The State of DeRuyter Reservoir, Madison County, NY and a Plan for the Management of DeRuyter Reservoir

Leah Gorman

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The State of DeRuyter Reservoir, Madison County, NY

Table of Contents

Chapter 1: Introduction

As humans alter natural environments, resource management is necessary to maintain aquatic ecosystems as sustainable resources that can be used and enjoyed by future generations. Management of lake ecosystems requires evaluation of three realms: 1) the abiotic composition of the landscape, 2) the biological community, and 3) human behaviors, and the ways in which these realms interact. Developing understanding within each of these areas can inform management decisions for stakeholders and promote resilience in coupled human-natural systems. By considering the origins of a waterbody, how it has changed, and the reasons why, predictions can be made about how and at what rates resource managers might expect change in the future, and how a given system might respond to management alternatives. Likewise, comparisons to morphologically similar waterbodies can help to understand the ecosystem on a broader scale and help to fill in gaps or shortcomings in data collection.

DeRuyter Reservoir, New York is valued for both recreation and for the native biological community the system supports. Additionally, the basin is a headwater to larger, downstream waterbodies of economic and ecological importance to New York State (Oneida Lake and Lake Ontario) and to the United States (St. Lawrence River and Chesapeake Bay). The goal of this study was to combine historical perspectives and contemporary data on DeRuyter Reservoir to assess the current state of the lake and promote informed short- and long-term management of the reservoir. Specifically, the objectives of this study were to compile available historical information, develop watershed-scale understanding, characterize the limnology, understand the present biota, and, finally, analyze the anthropogenic uses and impacts of the system. These data will be used in the development of a stakeholder-based, comprehensive management plan for DeRuyter Reservoir to guide decision-making in the present and future.

Chapter 2: History

In the year 1860, construction of a dam began in the Town of DeRuyter, Madison County, New York that resulted in the formation of Tioughnioga Lake. It was a three-year-long, $100,000 state-funded project engineered by Charles A. Beach. The dam was built to create water reserves to ensure water levels for the fluid operation of the Erie Canal east of Syracuse. A number of other reservoirs were created in Madison County around the same time for this purpose. These included Erieville Reservoir (now Tuscarora Lake), Eaton Brook Reservoir, Bradley Brook Reservoir, Kingsley Brook Reservoir (now Lebanon Reservoir), Madison Reservoir (now Lake Moraine), and Upper and Lower Leland Ponds giving the county the nickname of the "Land of Reservoirs" (Burdick 1940). Now called DeRuyter Reservoir, likely due to comparatively easier pronunciation (anecdotal), the waterbody is used primarily for local recreation. The reservoir, at an elevation of 400 m above sea level, remains as the largest of the canal system reservoirs in Madison County, with a surface area of 2.25 km^2. The primary outlet of the lake, Limestone Creek, is located at N42°82.7' W75°90.1'.

In 1934, the Conservation Department, now the New York State Department of Environmental Conservation (NYSDEC), conducted a comprehensive biological survey of the Susquehanna River basin and included a summary of conditions in DeRuyter Reservoir in the report, as follows:

> “DeRuyter Reservoir is maintained as a Barge Canal feeder. Most of its water comes from the upper part of the Tioughnioga Creek. A large part of the lake is less than 30 feet (9 m) deep, a very small area having a maximum depth of 48 feet (15 m). There is a good supply of oxygen at all depths. Vegetation is scant. The reservoir has an average draw of 6 to 7 feet (2 m) and can be drawn down 18 1/2 feet (6 m). It is reported that good fishing may be had here for small-mouthed bass, pike-perch (walleye), pickerel, bullheads and sunfish. There is fair fishing for yellow perch. Many fishermen visit the lake at all seasons. Forage fish and crayfish are plentiful. Many young small-mouthed bass were taken. Pike-perch and small-mouthed bass are recommended for stocking. More intensive fishing for sunfish would benefit the other species, especially the yellow perch.... Dense weed beds form a conspicuous marginal zone around this small, relatively shallow lake with a muddy bottom. The predominant species include the pondweeds (*Potamogeton amplifolius* and *P. natans*) in great abundance, blunt-leafed pondweed, waterweed, large duckweed, mud plantain and waterlilies."
>
> (NYS Conservation Department 1934; modified to add metric equivalencies)

Today, DeRuyter Reservoir is designated by NYSDEC as a Class B lake. Class B lakes support use for contact recreation such as swimming and non-contact recreation such as boating and fishing. Class B lakes do not qualify by NYSDEC standards for drinking water while Class A lakes do. Class B lakes typically have a water transparency of 2-3 m, phosphorus (P) levels around 15-20 $\mu g\ l^{-1}$ P, no visible water color, and a basic pH (NYSFOLA 2009).

In 1998 DeRuyter Reservoir was added to the NYSDEC 303(d) list of impaired waterbodies and subsequently recognized by the United States Environmental Protection Agency (EPA) for excessive external nutrient loading (https://www.epa.gov/nps/nonpoint-source-success-stories). The three primary sources of impairment were determined to be from sediment, agriculture, and private septic systems. With the EPA impaired waterbody designation, local organizations received funding for work within the watershed from the following programs: the Finger Lakes-Lake Ontario Watershed Protection Alliance (FLLOWPA), the Oneida Lake Watershed Task Force through the Oneida Lake Watershed Agricultural Program, and the New York State Environmental Program Fund (EPF) through the NYS Agricultural Nonpoint Source Abatement and Control Program (ANSCAP). Beginning in 2001, the Madison County Soil and Water Conservation District (SWCD) worked with three local farms on Comprehensive Nutrient Management Plans (CNMPs), and in 2007 the SWCD worked on a sediment control project in collaboration with the Madison County Planning Department with support from FLLOWPA. Following reduction in water column P, DeRuyter Reservoir was removed from the state’s 303(d) list in 2008 and has since been considered an EPA success story (https://www.epa.gov/nps/nonpoint-source-success-stories). The Madison County SWCD continues to work with farms within the watershed on nutrient management techniques. It is currently in the process of implementing its 2015–2020 Agriculture Environmental Strategic Plan, a five-tiered plan to assist farmers in understanding and mitigating environmental risks within the county (Madison County SWCD 2015).

Despite the EPA-designated success story in the late 1990s, DeRuyter Reservoir is currently listed on the NYSDEC Priority Waterbodies List for the Susquehanna River basin as a component of the East Branch Tioughnioga sub-basin. The listing was assigned in 2009 due to minor impairment of recreational uses by excessive algal and macrophyte growth in lake. The suspected cause for the excessive primary production was listed as nutrients, likely from agriculture (NYSDEC 2009).

a. Socioeconomic Characteristics

The lake lies within Madison (towns of DeRuyter and Cazenovia) and Onondaga (Town of Fabius) counties, and the watershed also lies within Cortland County (Town of Cuyler). As of 2009, a total of 301 tax parcels fall within 50 feet of the lake having a total value of $46,736,400 (Madison County Planning Dept. 2009). According to the 2011 U.S. Census, 13,187 individuals resided within the boundaries of the DeRuyter drainage basin. Median income and education levels of residents 25 and older for each of the three counties were estimated by the US Census Bureau in 2015 (Table 2-1).

Table 2-1. Estimates of income and education level in three counties of the DeRuyter drainage basin from U.S. Census Bureau (2015). Annual income is reported in 2015 USD.

County	Median household income (USD)	% with at least a high school degree	% with at least a bachelor’s degree
Madison County	$54,145	90.4	26.2
Onondaga County	$55,092	90.2	34.1
Cortland County	$49,514	89.9	23.6

b. Lake Interest Groups

Two major interest groups are currently present on DeRuyter Reservoir: the Tioughnioga Lake Association (TLA) and the Tioughnioga Lake Preservation Foundation (TLPF). The first meeting of the TLA, formerly named the Tioughnioga Lake Club, was held in 1939 with 25 members in attendance. Initial projects included taking care of garbage cans placed for picnics around the lake, advocating for a state police presence around the lake, advocating to keep the water level as high as possible, and the inception of a conservation committee tasked with stocking the lake with black bass (*Micropterus* spp.) and northern pike (*Esox lucius*) fry. The lake residents formed the TLA with intentions of expanding membership and taking an active role in the preservation of the lake (Burdick 1940). The TLA has traditionally functioned as a social organization (i.e., responsible for organizing summer events on the lake), but it has also been a part of several management efforts on the lake and within the watershed. TLA archives are currently kept in the Town of DeRuyter town hall.

In 2012, the TLPF was formed as a 501c3, tax exempt environmental organization. The foundation was intended to function as a focused organization tasked with seeking grants and other funding to support research and management that will further the long-term resiliency of the lake. The organization operates under the mission to “protect, preserve, and enhance the environmental integrity of DeRuyter Lake." The TLPF has organized funding for invasive plant management efforts, including early season mechanical harvesting of curly leaf pondweed (*Potamogeton crispus*) and research-based management for biological control of Eurasian watermilfoil (*Myriophyllum spicatum*).

Weekly bass fishing tournaments have traditionally been held during bass season (Father's Day through Labor Day weekend) on Sundays since the mid-1990s, and an annual Triathlon (since 2008) occurs on the lake. The latter event is organized by the DeRuyter Lake General Store, located at the south end of the lake, in conjunction with a private boat launch.

Chapter 3: Drainage Basin

a. Physical Parameters

Over two million years ago, glaciation formed valleys on the divide between the Oswego and Susquehanna watersheds. At one point, those valleys extended north and south across the Alleghany Plateau in central New York. Over time, these valleys filled in, forming the well-known Finger Lakes and other, smaller lakes in Madison County. DeRuyter Reservoir itself was originally a stream that flowed through one of these small valleys prior to being dammed in 1860. The deepest point of the lake ($z = 16.8$ m) is located in the northern region near the dam, whereas the southern portion of the lake remains relatively shallow (Figure 3-1). The surface area of the waterbody is 2.25 km^2 and the relative depth, as defined by Delebecque (1898) and indicated below, is 0.99 % (Table 3-1):

$$Z_r = \frac{50Z_m\sqrt{\pi}}{\sqrt{SA}}$$

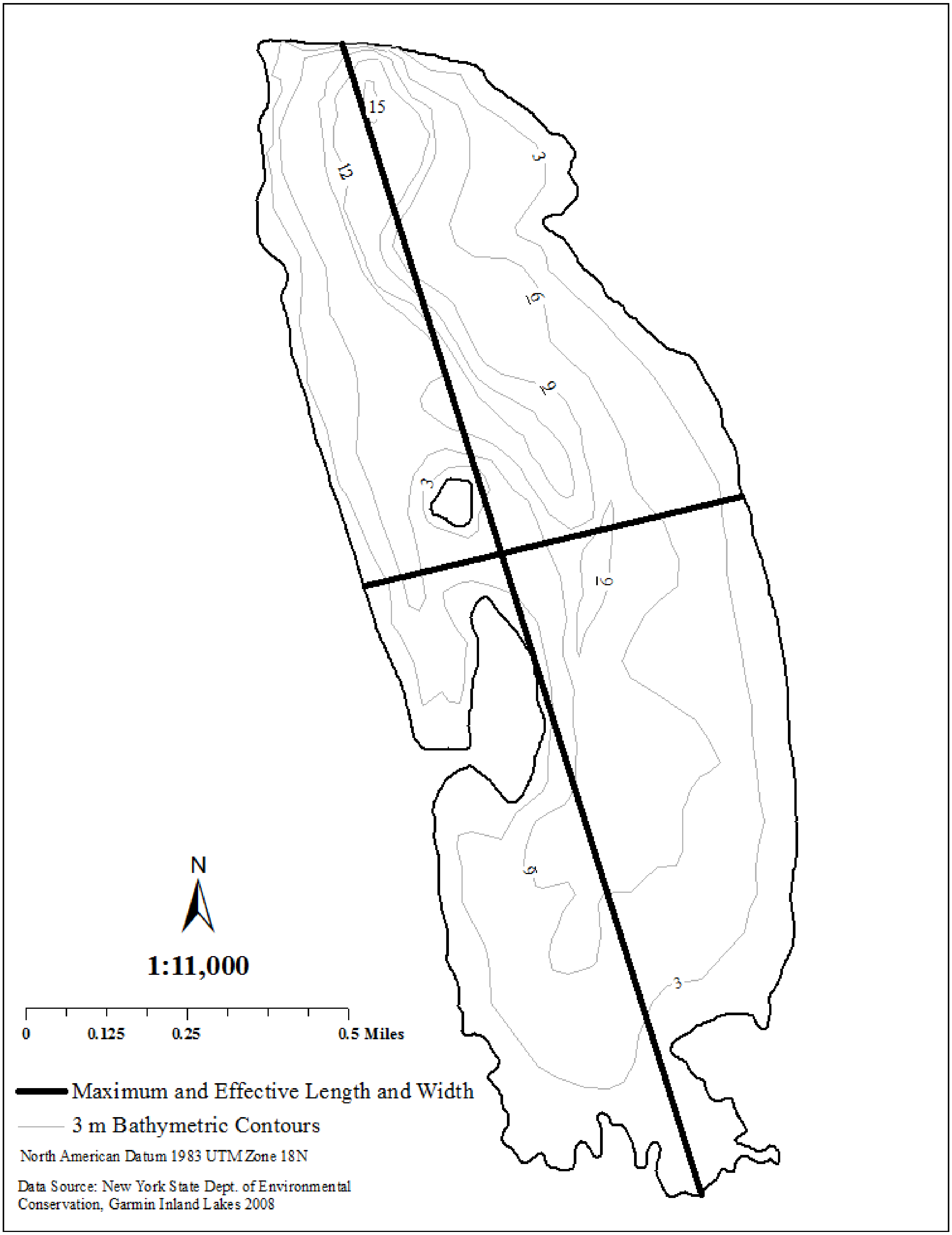
where Z_r is relative depth, Z_m is maximum depth, and SA is surface area. Water volume held by the basin (Table 3-1) was calculated by the standard volume equation (Kalff 2001):

$$V = \sum\left(\frac{SA_n + SA_{n+1}}{2}\right) \cdot h$$

where V is volume, h is height, and SA_n is the surface area of each bathymetric interval, based on each of 6 bathymetric contours from NYSDEC (Table 3-2, Figure 3-2). Shoreline development, an index of how far the shape of a given waterbody deviates from a circle where $D_L = 1$ indicates a perfect circle and $D_L >> 1$ indicates dendritic shorelines (Hutchinson 1957), was calculated as:

$$D_L = \frac{SL}{2\sqrt{\pi SA}}$$

where D_L is shoreline development, SL is shoreline length, and SA is lake surface area.



Data Source: New York State Dept. of Environmental Conservation, Garmin Inland Lakes 2008

Figure 3-1. Bathymetric map of DeRuyter Reservoir with 10 feet contour lines. Thick, straight lines represent maximum (effective) length and width.

Table 3-1. Physical characteristics of the DeRuyter Reservoir basin in the International System of units and common English units when applicable.

Physical characteristic	SI unit	English unit
Maximum length	3.01 km	1.87 mi
Maximum effective length	3.01 km	1.87 mi
Maximum width	0.96 km	0.60 mi
Maximum effective width	0.96 km	0.60 mi
Maximum depth	16.80 m	55.12 ft
Mean depth (Z_m)	5.40 m	17.70 ft
Relative depth[1] (Z_r)	0.99 %	
Surface area (SA)	2.25 km^2	554.22 ac
Volume[2] (V)	12,142,777 m^3	428,818,122 ft^3
Total shoreline length (SL)	9.99 km	6.21 mi
Shoreline development[3] **(**D_L**)**	1.26	
Watershed area	10.11 km^2	2,497 ac
Watershed:lake ratio	3:1	

Table 3-2. Area and volume estimates for the basin based on 3 m bathymetric intervals delineated in Fig 3-1.

Depth (m)	Area (m^2)	Area (ac)	% Area	Volume (m^3)	Cumulative volume (m^3)	% volume	Cumulative volume (%)
0	2,242,865	554.22	100.00	0	0	0.00	0.00
3	1,677,029	414.4	74.77	5,973,918	5,973,918	49.20	49.20
6	837,462	206.94	37.34	3,832,085	9,806,003	31.56	80.76
9	240,996	59.55	10.74	1,643,570	11,449,573	13.54	94.29
12	105,323	26.03	4.70	527,789	11,977,362	4.35	98.64
15	3,217	0.8	0.14	165,415	12,142,777	1.36	100.00
Total:	5,106,892	1,261.94		12,142,777			

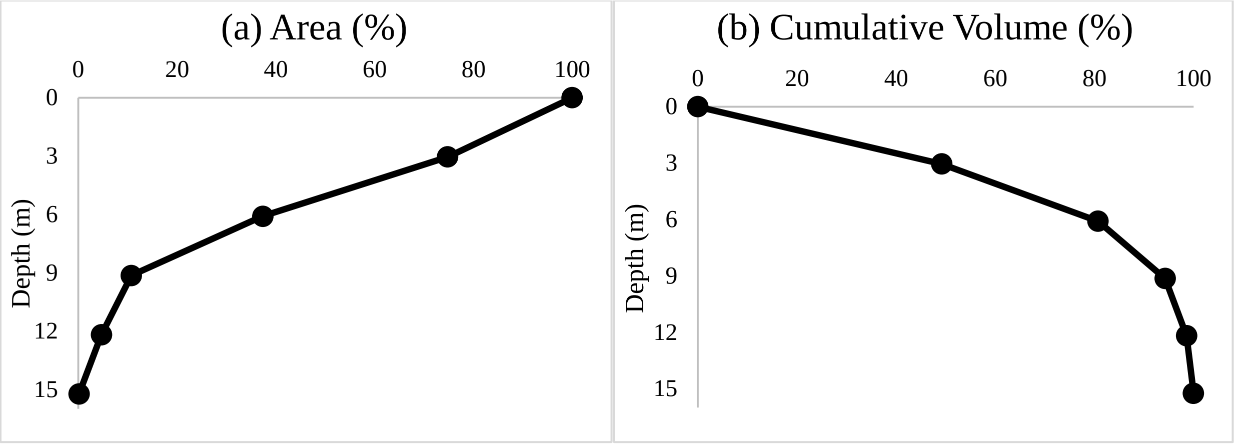


Figure 3-2. Area (a) and cumulative volume (b) for DeRuyter Reservoir at z = 0, 3, 6, 9, 12, and 15 m. Raw values are listed in Table 3-2.

b. Dam and Reservoir Characteristics

The DeRuyter Reservoir Dam, located in the Town of Fabius, is a single spillway dam in the northwest corner of the lake. It is owned by the New York State Canal Corporation. The structure is ~ 400 m in length, ~ 114 m in width, and a maximum of 23 m in height with an average of 5.6 m (Burdick 1940). The dam is designated a High Hazard Class C dam by the NYSDEC, referring to hazards to communities downstream if the dam were to fail. In recent years the dam has been subject to several mandatory assessments.

An Engineer Assessment Report for the dam was drafted by Bergmann Associates on 19 August 2012. The report evaluated compliance with the NYSDEC Guidelines for Dams (1989). Sections 6.32 (capacity to discharge 75 % of the lake in 48 hours) and 7.1 (release of 90 % of the lake below the low-set (second) spillway within 14 days in case of emergency) were not satisfied. Two years later, the most recent routine visual inspection was conducted on 20 August 2014 by a NYSDEC Division of Water environmental engineer, and a report subsequently submitted to the NYS Canal Corporation. The most prevalent problems were excessive vegetation growth and accumulation of woody debris on both upstream and downstream faces of the dam (NYSDEC 2014b).

Per New York State Environmental Conservation Law and Dam Safety Regulations 6NYCRR Part 673, Class B (intermediate risk) and Class C dams are required to develop and maintain an Emergency Action Plan (EAP). The EAP for the DeRuyter Reservoir dam was submitted to NYSDEC in 2014 and amended in 2015 and 2016.

Many reservoirs have short water retention time due to uses such as water supply, hydropower, or flood control. When reservoirs are formed by damming rivers, these systems tend to have characteristics of both rivers from which they were created and natural lakes that they mimic, and therefore ought to be characterized separately (Hayes et al. 2017). Water in DeRuyter Reservoir is no longer used for any specific objective downstream (i.e., Erie Canal operation) and therefore water is not exchanged as frequently. However, DeRuyter Reservoir continues to exhibit common physical attributes of reservoirs which can be used to guide insight into its limnological and biological characteristics.

Reservoirs tend to differ from natural lakes in terms of physical structure, hydrodynamics, and turbidity (Kimmel and Groeger 1984). Typical drowned river valley reservoirs, like DeRuyter Reservoir, conform to a trapezoidal shape, increasing in depth from upstream to downstream, with maximum depth at the face of the dam (Straškaba et al. 1993). They generally experience a shorter hydraulic retention time (Moore and Thornton 1988). The shallow, upstream portion of a reservoir, or the riverine zone, tends to be the most turbid with large amounts of suspended solids (Kimmel and Groeger 1984).

Large reservoirs can display longitudinal changes from more riverine conditions in upstream areas to more lacustrine conditions in downstream reaches (Kimmel and Groeger 1984). DeRuyter Reservoir does not have a dendritic shape and does not experience extreme physical changes longitudinally, but the deepest point is located by the dam in the north end while the south end remains shallow (Figure 3.1), as in many other reservoirs. The water column at the shallow south end remains mixed throughout the year, while that at the deep north end is dimictic, allowing for potentially different biological communities within these areas.

Geomorphological characteristics unique to reservoirs can influence the biotic community within the waterbody. Reservoirs are typically located in fertile drainage basins, and therefore have an initially higher trophic status. Across the world, reservoirs experience higher nutrient loading on average (Thornton 1980) and consequently tend to undergo eutrophication faster than natural lakes (Kimmel and Groeger 1984). Studies have shown spatial heterogeneity across large, dendritic reservoirs in water quality parameters including total phosphorus, chlorophyll *a*, and total suspended solids (Kennedy et al. 1982) and in phytoplankton production and biomass (Kimmel and Groeger 1984). Though DeRuyter Reservoir is not dendritic, these biological trends across the waterbody may be apparent on a much smaller scale.

The ability to control water levels is a unique management opportunity in impounded, lentic systems (Cooke et al. 2005). For example, water level 'drawdowns' can be used to expose littoral zones and limit seedbanks and rootstocks of nuisance macrophytes. They can also be used to 'flush' waters with undesirable chemistry such as high nutrient levels, low oxygen, or high chl. *a*.

c. Land Use and Sub-Drainage Basins

Due to the steep shorelines along the east and west sides of the lake (Figure 3-3), the total catchment area of DeRuyter Reservoir is just 10.11 km^2, a watershed:lake area ratio of 3:1

(Table 3-1). The majority of the watershed (60 %) is forested, whereas only 6 % is developed consisting mostly of shoreline residences (Figure 3-3). Although lack of development is generally beneficial for water quality, logging in the forested areas of the watershed is common, potentially contributing to nutrient run-off. About 23 % of the watershed is agricultural, most of which is confined to the south end. The whole catchment basin was divided into 18 sub-basins given the designations A-R (Figure 3-3) to gain a further understanding of surface water movement and prioritize efforts for watershed management activities. Surface water enters the lake through 34 natural and artificial (i.e., pipes and culverts) inlets (Figure 3-3).

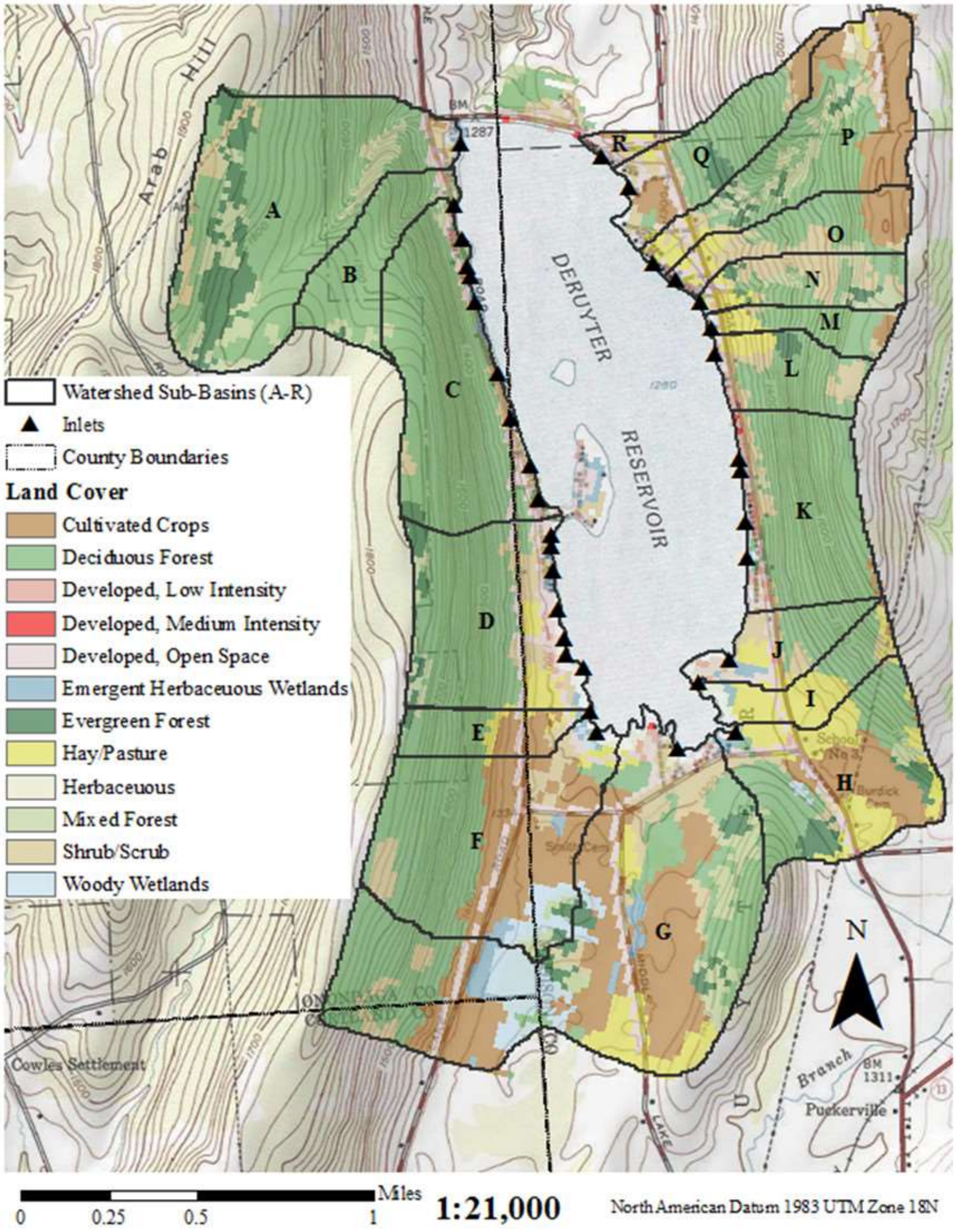
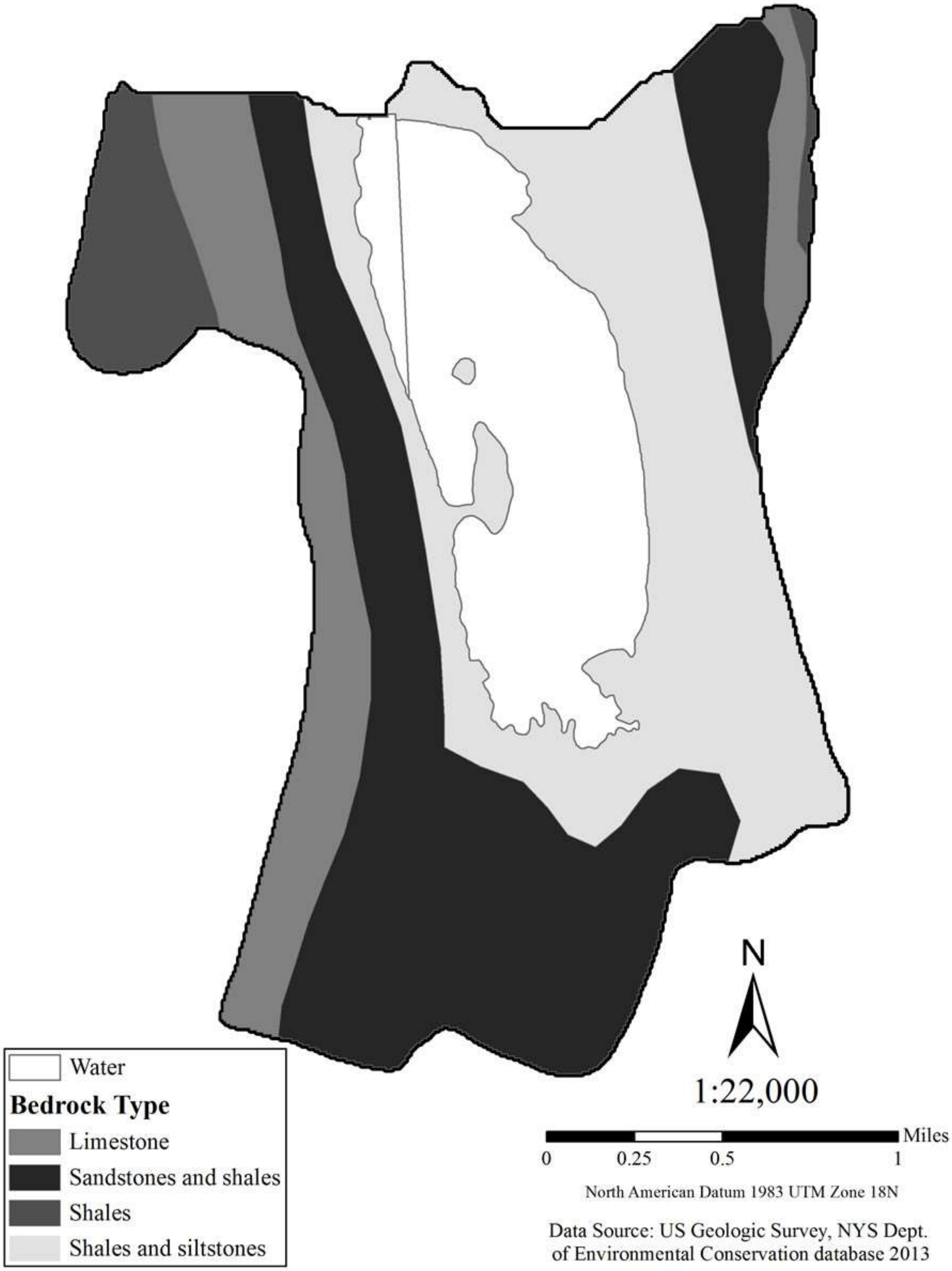


Figure 3-3. Land cover of the DeRuyter Reservoir drainage basin delineated by the U.S. Geological Survey *StreamStats* (Ries et al. 2008) with county lines. Estimated sub-drainage basins of specific surface water drainage patterns are given designations A through R. Thirty-four surface water inlets are designated by triangles. Sub-basins C, D, and K do not represent single inlets, rather general surface flow convergence into multiple, artificial inlets.

d. Geology

The bedrock within the watershed of DeRuyter Reservoir, a combination of Middle Devonian shale, limestone, and siltstone (Figure 3-4), is covered by an array of soils. For detailed description of soil types, refer to the USDA Web Soil Survey (www.websoilsurvey.sc.egov.usda.gov). Based on the described soil types, the Web Soil Survey breaks down expected drainage patterns and suitability for potential development. One way in which these characteristics are presented is by hydrologic soil groups, a system that helps to estimate run-off potential. Regions are given an A-D ranking based on soil type where group A exhibits high infiltration and low run-off potential; these soils are usually deep, well drained sands, and group D exhibits opposite characteristics. Groups with a combination of two letters denote that the 1st letter represents drained areas and the 2nd letter, undrained areas. The largest portion of the DeRuyter Reservoir watershed consists of C, C/D, and D, finer soils, such as clays, indicating slow water transmission and therefore high run-off potential (Figure 3-5).

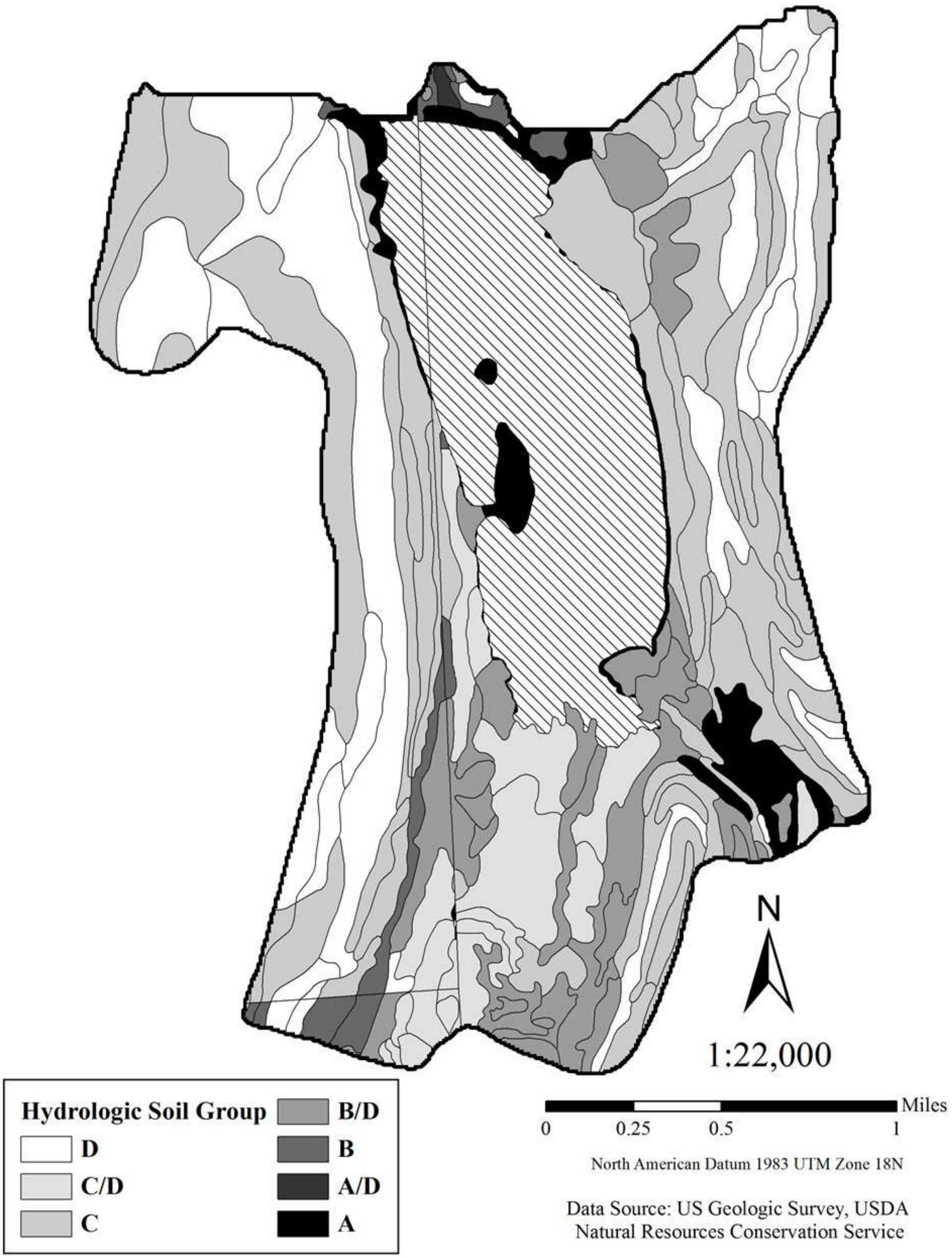
Combining the soil types with slope of the landscape, the Web Soil Survey also delineates limitations for septic tank absorption fields. The DeRuyter Reservoir watershed comprises 'very limited' and 'somewhat limited' soils (Figure 3-6). A limited landscape for septic fields is characteristic for New York State (Soil Survey Staff et al. 2017). This does not necessarily mean that use of septic systems must be avoided, rather that proper monitoring and updating are necessary and must scale with the wastewater load. Most of the regions directly along the shoreline falling under the 'very limited' category are located in the town of Fabius, Onondaga County. See Chapter 7: On-Site Residential Wastewater Systems for details on numbers of individual wastewater treatment systems, types, and typical annual maintenance efforts.



North American Datum 1983 UTM Zone 18N

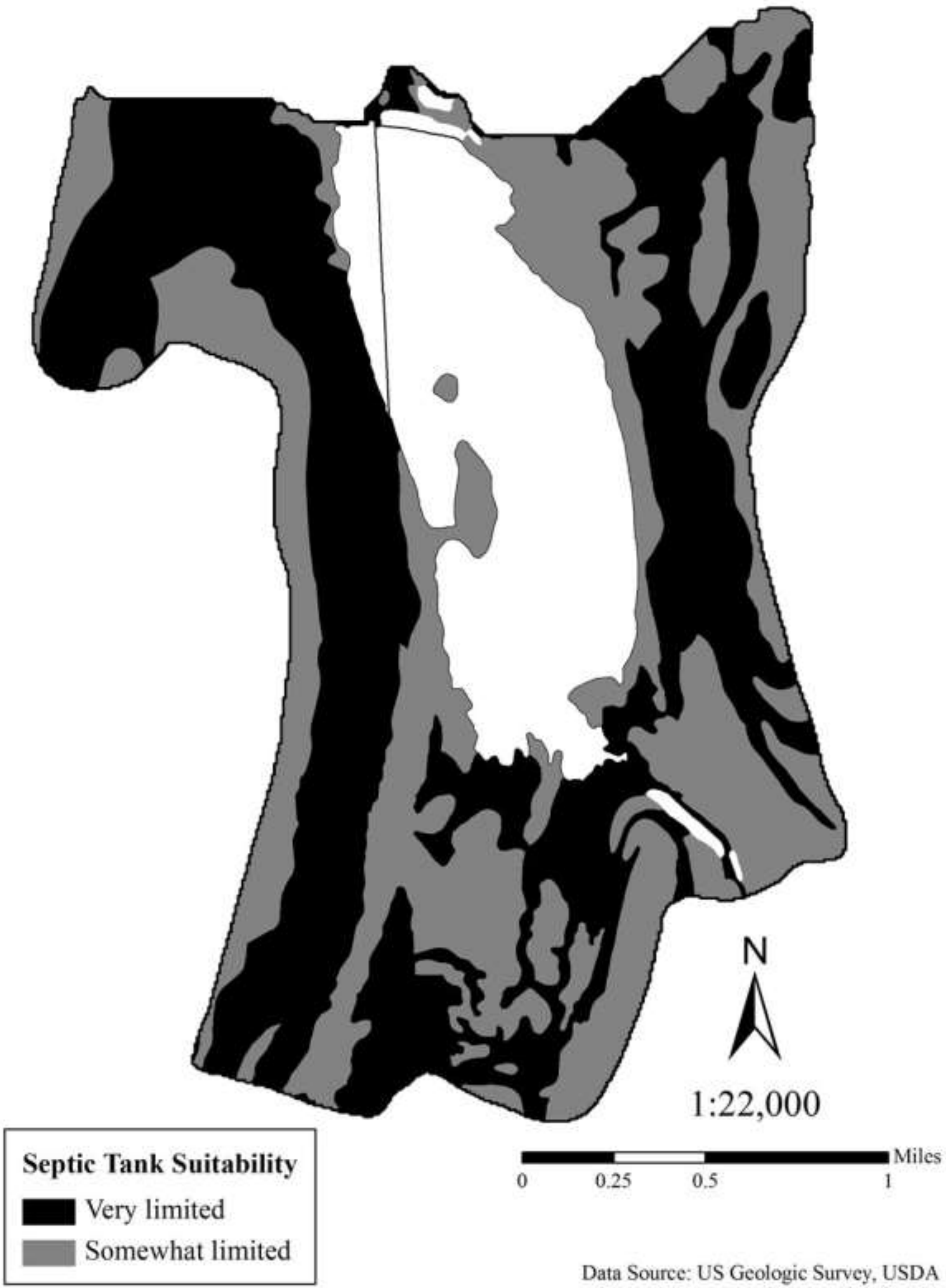
Data Source: US Geologic Survey, NYS Dept. of Environmental Conservation database 2013

Figure 3-4. Bedrock geology of the DeRuyter Reservoir drainage basin (Soil Survey Staff et al. 2017) delineated by the US Geological Survey (Ries et al. 2008).



Data Source: US Geologic Survey, USDA Natural Resources Conservation Service

Figure 3-5. Hydrologic soil groups of the DeRuyter Reservoir drainage basin (Soil Survey Staff et al. 2017) delineated by the US Geological Survey (Ries et al. 2008).



Data Source: US Geologic Survey, USDA
Natural Resources Conservation Service

Figure 3-6. Septic tank suitability based on slope and soils of the DeRuyter Reservoir drainage basin (Soil Survey Staff et al. 2017) landscape delineated by the US Geological Survey (Ries et al. 2008).

e. Water Levels

Starting in 1966, DeRuyter Reservoir has undergone annual drawdowns of approximately 1 m in October. The reservoir is refilled naturally by spring snowmelt and runoff. A small dam near the south end of the lake can be used to refill the lake with water from the Tioughnioga River. However, the gate has not been opened since the early 1990s due to opposition from stakeholders. The watershed associated with the Tioughnioga River has comparatively larger agricultural input and would likely cause an influx of more nutrients into DeRuyter than from its typical sources.

f. Climate

Lakes across the world are changing in response to climate change (Blumberg and DiToro 1990, Murdoch et al. 2000, Jeppesen et al. 2009). Less precipitation and prolonged periods of drought are causing lower lotic flows, reduced water velocities, and longer lentic residence times. Increases in temperature and periods of drought are causing longer periods of stratification, which allows algal blooms to be more persistent (Paerl and Huisman 2008, O’Neil et al. 2012). Increases in biological oxygen demand (BOD) and NH_4^+ concentration and a decrease in dissolved oxygen (DO) are predicted (Mimikou et al. 2000). In Lake Erie, increased decomposition due to warmer temperatures are predicted to cause long-term decreases in hypolimnetic dissolved oxygen (Blumberg and DiToro 1990).

Conversely, greater frequency and intensity of flash flooding events will also increase in-lake production due to increased run-off in temperate lakes. Increased phosphorus loading into lakes due to changes in climate patterns has shown effects across the aquatic food web. Jeppesen et al. (2009) studied Danish lakes with a recent upswing in nutrient loading. They found an overall increase in primary production as increased chl. *a*, a decrease in algal community diversity and an increase in cyanobacterial abundance. The shift to less desirable food sources has caused decreased body size in zooplankton grazer populations, including cladocerans and copepods in the studied lakes.

Historically, DeRuyter Reservoir has frozen in December and thawed in late March or April as observed by lake residents. During the winters of 2015-2016 and 2016-2017, the lake periodically froze and thawed; it did not remain frozen for the typical 3+ months. This pattern in which temperate dimictic lakes do not remain frozen throughout winter months may become more typical as temperatures continue to rise, causing shifts to patterns typical of warm monomictic lakes (Murdoch et al. 2000) such as the larger Finger Lakes.

Air temperature data collected in DeRuyter Reservoir through the Citizen Statewide Lake Assessment Program (CSLAP) administered by the New York State Federation of Lake Associations (NYSFOLA) since 1988 suggests a significant increase in air temperature over time (n = 227, $p < 0.0005$, $R^2 = 0.797$, linear regression; Figure 3-7). Seasonal mean air temperature has increased by about 3 °C during the past several decades. This potentially affects productivity of DeRuyter Reservoir by extending the growing season, as has been demonstrated in other temperate lakes (Murdoch et al. 2000).

