continuation of monitoring will ensure that need is met in the future.

Most modern aquatic plant management plans that incorporate herbicides emphasize rotation of treatment areas or methods to avoid development of herbicide resistance. Repeated use of herbicides with the same mode of action can result in more rapid exposure of resistant biotypes than does alternating herbicides with different modes of action (Richardson 2008). With a limited number of herbicides currently allowed in the Adirondacks, there is greater risk for development of herbicide resistance. The only two aquatic herbicides that have been sanctioned for use to any degree in the Adirondack Park are Class 4 systemic herbicides and have the same mode of action. Product labels for commercial formulations of both recommend that treatment not be reapplied to the same area more than two years in a row. Without an approved alternative (e.g., a contact herbicide or a systemic herbicide such as a "shikimate pathway disruptor"), the PLA will need to account for this in any project proposals and long-term planning.

Triclopyr - Eurasian watermilfoil is sensitive to herbicides containing the active ingredient triclopyr, and it is one of the recommended target species for use in New York State (ENSR 2007). Triclopyr is an organic compound that is widely used as a systemic herbicide and fungicide in the United States. In New York State, herbicides containing triclopyr are approved for use within permit restrictions. Triclopyr is a highly selective, systemic herbicide. It is selective because it targets dicotyledonous plants, or dicots such as Eurasian watermilfoil (ENSR 2007). Monocotyledonous plants, or monocots like many pondweeds and grasses, are unaffected by it. Triclopyr is also a systemic herbicide, meaning that it enters and kills plants from the inside rather than killing it on contact, generally taking longer to show visible signs of affects than "contact" herbicides. It mimics a natural growth hormone, auxin (SERA 1996). It is usually applied to leaves and exposed stems. It enters the plant here and travels to its root system where it disrupts metabolism and kills the plant by promoting uncontrollable growth. It kills the entire plant, including its roots, so can be more efficient at eliminating plant beds than hand or suction harvesting and may be preferrable over contact herbicides for control of large or dense beds.

Use of triclopyr in lakes within the Adirondack Park for Eurasian watermilfoil control requires that non-target impacts such as those to wetlands be minimized (APA 2014). General guidance provided in APA (2014) is that triclopyr is best used for control of large or dense beds until they can be controlled through alternative means such as hand harvesting. This and other herbicides are not recommended for treatment of sparse beds with few plants or for whole-lake applications within the Adirondack Park (APA 2014).

ProcellaCOR – The active ingredient in the recently developed commercial herbicide ProcellaCOR® is a chemical named florpyrauxifen-benzyl (SePRO 2019). It is selective and systemic, causing plant death in a similar fashion as triclopyr. ProcellaCOR® has been rapidly adopted by lake management community because of these features and because it achieves control at lower dosages than is typical of systemic herbicides (TRC Environmental 2017). The first one-time application of ProcellaCOR® within the Adirondack Park occurred in Minerva Lake, Essex County, NY in June 2020 where short-term reduction of Eurasian watermilfoil was deemed successful (APA 2020). In 2021, several lakes within the Adirondack Park applied for permits to use ProcellaCOR® (APA 2022).

Limited guidance is currently available for use of ProcellaCOR® within the Adirondack Park. Information about long-term control or non-target effects is still being investigated (APA 2020). However, many or all best management practices identified by APA (2014) also apply to use of ProcellaCOR®.

Alternative 5: Integrated pest management

At a basic level, integrated pest management refers to the combination of multiple management strategies to achieve control of nuisance species such as Eurasian watermilfoil and other plants. It has become increasingly adopted in recent decades and is especially common in multi-use or multi-stakeholder management contexts where nuisance species are managed adaptively due to the flexibility it confers. However, IPM also requires regular monitoring and careful thought about compatibility, timing, and siting of various control methods. Adoption of an integrated approach to pest management allows combinations of alternatives above within the existing operational framework of PLA and partnerships.

5.1.4 Monitoring

Any aquatic plant management plan should be guided by results of monitoring data. The PLA has a demonstrated commitment to monitoring aquatic plant communities. This commitment should be continued through one or more alternatives in the future.

Alternative 1: Volunteer sampling

The PLA has relied on volunteers to conduct local hand harvesting and to mark milfoil beds for contracted harvesting for about a decade now. They have expanded this to establish about 500 volunteer monitoring sites through the Lake Tracker program in collaboration with APIPP during recent years (Schwartzberg et al. 2021). This program provides multiple benefits ranging from stakeholder participation and buy-in to reduced cost of record keeping and monitoring and improved understanding of changes to plant densities. Participation in this program should be continued or expanded in the future due to these benefits. If expanded, the program could include such information as estimated relative abundance of Eurasian watermilfoil at fixed sampling locations or additional information about native species composition that could be used to supplement monitoring efforts such as estimation of plant biovolume through mapping (e.g., Schwartzberg et al. 2021).

Alternative 2: Mapping

In recent years, the PLA began participation in the APIPP Early Detection program in 2018 and the Lake Management Tracker program in 2019 (APIPP 2018, Schwartzberg et al. 2021). Through these programs, APIPP staff and local volunteers collect information about estimated surface area of plant beds, density (e.g., percent coverage) and composition (e.g., percent milfoil). The Early Detection program is a relatively high-resolution visual survey of the lake that includes mapping plant bed outlines as polygons using a GPS by kayak so inference can be made about relative abundance of invasive species using geographic information software (GIS) programs. The volunteer program relies primarily on visual observation and estimated relative abundance of Eurasian watermilfoil at fixed volunteer sampling locations. Both can provide valuable information. These tools provide a standardized way of quantifying plant abundance, and changes in abundance, from year to year. The PLA should continue annual participation in the Lake Management Tracker program in addition to semi-annual participation in the Early Detection program (currently conducted once every three years but subject to change based on monitoring priorities).

Sonic mapping of plant biovolume is an alternative to visual or rake-toss surveys that can provide additional information not readily collected through visual surveys. If pursued, vegetative mapping should be combined with volunteer or contracted sampling data that can be used to determine percent relative abundance of focal species (Eurasian watermilfoil) by site to derive estimated acreage or biovolume. Ideally, this type of mapping and associated point sampling should be conducted annually to guide treatment options for the following year(s), but biannual monitoring could suffice if matched appropriately to management action timelines. The APIPP surveys are beginning incorporate this technology and the PLA can reach out directly to APIPP to determine whether this is something that could be implemented at Paradox Lake within or in addition to current monitoring efforts. Alternatively, many lake management companies and regional academic institutions are capable of conducting sonic plant mapping surveys.

Alternative 3: Documentation of management efforts

A large amount of data is collected on Paradox Lake each year. These data include volunteer and paid data collection. The results of monitoring efforts have been reliably reported by the individual entities collecting or compiling data (e.g., AWI, APIPP, CSLAP, consultants, NYSDEC). Generating an annual report summarizing all of these efforts on Paradox Lake each year could be useful moving forward and would facilitate book-keeping and data collection necessary for permits or grants. Ideally, such a report could synthesize results from APIPP stewardship programs, AWI/ALAP water-quality monitoring, APIPP invasive species reports, volunteer hand-harvesting, and/or paid contractors. Although the PLA does a commendable job making these resources available and keeping them current, compiling the results in a centralized report may be helpful in seeking permits or funding in the future by making the information easier to consolidate. Likewise, it would facilitate updates to the current management document or analogous plans in the future.

5.1.5 Evaluation

Monitoring data and results should be evaluated regularly to determine whether management goals and objectives are being met and whether those goals and objectives remain relevant. This could range from qualitative evaluation of public perceptions to quantitative analysis of the results in collaboration with regional, academic, or municipal partners. However, without evaluation, it is not possible to determine whether control efforts for Eurasian watermilfoil are successful or whether they need to change.

5.1.6 Adapt

Depending on the results of evaluation, management objectives or approaches may need to be adapted. Failure to achieve management objectives in a specified timeframe may mean that a control method is not working, that targets were overly ambitious, or that evaluation does not fit the monitoring scheme. Each of these provides an opportunity to assess and update management of Eurasian watermilfoil regularly to ensure the best possible outcome.

5.2 Water quality

Every aspect of lake management is affected by lake water quality. Sustainable management is not possible without understanding what is achievable based on the physical and chemical characteristics of a lake. Analysis of recent and long-term trends in water-quality parameters of the upper and lower basins of Paradox Lake indicated that the lake as a whole has excellent water quality compared to many regional lakes. Although the upper basin has historically been and continues to be more productive than the deeper lower basin, it has exhibited reduced productivity in recent years, becoming increasingly similar. Despite anecdotal stakeholder perceptions of reduced water clarity or concerns related to the use of road salt in the watershed, long-term data suggest that water clarity has increased, algal production has decreased, and that there has been no measurable increase in either chloride or sodium levels that might be associated with road salt in the past 7 years. Therefore, the issues addressed in this section focus on preservation of current trophic status and minimizing human impacts on the lake in the future through near-lake and watershed best management practices.

5.2.1 Outreach

As with invasive species management, outreach associated with water-quality objectives, monitoring, and stewardship will benefit long-term sustainable management of Paradox Lake. This outreach likewise will occur on both public-facing and institutional fronts. Clear communication of the value of lake water-quality monitoring and the results of volunteer monitoring efforts will help keep lake users and other stakeholders informed of the current state of the lake and could help alleviate concerns and prioritize PLA efforts to management areas that are currently most pressing. Likewise, regular communication with organizing entities (e.g., APIPP, AWI, NYSDEC, NYSFOLA) regarding program updates and options will help maintain a valuable long-term resource and prioritize additional monitoring needs within volunteer programs such as CSLAP and ALAP. As with other outreach efforts, the PLA has made commendable efforts in these regards historically and formalization of these duties through an existing Board position or appointee would ensure their continuation in the future.

5.2.2 Objectives

The PLA should establish objectives for maintaining desirable limnological (water-quality) characteristics for both the short-term and long-term. A reasonable over-arching goal for water-quality might be to "promote water-quality that assures continued ecological function and supports achievement of human values associated with current Class AA designation into the future." Specific objectives could include maintaining specific water-quality parameters relative to action thresholds. For example, objectives for total phosphorus could include maintaining annual total phosphorus concentrations < 20 µg/L or preventing total phosphorus from increasing during a specified time. Success toward these objectives could be measured and reported annually based on volunteer monitoring data or evaluated periodically for long-term trends not accounted for in annual reporting of volunteer monitoring data (e.g., Section 3 of this document). Specific short-term or long-term management responses can be specified in advance or implemented if those objectives are not met.

5.2.3 Monitoring

Alternative 1: Volunteer monitoring programs

Ongoing monitoring is necessary to maintain baseline understanding of conditions and so managers understand issues as they arise or evaluate the success of management strategies that have been implemented. Since 2003, the Paradox Lake Association has participated in some form of volunteer monitoring annually through CSLAP (2003-2013) or ALAP (2014-2021). Participation in these programs, in addition to contracted lake monitoring during the same period (Aqualogic Inc., 2000-2014), has resulted in an invaluable long-term water-quality data set to date. These programs also provide annual assessments and publicly accessible reports that can be easily understood by non-scientists or managers that will assist with outreach efforts on all fronts. Because of the high value of these data relative to the low cost, continued annual participation represents a high priority for ongoing management of Paradox Lake.

Alternative 2: Contracted water quality monitoring

The alternative to volunteer monitoring programs is to hire a professional monitoring company to perform ongoing monitoring of water quality parameters and specific physical and biological surveys. This option is significantly more expensive than volunteer-operated programs like CSLAP and ALAP and may or may not confer added benefit depending on duration, intensity, or characteristics monitored. However, these two options should not be considered mutually exclusive, and there may be years during which both are necessary depending on monitoring and management needs. For example, private companies have capacity to measure more parameters (e.g., oxygen) than may be available in volunteer monitoring programs or may wish to monitor water quality before and after, for example, an herbicide application.

5.2.3 Management options

Despite that most water-quality indicators suggest the lake has become less productive or remained stable in recent years, actions can still be taken to ensure it remains that way in as much as is possible. These actions can include a combination of near-lake and watershed activities. Some of these alternatives require voluntary or subsidized participation by watershed residents whereas others can be or are directly specified in local or regional land use ("zoning") regulations. In general, the recommendations are of low urgency but high importance for long-term sustainability of lake water quality. The APA provides a Citizen's Guide to current land use codes and regulations (APA 2001) that may be helpful in navigating park-wide land use regulations set forth in the Adirondack Park State Land Master Plan (APA 2019) and local land use codes.

Alternative 1: Residential best practices

There are a number of residential best practices that watershed residents can take to help ensure sustainable water-quality in the future. These can include practices ranging from those designed to increase soil infiltration of ground water and reduce runoff, to those that limit nutrient or sediment additions to groundwater or runoff and improving efficiency and useable life of septic systems.

Reducing runoff from impermeable surfaces – Impermeable surfaces include such paved features as parking lots and roadways but can also include buildings and other structures that prevent water from contacting and infiltrating soil. There are many residential best practices that watershed residents can implement voluntarily to help reduce runoff from impermeable surfaces on their properties. A few of these include:

- Limiting new development of impermeable surfaces such as driveways and paved paths.
- Replacing impermeable materials (macadam) with permeable materials (e.g., stone) that will not run off and will promote rainwater infiltration
- Installation of gutter systems and downspouts if not present
- Installation of rainwater collection barrels on downspouts of gutter systems to collect runoff and reduce movement rate from buildings to ground
- Construction of "rain gardens" or rain-filled ponds that can be used to reduce rate of water runoff to lake
- Avoiding clearing large areas for yard, which increases runoff compared to shrubs, trees, or other decorative plantings
- Maintaining a buffer of native vegetation between residences and lake shore to reduce runoff and erosion

Reducing residential nutrient loading – Nutrients may be exported from human residences in many ways. A variety of simple at-home solutions can reduce the amount of nutrients loaded to the lake from residences such as:

- Limiting use of lawn and garden fertilizers
- Using phosphorus-free or low-phosphorus dish and laundry detergents
- Using centralized vehicle washing and decontamination facilities for cars, boats, and other vehicles rather than washing at home
- Avoiding disposing yard trimmings, brush piles, leaves, or siting composting bins near the lake shore
- Preventing shoreline use by Canada geese or other waterfowl gathering in large numbers due to human modifications (e.g. large lawn spaces that attract waterfowl)
- Moving open-air fire pits or burn piles away from the lake shore
- Avoiding use of sand for artificial beach creation or for traction during winter weather
- Erecting silt fences where landscaping or home repair projects result in exposure of mobile sediments such as sand or clay

Alternative 2: Road salt reduction or alternative deicers

There are nearly 3,000 lane miles of roadway that are treated with road salt annually in the Adirondack Park (Kelting et al. 2012). An estimated 77% of surface waters in the Adirondack Park are impacted by salts from road runoff in one way or another (Regalado and Kelting 2015). Therefore, concerns about the impacts of road salt on lakes within the park are common. While ongoing monitoring is still necessary to determine the long-term impacts, historical data from CSLAP and ALAP indicate that this salt deposition may be causing increases to chloride and sodium levels in regional lakes and may even influence lake dynamics

(Wiltse et al. 2020). Analysis of available limnological data for Paradox Lake suggested that mean sodium (5.1 mg/L) and chloride (8.2 mg/L) levels are currently well below those corresponding to acute toxicity for most aquatic organisms (USEPA 1988), and there has been no significant increase in either of these variables since ALAP monitoring began in 2014. These values are, however, slightly higher than averages reported for Adirondack Lakes (Kelting et al. 2012). Additionally, mean lake-wide concentration of calcium (7.8 mg/L) is currently below thresholds required for survival and reproduction of invasive bivalves such as zebra mussels (*Dreissena polymorpha;* Frischer et al. 2005) and quagga mussels (*D. rostriformis*; Davis et al. 2015). Although no long-term trends were detected in Paradox Lake, the present study did not account for fine-scale seasonal fluctuations during which isolated toxicity events may occur (i.e., periods of salt application) and exert influence on biological communities immediately adjacent to roads.

Stakeholders may petition for reduced amount of salt used on roadways within close proximity to Paradox Lake or consideration of alternative de-icers within the constraints of public safety needs to alleviate immediate concerns related to this issue. A review of alternatives, costs, and effects is presented in Kelting and Laxson (2010). Continued outreach and activism are necessary to achieve desired results. Since the roads surrounding Paradox Lake are under a combination of state, local, and private jusrisdictions, outreach at various levels in necessary. This could include collaboration with or support of other local advocacy groups to streamline messaging and implementation. Use of sand or dirt as a traction material near the lake should be avoided where possible due to potential for sedimentation and loading of bound inorganic phosphorus into the lake (Albright 2005).

Alternative 3: Residential wastewater management

All residences at Paradox Lake have onsite residential wastewater treatment (septic systems). Soil suitability for most of the residential areas surrounding the lake have been classified as “very limited” by the USGS Web Soil Survey (Figure 1.4). All septic systems inherently release nutrients such as nitrogen and phosphorus that enters groundwater and lakes to varying degrees depending on local geological and meteorological conditions, distance from shorelines, and other factors such as age. Poorly sited or maintained septic systems do so more rapidly. Over time, this promotes plant and algal growth and can have negative impacts on human uses or health.

A basic starting point is to review local land use (zoning) regulations regarding installation, inspection, and maintenance of residential and commercial wastewater treatment systems to ensure that they align with best recommended practices. This can include stipulations for new and existing systems and could be tailored to the watershed as a whole or based on proximity to the lake or other waterbodies. Any enforceable changes to expectations for septic installation, inspection, or maintenance would need to be approved within hamlets or towns surrounding the lake and codified in their land use planning documents.

Septic upkeep can be a contentious issue within lake-side communities. Inspections and pumping are relatively inexpensive (hundreds of dollars), but replacement of a failed system can be costly (thousands or tens of thousands of dollars). Inspection and education programs should be a community-wide effort and care should be taken to help other residents and not work against them. Provide residents with information on the consequences of faulty systems, how to have tanks inspected and maintained, and the costs associated with doing so. The PLA could consider coordinating, subsidizing, or facilitating a lake-wide inspection program to encourage residents to have tanks tested and pumped regularly. Ideally, septic tanks should be inspected and pumped every 3 - 5 years to ensure proper function. If done in "cohorts", it may be possible to reduce individual costs to residents by clustering pump-outs for certain areas and potentially reduce travel charges by the pumping company or facilitate cost-sharing.

5.2.4 Evaluation

Periodic assessment of trophic status and other indicators will facilitate short-term and long-term decision making related to practices that can impact water quality in Paradox Lake. At minimum, the PLA should use results of annual volunteer water quality monitoring to evaluate current status and determine whether additional actions are needed. Likewise, if these data are combined with known changes in land use, infrastructure maintenance, or local ordinances, then they can be used to explore how changes to human behaviors have influenced the lake (something that was not done in the present study). Supplemental information in that case should include keeping of records associated with these changes.

5.3.5 Adapt

Periodic review of changes to the watershed and mitigative strategies are required to adapt maintenance and management activities as needed. New technologies and approaches to alleviating watershed and near-shore pressures on lakes are constantly being developed. In addition to monitoring of water quality and vetting local regulations, the PLA should keep abreast changes and developments that can be used to promote continued high quality of water in the lake for the future.

5.3 Public use and access

Paradox Lake serves public users both locally and regionally. Most common uses of the lake include swimming, boating (motorized and non-motorized), fishing, and aesthetic enjoyment according to the 2017 stakeholder analysis. Because these activities are regulated or managed by local or state legislation, their continued management will require close collaboration with responsible entities. Below, we briefly address issues that were raised during the 2017 public stakeholder survey to help prioritize focal areas for future management in this multi-use public lake. However, we note that management on any of these fronts will require public input and close collaboration with management entities.

5.3.1 Boating

Paradox Lake, along with many others in the Adirondack Park has seen an increase in public use as population has increased. In 2020, more than 1,200 boats were intercepted and inspected at the Paradox Lake boat launch and Severence decontamination station as part of the AWI boat inspection program, accounting for nearly 2,000 visitors (AWI 2020). With this number of visiting boats in addition to numerous shoreline residents owning boats, in is unsurprising that motorized boat traffic was a concern of many stakeholders.

Paradox Lake supports a variety of motorized and non-motorized boating activities from paddling and wildlife viewing to fishing, contact recreation, and enjoying aesthetics. It is important that any regulations on boat use incorporate this same variety of perspectives that make the lake important to people. Out-right bans on motorized watercraft are unlikely to be adopted or enforced either locally or regionally. However, there are a number of options available that could alleviate current concerns, including specialized or extended no-wake zones, decibel (noise) restrictions for motorized watercraft, speed limits, or daylight limits. Any decision related to these types of regulations should seek representative public feedback from the widest range of users possible, realizing that the number of seasonal users of the lake may outnumber residents. Regardless of additional actions taken, the PLA may wish to install signage at boat launches or other appropriate, visible locations regarding sensitive areas such as the narrows (see below) or other areas within 100 ft of shorelines where wakes are prohibited by New York State law.

5.3.2 Fisheries

The Paradox Lake fishery is well known among residents and regional anglers but understudied. Currently, the lake appears to support balanced cold and warm water fisheries that have the potential to attract visitors and benefit the local economy. To best manage the fishery, clear goals and expectations must be established. There appears to be a disconnect between the concerns of immediate stakeholders (anglers who live on Paradox Lake or have a generational connection), secondary stakeholders (non-angler residents), and all other stakeholders (visiting anglers). No quantitative surveys were completed on fishery perception, but the 2017 stakeholder analysis and conversations with stakeholders indicate that those who live on Paradox Lake are more concerned with the natural state of the fishery whereas visiting anglers (including recreational and commercial tourists) are more concerned with the presence and size of specific species.