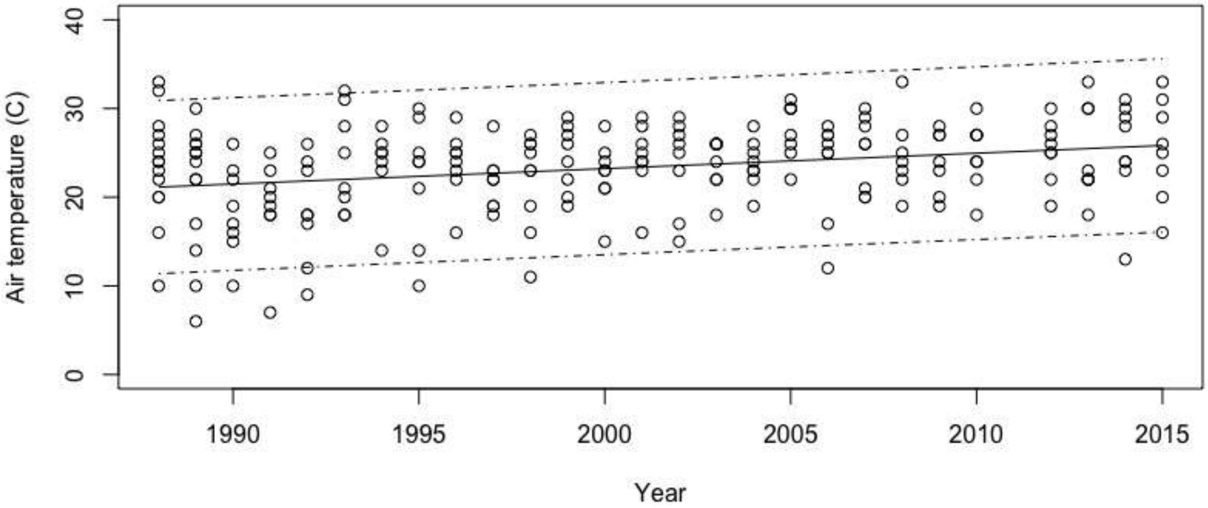


Figure 3-7. Air temperature (°C) over DeRuyter Reservoir collected once or twice a month (dependent of each year's sampling schedule) from June through September annually as part of CSLAP monitoring. Open circles are raw data, the solid line indicates a linear regression of year on air temperature (y = 0.17x – 324.16), and dashed lines represent 95 % CI.

g. DeRuyter Reservoir as a Part of Larger Drainage Basins

DeRuyter Reservoir is located on the divide of the Eastern Lake Ontario and Chesapeake Bay watersheds, both of state and national importance. The basin drains northward into Limestone Creek where it connects to Chittenango Creek flowing into Oneida Lake. Oneida Lake drains into the Oneida River, connects to the Oswego River and eventually ends up in the St. Lawrence River via Lake Ontario. The Oneida Lake watershed (Figure 3-8) covers 3,532 km^2 of New York State within six counties and includes 69 cities, towns, and villages (CNY Regional Planning and Development Board 2004); the DeRuyter watershed takes up a mere 0.29 % of the Oneida Lake watershed.

While DeRuyter Reservoir flows northward during much of the year, water can also flow south into the East Branch Tioughnioga river in the Susquehanna drainage basin during high water levels, eventually flowing into the Chesapeake Bay (Figure 3-9). DeRuyter Reservoir has therefore been placed on a list of priority waterbodies in this southern flowing watershed of New York. Though the lake and the surrounding drainage basin (Figures 3-8 and 3-9) account for only a fraction of these watersheds, water quality issues in DeRuyter Reservoir may have important implications downstream due to its position in the headwaters of two of the largest Atlantic Coastal drainages in North America (Figure 3-10).

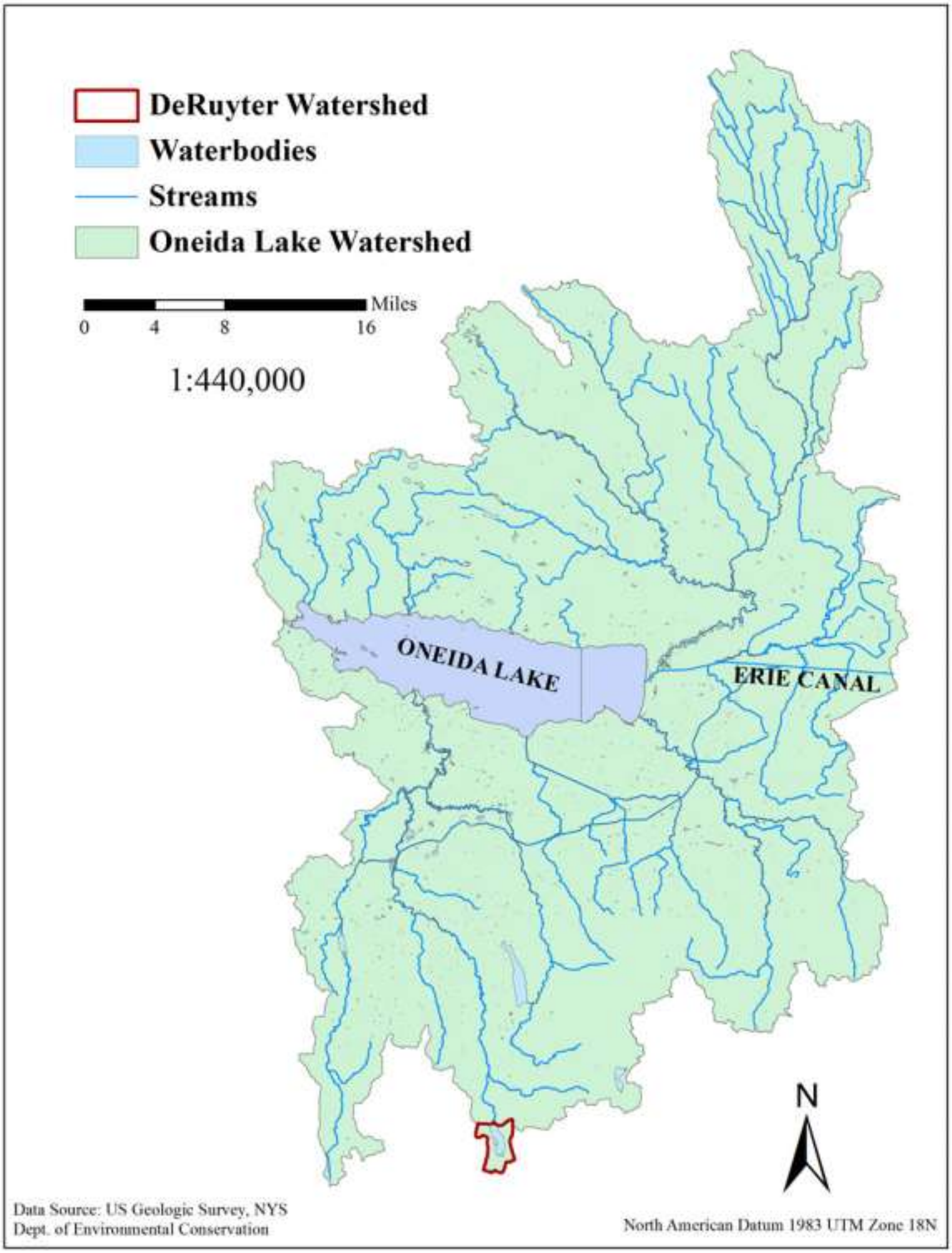


Figure 3-8. The Oneida Lake drainage basin highlighting the location of the DeRuyter Reservoir drainage basin on the southern edge (Ries et al. 2008).

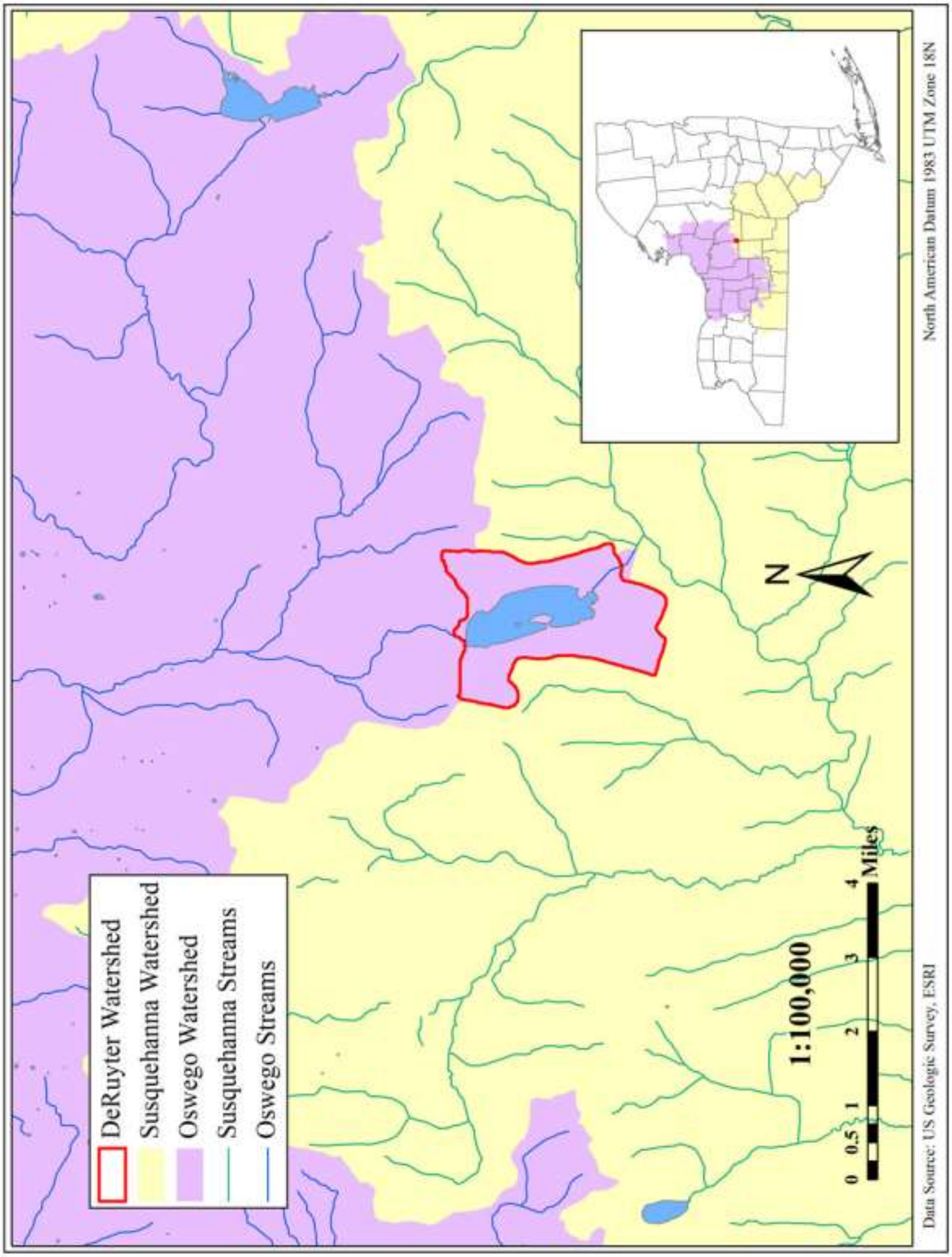
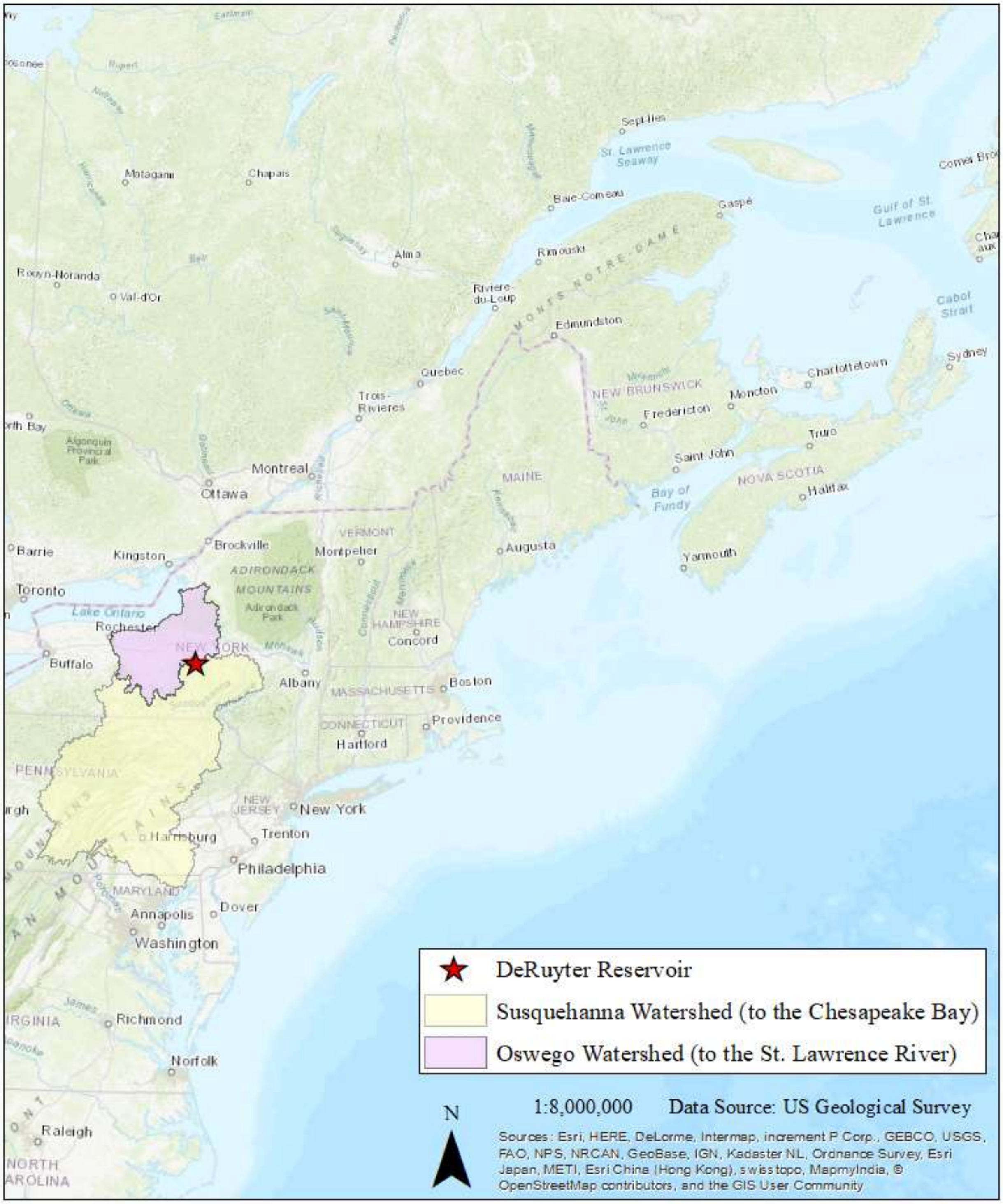


Figure 3-9. Major NY drainage basins with the DeRuyter Reservoir drainage basin along the border (Ries et al. 2008).



1:8,000,000 Data Source: US Geological Survey

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 3-10. Map of northern US Atlantic Ocean coastline highlighting the DeRuyter Reservoir watershed in respect to Susquehanna and Oswego watersheds.

Chapter 4: Limnological Characterization

Introduction

An understanding of physical and chemical properties of a waterbody and how they interact can help to develop a sense of the current state of a body of water, and the biological and ecological implications thereof. Different temperature and oxygen levels are related to patterns in stratification and mixing and can result in the potential for anoxia. Periods of anoxia can result in bioavailability of limiting nutrients such as nitrogen and phosphorus. Externally and internally loaded, bioavailable forms of nitrogen and phosphorus can increase productivity and in turn cause hypolimnetic anoxia with a positive feedback loop (increased nutrients > increased production > increased decomposition > increased anoxia > increased nutrients). Physical differences in temperature and oxygen levels in the waterbody, as well as different chemical structures (i.e., ionic concentration, macro and micronutrient availability [Warne 2014]), can support specific organisms. Changes to the watershed due to anthropogenic activity (i.e., alteration of natural water course, road salt usage, external nutrient loading due to increased impervious surfaces, agriculture, and waste disposal, and the introduction of non-native organisms) can have a substantial effect on the acceleration of these processes. Water quality monitoring can help to quantify effects of these changes on the waterbody.

In addition to general ecosystem functioning, changes in water quality can impact intended uses for a given waterbody. DeRuyter Reservoir is used primarily for recreation. Stakeholders want the lake to remain a waterbody that is desirable for contact recreation and does not present any potential health hazards due to degraded water quality (i.e., toxic cyanobacteria).

NYSDEC uses a set of water quality standards to determine whether or not waterbodies support best intended uses based on common limnological parameters. Limnological data are needed to fully understand how the lake has changed, to help infer what has contributed to present conditions, and to predict future patterns in water quality. The objective of this study was to characterize seasonal changes in water quality parameters commonly used to make lake management decisions. To achieve this objective, water quality parameters, including Secchi depth, temperature, dissolved oxygen, TP, TN, chlorophyll *a*, specific conductance, pH, alkalinity, and concentrations of major ions were studied for a full calendar year spanning 2015 and 2016 in DeRuyter Reservoir.

CSLAP, administered by NYSFOLA and NYSDEC, trains lakeside residents to collect water quality data for a statewide database. CSLAP data helps lake stakeholders identify historical reference condition and trends over time needed for long-term management decisions. CSLAP monitoring on DeRuyter Reservoir began in 1988 and has continued annually, excluding 2011 due to limited statewide resources. Parameters include temperature, TP and TN, calcium, true color, Secchi depth, specific conductivity, chl. *a* and pH. Water quality has remained within range of typical mesotrophic systems of its kind, but has recently been affected by multiple invasive species, particularly *Dreissena polymorpha* (zebra mussel).

Zebra mussel establishment potential in a particular waterbody can be predicted from water quality parameters such as pH, alkalinity, and calcium, as the organism requires sufficient dissolved calcium to build their shell (Hincks and Mackie 1997). The species has been called an ecosystem engineer due to correlated changes in water clarity, chl. *a*, and algal community dynamics that follow introduction (Varnderploeg et al. 2001, Karatayev et al. 2002, Knoll et al. 2008). However, less is known about changes to other water quality parameters such as pH and conductivity.

Zebra mussels, *Dreissena polymorpha* Pallas (1773), are native to Southern Russia, but were first found in the United States in 1988 in Lake St. Clair in Michigan (Griffiths et al. 1991) and have since spread throughout the Great Lakes, and subsequently throughout North America to both coasts. The mussels were likely introduced by ballast water from a foreign ship (Roberts 1990) and have continued spreading through overland transport by recreational boaters. The first zebra mussel was found in DeRuyter Reservoir in 2006 on a paddle boat on the south end of the lake (Adssitt, pers. comm.). Zebra mussels thrive due to lack of ecological constraints on growth and reproduction in waterbodies to which it has been introduced, typical of invasive species (Sakai et al. 2001). Their ability to use most hard substrates as habitat and their propensity for dispersal combined with high fecundity (Carlton 1993) has contributed to negative ecological and economic effects (Karatayev et al. 2002).

There is often a lag time between actual entrance of an invasive species into an ecosystem and detection by humans. This can hinder the success of early detection rapid response efforts. Though zebra mussels were first detected in DeRuyter Reservoir in 2006, water quality parameters appeared to shift a few years prior to that, around 2003-2004. Therefore, annual trends in CSLAP data collected in DeRuyter Reservoir were evaluated to determine how parameters have changed, to predict direction of future changes, and to gain a more exact understanding of zebra mussel entrance time.

Methods

From 10 October 2015 through 05 December 2016, water chemistry data were collected monthly October through May and bi-weekly in summer with the onset of stratification (June through September). Due to an unusually warm winter of 2015 to 2016 resulting in only partial ice, no sampling was possible from December 2015 to March 2016.

Sampling occurred during the late morning, typically around 10:00 EST, at the deepest point of the lake (depth [z] = 15-16 m) according to a Speedtech® Depthmate portable sounder (Laylin Associates, Unionville, USA) at N42°82.6’, W-75°89.8’ (Figure 4-1). Depth profiles of temperature (°C), specific conductivity (µS cm^{-1}), pH, percent dissolved oxygen (DO), and DO

($mg\ L^{-1}$) were collected at 1 m intervals from just below the surface ($z = 0$ m) to approximately $z = 15$ m with a YSI 650MDS with a 6-Series multi-parameter Sonde (YSI Inc., Yellow Springs, USA) calibrated prior to use according to manufacturer instructions (YSI Inc. 2009). A Secchi disk was used to estimate water transparency. The disk was lowered vertically into the water column until it was no longer visible and that depth was recorded to the nearest 10 cm. The disk was then raised until visible again and that depth was recorded similarly. An average of the two depths represented the Secchi depth (Wetzel and Likens 2000). Three consecutive Secchi disk readings were collected each sampling date and averages were calculated.

Previous studies sampled identical parameters in the southern portion of the lake, basin 2 ($z = 7$ m; Figure 4-1). Values in this region of the lake were similar to those of basin 1, but showed a lack of stratification during summer months (Lord and Pokorny 2013, Lord et al. 2015, Lord and Reyes 2016, Lord 2017). Sampling in just the deep north basin was thought to be sufficient for the present study to capture periods of anoxia during stratification, whereas this was not an issue in the south basin.

Water samples were collected at $z = 0, 3, 6, 9, 12$, and 15 m with a Wildco© 1.2 L opaque PVC Kemmerer Sampler (Wildlife Supply Company, Yulee, USA); ~250 ml unfiltered samples were preserved with 1 ml H_2SO_4 and stored at room temperature until analysis in 250 ml plastic bottles. Concentrations of nitrate + nitrite ($mg\ l^{-1}$ N), total nitrogen ($mg\ l^{-1}$ N), and total phosphorus ($\mu g\ l^{-1}$ P) were determined with a Lachat QuikChem FIA+ Water Analyzer (Hach Company, Loveland, USA) following the standard protocols at SUNY Oneonta Biological Field Station (Table 4-1). Surface and bottom (z ~15 m) 500 ml water samples were collected bi-monthly in fall, winter, and spring, and monthly during summer (June-September) to quantify alkalinity, Ca^{2+} hardness, and chloride levels. Samples were stored in plastic bottles at room temperature for up to a month. These parameters were estimated by titration and calculated by the following equations (Table 4-1; Way 2012):

$$\text{alkalinity (mg l}^{-1}\text{CaCO}_3\text{) = ml of titrant} \cdot \frac{1{,}000}{\text{100 ml sample}}$$

$$\text{calcium hardness } \left(\text{mg l}^{-1}\text{CaCO}_3\right) = \text{ml 0.0100 N EDTA titrant} \cdot \frac{1{,}000}{\text{50 ml sample}}$$

$$\text{chloride (mg l}^{-1}\text{) = (sample value-blank value)} \cdot 0.0141\ \text{N} \cdot \frac{35{,}450}{\text{ml sample}}$$

(where N = normality of EDTA)

A 500 ml surface water sample was taken with an opaque plastic bottle to prevent further photosynthesis. Samples were also collected at the thermocline twice in July and once in August. Immediately upon return to the lab from the lake (~ 90 minutes) 100–500 ml of water, dependent on how productive the lake was on a given day, were filtered through a 47 mm Whatman ® GF/A glass fiber filter (General Electric, Fairfield, USA) with a low-pressure vacuum pump (15 psi), and stored at -20 °C wrapped in aluminum foil until further processing. According to Arar and Collins (1997), modified by Mehlrose and Yokota (2016), filters were then submerged in 10 ml buffered acetone (90 % C_3H_6O, $MgCO_3$) for 3 hours. Samples were centrifuged at 10,000 × *g* for 10 minutes with a Thermo Scientific Sorvall Legend XI centrifuge (Thermo Fischer Scientific Inc., Waltham, USA). Chl. *a* concentration in the extract was measured with a Turner Designs TD 700® fluorometer (Turner Designs ©, San Jose, USA) and converted into in-lake concentration as:

$$\text{chl. } a \left(\mu\text{g l}^{-1}\right) \text{ in whole sample} = \text{concentrated chl. } a \left(\mu\text{g l}^{-1}\right) \cdot \frac{\text{extract volume (ml)}}{\text{sample filtered (ml)}}$$

All depth-dependent parameters (e.g., temperature, dissolved oxygen, etc.) were interpolated between sampling events and displayed as isopleths with the akima package (Akima and Gebhardt 2016) in R (R Core Team 2016).

CSLAP also collected water quality data from 1988 through 2015, with the exception of 2011. Parameters included surface and bottom (z ~ 13 m) temperature, transparency (Secchi depth), true color, surface pH, surface calcium, surface conductivity, surface chl. *a*, and both surface and bottom TP, NO_3, NH_4, and TDN (NYSDEC 2015a). Collection occurred from May through October either monthly or bi-weekly, varying between years. CSLAP samples were taken from the water column at basin 1(~16 m; Figure 4-1). Surface samples were collected at z = 1.5 m. The CSLAP samples were analyzed by NYSDEC (http://www.dec.ny.gov/docs/water_pdf/cslaplkpara.pdf 5/9/17).

CSLAP data were analyzed for changes over time with either a linear regression model or a piecewise regression model in R (R Core Team 2016). Where necessary, water quality parameters were transformed prior to analysis in order to meet distributional assumptions. Temperature, color, calcium, and bio-available nutrients were evaluated by standard linear regression:

$$y = mx + b$$

(where y is water quality parameter, x is year, m is slope, and b is the y-intercept)

Four parameters (pH, specific conductivity, chl. *a*, and Secchi depth) were chosen to further evaluate historical trends hypothesized to be related to establishment of a zebra mussel population in the reservoir. Variables were transformed prior to analysis in order to meet distributional assumptions. When examining the raw data plotted by year, two different linear relationships were visually apparent. The first covered the period from 1988 to early 2000s and the second from the early 2000s to 2015, with a shift somewhere between 2003 and 2005. Mean squared error (MSE) was calculated to determine which year was the best break point that minimized the residuals (2003, 2004, or 2005). The year 2004 had the lowest MSE for all four parameters. Four piecewise regressions (one for each water-quality variable) were specified with 2004 as the breakpoint:

$$\log(y) \sim x \cdot (x < 2004) + x \cdot (x > 2004)$$

where x was year and y was the water quality parameter (pH, specific conductivity, chl. *a*, and Secchi depth). Main effects and interactions were specified for both intercept and slope. Assumptions of the linear regression models were independence of observations, normality of residuals, and homogeneity of variances.

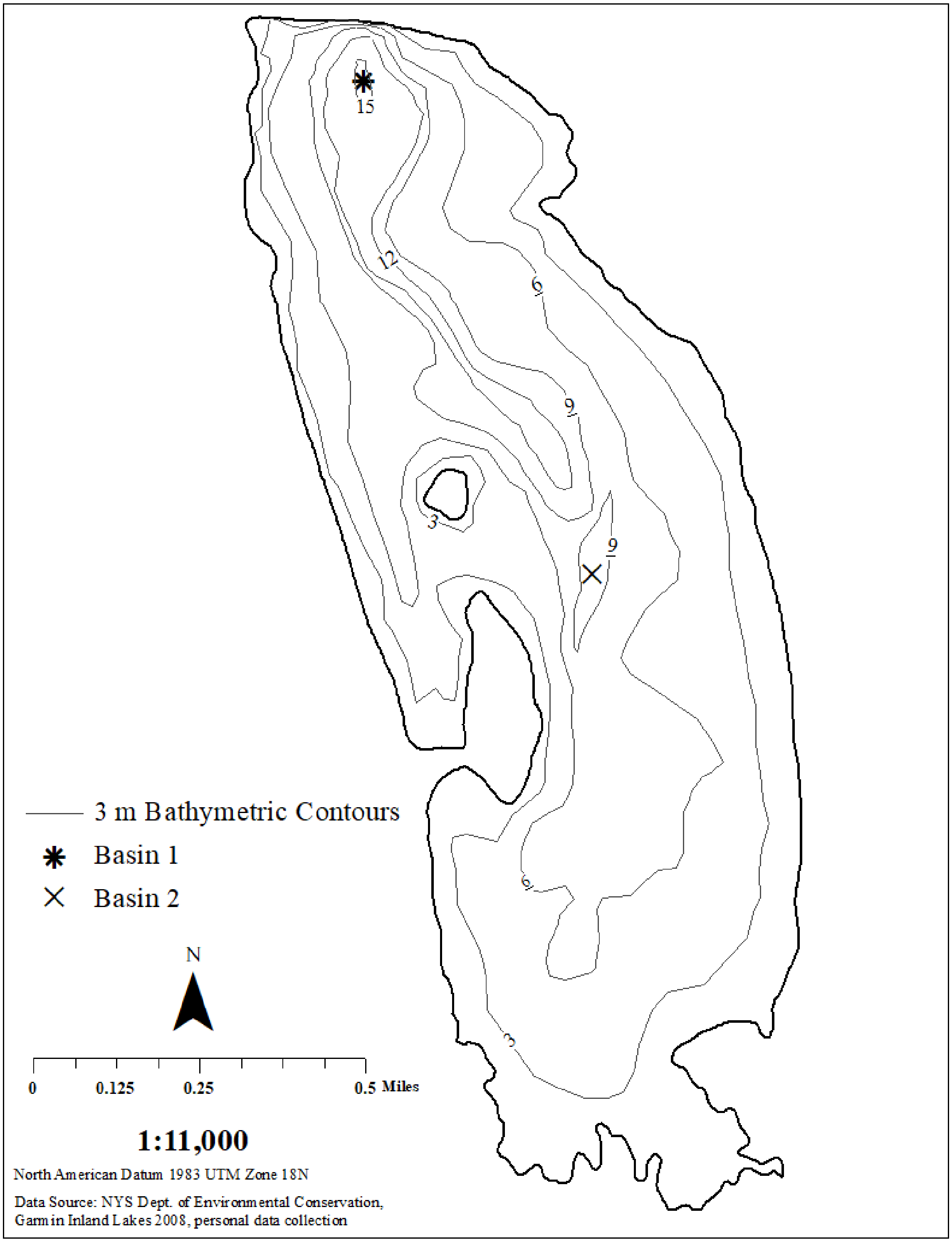


Figure 4-1. Location at which limnological parameters were sampled for this study and for CSLAP (NYSDEC 2015a). Both basin 1 and 2 were sampled for Lord's studies (Lord and Pokorny 2013, Lord et al. 2015, Lord and Reyes 2016, Lord 2017).

Table 4-1. Methods used for estimating chemical concentrations of specific water quality indicators.

Parameter	Preservation	Method	Reference	Detection Limit
Total phosphorus	H_2SO_4 to pH < 2	Persulfate digestion followed by single reagent ascorbic acid	Liao and Marten 2001	4 µg l^{-1} P
Total nitrogen	H_2SO_4 to pH < 2	Cadmium reduction method following peroxodisulfate digestion	Pritzlaff 2003; Ebina et al. 1983	0.04 mg l^{-1} N
Nitrate + nitrite	H_2SO_4 to pH < 2	Cadmium reduction method	Pritzlaff 2003	0.02 mg l^{-1} N
Calcium	Store at 4°C	EDTA trimetric method	EPA 1983	If low, use more sample
Chloride	Store at 4°C	Mercuric nitrate titration	APHA 1989	If low, use more sample
Alkalinity	Store at 4°C	Titration to pH= 4.6	APHA 1989	If low, use more sample

Results and Discussion

Temperature

DeRuyter Reservoir has historically been dimictic, typical of moderately deep temperate lakes. The lake stratified in summer and winter, with one mixing event in the fall and one mixing event in the spring (Figure 4-2). However, during the winters of 2015 and 2016 the lake did not remain entirely frozen for the historical 3+ months. Rather, the lake had periodic and patchy ice cover. Surface temperatures in DeRuyter Reservoir have increased significantly since 1988 (n = 227, $p = < 0.05 \times 10^{12}$, $R^2 = 0.1832$, linear regression; Figure 4-3) and bottom temperatures have increased significantly since 1993 (n = 106, $p < 0.0005$, $R^2 = 0.1151$, linear regression; Figure 4-4). A continued increase in temperature due to the changing climate can lead to changes in food web dynamics (Jeppesen et al. 2009), longer periods of stratification, and subsequent longer periods of anoxia (Blumberg and DiToro 1990). Anoxia will lead to internal loading of phosphorus from bottom sediment (Nürnberg 1984).

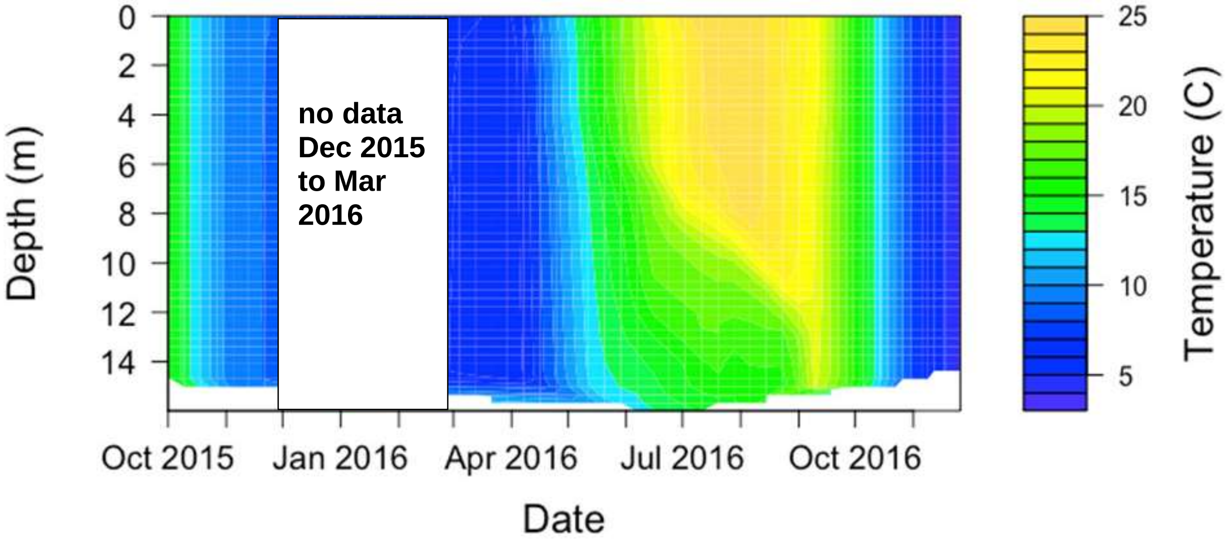


Figure 4-2. Temperature (°C) profile of the water column from October 2015 to December 2016. Measurements were not taken from December 2015 to March 2016.

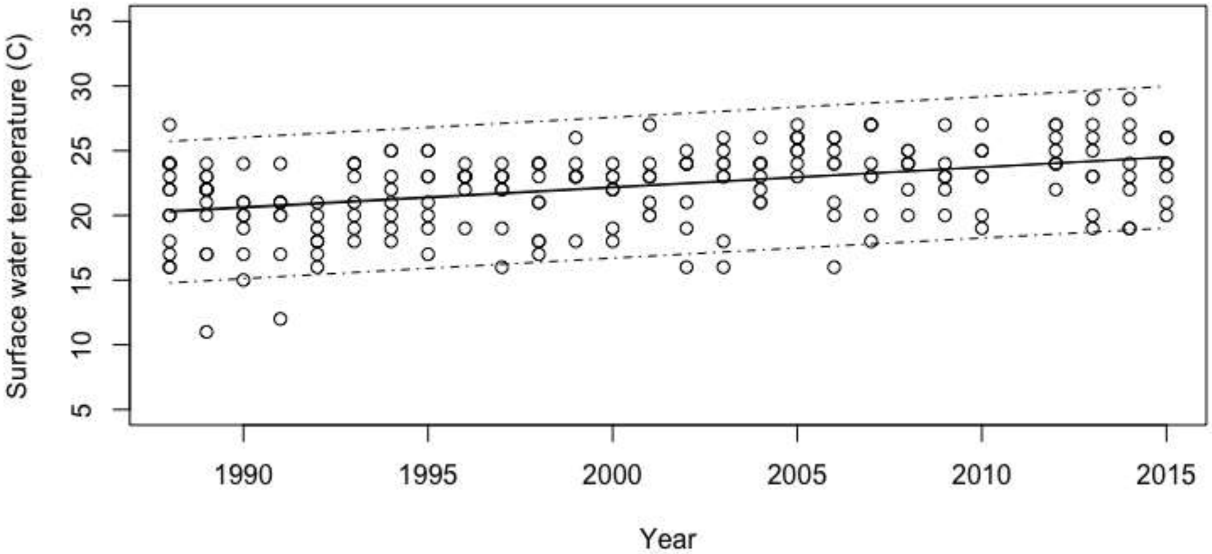


Figure 4-3. Surface temperature (°C) of DeRuyter Reservoir measured by CSLAP annually from 1988 to 2015, excluding 2011. Data were collected on multiple occasions from May through October of each year. Open circles represent raw data, the solid line indicates a linear regression of year on temperature (y = 0.16x – 291.59), dashed lines represent 95 % CI.

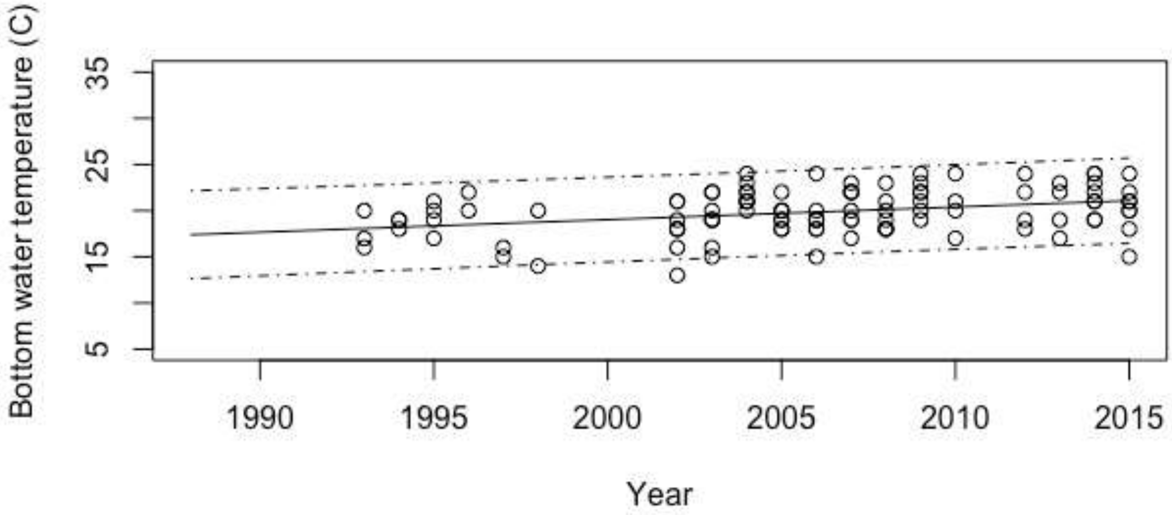


Figure 4-4. Bottom temperature (°C) of DeRuyter Reservoir measured by CSLAP annually from 1988 to 2015, excluding 2011. Data were collected on multiple occasions from May through October of each year. Open circles represent raw data, the solid line indicates a linear regression of year on temperature (y = 0.14x – 254.08), dashed lines represent 95 % CI.

Dissolved Oxygen

Isopleths of water column dissolved oxygen (DO) throughout the sampling period as % saturation (Figure 4-5) and as mg l^{-1} (Figure 4-6) show > 80 % saturation during most of the year, but an extended period of anoxia occurred in the hypolimnion from June through September. The largest portion of the water column was anoxic on 07 August 2016, up to about z = 9 m (Figure 4-7). Under NYCRR Part 703.3, New York State water quality standards for water column dissolved oxygen require a minimum daily average of 5 mg l^{-1} at all depths and state that at no time should DO be less than 4 mg l^{-1}. Lower DO levels are considered unsuitable habitat for fish and other animals. Anoxic hypolimnetic waters can lead to internal P loading into the water column due to release from sediment (Nürnberg 1984) which can lead to increased productivity in the lake.

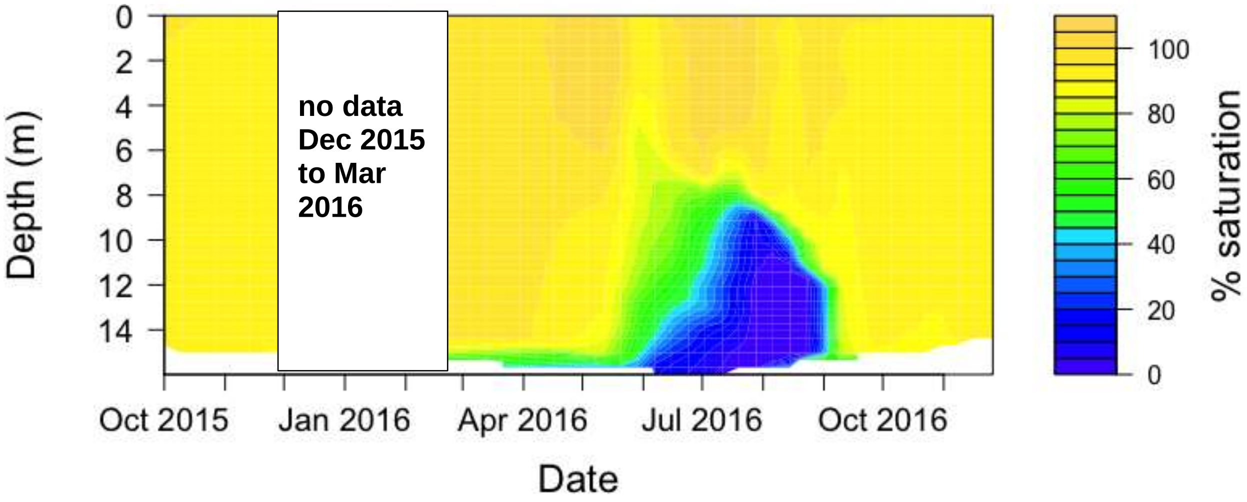


Figure 4-5. Dissolved oxygen (% saturation) profile of the water column from October 2015 to December 2016. Measurements were not taken from December 2015 to March 2016 due to weather conditions.

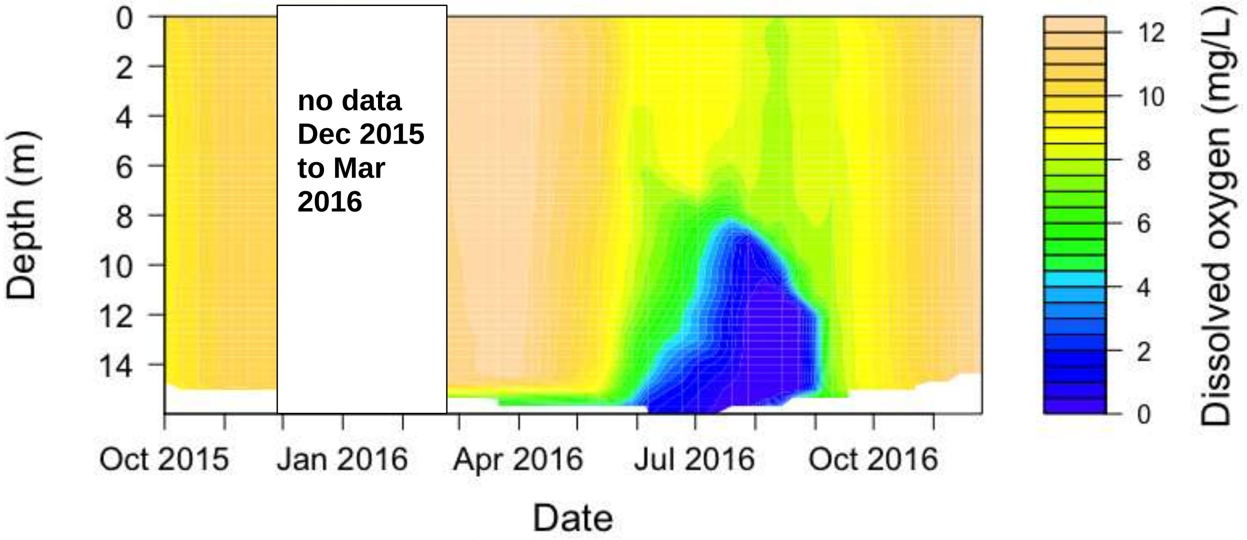


Figure 4-6. Dissolved oxygen (mg l^{-1}) profile of the water column from October 2015 to December 2016. Measurements were not taken from December 2015 to March 2016 due to weather conditions.

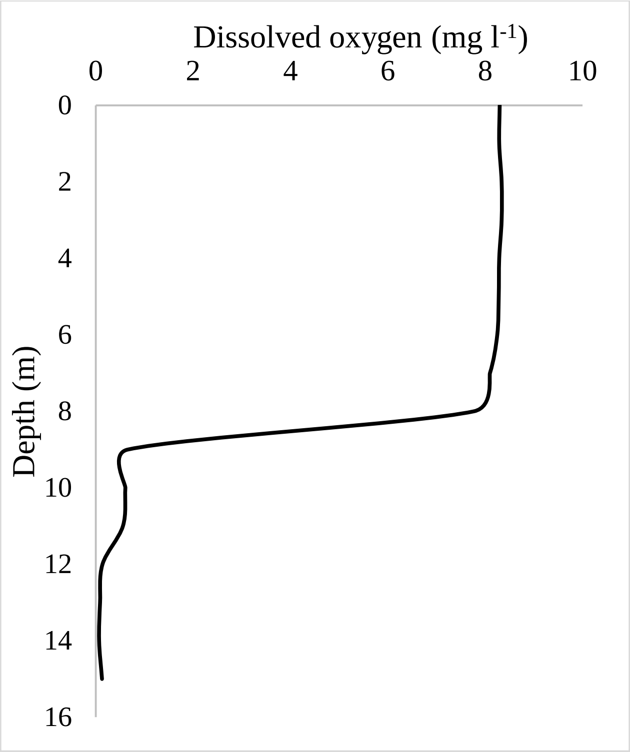


Figure 4-7. Water column profile of dissolved oxygen (mg l^{-1}) on 07 August 2016. Readings were taken at 1 m intervals.

Nutrients

Over the sampled period, average surface TP was 15.79 µg l^{-1} P, ranging from 7.00 to 32.00 µg l^{-1} P and average bottom TP was 22.67 µg l^{-1} P, ranging from 8.00 to 77.00 µg l^{-1} P (Figure 4-8). Average surface TN was 0.26 mg l^{-1} N, ranging from 0.13 to 0.57 mg l^{-1} N and average bottom TN was 0.29 mg l^{-1} N, ranging from 0.12 to 0.54 mg l^{-1} N (Figure 4-9). Nitrate and nitrite combined was typically below measurement detection. Average surface TP fell below NYSDEC's threshold of 20 µg l^{-} P for lakes intended for contact recreation (NYSFOLA 2009) and within range for designation as a mesotrophic lake.

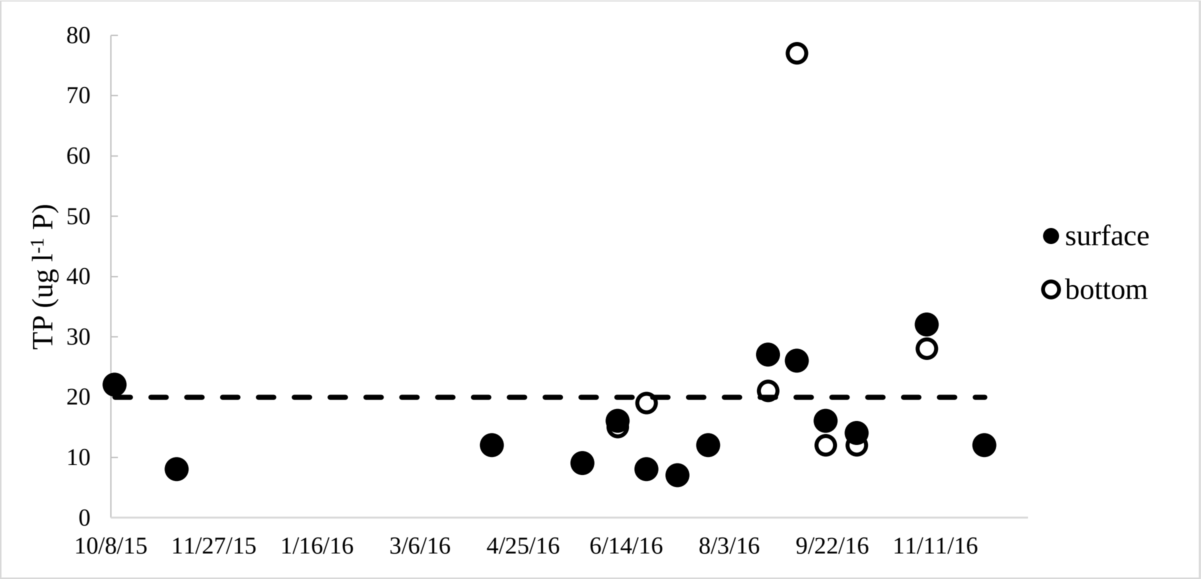


Figure 4-8. Surface (z = 0 m) and bottom (z ~16 m) TP phosphorus (µg l^{-1} P) on sampled days. Dates with only filled in circles represent overlap in data. Dashed line represents maximum amount of P (20 µg l^{-1} P) to be allowed in a waterbody, designated by NYSDEC.

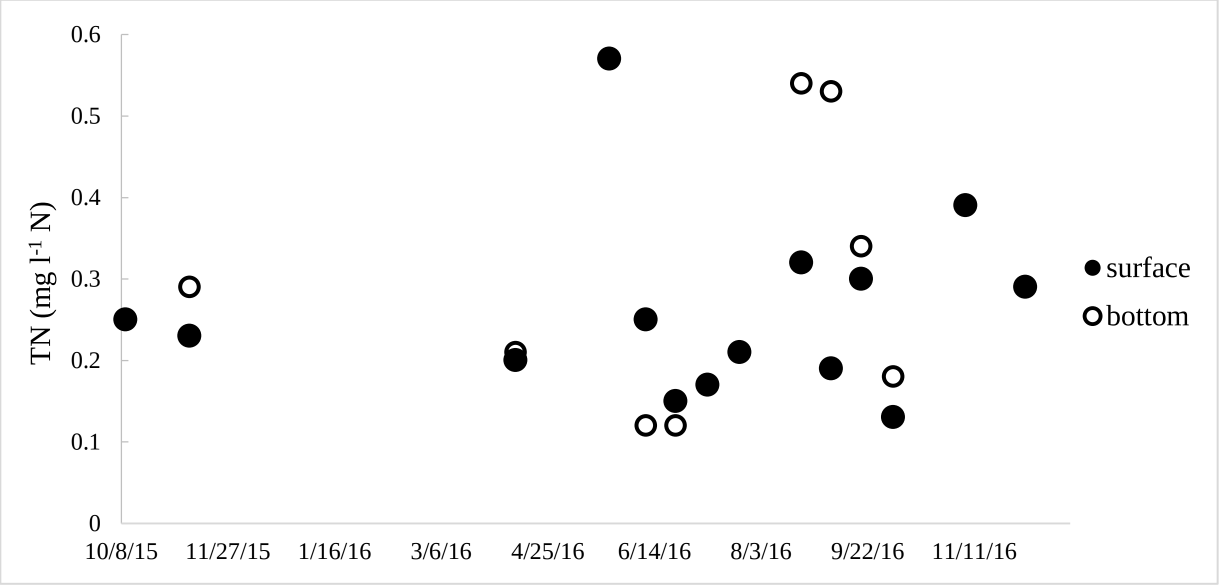


Figure 4-9. Surface (z = 0 m) and bottom (z ~16 m) TN (mg l^{-1} N) on sampled dates. Bottom TN was below detection on 07 November 2016. Dates with only filled in circles represent overlap in data.

On 07 August 2016 TP and TN were far higher than the typical range (i.e., surface and bottom TP at 137 and 87 µg l^{-1} P, respectively). Lab errors were unlikely as other samples ran through the auto-analyzer did not have similar problems and samples were ran a second time for quality assurance. These data were omitted from averages and figures intended to show seasonal trends, but are of interest to future studies. This increase in nutrients occurred in conjunction with anoxia of the entire hypolimnion on the same date (Figure 4-7). This date was at the end of the annual *Myriophyllum spicatum* (Eurasian watermilfoil) large-scale mechanical harvesting operation that occurs throughout the littoral zone of the lake. It is speculated that nutrients were released from plant fragments left in the water column and cut plants that remained rooted. Macrophytes hold large quantities of N and P, which are released directly from their tissue as they decompose (Hill 1979). As most submerged macrophytes acquire the majority of their nutrients from sediment, release through decomposition can potentially be considered a form of internal nutrient loading into the lake and lead to increased algal biomass (Carpenter and Lodge 1986). A large-scale harvesting effort would likely cause this process to happen during a much shorter period and over a larger area than natural macrophyte senescence after a growing season.

Though the 2016 summer season was unusually dry, tributaries were sampled after rain events in the fall. On 07 November 2016, a water sample was collected from the main inlet at the southeast corner of the lake and measured at 64 µg l^{-1} TP, 1.21 mg l^{-1} TN, and 1.04 mg l^{-1} N as nitrate + nitrite. Total phosphorus was double that of water column values. On two dates following rain events (19 September 2016 and 05 December 2016) constructed inlets entering the west end of the lake were flowing and therefore collected for nutrient analyses. On 19 September 2016, 3 inlets measured 10, 14, and 22 µg l^{-1} TP, 0.76, 0.08, and 0.41 TN, and 0.75, 0.03, and 0.37 µg l^{-1} N as nitrate + nitrite.

Of the historical CSLAP data, no significant differences were found in surface TP from 1988-2015 ($p < 1$, $R^2 = 0.002$, linear regression) and in surface TN from 2002-2015 ($p < 0.5$, $R^2 = 0.007$, linear regression). Despite concerns of external loading into the lake from storm water run-off, individual septic systems, logging, and agriculture, no significant long term changes in TP and TN were observed from 1988 to 2015. This is likely due to a combination of factors including a small watershed, high flushing rates due to reservoir morphology (Moore and Thornton 1988), and nutrient sequestration by increased macrophyte growth due to the introduction of invasive species.

Secchi Depth

Secchi depths ranged from 2.5 to 7.3 m with a mean of 4.5 m (Figure 4-10). The average Secchi depth fell within the range of a typical mesotrophic system (2-5 m) and is clearer than that of NYSDEC Class B lakes standard of 2-3 m (NYSFOLA 2009). Secchi depth increased significantly from 2004 to 2015 ($p < 0.05$), and a significant difference was found between the two piecewise regressions from 1988 to 2004 and 2004 to 2015 ($p < 0.05$; Figure 4-11).

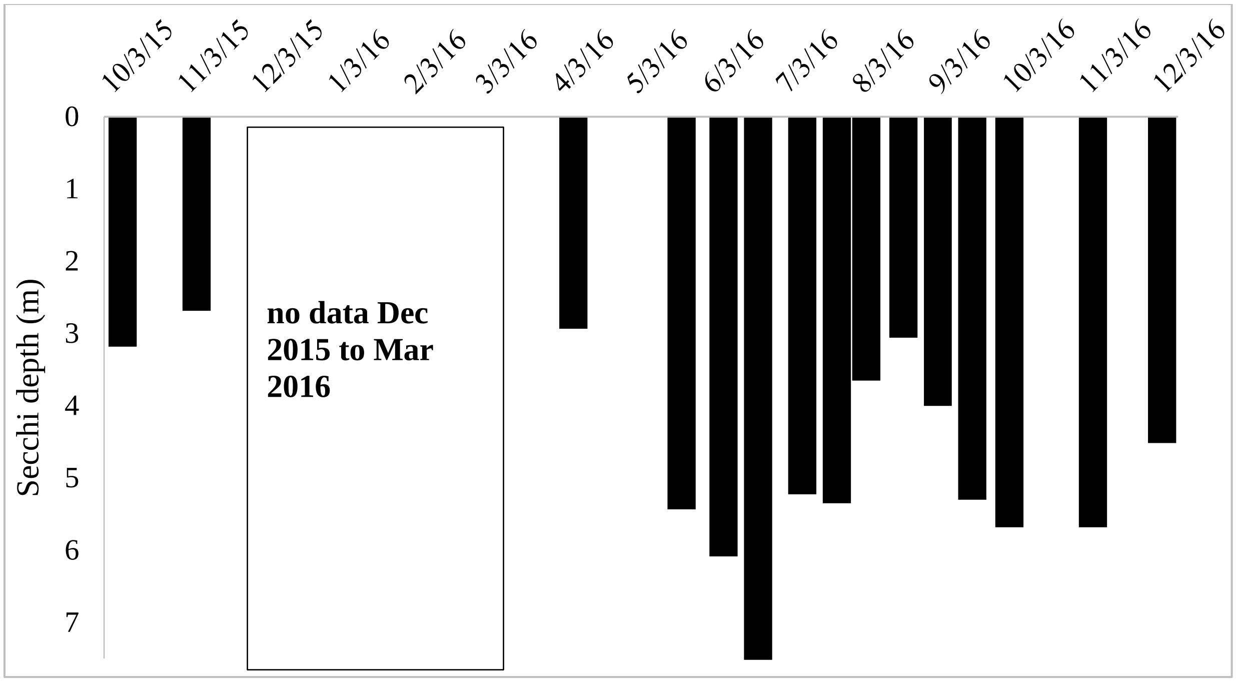


Figure 4-10. Secchi depth (m) measured throughout October 2015 to December 2016 sampling period. Measurements were not taken from December 2015 to March 2016.

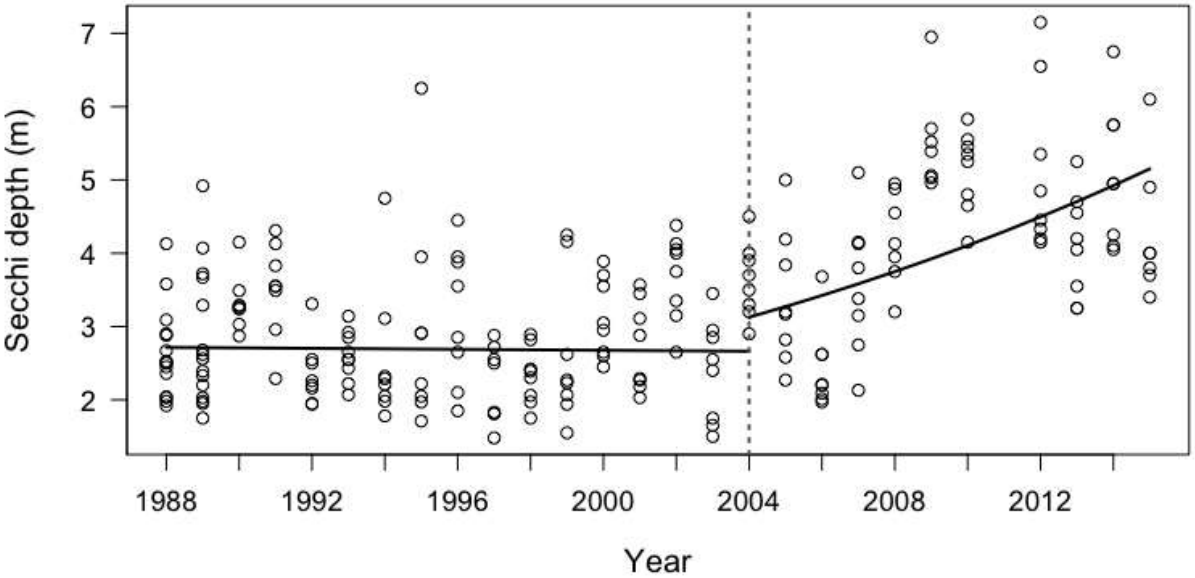


Figure 4-11. Piecewise regression (solid lines) of annual Secchi depth (m) in DeRuyter Reservoir from 1988 to 2015 in which the break-line is at 2004 (dashed line) where the line for $x < 2004$ is $e^y = -0.0012x + 3.43$ and the line for $x > 2004$ is $e^y = 0.045x - 89.722$.

Chlorophyll a

Chl. *a* in DeRuyter Reservoir varied widely, ranging from 1.3 to 24.4 μg l^{-1}, though with most calculated values within the typical mesotrophic range of 2-8 μg l^{-1} (Figure 4-12). On 19 September 2016 chl. *a* was measured as 24.4 μg l^{-1}, likely due to a short-lived algal bloom that was reported to be gone the following day. Similar short-lived blooms were observed by shoreline residents through October 2016, with no long-term persistence (Chapter 5). Increased algal community biomass in freshwater systems in Florida have been correlated with shifts to an algal community dominated by cyanobacteria (Canfield et al. 1989).

A significant difference in chl. *a* before and after 2004 was found between the piecewise regressions from 1988 to 2004 and 2004 to 2015 ($p < .005$). A significant decrease in chl. *a* was observed from 2004 to 2015 ($p < 0.0005$; Figure 4-13).

Thermocline chl. a levels were similar to chl. *a* levels of the surface waters on corresponding dates, indicated algal production throughout the epilimnion in summer months (Table 4-2).

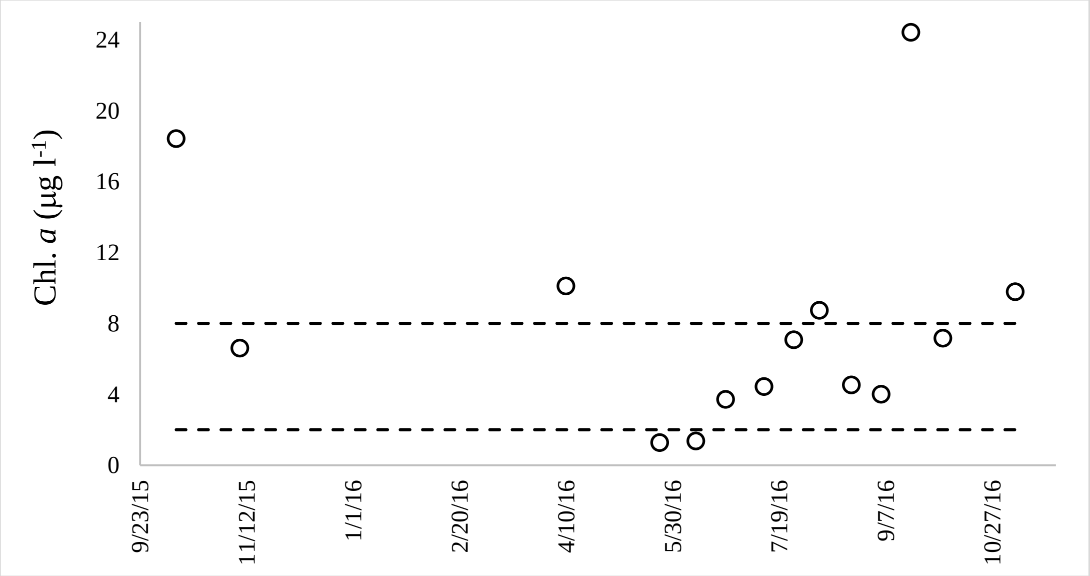


Figure 4-12. Surface chl. *a* in DeRuyter Reservoir, NY from October 2015 to November 2016. Lines indicate NYSDEC lower and upper thresholds used in classifying mesotrophic lakes. Readings greater than or equal to 8 µg l^{-1} are characteristic of a eutrophic system and less than or equal to 2 µg l^{-1} are characteristic of oligotrophic systems.

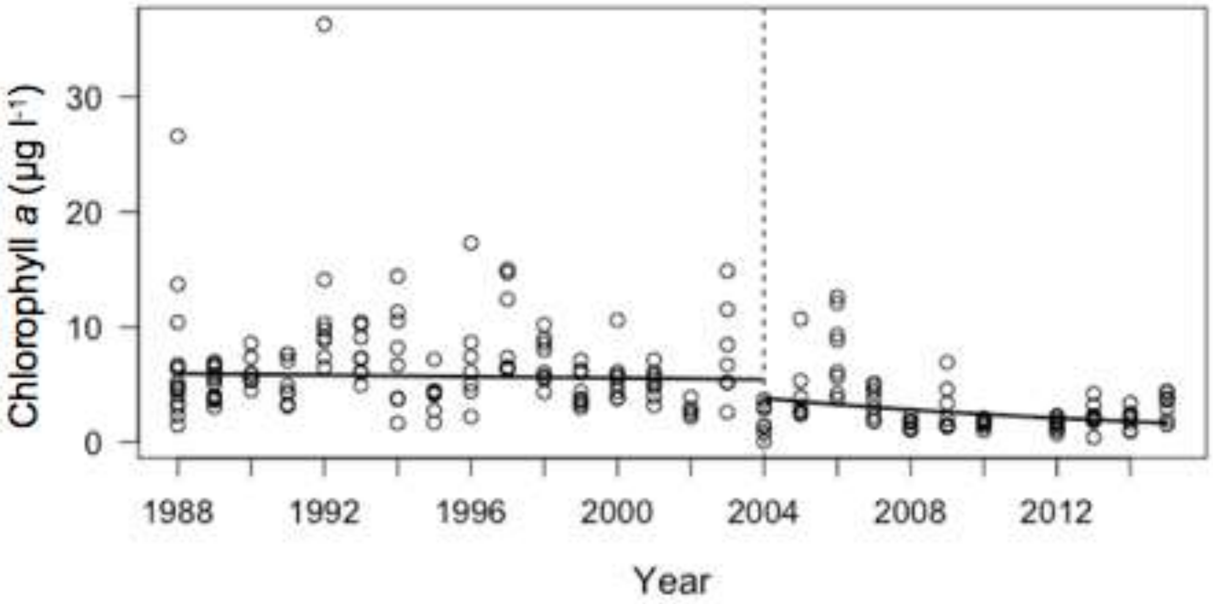


Figure 4-13. Piecewise regression (solid lines) of annual chl. *a* (µg l^{-1}) in DeRuyter Reservoir from 1988 to 2015 in which the break-line is at 2004 (dashed line) where the line for x < 2004 is $e^y = -0.0060x + 12.79$ and the line for x > 2004 is $e^y = -0.076x + 153.29$.

Table 4-2. Chl. a (µg l^{-1}) at the (moving) thermocline on three sampling dates in July and August 2015.

Date	$Z_{thermocline}$ (m)	Chl. a (µg l^{-1})
12 July 2016	9	6.5
26 July 2016	6	7.6
7 August 2016	9	6.7

Color

DeRuyter Reservoir has historically been classified as uncolored, but CSLAP measurements have increased significantly over time since 1988 (n = 225, p = 0.5 x 10^{-6}, R^2 = 0.140, linear regression; Figure 4-14). From 1988 to 2003, annual true color averages ranged from 2.38 ptu to 7.50 ptu. From 2004 to 2013 annual averages ranged from 9.20 ptu to 15.43 ptu. In 2014 and 2015, averages were 5.14 ptu and 5.86 ptu, respectively.

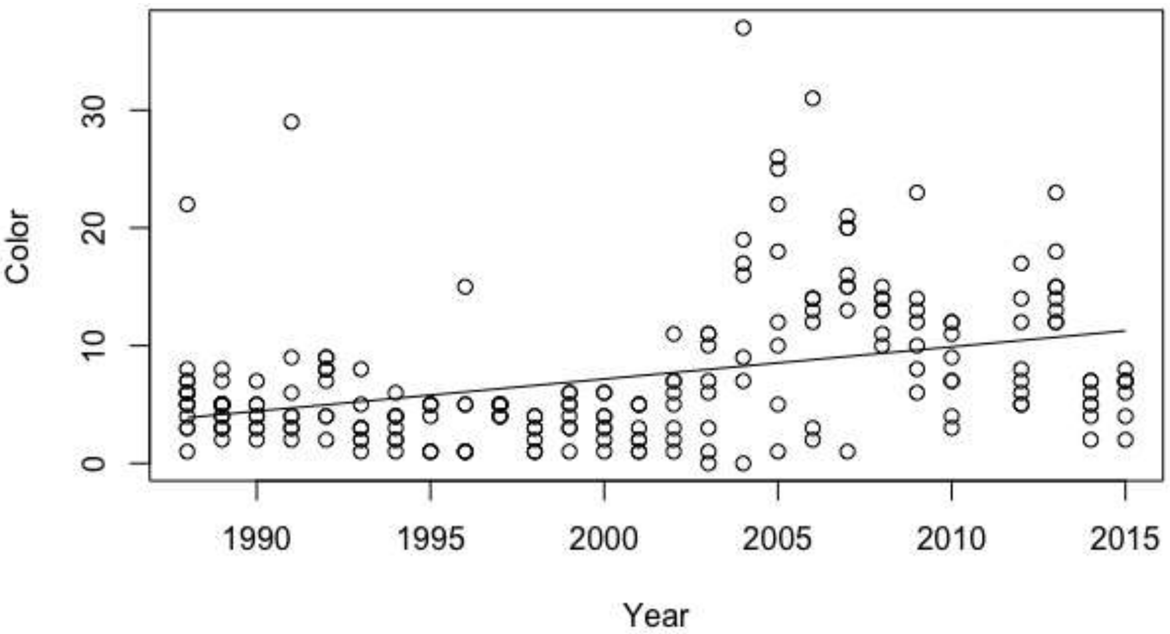


Figure 4-14. Surface true color (ptu) of DeRuyter Reservoir measured by CSLAP annually from 1988 to 2015, excluding 2011. Data were collected on multiple occasions from May through October of each year. Open circles represent raw data and the solid line indicates a linear regression of year on temperature (y = 0.27x – 539.46).

True color is an index of dissolved humic matter in a lake used to quantify the amount of material of allochthonous origin (Wetzel and Likens 2000). Color concentration in lakes is a positive function of watershed: lake ratio (Gorham et al. 1986, Engstrom 1987). Watersheds with steep slopes, characteristic of DeRuyter Reservoir, typically exude less color because faster precipitation of soil and dissolved organic matter from the watershed into the lake occurs (Gorham et al. 1986). A wide range in measurements within each sampling season around 2004–2013 could be due to change in CSLAP sampling technique (NYSDEC 2015a). Measurements in 2014–2015 were within the historical range indicating a return to previous conditions or a refinement of methods.

pH and Major Ions

DeRuyter Reservoir was slightly basic throughout the sampling period (Figure 4-15). Over period monitored for this study, pH in surface waters ranged from 7.70 to 8.86 with a mean of 8.00. Bottom water pH ranged from 7.22 to 8.12 with a mean of 7.74. From 2004 to 2015 there was no significant difference in pH ($p < 1$; Figure 4-16). There was also no significant difference between the two regressions from 1988 to 2004 and 2004 to 2015 ($p < 1$).

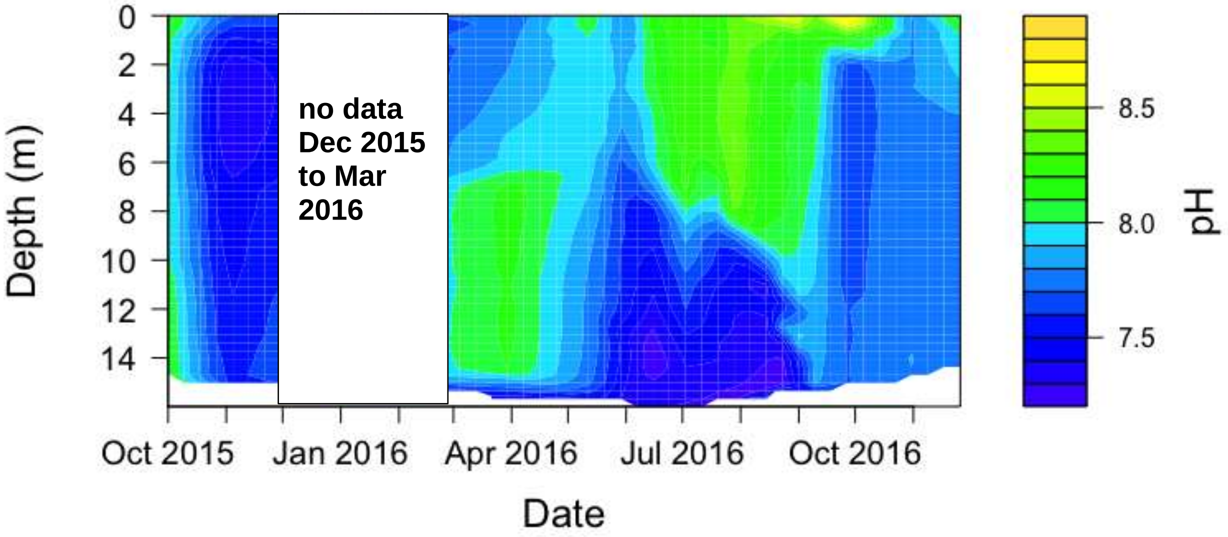


Figure 4-15. pH profile of the water column from October 2015 to December 2016. Measurements were not taken from December 2015 to March 2016; therefore, these months are likely not accurately depicted.

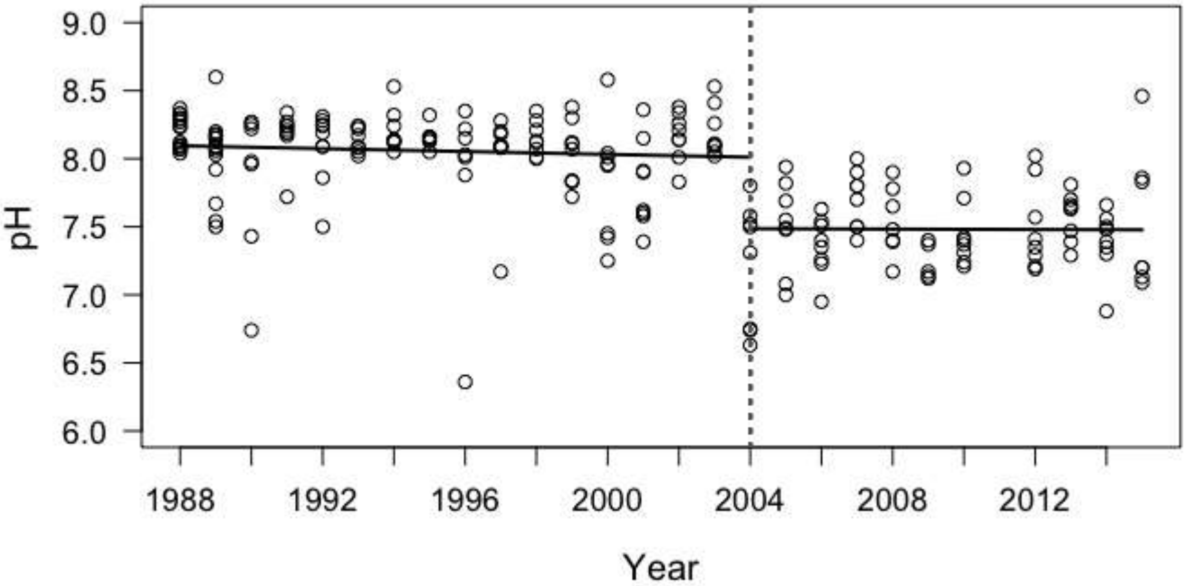


Figure 4-16. Piecewise regression (solid lines) of annual surface pH in DeRuyter Reservoir from 1988 to 2015 in which the break-line is at 2004 (dashed line) where the line for x < 2004 is $e^y = -4.6E^{-4}x + 3.38$ and the line for x > 2004 is $e^y = 9.71E^{-5}x + 2.17$.

Due to the limestone geology surrounding DeRuyter Reservoir, the lake exhibited moderate to high alkalinity. From 10 April 2016 to 04 October 2016 surface alkalinity ranged from 77 mg l^{-1} $CaCO_3$ to 90 mg l^{-1} $CaCO_3$, with a mean of 83.4 mg l^{-1}; bottom alkalinity ranged from 75 mg l^{-1} $CaCO_3$ to 94 mg l^{-1} $CaCO_3$, mean of 87.6 mg l^{-1} $CaCO_3$ (Figure 4-17). DeRuyter

Reservoir exhibited calcium levels consistent with moderately soft water lakes. Surface calcium hardness ranged from 46 mg l^{-1} $CaCO_3$ to 62 mg l^{-1} $CaCO_3$, a mean of 54 mg l^{-1} $CaCO_3$ and bottom calcium hardness ranged from 46 mg l^{-1} $CaCO_3$ to 60 mg l^{-1} $CaCO_3$, a mean of 57 mg l^{-1} $CaCO_3$ (Figure 4-18).

These alkalinity values were expected given the slightly basic pH and calcium hardness in the lake. These three parameters have a combined effect on the biological community in which a waterbody can support. For example, non-native zebra mussel (*Dreissena polymorpha*) growth is dependent on sufficient levels of water column calcium to build their shell. They persist in waters with at least 8.5 mg l^{-1} calcium, alkalinity greater than 17 mg l^{-1} $CaCO_3$, hardness of at least 31 mg l^{-1}, and a generally basic pH; survival and reproduction, as well as individual shell size, are likely driven by a combination of calcium and pH levels (Hincks and Mackie 1997). Whittier et al. (2008), based on a compilation of values in the literature, developed a ranking of water column calcium concentrations to determine a given lake's susceptibility for *D. polymorpha* population establishment. The ranking designated < 12 mg l^{-1} Ca^{2+} as very low risk, 12-20 mg l^{-1} Ca^{2+} as low risk, 20-28 mg l^{-1} Ca^{2+} as moderate risk, and > 28 mg l^{-1} Ca^{2+} as high risk. To evaluate the susceptibility of DeRuyter Reservoir to zebra mussels, using the Whitter et al. (2008) ranking system, surface and bottom calcium concentrations (mg l^{-1} Ca^{2+}) from DeRuyter Reservoir were derived from Ca^{2+} hardness as mg l^{-1} $CaCO_3$ values by subtracting the molar mass of the carbonate ion from the hardness value measured on each sampling date. Surface and bottom calcium levels in DeRuyter mostly fall within the moderate range of zebra mussel risk, with 3 exceptions falling just under 20 mg l^{-1} Ca^{2+} (Figure 4-19).

Surface calcium (mg l^{-1} Ca^{2+}) has decreased significantly since 2003 (n = 20, p = < 0.05, $R^2 = 0.287$, linear regression; Figure 4-20). Though no data was collected prior to 2003, the decline was around the time zebra mussels were predicted to enter the lake in 2004. Calcium uptake by zebra mussels likely led to this decrease. More recent introduction of the non-native macroalga *Nitellopsis obtusa* (Chapter 5) may also have contributed as Ca^{2+} is required for growth (Pullman and Crawford 2010).

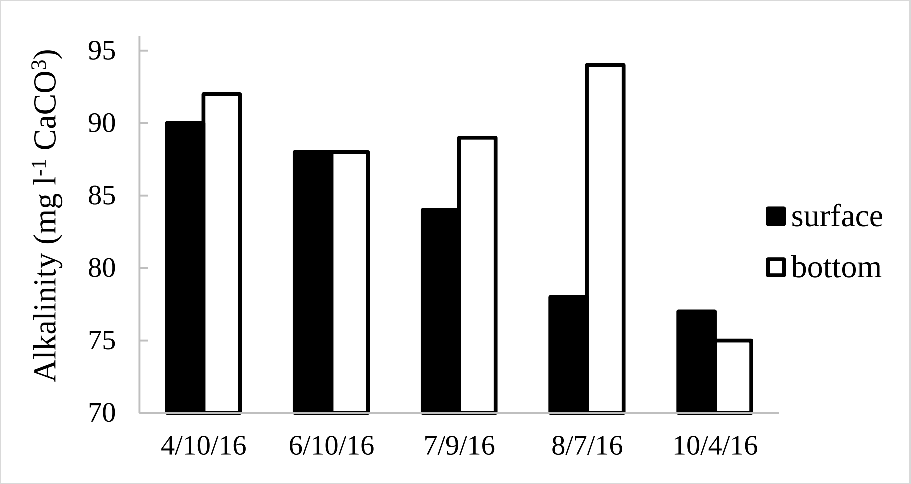


Figure 4-17. Alkalinity as mg l^{-1} $CaCO_3$ in 2016 from surface (z = 0 m) and bottom (z ~ 16 m) waters.

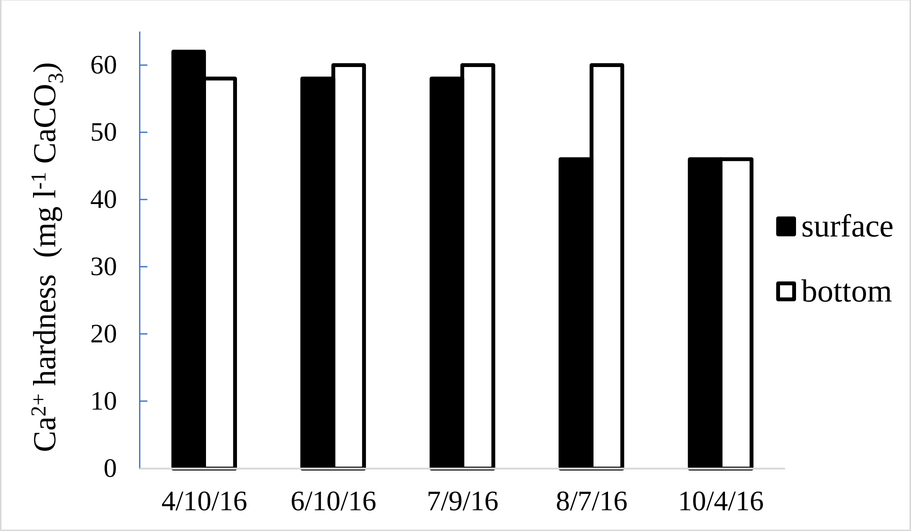


Figure 4-18. Ca^{2+} hardness as mg l^{-1} $CaCO_3$ in 2016 from surface (z = 0 m) and bottom (z ~ 16 m) waters.

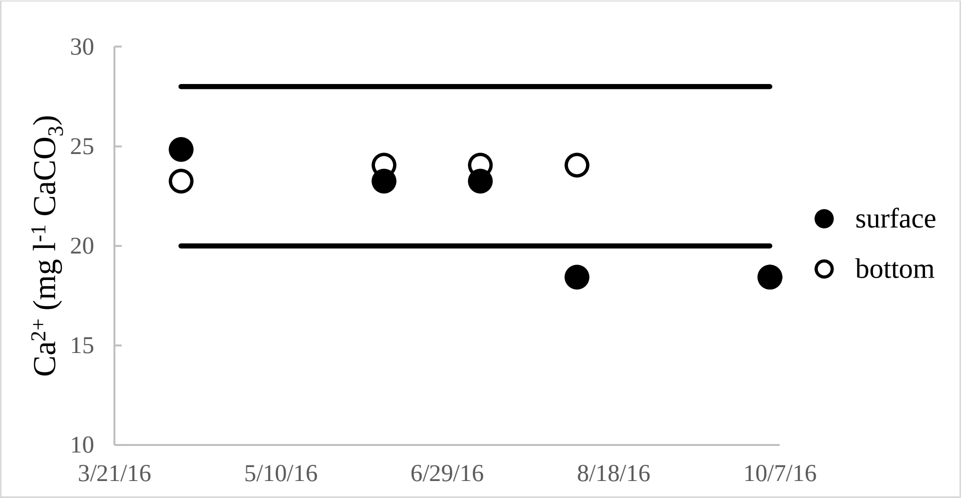


Figure 4-19. Ionic calcium (mg l^{-1} $CaCO_3$) at the surface (z = 0 m) and at the bottom (z ~ 16 m) in DeRuyter Reservoir. Dashed lines indicate minimum (20 mg l^{-1}) and maximum (28 mg l^{-1}) designated for moderate *D. polymorpha* risk (Whittier et al. 2008).

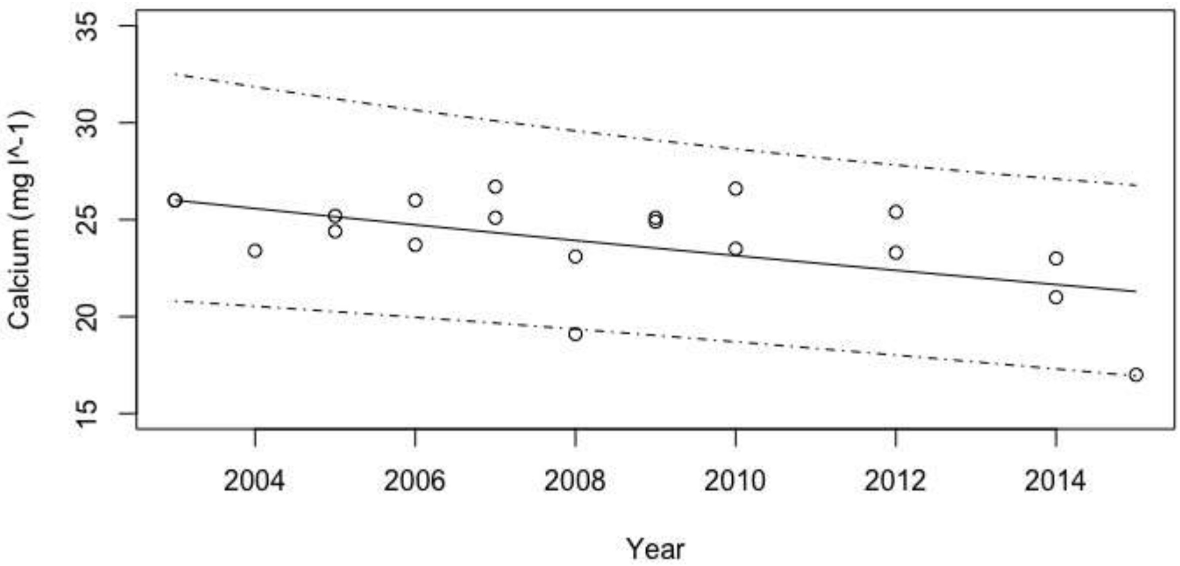


Figure 4-20. Surface calcium (mg l^{-1}) of DeRuyter Reservoir measured by CSLAP annually from 2003 to 2015, excluding 2011 and 2013. Data were collected from May through October of each year. Open circles represent raw data, the solid line indicates a linear regression of year on calcium concentration ($y = -0.02x + 36.59$), and dashed lines represent 95 % CI.

Chloride concentration throughout the sampling period remained relatively consistent. Surface chloride ranged from 8.50 to 11.00 mg l^{-1} Cl^-, with a mean of 9.87 mg l^{-1} Cl^- and bottom chloride ranged from 9.00 to 15.50 mg l^{-1} Cl^-, a mean of 10.75 mg l^{-1} Cl^- (Figure 4-21). Chloride concentrations in nearby Otsego Lake (Otsego County, NY) have increased drastically since first recorded in the 1920s (~1 mg l^{-1} Cl^- to ~ 6 mg l^{-1} Cl^-) , likely due to increased winter salting of roads and septic system discharge (Harman et al. 1997). Though long-term data on chloride concentrations are not available, DeRuyter Reservoir and lakes across the region have likely undergone an increase similar to that observed in Otsego Lake. There is yet to be a consensus on direct effects of increased salt concentrations on ecosystems due to road salt, though effect on development of young organisms leading to long-term impairment into adulthood are likely (Findlay and Kelly 2011). Different organisms will also have varying tolerances to increased salt levels.

Surface conductivity ranged from 0.161 µS cm^{-1} (05 September 2016) to 0.194 µS cm^{-1} (12 July 2016), an average of 0.178 µS cm^{-1}. Bottom conductivity ranged from 0.163 µS cm^{-1} (09 November 2015; 04 October 2016) to 0.221 µS cm^{-1} (07 August 16), an average of 0.190 µS cm^{-1} (Figure 4-22). Measurements within these ranges have no known implications on water quality and are comparable with other NY lakes. Any observed increases in specific conductivity could be indicative of a large input of total dissolved solids. There was a significant increase in specific conductivity (µS cm^{-1}) from 2004 to 2015 compared to years prior ($p < 0.05$; Figure 4-23), but no statistical difference between the two regressions from 1988 to 2004 and 2004 to 2015 ($p < 0.5$).

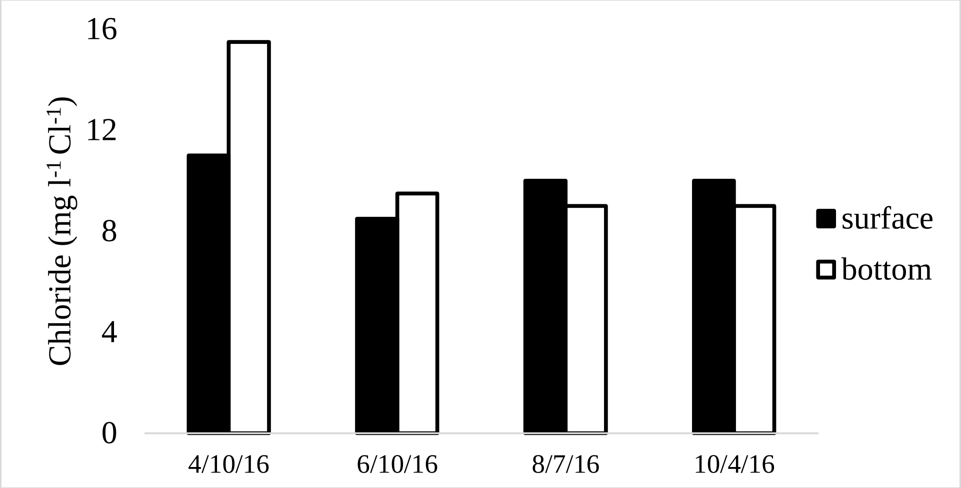


Figure 4-21. Chloride concentration (mg l^{-1}) on four sampling occasions in 2016 from surface (z = 0 m) and bottom (z ~ 16 m) waters.