Because Paradox Lake is a public waterbody, changes to fisheries management must be conducted in consultation with NYSDEC Region 5 Fisheries managers. As with efforts associated with Eurasian watermilfoil and water quality, the PLA may wish to appoint or elect a liaison to streamline communications with these individuals. The Region 5 office is charged with a large geographic expanse, and as such there are real constraints on the frequency and intensity with which the fisheries of Paradox Lake can be sampled. However, surveys on the scale of once per decade or two may not provide adequate information for use in management, and as such the PLA may need to contract any desired fisheries surveys through a qualified lake management company or academic institution.

5.3.3 Ecologically sensitive areas

There is value in protecting ecologically sensitive areas such as the narrows as these can confer substantial ecological services such as water filtration, reduction of wave action, and sediment stabilization. These areas may also serve as critical habitat for wildlife or less common species. The narrows is one such location within Paradox Lake. The preliminary delineation conducted as part of this study indicated that the narrows wetland is largely in-tact and possesses some characteristics and taxa not typical of other shorelines around the lake. It likely promotes nutrient sequestration in the lake through the physical restriction it creates to waterflow between basins and through direct uptake by plants in the wetland area.

The PLA could consider additional measures to ensure continued protection of the narrows and by extension the lake proper. Signage could be posted or made visible regarding boat wakes in the narrows if not already present. Given the water depth in this channel and the mean distance to shoreline from the center of the channel, much of the narrows falls within 100 ft of the nearest shoreline and is therefore a no-wake zone according to New York State law. Additional protective measures could be implemented under the authority of local municipalities within the context of land-use or zoning regulations. This would help prevent deepening of the channel or unintended consequences of wave action on sensitive plants in the transitional zone between the wetland and the upland in this area.

State of the Lake Report for Paradox Lake

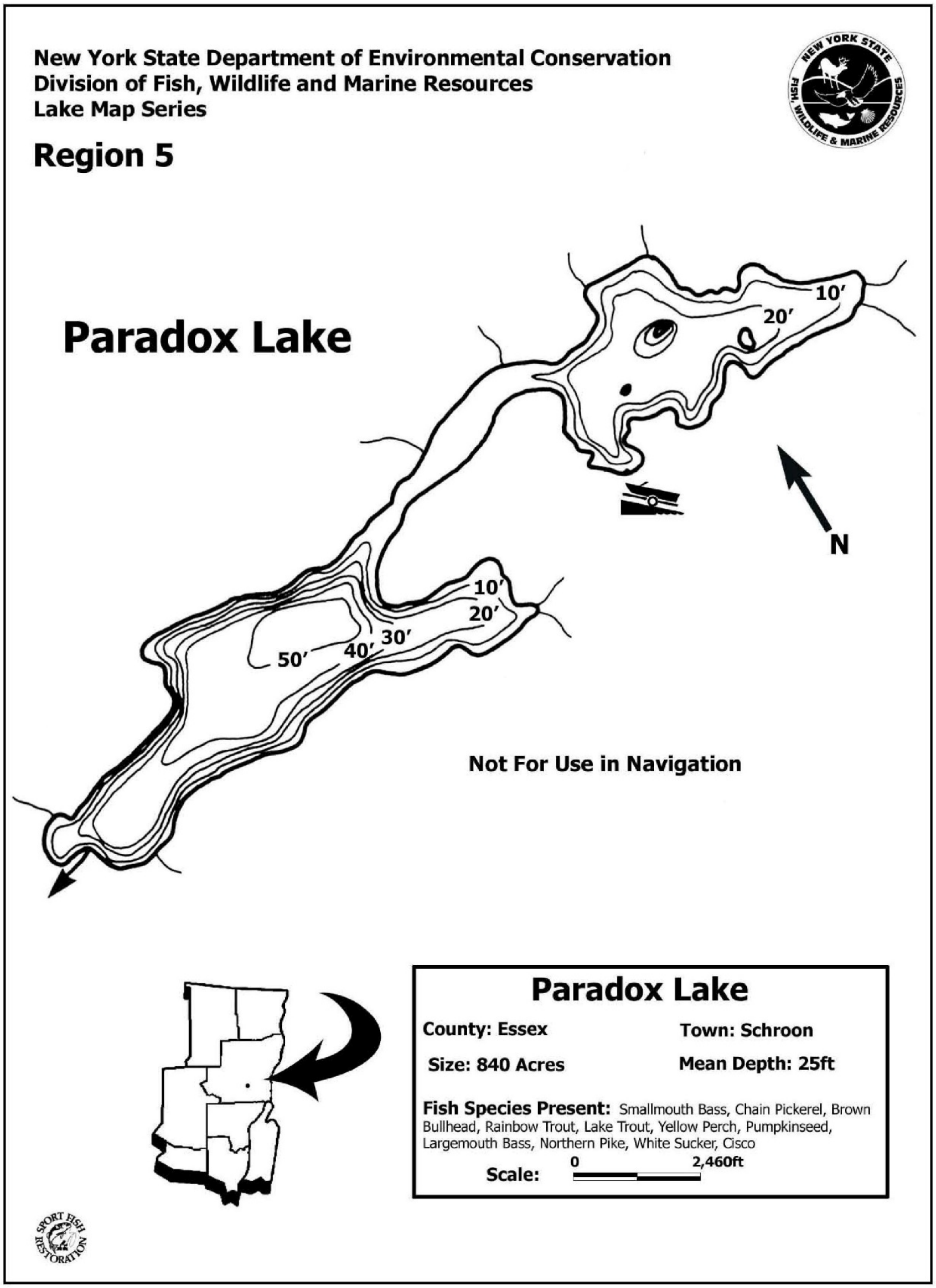
1 Physical Lake and Watershed Characteristics

1.1 Lake Characteristics

Paradox Lake is a New York State Department of Environmental Conservation (NYSDEC) class AA lake in the Town of Schroon, NY. The NYSDEC designates AA classification to waterbodies used as a source for drinking water and primary and secondary contact recreation. The lake is composed of two distinct basins separated by a narrow channel (Figure 1.1) referred to as "the narrows." The smaller upper basin has a maximum depth of 12 m and the larger lower basin has a maximum depth of 16 m. The total surface area of the lake is about 931 acres (Laxson et al. 2015b; Table 1.1).

1.2 Watershed characteristics

The Paradox Lake drainage basin is 11,978 acres of land that includes variable topography and landcover. Several surface water features such as streams, ponds, and other lakes are contained in the watershed (Figure 1.2). Highway NY-74 runs along the southern shore of the lake, and several small private roads lead to shorefront residences around the rest of the lake.



Paradox Lake

County: Essex
Town: Schroon
Size: 840 Acres
Mean Depth: 25ft

Fish Species Present: Smallmouth Bass, Chain Pickerel, Brown Bullhead, Rainbow Trout, Lake Trout, Yellow Perch, Pumpkinseed, Largemouth Bass, Northern Pike, White Sucker, Cisco

Scale: 0 2,460ft

Figure 1.1. Bathymetric map of Paradox Lake (NYSDEC, no date).

Table 1.1. Physical characteristics of Paradox Lake, NY as described by the New York State Department of Environmental Conservation (NYSDEC, no date), or Laxson et al. (2015). *Indicates values updated in Laxson et al. (2015b) from available NYSDEC maps.

Parameter	Value
Elevation	249 m
Surface area	377 ha*
Maximum effective length	6.4 km
Maximum effective width	1.2 km
Shoreline length	19.3 km
Maximum depth	16 m
Mean depth	7.6 m
Mean thermocline depth	7 m

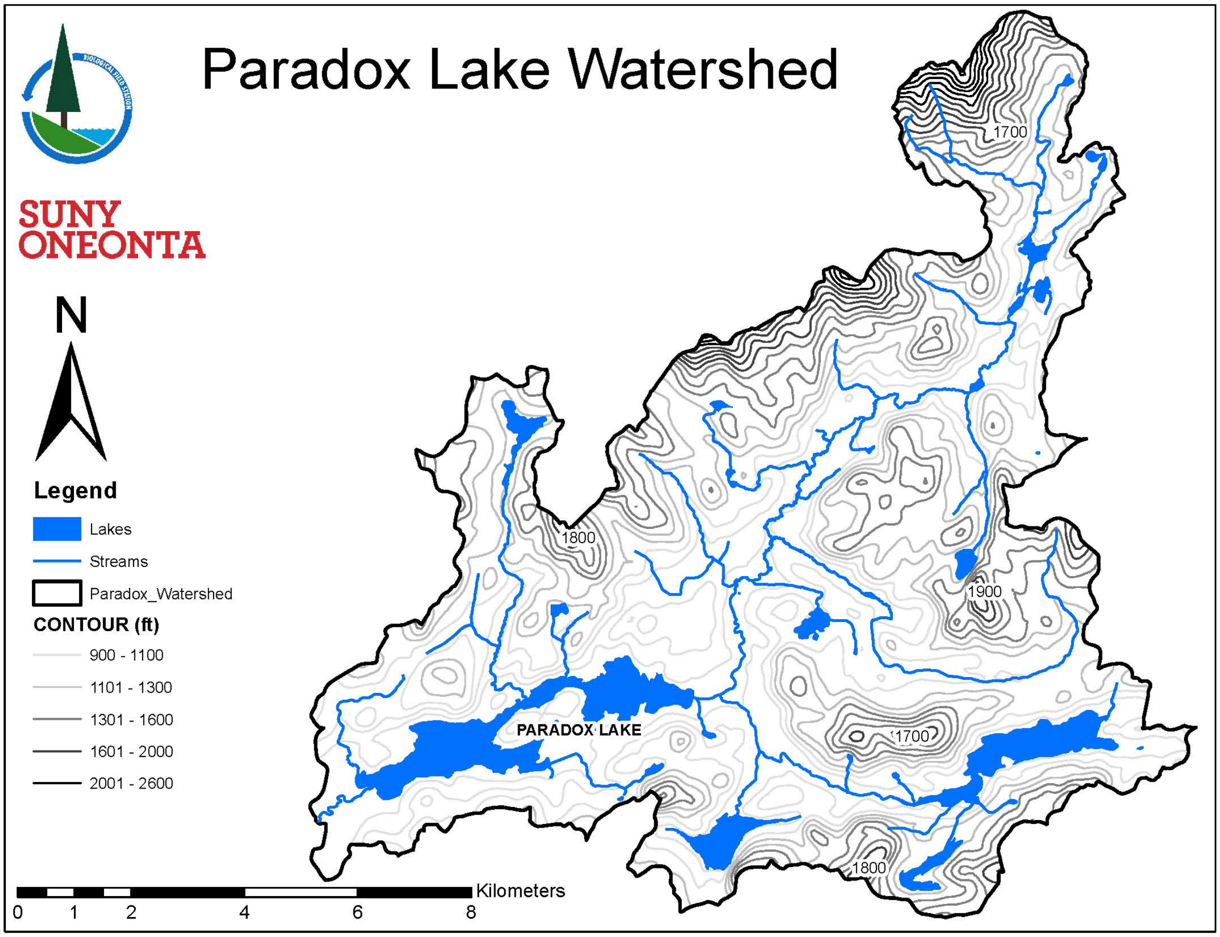


Figure 1.2. Paradox Lake watershed showing 200 ft elevation contours and locations of major waterbodies (Reyes 2016).

1.3 Geology and soils

The geology surrounding Paradox Lake was first described by professor J. F. Kemp of Columbia University in 1901 during a survey of the Adirondack Mountains of New York State (Peck 2016). The Adirondack Mountains are composed centrally of plutonic high peaks and surrounded by lower hills composed mostly of gneiss (a metamorphic rock similar to granite). The entire region is marked with faults – some as recent as the beginning of the last ice age.

The Paradox Lake quadrangle is in the southeastern portion of the Adirondack Mountains and Adirondack State Park and was first reported by Ogilvie (1905). Gneiss underlies much of the quadrangle, including the basins of Paradox Lake. Higher peaks within this quadrangle are composed of plutonic rock that characterizes most of the Adirondack high peaks. Some deep valleys – especially near the Schroon River the outlet from Paradox Lake – are composed of limestone (Figure 1.3).

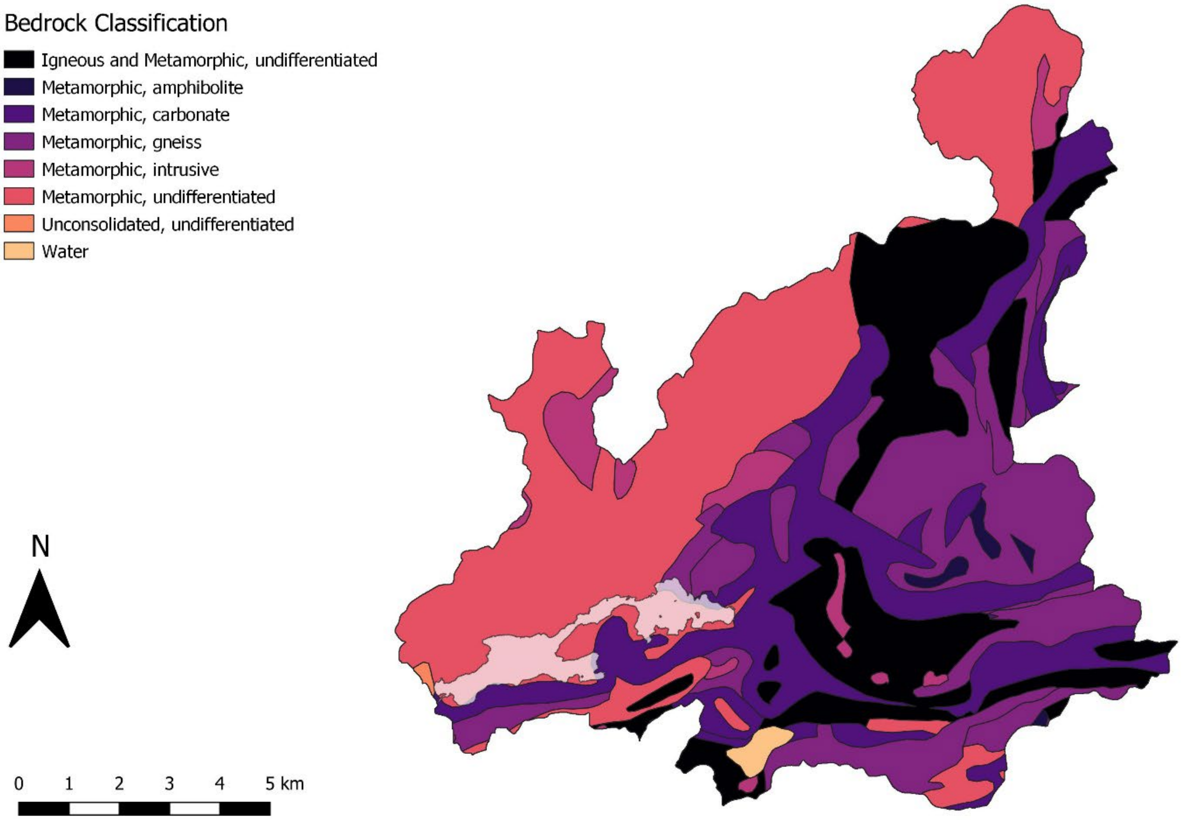


Figure 1.3. Bedrock map of the Paradox Lake watershed (NYS Museum 1999). Paradox Lake is transparent to show boundaries of bedrock types underlying the lake.

Soil within the drainage basin is primarily composed of Becket-Tunbridge complex, Tunbridge-Lyman complex, and Lyman-Knob complex – loamy soil types from gneiss parent material (USDA 2017). All three soil classes are typical of hillsides and mountainsides. They are bouldery, well-drained, and have low likelihood of flooding or ponding (USDA 2017). For these features and logistical difficulties associated with shallow depth to bedrock, the geology of the watershed is not well suited for conventional septic systems (Figure 1.4).

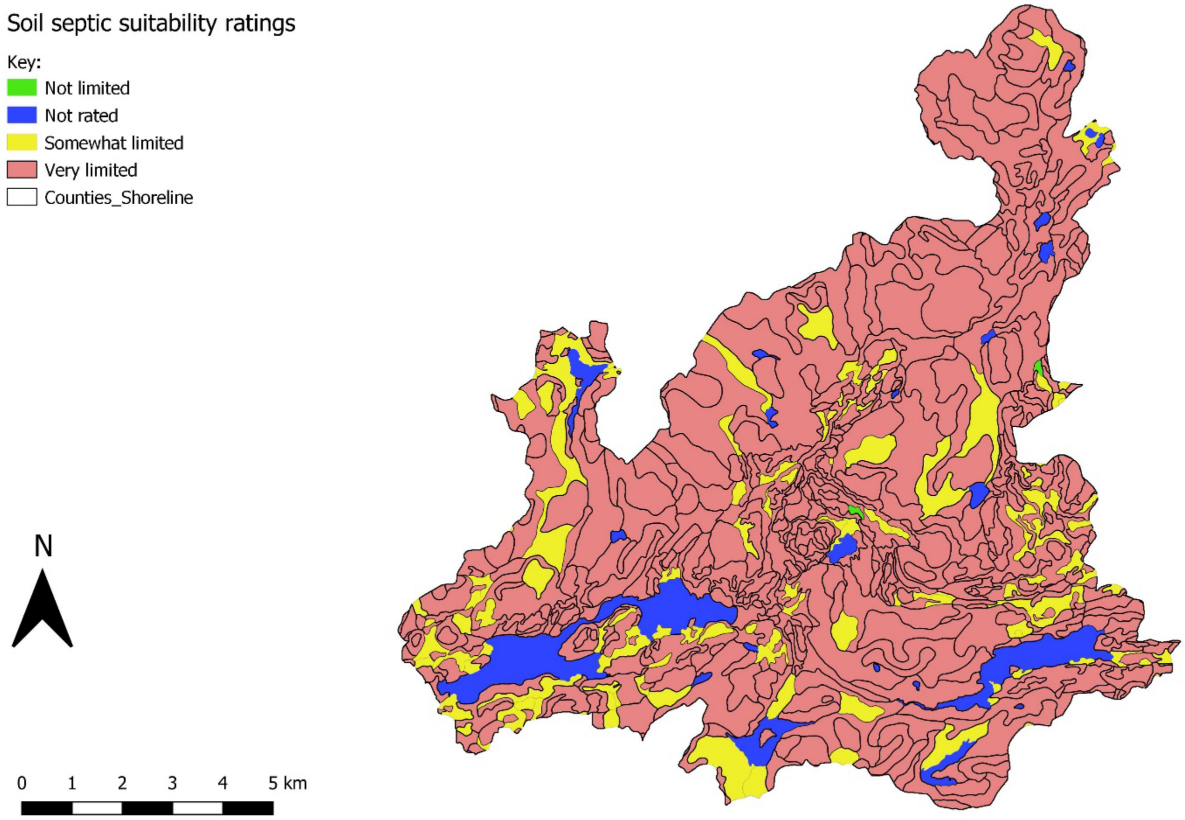


Figure 1.4 Soil septic suitability ratings within the Paradox Lake watershed (USDA 2017).

1.4 Land Use

Land use in the watershed consists primarily of forested classifications (84%, Figure 1.5). About 25% of the watershed is deciduous forest, 56% is evergreen, and 24% is mixed (Table 1.2). Woody and emergent wetlands constitute approximately 8.6 km^2, or about 7% of the watershed and open water accounts for another 7.5 km^2 (6%). Developed land in the watershed includes open spaces, and varying degrees of intensity (1.9%), as well as pasture and hay fields (0.25%). In total, developed lands account for a little over 2% of the watershed, however, virtually all development was focused along major waterways in valleys and around Paradox Lake or nearby waterbodies (Figure 1.6). Medium and high-intensity development occurred almost exclusively along lake shores within the watershed.