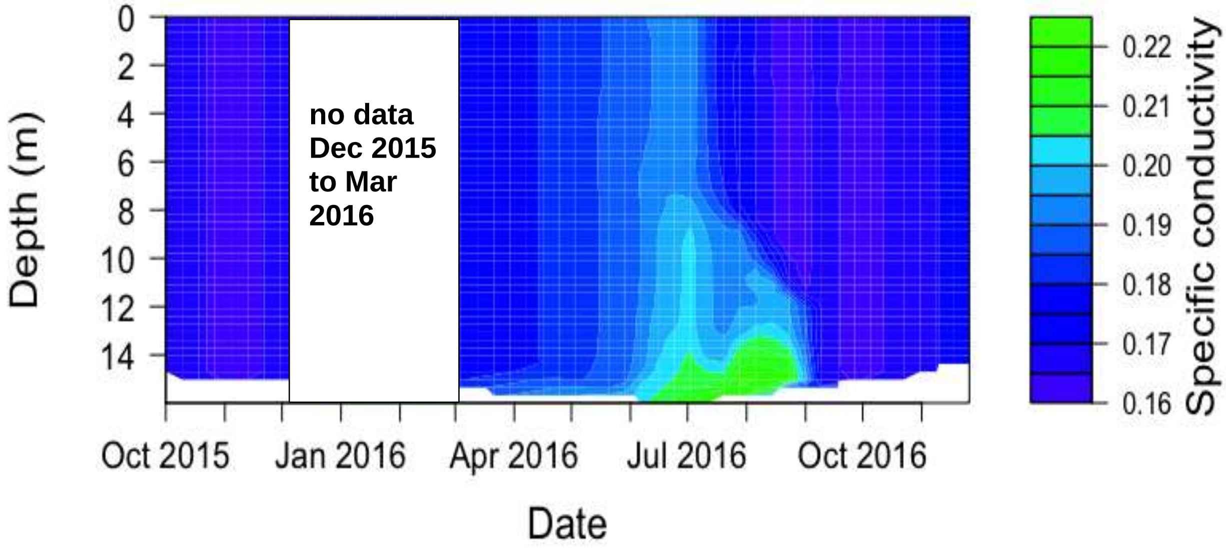


Figure 4-22. Specific conductivity (µS cm^{-1}) profile of the water column from October 2015 to December 2016. Measurements were not taken from December 2015 to March 2016; therefore, these months are likely not accurately depicted.

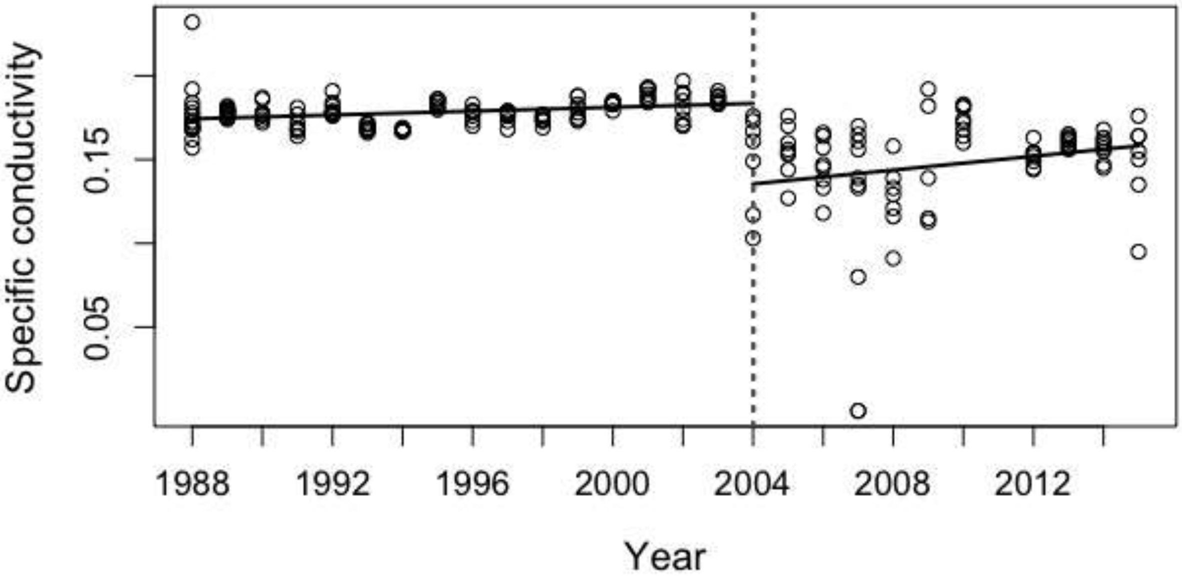


Figure 4-23. Piecewise regression (solid lines) of annual surface specific conductivity (µS cm^{--1}) in DeRuyter Reservoir from 1988 to 2015 in which the break-line is at 2004 (dashed line) and the line for x < 2004 is $e^y = 5.1E^{-4}x - 0.97$ and the line for x > 2004 is $e^y = 0.002x - 4.01$.

Changes in pH, Secchi depth, chl. *a* and specific conductivity trends were apparent beginning in 2004. It is likely that zebra mussels established their population in the lake around this time although they were not detected until two years later in 2006 (Adssitt pers. comm.). While no significant difference in pH between the two time periods was detected, there is a visually apparent difference in intercept. The finding of no significance is likely due to the variance of pH within each year. Both regressions show stable pH lines with slopes close near 0 ($-4.6E^{-4}$ and $-9.7E^{-5}$), but with two different intercepts, from around a pH of 8 initially to around a 7.5 pH. If a single standard linear regression were run from 1988 to 2015, one might assume that a significant, linear decrease occurred in pH towards acidic conditions. This could be misleading in terms of management decision-making. The piecewise model showed two stable states, more accurately depicting annual trends. A similar trend was noticed in specific conductivity, though now the parameter is understood to be increasing at a significant rate.

As zebra mussels require calcium to build their shells (Whittier et al. 2008), a possible contribution to the change in specific conductivity may be due to changes in ion concentration in the water column as their population size gradually increased over time. An increase in Secchi depth and a decrease in chl. *a* with *D. polymorpha* establishment were both expected, as an individual zebra mussel can filter up to ~ 1 liter of water each day feeding on phytoplankton (Fanslow et al. 1995). Lake stakeholders may initially be satisfied with the improved water clarity, but over time a shift towards potentially toxic cyanobacteria is expected due to selective preference against these species by zebra mussels (Vanderploeg et al. 2001, Knoll et al. 2008).

At this time, there are arguably no successful long-term management solutions to control or eradicate zebra mussels once established in a waterbody. Therefore, stakeholders must adapt to the regime change and manage water quality with adjusted reference conditions from the piecewise trends.

Chapter 5: Biota

a. Macrophytes

Introduction

DeRuyter Reservoir holds a moderately diverse community of aquatic plants and macroalgae. Over time the introductions of non-native invasive macrophyte species have impacted the diversity and size of the macrophyte community. Tioughnioga Lake Association meeting minutes from 1963 were the first documented instance of the lake having a “weed problem.” The species of concern then was likely *Myriophyllum spicatum* Linnaeus (Eurasian watermilfoil). *Myriophyllum spicatum* was first introduced to North America in the Chesapeake Bay area during the late nineteenth century, likely by ship ballast water or aquaria trade (Reed 1977) and has since caused major ecological and economic damage in waterbodies across the continent (Pfingsten et al. 2017).

Myriophyllum spicatum is generally better understood and documented than other invasive macrophyte species with more recent introductions into the region. The plant tends to grow most abundantly in waters $z = 1\text{–}3$ m, propagates by root crowns, and reproduces by vegetative fragments leading to rapid spread throughout a waterbody; the population is well established by April, prior to many native macrophytes and can tolerate a wide range of limnological conditions (Aiken et al. 1979). Documentation of *M. spicatum* in DeRuyter Reservoir has occurred since 2011 (Lord and Pokorny 2013).

Beginning in the summer of 2011, aquatic macrophytes in DeRuyter Reservoir have been surveyed annually in conjunction with insect herbivory on *M. spicatum*, and the results have been reported to the Madison County Planning Department. This study aimed to determine the applicability of using naturally occurring herbivorous insect populations as a biological control for the invasive macrophyte. Point Intercept Rake Toss Relative Abundance Method (PIRTRAM) was used at 20 sampling locations randomly selected along the z = 10 ft (~3 m) bathymetric contour (Lord and Pokorny 2013). The same sites were re-sampled each year from 2014 to 2016 (Lord et al. 2015, Lord and Reyes 2016, Lord 2017).

The results of the study above indicated stable biovolume-based total macrophyte abundance at each sampling site over the study period. Biovolume of *M. spicatum* increased each year from 2011 to 2014 (Figure 5-1). A slight decrease in abundance was observed in subsequent years, but there was little change between 2015 and 2016. Native plants with frequent occurrences included *Elodea* sp., *Ceretaphyllum demersum* (coontail), *Vallisneria Americana* (wild celery), and *Potamogeton zosterformis* (Lord and Pokorny 2013, Lord et al. 2015, Lord and Reyes 2016, Lord 2017). These macrophyte surveys provide insights into the inter-annual dynamics of the macrophyte community in DeRuyter Reservoir, albeit with some limitations stemming from their primary focus on *M. spicatum*. More recently, *Potamogeton crispus* Linnaeus (curly leaf pondweed) and abundant *Nitellopsis obtusa* (starry stonewort) were discovered in the lake.

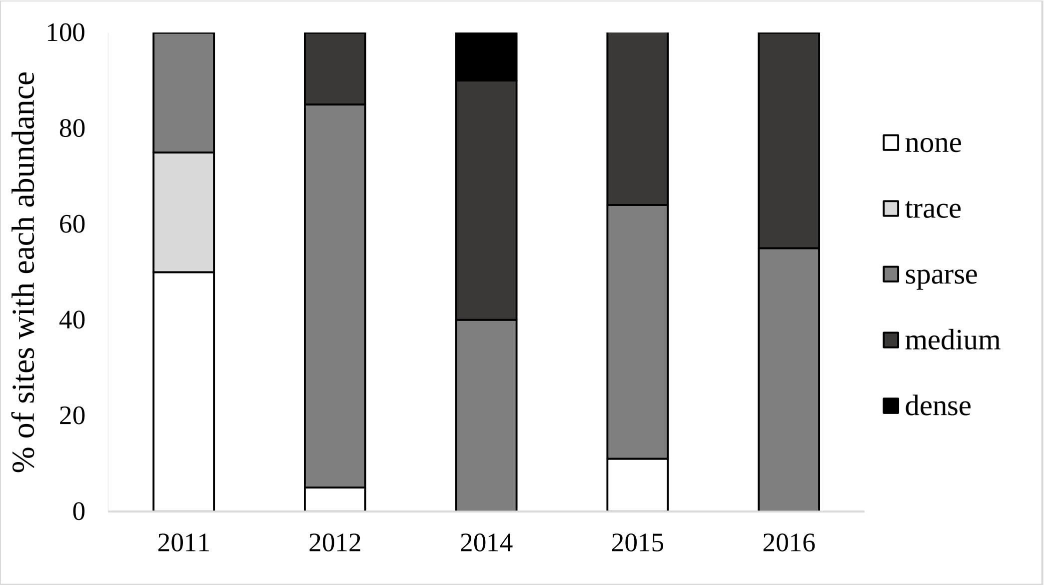


Figure 5-1. Annual biovolume-based abundance of *Myriophyllum spicatum* in DeRuyter Reservoir, NY as percentages based on an average of individual abundances at each of 20 sample sites. Abundance was based on an observed volume ranking (none, trace, sparse, medium, or dense) on rake tosses performed at each site. Data were combined from five studies over 6 years (Lord and Pokorny 2013, Lord et al. 2015, Lord and Reyes 2016, Lord 2017).

Native to Europe, Asia, Africa, and Australia, *P. crispus* has inhabited much of the world, also occupying large portions of North America and New Zealand. The plant was first identified in North America in the mid-1800s in Philadelphia and has since spread through the Great Lakes Region and now through much of the continent (Stuckey 1979). Catling and Dobson (1985) and Bolduan et al. (1994) provided thorough reviews of the growth patterns of *P. crispus*, a perennial herbaceous, submerged pondweed, in its native and introduced ranges. *Potamogeton crispus* is particularly successful in alkaline, nutrient rich, calcareous waters. In temperate regions, *P. crispus* overwinters, grows in early spring, typically one of the first macrophytes to appear, and senesces for the season by early July (Bolduan et al. 1994). The population in DeRuyter Reservoir follows similar short-lived growth patterns and has therefore not been well documented other than observations of a dense bed surfacing annually in June in the southeast corner of the lake by the main inlet. Early season die-offs of *P. crispus* monocultures are known to cause water column oxygen loss and subsequent algal blooms due to the large amount of decomposing plant material (Bolduan et al. 1994).

The most recent known macrophyte species introduced to DeRuyter Reservoir was *Nitellopsis obtusa* (N.A.Desvaux) J.Groves 1919 (Guiry 2016). This macroalga was first reported in North America in 1983 in the Lake St. Clair- Detroit River system (Schloesser et al. 1986) and is native to Europe and Asia, where it is even considered endangered in some parts of that range (jncc.defra.gov.uk). It has since been introduced to several lakes in central New York (Eichler 2010), including Lake Moraine and Cazenovia Lake, two popular recreational lakes in

Madison county. Thus, there exists a high likelihood that *N. obtusa* was brought in by boat or carried on waterfowl from a nearby waterbody and that physical and chemical properties of DeRuyter Reservoir allowed for the species to thrive.

Ecological and socioeconomic effects of *N. obtusa* introduction are still poorly characterized. It grows in shallow and deep waters, in shade and in full sun, and tends to colonize low traffic areas of lakes, but also thrives in areas of high boat traffic when other available space is limited (Pullman and Crawford 2010). Research in a region of Lake Ontario has shown a population of *N. obtusa* to do best under high conductivity, water hardness, and nitrate:nitrite ratios, and low exposure to wind and wave action (Midwood et al. 2016).

Nitellopsis obtusa was first documented in DeRuyter Reservoir in 2014 at 42° 48’ 3.6”, 75° 53’ 12.2” in a study determining the extent of the species throughout New York State waterbodies (Sleith et al. 2015). However, the full extent of the introduction in DeRuyter Reservoir was unknown until the 2016 growing season. The macroalga has the potential to reduce macrophyte species richness (Brainard and Schulz 2017), change sediment chemistry, reduce fish spawning habitat, and develop a synergistic mutualism with zebra mussels (Pullman and Crawford 2010). Additionally, *N. obtusa* can outcompete other regionally prevalent invasive macrophytes including *M. spicatum* and *P. crispus*.

Changes in the macrophyte community of a lake due to events such as non-native species introductions can affect the lake ecosystem due to subsequent reduction in native plant diversity (Madsen 1994, Brainard and Schulz 2017) and a decline in suitable fish habitat typically provided by native macrophytes (Radomski and Goeman 2001). For this study, additional macrophyte surveys were conducted to investigate community dynamics, particularly in relation to *M. spicatum*, and to specifically determine the abundance and growth patterns of the most recent invader *N. obtusa* to determine management implications of the introduction.

Methods

Macrophytes in DeRuyter Reservoir were initially surveyed in mid-July of 2016 to determine the extent of the littoral zone and the macrophyte community composition. A special rake (2 garden rakes welded together with line attached) was tossed around the lake following a zig-zag pattern. For each rake toss a depth (m) from a Speedtech® Depthmate portable sounder (Laylin Associates, Unionville, USA) and a GPS point with a Garmin GPSMAP® 60CSx (Garmin Ltd., Canton of Schaffhausen, CH) were recorded. On each rake toss where *M. spicatum* was present, the number of other macrophyte species present on the rake was counted, and individual species were recorded to discern whether *M. spicatum* grew as a monoculture in any region of the lake. Macrophytes were visually identified according to Crow and Hellquist (2006). The extent of the littoral zone was estimated based on rake toss locations where macrophytes were and were not present, in conjunction with bathymetry. Recorded GPS points were connected and surface area of the littoral zone was calculated in ArcGIS (Esri, Redlands, USA).

Upon discovery of *N. obtusa* during the initial survey, two identical surveys were conducted on 28 July and 12 September 2016 to discern *N. obtusa* location, density, and additional macrophytes also growing in selected locations. Forty sites were visited on the lake on both occasions using the zig-zag technique. For the July survey, rake tosses were executed beginning at the southwest corner of the lake and continued at points following a zig-zag pattern. Observations helped to determine the extent of *N. obtusa* at specific regions of the lake. For each rake toss a water column depth and GPS coordinates were recorded. If *N. obtusa* was not identified, no further data were collected; when identified, the overall biovolume of each species pulled up was given a 1-4 abundance ranking (1 = trace plants [0.0001-2.000 g m^2 dry weight], 2 = sparse plants [2.001-140.000 g m^2 dry weight], 3 = medium plants [140.001-230.000 g m^2 dry weight, and 4 = dense plants [230.001+]; Braun-Blanquet 1932, modified by Lord and Johnson 2006 per aquatic vegetation) and the same was determined for every other macrophyte species present at that location. The same experimental design was used during the September survey. The September survey was conducted to collect mature specimens for confirmation of the characteristic star-shaped rhizoids and to determine seasonal growth patterns *N. obtusa*. *Nitellopsis obtusa* data were mapped in ArcGIS to determine extent in the lake and patterns throughout the growing season. Data on *M. spicatum* growth as collected in July was also retrieved during the September survey.

Results

Approximately 1.28 km^2 (about 55 %) of the lake surface area were delineated as littoral zone (Figure 5-2). Macrophytes typically grew from the shoreline to about the z = 6 m bathymetric contour. Most species were submerged, as opposed to floating (Table 5-1). *Myriophyllum spicatum* was growing in locations throughout the littoral zone of the lake, but not as a monoculture. At almost every location surveyed both in July and September *M. spicatum* was growing along with at least one, and up to six, other species (Figure 5-3). Other notable macrophytes present on rake tosses included *Elodea canadensis* (Canadian waterweed), *C. demersum*, *V. americana*, and *N. obtusa*.

Figure 5-2. Estimated littoral zone of DeRuyter Reservoir based on surveys conducted during the 2016 growing season and bathymetric mapping.

Table 5-1. List of floating and submerged macrophytes in DeRuyter Reservoir from previous studies (Lord and Pokorny 2013, Lord et al. 2015, Lord and Reyes 2016) and confirmed during the 2016 survey. 'Rare' indicates presence on New York State's Rare Plant List (Young 2010). 'Invasive' indicates a species non-native to New York and known to cause ecologic or economic harm in the region. 'Prohibited' indicates presence on the New York State Prohibited and Regulated Invasive Plants list (NYSDEC 2014a). Reproductive strategies of each species were identified per Crow and Helquist (2006).

Species name	Common name(s)	Reproductive mode	Other notes
Chara vulgaris	Muskgrass; stonewort	Sexual or asexual, monoecious or dioecious	Submerged, free floating, macroalga
Nitella sp.	Stonewort	Sexual or asexual, monoecious or dioecious	Submerged, free floating, macroalga
Nitellopsis obtusa	Starry stonewort	Sexual or asexual, monoecious or dioecious	Submerged, free floating, macroalga, invasive
Cerataphyllum demersum	Coontail; hornwort	Perennial, monoecious	Submerged, free-floating, evergreen
Ranunculus trichophyllus	Water buttercup; water crowfoot	Perennial	Submerged
Myriophyllum spicatum	Eurasian watermilfoil	Perennial	Submerged, invasive, prohibited
Alisma gramineum	Water plantain	Perennial, rhizome, monoecious	Submerged, rare
Valisneria americana	Wild celery; eelgrass	Perennial, dioecious	Submerged
Elodea canadensis	Canadian waterweed	Perennial, monoecious or dioecious	Submerged
Naja flexilis	Slender naiad	Annual	Submerged, free floating
Stuckenia pectinata	Sago pondweed	Perennial, rhizome	Submerged
Potamogeton crispus	Curly leaf pondweed	Perennial	Submerged, invasive, prohibited
Potamogeton illinoensis	Illinois pondweed	Perennial	Submerged
Potamogeton natans	Floating leaf pondweed	Perennial	Floating
Potamogeton pusilus	Small pondweed	Perennial	Submerged
Potamogeton richardsonii	Richardson's pondweed	Perennial	Submerged
Potamogeton zosterformis	Flat leaf pondweed	Perennial	Submerged
Heteranthia dubia	Water stargrass	Perennial or annual	Submerged

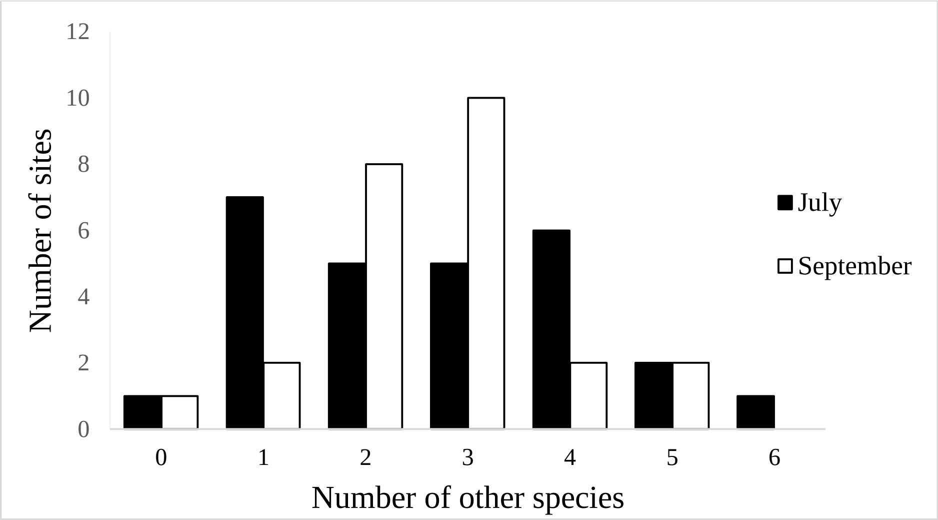


Figure 5-3. Number of macrophyte species in addition to *M. spicatum* at rake toss sites specifically where *M. spicatum* was present in July (n = 27) and September (n = 25) of 2016.

Nitellopsis obtusa was present throughout the lake, but was most abundant in the south end (Figure 5-4). Density rankings of 4 were consistently observed in July along the south end shoreline. *Nitellopsis obtusa* was not detected in areas shallower than approximately z = 4 m along the eastern shoreline, which was dominated by *M. spicatum* and natives such as *E. canadensis* and *C. demersum*. Rather, it was observed at z = 6 m throughout the rest of the lake as a monoculture, apart from occasional *C. demersum*. Thus, *N. obtusa* seems to be pioneering these deeper regions of the lake. Macrophytes collected on rakes along with *N. obtusa* included *E. canadensis* and *M. spicatum* most frequently and *V. Americana*, *C. demersum,* and *Chara vulgaris* less frequently.

In September *N. obtusa* growth appeared to have slowed since late July. However, the population continued to shift around the lake. While some areas where it was found initially had less or none in September, other areas with none present in July were infested in September. Similar macrophytes to the July survey were growing alongside *N. obtusa* (*E. canadensis, M. spicatum*, *C. demersum*, and *V. Americana).*

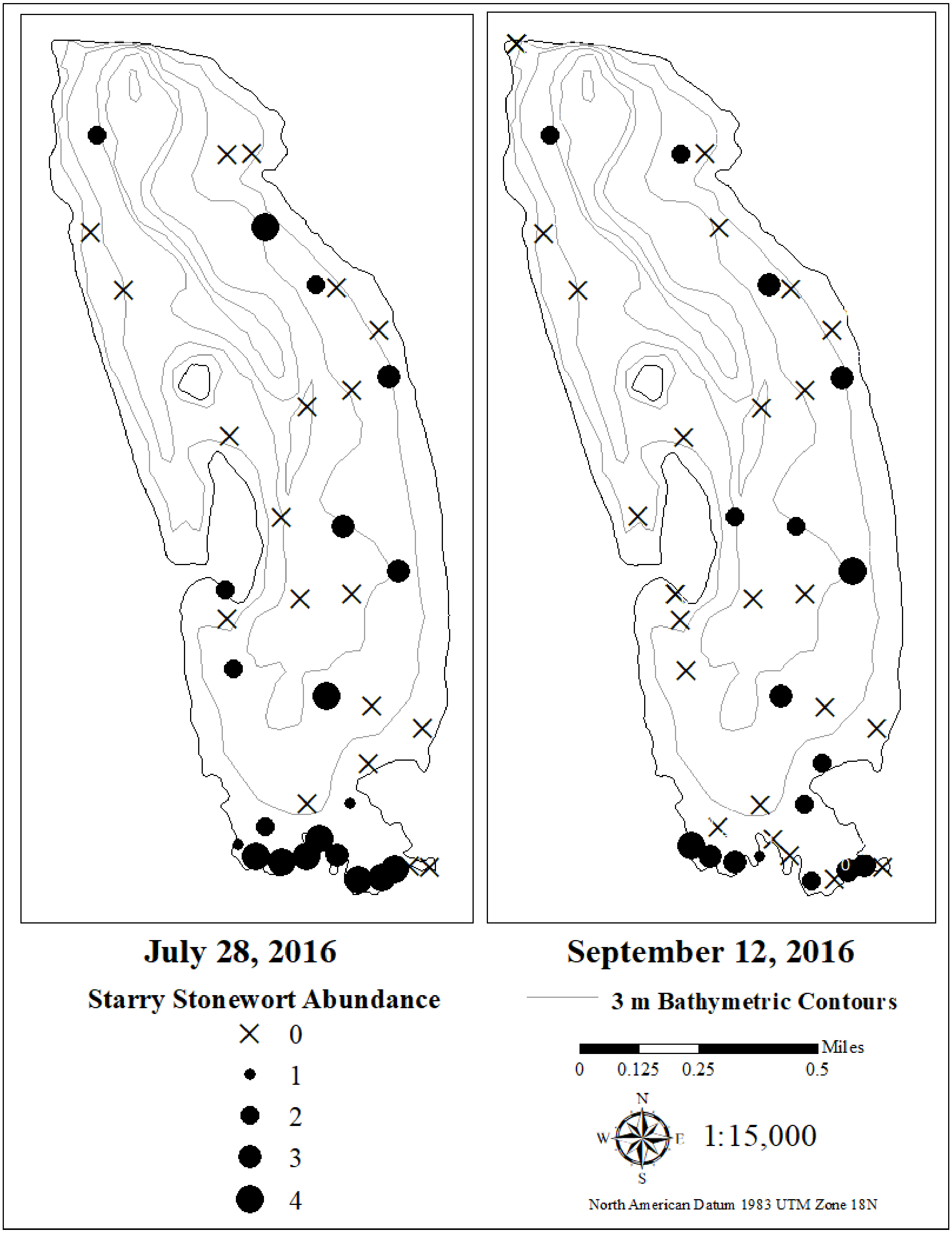


Figure 5-4. *N. obtusa* abundance at each location (circles) on July 28 and September 12, 2016. Abundance is ranked with no *N. obtusa* represented by a black X and present locations are marked with a black circle of increasing size.

Discussion

According to the NYS Conservation Department Biological Survey of the Susquehanna River basin conducted in 1934, DeRuyter Reservoir was historically dominated by large leaf pondweed (*Potamogeton ampifolius*) and floating leaf pondweed (*P. natans*). Also present at that time were blunt leaf pondweed (*P. obtusifolius*), waterweed (*Elodea*), large duckweed (*Spirodela polyrhiza*), mud plantain (*Alisma*), and waterlilies (NYS Conservation Dept. 1934). In recent years, waterlilies have not been documented in the lake. *Potamogeton natans* was found during the July 2016 survey in one location at the south end of the lake; it was not documented in any previous surveys in recent years (Lord and Pokorny 2013, Lord et al. 2015, Lord and Reyes 2016). *Potamogeton ampifolius* had also not been found in the lake in recent years, last recorded in the lake in 1990 (NYSDEC 2005). Annual mechanical harvesting beginning in the late 1980s could have contributed to the removal over time of *P. ampifolius*.

In 24 Minnesota lakes, Radomski and Goeman (2001) observed a reduction in vegetation and a change in macrophyte community structure due to shoreline development. Littoral zones adjacent to developed shorelines largely had submerged vegetation while undeveloped shorelines also had emergent and floating-leaf plants. Increased development around DeRuyter Reservoir may have contributed to the loss of floating leaved plants previously documented in high abundance.

Anthropogenic changes to the biological community including the introduction of non-native macrophytes species as well as animals such as zebra mussels (Zhu et al. 2006) and to the landscape such as an increasingly developed shoreline (Radomski and Goerman 2001) and mechanical harvesting also may have played a large part in changing the macrophyte community dynamics of DeRuyter's littoral zone.

Nitellopsis obtusa is considered a cryptic invader, as it typically grows in deeper water. As it was present in locations throughout the lake in 2016, *N. obtusa* was likely present in DeRuyter Reservoir for several years prior to initial detection in 2014 (Sleith et al. 2015). However, it is likely that the population size has not reached its carrying capacity. *Nitellopsis obtusa* was growing in deeper areas of the lake (up to $z = 7$ m) than typical macrophyte growth ($z \sim 1\text{-}5$ m), colonizing areas with little to no competition with other macrophytes, whereas *M. spicatum*, *C. demersum,* and *E. canadensis* dominated shallow areas. Forty miles east of DeRuyter Reservoir, in Lake Moraine the dominant macrophyte species has shifted from *M. spicatum* to *N. obtusa* since the discovery of *N. obtusa* in 2007 (German and Albright 2014). This trend may begin in DeRuyter Reservoir as *N. obtusa* could spread from deeper to shallower areas of the lake.

Nitellopsis obtusa poses a threat to DeRuyter Reservoir's biodiversity and food web dynamics. In a study of four other lakes in central NY, species richness of macrophytes decreased as *N. obtusa* biomass increased (Brainard and Schulz 2017). While its introduction tends to cause negative economic and ecological effects (Pfingsten et al. 2017), *M. spicatum* provides a better fish habitat than *N. obtusa* - anglers tend to not be hindered by *M. spicatum* growth (Aiken et al. 1979). Though *M. spicatum* was present throughout the littoral zone of DeRuyter Reservoir, it appeared to be integrated into the native macrophyte community without dominance. Compared to *M. spicatum,* areas with *N. obtusa* outcompeted native taxa causing lower species richness in macrophyte beds where present.

Calcium requirement for *N. obtusa* growth is poorly understood. DeRuyter reservoir has moderate calcium levels (~ 24 mg l^{-1} Ca^{2+} in 2016) which have declined in recent years, hypothesized to be in conjunction with *Dreissena polymorpha* growth in the lake (Chapter 4) as they require calcium to build their shells. While initial observations in Michigan lakes supported simultaneous growth of *N. obtusa* and *D. polymorpha* (Pullman and Crawford 2010), continued reduction in calcium over time may limit *N. obtusa* growth.

b. Phytoplankton

Introduction

While chlorophyll *a* concentration in a water sample is an essential limnological parameter used in quantifying phytoplankton concentration in a waterbody at the given time and depth (Chapter 4), taxonomic composition of the phytoplankton assists in making ecosystem level inferences as the presence of certain algal taxa may have important ecological and human health consequences. For instance, certain taxa of planktonic cyanobacteria have the potential, under proper conditions, to produce toxins that are then released into the water column. Knowing, at a minimum, presence of these taxa can help predict future trends and inform preventative management.

DeRuyter Reservoir CSLAP reports were used to understand broad trends in planktonic algal community composition in the 1990s and in recent years. As a supplement, observations of visible blooms throughout the lake were collected on sampling dates and in response to bloom reports by stakeholders.

Methods

An 250 mL open water sample (z = 1.5 m) was collected through CSLAP (Figure 4-1) on 04 July 1992 and analyzed by SUNY Environmental Science and Forestry (ESF) for present algal species (NYSDEC 2005). From 2013 to 2015 CSLAP volunteers collected bi-weekly 250 mL open water samples (z = 1.5 m) from June through September at basin 1 (Figure 4-1), and general algal community composition was categorized by SUNY ESF into major groups such as ‘blue-green algae’ (cyanobacteria; Phylum Cyanophyta), ‘green algae’ (Phylum Chlorophyta), diatoms (Phylum Bacillariophyta), and ‘other algae’ which could include any other phyla (NYSDEC 2015). The latter reports documented annual and seasonal variability in the algal community.

Additionally, during the sampling period (October 2015 to December 2016), when colonial or filamentous algal growth in the lake was visible to the naked eye, a water sample was collected and identified at least to genus.

Results

The 04 July 1992 sample contained *Gymnodium* sp. (dinoflagellate; Phylum Pyrrophyta), *Botryococcus braunii* (green algae; Phylum Chlorophyta), *Anabaena planctonica* (cyanobacteria; Phylum Cyanophyta), and *Ceratium hirundinella* (dinoflagellate; Phylum Pyrrophyta).

In 2013, green algae were most dominant throughout the sampling season. Cyanobacteria were present, but not dominant, on 21 July 2013 (~33 %) and 2 September 2013 (~20 %). In 2014, diatoms were the most frequently observed group throughout the season, with the exception of 'other algal' dominance on 03 August 2014 (100 %) and cyanobacterial dominance on 01 September 2014 (~75 %). In 2015 the phytoplankton community shifted from nearly 100 % diatoms in June and July to a combination of 'other algae' and cyanobacteria in August (60 % and 40 %, respectively) and September (50 % and 50 %, respectively). No green algae were identified all season.

During the 2016 macrophyte surveys, micro-algal growth was visible in conjunction with submerged macrophtyes. Throughout the littoral zone various macrophytes were covered in epiphytic *Gleotrichia* sp. (Phylum Cyanophyta) in September. Additionally, filamentous green algae (Phylum Chlorophyta), mostly comprised of *Spirogyra* sp., were growing around submerged macrophytes, most notably *Myriophyllum spicatum*, throughout summer months.

Planktonic cyanobacterial blooms on 19 September 2016 corresponded with a heightened surface chl. *a* concentration (24.4 μg l^{-1}; Chapter 4). Micro-algal species identified on this date were all colonial cyanobacteria including few colonies of *Microcystis* sp. and comparatively many colonies of *Dolichospermum sigmoideum* (Nygaard) Wacklin, L.Hoffmann & Komárek (Wacklin et al. 2009). On 30 October 2016, a monoculture of *D. sigmoideum* was identified in a surface sample collected in response to a stakeholder report of a visible bloom along the western shoreline of the lake.

Discussion

In waterbodies, epiphytic microalgae can act parasitically to macrophytes. Periphyton tend to do well in shallow, nutrient-rich areas of a lake, out-competing macrophytes through shading (Sand-Jensen and Borum 1991). While littoral periphyton, including epiphytic taxon, were prevalent in DeRuyter Reservoir throughout the 2016 growing season, no research has been conducted on how the symbiosis affects macrophyte growth in DeRuyter Reservoir. This may be of further interest as these occurrences were observed throughout the littoral zone. If macrophyte growth is inhibited by parasitic algal colonies, DeRuyter Reservoir could experience a shift to a more turbid, algal dominated system in which nutrients previously sequestered by macrophytes are more readily available to unwanted algae and cyanobacteria.

Cyanobacteria were abundant in early September in 2014 and 2015 CSLAP reports and in the 2016 season. Though CSLAP did not collect algal community data in October of prior years, 2016 reports suggested that cyanobacterial growth, notably *D. sigmoideum*, can continue into October, provided suitable growing conditions such as high temperature.

As with all species of the Order Nostocales, *D. sigmoideum* has structures that set them apart from algae and other taxa of cyanobacteria. In addition to standard vegetative cells, members of Nostocales form heterocysts, or nitrogen-fixing cells (Kumar et al. 2010). The development of these cells is controlled by environmental factors such as the availability of nitrogen and light (Spencer and King 1985). Heterocysts provide an anaerobic environment suitable for nitrogen fixation; once the process of nitrogen fixation completes, these cells undergo apoptosis rather than reproduction. This process gives *D. sigmoideum* a competitive advantage over other phytoplankters under nitrogen limitation. Nitrogen limitation due to an influx in P with the onset of fall mixing could be contributing to abundant *D. sigmoideum* in DeRuyter Reservoir.

Toxin production by cyanobacteria is reliant on both genetics and growth conditions (Carmichael 2001). Toxins can be used as a chemical defense mechanism in response to grazing by zooplankton (Jang et al. 2003). *Dolichospermum spp.* presence in freshwater systems have been associated with releases of neurotoxins, primarily anatoxin-a, toxic to humans and other animals upon ingestion, aspiration, dermal contact, or inhalation (Li et al. 2016). Basic morphological identification of the species cannot determine toxin production (Beltran and Neilan 2000), so further evaluation of *D. sigmoideum* blooms through DNA testing is used to determine presence or absence of toxic strains of the species.

One potential mechanism enhancing fall cyanobacterial blooms in DeRuyter Reservoir is nutrient release from sediment due to hypolimnetic anoxia. This late summer period of anoxia contributes to internal P loading in DeRuyter Reservoir (Chapter 4). This, followed by fall lake turnover, bringing hypolimnetic nutrients to the surface has likely caused increased chl. *a* and cyanobacterial blooms with toxin producing potential. These blooms may worsen as temperature increases, duration of hypolimnetic anoxia and growing season lengthen, and precipitation patterns are altered due to climate change (O'Neil et al. 2012). Practices in DeRuyter Reservoir to control plant growth, such as mechanical harvesting, may exacerbate this internal loading cycle by causing synchronous decomposition of large amounts of plant biomass throughout the lake from cut material. Additionally, analyses of nutrient samples collected during the summer of 2016 suggest an increase in water column TP following mechanical harvesting (Chapter 4).

c. Literature Review: Herbivorous Macroinvertebrates of *M. spicatum*

Introduction

A concern for the recreational impediment and biodiversity loss caused by *M. spicatum* has led to the need to control the plant's growth in DeRuyter Reservoir. Short-term mechanical harvesting has occurred on the lake since the 1980s to the dissatisfaction of stakeholders in search of a more long-term strategy. This has led to the implementation of research-based management focused on the utility of herbivorous macroinvertebrates already with populations present in the lake as a control method (as opposed to supplemental stocking). *Myriophyllum spicatum* growth is controlled by predation from at least 25 insects in its native range (Spencer and Lekić 1974). Part of the success of an invasive species is often attributed to the lack of predators in their introduced regions, which forms the basis of hypotheses including the evolution of increased competitive ability (Blossey and Notzold 1995) and the enemy release hypothesis wherein introduced species have no natural enemies in the subjected ecosystem giving them a competitive advantage (Williamson 1996).

In the late 20th century research began on herbivorous insects adapted to the invasion of *M. spicatum* in North America and their potential for augmentative biological control. They included *Cricotopus myriophylli* Oliver (Kangasniemi et al. 1993, MacRae et al. 1990), *Euhrychiopsis lecontei* Dietz (Sheldon and Creed 1995), and *Acentria ephemerella* Denis and Schiffermüller (= *Acentria nivea* Olivier; Johnson et al. 1997). Madison county has been a focal region for research on the implementation of herbivorous macroinvertebrates as a control of *M. spicatum* primarily through the SUNY Oneonta Biological Field Station (Harman and Albright 2001). DeRuyter Reservoir has been the subject of a biological control study since 2011. All three insects above as well as an unspecified species of long-horned caddisfly (Family Leptoceridae) have since been identified on *M. spicatum* specimens from the lake (Lord and Pokorny 2013, Lord et al. 2015, Lord and Reyes 2016, Lord 2017).

***Euhrychiopsis lecontei* Dietz**

Eurhrychiopsis lecontei (Coleoptera: Curculionidae), the milfoil weevil, is native to the northern tier of the US and British Columbia. The weevil has shifted hosts from *Myriophyllum sibiricum* (northern watermilfoil) to *M. spicatum* where the latter has been introduced (Sheldon and Creed 1995). Various studies have shown negative impacts of *E. lecontei* on *M. spicatum* (Creed et al. 1992, Sheldon and Creed 1995) and a decline in the *M. spicatum* population in systems with *E. lecontei* present (Creed 1998). Through feeding, *E. lecontei* damages *M. spicatum* meristems, thereby halting stem growth (Sheldon and Creed 1995). It tends to be most abundant in large, shallow areas of water and host plant beds along relatively natural shorelines (Jester et al. 2000). The weevil overwinters in wet soils along shorelines. A speculated negative effect of sunfish predation on weevil abundance has been studied by various groups; however, no consensus has been reached on the presence of this interaction (Sutter and Newman 1997, Cornwell 2000, Ward and Newman 2006, Maxson 2016). *Euhrychiopsis lecontei* has been identified each studied year in DeRuyter Reservoir, but at low population densities (1 adult, 3 larvae, and 13 eggs in 2016; Lord and Pokorny 2013, Lord et al. 2015, Lord and Reyes 2016, Lord 2017).

***Cricotopus myriophylli* Oliver**

The definitive native range of *Cricotopus myriophylli* (Diptera: Chironomidae), the milfoil midge, remains unknown, but an observed strong preference for *M. spicatum* over native macrophytes suggests the midge was introduced to North America (MacRae et al. 1990). *Cricotopus myriohypllli* feeds on the apical meristem of *M. spicatum*, which prevents the plant from reproducing (Kangasniemi et al. 1993). Successful control of *M. spicatum* likely due to a large *C. myriophylli* population was documented in the Okanagan Valley lakes system of British Columbia (MacRae et al. 1990). *Cricotopus myriophylli* does not appear to undergo true diapause (MacRae and Ring 1993) and has been observed surviving several weeks under ice cover. As *M. spicatum* and *C. myriophylli* are both cold tolerant, *C. myriophylli* is a good candidate as a biological control agent. Densities of approximately 500 larvae m^{-2} prevented *M. spicatum* from surfacing (Kangasniemi et al. 1993). *Cricotopus myriophylli* was present in

DeRuyter Reservoir, at times in high densities (1,244 individuals identified in total throughout the 2016 study), but most observed *M. spicatum* stems had no apparent damage (Lord and Pokorny 2013, Lord et al. 2015, Lord and Reyes 2016, Lord 2017).

Acentria ephemerella **Denis and Schiffermüller**

Acentria ephemerella (Lepidoptera: Crambidae), the aquatic macrophyte moth, is best documented in its native range of Europe and Asia. The moth was first recorded in North America in 1927 in Montreal, Quebec (Sheppard 1945). It was recognized as a generalist feeder and in a laboratory was observed feeding on *M. spicatum*, *Ceratophyllum demersum*, *Elodea canadensis,* and *Hydrilla verticillata* specimens from New York (Batra 1977). However, *A. ephemerella* was observed to not feed on certain macrophytes when available such as *Chara vulgaris*, *Nitella* sp., *Heteranthia dubia*, and *Ranunculus tricophyllis* (Johnson et al. 1997), all of which are present in DeRuyter Reservoir. Gross et al. (2001) documented that *A. ephemerella* preferentially fed on *M. spicatum* over native *E. canadensis*, and Johnson et al. (1997) reported a decline in *M. spicatum* biomass and a subsequent increase in native macrophyte biomass after the introduction of the moth in nearby Cayuga Lake, NY. These studies found destructive apical stem damage on *M. spicatum* due to *A. ephemerella* feeding, but no equivalent damage on native macrophytes on which the moths were also feeding on.