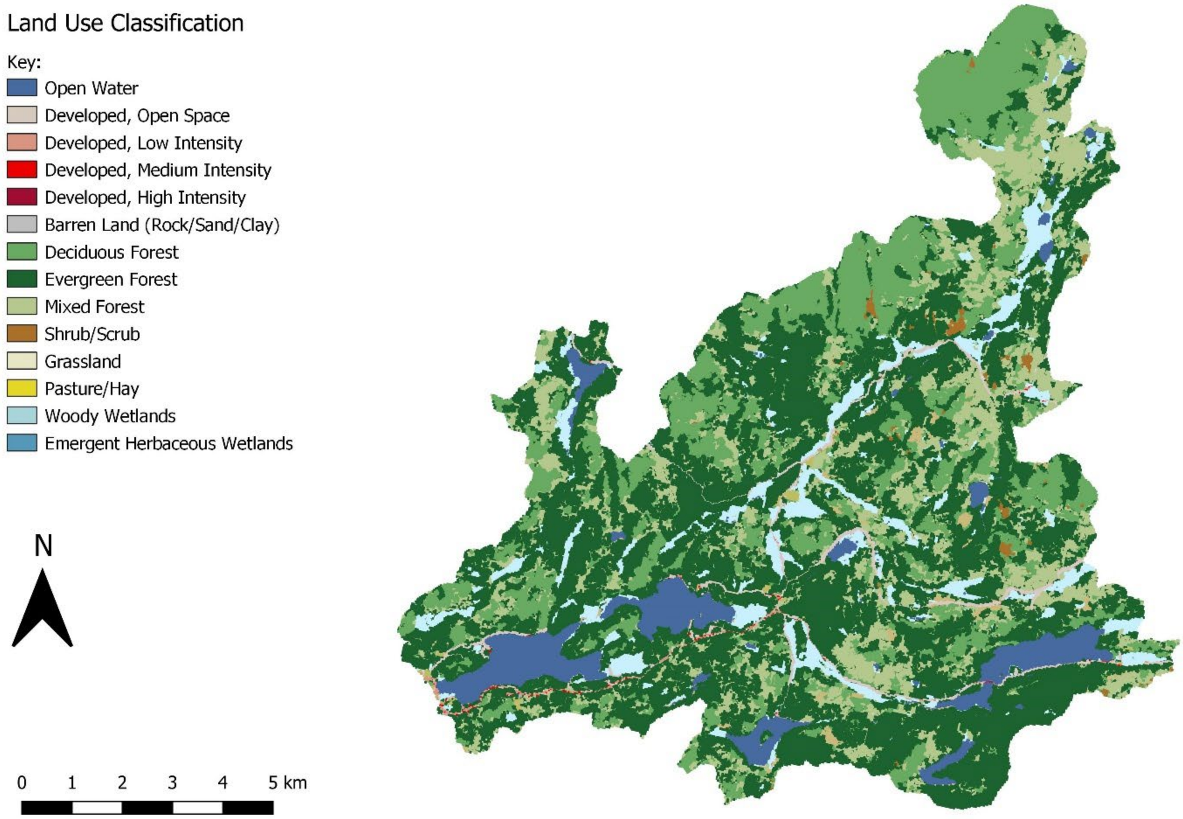


Figure 1.5. Land use classification within the Paradox Lake watershed (MRLC 2016).

Table 1.2. Areas (km^2) and percent occurrence of land uses within the Paradox Lake watershed (MRLC 2016).

Land use classification	Area (km^2)	Percentage
Open Water	7.464	5.93%
Developed, Open Space	1.925	1.53%
Developed, Low Intensity	0.370	0.29%
Developed, Medium Intensity	0.119	0.09%
Developed, High Intensity	0.004	0.00%
Barren Land (Rock/Sand/Clay)	0.032	0.03%
Deciduous Forest	25.255	20.05%
Evergreen Forest	56.392	44.78%
Mixed Forest	23.590	18.73%
Grassland	1.176	0.93%
Pasture/Hay	0.303	0.24%
Shrub/Scrub	0.679	0.54%
Woody Wetlands	7.288	5.79%
Emergent Herbaceous Wetlands	1.344	1.07%
Total	125.941	100.00%

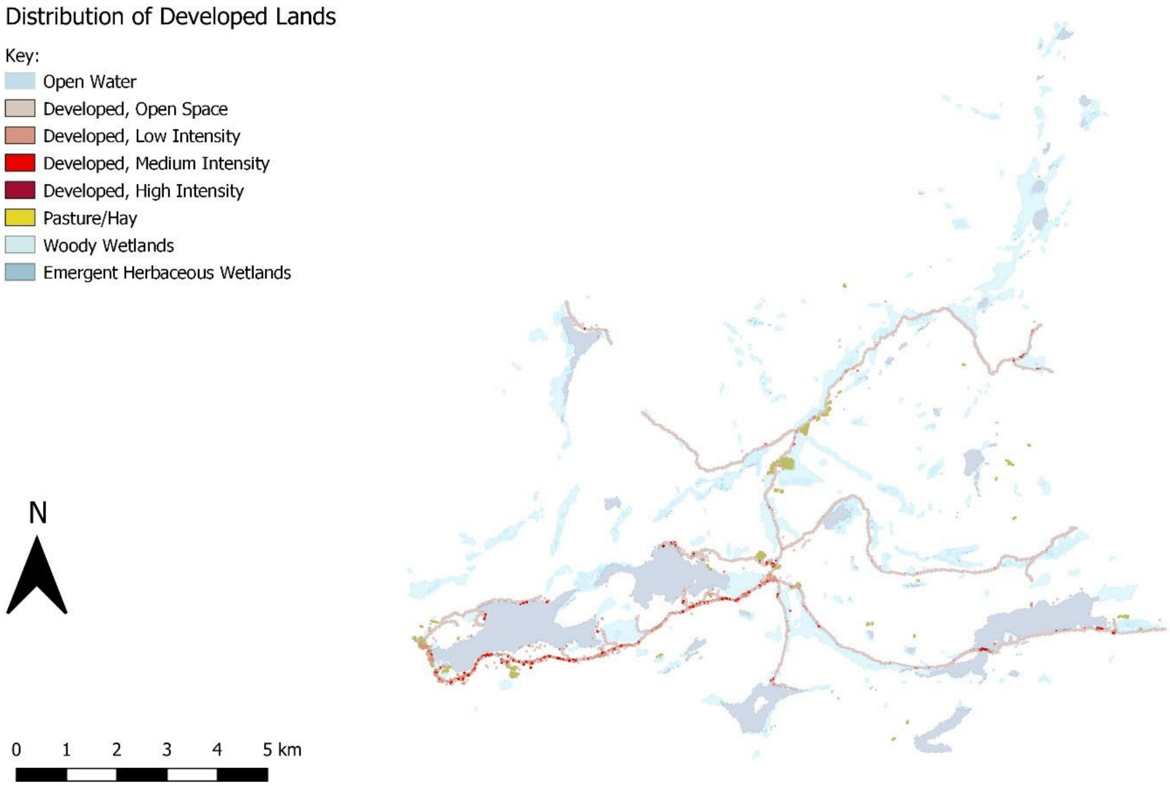


Figure 1.6. Distribution of developed lands showing general proximity of development relative to various waterways (MRLC 2016).

2 Stakeholder Perceptions Survey

2.1 Introduction

Practical management of natural resources is incomplete without stakeholder analysis. Stakeholder theory was introduced into business management by R. Edward Freeman in 1984 (Freeman 2010), and the definition has since been expanded upon and applied to other management areas. Stakeholder analysis in natural resource management emphasizes equity in decision making and overall transparency in management strategy, and the prevalence of its use is largely a reaction to projects that have failed due to lack of understanding of stakeholder dynamics (Reed et al. 2009).

Resource management success by a stakeholder group is largely dependent on community attributes – like population, income, and level of education – as well as institutional characteristics like laws, regulations, and citizen monitoring programs (Snell et al. 2013). For areas with the presence of several institutions, collaboration is critical in successful management. Collaboration between institutions and the inclusion and accountability of stakeholder groups contributes to the success of a project (Norris 1984).

The stakeholders of Paradox Lake include the PLA, non-member residents and non-resident lake users, in addition to municipalities and public and private resource managers. In the absence of previous stakeholder analyses for Paradox Lake, a survey of stakeholder values and concerns was conducted in 2017. The primary purpose was to prioritize areas of concern related to Paradox Lake and ensure opportunity for participation in decision making and resource management.

2.2 Methods

A nine-question survey was created using Survey Monkey and distributed to Paradox Lake stakeholders after approval by the SUNY Oneonta Institutional Review Board (IRB protocol #2016-116). An online survey was deemed appropriate because about half of the PLA members are seasonal residents and were not present at local residences during the survey. It was intended for the questionnaire to take approximately ten minutes to complete.

Stakeholders were invited to participate in the survey through the PLA email list, direct email from the primary investigator, in-person contact at Paradox Lake, or by another survey participant. Anyone who uses Paradox Lake was permitted to participate in the survey. Stakeholders were categorized by residence location: directly on Paradox Lake (on the shoreline), adjacent to Paradox Lake (within one quarter of a mile of the shoreline), within the Paradox Lake watershed, and outside the Paradox Lake watershed. The survey allowed one survey completion per device (computer, smart phone, etc.) to limit submission of multiple survey responses per individual. Individuals within a household were permitted to respond, but no more than one response per individual was allowed.

Questions addressed stakeholder concerns with common lake management issues, satisfaction with current management, and their primary uses of the lake. Questions were created based on past work on Paradox Lake, initial discussion with stakeholders, and other common concerns surrounding lake management in New York. An open dialogue box was included at the end of the survey to provide stakeholders with a platform to voice concerns not directly addressed in other survey questions. After the survey, stakeholders were invited to meet with the primary investigator to address or expand on any concerns.

2.3 Results

2.3.1 Demographics

Of 104 respondents, 62% owned a residence directly on Paradox Lake, 28% lived adjacent to the lake, and 10% lived within the watershed (Figure 2.1). There were no respondents from outside the watershed. Of the stakeholders who owned property directly on the lake, 41% owned property on the upper basin and 59% owned property on the lower basin (Figure 2.2).

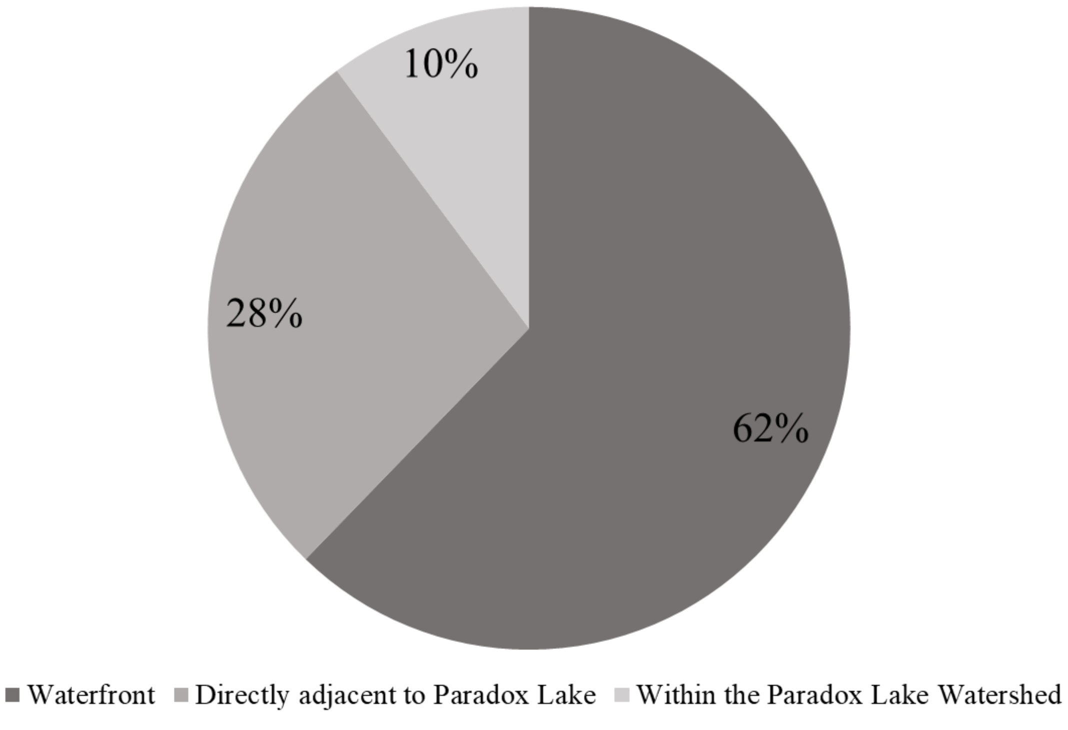


Figure 2.1. Responses to Paradox Lake stakeholder survey question: Which of the following best describes your residence?

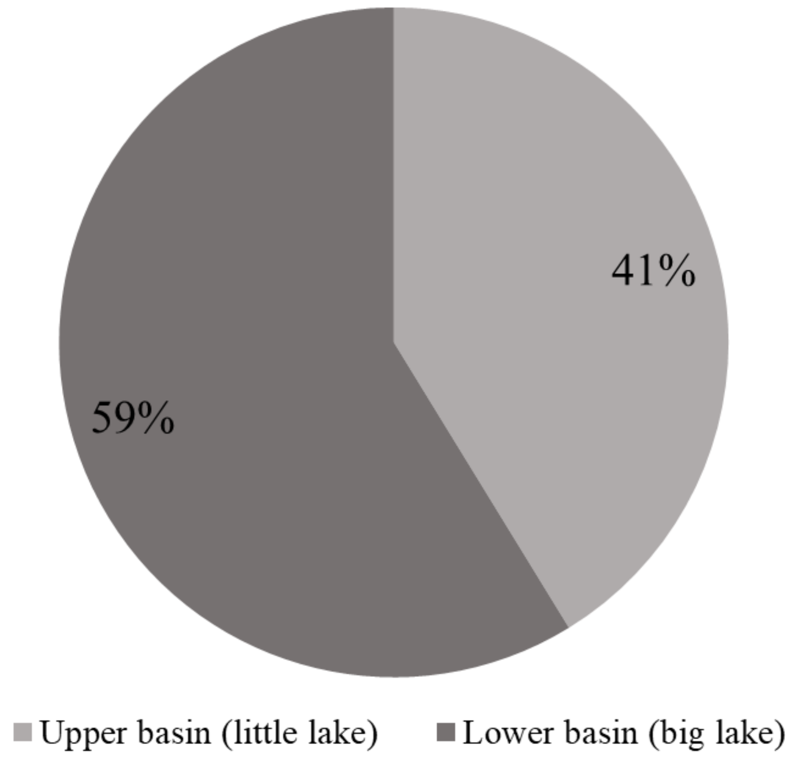


Figure 2.2. Responses to Paradox Lake stakeholder survey questions: If you live directly on Paradox Lake, which of the following best describes your residence?

2.3.2 Lake Use

The most common uses of Paradox Lake were swimming (28%), boating (canoe/kayak) (25%), and boating (motor) (22%) (Figure 2.3). About 10% of responses were for activities other than these. The most common were water skiing, relaxing, or enjoying the view.

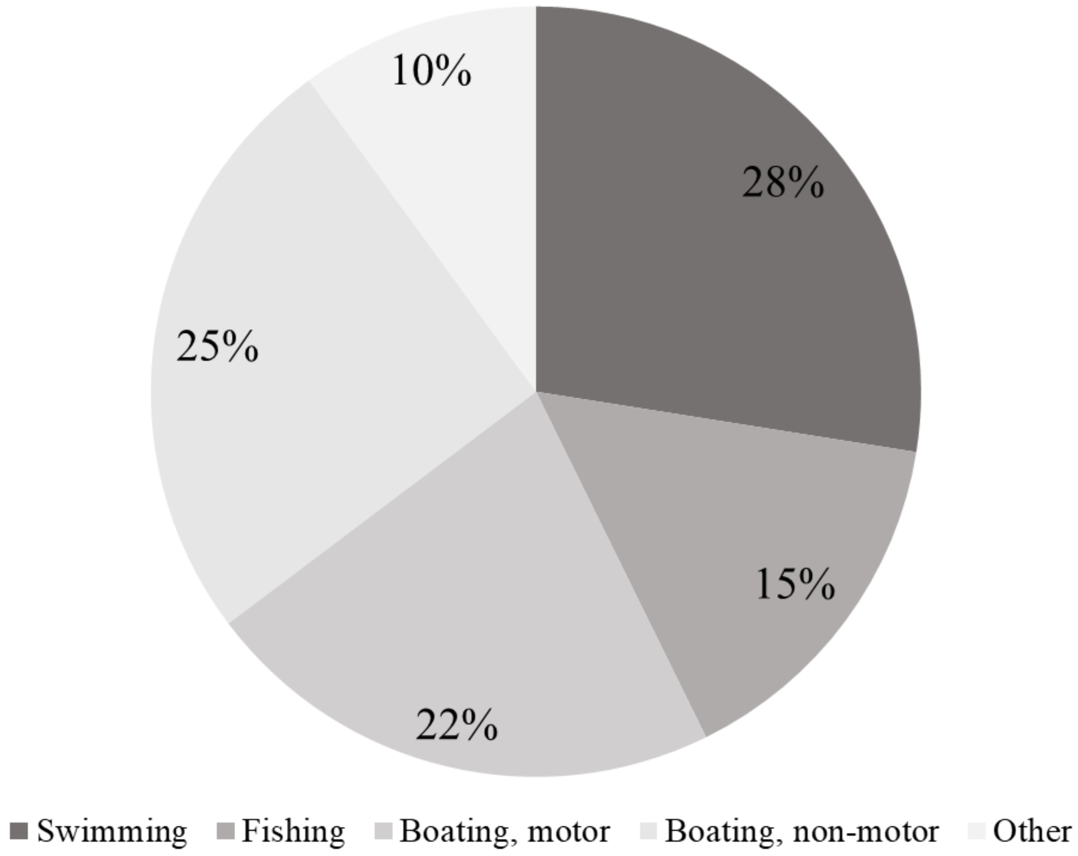


Figure 2.3. Responses to Paradox Lake stakeholder survey question: What are your primary uses of Paradox Lake (choose 3)?

2.3.3 Perception of Issues

Stakeholder perceptions of management issues were gauged by asking respondents to rate their level of concern with common environmental issues in lakes and their level of satisfaction with current management practices in Paradox Lake.

Invasive plants were the top concern of stakeholders (Figure 2.4). Eighty-eight percent (88%) of stakeholders responded that this was the issue about which they were “most concerned,”. The remaining 12% responded that they were “moderately concerned” about invasive species. The second and third most concerning issues were aesthetics (58% were “most concerned”) and water clarity (55% were “most concerned”).

Most stakeholders were generally satisfied with current management practices (Figure 2.5). More stakeholders responded as “satisfied” with the PLA boat launch staff (68%) than the NYSDEC boat launch staff (34%) though no reasons were provided. About half (54%) were satisfied with current in-lake invasive species management. Satisfaction varied the most regarding to public fisheries management: 42% were satisfied, 23% were somewhat satisfied, 5% were not at all satisfied, and 30% did not know.

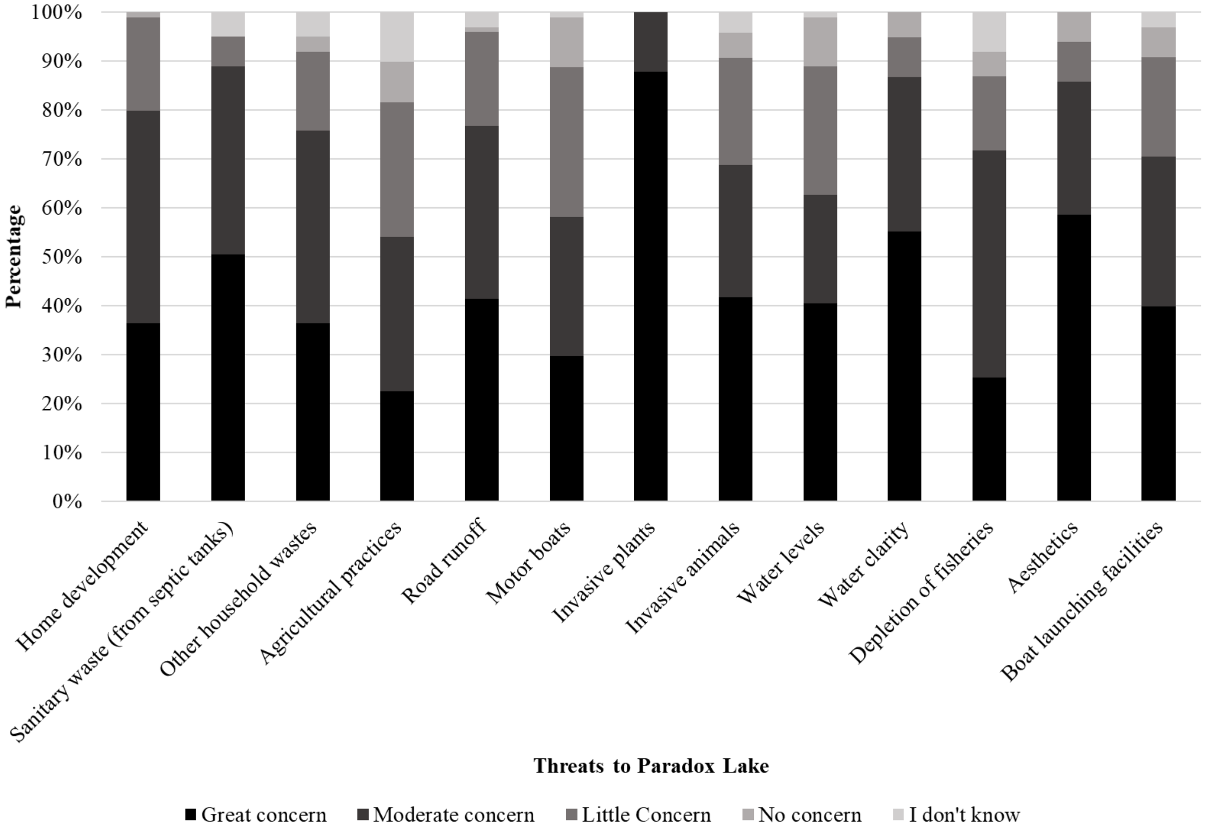


Figure 2.4. Responses to Paradox Lake stakeholder survey prompt: please rate your level of concern for the following items.

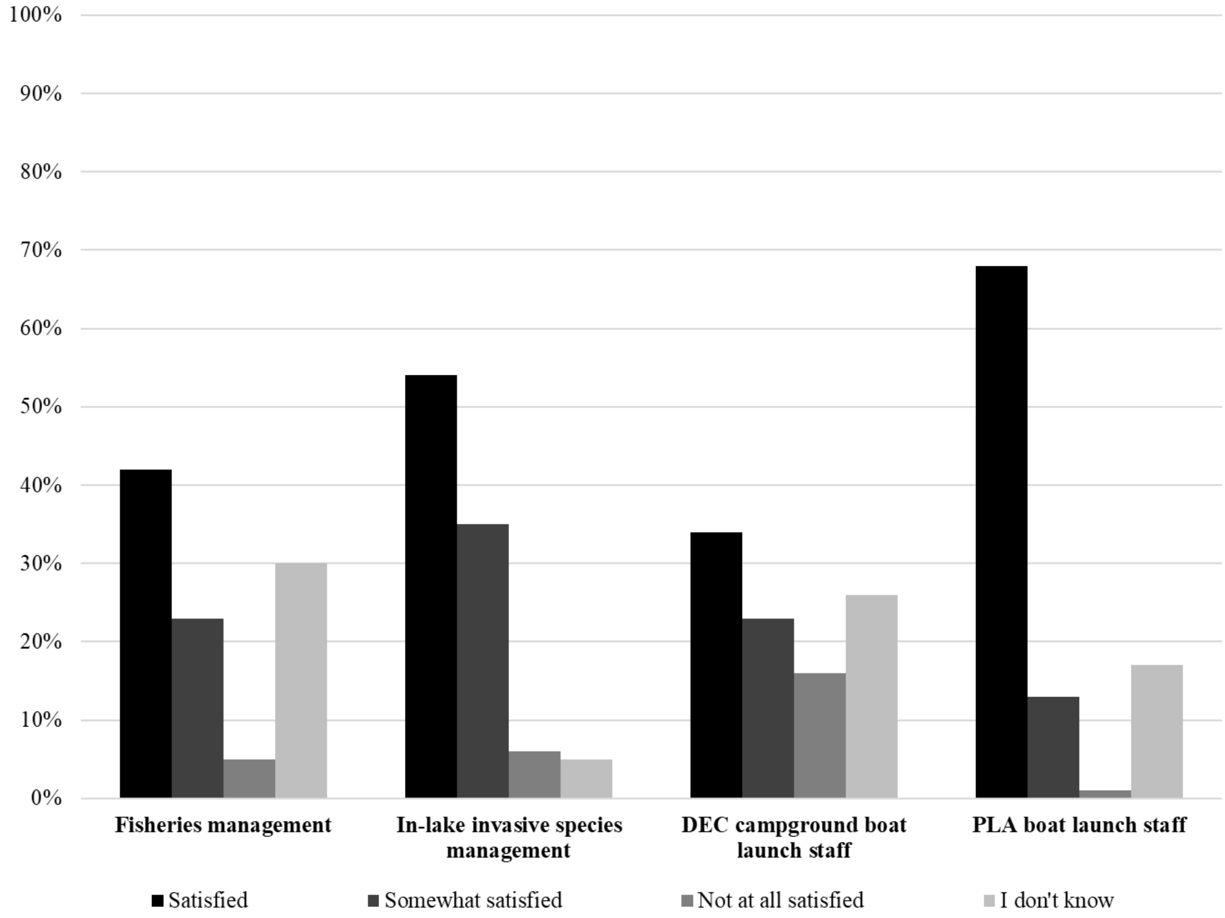


Figure 2.5. Responses to Paradox Lake stakeholder survey prompt: please rate your level of satisfaction of the following management practices.

2.4 Discussion

The three most common concerns of stakeholders at Paradox Lake were invasive plants, overall aesthetics, and water clarity. Invasive macrophyte growth was the top concern of most Paradox Lake residents. Eurasian watermilfoil (*Myriophyllum spicatum* and curly-leaf pondweed (*Potamogeton crispus*), were discovered in the lake in 2008 and 2009. Since then, the PLA has been active in the planning and implementation of contracted and volunteer hand-harvesting annually to control the growth. Thousands of curly leaf pondweed and Eurasian watermilfoil plants have been removed annually by volunteers (Figure 2.6) and contracted hand-harvesting by Adirondack Ecologists, LLC 2008-2013 and by Aqualogic, Inc. since 2017. The active participation of members likely also contributes to the high level of satisfaction with current in-lake invasive species management. There was more variability in the level of stakeholder satisfaction in management practices that did not have active stakeholder involvement. More stakeholders were satisfied with PLA boat launch staff, funded and staffed by PLA members, than they were with NYSDEC boat launch staff, which also may indicate positive value associated with involvement.

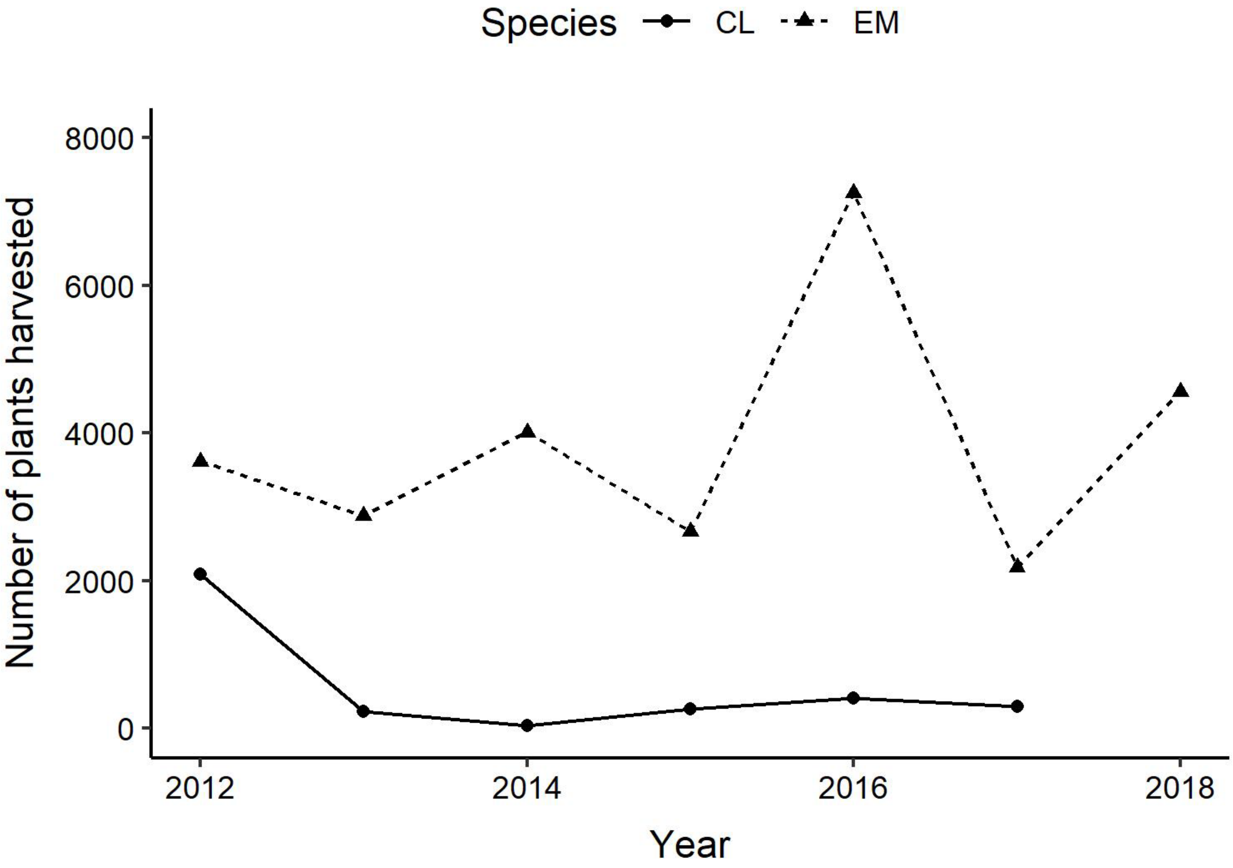


Figure 2.6. Number of individual curly leaf pondweed (CL) and Eurasian watermilfoil (EM) plants harvested by Paradox Lake Association volunteers since 2012. Note that number of plants is not representative of biomass removed.

Overall aesthetics were the second most concerning issue among stakeholders. In follow up, many residents expanded on this with specific concerns about aesthetic enjoyment of the waterbody and safety. These included the presence of numerous motorboats in the summertime, new development on the shore of the lake, and an increase in algal growth over the past decade.

Although many stakeholders own and operate motorboats on Paradox Lake, the increase in motorized traffic in the summer was a contentious issue among stakeholders, as indicated by the variety of ratings for concerns (Figure 2.4). Several stakeholders mentioned the increase in noise – especially in the early morning and late evening – was their biggest concern with motorboat use on the lake. Other stakeholders expressed their concern that the results of this questionnaire would be used as a foundation for banning motorboats on Paradox Lake. The variety of perspectives suggests that sustainable decisions about motorboat policies will need to include representation of multiple constituencies.

Home development was not highly rated as a concern, but many stakeholders raised the issue of shoreline development in terms of aesthetics. Although developers within Adirondack Park face more severe restrictions in terms of building, hamlets – areas of settlement where the Adirondack Park Agency (APA) encourages cluster development – have fewer restrictions than other areas within Adirondack Park. Paradox, New York is a hamlet within the Town of Schroon that borders almost the entirety of Paradox Lake. Any development within a hamlet needs to be at least 50 feet from the nearest shoreline compared to 75 ft required in low-intensity development areas or 100 ft setbacks required within natural resource management areas (§806 Adirondack Park Agency Act 1971).

Algal blooms were also mentioned in terms of aesthetics. Several stakeholders mentioned that they have noticed larger and more frequent algal blooms during the growing season. Algal growth also is related to water clarity, which was the third most concerning issue for Paradox Lake stakeholders.

This stakeholder analysis highlights several prominent values that are shared among stakeholders and demonstrates variability in other values. Most stakeholder concerns related primarily to invasive plants, water quality, and recreational and aesthetic value. These concerns, in addition to available in-lake and watershed data collected to date, will be used to guide investigations into the current state of Paradox Lake and its watershed and provide management objectives and alternatives for long-term management.

3 Physical and Chemical Characterization

3.1 Introduction

The physical and chemical characteristics of a lake directly impact its usability and value. For example, dissolved oxygen (DO) loss in the hypolimnion of a lake can reduce cold water fish species habitat and induce internal loading in a lake (Pettersson 1998), and water quality (Nicholls and Crompton 2018) and clarity (Clapper and Caudill 2014) have been linked to property value of lakefront homes. Understanding the physical and chemical characteristics of a lake is therefore necessary for making and implementing informed management decisions. Long-term monitoring of a lake can provide insight into temporal trends and establish a baseline against which management goals can be established.

A variety of limnological monitoring data have been collected from Paradox Lake during the past two decades. The PLA has participated in volunteer-based programs such as the Citizens

Statewide Lake Assessment Program (CSLAP) administered through the New York State Federation of Lake Associations (NYSFOLA) and the NYSDEC (2003 - 2011). They have participated in the Adirondack Lake Assessment Program (ALAP) through the Adirondack Watershed Institute (AWI) at Paul Smith's College since 2014 (2014 - 2020).

The purpose of this section was to provide an overview of the past and current conditions of Paradox Lake. To do this, we compiled data from volunteer monitoring programs to unify available information and provide guidance for the management plan. This included data from CSLAP and ALAP monitoring programs as available 2003-2020. Secondarily, we investigated long-term trends in parameters through the lens of the combined data sets.

3.2 Methods

3.2.1 Data sources

Available data were compiled from the CLSAP and ALAP monitoring efforts to date. The data sets were combined based on common variables and re-organized to facilitate analysis of long-term trends across data sets. For CSLAP, this included data for Secchi depth, total phosphorus, chlorophyll *a*, true color, and total nitrogen from 2003 through 2011 depending upon basin (Kishbaugh 2017). For the ALAP monitoring, the data included Secchi depth, total phosphorus, chlorophyll *a*, true color, pH, specific conductance, alkalinity, chloride, calcium, and sodium from 2014 through 2020 (Laxson et al. 2015a, 2016, 2017, 2018, 2019; Laxson 2020; Yerger et al. 2021). We did not analyze long-term trends in nitrate + nitrite from ALAP monitoring data because most values were either missing or were below the detection limit for this parameter.

Trophic status indicators (TSI) were developed to allow lake managers to draw inference about the productivity of a waterbody with respect to important indicators such as chlorophyll *a*, Secchi depth, and total phosphorus (Carlson 1977). We calculated TSIs for chlorophyll *a* (CHL), Secchi depth (SD), and total phosphorus (TP) based on predictive equations from Carlson (1977) as follows:

$$\mathrm{TSI(CHL)} = 9.81 \times \log_e(\mathrm{CHL}) + 30.6$$

$$\mathrm{TSI(SD)} = 60 - 14.41 \times \log_e(\mathrm{SD})$$

$$\mathrm{TSI(TP)} = 14.42 \times \log_e(\mathrm{TP}) + 4.15$$

3.2.1 Statistical analysis

We conducted statistical analyses to determine whether we could detect trends in total nitrogen, total phosphorus, Secchi depth, chlorophyll *a*, pH, alkalinity, true color, specific conductance, chloride, sodium, or calcium with respect to differences between upper and lower basins of the lake, months, and years. For each analysis, we $\log_e$-transformed the response variables to meet assumptions about normality and zero-constrained measurements. We considered a suite of 13 statistical models for each parameter that used all combinations of the explanatory variables "basin" (categorical), "month" (categorical), and "year" (numeric) along with potential interactions between explanatory variables.

For each water quality parameter, we used general linear models to test the isolated or combined effects of basin, month, and year on the parameter of interest using R (R Core Team 2021). We used Akaike Information Criterion corrected for sample size (AICc) to choose the best supported model of each parameter (Burnham and Anderson 2002) within the *AICcmodavg* package (Mazerolle 2020). We used least squares estimation with appropriate sum of squares calculation corresponding to each model (Fox and Weisber 2019) to determine statistical significance of effects. We plotted observed data against model predictions for each parameter for which the best model included at least one of the explanatory variables (basin, month, year) using the *ggplot2* package (Wickham 2016).

3.3 Results

We noted significant changes in total nitrogen, total phosphorus (surface and bottom), Secchi depth, chlorophyll *a*, pH, alkalinity, specific conductance, and calcium with respect to at least one of the explanatory variables of interest (basin, month, year). We failed to detect changes in true color, chloride, or sodium between basins, among months, or through time. Results for each parameter are presented below.

3.3.1 Total nitrogen

Total nitrogen, measured only in CSLAP data, was highly variable but decreased slightly (linear regression, R2 = 0.03, DF = 117, t = -1.788, p = 0.076) from 2003 through 2011 (Figure 3.1). The mean predicted total nitrogen concentration was 0.31 μg/L in 2003 (95% confidence interval [CI] = 0.12 – 0.51 μg/L) and 0.24 2011 μg/L in 2011, 95% confidence interval = 0.09 – 0.24 μg/L). Measurements were less variable in recent years.

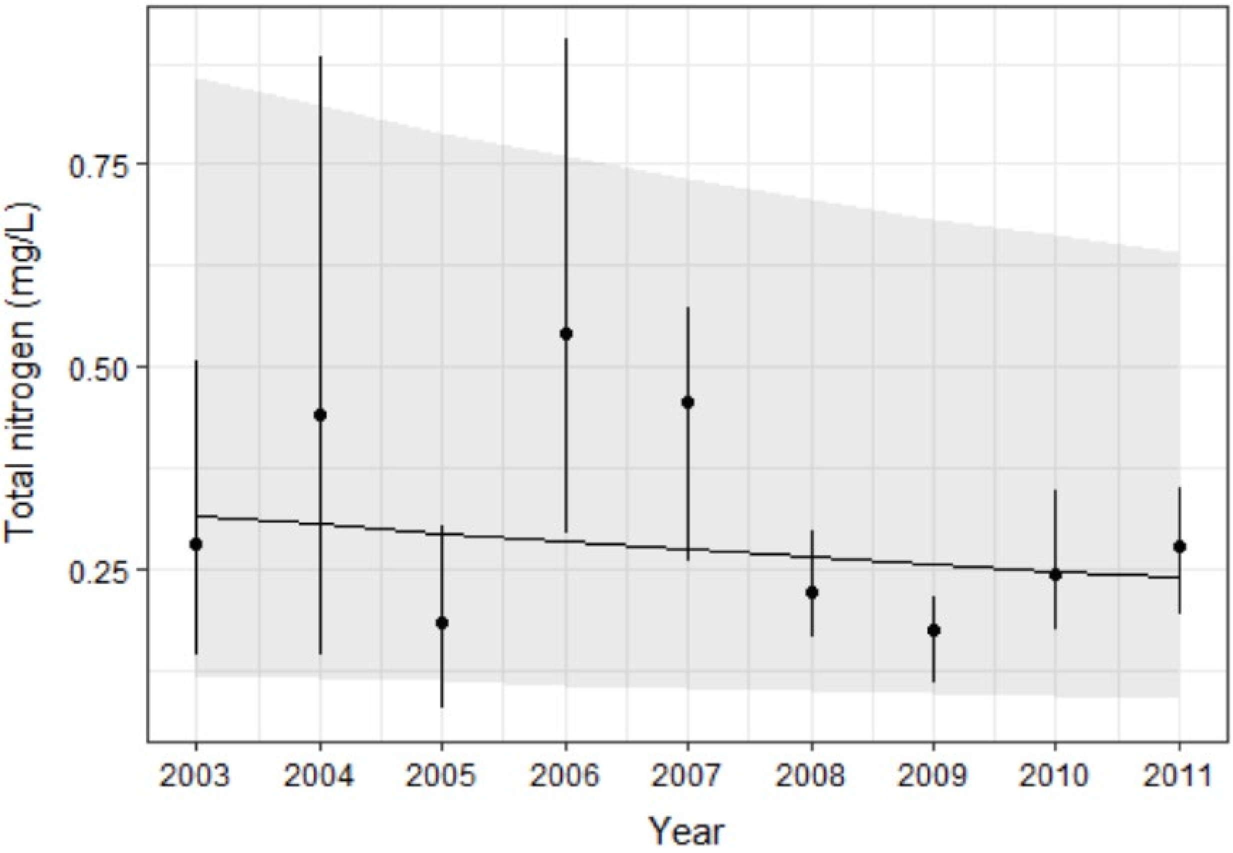


Figure 3.1. Observed and model-predicted total nitrogen by year. Black dots are annual means and vertical black lines are 95% confidence intervals. The diagonal black line is the mean model-predicted total nitrogen for each year and the gray polygon is the 95% prediction interval.

3.3.2 Total phosphorus

Separate trends were observed in total phosphorus measured at the surface and at the bottom of the lake. Surface samples were available for a longer time period (2003-2020) than bottom samples (2003-2011) due to differences between CSLAP (2003-2011) and ALAP (2014-2020) monitoring protocols. Total phosphorus at the surface differed significantly between basins (analysis of covariance [ANCOVA], DF = 1, 190; $F = 23.6$, $p < 0.001$), and changed differently across years within basins (ANCOVA, DF = 1, 190; $F = 3.9$, $p = 0.49$), although total phosphorus generally decreased from 2003 through 2020 across basins (ANCOVA, DF = 1, 190; $F = 54.0$, $p < 0.001$). These differences explained about 28% of the variability of total phosphorus in surface samples ($R^2 = 0.28$).

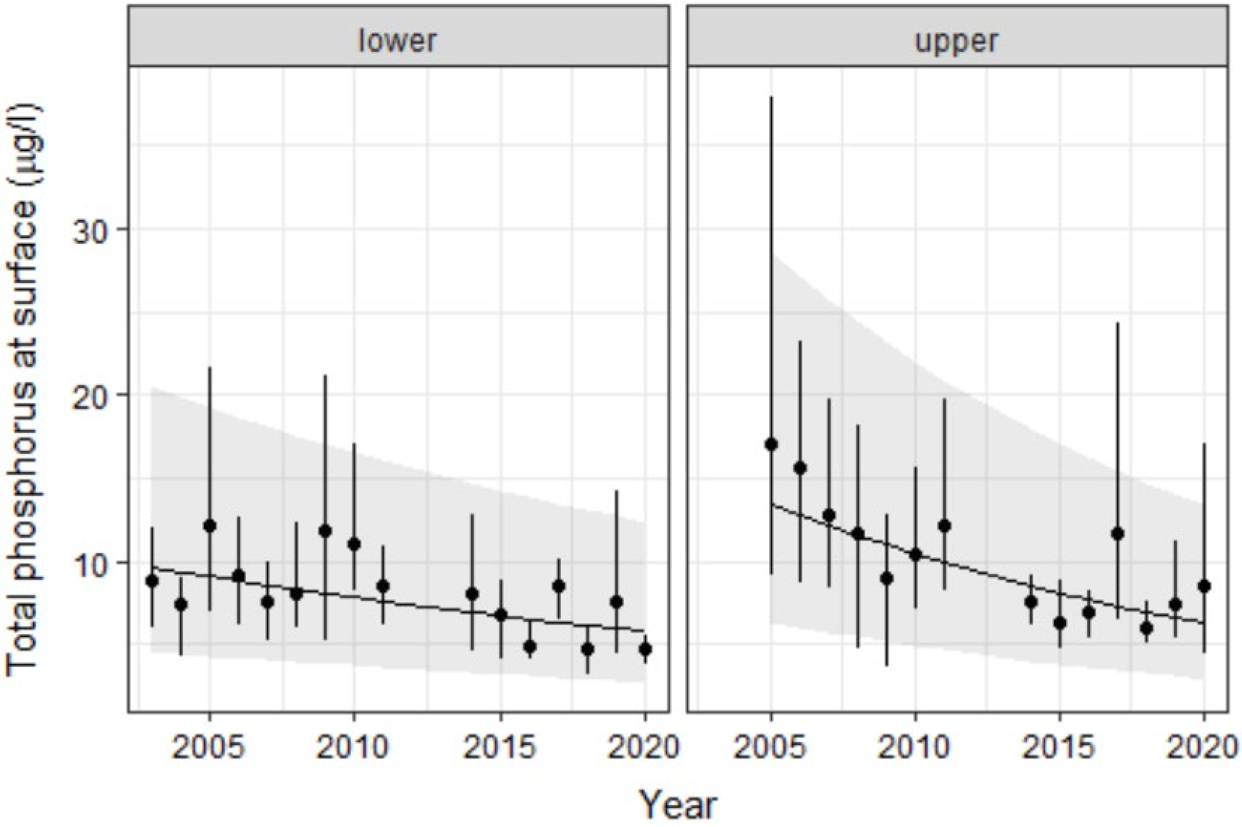


Figure 3.2. Total phosphorus concentration at the surface of the lower and upper basins across years. All symbols are defined as in Figure 3.1.