The eggs, caterpillars, and most adult female *A. ephemerella* are strictly aquatic, some females develop rudimentary wings, and some even develop the ability to fly, and mature adults are nocturnally active and only live for about 24 hours (Batra 1977). Dispersal across drainage basins has occurred most frequently by overland transport of *M. spicatum* stems with individuals of *A. ephemerella* attached, assisted also by direct movement of the occasional winged-female (Scholtens and Balogh 1996). *Acentria ephemerella* overwinters on macrophytes, typically burrowing in stems of *M. spicatum* (Batra 1977). Of 5 studied central New York lakes, there was a positive correlation observed between the moth abundance and both lake surface area and mean depth (Johnson et al. 2000). Compared to the lakes studied, DeRuyter Reservoir can be categorized as a larger lake, suggesting potential for a successful *A. ephemerella* population. Despite being a non-native, *A. ephemerella* has not been reported to reach nuisance levels in a North American waterbody.

In DeRuyter Reservoir, a single moth larva was identified on the tip of an *M. spicatum* stem in the summer of 2015 (Lord and Reyes 2016) and a single larva was found in the summer of 2016 (Lord 2017). A population of *A. ephemerella* in the lake could successfully establish due to the patchy distribution of *M. spicatum*. If a decline in *M. spicatum* density in the lake was to occur, alternative feeding options including native macrophytes *C. demersum* and *E. canadensis* are present in the lake. The generalist behavior of *A. ephemerella* would not result in an herbivore-host plant relationship commonly experienced with the weevil wherein the herbivore population has a subsequent sharp decline following plant decline.

Family Leptoceridae

In addition to the three known *M.spicatum* herbivores, a long-horned caddisfly (Tricoptera: Leptoceridae) has also been reported on *M. spicatum* in DeRuyter Reservoir but does not appear cause significant damage to the plant (Lord and Pokorny 2013, Lord et al. 2015, Lord and Reyes 2016, Lord 2017). Native throughout North America, members of Leptoceridae are known to consume native and introduced watermilfoils and use their material to build cases (Wiggins 1977). The tardy caddisfly (*Trianodes tardus*), for example, was associated with declines in population density of *M. spicatum* in British Columbia (Kangasniemi 1983). Parsons et al. (2011) observed an average of 0.07 *T. tardus* individuals per *M. spicatum* stem in Washington state lakes and concluded that the population density of the former was not high enough to effectively control the plant population. Although the caddisflies in DeRuyter do not appear to cause herbivory damage to *M. spicatum*, they may be contributing to long-term stress on the host plant.

Discussion

In recent years, 4 insects with the potential to act as a *M. spicatum* biological control agent were identified on *M. spicatum* stems in DeRuyter Reservoir (*E. lecontei*, *C. myriophylli*, *A. ephemerella*, and an unspecified long-horned caddisfly). As of 2016, no one species appears to dominate over the other three or cause significant control to the population of *M. spicatum* in the lake. Research in central NY and in other regions in North America affected by invasive *M. spicatum* can be used to better understand the potential of each of the four insects on *M. spicatum* in DeRuyter Reservoir.

Euhrychiopsis lecontei and *A. ephemerella* are herbivores requiring the same resource- the apical meristem of *M. spicatum*. Johnson et al. (1997) surveyed *E. lecontei* and *A. ephemerella* densities in 35 lakes across the finger lakes region. While both *A. ephemerella* and *E. lecontei* were present in most lakes, codominance was rare (i.e., each lake would typically have a large population of *A. ephemerella* or a large population of *E. lecontei*, not a large population of both simultaneously). Interspecific competition between *A. ephemerella* and *E. lecontei* occurred in lakes with both species present, with a negative correlation between the densities of the two species (Johnson et al. 2000). Due to competitive exclusion (Hardin 1960), the ability for a single insect population to grow large enough to control *M. spicatum* may be hindered. Competition may be contributing to small insect populations in DeRuyter Reservoir.

Morphology of DeRuyter (relatively large and deep), *M. spicatum* distribution (patchy), and annual drawdowns of the lake are likely to be more favorable conditions for *A. ephemerella* than *E. lecontei*. A negative correlation previously was found between *E. lecontei* abundance and lake surface area and mean depth among 5 central New York lakes in which *E. lecontei* was most successful in small ponds with *M. spicatum* growing as a dense monoculture where individuals can move between plants with ease (Johnson et al. 2000). *Myriophyllum spicatum* in DeRuyter Reservoir, however is patchy. The *M. spicatum* patchiness and large surface area of DeRuyter Reservoir (2.25 km^2) are more conducive to a large population of *A. ephemerella* which can fly between small beds (Johnson et al. 2000). Additionally, as they overwinter on shore, *E. lecontei* tend to be more successful in areas with natural shoreline as opposed to developed shoreline (Jester et al. 2000). Annual fall drawdowns in DeRuyter Reservoir likely stress overwintering *E. lecontei* as individuals retreat to recently exposed shore that will refill before it comes time for them to emerge next season. *Acentria ephemerella,* however, overwinter on submerged macrophytes and are not impacted by this activity.

The distance an *A. ephemerella* adult can travel is not documented, but there is high likelihood of travel between nearby drainage basins by movement of plant stems and occasionally by winged females. Of the nine lakes evaluated in Madison County for the presence of three insects, six lakes (Bradley Brook, Hatch Lake, Lebanon Reservoir, Upper and Lower Leland Ponds, and Tuscarora Lake) had populations of *A. ephemerella* identified (Harman and Albright 2001). The distance from these waterbodies to DeRuyter ranges from approximately 11 km (6.8 mi; Tuscarora Lake) to 26 km (16.2 mi; Leland Ponds). Therefore, *Acentria ephemerella* has the potential for multiple re-introductions into DeRuyter Reservoir which could lead to a higher population density and increased control of *M. spicatum*.

To wholly evaluate the viability of herbivorous macroinvertebrates as a bio-manipulation strategy, an understanding of primary consumers and top predators in DeRuyter Reservoir is necessary. Lord (2003) compared Lebanon Reservoir and Otsego Lake (Otsego County, NY) to develop a hypothesis of food web dynamics and *M. spicatum* control. Otsego Lake, with a diverse fish community, had herbivores consistently present and limited *M. spicatum* growth, whereas Lebanon reservoir, with few fish species, predominantly bluegill (*Lepomis macrochirus*), herbivore damage to *M. spicatum* was rare, and *M. spicatum* was abundant.

Though four herbivorous insects have been identified on *M. spicatum* in DeRuyter Reservoir, none aren't currently at densities sufficient to control *M. spicatum* currently. Certain characteristics of DeRuyter Reservoir (morphology, *M. spicatum* distribution, and annual lake management activities) suggest potential for success of *A. ephemerella* as the primary biological control agent over *E. lecontei*, *C. myriophylli*, and a long-horned caddisfly.

d. Fish

Introduction

The fish community in DeRuyter Reservoir has a long history of intensive management and fish stocking (Appendix A). The NYSDEC has supplemented the naturally occurring fishery since 1931 when 3,600 fingerling brown trout (*Salma trutta*) were first stocked in the lake. In 1935 stocked fish included 50 adult black crappie (*Pomoxis nigromaculatus*), 2,000 smallmouth bass (*Micropterus dolomieu*) fry, 625,000 walleye (*Sander vitreus*) fry, and 2,500 yellow perch (*Perca flavescens*) fingerlings. From 1936 to 1953 walleye and smallmouth bass fry were stocked annually with few exceptions; typical annual stocking sizes were 250,000 to 1,050,000 individuals for walleye and 188 to 6,000 individuals for smallmouth bass. The NYSDEC stocked walleye fry annually from 107 to 3,000,000 individuals from 1954 to 2013. From 2014 to 2016, and with plans of continuing through 2019, walleye fingerlings have been stocked as part of a biological control project to reduce *Myriophyllum spicatum* growth by reducing predation on *M. spicatum* predators by sunfishes (Lord et al. 2015, Lord and Reyes 2016, Lord 2017).

Both open-water and ice fishing in DeRuyter Reservoir are popular with recreational anglers. Largemouth bass, *Micropterus salmoides*, have historically been the most popular fish for recreational and tournament angling in the lake. Anglers have expressed concerns about increased frequency of catching smaller largemouth bass in recent years. Walleye is also a popular fish among the anglers, although they are often dissatisfied with small individual fish sizes and low population density. Tioughnioga Lake Association meeting minutes from 1984 stated that “walleye still seem to be small – only 16 in seen,” suggesting historical dissatisfaction with the walleye population in DeRuyter Reservoir.

Over the past two decades, a number of fisheries surveys have been conducted in DeRuyter Reservoir by NYSDEC and SUNY Cobleskill with various objectives (Table 5-2). In general, NYSDEC surveys took place in fall months (September-October), whereas SUNY Cobleskill surveys took place in summer months (June-July). These data were evaluated to better understand the general fish community composition in the lake and to gain further insight into species of recreational and research concern, specifically largemouth bass, walleye, and sunfishes (bluegill [*Lepomis macrochirus*] and pumpkinseed [*Lepomis gibbosus*]).

Table 5-2. Fisheries surveys on DeRuyter Reservoir from 1996 to 2016 by either NYSDEC (NYSDEC 1996, NYSDEC 2012, NYSDEC 2013, NYSDEC 2015b) or a collaborative effort with SUNY Cobleskill and SUNY Oneonta (Lord, unpublished data).

Date	Agency	Gear	Target/Purpose
10/30/1996	NYSDEC	Electrofishing, 12 sites	All fish
7/8/2008	SUNY Cobleskill, SUNY Oneonta	Electrofishing, 5 sites	All fish, sunfish Abundance
6/30/2011	SUNY Cobleskill, SUNY Oneonta	Electrofishing, 5 sites	All fish, sunfish abundance
6/27/2012	SUNY Cobleskill, SUNY Oneonta	Electrofishing, 5 sites	All fish, sunfish abundance
10/24/2012	NYSDEC	Electrofishing, 4 sites	Walleye
9/26/2013	NYSDEC	Electrofishing, 4 sites	Walleye, bulk fish data
6/26/2014	SUNY Cobleskill, SUNY Oneonta	Electrofishing, 5 sites	All fish, sunfish abundance
6/24/2015	SUNY Cobleskill, SUNY Oneonta	Electrofishing, 5 sites	All fish, sunfish abundance
10/22/2015	NYSDEC	Electrofishing, 4 sites	Walleye
7/11/16	SUNY Cobleskill, SUNY Oneonta	Electrofishing, 5 sites	All fish, sunfish abundance

Methods

Data collected on fish of interest for research and management purposes and also fish of interest for recreational angling were analyzed to discern population size structures and how they had changed in recent years. Largemouth bass were selected for further analyses as the species is understood as the popular fish for recreational angling. Walleye, bluegill, and pumpkinseed were also selected as these species are of concern for whole ecosystem research and management of the lake. These fishes are of casual recreational angling interest as well.

Length categories proposed by Gabelhouse (1984) were used to understand the population distribution based on size of individual fish (Table 5-3). Proportional size distribution (PSD; Guy et al. 2007) was calculated with all fish measured for every surveyed year using quality and stock lengths for each species and the following equation:

$$\text{PSD} = \frac{\text{\# of fish} \geq \text{quality length}}{\text{\# of fish} \geq \text{stock length}} \cdot 100$$

A high or low PSD in a given year or wide variation over time suggests a fish population with functional problems (Anderson and Neumann 1996). Acceptable PSDs for bluegill and pumpkinseed fall within 20 to 60, for walleye from 30 to 60, and for largemouth bass from 40 to 70 (Willis et al. 1993).

Table 5-3. Length (mm) categories for largemouth bass, walleye, bluegill, and pumpkinseed proposed by Gabelhouse (1984).

Species	Stock	Quality	Preferred	Memorable	Trophy
Largemouth bass	200	300	380	510	630
Walleye	250	380	510	630	760
Bluegill	80	150	200	250	300
Pumpkinseed	80	150	200	250	300

Length frequency histograms were created to understand population size structures. Largemouth bass distributions were analyzed for surveys in 1996, 2008, 2011, and 2016; walleye in 1996, 2013, and 2015 due to lack of sufficient data in other years; pumpkinseed in 1996, 2008, 2011, and 2016; and bluegill in 2008, 2011, and 2016.

Results

The 2016 survey included a total of 959 individual fish. The three taxa most frequently caught were pumpkinseed (303), yellow perch (244), and bluegill (182; Figure 5-5). While species composition varied, species richness had remained unchanged over the past two decades, with 15 species documented in both 1996 (black crappie and margined madtom [*Noturus insignis*] were present while yellow bullhead (*Ameiurus natalis*) and bluegill were not detected) and in 2016 (Table 5-4). These data suggested that DeRuyter Reservoir supported both cool- and warm-water fisheries (about 17-24 ° C and 25-31 °C, respectively). Although non-native common carp (*Cyprinus carpio*) was identified in 2008, it was not detected in any subsequent survey.

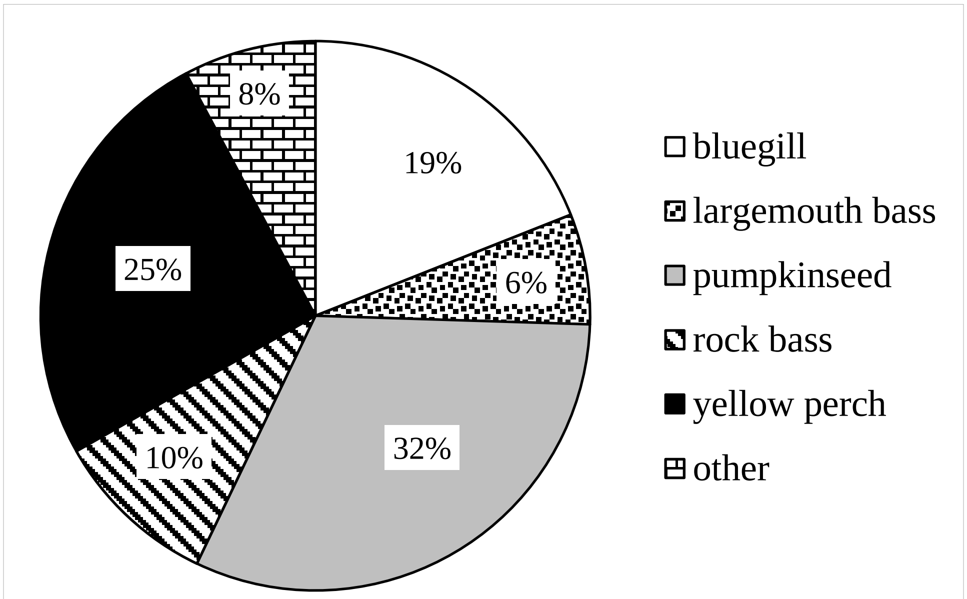


Figure 5-5. Relative abundance (%) of each fish species caught in 2016 electrofishing survey of DeRuyter Reservoir (Lord, unpublished data). Fish species with 2 % or less abundance fell under the category 'other'. These species included brown bullhead (*Ameiurus nebulosus*), banded killifish (*Fundulus diaphanous*), bluntnose minnow (*Pimephales notatus*), chain pickerel (*Esox niger*), golden shiner (*Notemigonus crysoleucas*), small mouth bass, spottail shiner (*Notropis hudsonius*), tessellated darter (*Etheostoma olmstedi*), walleye, and yellow bullhead.

Table 5-4. Fish species recorded in DeRuyter Reservoir during surveys by SUNY Cobleskill in 2008, 2011, 2012, 2014, 2015, and 2016 (Lord, unpublished data).

Species name	Common name	Family	Temperature Tolerance	Years Found
Cyprinus carpio	Common carp	Cyprinidae	Warmwater	2008
Notemigonus crysoleucas	Golden shiner	Cyprinidae	Warmwater	2008, 2011-2016
Notropis atherinoides	Emerald shiner	Cyprinidae	Warmwater	2008, 2012
Notropis hudsonius	Spottail shiner	Cyprinidae	Warmwater	2008, 2011-2014, 2016
Pimephales notatus	Bluntnose minnow	Cyprinidae	Warmwater	2008, 2011-2016
Umbra limi	Central mudminnow	Umbridae	Warmwater	2014
Ameiurus natalis	Yellow bullhead	Ictaluridae	Warmwater	2016
Ameiurus nebulosus	Brown bullhead	Ictaluridae	Warmwater	2008, 2011-2016
Esox niger	Chain pickerel	Esocidae	Warmwater	2011-2016
Fundulus diaphanous	Banded killifish	Fundulidae	Warmwater	2008, 2011 - 2016
Ambloplites rupestris	Rock bass	Centrarchidae	Coolwater	2008, 2011-2016
Catostomus commersonii	White sucker	Centrarchidae	Coolwater	2011-2015
Lepomis gibbosus	Pumpkinseed	Centrarchidae	Warmwater	2008, 2011-2016
Lepomis macrochirus	Bluegill	Centrarchidae	Warmwater	2008, 2011-2016
Micropterus dolomieu	Smallmouth bass	Centrarchidae	Warmwater	2008, 2011-2016
Micropterus salmoides	Largemouth bass	Centrarchidae	Warmwater	2008, 2011-2016
Pomoxis nigromaculatus	Black crappie	Centrarchidae	Warmwater	2014-2015
Etheostoma olmstedi	Tessellated darter	Percidae	Coolwater	2008, 2011-2016
Perca flavescens	Yellow perch	Percidae	Coolwater	2008, 2011-2016
Sander vitreus	Walleye	Percidae	Coolwater	2008, 2011-2016

Largemouth bass PSDs for each surveyed year prior to 2016 (PSD of 48) were high, characteristic of a fishery comprised of mostly larger fish (Figure 5-6a). Years 2013 to 2016 suggested an annual decrease in PSD (Fig 5-6a). Size distribution in 1996, 2008, and 2011 implied a bimodal distribution of largemouth bass with one mode between 100 and 130 mm and the second between 350 and 380 mm, whereas most fish measured in 2016 were smaller than stock length (200 mm; Figure 5-7). While no fish were measured at trophy lengths, individuals of preferred length were surveyed in 1996, 2011, and 2016.

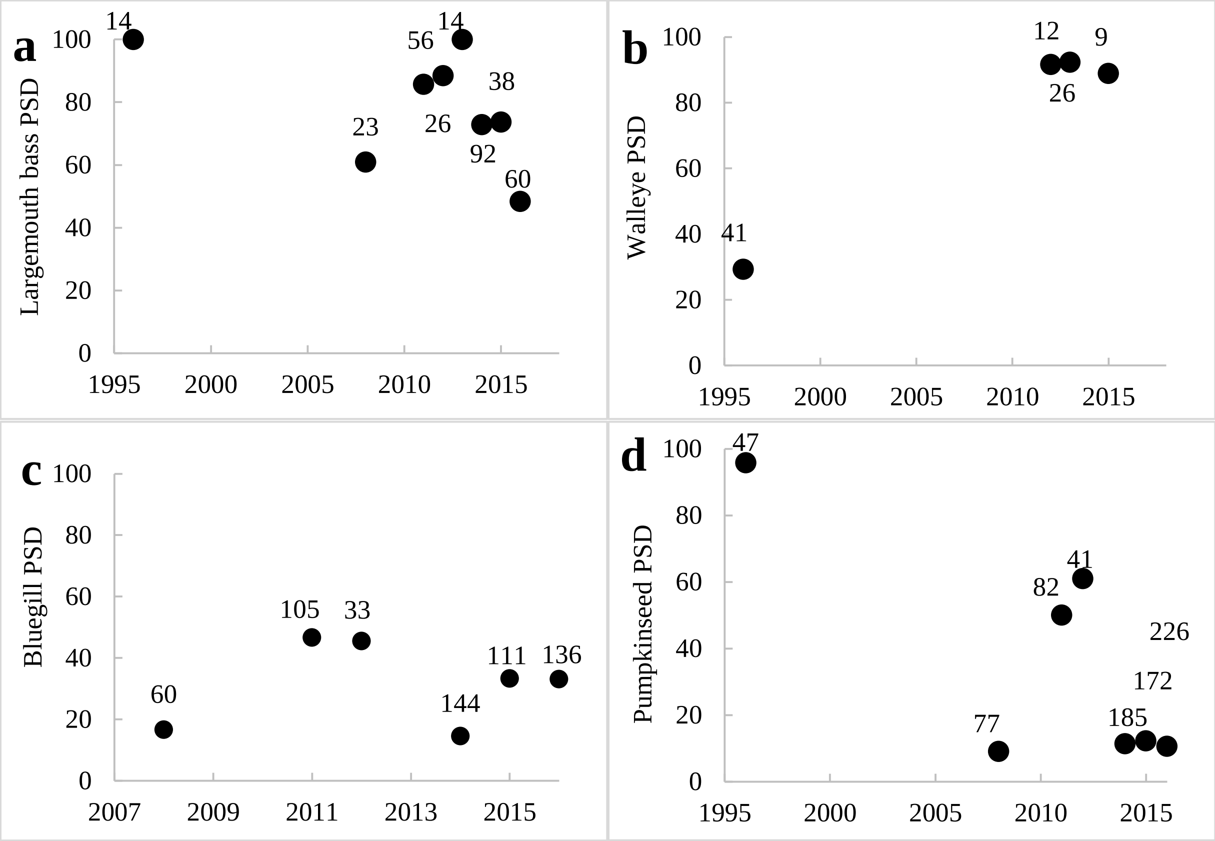


Figure 5-6. PSD by the survey year in DeRuyter Reservoir for (a) largemouth bass, (b) walleye, (c) bluegill, and (d) pumpkinseed (NYSDEC 1996; NYSDEC 2012; NYSDEC 2013; NYSDEC 2015b; Lord, unpublished data). Numbers associated with each point are the stock sample size (n) for that year. Walleye PSD was not calculated in 2008, 2011, 2014, and 2016 due to small sample sizes. No bluegill were caught in 2008.

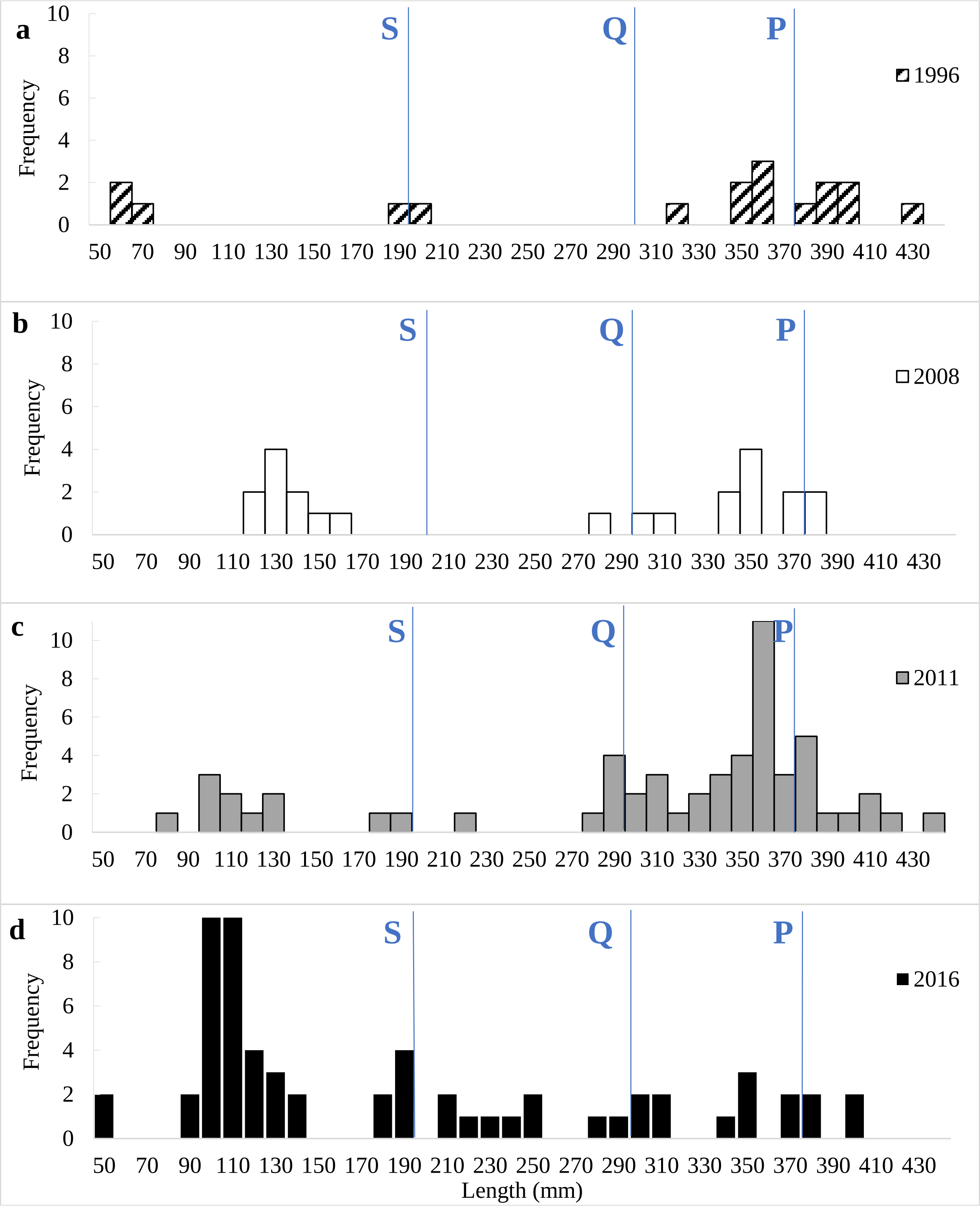


Figure 5-7. Length frequency histogram of largemouth bass in DeRuyter Reservoir based on data collected in (a) 1996 where n = 17, (b) 2008 where n = 23, (c) 2011 where n = 57, and (d) 2016 where n = 62. (NYSDEC 1996; Lord, SUNY Oneonta, unpublished data) S, Q, and P and their adjacent blue lines represent stock, quality, and preferred lengths for largemouth bass (Gabelhouse 1984). No fish were within the range of memorable or trophy lengths.

In the past 6 years, few walleye were caught in the surveys. In 1996, walleye PSD was 29 whereas PSD from 2011-2016 ranged from 89 to 100, but sample sizes (n = 9-26) in the later years were all too small to reliably estimate PSD (Figure 5-6b). These data indicated that walleye in the lake were surviving and growing but not reproducing. Only one, stock size walleye was recorded in 2008, therefore a PSD of 0 was calculated for this year; this was unlikely to be representative of the actual population at the time. In 1996, the lengths were widely distributed from 180 to over 630 mm, spanning from below stock to memorable lengths (Figure 5-8). In 2013 and 2015, few fish were below quality length. No trophy length fish were caught in any survey.

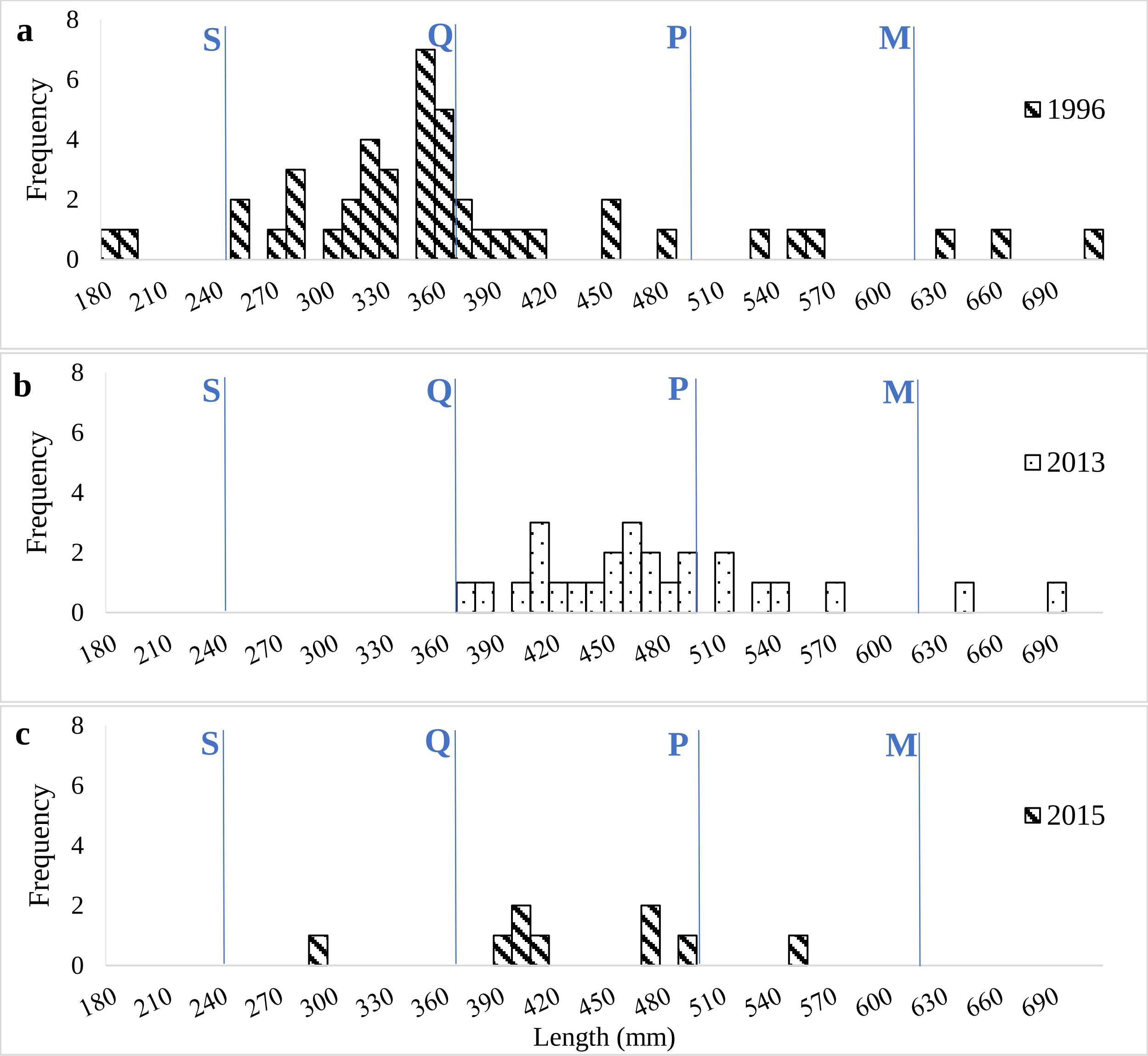


Figure 5-8. Length frequency histogram of walleye in DeRuyter Reservoir based on data collected by NYSDEC in (a) 1996 where n = 45, (b) 2013 where n = 26, and (c) 2015 where n = 9. S, Q, P, and M and their adjacent blue lines represent stock, quality, preferred, and memorable lengths for a walleye fishery (Gabelhouse 1984). No fish were longer than trophy length.

Bluegill PSD in each year surveyed ranged widely from 14 (2014) to 46 (2011); 33 in 2016 (Figure 5-6c). Pumpkinseed PSD was high in 1996 (96) and similar ranges as bluegill in recent years ranging from 9 (2008) to 6 (2012); 11 in 2016 (Figure 5-6d). The 1996 NYSDEC survey likely did not include smaller individuals, skewing the PSD calculation for that year. In 2008 bluegill lengths ranged from 50 to 180 mm and expanded in 2011 and 2016 to a range of 40 to over 210 mm with a handful of preferred length fish (Figure 5-9). Although large amounts of both sunfish species were identified in 2016 relative to other fishes in the lake, most were stock length (Figure 5-10).

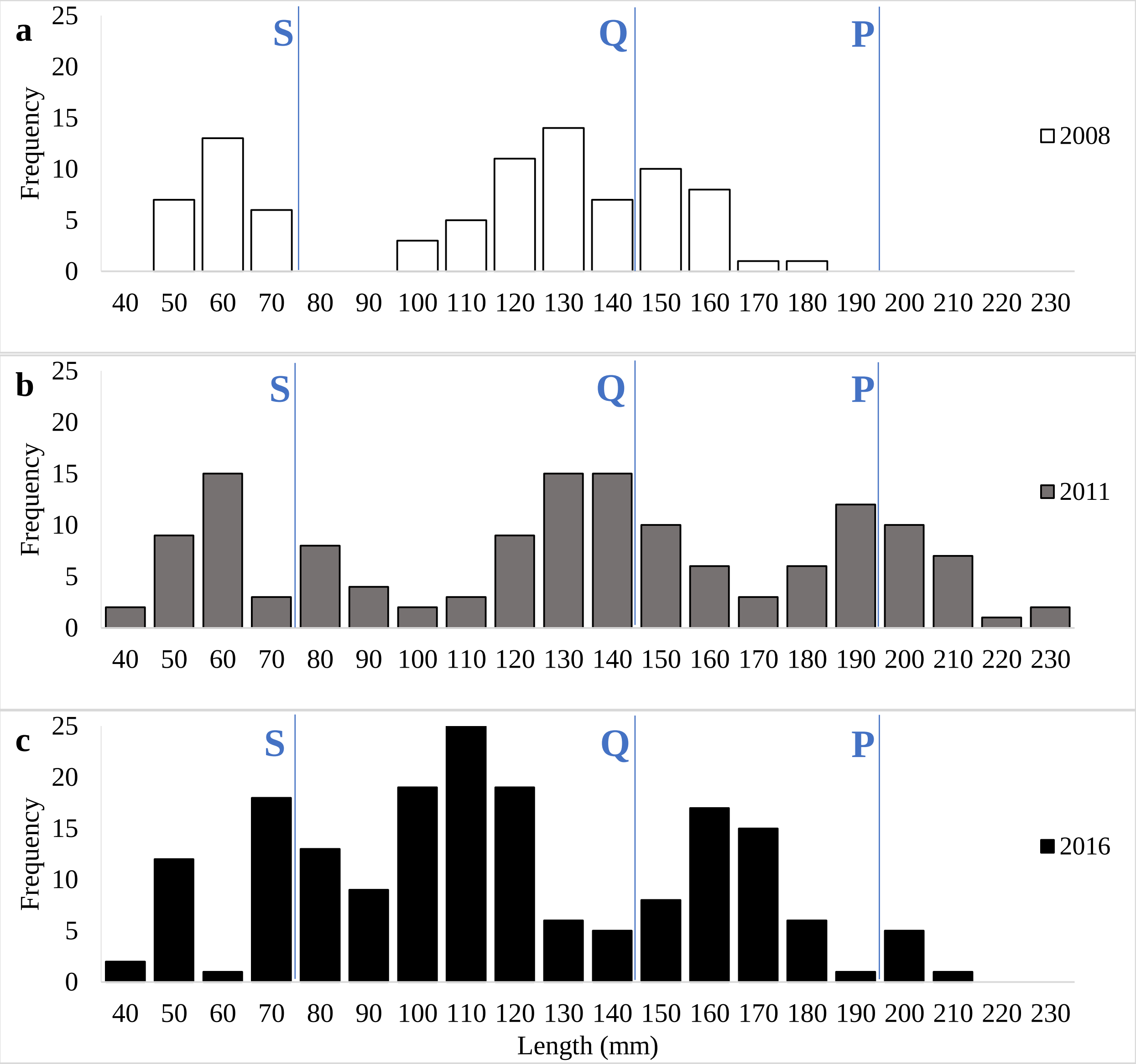


Figure 5-9. Length (mm) frequency of bluegill in DeRuyter Reservoir based on data collected in (a) 2008 where n = 86, (b) 2011 where n = 142, and (c) 2016 where n = 182. (Lord, unpublished data) S, Q, and P and their adjacent blue lines represent stock, quality, and preferred length for a bluegill fishery (Gabelhouse 1984). No fish measured fell within the range of memorable or trophy lengths.

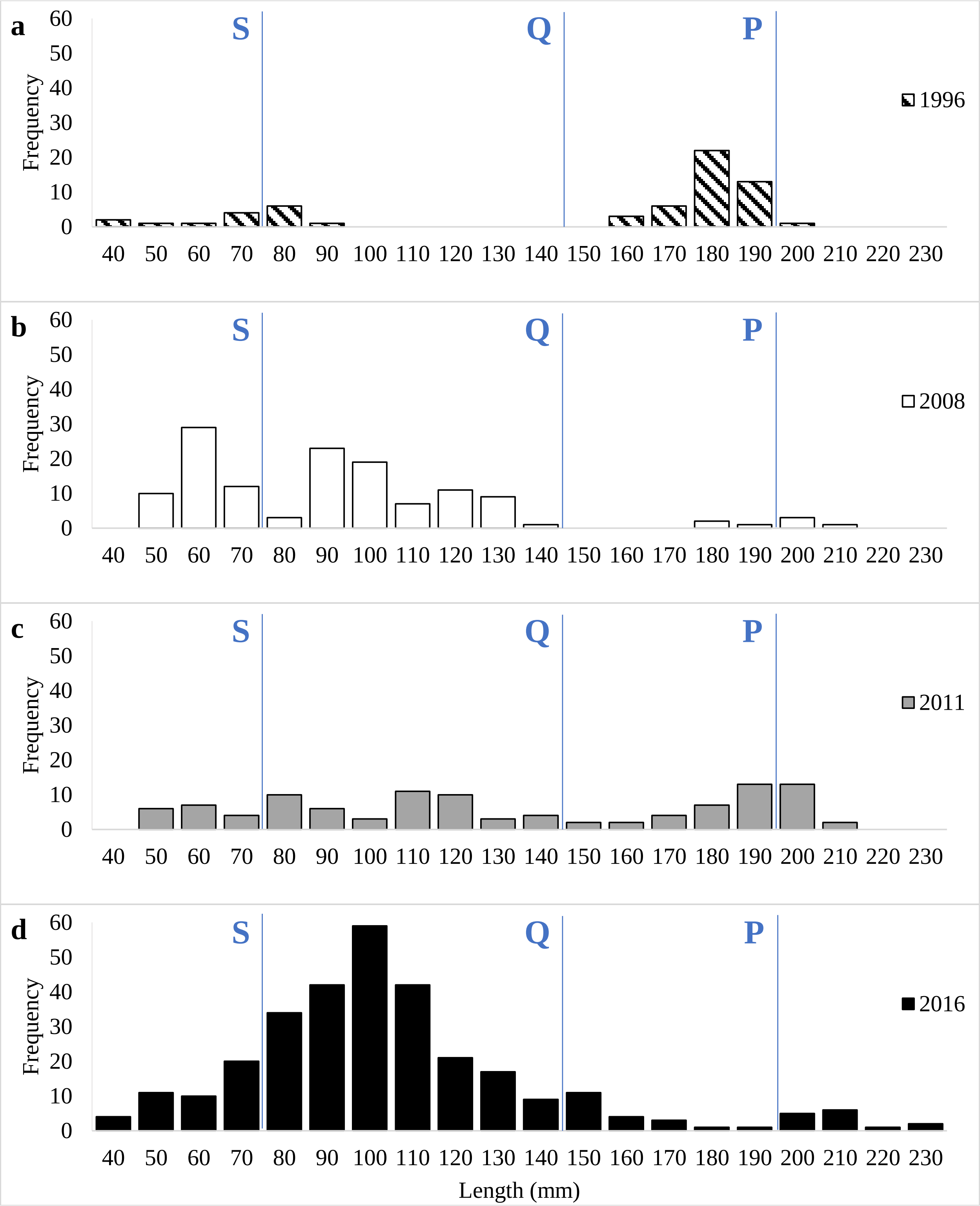


Figure 5-10. Length (mm) frequency of pumpkinseed in DeRuyter Reservoir based on data collected in (a) 1996 where n = 60, (b) 2008 where n = 131, (c) 2011 where n = 107, and (d) 2016 where n = 303 (NYSDEC 1996; Lord, unpublished data). S, Q, and P and their adjacent lines represent stock, quality, and preferred length for a pumpkinseed fishery (Gabelhouse 1984). No fish measured fell within the range of memorable or trophy lengths.

Discussion

Despite angler dissatisfaction expressed for largemouth bass size, the 2016 survey data suggested a balanced fishery with a PSD right at about 50. In recent years (2008 – 2016), a rise and decline in largemouth bass PSD was observed. However, a lack of data from 1997 to 2007 prevented detailed analysis of long-term trends for any of the target species. In the future, tournament anglers could assist in filling data gaps by recording lengths of fish caught during weekly summer events. However, this could result in bias toward larger fish if tournament performance were size-based due to gear selectivity for the largest fish.

Bluegill were not recorded in the 1996 survey, which suggested that either all bluegill were young of year and therefore were not collected, or that bluegill entered the lake in a later year by unnatural origin (i.e., unofficial stocking/bait dumping). In surveyed years from 2008 to 2016, the bluegill population was balanced with respect to PSD, indicating a fishery dominated by large fish and that recruitment was not limited. According to guidelines developed by Green (1989) to understand interactions between largemouth bass and panfish, largemouth bass and bluegill populations in DeRuyter Reservoir were balanced in relation to each other based on 2016 PSDs of 33 (bluegill) and 48 (largemouth bass). An inverse relationship between PSD of largemouth bass and that of bluegill is typical (Guy and Willis 1990). If an annual decrease in PSD of largemouth bass in DeRuyter Reservoir continues in upcoming years, bluegill PSD could increase.

Although largemouth bass commonly prey on sunfish, a controlled laboratory experiment detected that largemouth bass preyed upon bluegill less successfully as submerged vegetation density increased (Savino and Stein 1982). Increased littoral vegetation density due to introduced macrophyte species into DeRuyter Reservoir could benefit bluegill by providing more structural refuge from predation. Conversely, the PSD of pumpkinseed from 2014-2016 in DeRuyter Reservoir was consistently low, indicating that cover provided by aquatic vegetation may be causing pumpkinseed to increase abundance to a population dominated by over-crowded, small individuals.

Most walleye surveyed were small (290-550 mm in 2015). PSDs were high in recent years due to small sample sizes likely not representative of the whole population. Nate et al. (2000) evaluated the fisheries of 172 northern Wisconsin lakes and found that average adult walleye abundance was higher in lakes with natural recruitment than in stocked lakes. High walleye PSD in DeRuyter Reservoir suggested a moderate amount of stocked individuals were surviving but not reproducing. While there is ample prey available for walleye, including yellow perch and centrarchids, they could be limited by their ability to reproduce naturally in the lake, due to factors such as availability of spawning habitat, predation, temperature, and cannibalism (Nate et al. 2000).

Also in northern Wisconsin lakes, Fayram et al. (2005) examined competitive and predatory interactions between walleye and largemouth bass. Population size of both species in studied lakes were inversely related. Juvenile and adult diets overlapped between the two species indicating resource competition, but adult largemouth bass tended to prey on juvenile stocked walleye. Stocked walleye survival was low in lakes with high largemouth bass abundance. Management of large populations of walleye and largemouth bass simultaneously in DeRuyter Reservoir may be difficult due to the competitive and predatory relationship with largemouth bass.

Chapter 6: Watershed Public Opinion Survey

Introduction

To successfully manage a lake, understanding its cultural components is arguably just as important as understanding its biological, physical, and chemical components. As unwanted primary production (i.e., harmful algal blooms, nuisance macrophytes) can impact lake use by stakeholders, certain cultural activities can impact the quality of the lake ecosystem (i.e. increased development in the watershed, degraded septic systems). Past management techniques may have only represented goals of certain lake interest groups and left out other stakeholders. To bridge these knowledge gaps and understand all interests in the lake, an opinion-based survey was distributed to all watershed residents.

As various management techniques for invasive aquatic plant control were currently in use by stakeholder groups at the time of mailing, the survey went into further detail with questions pertaining to satisfaction with the current techniques and attitudes toward various aquatic plant management alternatives. Current management included large-scale mechanical harvesting for *Potamogeton crispus* and *Myriophyllum spicatum* and research-based biological control by trophic cascade for *M. spicatum*.

Methods

An anonymous survey was distributed, beginning in April 2016 and open through July 2016, to all property owners in the DeRuyter Reservoir watershed (Ries et al. 2008). Addresses were retrieved from the 2010 US census data of Madison, Onondaga, and Cortland, and surveys were distributed by mail. To maximize responses and reach stakeholders who are not property owners (such as renters), the survey was distributed online by email to members of the Tioughnioga Lake Preservation Foundation. It was sent to more than 350 people.

The survey was designed to develop a basic understanding of stakeholder concerns, opinions, and goals for DeRuyter Reservoir (Appendix 2). In addition to collecting information about these concerns, specific questions were included to understand socio-economics of stakeholders that use the lake and how they use it.

A Pearson's chi-square test was ran to determine correlation between responses of those who were satisfied, neutral, and not satisfied with current plant management activities (question 8) and opinions on the use of each type of management strategy (question 9).