Total bottom phosphorus was measured only during years 2003-2011 through CSLAP monitoring. We observed significant differences between basins (t-test, DF = 86; F = 13.6, $p < 0.001$), and failed to detect effects of month or year on total bottom phosphorus. Differences between basins alone explained about 68% of the variability in total bottom phosphorus ($R^2 = 0.68$). The upper basin (mean = 39.2 µg/L, 95% CI = 13.6-112.9 µg/L) had higher total phosphorus concentrations at the bottom than the lower basin (mean = 8.5 µg/L, 95% CI = 3.0-24.6 µg/L) across months and years.

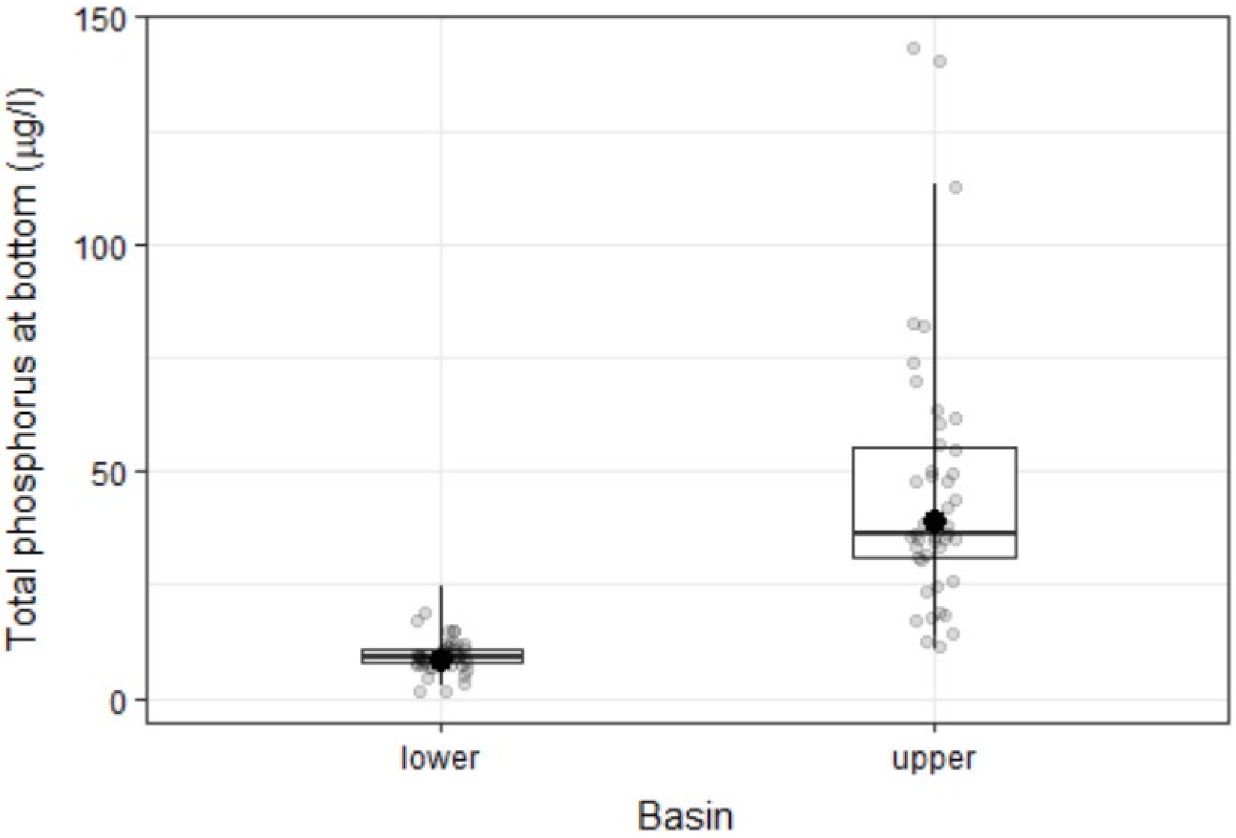


Figure 3.3. Total phosphorus at the bottom of the lower and upper basins of Paradox Lake 2003-2011. Transparent points are observed data described by box-and-whisker plots within which the bold horizontal line is the median, the box ends are the 25th and 75th percentiles, and whiskers approximate the first and 99th percentiles. Black dots with vertical lines are the mean and 95% prediction interval for predicted total phosphorus at the bottom across all months and years.

3.3.3 Secchi depth

Secchi depth varied between basins (ANCOVA, DF = 1, 185; F = 6.9, p = 0.009), among months (DF = 5, 185; F = 2.7, p = 0.02) and the change over time depended upon basin (DF = 1, 185; F = 6.8, p = 0.009). The differences between basins, months, and across years explained about 36% of the variation in Secchi depth ($R^2 = 0.36$) from 2003 through 2020. The upper basin (mean = 3.7 m, 95% CI = 3.1-4.4 m) had lower Secchi depth across all years than the lower basin (4.8 m, 95% CI = 4.3-5.2 m). Secchi depth was generally lowest in June and increased until August in both basins across years (Figure 3.4). While we failed to detect significant changes in Secchi depth within the lower basin across years (DF = 1, 185; F = 0.9, p = 0.33), mean Secchi depth in the upper basin increased from a model-predicted mean of 3.0 m (2.0-4.7 m) in 2003 to 4.5 m (2.9-7.0 m) in 2020.

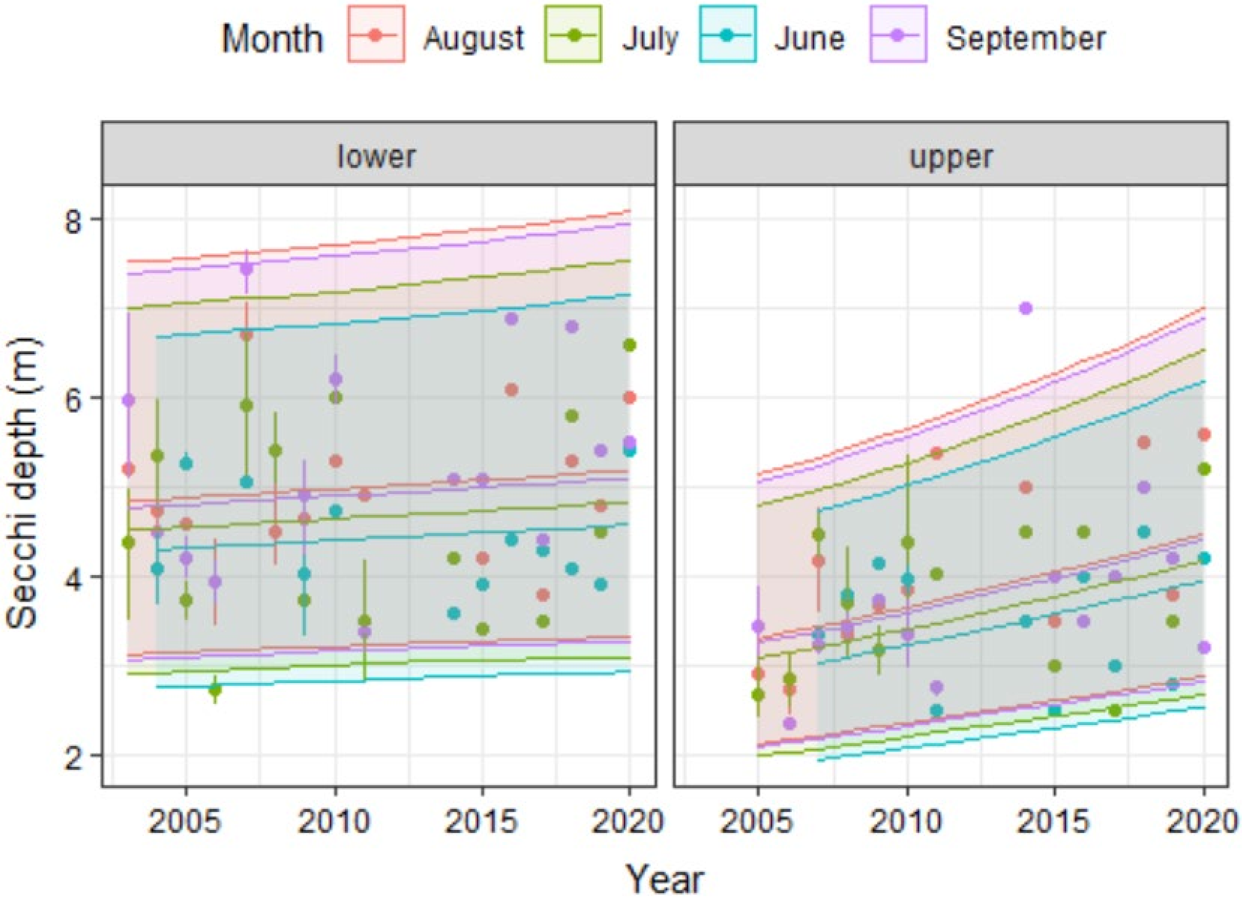


Figure 3.4. Secchi depths in Paradox Lake within lower (left) and upper (right) basins across years within months (colors). The solid dots are mean Secchi depth within months and basins and vertical lines are 95% confidence intervals for observed samples. The colored diagonal lines are model-predicted Secchi depth by month and the colored polygons are 95% prediction intervals from ANCOVA.

3.3.4 Chlorophyll a

Chlorophyll *a* varied among months (ANCOVA, DF = 5, 180; F =4.2, p < 0.001) and between basins (DF = 5, 180; F = 21.5, p = 0.001), and decreased slightly across years (DF = 1, 180; F = 3.1, p = 0.08) in both basins (Figure 3.5), explaining about 19% of the variation in chlorophyll *a* 2003-2020 ($R^2 = 0.19$). Chlorophyll *a* concentration was higher in the upper basin (mean = 2.5 µg/L, 95% CI = 1.4 – 4.3 µg/L) than in the lower basin (mean = 1.5 µg/L, 95% CI = 1.1 – 2.2 µg/L) across years and months.

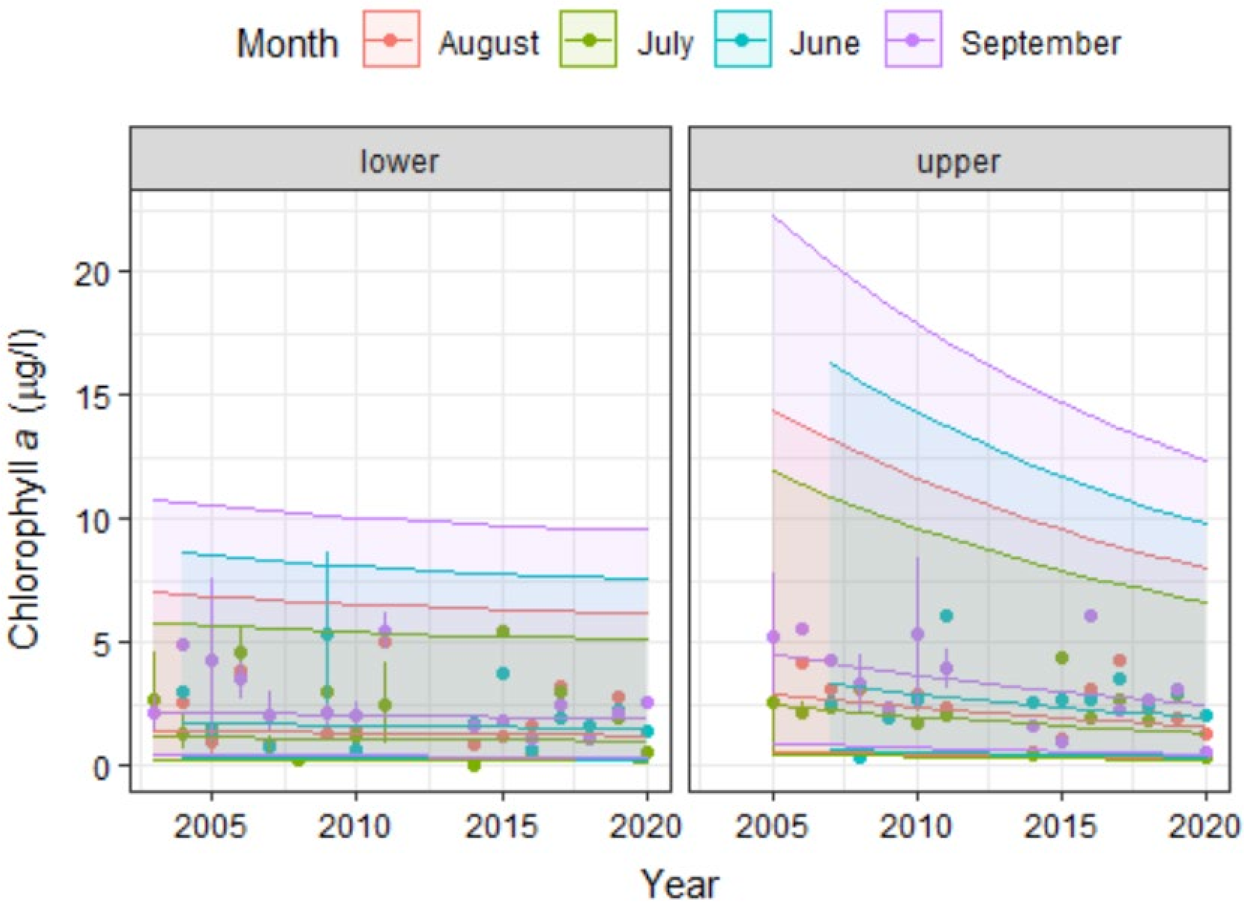


Figure 3.5. Chlorophyll *a* concentration in Paradox Lake within lower (left) and upper (right) basins across years within months (colors). All symbols are defined as in Figure 3.4.

3.3.5 pH

We detected significant changes in pH across years (linear regression, DF = 68, F = 37.7, $p < 0.001$), explaining about 36% of the variation in pH ($R^2 = 0.36$) but we failed to detect any differences between basins or among months. The mean pH in Paradox Lake increased across years within the 2014-2020 ALAP monitoring data (Figure 3.6). The model-predicted mean increased from 7.02 (6.14-8.03) in 2014 to 8.11 (7.09-9.27) in 2020, suggesting that the lake has become increasingly alkaline.

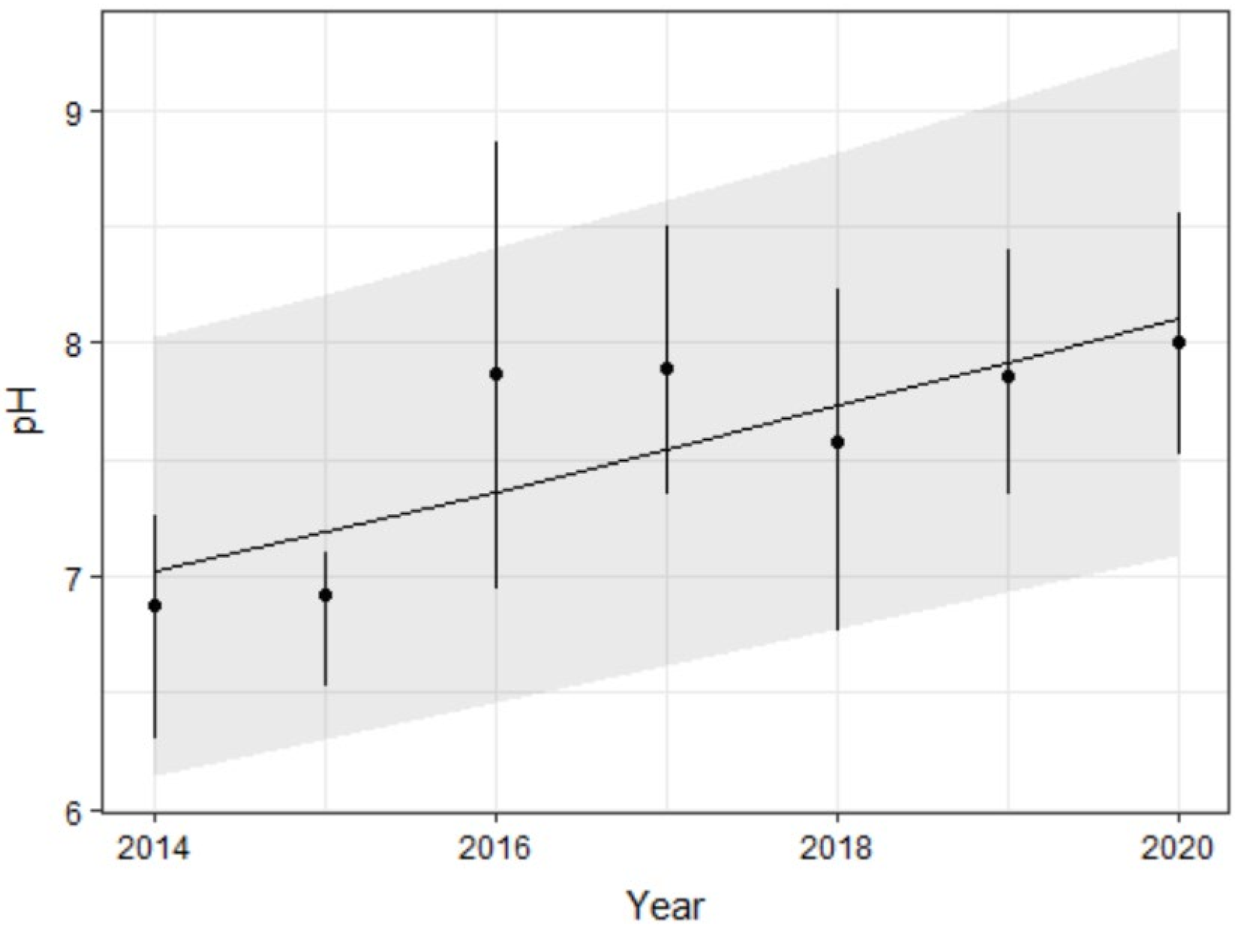


Figure 3.6. pH at the surface of the lower and upper basins across years (2014-2020) represented in ALAP monitoring data for Paradox Lake. All symbols are defined as in Figure 3.1.

3.3.6 Alkalinity

The alkalinity (capacity to buffer changes in pH) in Paradox Lake varied between basins (ANCOVA, DF = 1, 23; F = 73.2, $p < 0.001$), among months (DF = 4, 23; F = 3.3, p = 0.03), and across years (DF = 1, 23; F = 18.7, $p < 0.001$). These three factors explained about 86% of the total variation in alkalinity ($R^2 = 0.86$) during the past 20 years (Figure 3.7). Mean alkalinity was higher in the upper basin (mean = 25.5 mg/L, 95% CI = 22.7-28.8 mg/L) than in the lower basin (mean = 21.8 mg/L, 95% CI = 19.4-24.6 mg/L) across all years and months. Alkalinity generally increased from June through August, decreasing again in September. Alkalinity increased similarly in the lower and upper basins from 2003 through 2020. In the lower basin, mean alkalinity increased from 20.5 mg/L (18.2-23.2 mg/L) in 2003 to 24.7 mg/L (21.8-28.1 mg/L) in 2020. In the upper basin, mean alkalinity increased from 24.0 mg/L (21.3-27.1 mg/L) in 2014 to 29.0 mg/L (25.6-33.0 mg/L) in 2020.

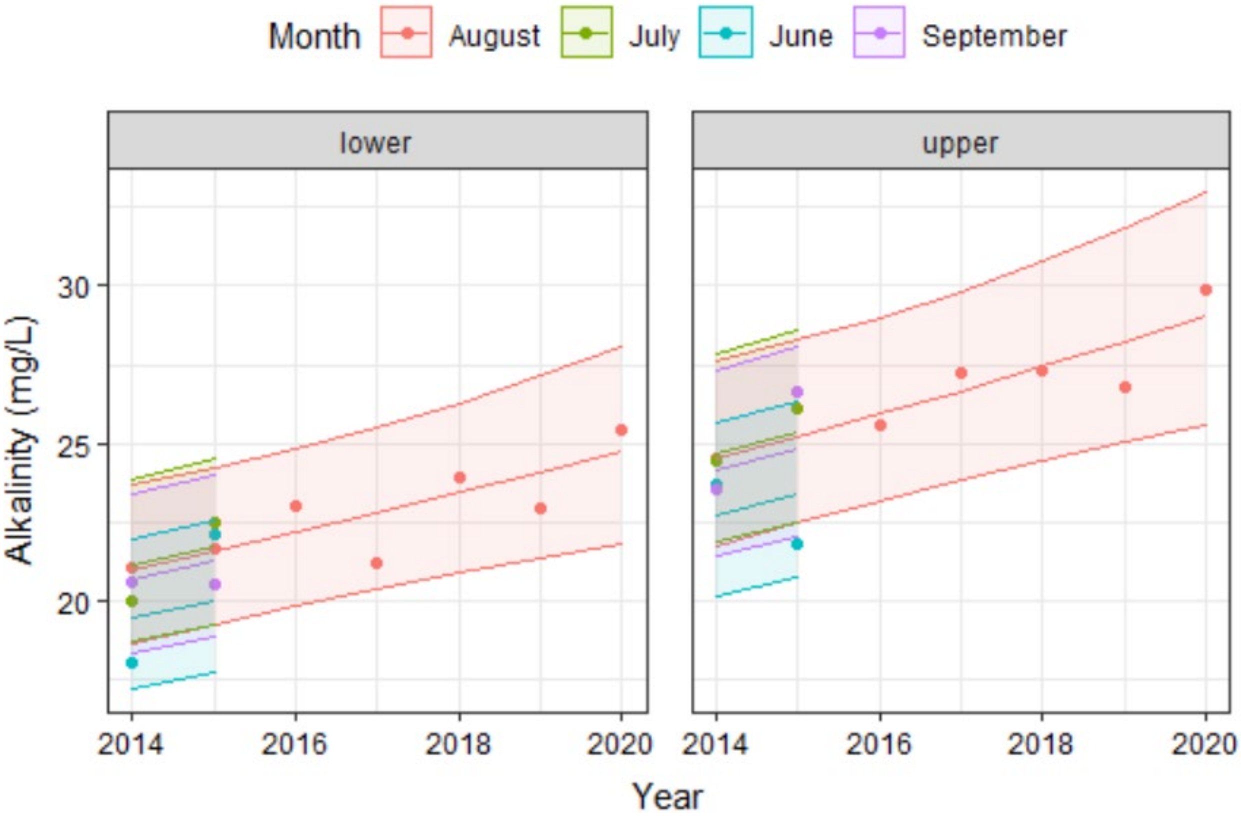


Figure 3.7. Alkalinity in the lower (left) and upper (right) basins of Paradox Lake across years and within months (colors). All symbols are defined as in Figure 3.4.

3.3.7 Specific conductance

Specific conductance varied significantly between basins (ANCOVA, DF = 1, 67; F = 10.7, p = 0.002) and across years (ANCOVA, DF = 1, 67; F = 6.3, p = 0.01), with these factors explaining about 20% of the variability in specific conductance ($R^2 = 0.20$). Specific conductance was higher in the upper basin (mean = 74 µS/cm, 95% CI = 62-89 µS/cm) than in the lower basin of Paradox Lake (mean = 69 µS/cm, 95% CI = 58-83 µS/cm). Changes in specific conductance across years were similar between the upper and lower basins. The lower basin increased from a mean of 66 µS/cm (55-80 µS/cm) in 2014 to 72 µS/cm (60-87 µS/cm) in 2020, while the upper basin increased from a mean of 71 µS/cm (59-86 µS/cm) in 2014 to 77 µS/cm (64-93 µS/cm) in 2020.

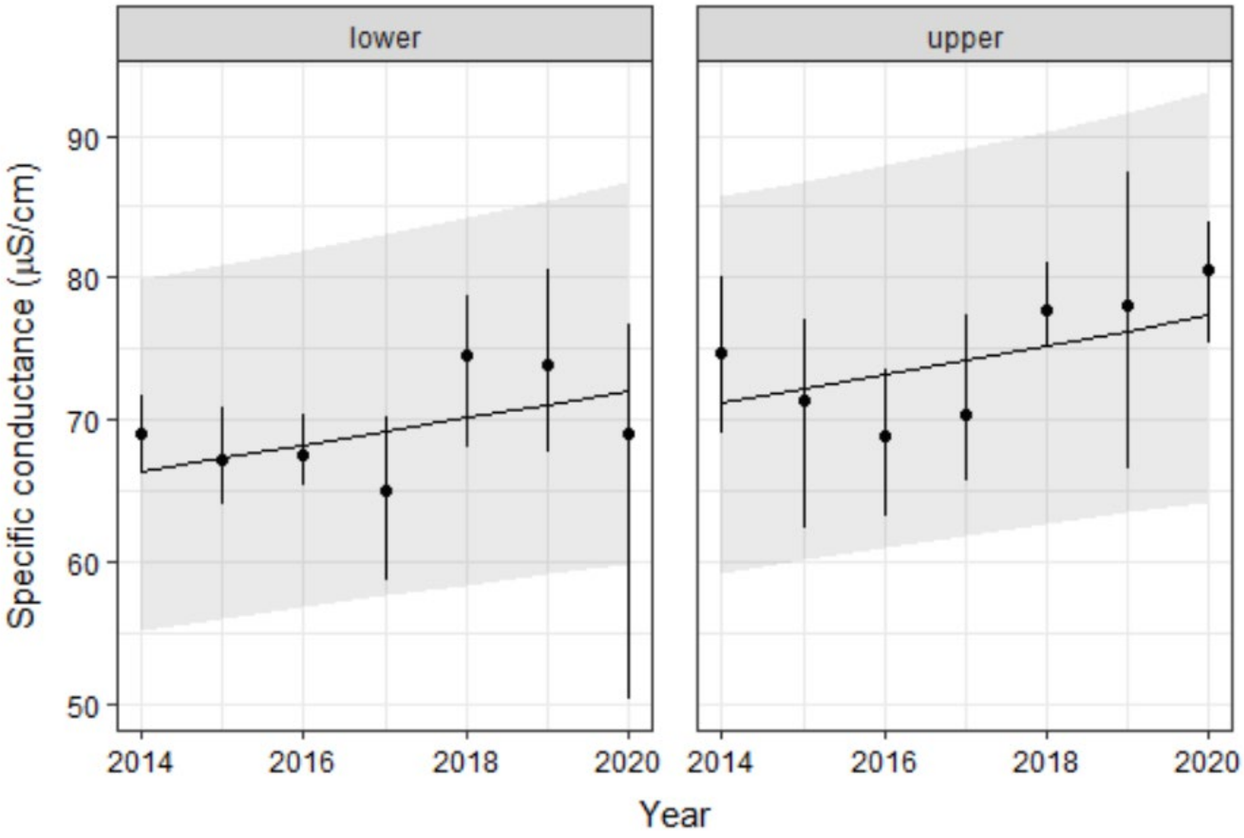


Figure 3.8. Specific conductance in the lower (left) and upper (right) basins of Paradox Lake from ALAP data 2014-2020. All symbols are defined as in Figure 3.1.

3.3.8 Calcium

Calcium concentrations varied between lower and upper basins of Paradox Lake (t-test, DF = 30; t = 4.48, $p < 0.001$). Although we failed to detect differences in calcium among months or across years, the differences between lakes explained more than 40% of the variability (R^2 = 0.42) in calcium from 2014 through 2020 (Figure 3.9). Mean calcium concentration was higher in the upper basin (mean = 8.3, 95% CI = 7.0-9.8) than in the lower basin (mean = 7.3, 95% CI = 6.1-8.6).

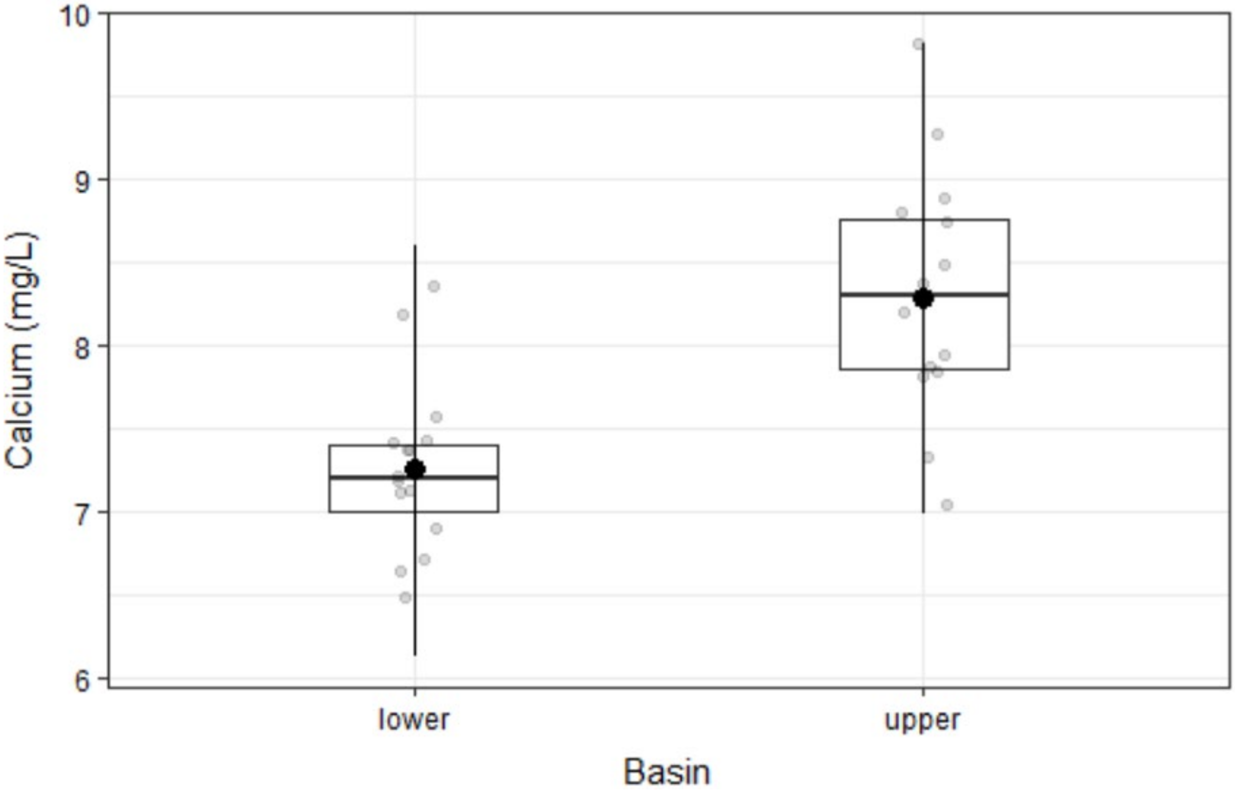


Figure 3.9. Calcium concentrations in the lower and upper basins of Paradox Lake, NY across months and years. All symbols are defined as in Figure 3.3.

3.3.9 Trophic status indices (TSI)

We investigated long-term trends in trophic status indices (TSI) based on a combination of monitoring data from CSLAP (2003-2011) and ALAP (2014-2020) depending on data availability. We found significant changes in TSI values between basins, months, and years. These changes depended on the parameter measured.

The TSI for chlorophyll *a*, TSI(CHL), fluctuated significantly between basins (ANOVA, DF = 1, 181; F = 16.8; $p < 0.001$) and months (ANOVA, DF = 5, 181; F = 3.28; $p = 0.007$), explaining about 15% of the total variation in TSI(CHL), but we failed to detect changes through time (Figure 3.10). The mean TSI(CHL) in the upper basin was 39 (25-61), slightly higher than the mean TSI(CHL) for the lower basin of 33 (21-52). The TSI(CHL) values were generally lowest during July and August across basins. Based on values of TSI for chlorophyll *a* the lower basin was classified as “oligotrophic” (unproductive) on average and the upper basin was classified as “meso-oligotrophic” (moderately productive) on average.

The TSI for Secchi depth, TSI(SD), varied significantly between basins (ANCOVA, DF = 1, 185; F = 83.3, $p < 0.05$), among months (ANCOVA, DF = 5, 185; F = 2.8, $p = 0.02$), and through time (ANCOVA, DF = 1, 185; F = 9.6, p = 0.002). The change in TSI(SD) varied between basins, and TSI(SD) only changed significantly in the upper basin (ANCOVA, DF = 1, 185; F = 6.1, p = 0.01), decreasing from a mean of 44 (37-52) in 2005 to a mean of 39 (33-47) in 2020 (Figure 3.11). These factors combined explained about 36% of the total variation in TSI(SD) ($R^2 = 0.36$). The TSI(SD) for the lower basin indicated that it is oligotrophic on average and has remained in that state since the start of monitoring whereas TSI(SD) for the upper basin has shifted from mesotrophic in the early 2000s to meso-oligotrophic or oligotrophic conditions in the most recent years.

The TSI for total phosphorus, TSI(TP), varied significantly between basins (ANCOVA, DF = 1, 280; F = 68.8, $p < 0.001$), and through time (ANCOVA, DF = 1, 280; F = 64.2, $p < 0.001$), but we failed to detect changes between months. Changes between basins and across years explained about 33% of the total variability in TSI(TP). The change in TSI(TP) varied between basins (ANCOVA, DF = 1, 280; F = 13.2, $p < 0.001$), with TSI(TP) decreasing significantly in both basins, but to a greater degree in the upper basin (Figure 3.12). In the lower basin, TSI(TP) decreased from a mean of 37 (24-58) in 2003 to a mean of 30 (19-46) in 2020 and in the upper basin TSI(TP) decreased from 50 (32-78) in 2005 to a mean of 30 (19-47) in 2020. The TSI(TP) for the lower basin indicated that it was oligotrophic historically and has become increasingly oligotrophic in recent years with few exceptions. The upper basin was historically classified as meso-eutrophic or eutrophic but has become steadily less productive with respect to TSI(TP) and was classified as oligotrophic in all recent years of sampling.

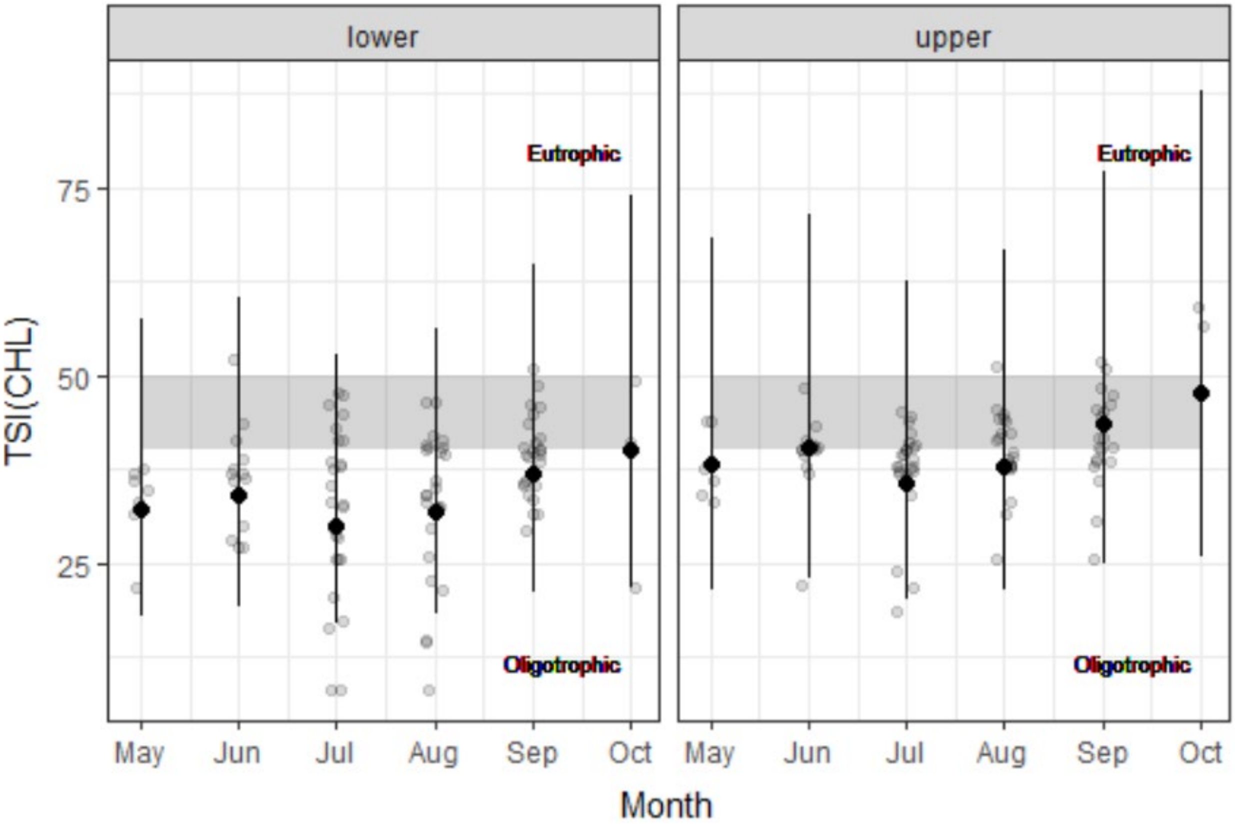


Figure 3.10. Trophic status index for chlorophyll *a* concentration (mg/L) in the lower (left) and upper (right) basins of Paradox Lake, NY by month. The horizontal shaded area represents "mesotrophic" (moderately productive) conditions. Lakes below this shaded area are classified as "oligotrophic" (unproductive) and lakes above the shaded area are "eutrophic" (highly productive). All other symbols are defined as in Figure 3.3.

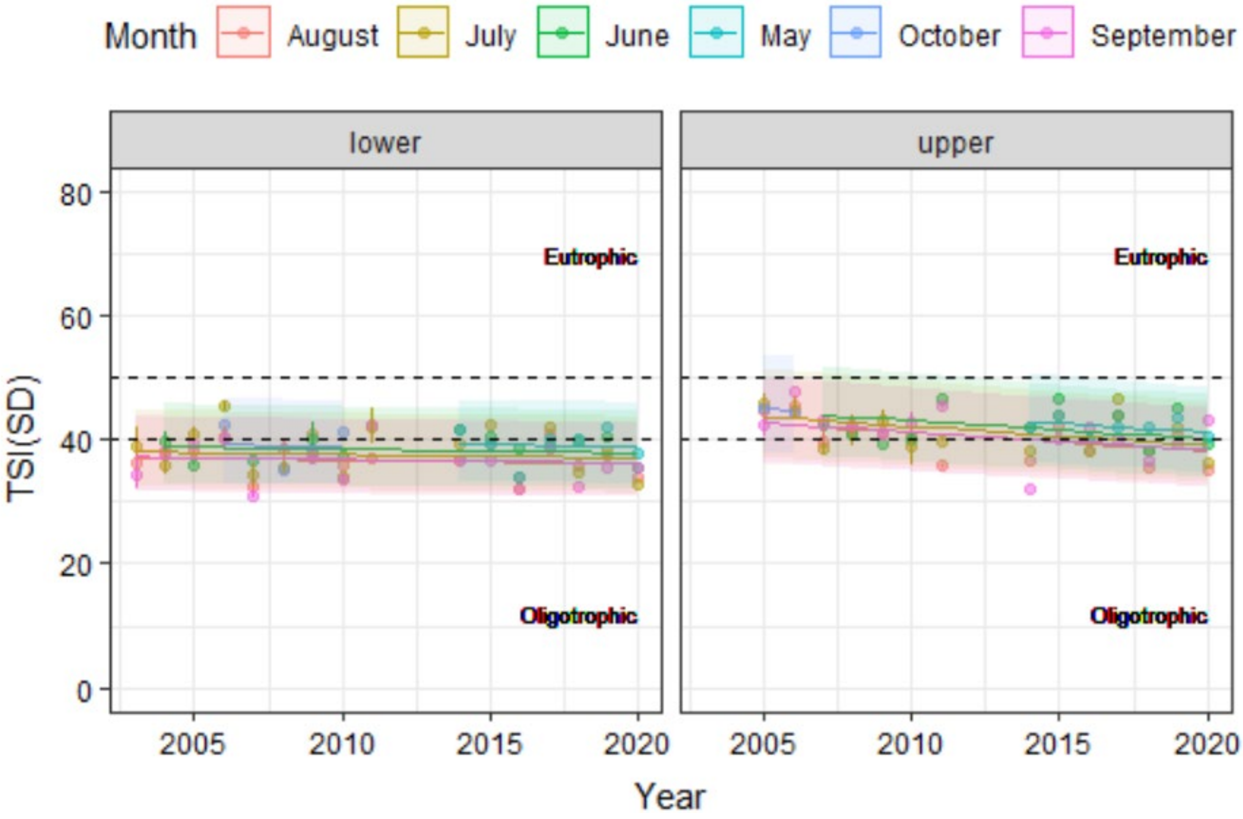


Figure 3.11. Trophic status index (TSI) for Secchi depth (m) in the lower (left) and upper (right) basins of Paradox Lake, NY across years and months (colors). The space between horizontal dashed lines represents “mesotrophic” (moderately productive) conditions. Lakes below this area are classified as “oligotrophic” (unproductive) and lakes above it are “eutrophic” (highly productive). All other symbols are defined as in Figures 3.4.