In order to gage long-term management goals, respondents were asked to self-assess their position on a spectrum of management objectives, with ecological sustainability on one end and lake use on the other. For example, in terms of plant growth in the lake, this question might be useful for determining whether stakeholders were more concerned about controlling invasive species to preserve the biodiversity for a resilient ecosystem or if they were more concerned about overgrowth of both native and non-native macrophyte species because they prevent access for activities such as boating, swimming, or fishing. Respondents were given five choices (ecological sustainability- most concern, ecological sustainability- moderate concern, neutral, use problems- moderate concern, or use problems- most concern). Results were adjusted from five choices to a seven-tiered spectrum for instances where two choices were selected, where 1 represented ecological sustainability (most concern) and 7 represented use problems (most concern). For example, if ecological sustainability (most concern) and use problems (moderate concern) were both chosen, the respondent would receive a 3 on the spectrum. When most concern was chosen for both ecological sustainability and use problems, the respondent would receive a 4, representing neutral.

Results

A total of 188 responses were received (54 % response rate). Of the respondents, the largest age group was 61-70 years old (37 %; Figure 6-1). The number of residents in each household ranged from 1 to 13 individuals, and the majority (63 %) had two residents. Just under 25 % of participants resided in the DeRuyter watershed year-round whereas about 75 % were seasonal residents. The majority of respondents (about 77 %) indicated use only during summer months and with varying frequency (Figure 6-2). Most respondents (87 %) swam in DeRuyter Reservoir (Figure 6-3). Other common uses, in descending order of popularity, included motorized (78 %) and non-motorized (72 %) boating, aesthetic enjoyment and wildlife viewing (62 %), and open water (59 %) and ice (9 %) fishing.

Respondents were most concerned with excessive weed growth (79 %) and invasive species (70 %) where management issues were concerned. Other categories for which a majority of respondents chose 'most concern' included individual septic systems (56 %) and algal blooms (49 %; Figure 6-4).

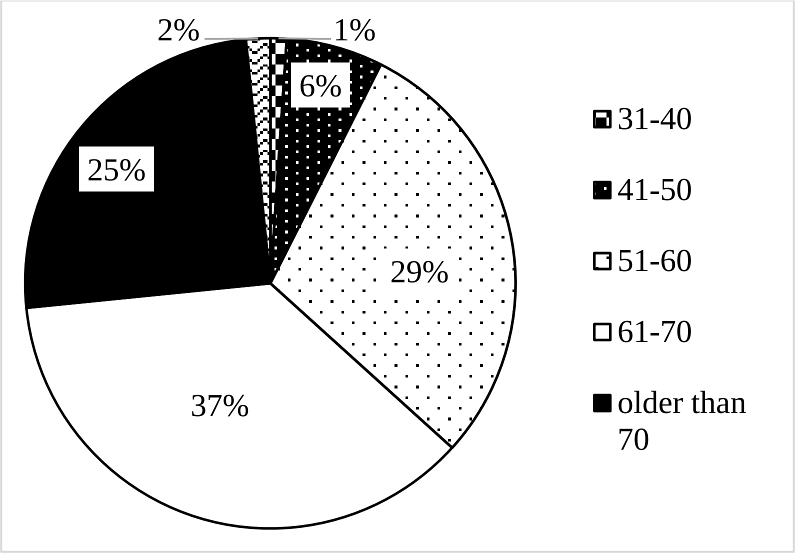


Figure 6-1. Percentage of public opinion survey respondents within 10-year age groups presented as percentages.

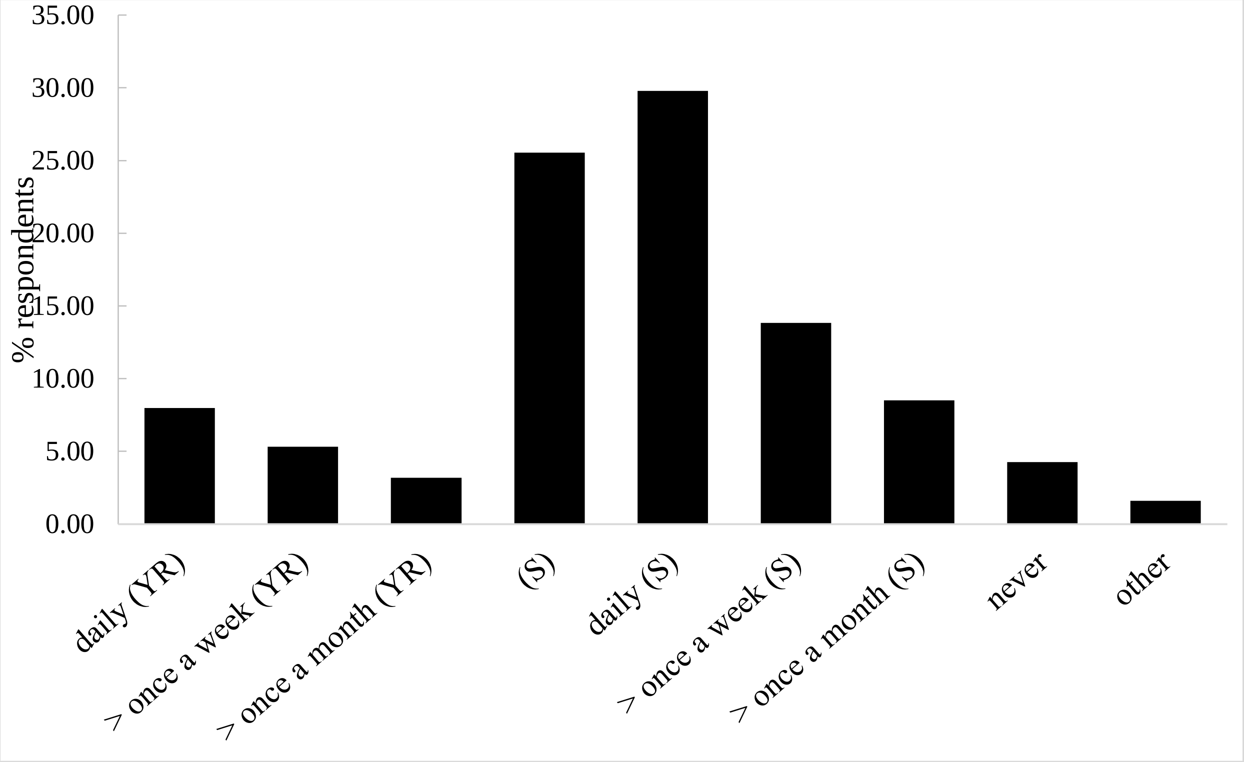


Figure 6-2. Responses on frequency of lake use by respondents as percentages. Year-round use is abbreviated as YR and seasonal summer use is abbreviated as S.

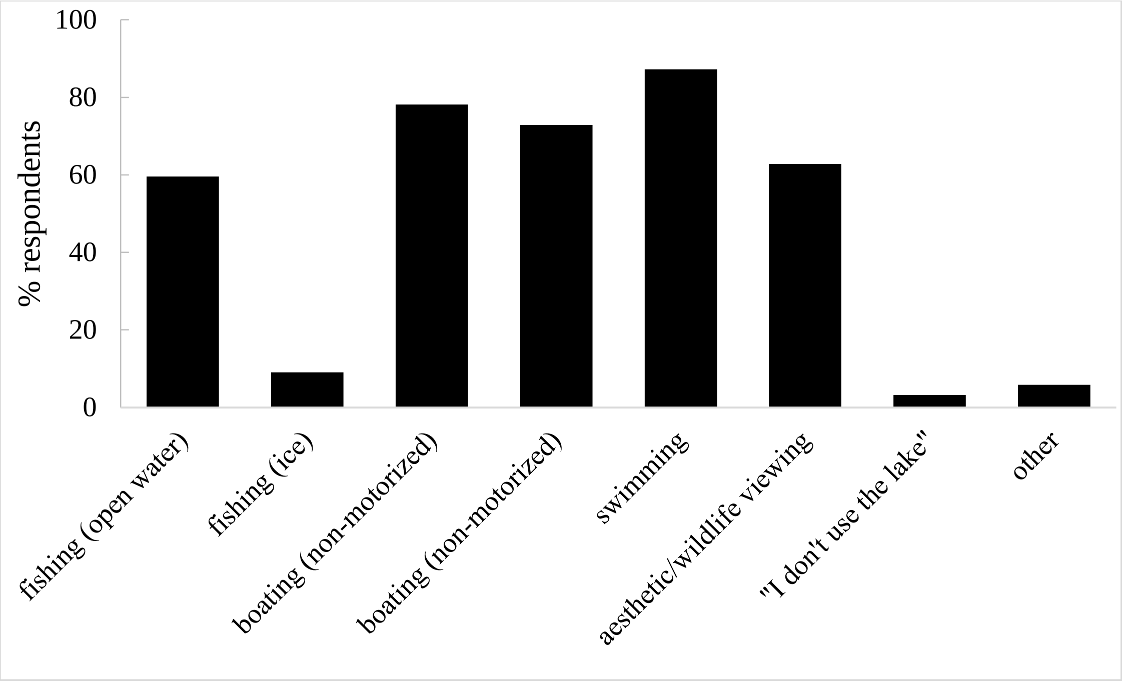


Figure 6-3. Percentage of respondents using the lake for various activities. Each respondent chose as many as were applicable. Lakes uses listed in the “other” category included socialization, water skiing, watering flowers, and dog swimming.

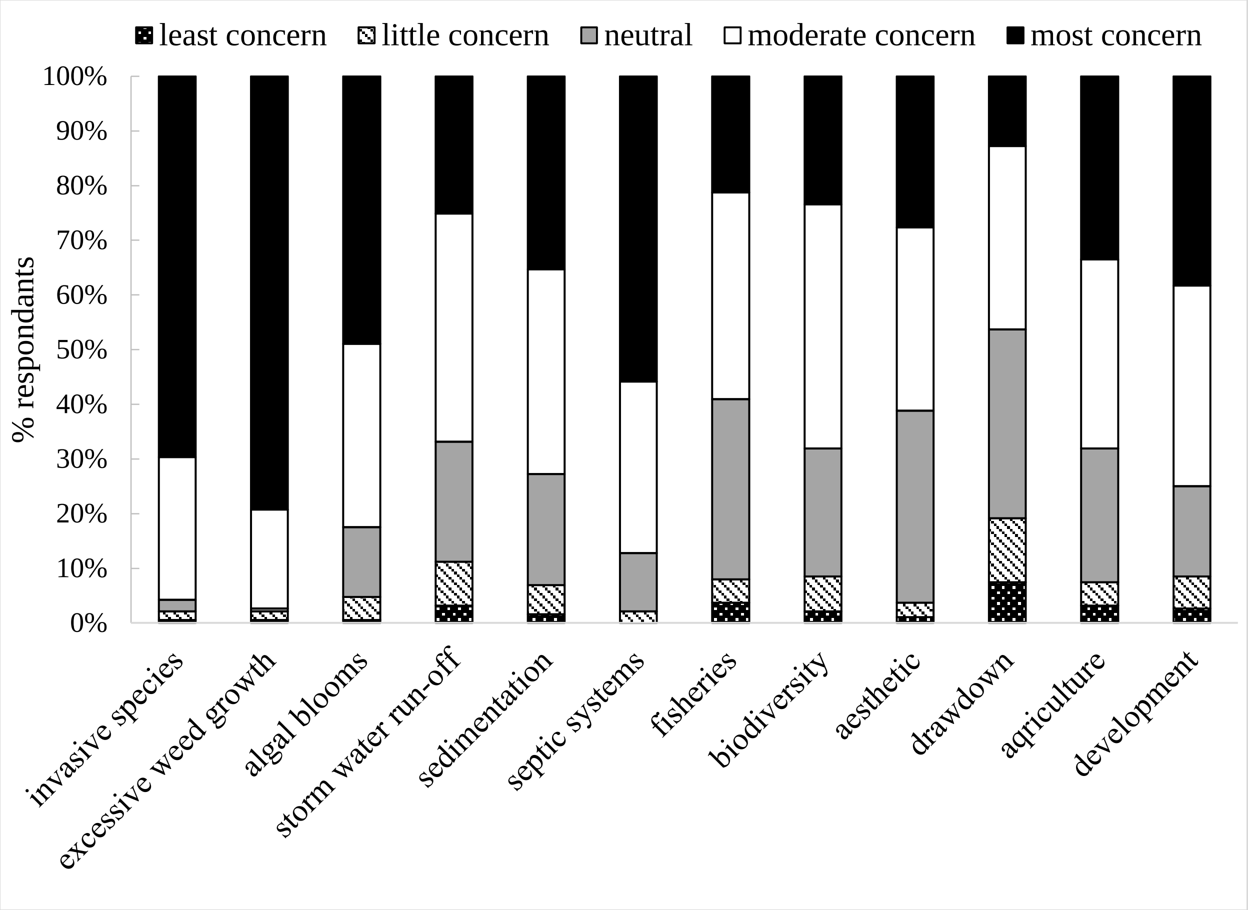


Figure 6-4. Concern levels of each perceived ‘lake issue’. Respondents were given the option of least concern, little concern, neutral, moderate concern, or most concern for each of 12 issues.

Thirty-six percent of respondents reported that they were satisfied with the current status of invasive plants in DeRuyter Reservoir, 28 % reported that they were not satisfied, and 36 % claimed neutrality, indicating a divide in opinions (Figure 6-5). Approval or strong approval for physical and biological means of controlling invasive plants were almost unanimous (about 90 % either approve or strongly approve for both methods), whereas a spread of strong disapproval to strong approval was expressed for chemical control measures (about 30 % approve or strongly approve and about 50 % disapprove or strongly disapprove; Figure 6-6). There was a significant difference between satisfaction of current methods and approval for the use of chemical controls ($\chi^2(8) = 30.442$, $p < 0.0005$, Pearson’s chi-squared test) indicating that those who were not satisfied with current management strategies were more likely to approve of the use of chemicals to manage plants (Table 6-1). There were no significant differences in respondent favor for physical removal or biological control based on satisfaction with current methods ($\chi^2(8) = 8.8705$, $p < 0.5$ and $\chi^2(6) = 7.093$, $p < 0.5$ respectively, Pearson’s chi-squared test).

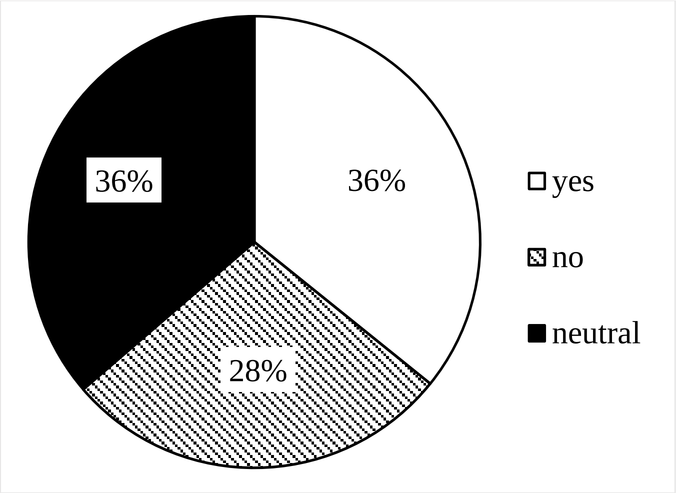


Figure 6-5. Respondents were asked if they were satisfied with the current methods in place for invasive plant control. They were given the options yes, no, or neutral. Results are reported as percentages.

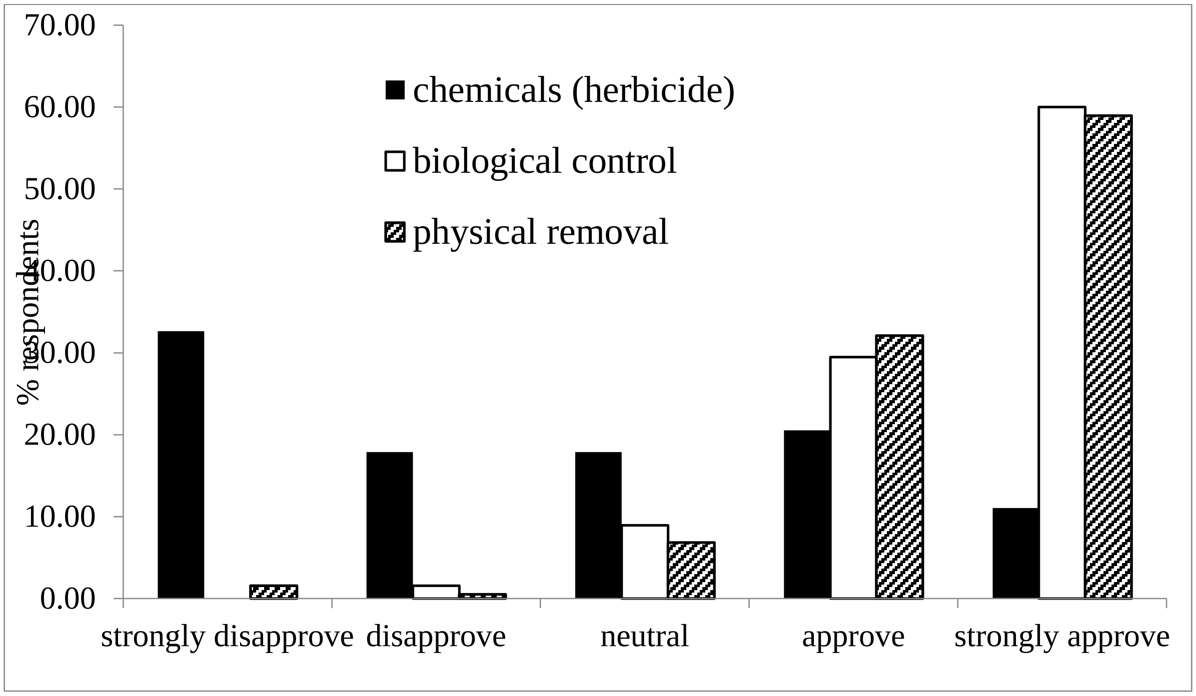


Figure 6-6. Approval rating for the potential use of three major methods of invasive control (chemicals, biological control, and physical removal) on DeRuyter Reservoir reported as percentages.

Table 6-1. Chi-square grid comparing approval for the use of chemical control for invasive plant management broken by how respondents answered the previous question, ‘are you satisfied with the present methods of invasive plant control used on DeRuyter Reservoir?’. Responses of ‘strongly approve’ and ‘approve’ and ‘strongly disapprove’ and disapprove’ were combined.

		Satisfaction with present method			
		Negative	Neutral	Positive	Subtotal
Support for chemical control	Disapprove	10 %	**19 %**	**22 %**	51 %
	Neutral	3 %	10 %	6 %	19 %
	Approve	**17 %**	4 %	9 %	30 %
	Subtotal	30 %	33 %	37 %	

The final question that was asked targeted stakeholder perspectives on long-term management goals. The largest group of responses were categorized as neutral (30 %) followed by ecological sustainability (most concern) with 28 % (Figure 6-7).

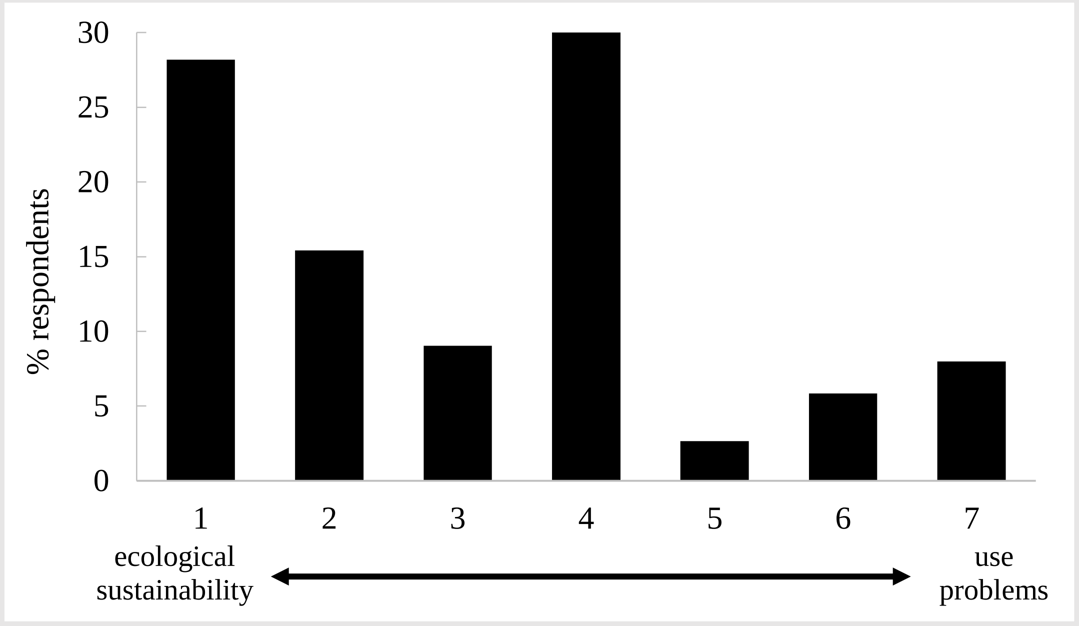


Figure 6-7. Responses to whether concerns for DeRuyter Reservoir align primarily with ecological sustainability or recreational use problems. 1 represented ecological sustainability (most concern), 4 was neutral, and 7 represents use problems (most concern).

Discussion

As three quarters of respondents were seasonal residents and the majority of lake use occurs in summer months, long-term management strategies ought to focus on preserving quality of recreational summer use but also must be cognizant of negative effects of high usage in the summer season. Potential negative effects of higher usage in summer than during the rest of the year can include, but are not limited to, increased nutrient release from septic systems due to more intensive use, greater boat traffic causing safety concern and spread of aquatic invasive species, and increased fishing pressure. The large number of respondents who chose swimming as a typical lake use confirmed that long-term management goals ought to keep water quality standards aligned with NYSDEC’s Class B lake designation, or lakes which support contact recreation.

Top stakeholder concerns aligned with findings of biological and limnological data collected for this report. At least four invasive species are present in the lake, and three of those are aquatic macrophytes growing at nuisance abundance. Other high-priority concerns included harmful algal blooms and individual septic system integrity. Individual septic systems on shoreline properties have the potential to leach excess nutrients into the groundwater and eventually the lake, especially if not properly maintained. Septic systems, among other sources of nutrient loading, can promote algal growth in the lake. In the fall of 2016 potentially harmful algal blooms were observed with the onset of fall mixing. Addressing nutrient loading can help to prevent these blooms from becoming worse in the future.

A divide in opinions on effectiveness of current invasive plant management was apparent. The divide could be attributed to multiple lake associations, to slow initial results from biological control efforts, and/or lack of widespread awareness of current efforts. Several of those falling in the neutral category were likely unaware of current strategies in place; some respondents explained in the margins that they chose neutral for this reason. This suggested that more communication and outreach amongst stakeholders is necessary. If a similar question were asked in a follow-up survey in the future, adding a ‘not sure’ category would make results more comprehensive. Those unsatisfied with current invasive plant management strategies were more likely to approve of using chemicals as a control method when compared with satisfied and neutral respondents who found chemical controls generally less favorable than physical and biological methods. Respondents that approved of chemical controls were possibly unhappy with the current state of macrophyte growth, either due to recreational impediment or in terms of biodiversity loss and felt the need for control or eradication by any means is necessary at this point in time. Others were possibly concerned with the potential for unintended consequences of chemical release into the environment. An evaluation of the cost and effectiveness of current management strategies and a potential restructuring of the use of these strategies is necessary to reach a better consensus among stakeholders in the future.

The largest fraction (30 %) of the respondents were neutral when deciding between sustaining the ecosystem and managing against recreational use impediment as long-term goals for DeRuyter Reservoir. However, about half of respondents (53 %) fell into one of three ranks for ecological sustainability as the priority. These results aligned well with the goal of this report to help inform long-term decision-making for management of DeRuyter Reservoir. To satisfy stakeholder needs, management goals ought to focus on long-term ecological sustainability for the system and its watershed, but will also address recreational use issues and impediments.

Chapter 7: On-Site Residential Wastewater Systems

Introduction

Nutrient runoff from failed or un-maintained septic systems is considered a source of water quality pollution (Carpenter et al. 1998; Withers et al. 2011). Biologically available forms of nitrogen and phosphorus can be released into a waterbody immediately from a failed system or slowly over time through groundwater from individual septic systems within a watershed boundary. The slope of the landscape, bedrock, soils, precipitation, and waste load contribute to quantities and timing of the nutrient release. The majority of the DeRuyter Reservoir drainage basin is designated as either somewhat limited to very limited in terms of onsite wastewater disposal suitability of soils and underlying geology (Soil Survey Staff et al. 2017).

Quanitifying the potential nutrient load generated from septic systems in the watershed can help to understand the potential negative impacts on water quality. Dillon and Rigler (1975) decided on a value of 0.8 kg person^{-1} year^{-1} to quantify expected phosphorus generation from conventional household septic systems; Albright and Waterfield (2010) conducted a study to develop an updated value of 0.58 kg person^{-1} year^{-1} for Otsego Lake, NY. This estimate was likely lower due to the ban of high phosphate detergent. Total phosphorus release from on-site residential wastewater systems in the watershed of DeRuyter Reservoir was estimated in order to evaluate its relative importance as an external P source for the lake. Additionally, the Town of DeRuyter distributed a survey to shoreline residents to better understand age and functionality of the individual septic systems.

Methods

An estimated total of P input from septic systems located in the DeRuyter Reservoir watershed was calculated by the following equation (Harman et al. 1997) and the P release rate from Albright and Waterfield (2010):

$$\text{Total P release} = (\text{permanent dwellings} * \text{average occupancy per household}_{\text{permanent}} * 0.58\ \text{kg P}) + (\text{seasonal dwellings} * \text{average occupancy per household}_{\text{seasonal}} * 0.33\ \text{year} * 0.58\ \text{kg P})$$

Values for dwelling category and average occupancy were derived from responses to the watershed public opinion survey (Chapter 6) and a seasonal dwelling was assumed used for one-third of a year.

In 2015, a survey was mailed out to 334 shoreline property owners on DeRuyter Reservoir as a collaboration with the towns of DeRuyter and Fabius. The TLA and TLPF disseminated the survey, which asked for the type of septic system, age of system, consideration of a system upgrade, typical annual maintenance cost, and residency status on the lake.

Results & Discussion

The annual total phosphorus released from septic systems located around the shoreline of DeRuyter Reservoir was estimated to be 247.83 kg P (Table 7-1).

Table 7-1. Total phosphorus contributions by individual septic systems of shoreline residents[4]. Assumed values were: 0.58 kg P person^{-1} year^{-1}; seasonal residency = 0.33 year; all other values from stakeholder public opinion survey.

Residency	Number of Dwellings	Average Occupancy	P input (kg)
Permanent	85	2.37	116.24
Seasonal	259	2.65	131.59
		Total:	247.83

Of the 334 property owners, 194 submitted responses (response rate: 58 %) (Town of DeRuyter, unpublished data). The majority of residents (60 %) had a conventional septic tank with a leach field whereas others had alternatives such as a holding tank, dry well, or raised bed (Figure 7-1). Approximately half of residents (49 %) had treatment systems between 6 and 20 years old. Eighty-six percent of the respondents had never considered a system upgrade. The majority of respondents (60 %) believed that their property was large enough to accommodate current standards for septic tanks and leach fields.

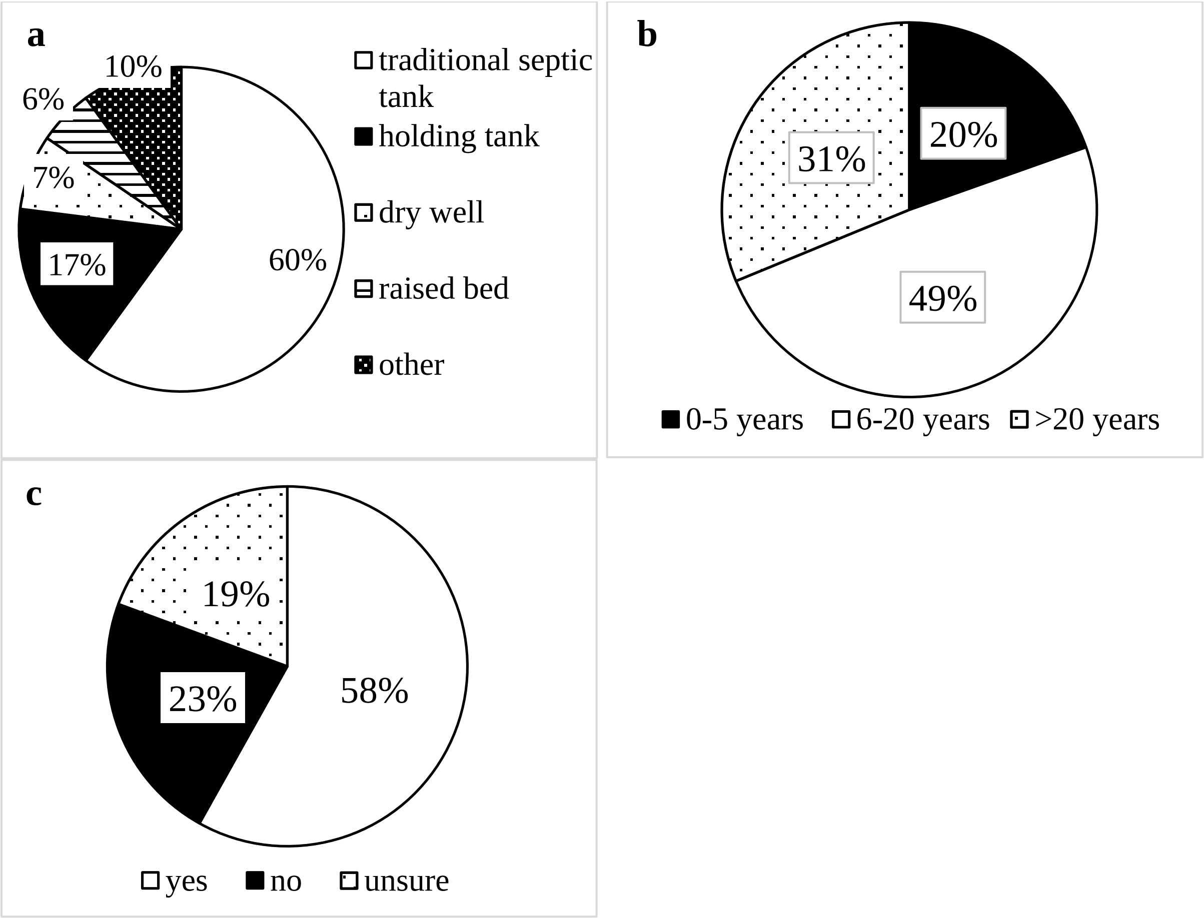


Figure 7-1. Select results of septic system survey conducted by the Town of DeRuyter (unpublished data). Questions included (a) the type of on-site wastewater treatment systems the respondent used, (b) how old the respondent's individual on-site wastewater treatment system was, and (c) if the respondent believed their property was large enough to accommodate current standards for septic tank/leach field. Results are reported as percentages of total respondents (n = 194).

The combination of unsuitable soils for septic systems and high population density directly on the lake shoreline alludes to the importance of understanding the role of septic systems as a factor in non-point external phosphorus loading over time into the lake. Old or failing systems can contribute to a higher nutrient load (Carpenter et al. 1998). As major lake management goals for DeRuyter Reservoir include control of macrophyte and algal growth, a focus on keeping septic systems up to date and regularly pumped out can contribute to reducing bio-available nutrients in the long-term.

Chapter 8: Conclusion – An Ecosystem Level Perspective

The state of DeRuyter Reservoir was evaluated to best understand the complex and dynamic interactions between the physical, chemical, biological, and anthropogenic components of the lake and watershed. Much of the data gathered for this report provided just a snapshot in time of the ecological history of the lake, a constantly evolving ecosystem. These data can be used to predict the causes of system changes and to inform decision-making.

Some key takeaways in relation to lake management concerns included: no significant changes in water column TP over the past 30 years; hypolimnetic oxygen loss during summer stratification causing internal P loading which is likely the primary cause of cyanobacterial blooms with the onset of fall mixing; the natural geologic make-up of the landscape will always be conducive to run-off; introductions of invasive species are likely making long-term changes to the ecosystem (chemically and biologically); there is an abundant community of secondary consumers in the lake (sunfish) that appear to be relieving grazing pressure on primary production. Fortunately, DeRuyter Reservoir is accompanied by a small, manageable watershed and there are opportunities to mitigate these occurrences to foster a more desirable state for the lake.

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Appendices

Appendix A. History of fish stocking in DeRuyter Reservoir compiled by NYSDEC (unpublished data). Length or size class is given where information is available.

Year Stocked	Fish Species (Common Name)	Number Stocked	Length (inches)
1931	Brown Trout	3,600	Fingerling
1935	Black Crappie	50	Adult
1935	Yellow Perch	2,500	Fingerling
1935	Smallmouth Bass	2,000	Fry
1935	Walleye/Pikeperch	625,000	Fry
1936	Smallmouth Bass	2,000	Fry
1936	Smallmouth Bass	2,620	2.5
1936	Walleye/Pikeperch	250,000	Fry
1937	Smallmouth Bass	1,275	4
1938	Smallmouth Bass	6,000	Fry
1938	Walleye/Pikeperch	800,000	Fry
1939	Smallmouth Bass	6,000	Fry
1939	Walleye/Pikeperch	1,050,000	Fry
1940	Smallmouth Bass	6,000	2
1940	Walleye/Pikeperch	800,000	
1941	Walleye/Pikeperch	800,000	
1942	Black Crappie	6,000	
1942	Walleye/Pikeperch	800,000	
1943	Smallmouth Bass	1,000	2
1943	Walleye/Pikeperch	800,000	
1944	Smallmouth Bass	5,280	2
1944	Walleye/Pikeperch	800,000	
1945	Smallmouth Bass	137	4
1945	Smallmouth Bass	18	10
1945	Walleye/Pikeperch	800,000	
1946	Walleye/Pikeperch	800,000	
1947	Walleye/Pikeperch	800,000	
1948	Smallmouth Bass	5,000	2
1948	Smallmouth Bass	5,000	2
1948	Walleye/Pikeperch	1000,000	
1949	Smallmouth Bass	4,000	2
1949	Walleye/Pikeperch	800,000	
1951	Smallmouth Bass	5,000	2
1951	Walleye/Pikeperch	800,000	
1952	Smallmouth Bass	3,636	2
1952	Walleye/Pikeperch	480,000	
1953	Smallmouth Bass	1,338	4
1953	Smallmouth Bass	4,000	3
1953	Walleye/Pikeperch	1,000,000	
1954	Walleye/Pikeperch	480,000	
1955	Walleye/Pikeperch	800,000	

1956	Walleye/Pikeperch	800,000	
1957	Walleye/Pikeperch	800,000	
1958	Walleye/Pikeperch	800,000	
1959	Walleye/Pikeperch	800,000	
1961	Walleye/Pikeperch	800,000	
1962	Walleye/Pikeperch	800,000	
1963	Walleye/Pikeperch	800,000	
1964	Walleye/Pikeperch	550,000	
1965	Walleye/Pikeperch	800,000	
1966	Walleye/Pikeperch	600,000	
1967	Walleye/Pikeperch	400,000	
1968	Walleye/Pikeperch	600,000	
1969	Walleye/Pikeperch	3000,000	
1977	Walleye/Pikeperch	544,000	0.4
1979	Walleye/Pikeperch	600,000	0.4
1981	Walleye/Pikeperch	107	3.5
1981	Walleye/Pikeperch	800,000	0.4
1982	Walleye/Pikeperch	800,000	0.4
1983	Walleye/Pikeperch	800,000	0.4
1984	Walleye/Pikeperch	1,152,000	0.4
1985	Walleye/Pikeperch	1,152,000	0.4
1986	Walleye/Pikeperch	1,152,000	0.4
1987	Walleye/Pikeperch	1,152,000	0.4
1988	Walleye/Pikeperch	1,152,000	0.4
1989	Walleye/Pikeperch	1,152,000	0.4
1990	Walleye/Pikeperch	5,500,000	0.4
2001	Walleye/Pikeperch	2,880,000	0.4
2002	Walleye/Pikeperch	2,880,000	0.4
2005	Walleye/Pikeperch	2,880,000	0.4
2006	Walleye/Pikeperch	2,880,000	0.4
2007	Walleye/Pikeperch	2,880,000	0.4
2008	Walleye/Pikeperch	2,880,000	0.4
2009	Walleye/Pikeperch	2,880,000	0.4
2010	Walleye/Pikeperch	2,880,000	0.5
2011	Walleye/Pikeperch	1,730,000	0.5
2012	Walleye/Pikeperch	1,730,000	0.4
2013	Walleye/Pikeperch	50,000	Fry
2014	Walleye/Pikeperch	10,000	Fingerling
2015	Walleye/Pikeperch	25,000	Fingerling
2016	Walleye/Pikeperch	8,000	Fingerling

Appendix B. Stakeholder Survey Questions

1. What is your age? *Circle one*
    a. under 20
    b. 20-30
    c. 31-40
    d. 41-50
    e. 51-60
    f. 61-70
    g. Older than 70

2. How many people are in your household? _____

3. Do you own property in the watershed? *Circle One*
    a. Yes
    b. No, I reside in rental property.
    c. No, other, please specify:

4. What is your residency status on the lake? *Circle one*
    a. Year-round
    b. Seasonal
    c. Other, please specify:

5. How frequently do you use the lake? *Select all that apply* (ex. If you use the lake daily in the summer only, choose both)
    a. Daily
    b. Couple times a week
    c. Couple times a month
    d. Summer only
    e. Never
    f. Other, please specify:

6. In what ways do you use the lake? *Select all that apply*
    a. Open water fishing
    b. Ice fishing
    c. Boating (Motorized)
    d. Boating (non-motorized- paddling/rowing)
    e. Swimming
    f. Aesthetic/ wildlife viewing
    g. I don’t use the lake
    h. Other, please specify:

7. Of the following potential "lake issues", how concerned are you with each? *Rank each as either least concern, little concern, neutral, moderate concern, or most concern*)

	Least Concern	Little Concern	Neutral	Moderate Concern	Most Concern
Invasive species					
Excessive aquatic plant/weed growth					
Algal blooms					
Storm water run-off					
Increased sedimentation					
Individual septic system integrity					
Fisheries					
Biodiversity (preserving native plants and wildlife)					
Aesthetics					
Impacts of drawdown					
Agricultural practices					
Development					

8. Are you satisfied with the present methods of invasive plant control used on DeRuyter Reservoir?

   a. Yes
   b. No
   c. Neutral

9. When dealing with control of invasive plants I approve of the use of

	Strongly Disapprove	Disapprove	Neutral	Approve	Strongly Approve
Chemicals (herbicides)					
Biological control					
Physical removal					

10. Do your concerns for DeRuyter Reservoir align primarily with ecological sustainability or recreational use problems?

    a. Ecological sustainability- most concern
    b. Ecological sustainability- moderate concern
    c. Neutral
    d. Use problems- moderate concern
    e. Use problems- most concern

11. Additional comments:

A Plan for the Management of DeRuyter Reservoir and its Watershed

Leah Gorman

Photo credit: Tioughnioga Lake Association

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State University of New York
College at Oneonta

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History of the Lake

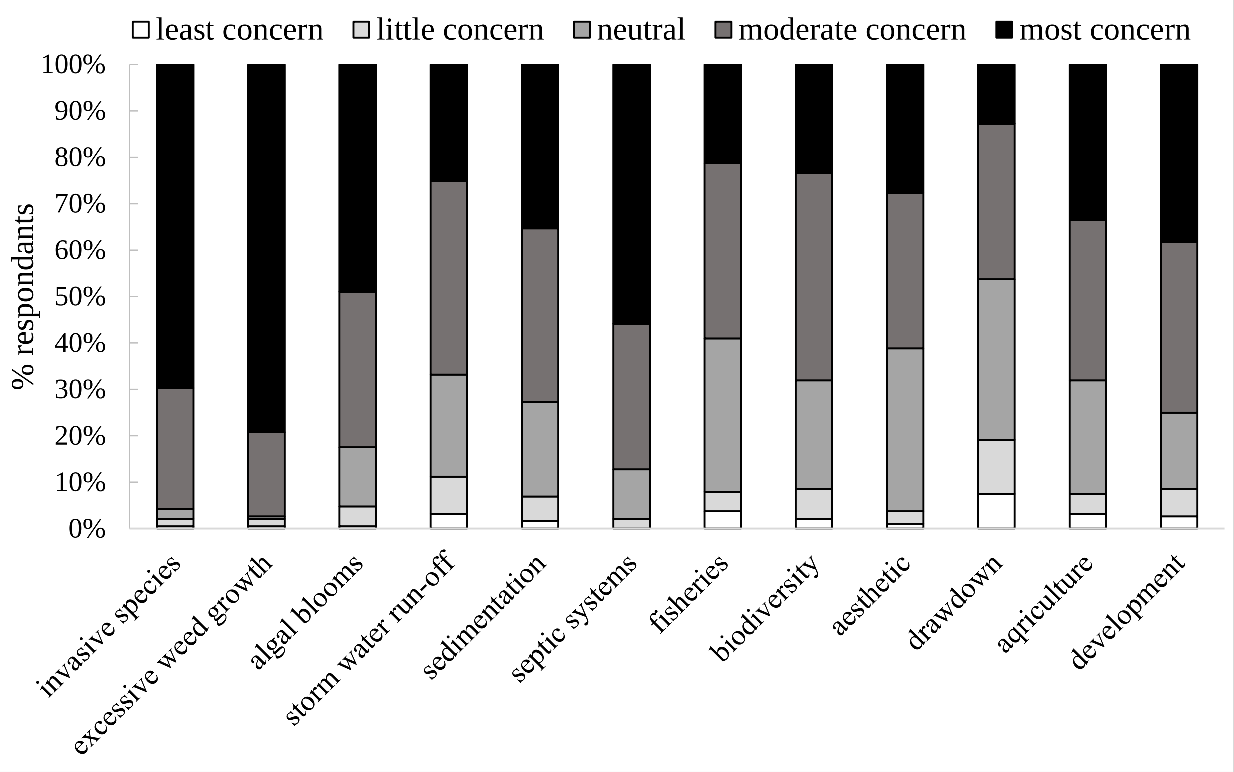
DeRuyter Reservoir, along with several other regional reservoirs, was built in the mid-1800s to create supplemental water reserves for Erie Canal operation. No longer used for that purpose, the reservoir is now used primarily for local recreation including swimming, boating, and fishing. The shores of DeRuyter Reservoir are a home to both seasonal and year-round residents. Weekly bass fishing tournaments in summer months and an annual triathlon are hosted on the lake, drawing in other area residents.

Organized interest in the conservation of DeRuyter Reservoir began in 1939 with the creation of the Tioughnioga Lake Association (TLA), which is still active on lake issues and hosts social functions for lakeshore residents. The TLA was accompanied more recently by the Tioughnioga Lake Preservation Foundation (TLPF), which was formed and designated as a 501(c)(3) organization in 2012. Both groups have implemented management strategies to protect the ecosystem of DeRuyter Reservoir and maintain its desirable recreational uses for residents and visitors.

Excessive weed (i.e., undesirable aquatic plant) biomass has resulted in the impairment of DeRuyter Reservoir; in 1998 the New York State Department of Environmental Conservation (NYSDEC) and, subsequently, the U.S. Environmental Protection Agency (EPA) listed the reservoir as impaired due to excessive external nutrient loading. Although species composition of the plant community has changed over time, dense vegetation has been present in the lake since the 1930s. Currently, the effects of 4 different invasive species and increased algal biomass have become prominent management problems in the reservoir.

Why a Lake Management Plan

As with any ecosystem, lakes and the organisms they support are constantly changing. Their use by humans changes as well. This leads to ‘lake problems,’- problems that either are negatively impacting intended uses of a lake, the expected ecological functioning, or both, and therefore change may be perceived differently by the varying stakeholders. Common lake problems in NY include rooted aquatic plants, algal blooms, boating safety, poor fishing, acid rain, oxygen deficits, lake levels, and turbidity (NYSFOLA 2009). Likewise, the top concerns of DeRuyter Reservoir residents include excessive weed growth, invasive species, septic systems, and algal blooms (Figure 1).



Figures 1. Concern levels of each perceived 'lake issue' from the 2016 DeRuyter Reservoir watershed public opinion survey. Respondents were given the option of least concern, little concern, neutral, moderate concern, or most concern for each of 12 issues.

A management plan, coupled with a state of the lake report, provides a comprehensive structure based on research and stakeholder goals to inform decision-making. With these documents, science-based strategies that are the most cost effective, ecologically sound, and aimed for the long-term resiliency of the lake can be selected for implementation.

Resiliency is defined as resistance to change. This is applicable to lake ecosystems, which are constantly responding to external pressures such as the introduction of invasive species, activities in the watershed, and a changing climate. Understanding the characteristics of an ecosystem that can resist the negative effects of these events will help contribute to long-term sustainability of a lake which supports diverse native organisms and its intended uses. Factors that can reduce ecological and societal resilience of aquatic ecosystems include biodiversity loss, habitat loss, and persistent harmful algal blooms.

Resiliency of an ecosystem can be conceptualized as a ball and 2 cups where one cup is the current state of the ecosystem and the other is the alternate state after a disturbance (Figure 2; Scheffer et al. 2001). The depth of the cup represents the resiliency of the ecosystem where less resiliency, or a shallow valley represents a more fragile ecosystem.

Management decisions should be made based on the understanding that the ecosystem may be gradually degrading (ex. external loading of nutrients worsening with increased watershed development) which would decrease the valley of the left cup, but a disturbance (or an extreme event), such as a hurricane, can lead to the turning point regarding poor water quality, or a shift to the right cup. Management activities should address the gradual changes that lead to a decrease in resiliency (i.e., shrinking the valley of the desirable state). Decisions must also acknowledge that major disturbances, while they are becoming more frequent, are difficult to predict.

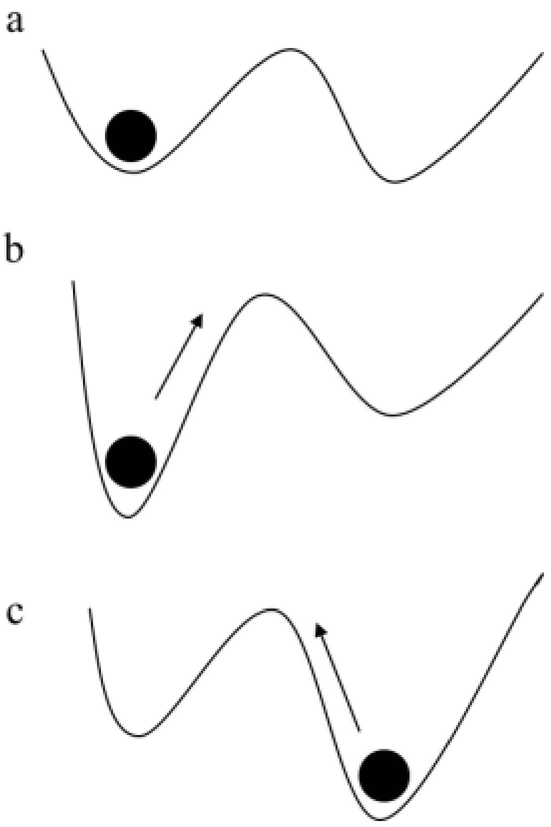


Figure 2. Ball and cup resiliency model based on Scheffer et al. (2001) where the left cup represents the current state of the ecosystem and the right cup represents the disturbed state; (a) shows two equal alternate states. In (b) the deep valley of the left cup indicates a resilient ecosystem that is not easily disturbed and the right valley is a disturbed state that is easy to recover from. In (c) the shallow valley on the left indicates a more fragile ecosystem that is easily disturbed, where the deep valley on the right indicates a major disturbance that is not easily recovered from. In reality, the ecosystem (left valley) is dynamic and will typically fall somewhere in between the representations of (b) and (c). Management goals should focus on an ecosystem more towards the deep valley of (b).

In general, it is important to recognize the need for long-term, adaptive management that addresses the root of the problem, wherein multiple, complementary strategies are implemented and adjusted over a time frame of many years. While short-term, issue-based strategies can alleviate immediate concerns (e.g., in-lake treatment of a HAB), these techniques will likely not prevent the problem from reoccurring and only serve to suppress the problem over the short term. These management strategies must be supplemented by preventative strategies, which may not produce immediate results, but help sustain the system in its desirable state.

Goals for the Lake

To achieve successful long-term management of a waterbody, a set of stakeholder goals must be established. Therefore, a list of goals for DeRuyter Reservoir were derived from NY water quality standards, present conditions of the lake, and historical trends in cooperation with the TLPF (Table 1). Similarly, goals were established for biological and physical parameters (Table 2) from ongoing studies in the reservoir. Some parameters appear to be improving since the beginning of CSLAP data collection (1988), such as greater **Secchi depth** and lower **chlorophyll *a*** concentrations, suggesting overall water quality improvement. However, these trends may be correlated with the introduction of invasive zebra mussels, as they consume algae, and are not currently attributed to any management strategies.

Table 1. Summary of water quality parameters addressed by NYS Part 700 water quality standards (of New York Codes, Rules, and Regulations), present conditions based on the state of the lake report, long-term trends from CSLAP, and management goals agreed upon by TLPF.

Water quality parameter	Standard for class B lakes	Present condition	Long-term trends	Management goals
Water clarity measured as Secchi depth	2-3 m	5 m (May-Oct 2016 mean)	Slight increase	Annual summer mean of 4-5 m
Total phosphorus at surface	No more than 20 $\mu g\ l^{-1}$	15 $\mu g\ l^{-1}$ (May-Oct 2016 mean)	No change	Annual mean of 10 $\mu g\ l^{-1}$ or less
pH	6.5-8.5	7.9	Slight decrease	Remain within 6.5-8.5
Chlorophyll *a* (algae) at surface	2-8 $\mu g\ l^{-1}$ (**mesotrophic**)	7 $\mu g\ l^{-1}$ (surface; May-Oct 2016)	Slight decrease	Remain within 2-8 $\mu g\ l^{-1}$

Table 2. Relevant biological and physical parameters supplementary to water quality standards to address long-term management of DeRuyter Reservoir, as agreed upon by TLPF.

Other Parameters	Present Conditions	Management Goals
Aquatic vegetation	3 invasive species, 15 native species	1. Preserve native diversity 2. Suppress present invasive species (eradication if possible) 3. Prevent new introductions
Fishery	Balanced largemouth bass population, small population of walleye, large populations of sunfish	1. Promote a balanced bass fishery 2. Decrease sunfish population (**secondary consumers**)
Recreational safety	Some concern of high boating traffic, concern of harmful algal blooms (HABs)	1. Promote safe boating 2. Have a response plan for when a potential HAB is found in the lake. 3. Prevent HABs in the long-term through water quality goals.
Dam	Class C High Hazard Dam	1. Educate public on this ranking

A set of logistical components of each management activity must be fully considered before implementation including a breakdown of responsibilities, how the activity will be funded, and a timeline for completion which can range from an immediate small task to a long-term action. Some strategies are specific to land owners while others will be most successful with a committee of representatives from both the TLA and the TLPF. Federal and state grant funding is available through federal, state, and private entities for many in-lake and watershed activities.

Other actions that can help to maximize success include continued monitoring, public education and outreach, and climate change awareness. Continued monitoring of the lake will make the success of each management activity measureable and will help to predict and prevent future problems. Long-term management strategies can be altered as the lake changes over time. Much of the continued monitoring can be achieved by collection of water quality data through CSLAP. Other monitoring may be more specific to what is being managed (i.e., the plant community or the fishery). Lake users are the best resource to watch out for unfamiliar organisms (potential invasive species) and harmful algal blooms, as they are the ‘eyes on the lake.’

Education and outreach should be a component of each management strategy to develop public understanding of the science behind each strategy and expected outcomes in relation to lake use. This can be addressed through the TLPF newsletter, mailing, the website, a social media account, or programming with local professionals (e.g., NYSDEC, Soil and Water Conservation Districts, etc.).

Additionally, monitoring of water chemistry will allow a better understanding of how the lake may respond to management differently in the future due to changing climate patterns. All lakes undergo the process of **eutrophication**. However, human activity and climate change are causing this process to progress much faster than would occur naturally. As air and water temperatures are rising, waterbodies in the northeastern U.S. are experiencing prolonged drought and more severe flooding; algal biomass will likely increase (Paerl and Huisman 2008, O'Neil et al. 2012), and non-native species may be more successful (Rahel and Olden 2008). Right now is the time to mitigate these potential impacts.

The remainder of this management plan will address specific areas of management activities that can be addressed, whether in the watershed or directly in the lake, to contribute to reaching the goals for DeRuyter Reservoir. Each area will include one or multiple recommendations that should all be considered for the long-term management of the system. Each recommendation may include an alternative activity that is either a minimized version of the recommendation or may be less feasible for varying reasons (e.g., cost, indirect impacts, stakeholder approval, etc.).

Areas for Management

I. Watershed

Watershed size, slope, geology, soil type, and land cover are all characteristics that contribute to the amount and the content of **run-off** expected to enter the waterbody. Many perceived 'lake issues' are really a symptom of a problem caused or amplified by human activities in the watershed. Development in the watershed alters the natural course of water and can cause the run-off of unwanted pollutants into the waterbody. **Point pollution** enters a waterbody from discreet sources, whereas **non-point pollution** enters a waterbody from diffuse origins. Non-point pollution can affect any waterbody with human activity present and, if identified, can be managed with a combination of both local and regional strategies. Potential non-point pollutants include nutrients, pathogens, suspended sediments, and toxic substances. Non-point sources of pollutants can include agriculture, erosion, impervious surface, motor vehicles, road salt, sedimentation, septic systems, and storm-water run-off. Although largely directed into the lake by a series of artificial inlets such as pipes and culverts, run-off into DeRuyter Reservoir appears to be characterized primarily by non-point sources of pollution.

Nutrients, primarily phosphorus (P) and nitrogen (N) are a major focus of lake management as excess **external and internal loading** of these nutrients fertilizes the lake and leads to higher primary production. Increased plant growth resulting from nutrient addition can interfere with recreation by impeding watercraft navigation. **Harmful algal blooms** can pose health risks to humans and animals, and overall, can also lead to a less resilient ecosystem where few species dominate.

Although 60 % of the DeRuyter Reservoir watershed is forested (Figure 3), run-off likely constitutes a substantial source of nutrients and contributes to sedimentation. This is due to a combination of activities such as agriculture and logging, presence of nuisance waterfowl, and pressure from septic systems, as well as the natural character of the landscape with steep slopes and poorly filtered soils.

Fortunately, there are many activities that can help to slow and filter run-off in the watershed. These actions vary with respect to time commitment, scale, and cost, but all have a common goal of reducing the amount of pollution entering the lake by slowing the course of water and/or filtering out contaminants from water. As the watershed of DeRuyter Reservoir is relatively small, only three times larger than the surface area of the lake, reductions to nutrient loading can be achieved, and will promote long-term protection of water quality.

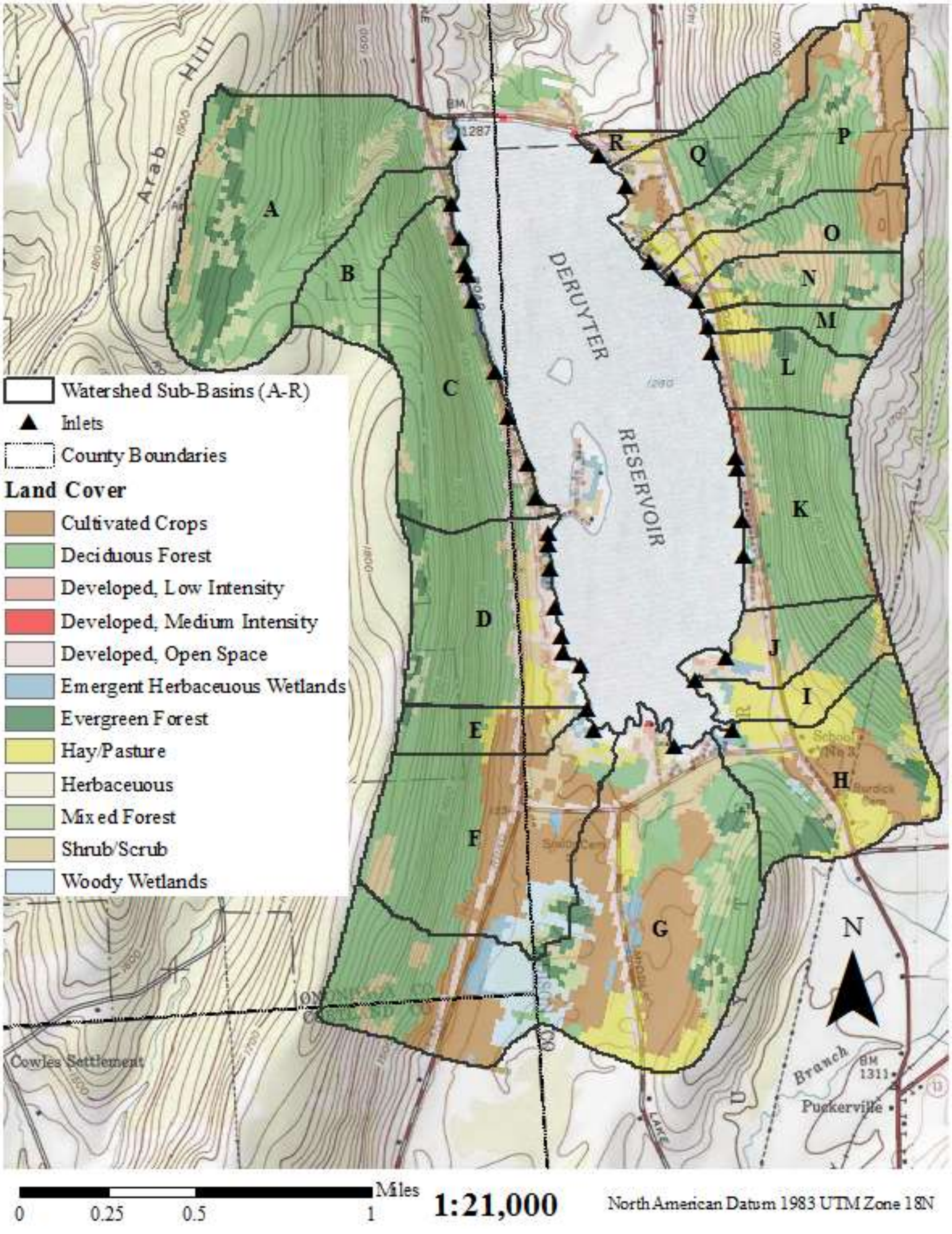


Figure 3. Land cover of the DeRuyter Reservoir drainage basin delineated by the U.S. Geological Survey *StreamStats* (Ries et al. 2008) with county lines. Estimated sub-drainage basins of specific surface water drainage patterns are given designations A through R. Thirty-four surface water inlets are designated by triangles. Sub-basins C, D, and K do not represent single inlets, rather general surface flow convergence into multiple, artificial inlets.

The need for water quality protection in the US was recognized in the early twentieth century. In the 1930s, Soil and Water Conservation Districts were developed for every county nationwide to assist landowners in practices to control soil erosion, conserve water resources, and protect water quality. More recently the US Environmental Protection Agency (EPA) developed 9 criteria for watershed management plans as an objective of their Nonpoint Source Program (EPA 2008). For successful watershed management, the following 9 elements must be addressed:

1. Identification of sources of pollution in the watershed
2. Identification of water quality goals
3. Identification of **best management practices** (BMPs)
4. Description of financial and technical assistance
5. Description of outreach and the role of stakeholders
6. Estimation of a schedule
7. Description of milestones
8. Identification of criteria for measuring water quality improvement, and
9. Description of a monitoring plan.

The EPA stresses the importance of adaptive management- each management activity must be implemented with the recognition that the ecosystem is dynamic (EPA 2008). A critical component of adaptive management is continued monitoring of responses to management actions. While watershed management activities as part of a comprehensive management plan generally don't result in immediately visible changes to the lake, the outcomes of these activities are intended to be long-lasting.

At the state level, the NYSDEC Division of Water provides support for watershed management projects through the Water Quality Improvement Project Program (https://www.dec.ny.gov/pubs/4774.html). Project categories relevant to the DeRuyter Reservoir watershed that may be eligible for grant funding include nature-based shorelines, storm-water retrofits, streambank stabilization/restoration and riparian buffers, and salt storage.

DeRuyter Reservoir has an average of 15 μg surface TP l^{-1} and 0.26 mg surface total nitrogen (TN) l^{-1}. Contrary to typical expectations of an increase in nutrient concentration with time, trends from CSLAP suggest no significant changes in TP or TN since 1988 (Table 1). Although there has been little change in nutrient concentrations since CSLAP monitoring began, it remains unknown what concentrations were prior to development around the lake. High concentrations compared to water column levels of both TP and TN at inlets in 2016 following rain events in September and December 2016 and at the main southern inlet in November suggest external loading of nutrients.

Early fall algal blooms and data collected in 2016 suggest **internal loading** (recycling of externally loaded nutrients) may contribute a significant source of nutrients during summer months. **Hypolimnetic** oxygen loss in August from decomposition is likely contributing to much of the internal nutrient loading. The onset of fall mixing then causes nutrients accumulated in the hypolimnion to move towards the surface where then HABs can occur. Few options exist to address internal loading in a moderately deep lake, such as DeRuyter Reservoir. Reducing initial external loading can help to decrease productivity in the lake which can slow the processes of internal loading over time.

Watershed management activities will help address multiple goals including preservation of current water clarity (4-5 m Secchi depth) and chlorophyll *a* (2-8 $\mu g\ l^{-1}$) and a decrease in surface TP (an annual average of 10 $\mu g\ l^{-1}$ P or less). These three parameters can be monitored from annual May-October CSLAP data and annual averages can be calculated.

To achieve these goals, stakeholders can strategize their implementation of management activities in the watershed through land use planning. Land use planning as a watershed management tool enables uniform action on both public and private lands. Land use regulations and local ordinances can be written to strengthen on-site wastewater treatment maintenance, ensure proper logging practices, and to enforce usage of riparian buffer zones. The Town of DeRuyter currently has a Lake-Watershed District written into its land use regulations. Various watershed BMPs to reduce external nutrient loading from human activities can be enforced through strengthened regulations. The Town of DeRuyter Lake Watershed District can be expanded with better defined boundaries- preferably to the boundary of the watershed. The Town of Fabius (and potentially the Towns of Cazenovia and Cuyler, though smaller) should mimic the DeRuyter Lake Watershed District.

Watershed Recommendation: Implement a variety of watershed BMPs to reduce non-point pollution, particularly P loading into the lake. The following suggestions are BMPs specific to DeRuyter Reservoir including developing legal protections through land use planning, maintaining septic systems, constructing riparian zones along the lake shoreline and inlets, keeping agricultural BMPs current, and reducing the nuisance waterfowl presence on the lake. Any combination of recommendations or alternatives will, to some degree, have positive benefits.

A. Wastewater Treatment Systems (WTS)

Onsite residential wastewater systems are used for wastewater treatment by landowners in the DeRuyter Reservoir watershed. Undertreated wastewater carries nutrients and bacteria that, if released in a lake, may have negative impacts on water quality. While failing systems can directly pollute a lake (point pollution), presence of many septic systems, operating, but old or unmaintained, can cause a slow increase in the loading of these pollutants over time (non-point pollution).

WTS Recommendation: Update land use planning to focus on continued maintenance of septic systems for the entire watershed. Updates should include improved enforcement of codes through regular inspection and requirements that septic system owners supply information on their system upon request (e.g., type, capacity, location, usage, age, maintenance, etc.).

- **Alternative:** Update land use planning to expand the boundary to a buffer larger than 100 ft (30.5 m) from shore in the Town of DeRuyter and develop identical protocols for properties within the Town of Fabius.

- **Alternative:** Develop a series of cluster systems in the watershed in which waste from multiple residences is directed to a single location, and far removed from the lake where it is treated. Cluster systems may be fairly large in capacity. Smaller versions of cluster systems resemble large on-site systems, whereas medium-to-large versions include a treatment component before water is dispersed. Cluster systems allow an optimal mixture of wastewater treatment options to best fit the community. The Cluster Wastewater Systems Planning Handbook (Lombardo 2004) provides a thorough framework for planning the use of cluster systems. While this management strategy could be costly, grants may be available to help offset the cost.
- **Timeline:** This is a long-term activity that will be achieved at the discretion of individuals willing to pursue these changes to be made in town land use regulations. Once these regulations are updated, enforcement must occur annually.

B. Storm-water Run-off

Storm water management focuses on capturing and filtering rain water that falls in the watershed before it enters the lake. Climate change is predicted to be increasing the frequency of flooding events, so BMPs should be used to mitigate these effects. A major focus of storm water management is in the reduction of **impervious surfaces** (Arnold and Gibbons 1996). Areas of focus include roadway management, forestry BMPs, and riparian corridor management. Some strategies are more involved and expensive than others, but any changes made should have a positive benefit on the lake in the long-term.

Impervious surfaces, inherent with human presence, are a relatively new addition to ecosystems. The root issue caused by roads and other impervious surfaces is the alteration of the natural water cycle. Other than general habitat destruction for native biota, increased impervious surfaces in watersheds lead to increased run-off and flooding, lower water tables due to less ground water infiltration, and increased erosion and sedimentation. Although a small watershed, DeRuyter Reservoir includes State Rt. 13 as well as several local roads.

Roadway management is intended to ensure storm water that is redirected by the presence of a road is sufficiently filtered before entering a lake. Activities generally involve using artificial structures along major roadways that capture water and settle out sediment and pollutants before the water reaches the lake (e.g., sediment basins or swirl concentrators). Agencies responsible for road maintenance should be identified and encouraged to install these structures where possible, as well as continue maintenance for optimal function. Private landowners in the watershed can also contribute to reducing impervious surfaces with rain gardens, rain barrels, and directly reducing the amount of paved surface on their property.

Forestry BMPs should be used to reduce the release and transport of sediment and dissolved organic material that adversely affect surface and ground waters. Examples include planned harvest operations, watercourse crossings, access routes, riparian buffer protection, road water management, sediment barriers, vegetation establishment, and hazardous material management. A manual developed by NYSDEC, NYS Forestry Best Management Practices for Water Quality provides a framework for integrating these practices into forestry operations (NYSDEC 2011).

It is estimated that in the past 200 years more than 80 % of riparian corridor in North America and Europe have been lost to development (Naiman et al. 1993). **Riparian buffer zones** are vegetated lands that border waterways including streams, rivers, lakes, and reservoirs. They provide many ecological benefits including water quality protection, stream bank stabilization, erosion and sedimentation reduction, slowed non-point source pollution (nitrogen, phosphorus, heavy metals), reduced flooding, shade (which controls temperatures to support aquatic life), and food and habitat for desirable wildlife. Riparian buffer zones additionally provide aesthetic & visual quality for landowners, privacy, sound reduction, and prevention of nuisance waterfowl (Bentrup 2008). They can help mitigate effects of climate change such as prolonged droughts and more frequent, intense flooding events.

Riparian buffer zones are defined by soil, landform, and vegetation constructed in three dimensions containing a combination of trees, shrubs, flowers, and grasses (Bentrup 2008; Figure 4). Riparian buffer zones are most effective in small headwater streams, but also provide benefits directly along lake shorelines (Bentrup 2008). The US Forest Service provides a guideline on riparian buffer zone width according to the slope of the landscape; steeper slopes require a wider buffer (USDA Forest Service 2004; Table 3). An overarching goal of riparian buffer zones is to promote “ecological diversity,” including the presence of both a diverse array of native species and ecological processes (Naiman et al. 1993) which, in turn, will promote an overall more resilient ecosystem.

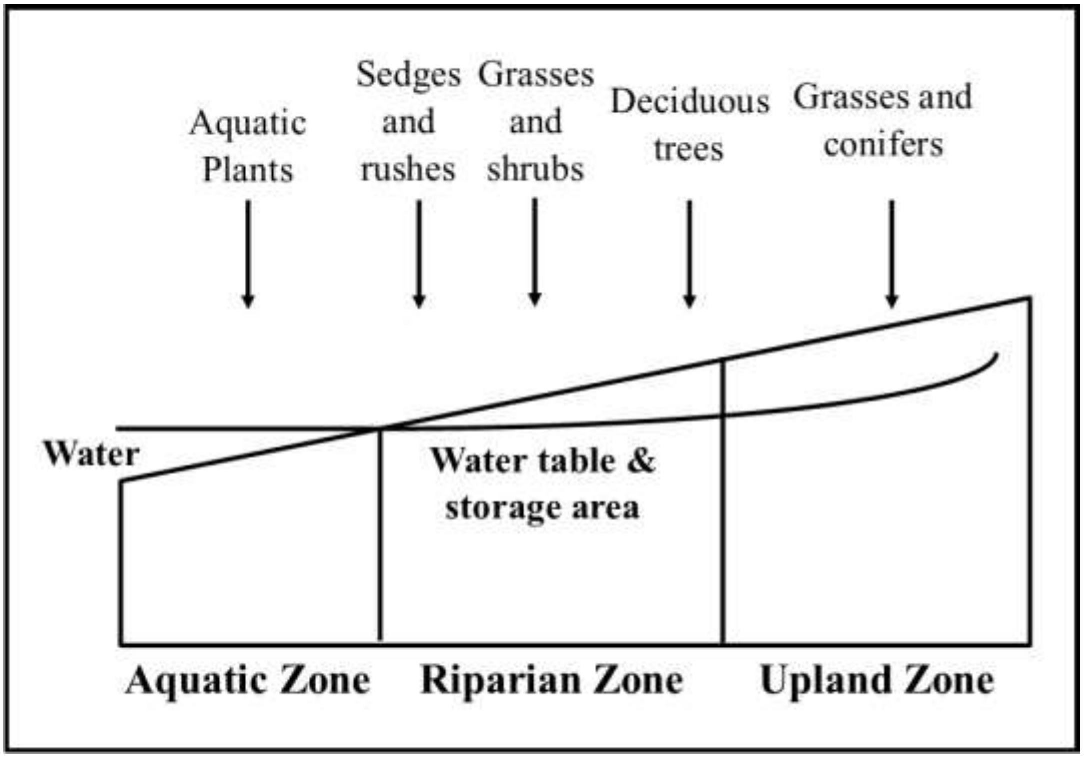


Figure 4. Example of a typical riparian zone design.

Table 3. Recommended buffer widths for riparian buffer zones based on slope of the watershed where it meets a stream or the lake's shoreline. Values are adjusted slightly to best fit the watershed (Modified from USDA Forest Service 2004).

Slope (%)	0-10	11-40	41+
Buffer width (ft)	100	125	150

Storm water Run-off Recommendation #1: Build vegetation buffers along inlets and the lake shoreline reflecting standard widths (Figure 5). Focus areas should be prioritized by **sub-basins**, delineated by localized water flow. Sub-basins with portions of stream in zone 3 should be of primary focus (basins A, B, I, P, and Q). Additionally, both eastern and western portions of the watershed have steep slopes. Landowners along these portions of the shoreline should focus efforts on riparian zones as well as other landowner strategies for slowing storm run-off such as rain barrels, rain gardens, keeping mowed lawn space to a minimum, especially at the water 's edge, and not fertilizing lawns. There are many online resources on methods and recommended plants, or you can contact your Madison County Cornell Cooperative Extension or Soil and Water Conservation District for advice.

- **Alternative:** Build vegetation buffers at minimized widths to the discretion of landowners.

- **Timeline:** This is an ongoing management activity. Full buffers should be completed over 5 years, by 2022. Sub-basins with areas in zone 3 should be prioritized, then zone 2, then zone 1 last. However, east and western shorelines should also be considered a priority due to steep slopes and less direct water flow.

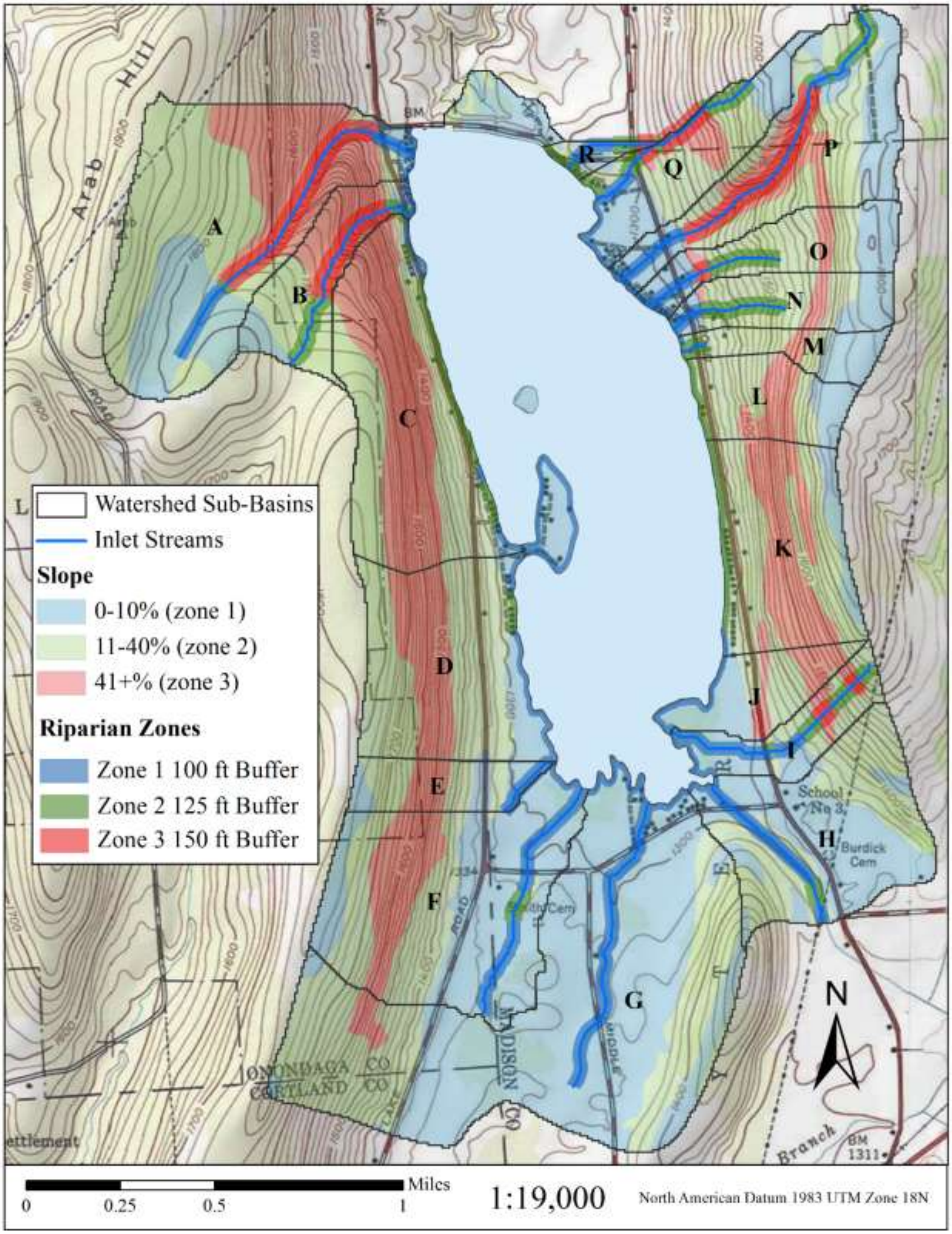


Figure 5. Riparian buffer zones delineated by slope of the landscape (Soil Survey Staff et al. 2017) and modified US Forest Service zone designations. Sub-drainage basins A-R are delineated based on the US Geological Survey.

It is very important that planted vegetation be native species. Two invasive wetland plants are already present along the lake's shoreline – common reed (*Phragmites australis*) and Japanese knotweed (*Fallopia japonica*). These plants should be removed if possible or at least suppressed from further spread. Removal should occur early in the growing season prior to seed production, fragments should be burned, and any remaining root stock should be chemically treated. Where possible, *Phragmites* stalks should be cut below the water's surface to flood the remaining stalks. For invasive plants along roadways, stakeholders must communicate with the county highway department to advocate for early season mowing to prevent new seeding and further spread.

There are state (NYSDEC Trees for Tribs and Water Quality Improvement Project Program) and federal (Chesapeake Bay Watershed Grant Program and Sustain our Great Lakes©) grant opportunities to assist in building riparian buffers. Plants can be found at local plant sales through organizations such as the Madison County Cornell Cooperative Extension or nurseries. Stakeholders can work with these organizations to host a plant sale for DeRuyter Reservoir residents.

Building riparian buffer zones provides opportunities to partner with other stakeholder groups. Farmers within the watershed can develop vegetation strips around their farmland, functioning to slow and filter run-off in the same ways buffers do along shorelines. Federal subsidies are available for farmers to complete these activities. Lake residents can partner with angler groups with shared interests, such as Trout Unlimited, to build streamside riparian buffers because streambank stabilization can also improve fish habitat, and these organizations have a long history of advocacy and implementation of protective measures. Partnerships such as these can also make restoration projects more attractive to funding groups because proposed projects would address concerns of multiple groups at once.

Storm water Run-off Recommendation #2: Add measures for riparian zone protection to local land use regulations for the area within the Lake Watershed District.

- **Timeline**: This is a long-term process that should be done in conjunction with other updates to land use regulations such as watershed septic system maintenance requirements.

C. Agriculture

About 23% of the DeRuyter Reservoir watershed is agricultural land encompassing three major farms, all of which are located in Madison County. These farms are currently working with the Madison County Soil and Water Conservation District (SWCD) to design and implement agricultural BMPs for nutrient management.

Agriculture Recommendation: The TLPF and TLA must develop a working relationship with the SWCD to assure stakeholder interest in water quality, ensure enforcement of agricultural BMPs by farmers, and work with the SWCD and farmers to ensure an optimal solution.

- **Timeline:** As there is currently no immediate concern with agriculture, this is an ongoing recommendation that should be revisited when a concern arises.

D. Nuisance Waterfowl

Presence of Canada geese (*Branta canadensis*) on waterbodies and along shorelines causes loading of nutrients and bacteria into a lake through their feces (Manny et al. 1994). Over the course of the lake management study (2015-2016), large populations of Canada geese were frequently observed residing in and around DeRuyter Reservoir. Reducing the goose population will contribute to reducing external nutrient loading. The United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) provides services in managing Canada geese and other nuisance waterfowl encouraging an integrated approach of multiple techniques for long-term management. Their services typically involve capture and relocation or removal (https://www.aphis.usda.gov/publications/wildlife_damage/content/printable_version/fs_waterfowl.pdf). Additionally, there are a number of management options for private property owners, some requiring a permit and others not (Table 4). It is recommended that any combination of these methods should be used to control Canada goose populations on the lake to slow external nutrient loading. One strategy is nesting prevention such as shaking eggs, oiling eggs with corn oil, puncturing eggs or chilling eggs. This requires a permit from US Fish and Wildlife Service that should be acquired if a landowner has a nest on their property. Modifying shoreline landscape to add vegetation will discourage geese and provide a **riparian buffer** to slow run-off as well.

Table 4. Accepted goose management activities. Any combination of these strategies should be encouraged for private landowners with high goose presence (Modified from www.aphis.usda.gov).

Activity	Strategies	Permit required?
Discourage feeding of waterfowl	• Signage at public areas, outreach through newsletters and/or social media	No
Modify the landscape	• Tall un-mowed grass or shrubs planted on shoreline properties as opposed to short green grass • Install barriers such as fences or hedges to control movement	No
Use scaring devices	• Loud noises • Pyrotechnics	No
Tamper with eggs	• Shaking • Oiling (corn oil) • Puncturing • Chilling	Yes (USFWS)
Direct removal	• Hunt (follow New York's Harvest Information Program for annual open season and take limits)	Yes (NYSDEC)

Nuisance Waterfowl Recommendation #1: To landowner's discretion, any combination of strategies outlined in Table 4 should be deployed to reduce goose populations. For example, if a nest is found on a landowner's property, they can acquire the proper permitting to tamper with eggs, etc.

Timeline: Management strategies for nuisance waterfowl is to be implemented indefinitely as issues arise at the discretion of landowners.

E. **Road Salt**

A recent topic of concern for watershed management is the effect of increased salinity on aquatic systems as a result of winter road salting. Although there are still a lot of unknowns on the extent of associated ecosystem degradation, there is a clear increase in sodium and chloride (the ingredients of standard road salt, the same as table salt) concentrations in northeastern US waterbodies near roads (Godwin et al. 2003, Likens and Buso 2009). While there is currently no apparent direct ecological damage from road salt in DeRuyter Reservoir, it may become a problem in the future.

While alternative chemicals to standard road salt are available, they tend to be more expensive and the extent of their environmental impacts are uncertain. Fortunately, there are a number of ways to reduce road salt and, therefore, de-ice streets in the winter through more economically and environmentally efficient ways. Kelly et al. (2010) proposed ten ways to minimize road salt use, including the use of Road Weather Information Systems, equipment calibration, only filling trucks with the amount of salt necessary for the route, use of temperature sensors, retrofitting trucks with applicator regulators, pre-wetting salt, use anti-ice strategies as opposed to de-icers, if using sand only use 5 % salt in your mixture, try alternative chemicals, and properly training truck drivers. Though not aligned with direct water quality goals of DeRuyter Reservoir primarily focused on lake productivity, loading of chloride is an area for stakeholders to be vigilant of as the lake is surrounded roadways that are salted in winter months.

Road Salt Recommendation: Express interest in road salt reduction with the goal of protection of native aquatic life to state and local highway departments. Develop a plan for reduction in the watershed. This may be an opportunity to work with other lake associations in Madison County.

- **Timeline:** Discuss feasibility of different strategies with county and state entities during winter of 2018-2019 to develop a road salt management plan to bring into implementation in winter of 2019-2020.

II. In-Lake

Many ‘lake issues’ are a direct result of undesirable biota or human activities within the lake, and in some cases watershed management alone is insufficient for providing preferable conditions. Rather, they are best addressed with **in-lake management strategies**. Examples of these issues can include, but are not limited to, boating safety, the introduction of invasive plants and animals, internal nutrient loading, and shifts in algal community dynamics. Additionally, interactions between these issues can exacerbate other problems in lakes, such as water quality concerns associated with the entrance of zebra mussels (*Dreissena polymorpha*). By understanding lake ecology, strategic management decisions can be made to mitigate potential problems for long-term resiliency.

A. Recreational Use

During peak weekends of summer, high volumes of boat traffic are observed on DeRuyter Reservoir creating potentially dangerous situations. Installing no wake zone buoys will help to slow down boaters in potentially hazardous areas and promote safe boating in the lake. Per New York State Navigation Law, within 100 ft (30.5 m) from the shoreline, a dock/pier, a raft/float, or an anchored vessel is a no wake zone (5 mph maximum speed) in any waterbody (NYS NAV § 45). To install buoys, Floating Object Permits must be submitted to the NYS Office of Parks, Recreation, and Historic Preservation Marine Services Bureau. Increasing the no wake zone to 200-500 ft from shore would also be beneficial for macrophyte management and erosion prevention. Figure 6 shows where no wake zones could be deployed in the lake at five intervals 100, 200, 300, 400, or 500 ft in relation to the lake’s **littoral zone**.

No wake zone buoys should be installed so that at least one is always visible when in the no wake zone. The number of buoys is dictated by the amount the TLPF and the TLA are willing to purchase and based on interest in a team to install and remove the buoys every year. It is recommended that a volunteer team be assembled to undertake and oversee this process.

Recreational Use Recommendation #1: Install no wake zone buoys at 500 ft from the lake's shoreline.

- **Alternative:** Install no wake zone buoys at a buffer less than 500 ft from shore, at a minimum of 100 ft.
- **Timeline:** Buoys should be installed by summer 2019 and re-installed annually.

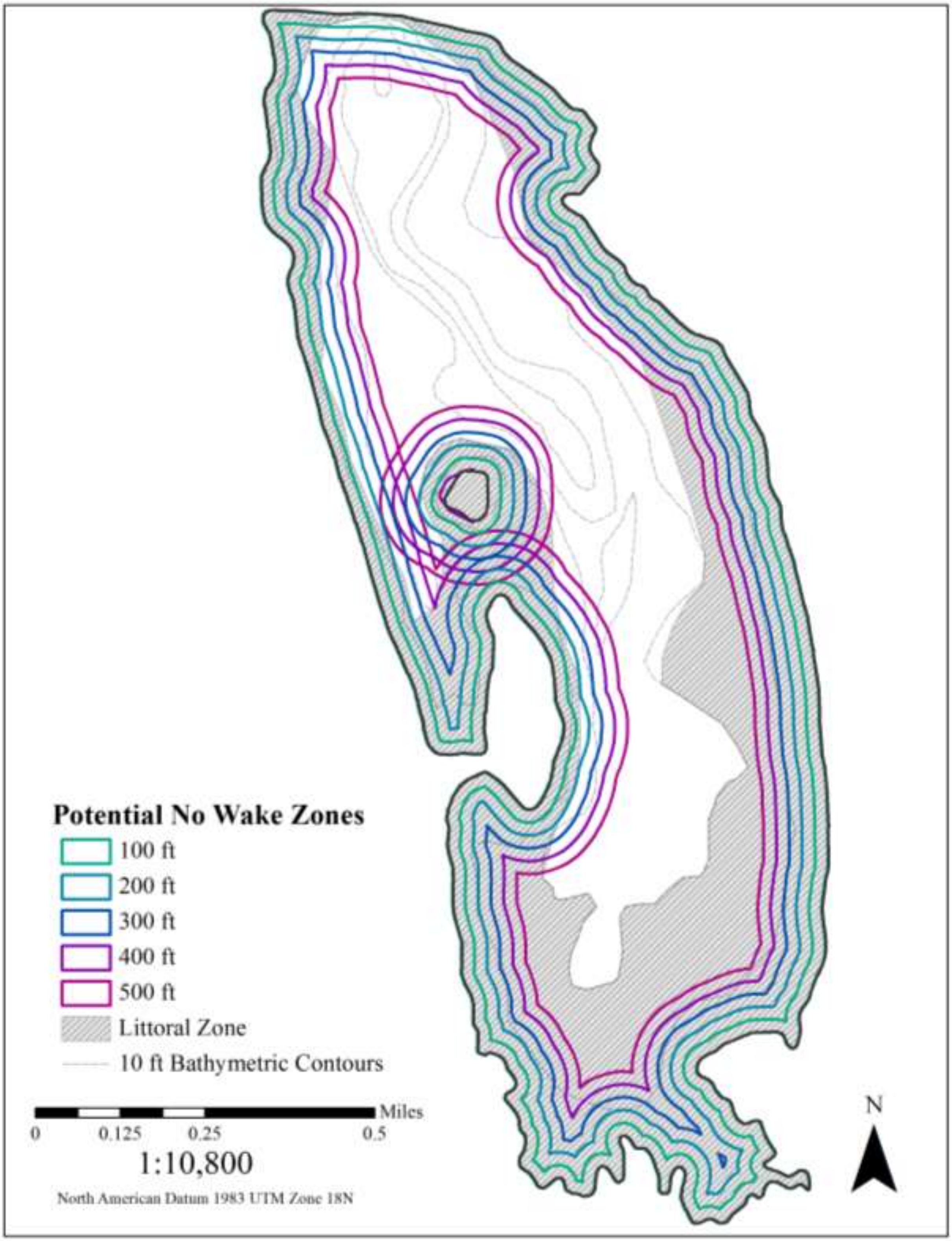


Figure 6. Inner buffers of DeRuyter Reservoir representing the potential 100 (standard), 200, 300, 400 and 500 ft no wake zones over current plant growth in the lake.

B. Primary Production

a. Harmful Algal Blooms (HABs)

DeRuyter Reservoir experienced short-lived, visible HABs in September and October 2016 consisting of species with potential for toxin production (*Dolichospermum sigmoideum*, *Microcystis* sp.). These events happened during fall mixing, when surface water temperatures decrease as air cools, and less dense warm water, potentially with higher nutrient concentrations due to internal loading from the sediment, rises to the photic zone. Although the 2016 blooms subsided within approximately 48 hours, now is the time to take preventative measures so the lake does not produce more persistent blooms in the future. Watershed management BMPs involving septic systems, storm-water run-off, agriculture, and riparian zones will help decrease external nutrient loading into the system, preventing unwanted increases in algal productivity. Refraining from harvesting large amounts of plants from the lake at once may also help to prevent algal blooms. HAB Recommendations will help to address water quality goals, as well as recreational safety goals.