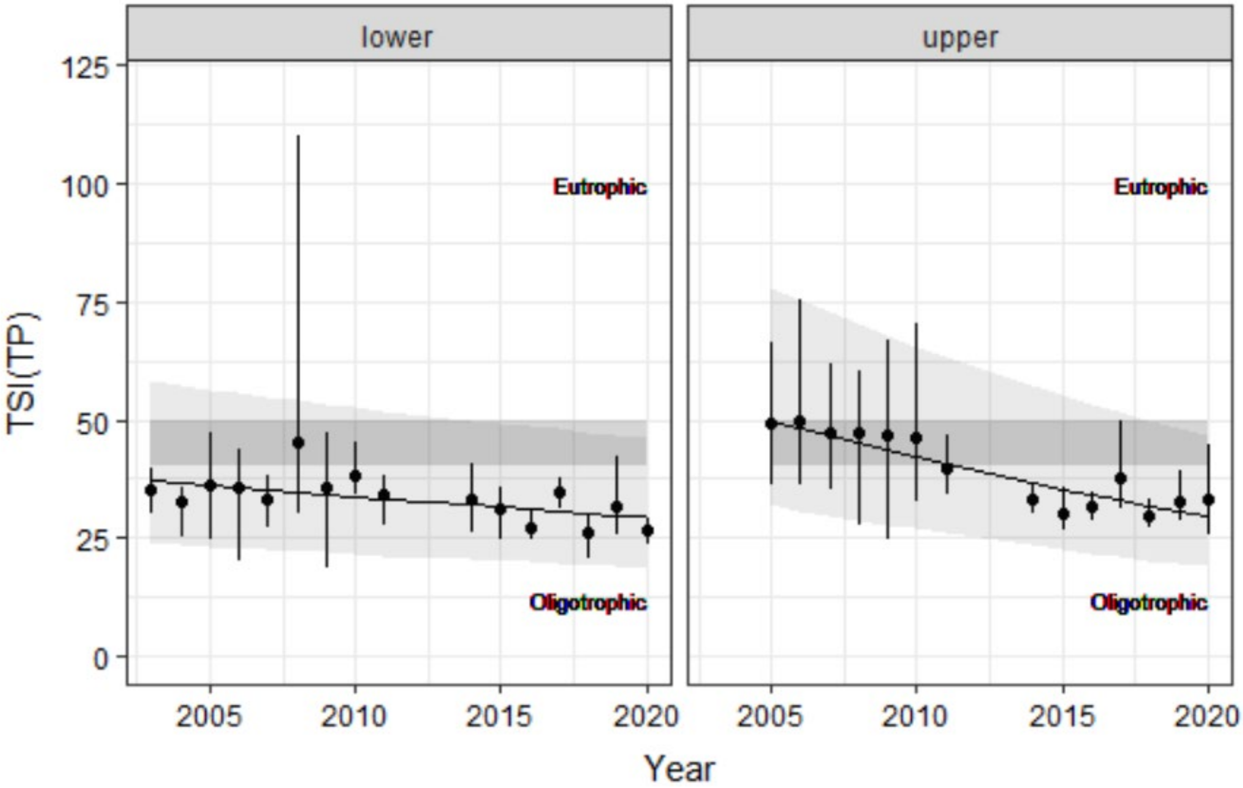


Figure 3.12. Trophic status index (TSI) for total phosphorus (µg/L) in the lower (left) and upper (right) basins of Paradox Lake, NY across years. The horizontal shaded area represents "mesotrophic" (moderately productive) conditions. Lakes below this shaded area are classified as "oligotrophic" (unproductive) and lakes above the shaded area are "eutrophic" (highly productive). All other symbols are defined as in Figure 3.1.

3.4 Discussion

This work demonstrated differences in water quality parameters between basins of Paradox Lake, NY, and changes within and across years using long-term data compiled through volunteer monitoring programs in which the Paradox Lake Association has participated. The upper basin was consistently more productive than the lower basin based on a wide range of environmental indicators. However, based on these same indicators the upper basin appears to have become increasingly less productive over time. Lake-wide changes in parameters such as alkalinity, pH, and specific conductance may be indicative of recovery from acid rain impacts during the 20th century. Finally, lack of changes in other parameters such as chloride and sodium concentrations may indicate limited impacts from sources of common concern such as road salt.

Common measures of productivity explored in this study (total nitrogen, total phosphorus, Secchi depth, and chlorophyll *a*) and associated trophic status indices (TSI) all indicated that the upper basin is historically more productive than the lower basin of Paradox

Lake. This finding generally aligns with previous reports (e.g., Laxson 2020; NYSDEC 2013) based on individual data sets that were combined for this work. All three TSIs classified the lower basin as “oligotrophic”, or unproductive. Oligotrophic waterbodies tend to exhibit lower nutrient concentrations, less algal and plant production, and reduced animal biomass relative to other lakes. Trophic classification of the upper basin varied with TSI metric, and two of the three TSIs indicated that trophic status of the upper basin has changed significantly over time. Both TSI(CHL) and TSI(SD) indicated that the upper basin has fluctuated within the range of “mesotrophic” (moderately productive) values since monitoring began. The TSI(CHL) values for the upper basin, on average, suggest that the lake is meso-oligotrophic (low to moderate productivity). The TSI(SD) values indicated that the upper basin has decreased in productivity from meso-eutrophic (moderately to highly productive) to meso-oligotrophic ranges in the past 20 years. Likewise, there was a substantial decrease in TSI(TP) across years, ranging from meso-eutrophic (moderately to highly productive) in 2005 to oligotrophic in 2020. Collectively, these results suggest that the upper basin, while still slightly more productive than the lower basin, has become less productive in recent years whereas the lower basin has remained consistently unproductive.

Both basins of Paradox Lake have become increasingly alkaline since the start of monitoring in 2003. The pH of both basins increased from about 7 (neutral) to about 8 (slightly basic) during the past 20 years. This change is likely associated with recovery from acidification during the mid-to-late 1900s, as the phenomenon can be observed regionally in available data (e.g., Kishbaugh 2017). Increases in alkalinity and specific conductance in both basins suggest that some of this increased buffering capacity is due to watershed inputs of ions following cessation of acid deposition. This seems to be supported by the fact that the upper basin, which is upstream of the lower basin in the watershed, generally had higher ion concentrations (e.g., calcium) in addition to lower Secchi depth and nutrient concentrations. The lack of change in either chloride concentrations or sodium ions since 2014 (Laxson et al. 2015, Laxson 2020) suggests that increases in specific conductance and buffering capacity within this system are not the result of inputs from winter road treatment (e.g., salt).

The results of this work demonstrate the importance of long-term monitoring data for understanding changes and fluctuations in water-quality parameters and trophic status over time. Many of the parameters measured through CSLAP and ALAP in the past 20 years are indicative of changes in trophic status and buffering capacity. These data are also helpful for understanding important differences between basins of Paradox Lake and seasonal changes within basins. Continued monitoring will facilitate informed management into the future.

4 Aquatic Plant Monitoring and Management History

4.1 Introduction

A diverse, native plant community is necessary to provide essential ecosystem functions including fish habitat and spawning ground, food for fish and waterfowl, and nutrient sequestration as plants use nutrients for growth. Rooted aquatic plants and algae are among the top three concerns of New York State (NYS) lake residents surveyed by the NYS Federation of Lake Associations (NYSFOLA 2009). While macrophytes are an essential component of lake ecosystems, they tend to be identified as a problem area due to their visible impacts on recreational activities. Paradox Lake stakeholders identified invasive plants and unwanted algal growth as the top two concerns when asked about threats to Paradox Lake (Section 2).

In 2008, Adirondack Ecologists, LLC (AE) identified Eurasian watermilfoil in a bay near the public boat launch on Paradox Lake. Since its discovery, volunteer and contracted divers have hand-harvested Eurasian watermilfoil annually with annual harvest records kept since 2008 (https://paradox-lake.com/reports-documents). In 2015, the Adirondack Park Invasive Plant Program (APIPP) conducted monitoring in Paradox Lake to compile a list of known species (Regalado et al. 2015), finding that approximately 13.5% of plant bed area was Eurasian watermillfoil. Surveyors identified 22 species including two non-native macrophytes – Eurasian watermilfoil and curly leaf pondweed (*Potamogeton crispus*). At the time of that survey, Eurasian watermilfoil growth was limited to 10 acres in seven beds in the upper basin (Figure 4.1).

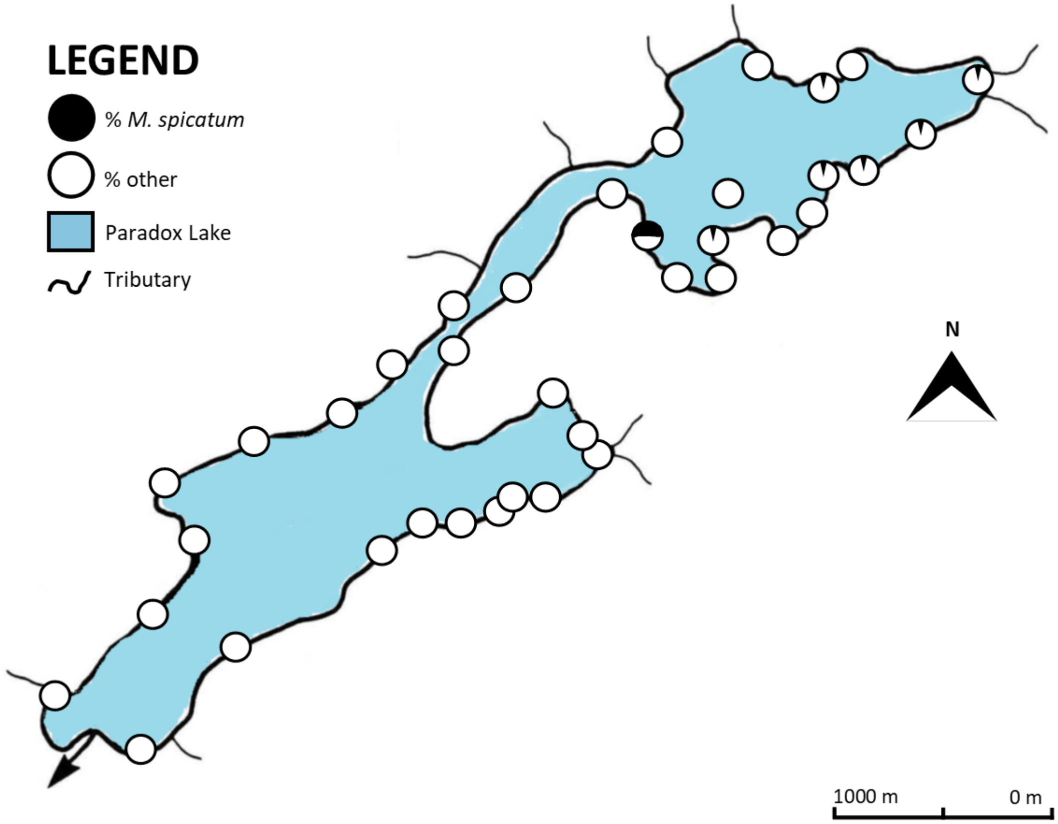


Figure 4.1. Map of Paradox Lake showing sampling sites and relative abundance of Eurasian watermilfoil from a 2015 macrophyte survey conducted by the Adirondack Park Invasive Plant Program (Regalado et al. 2016. Each circle represents a sampling location used by Regaldo et al. (2016). White represents native plant growth, and black represents Eurasian watermilfoil growth.

The Paradox Lake Association has hired Aqualogic Inc. annually 2016-2021 to perform diver- harvesting on high-impact areas of the lake in the upper basin and the narrows. The firm conducted some diver-assisted suction harvesting in 2017-2018 but discontinued those efforts in 2019 because plant beds were not thought to be dense enough at the time (Paradox Lake Association, personal communication). Despite volunteer hand harvesting and contracted harvesting, Eurasian watermilfoil was identified in several new areas throughout the lower basin in 2018 and has continued to spread.

In addition to a diverse aquatic macrophyte community, Paradox Lake is bordered by several wetlands, the largest located on the northern shore of the narrows. Like aquatic macrophytes, wetland plants serve a variety of ecosystem functions and provide numerous ecological services that benefit humans. There are no previous surveys of the narrows wetland. The wetland does not meet the criteria to be listed as a protected wetland by New York State or by Adirondack Park, but it undoubtedly confers many benefits such as nutrient and sediment uptake and sequestration.

The purpose of this study was to provide information on milfoil expansion in 2017-2018 following the 2015 survey and to provide a brief characterization of the wetland on the north shore of the narrows. First, a follow-up survey to the 2015 study was conducted to assess any changes in milfoil abundance during that period. Second, a partial wetland delineation was conducted to provide a baseline understanding of soil and vegetative characteristics on the north shore of the narrows. Because several years have passed since these studies were conducted, we also integrate these results with those from monitoring studies that were conducted 2018–2021 in the discussion section.

4.2 Methods

4.2.1 In-lake Eurasian Milfoil Monitoring

A survey was conducted 2017 – 2018 to document areas of milfoil growth and changes since the 2015 survey. The survey was completed over the course of two seasons for comparison with the 2015 survey. A single, comprehensive survey was not completed to avoid disturbing active marking and management of Eurasian milfoil by volunteers and contracted divers. Sites were chosen based on the 2015 macrophyte survey by the APIPP (Regalado et. al 2016). Where distance between 2015 sites was greater than 300 m, additional sites were added.

Samples were taken at each site by rake toss. At each sample site, we tossed a rake three times and categorized the plant abundance based on percentages of Eurasian watermilfoil and all other plants for comparison with previous results. Where possible, one rake was tossed directly in front of the boat and two rakes were tossed from either side of the boat. Care was taken to avoid raking areas with marked Eurasian watermilfoil plants that were being actively managed by the PLA. Visual observation of plant growth using a GoPro underwater camera was used in place of a rake toss near plant markers.

4.2.2 Narrows Wetland Characterization

A portion of the narrows wetland edge was delineated using the US Army Corps of Engineers (USACE) delineation method originally described in the USACE Wetland Delineation Manual (USACE 1987). Five points (1-5) approximately 5 meters apart were flagged along what appeared to be the wetland edge. At each flag, two points were marked: one point 5 meters into the wetland and one point 5 meters upland. Plant species were identified, soil was described, and water table depth was observed for each wetland and upland point.

4.3 Results

4.3.1 In-Lake Eurasian Milfoil Monitoring

Nineteen aquatic macrophyte species were identified by collection or observation during 2018, all of which were observed in the 2015 APIPP survey (Regalado et al. 2016). Both Eurasian watermilfoil and curly leaf pondweed were still present in Paradox Lake. The total number of sites at which Eurasian watermilfoil was present increased from 7 in 2015 to 10 sites in the 2017-2018 survey. This included new locations along the north shore of the upper basin and Briar Point on the southwestern most shore of the narrows, as well as new locations in the narrows and one new location in the lower basin. Likewise, Eurasian watermilfoil was not found at some sites in the upper basin at which it was previously observed. Curly leaf pondweed was identified at more sites in the 2017-2018 survey than in 2015 but was still contained to the upper basin at that time.

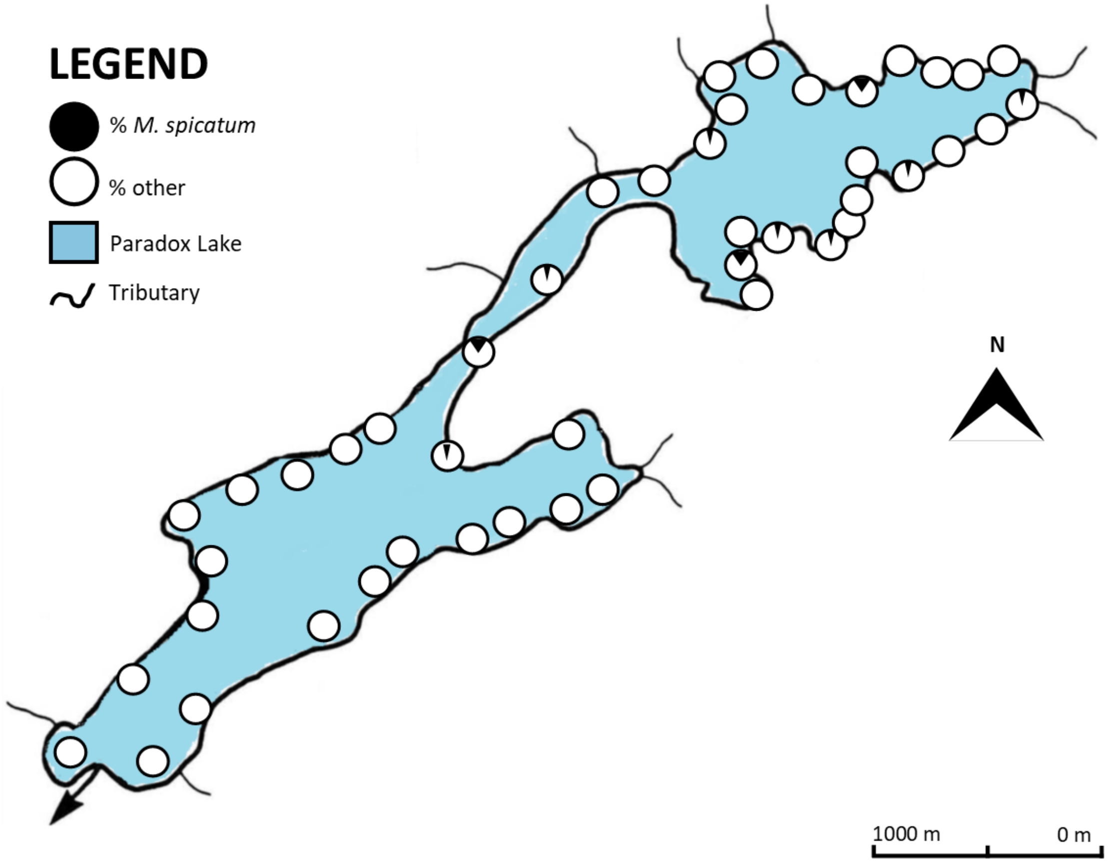


Figure 4.2. Map of Paradox Lake showing sampling sites from 2017-2018 macrophyte survey. Each circle represents a sampling location. White represents plant growth, and black represents Eurasian watermilfoil (*M. spicatum*) growth.

4.3.2 Narrows Wetland Characterization

Within the wetland, hydric soils, shallow water table, ponded water, water-stained leaves and tree trunks, and swollen/buttressed tree trunks (Figure 4.3) were present. Soil was "mucky peat" throughout the whole wetland and transitioned to aquatic plant beds at sampling points nearest to the lake shore. Dominant plant species at delineation points included *Cyperus sp.*, *Carex comosa*, *Sphagnum sp*., and *Juncus canadensis*. *Quercus velutina* was present in most wetland plots, but there were only about 15 trees in the entire wetland. Plots fell underneath them in 4 of 5 points.

On the upland slope, soil quickly and visibly changes within 2-3 feet (Figure 4.3). Upland soil was sandy or bedrock. In some cases, we could not dig a hole due to the shallow bedrock.

The most common plants identified included *Tsuga canadensis*, *Osmunda cinnamomea*, *Acer rubrum*, *Acer sacharrinum*, *Pinus strobus*, and *Thuja occidentalis*.

Figure 4.3. The narrows wetland looking southwest down the narrows into the lower basin. There is a visible distinction between the wetland (left) and upland (right).

4.4 Discussion

The results of the in-lake plant survey conducted in 2017-2018 largely confirmed results of previous work and can be used to bridge the gap between this and more recent surveys. Results suggested that Eurasian watermilfoil had expanded to the lower basin by 2018 and that it continued to spread through the upper basin following introduction and hand harvesting efforts. Despite changes in distribution, overall abundance of Eurasian Milfoil at individual sampling sites remained relatively low and appeared to change minimally from 2015 through 2018.

The Paradox Lake Association began working with APIPP to quantify plant abundance and management progress in 2018 after the present study. A survey was conducted in 2018 to map vegetative biomass (APIPP 2018) and establish volunteer monitoring sites. This survey indicated that milfoil abundance had been reduced to about 1 acre but the survey occurred after treatment that year. Trained volunteers participated in the Lake Management Tracker program offered through APIPP in 2019 and 2021 (T. Petrongolo, PLA, Personal Communication). The program was designed to help lake associations monitor management progress. More than 500 monitoring sites have been established through the program. Results from these recent surveys indicate that Eurasian watermilfoil has continued to expand to new sites in the narrows and the lower basin in recent years despite management efforts to date. In 2021, more than 50 beds were documented containing about 14 acres of Eurasian watermilfoil despite that the survey occurred after hand harvesting that year (Schwartzberg et al. 2021). The largest beds were located near the inlet to Paradox Lake in the upper basin, but additional beds were observed in the narrows and along the southeast bay of the lower basin (Schwartzberg et a. 2021).

5 Fisheries Surveys and Analysis

5.1 Introduction

Freshwater fish provide outdoor recreational opportunities, they constitute a significant source of economic revenue for many lake communities and can serve as a local protein source. They are useful ecological indicators, and they are important for maintaining ecological balance in lakes acting as predators and prey within foodwebs. Understanding the fishery of a lake is therefore critical in making management decisions because changes to the fish community can affect the food web structure (e.g., Harman et al. 2002), and changes to limnological conditions can affect habitable zones within a lake for certain species like lake trout (*Salvelinus namaycush*).

Paradox Lake supports fisheries for both coldwater species such as lake trout and warm-water fishes such as largemouth bass (*Micropterus salmoides*). The NYSDEC conducted surveys in 1985, 2003, and 2014 (NYSDEC 2022). The two most recent surveys targeted coldwater fish, specifically lake trout, using gill netting whereas the 1985 survey used multiple fishing gears to characterize both warmwater and coldwater communities. Paradox Lake supports a native population of lake trout that is the target of many anglers on Paradox Lake, along with popular bass (*Micropterus* sp.) and panfish fisheries for species such as yellow perch (*Perca flavescens*), black crappie (*Pomoxis nigromaculatus*), and other sunfishes (*Lepomis* sp.).