HAB Recommendation #1: While current management recommendations for HABs are preventative, it is also recommended to have prepared a response plan for when a HAB occurs. Reports of HABs can be made to NYSDEC using their Suspicious Algal Bloom Report Form found on their website. Take photos and notes of any details. Follow recommendations from NYSDEC on whether contact recreation in the lake should be discouraged or if conditions remain safe. Lake users should be kept informed with the status of the situation. HABs can also be reported to national databases such as Lake Observer (https://www.lakeobserver.org/) or bloomWatch (https://cyanos.org/bloomwatch/).

- **Timeline:** A response plan should be developed immediately and enacted if and when a HAB occurs in the lake.

HAB Recommendation #2: Work through watershed management activities to reach goals related to average annual TP reduction. Continue monitoring surface water TP through CSLAP.

- **Alternative:** Use spot chemical treatments, such as a copper based algaecide, in areas affected by algal growth. This is a short-term strategy used to manage growth of algae or cyanobacteria within the season if it is creating a problem for lake users (i.e., inhibiting swimming). This will not prevent HABs in the lake in future years. Long-term reliance on this tool can lead to accumulation of copper in the lake sediment to a toxic level.
- **Alternative:** New technologies in phosphorus inactivation or interception by aluminum compounds, most often aluminum sulfate (alum), are available in most of the US. While currently not permitted in NY, if legislation is changed, this could be a useful tool to prevent HABs in DeRuyter Reservoir used either in the water column or as a drip system at the main southeastern inlet in which much of the external loading occurs.
- **Timeline:** The recommendation is a long-term strategy to be monitored and re-evaluated annually by CSLAP chlorophyll *a* measurements. Alternatives can be used if the need for more immediate management of HABs was deemed necessary.

b. Nuisance/Invasive Macrophytes

The term **macrophyte** refers to any plant (vascular or non-vascular) or macroscopic alga (typically those of the order *Charales* in freshwater) growing in a body of water. Three known species of non-native macrophytes are present in DeRuyter Reservoir: *Myriophyllum spicatum* (Eurasian watermilfoil; EWM), *Potamogeton crispus* (curly leaf pondweed; CLP), and most recently, *Nitellopsis obtusa* (starry stonewort; SS). A variety of management strategies have been implemented, generally focusing on direct harvesting of plant material and more recently with biological control, with less stakeholder satisfaction than desired.

According to the 2016 watershed public opinion survey, about one third of watershed residents were satisfied with current methods (Figure 7). A consensus among residents supported the uses of biological control and physical removal as management strategies. However, support of chemical usage (i.e., herbicides) was not similarly unanimous (Figure 7). Management alternatives will therefore focus on various types of the first two categories (biological and physical), but some general direction are described below should the latter route (chemicals) be chosen in the future.

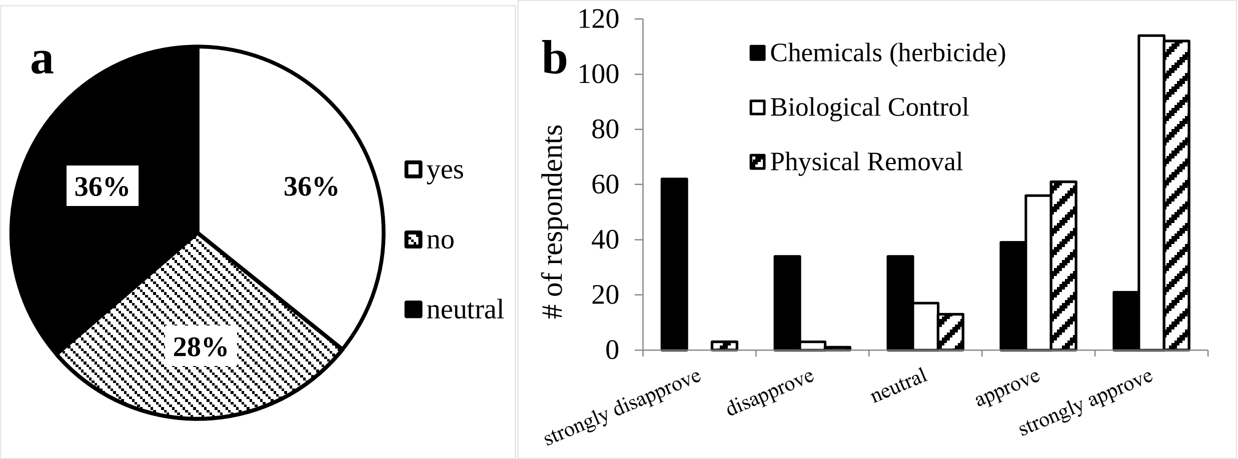


Figure 7. Results of watershed public opinion survey regarding **(a)** if the respondent is satisfied with current plant management strategies used in DeRuyter Reservoir and **(b)** if the respondent approves of chemical, biological, and physical control strategies for plant management in the lake.

Macrophyte management goals will be primarily focused on the overall long-term management of the lake and will therefore must address the potential for indirect impacts and unintended consequences. The focus will be removal of **invasive species** for reestablishment of native biodiversity with the overarching goal of restoring a resilient, macrophyte dominant system, as opposed to an algal dominant system with a potential for toxic blooms. Management goals will also take into consideration impediment of recreational use, including boating and swimming, by macrophyte growth.

Macrophyte Management History

TLA meeting notes from 1963 marked the first discussion of "weed problems," likely referring to the introduction of EWM. Beginning in the late 1980s, and still occurring annually in summer, the TLA contracts out the use of a mechanical harvester to remove EWM from areas of the lake in which its growth impedes recreation. In 2013, CLP was discovered in the lake.

In 2014, two invasive plant control projects began with funding from the TLPF. CLP was removed through hand pulling by suction harvester with dissatisfaction. This method was deemed inefficient by the TLPF in terms of cost and biomass removed. In 2015 and 2016, CLP was harvested by mechanical harvester as EWM has been, but done early in May or June. Also beginning in 2014, an experimental, long-term biological control project to manage EWM began. The TLPF contracted a researcher to study the presence of macroinvertebrates known to feed on EWM in DeRuyter Reservoir. Based on currently present insects, damage on EWM tips likely caused by those insects, and the fish community structure, it was recommended for walleye (*Sander vitreus)* to be stocked annually. Walleye stocking was intended to induce a trophic cascade with the goal of reducing abundance of sunfishes in the lake, increasing insect population density due to less predation pressure from the sunfishes, and therefore reducing EWM to desirable levels (Lord and Pokorny 2013, Lord et al. 2015, Lord and Reyes 2016, Lord 2017). The project was planned to take course over a 6-year period.

The TLPF and TLA were made aware of the SS introduction in the summer of 2016. The distribution of the macroalga in the lake was evaluated for the potential of an early detection-response in 2016, but was found too densely spread throughout the lake. No control of SS has been implemented to date. However, successful management of SS in its introduced range in the United States is poorly understood at this time.

Current Status

CLP

Residents seem to be most satisfied with the early season large-scale mechanical harvesting of CLP (funded by TLPF). Although CLP (Figure 8) typically dies off by early July, its growth restricts early season boating. Removing CLP from the lake prevents nutrient remineralization and oxygen loss from large biomass die-offs. Harvesting will help to prevent growth of new plants by seed throughout the lake, but will not prevent those individual plants from growing in subsequent years. CLP **turions** can remain buried and viable in the sediment for many years. These turions need to be removed from the sediment if eradication is intended.

Figure 8. Pressing of curly leaf pondweed from DeRuyter Reservoir, July 2016.

Potential indirect impacts:

- Large-scale harvesting in areas with CLP will likely kill and/or remove desired herbivorous insects from the lake, reducing their abundance, thereby diminishing biological control efforts for EWM.
- A mechanical harvester is non-selective. Removal of many native plants is largely unavoidable.
- Clipping fragments of CLP and other non-target plants that reproduce vegetatively can cause further spread around the lake.
- Slowing the growth of plants in the lake can cause a shift to more algal and cyanobacterial growth as nutrients that would otherwise be used by the plants become available to algae.

EWM

As a result of the TLPF's research-based EWM management project, four species of insects have been found growing on EWM plants from DeRuyter Reservoir including the milfoil weevil (*Euhrychiopsis lecontei*), the milfoil midge (*Cricotopus myriophylli*), the aquatic macrophyte moth (*Acentria ephemerella*), and a long-horned caddisfly (Family Leptoceridae). These insects were not stocked into the lake, and there is no intention of stocking insects due to concern of a quick loss from fish predation. They are found mostly at low densities with some damage to stems and leaves. The TLPF is following the recommendation by the researcher to stock walleye fingerlings for 6 years as an attempt to reduce predation on the herbivorous insects by sunfish (Lord 2017). Walleye was chosen due to its fast growth rate in the northeast (detailed recommendations on fisheries management, including the stocking of walleye, can be found in the fisheries section). Currently, small population sizes of each insect species, as well as the small amounts of damage on EWM tips suggest that predation pressure on these insect populations is too high for successful bio-control.

In a study of central NY lakes, Johnson et al. (2000) found that the milfoil weevil and aquatic macrophyte moth competed for resources such as food and space. Large populations of the two species did not exist simultaneously in any lake, while one species dominated over the other in population size. Based on my review of the literature, the aquatic macrophyte moth is likely to be most successful in controlling EWM in DeRuyter Reservoir as compared to the other present insects.

Due to the morphology of DeRuyter Reservoir, current lake management practices, and the distribution of EWM throughout the lake, the aquatic macrophyte moth should be more successful in controlling EWM than the milfoil weevil. Biocontrol of EWM with the milfoil weevil has shown most success in small, shallow ponds where EWM grew essentially as a **monoculture** throughout the whole lake (Johnson et al. 2000). In those situations the milfoil weevil easily moved between individual plants. DeRuyter Reservoir is relatively larger and deeper than the studied ponds and EWM growth is patchy (EWM does not grow in large monocultures throughout the lake). It grows in small patches alongside other macrophyte species. The moth can easily move between EWM beds due to its ability to fly. Additionally, the aquatic macrophyte moth is more likely to survive the annual winter drawdowns in DeRuyter Reservoir as it overwinters on its host plants, not in soils along shore as the milfoil weevil does.

Figure 9. Pressing of Eurasian watermilfoil from DeRuyter Reservoir, July 2016

Potential indirect impacts

- There is no known negative effect of stocking walleye into the lake. An increase in population size of a top predator into a waterbody can also generally contribute to a reduction in feeding pressure by small fish on zooplankton, leading to survival of more large-bodied native zooplankton, and subsequent reduction in algae due to their grazing.

In addition to the bio-control project, the TLA funds annual large-scale mechanical harvesting of EWM, typically in late July. This occurs in littoral areas with dense EWM growth occurring throughout the lake with the goal of opening up the lake to boater traffic.

Potential indirect impacts:

- Large-scale harvesting in areas with EWM will likely kill and/or remove the desired herbivorous insects from the lake, as they spend all or most of their lives on individual EWM plants (Sheldon and O'Bryan 1996). This will reduce the size of their population, therefore reduce effectiveness of biological control efforts.
- A mechanical harvester is non-selective. In addition to the targeted EWM, removing many native plants that must reproduce by seed is largely unavoidable. EWM almost always grows alongside native plants as opposed to as a **monoculture** in DeRuyter Reservoir.
- Creating fragments of CLP, and other non-target plants that reproduce vegetatively can cause further spread around the lake.
- Slowing the growth of plants in the lake can cause a shift to more algal and cyanobacterial growth as nutrients that would otherwise be used by the plants are now available.
- Decomposition of plant fragments generated from harvesting may decrease water column dissolved oxygen and therefore, cause internal loading of nutrients. This could be contributing to increased algal growth in August and September.

SS

Starry stonewort presence in the lake was first known to stakeholders in summer 2016 (Figure 10). It was already widespread within the lake, precluding an early detection response. Little research has been done on this macroalga (Pullman and Crawford 2010). As it spreads throughout inland lakes of the Great Lakes basin, the need for research is apparent and underway.

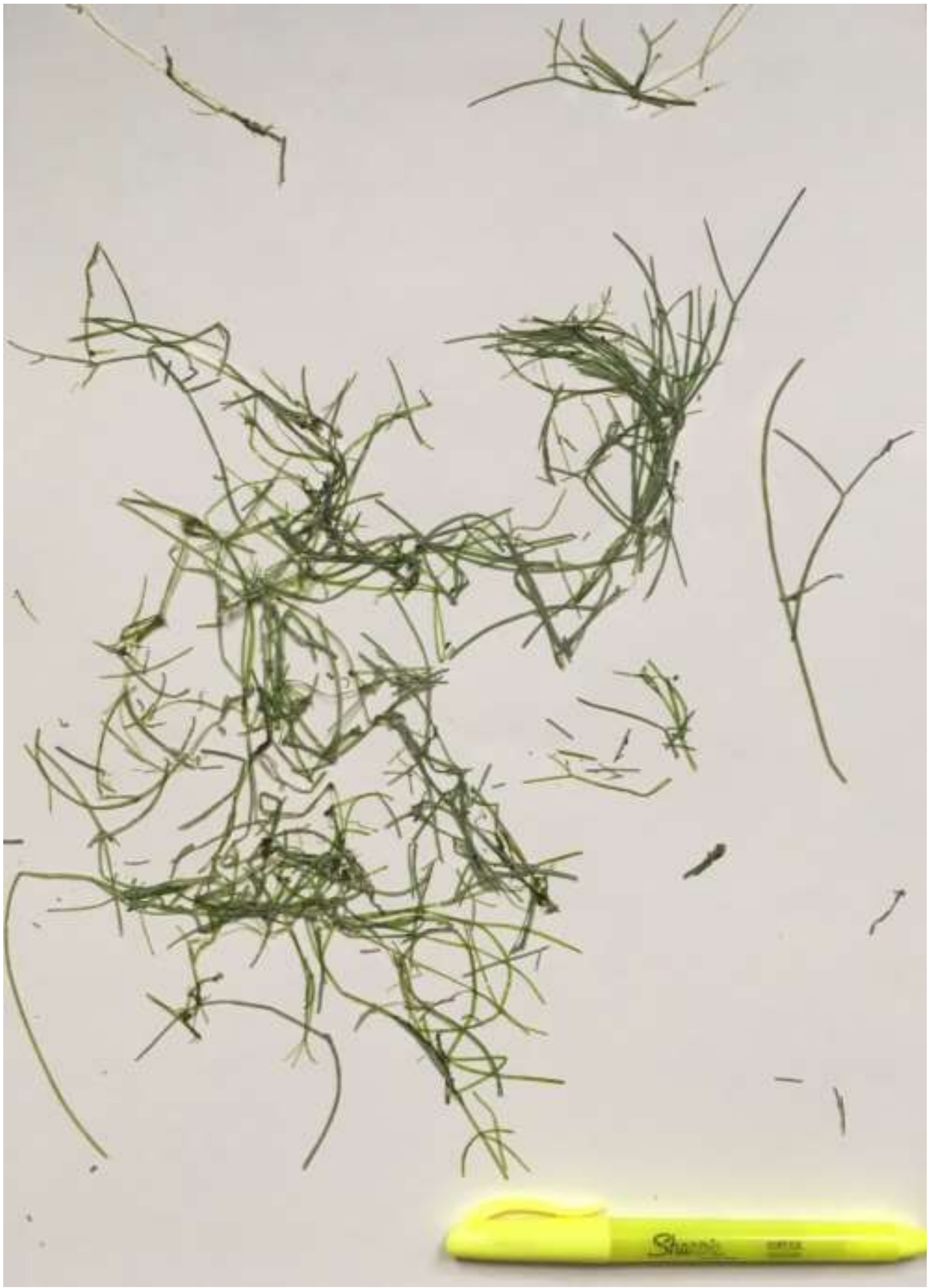


Figure 10. Pressing of starry stonewort from DeRuyter Reservoir, September 2016.

Macrophyte Recommendation #1: Stop mid-season mechanical harvesting of EWM.

- **Alternative:** Reduce the amount of lake area where EWM is harvested by developing harvesting zones. This will be less harmful to the herbivorous insect populations. The size of harvesting zones can be gradually decreased annually. Additionally, during harvesting events, a boat or boats should follow the harvester with nets to pick up fragments to prevent further spread around the lake. Use Appendix A to maintain macrophyte harvesting records so that effectiveness of mechanical harvesting can be evaluated objectively.
- **Timeline:** This can be implemented immediately. If alternative is chosen, harvested area should be decreased each year.

Macrophyte Recommendation #2: Continue harvesting CLP early in the season to prevent further growth and to prevent the development of overwintering turions. This will also help to prevent oxygen loss by large biomass die-off. Harvest as selectively as possible and have a boat follow harvester to collect fragments by net. Each year assess extent of CLP and collect information on harvesting event to evaluate effectiveness of the harvesting program (Appendix A).

- **Alternative:** Stop harvesting CLP. This will allow insects to continue population growth unharmed; CLP dies back by early July, typically right before the peak of summer recreational use. However, leaving the plants to eventually die and decompose can lead to favorable conditions for harmful algal blooms.
- **Timeline:** Continue current strategy and re-access need each year.

Macrophyte Recommendation #3: Installing no wake zone buoys promotes safer boating, but can also result in ecological benefits. Extend the width of the no wake zone to prevent mechanical fragmentation by boat propellers and therefore further spread of nuisance macrophytes, as well as stabilize the shoreline near major inlets by preventing erosion and, in turn, nutrient release in the most southern region of the lake. Extending the zone to 500 ft is preferred, but any width between 100 and 500 ft can provide benefits (Figure 6).

- **Timeline:** Buoys can be purchased and installed by summer 2019.

Macrophyte Recommendation #4: Stay abreast with advances in the field of SS management. This is a current topic of concern in NY and other states in the Great Lakes basin. Lake managers in neighboring states are finding success with the use of copper compounds. While this may provide sufficient SS control, there may be concern with regulatory constraints by NYSDEC with high of copper levels in sediment (>33 mg/kg Cu dry weight).

- **Timeline:** Ongoing. As new management strategies arise each should be assessed for feasibility in DeRuyter Reservoir.

General Macrophyte Management Alternatives

The following management strategies are listed as alternatives to the preceding recommendations should the more desirable recommended strategies not be feasible, results do not satisfy stakeholders, or a different species be introduced to the lake. These alternatives are not specific to certain taxon.

- **Alternative:** Install benthic mats. Benthic mats, also called benthic barriers or lake blankets, are a material, typically tarp, laid over an area to block light and prevent plant growth. These are best suited for small, newly infested areas or high use areas such as a beach. Benthic mats must be properly maintained, including removal at the end of each growing season. Those using a benthic mat must understand that all organisms in the covered area will not survive and they are therefore not suitable for areas with rare or otherwise desirable species.

- **Alternative:** Increase the height of the annual fall drawdown by 10-20 ft to expose the sediment and therefore desiccate rootstalk and seed banks. This activity may also kill desirable native species. Conversely, some species, including some invasive macrophytes, tend to be more successful in years following drawdowns (Cooke et al. 2005). In addition, unpredictable weather patterns, such as a spring with low snow melt and below average precipitation, may lead to low lake levels during the following summer.

- **Alternative:** A 'drum harvester' can harvest entire plants including the roots (e.g., Eco Harvester: http://www.lakeweedharvester.com/eco-harvester/). This machine can be a more long-term strategy for control and eventual removal of EWM and CLP from the lake. The use or purchase of this type of harvester (~$70,000) would be more expensive than what is typically used.

- **Alternative:** Stocking sterile grass carp (*Ctenopharyngodon idella*) a bio-control can be a popular, inexpensive strategy. When the grass carp is stocked at the recommended rate, it can be a successful management tool. However, grass carp tends to prefer other macrophytes over EWM (Dibble and Kovalenko 2009) and would potentially eat much of the native vegetation in DeRuyter Reservoir first.

- **Alternative:** If stakeholders are still unsatisfied with macrophyte growth in the lake, herbicide treatments are available. There are two main modes of action of aquatic herbicides- contact and systemic. Contact herbicides are fast-acting as they damage the plant tissue upon contact, whereas systemic herbicides are slower acting because they are absorbed by the plant and translocated to the stem, leaves, or roots, causing damage at critical growth points. Different herbicides are appropriate for different scenarios and management goals. Sometimes a combination of these two types are successfully used. There are various herbicides available that can be selective to the species of concern, allowing desirable native species to persist through treatments. If this alternative is used, the goal for the project must be established, whether that is eradication of a specific species, short-term control of macrophyte growth in the lake for ease of recreation, or to address other concerns.

C. Fisheries

Recreational angling is popular on DeRuyter Reservoir by residents and visitors. Weekly tournaments in summer months are held for largemouth bass (*Micropterus salmoides*; LMB). Anglers are also interested in catching walleye (*Sander vitreus*) and sunfishes (*Lepomis spp.*) recreationally. Anecdotal concern about decreasing sizes of LMB in recent years was expressed by anglers at DeRuyter Reservoir. However, 2016 surveys showed a stable size distribution of largemouth bass in the lake (Paul Lord, SUNY Oneonta, unpublished data). Over time, changes in the macrophyte community due to invasive species such as starry stonewort may affect LMB populations (i.e., decreased structure for sunfish habitat may lead to increased mortality and reduced reproduction, which may lead to reduced food availability for LMB.) Local anglers anecdotally report traditionally fishing for LMB in beds of large leaf pondweed (*Potamogeton ampifolius*). According to the 1934 biological survey of the lake (NYS Conservation Department 1934), large leaf pondweed was a dominant plant at the time. However, surveys in recent years (2011 – 2016) have not reported this plant species. Floating pondweed (*Potamogeton natans*), also reported to be dominant in the lake in 1934 was found for the first time in recent years in 2016, indicating potential for native plant reestablishment. Management actions to control invasive macrophytes, addressed earlier, can help to restore the native macrophyte community. A more diverse macrophyte community can help improve conditions for LMB fishing.

The DeRuyter Reservoir fishery has been historically manipulated, with annual fish stocking dating back to 1931. Stocked fish included brown trout (*Salma trutta*), black crappie (*Pomoxis nigromaculatus*), yellow perch (*Perca flavescens*), smallmouth bass (*Micropterus dolomieu*), and walleye. Various numbers and sizes of walleye have been stocked into the lake almost every year since 1935. Since 2013, walleye fingerlings have been stocked annually for top-down bio-control of Eurasian watermilfoil with plans to continue through 2019 (Lord 2017). Despite seemingly frequent stocking, few walleye have been collected from the lake during recent fisheries surveys (NYSDEC 2015). This implies that many stocked walleye are not surviving and that the surviving individuals are not reproducing enough to sustain the population. Walleye are difficult to collect with the gears employed to date (e.g., electro-fishing), so these findings should be interpreted with caution.

Fisheries Recommendation #1: Continue with recommended walleye stocking program. If interested in the full potential for biological control, comply with stock recommendations (size and number of fish) based on research (Lord 2017); the goal of this stocking is to facilitate a top-down trophic cascade. While aimed at reducing sunfish populations to reduce mortality of herbivorous insects, this can also help decrease algal growth by reducing zooplankter mortality through predation by young sunfish. Anglers must comply with current walleye fishing regulations (1st Saturday in May through March 15, minimum length 18”, daily limit 3). However, catch and release of walleye should be encouraged.

- **Timeline:** Annual stocking for 2018 and 2019 following recommendations on amount and size of fish (Lord 2017). In 2020, TLPF members should re-evaluate the stocking program and decide whether to continue or not.

Fisheries Recommendation #2: Encourage removal of bluegill and pumpkinseed up to daily take limit (50) rather than catch and release fishing. This can either simply be advertised through social media, newsletters, etc. or can be more seriously accomplished through events such as a sunfish tournament.

- **Timeline:** Concurrent with walleye stocking.

Fisheries Recommendation #3: Start an angler diary program in which records are kept of each fish caught by species and length. The program can be modeled after the NYSDEC New York

Angler Diary Program held on larger lakes in the state. Data collected by anglers should include date, number of anglers, area of lake fished, time started and time finished, type of fishing (boat, shore, ice), target species and for each individual fish caught the species, **total length**, if it was kept or released, and identification number if a tag is present. This can be made available on an online shared datasheet such as Google Spreadsheets. Data also can be used to understand angler satisfaction if, in the future, the LMB fishery should be re-evaluated for management. Although a participatory, educational opportunity for DeRuyter Reservoir anglers there are some shortfalls with this method of data collection such as size selection.

- **Timeline:** Annual participation should be re-evaluated each year to decide whether to continue based on value of the collected data and enthusiasm of participants. This program can be set up as a pilot in 2019 and if successful, solidified for 2020 when biological control research is concluded. Data can be recorded year-round.

D. Dam Integrity

The DeRuyter Reservoir dam is designated a Class C High Hazard dam by NYSDEC. This refers to the risk level downstream if the dam were to break. The dam is currently owned and maintained by NYS Electric and Gas Corporation (NYSEG). Residents should be aware of this designation and should direct questions to NYSEG. No actions by lake residents are recommended at this time.

E. Prevention of New Invasions

Though DeRuyter Reservoir currently supports populations of at least four aquatic invasive species (AIS; zebra mussel, Eurasian watermilfoil, curly leaf pondweed, and starry stonewort), there are many other AIS present in other local waterbodies. Once in a waterbody, many AIS cannot be fully eradicated, therefore prevention of new invasions is crucial. A major way to prevent unwanted species introductions into the lake is by educating lake users. This can be accomplished through social media, educational workshops, and signage at the boat launch, utilizing a boat launch steward to inspect incoming boats and equipment, and installing a nearby boat decontamination station. Effective as of 25 May 2016, NYSDEC has implemented Environmental Conservation Law NYCRR Chapter V Part 576, requiring users of any state waters to take reasonable precautions to prevent AIS transport by cleaning, draining, and treating their boats upon both launching and retrieving. This regulation followed the release of a prohibited and regulated species list (Part 575) including aquatic invasive animals and plants. Implementing a boat steward program and making available a boat washing station will help lake users to comply with these new regulations.

While weekly fishing tournaments are a great opportunity for recreation on the lake, they draw in boats that use other waterbodies. Live wells, bait buckets, fishing lines, and other angling equipment provide opportunities for AIS to ‘hitchhike’ overland from one body of water to another (Johnson et al. 2001). Additionally, aquatic plants easily entangle on any boat, especially on outboard motors and trailers. Dreissenid mussels (zebra and quagga mussels) easily hitchhike on this entangled plant material. Quagga mussels can occupy a broader habitat than zebra mussels as they can persist in deeper waters (wider habitat range) and tend to grow larger (Mills et al. 1993). Funding towards prevention of AIS is small relative to expected management costs after invasion. This is evident in EWM which has caused economic loss across the country in control costs and depreciated shoreline property values (Zhang and Boyle 2010).

AIS Prevention Recommendation #1: Implement a watercraft launch inspection (boat steward) program to have daily coverage of the DeRuyter Reservoir boat launch from Memorial Day weekend to Labor Day weekend. The employed boat steward(s) will educate boaters on the threats of AIS and inspect boats for signs of AIS upon launching and retrieving into the lake in compliance with NYS regulations.

- **Alternative:** Any coverage less than the recommended daily coverage to a minimum of having a steward present during weekend fishing tournaments. Though employing formal boat stewards is best, volunteers can be utilized if stewards are not available.

In past years funding has been made available through NYSDEC for small boat stewarding programs. Otherwise, partnering with towns may help to offset costs. Boat steward training, outreach materials, and data collection methods are available through the Finger-Lakes Partnership for Regional Invasive Species Management, NYSDEC, or Paul Smith's College Adirondack Watershed Institute. The NYS Watershed Inspection Steward Program Handbook (Cornell 2014) developed by NY Sea Grant is a useful resource in developing a successful program.

An added benefit of boat stewarding is the potential for community involvement. Retired residents can participate, high school students can have a first summer job, and it can help engage the younger generation in lake stewardship. Additionally, local college and university students can participate for summer employment and can potentially do personal research which could benefit them and be used towards the management of the lake.

- **Timeline:** The program should begin in the summer of 2018 and can be further developed and altered to suit the needs for each season.

AIS Prevention Recommendation #2: A decontamination station (boat wash) should be set at a location away from the lake. The primary purpose of these facilities are to kill small-bodied animals that could be attached or in standing water and are not easily seen. The boat wash should use high heat (NYSDEC recommends a minimum of 140 ºF [60 ºC] for at least 30 seconds) and high pressure if possible.

- **Alternative:** Provide resources to lake residents and users on how to decontaminate boats and equipment on their own through social media, newsletters, or mailings. Lake residents must understand that it is their duty for their visitors bringing personal boats and equipment from other waterbodies to clean these items to the best of their ability.
- **Timeline:** Decontamination facilities or educational resources should be available by the 2018 summer season and should be updated annually to suit needs and best target species of concern.

Lake users must be vigilant of unusual organisms, potentially new introductions of invasive species, growing in the lake through each summer season. For example, lake users can build rake toss tools for monitoring macrophytes. A rake toss is made up of two metal rake heads and a line at least 10 m long. The rake heads can be welded together or held together by hose clamps and the line attached at the end. The tool can be thrown out from a boat or from the shoreline (Lord and Johnson 2006). If a potential invasive species is found, a GPS location should be recorded and samples should be placed in a refrigerator in a sealed baggie or container for positive identification by a professional such as NYSDEC or Finger Lakes PRISM. A free online tool called NY iMapInvasives© can be used to track distribution of many invasive species throughout NY State.

The following are examples of invasive macrophytes, invertebrate, and fish that are present in NY and potential response strategies with the goal of eradication. The list is incomplete; those interested should refer to the NYS Prohibited and Regulated Species List for other statewide invasive species or Finger Lakes PRISM resources for more regional threats. All reports of species presence are based on iMapInvasive© records (iMapInvasives 2017).

Macrophytes

In general, invasive macrophytes in a waterbody cause restricted navigation, reduction in **species richness** of desirable native macrophytes, and lead to large synchronous die-offs. Increased decomposition from a large plant population can cause oxygen depletion in the water column. This can potentially lead to fish kills or harmful algal blooms (i.e., oxygen depletion can lead to internal nutrient loading and those nutrients can be used by algae and cyanobacteria).

- *Hydrilla* (*Hydrilla verticillata*), native to Asia, is often considered a perfect weed due to its fast growth and competitive abilities (Langeland 1996). The closest known occurrence of Hydrilla is in Cayuga Lake (Tompkins County), but it has also been reported in several other locations in NY. Dioecious forms have historically been invasive and managed in southern US; in NY, the monoecious form of *Hydrilla* is present, of which less about successful management is known (True-Meadows et al. 2016). *Hydrilla* develops characteristic **turions** and potato-like **tubers.** The leaves look very similar, and are therefore easily confused with *Elodea* spp., a native of which one species is present in DeRuyter Reservoir. *Elodea* typically has leaves in whorls of 3 along its stem with smooth edges, while *Hydrilla* typically grows in whorls of 4 or 5 along its stem with serrated edges on leaves and their margin. If *Hydrilla* is confirmed in the lake, it is strongly recommended that an herbicide treatment is used with a goal of eradicating the species from the lake. There are currently herbicides on the market that can be successful at low dosages and do not pose any known threats to wildlife or human health such as fluridone or endothall. If, in the future, *Hydrilla* was found in DeRuyter Reservoir, a NYS licensed herbicide applicator should be contacted to access the situation and employ the best suited application technique.

- Water chestnut (*Trapa natans*), native to Europe, is currently widespread throughout NY. A floating leaf plant, its leaves forms a rosette and develops **adventitious** roots along stem that resemble watermilfoils. Nutlets, their woody seed pods develop from the rosettes and drop to the sediment to overwinter. Water chestnut in North America acts as a true annual in that new growth only occurs through a new nutlet. This makes eradication through hand pulling possible if detected early. If found, train volunteers on the lake to identify and pull annually and throughout the growing season.

- European frogbit (*Hydrocharis morsus-ranae*), native to Europe and northern Asia, is currently widespread along eastern Lake Ontario region and scattered throughout state. It is present in nearby Cazenovia Lake. Catling et al. (2003) thoroughly reviewed what is known of its North American occurrence. European frogbit is a **free-floating**, **stoloniferous** aquatic plant in the same family as *Hydrilla* and *Elodea*. Like *Hydrilla*, it produces turions. It tends to grow in very shallow waters and wetlands. Similar to water chestnut, in introduced waterbodies European frogbit grows rapidly during the summer creating a dense canopy blocking light from reaching below the surface. At low densities, the plant can be hand pulled. However, European frogbit reproduces vegetatively, therefore care must be taken to remove all plant parts as to not assist in further spread by fragmentation. If hand pulling, events should occur in spring or early summer, before turions have fully developed.

Invertebrates

- The spiny waterflea (*Bythotrephes* *longinamus*) and the fishhook waterflea (*Cercopagis pengoii*), both native to Europe and Asia, are large-bodied **zooplankters** that can alter the ecosystem dynamics in waterbodies they are introduced to (Yan et al. 2001, Brown and Balk 2008). They are **zooplanktivores**, meaning they consume smaller, typically native zooplankton species that are essential components to lake ecosystems as they consume algae and are a primary food source for small fish. The fishhook waterflea is currently present in Lake Erie, Lake Ontario, and a number of Finger Lakes. The spiny waterflea has been found in Lake Erie, Lake Ontario, Lake Champlain, Lake George, and various smaller lakes in the southern region of the Adirondack Park. These small animals are often spread through fishing equipment as they attach to lines or can be easily unnoticed in any bilge water, live wells, or bait buckets (Jacobs and MacIsaac 2007). There currently are no known successful eradication strategies for spiny or fishhook waterfleas. If either species were to be found in the lake, focus should be on containment from further spread into other waterbodies.

- The quagga mussel (*Dreissena rostriformis bugensis*), native to Ukraine and Ponto-Caspian Sea, is closely related to the zebra mussel. Typically, quagga mussels are larger and can live in deeper waters (found in up to 130 m in Lake Ontario) than zebra mussels enabling them to exist in a wider range of habitats (Mills et al. 1993). They are currently widespread in the Finger Lakes, but occur in few other waterbodies in the state. The two species are distinguishable because zebra mussels have a flattened ventral side (shells will stand up on a flat surface) while quagga mussels will fall over. There are not management strategies available for a well-established invasive mussel populations in a lake, but if detected early, there are recent innovations in chemical treatments for mussels such as Zequanox® (https://marronebioinnovations.com/molluscicide/zequanox/). If found in the lake and there is interest in eradication, a professional can be contacted. Concern for non-target impacts should be addressed with chemical treatment.

- The bloody red shrimp (*Hemimysis anomala*), native to the Black Sea, the Azov Sea, and the eastern Ponto-Caspian Sea, was first discovered in Lake Michigan in 2006 (Pothoven et al. 2007). It has since been reported in Cayuga Lake, Seneca Lake, and throughout the Erie Canal. As it was recognized more recently than the other mentioned invasive invertebrates, there is less known about the invasiveness of the bloody red shrimp. However, it occupies a similar niche as spiny and fishhook waterfleas in that it consumes large quantities of native zooplankters. From a review of closely related mysids, Ricciardi et al. (2012) predicted potential ecological impacts of a bloody shrimp introduction into a waterbody including a reduction of native zooplankton diversity and altered nutrient cycling. The bloody red shrimp can occupy a wide range of depths from < 1 m to > 50 m. They are nocturnal and can be found at night as bright red swarms near docks in invaded waterbodies. Similar to the invasive waterfleas, focus should be placed on containment if bloody red shrimp were to be found in DeRuyter Reservoir.

Fish

Invasive fish are often brought to the area intentionally. Many fish species that are commonly used in aquaria or as bait fish are now listed as prohibited or regulated in NY. Regardless of species, it is important to not release fish from an outside source into a waterbody without a permit.

- The round goby (*Neogobius melanostomus*), native to Europe and Asia, is currently reported in the Great Lakes, the St. Lawrence River, Oneida Lake, the Erie Canal, and several smaller waterways in NY. It is a small (~10 cm), bottom dweller that consumes aquatic insects, snails, smaller fish, and fish eggs, as well as zebra mussels. Part of its success is believed due to its use of the abundant zebra mussels in the Great Lakes region as a primary food source (Ray and Corkum 1997). Though zebra mussel consumption seems positive, there is concern that this will cause **bioaccumulation** of toxins up the food web as round gobys are consumed by larger fish (Kwon et al. 2006).

AIS Prevention Recommendation #3: Educate lake users on AIS identification and on awareness of nearby lakes with major threats through workshops and/or online resources.

- **Timeline:** Ongoing, adapted annually to address new regional threats

AIS Prevention Recommendation #4: Have a rapid response plan for new invasions. There are many resources through state and local agencies to assist in decision-making and funding for rapid response management. The NYSDEC “Rapid Response for Invasive Species: Framework for Response" outlines a process for decision-making in the event of an early detection of an invasive species. Their Invasive Species Rapid Response and Control Grant Program awards grants annually to assist organizations in response efforts. Federally, the National Fish and Wildlife Foundation awards annual grants through their Pulling Together Initiative for similar activities.

- **Timeline:** Ongoing, adapted annually to address new regional threats.

Conclusions

Other than to support its direct intended uses (recreation, etc.), a well managed lake can provide many valuable **ecosystem services** for stakeholders including the intended ecological and economic benefits, as well as indirect physical and mental health benefits derived from aesthetic value. Long-term, comprehensive management of a lake relies on the understanding of the many complex biological, chemical, and physical factors within the lake basin as well as the watershed. Stakeholders must agree on goals and make further adaptive decisions based measurable results of management activities. At a time when our environment is rapidly changing, our freshwater supply is reacting to these changes. The issues that the users of DeRuyter Reservoir face are not isolated issues. When making management decisions, stakeholders should always be aware of current topics and advancements in the field of lake management. The quality of our freshwater reserves depends on the collaboration of scientists, government officials, and affected citizens and starts with localized planning.

Watershed management activities are important to reduce external nutrient loading and, in turn, reduce productivity in DeRuyter Reservoir. While some watershed management activities are more expensive and time consuming, any degree and combination of watershed management should provide long-term benefit to the lake. For invasive macrophyte management, current harvesting should be re-evaluated, no wake zone buoys should be installed in the littoral zone, and the starry stonewort population should be closely watched. Continued monitoring of the lake (e.g., water chemistry, biological communities, early detection of invasive species, harmful algal blooms) is essential to successful implementation of the management plan.

Glossary

Best management practice: a strategy that is determined to be the most effective (ecologically and economically) means of preventing non-point source pollution from entering a waterbody.

Bioaccumulation: buildup of a toxic substance through the food web through consumption.

Chlorophyll *a*: a pigment found in primary producers, such as plants and algae that is essential for photosynthesis. Lake managers measure quantity of chlorophyll *a* in water samples as an indicator of algae.

Ecosystem services: a positive benefit that wildlife or a whole ecosystem provides to people

Eutrophication: the natural process of a waterbody retaining nutrients and becoming more productive over time. This process is greatly sped up by human activity in the watershed that causes increased nutrient loading.

External loading: the process of waterborne substances (such as soil particles, nitrogen and phosphorus) from the watershed entering a given waterbody

Free-floating aquatic plant: a plant that grows in water with a primary floating leaf and is not rooted to the sediment; its roots dangle from the floating leaf.

Harmful algal bloom: a visible bloom of algae or cyanobacteria that can cause harm to humans and animals

Hypolimnion: the bottom, un-mixed layer of a thermally stratified lake. The epilimnion is the top, mixed portion and the metalimnion, or thermocline is, the middle layer.

Impervious surface: land surfaces such as paved areas or rooves, that repel rainwater rather than absorb it. These surfaces alter the natural flow of water from the watershed into the waterbody.

In-lake management strategies: refers to any type of management strategy directly in the waterbody. This can include anything from herbicide or algaecide application, mechanical harvesting, fish stocking, aeration, etc., but does not include watershed management activities.

Internal loading: the process of substances, such as nutrients or metals, from the sediment being released into the water column. Internal loading typically occurs when loss of oxygen in the water column causes chemical processes that release said substances. Internal loading of phosphorus and nitrogen is a common concern in lake management.

Invasive species: a species that is non-native to the ecosystem of concern and causes or is likely to have a significant negative ecological or economic impact, or harm to human health. Invasive species differ from a non-native or exotic species that has come from another region and is able to persist, but does not cause any known harm.

Littoral zone: the area of a waterbody where sunlight penetrates through to the bottom allowing macrophytes to grow.

Macrophyte: an aquatic primary producer that can be seen with the naked eye such as a vascular plant or freshwater macroalga.

Mesotrophic: term used for lakes with an intermediate level of ecosystem productivity. Lake trophic states are typically determined by water quality parameters including chlorophyll *a*, Secchi depth, and total phosphorus. Oligotrophic lakes are the least productive and eutrophic lakes are the most productive.

Monoculture: a term typically used in agriculture referring to the cultivation of a single crop. For lake managers, a monoculture refers to an instance of one species of macrophyte, usually an invasive species, growing alone over a large area of the waterbody.

Non-point pollution: pollution into a waterbody that comes from diffuse origins.

Point pollution: pollution into a waterbody that comes from a discreet origin.

Secondary consumer: a carnivore that feeds on herbivores. In biological control efforts for Eurasian watermilfoil management, sunfish are a relevant secondary consumer as they feed on the insects targeted as biological control agents.

Riparian zone: the interface between the land and a body of water including a river, stream, pond, lake, or reservoir. Vegetated buffers in riparian zones can provide many ecological benefits such as improved water quality and expansion of wildlife habitat.

Run-off: overland flow of water into the lake from excess storm water, snow melt, or saturated soils. Run-off is a concern of lake managers because it is a major source of non-point pollutants, as water enters the lake un- or minimally filtered. Run-off can be filtered naturally by plants or by artificial structures.

Secchi depth: a measurement taken with a black and white disc from the surface of the waterbody at the deep basin to determine water transparency. The disc is lowered by a line as far as the user can see it. The distance the line traveled through the water column is the Secchi depth of the lake at that given time. Higher Secchi depths indicate more transparent, less turbid waters.

Species richness: determination of the diversity of a community, such as of plants or of fishes, in an ecosystem by the number of different species present. High species richness indicates a biologically diverse community.

Stolon: often called runners; stems which grow horizontally, connecting multiple plants. Plants with stolons are referred to as stoloniferous.

Sub-basin: A term referring to the sectioning of one larger watershed into smaller watersheds, or basins based on localized stream flow. Each smaller watershed is referred to as a sub-basin.

Total length: the length of a fish measured from the tip of its snout to the end of its caudal (tail) fin.

Tuber: Enlarged structures grown from certain plants to store nutrients for overwintering. Aquatic plants that grow tubers release them into the sediment to grow in a future season. Some tubers can remain viable for many years. Potatoes are also tubers.

Turion: An overwintering buds produced by some aquatic plants that detaches and remains dormant in the sediment. Turions can remain viable for many years.

Watershed: the land surrounding a body of water in which the surface water drains into

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Appendix

Appendix A. Example chart of information to collect on each plant harvesting event in the lake.

Date	**Target Species**	**Method**	**Hours spent**	**Cost**	**Funding source**	**Volume Before**	**Volume Removed**

OCCASIONAL PAPERS PUBLISHED BY THE BIOLOGICAL FIELD STATION (cont.)

No. 38. Biocontrol of Eurasian water-milfoil in central New York State: *Myriophyllum spicatum* L., its insect herbivores and associated fish. Paul H. Lord. August 2004.
No. 39. The benthic macroinvertebrates of Butternut Creek, Otsego County, New York. Michael F. Stensland. June 2005.
No. 40. Re-introduction of walleye to Otsego Lake: re-establishing a fishery and subsequent influences of a top Predator. Mark D. Cornwell. September 2005.
No. 41. 1. The role of small lake-outlet streams in the dispersal of zebra mussel (*Dreissena polymorpha*) veligers in the upper Susquehanna River basin in New York. 2. Eaton Brook Reservoir boaters: Habits, zebra mussel awareness, and adult zebra mussel dispersal via boater. Michael S. Gray. 2005.
No. 42. The behavior of lake trout, *Salvelinus namaycush* (Walbaum, 1972) in Otsego Lake: A documentation of the strains, movements and the natural reproduction of lake trout under present conditions. Wesley T. Tibbitts. 2008.
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