The goal of this study was to compile available historical information and conduct an updated survey of warm-water, littoral fish communities in Paradox Lake. To do this, we compiled historical sampling records from the NYSDEC statewide fishery database (NYSDEC 2022) and conducted an electrofishing survey in fall 2017. We estimated catch per unit effort (CPUE) and proportional size distributions (PSD) for fish caught using both historical and contemporary data to provide updated estimates from which future researchers can detect changes in community or species structure.

5.2 Methods

The NYSDEC conducted fisheries surveys in Paradox Lake in 1985, 2003, and 2014. The 1985 survey included four sampling methods (angling, electrofishing, gill netting, and minnow traps) to sample both warm and coldwater fish communities. Both the 2003 and 2014 surveys employed gillnets to sample the coldwater fishery, including lake trout and cisco, or lake herring (*Coregonus artedi*). Data were summarized across all years and gears to provide an historical baseline for comparison of NYSDEC data with data collected by electrofishing in 2017.

Electrofishing was used to sample littoral fish communities on October 25, 2017 at eight sites in Paradox Lake, including three sites in the upper basin, one site in the narrows, and four sites in the lower basin. Starting points for each transect were chosen to ensure multiple types of shoreline were surveyed including bedrock, plant beds, and soft bottom. Surveys ran from the starting point along the shoreline until the completion of the run (approximately 30 minutes).

Sample collections were separated into all fish and gamefish runs (Green 1989). Six, 30-minute all-fish runs and two, 15-minute gamefish runs were conducted. All species and ages of fish except young of the year (YOY) were collected during all-fish runs. Only largemouth bass, yellow perch, northern pike (*Esox lucius*), and chain pickerel (*Esox niger*) were collected during gamefish runs. Total length (mm) of individuals was measured for all species after each run.

Proportional size distribution (PSD; Willis et al. 1993) is a size-structure index that is commonly used to assess the relative abundance of large and small individuals within and between fish communities. The index is calculated as the number of fish of “stock” size that are also of “quality” size. For a given species, stock size is defined as the minimum “catchable” size. The definitions of larger size groups also vary between species, and are loosely based on angler perceptions of what constitutes “quality”, “preferred”, “memorable”, or “trophy” sizes for that species, often based on percentages of world-record sizes (Gabelhouse 1984). Proportional size distribution of quality length fish (PSD_Q) was calculated for all species for which threshold sizes are defined and for which sufficient data were available for both the NYSDEC surveys and the 2017 electrofishing survey as:

$$PSD_Q = \left(\frac{Number\ of\ fish\ \geq quality\ length}{Number\ of\ fish\ \geq stock\ length}\right) \times 100$$

The results of PSD were interpreted with additional information from length-frequency histograms. Length-frequency histograms are plots that provide a visual representation of the number of fish in 10-mm (1/2 in) size groups. They can be used to better understand trends in PSD values, as well as to understand the presence or absence of specific age groups where data are sufficient.

Catch per unit effort (CPUE) was calculated for all species collected in the 2017 electrofishing survey. The CPUE was expressed as the number of fish caught per hour of electrofishing time for each species. This standardized unit allows comparison of relative abundances between species within surveys.

5.3 Results

5.3.1 NYSDEC Fishery Surveys (1985, 2003, 2014)

A total of 1,153 fish representing 17 species were collected in NYSDEC fisheries surveys conducted in 1985, 2003, and 2014 (Table 5.1). The most common species collected in warmwater fisheries surveys were yellow perch (n = 407), pumpkinseed (*Lepomis gibbosus*, n = 108), and white sucker (*Catostomus commersonii*, n = 92). The least common species collected were Johnny darter (*Etheostoma nigrum*) and central mudminnow (*Umbra limi*, n = 1).

Calculated PSD_Q values for warmwater predator species (e.g., largemouth bass, chain pickerel) ranged from 31 to 60, indicating that predator populations were generally balanced between large and small individuals during the 1985 survey. Likewise, PSD_Q values for prey species within the warmwater community indicated that prey populations exhibited general balance in the proportion of small and large individuals present (Table 5.1). Together, these results suggest that the warmwater fish community was generally well balanced ecologically during the 1985 survey. Length-frequency histograms that a variety of sizes were present for most of the warmwater species collected, with largemouth and smallmouth bass reaching sizes of 500 mm (20 in) and yellow perch reaching sizes of about 300 mm (12 in, Figure 5.1).

Coldwater fisheries surveys in 2003 and 2014 resulted in collection of both cisco and lake trout. The PSD_Q for lake trout indicated that their population was skewed toward small individuals during these most recent surveys of the coldwater fish community (Figure 5.2). However, large individuals (> 25”) were collected during the 2014 sample and separate analysis of PSD_Q by year indicated that estimated lake trout PSD_Q increased between 1985 ($PSD_Q = 5$), 2003 ($PSD_Q = 9$), and 2014 ($PSD_Q = 92$).

Table 5.1. Number of individuals and PSD_Q for species collected during NYSDEC Fisheries surveys in 1985, 2003, and 2014. Coldwater species (cisco, lake trout, rainbow trout) were surveyed by gillnet surveys in 2014. All other (warmwater) fish were collected during a 1985 electrofishing survey.

Common name	Species	Number caught	PSD_Q
Brown bullhead	*Ameiurus nebulosus*	91	89
Central mudminnow	*Umbra limi*	1	-
Chain pickerel	*Esox niger*	19	31
Cisco	*Coregonus artedi*	183	-
Golden shiner	*Notemigonus crysoleucas*	26	-
Johnny darter	*Etheostoma nigrum*	1	-
Lake trout	*Salvelinus namaycusch*	139	15
Largemouth bass	*Micropterus salmoides*	13	43
Pumpkinseed	*Lepomis gibbosus*	108	37
Rainbow smelt	*Osmerus mordax*	19	-
Rainbow trout	*Oncorhyncus mykiss*	3	100
Redbreast sunfish	*Lepomis auritus*	9	-
Rock bass	*Ambloplites rupestris*	24	57
Smallmouth bass	*Micropterus dolomieu*	5	60
White sucker	*Catostomus commersonii*	92	97
Yellow bullhead	*Ameiurus natalis*	13	85
Yellow perch	*Perca flavescens*	407	64

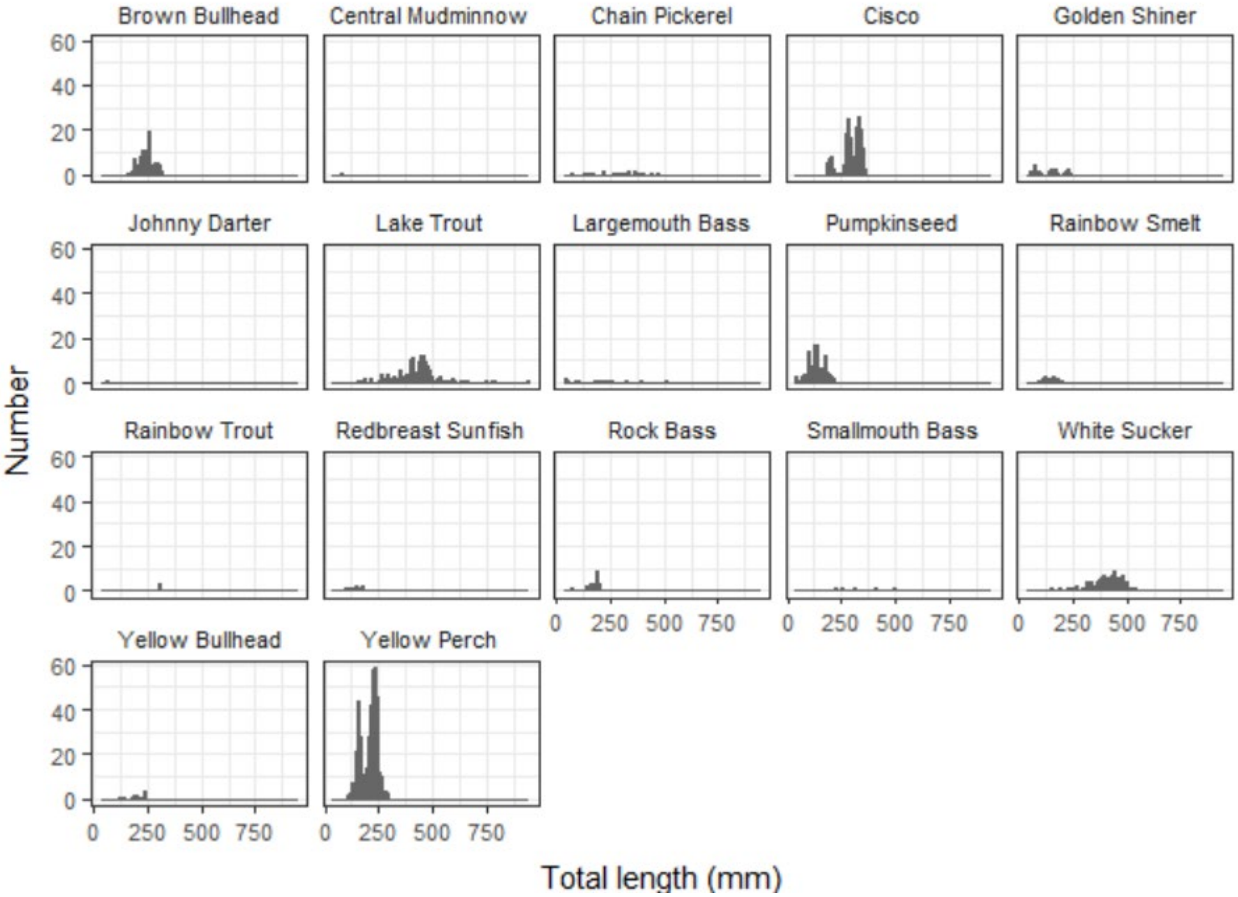


Figure 5.1. Length-frequency histograms for species collected during NYSDEC Fisheries surveys in 1985, 2003, and 2014. Coldwater species (cisco, lake trout, and rainbow trout) were surveyed by gillnet surveys in 2014. All other (warmwater) fish shown were collected during a 1985 electrofishing survey.

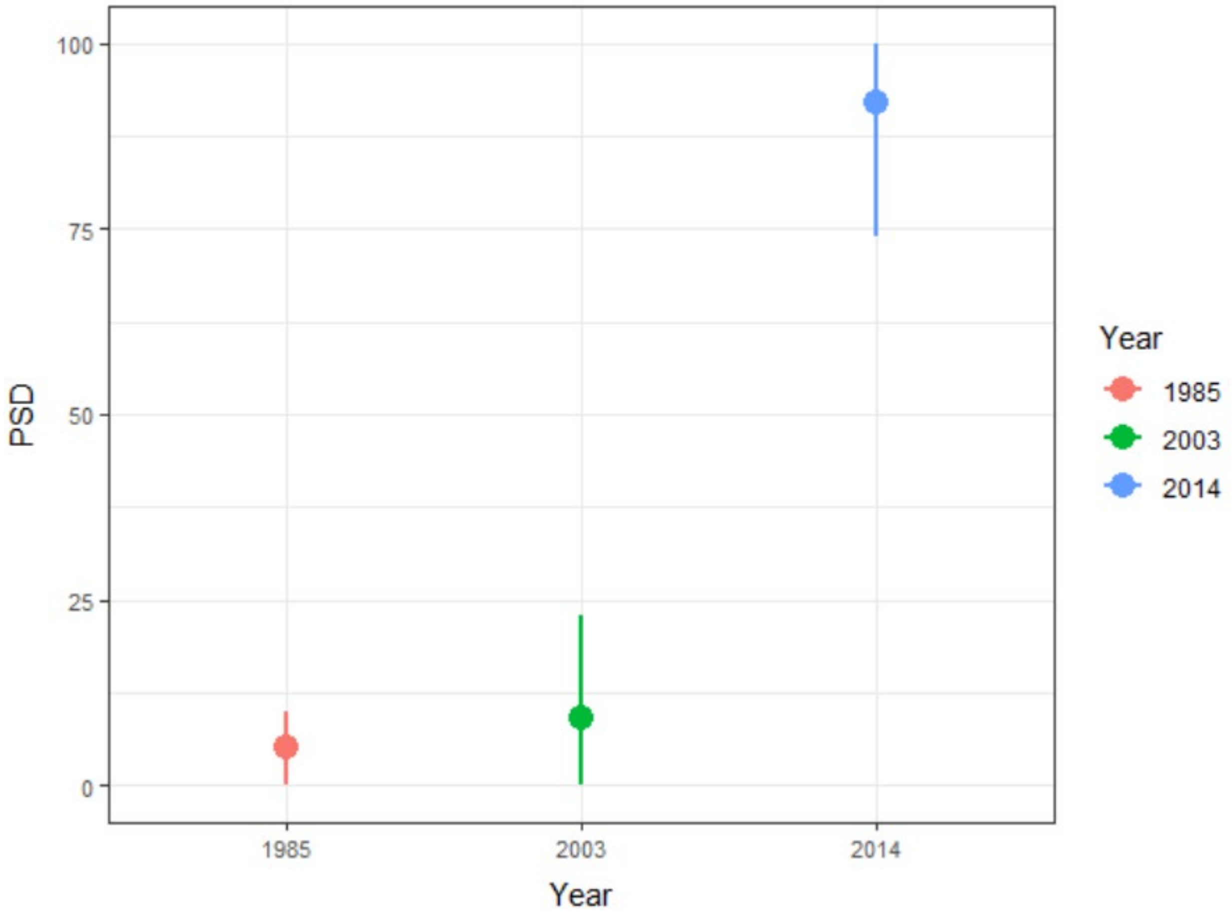


Figure 5.2. Estimated proportional size distribution (PSD) of lake trout collected from Paradox Lake by NYSDEC Fisheries surveys in 1985, 2003, and 2014.

5.3.2 SUNY Oneonta Electrofishing Survey (2017)

A total of 408 fish were collected during the 2017 electrofishing survey, representing 13 species (Table 5.2). Species that were not encountered during this survey but were collected by NYSDEC included central mudminnow, cisco, Johnny darter, lake trout, rainbow smelt (*Osmerus mordax*), redbreast sunfish (*Lepomis auritus*), and yellow bullhead (*Ameiurus natalis*). Black crappie, bluegill (*Lepomis macrochirus*), emerald shiner (*Notropis atherinoides*), and northern pike (*Esox lucius*) were collected in 2017 but were not collected by NYSDEC in 1985, 2003, or 2014 surveys. Bluegill (n = 93), pumpkinseed (n = 63) and yellow perch (n = 49) were the most abundant species collected in the 2017 electrofishing survey. Emerald shiner (n = 3) was least abundant.

Proportional size distribution (PSD_Q) indicated that the status of warmwater species in the Paradox Lake remained balanced in the 2017 electrofishing survey (Table 5.2), suggesting a similar status for most warm water fish populations as observed in 1985 (Table 5.1). Similarly, length-frequency histograms continued to indicate a wide variety of sizes for most species (Figure 5.3). As a whole, these data supported that the warmwater fish community has remained balanced.

Table 5.2. Catch per unit effort (CPUE in fish per hour) and PSD_Q for species collected during the 2017 electrofishing survey across all sites on Paradox Lake.

Common Name	Scientific Name	Number caught	CPUE (fish/hr)	PSD_Q
Black crappie	*Pomoxis nigromaculatus*	11	0.9	75
Bluegill	*Lepomis macrochirus*	93	7.5	13
Brown bullhead	*Ictalurus nebulosus*	8	0.7	83
Chain pickerel	*Esox niger*	30	2.5	40
Emerald shiner	*Notropis atherinoides*	3	0.3	-
Golden shiner	*Notemigonus crysoleucas*	42	3.3	-
Largemouth bass	*Micropterus salmoides*	47	3.8	65
Northern pike	*Esox lucius*	10	0.8	100
Pumpkinseed	*Lepomis gibbosus*	63	5.2	29
Rock bass	*Ambloplites rupestris*	30	2.4	41
Smallmouth bass	*Micropterus dolomieu*	11	0.9	50
White sucker	*Catostomus commersonii*	12	1.0	100
Yellow perch	*Perca flavescens*	49	4.1	55

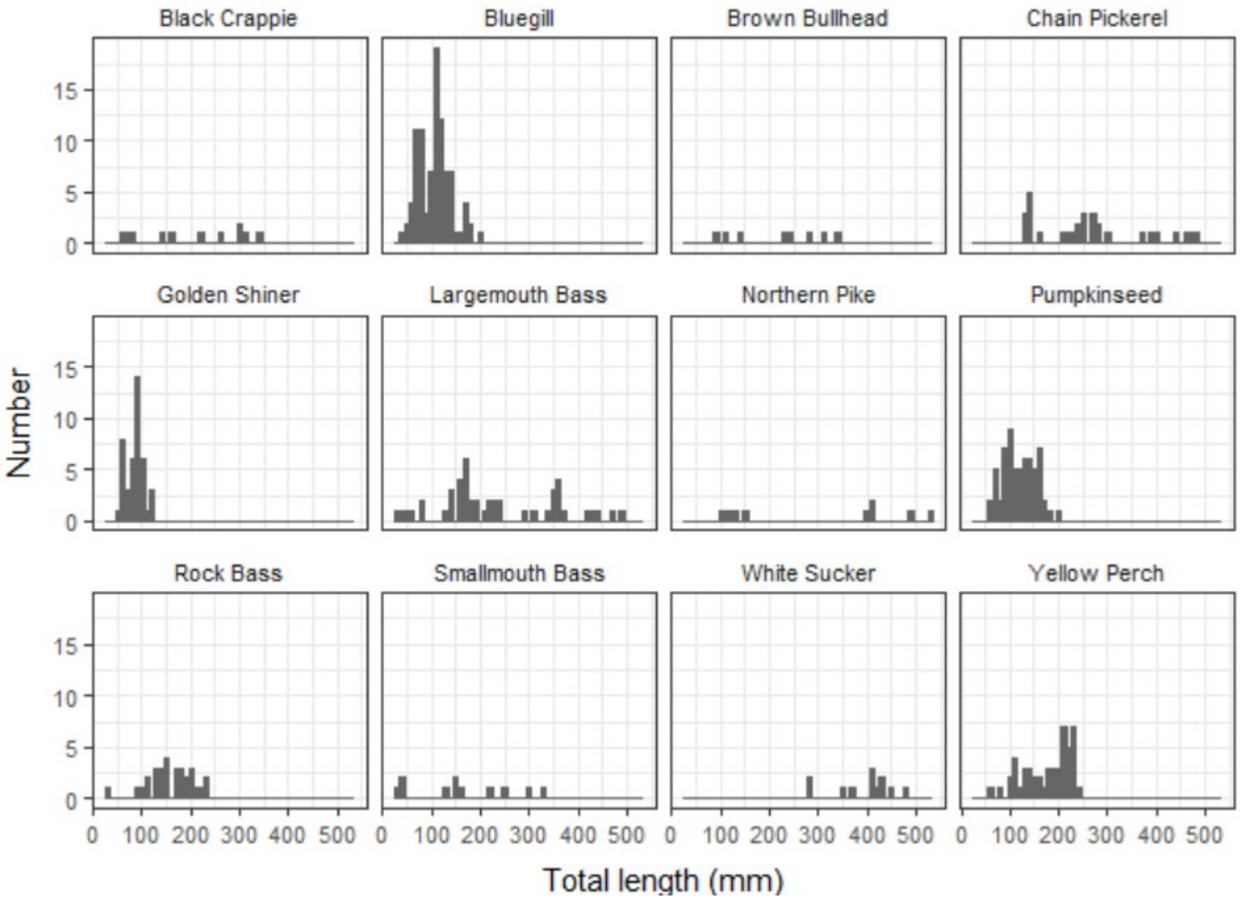


Figure 5.3. Length-frequency histograms for species collected during the fall 2017 electrofishing survey.

5.4 Discussion

The warmwater fishery of Paradox Lake remains balanced with respect to predator and prey species present. Within species, there is also evidence of balance between large and small individuals. These characteristics appear to have persisted since the first warmwater fishery surveys of the lake in 1985, but it is important to recognize that these data sets only represent snapshots in time and may not be indicative of what has happened in the time between surveys.

The estimated proportion of quality-sized lake trout in Paradox Lake (PSD_Q) appears to have increased substantially between 2003 and 2014 surveys. It is unknown at this time what is the cause for the relative increase. Because the trophic status of the lower basin has remained relatively constant and the upper basin has decreased in productivity, this is most likely related to sampling methodologies and locations, stocking practices, harvest regulations, or some combination thereof.

Several species that were detected in 1985 warmwater fishery surveys were not detected in the 2017 electrofishing survey. Some of these species (central mudminnow and Johnny darter) are less common than others, and it is possible that redbreast sunfish or yellow bullhead were collected in 2017 but mis-identified as a congener present in the waterbody. This result underscores the importance of regular monitoring to understand whether differences are biologically meaningful or simply due to patterns in species detectability.

Four species were observed in 2017 that were not previously collected from the lake, including black crappie, bluegill sunfish, emerald shiner, and northern pike. It is unknown whether these species were present in the lake during the 1985 NYSDEC electrofishing survey. Each of these species is associated with one or more angling uses, and thus the most likely vector of introduction would have been through stocking (black crappie, bluegill, northern pike) or use as bait fish (emerald shiner) if they were not already present in the lake, but not detected, in the 1985 survey. Regardless of whether these are introduced populations or were simply not detected in 1985 surveys, the presence of these species does not appear to have negatively influenced size structure of commonly sought-after species in the warmwater or coldwater fisheries in Paradox Lake in any obvious way.

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