The state of Brant Lake, & Brant Lake management plan

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AT ONEONTA

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The State of Brant Lake

Brant Lake, like many other northeastern lakes, faces threats to its ecological and recreational balance. Eurasian watermilfoil growth, potential aquatic invasive species introductions and cultural eutrophication threaten desired uses in both the short and long term. In order to address these issues, the Brant Lake Association (BLA), along with the Town of Horicon (TOH), has made an arrangement with SUNY Oneonta to develop a comprehensive lake management plan. This plan is designed to provide guidance for the sustainable recreational and ecological use of the lake long term. In order for a comprehensive plan to be developed, a thorough understanding of the lake and its drainage basin is necessary. Understanding the characteristics of the lake and its basin, its physical and chemical limnology along with the biota that reside within, creates a baseline to where future management objectives can either strive for or exceed. The goal of this chapter is to provide a synthesis of past and current information on the state of Brant Lake. Specifically detailed are: (1) lake and watershed characteristics and history of ecological study (2) physical and chemical limnology and (3) fisheries. We anticipate that this document will provide stakeholders with a firm understanding of the lake which will inform management decisions.

Chapter 1. Lake and Watershed Characteristics and History of Study

Introduction

Brant Lake (18 T 605637 E, 4842183 N) is a dimictic waterbody of glacial origin located within the town of Horicon, NY (Figure 1). It is the largest lake wholly contained within Warren County. The lake drains to the southwest via the Schroon River which is a part of the Upper Hudson River basin. The lake has a surface area of 548 hectares (1,440 acres) and a maximum depth of about 19.8 meters (65 feet; Table 1). The drainage basin is 10,339 hectares (25,547 acres), with a surface area to basin ratio of 19:1. The basin is located within the towns of Horicon and Hague (Warren County) and a small portion in Essex County. Brant Lake has an elevation of 799 ft above sea level. Brant Lake and its tributaries were designated as class AA waters by the New York State Department of Environmental Conservation (NYSDEC). Waterbodies classified as AA are best used for drinking water, primary and secondary contact recreation and fishing.

Table 1. Morphological Characteristics of Brant Lake. Data compiled from Eichler (1990), Wick and Lieberum (2000) and Waterfield et al. (2016). Volume was estimated by the summation of the frusta of a series of truncated cones (Wetzel 2001) based on the bathymetric map from Waterfield (2016). The volume was calculated from the following strata (0-1 m, 1-2 m, 2-4 m, 4-6 m, 6-8 m, 8-10 m, 10-12 m, 12-14 m, 14-16 m, 16-18 m and 18-18.9 m).

Parameter	Metric	English
Length	8.32 km	5.17 mi
Max width	1.42 km	0.88 mi
Surface area	584 ha	1,440 ac
Max depth	19.8 m	65 ft
Mean depth	7.01 m	22.99 ft
Volume	40,938,158 m^3	33,189 ft
Shoreline length	26.4 km	16.4 mi
Shoreline development		2.87
Hydraulic retention time		1 year

The basin comprises 14 tributaries with measurable flow and eight of these streams had flows less than 2 cubic feet per second (Wick and Lieberum 2000). The largest of these streams, with the largest drainage area, is Spuytendivel Brook (Table 2), which is located in the northeastern portion of the lake.

Table 2. Drainage areas of selected sub basins contained within the Brant Lake drainage basin. Numbers in parenthesis indicate the acreage conversion from hectares.

Basin name	Drainage area (ha)	Acres
Beaver Pond	1,051	2,598
Bennett Pond	608	1,504
Lily Pond Brook	815	2,016
Pine Hill	202	499
Redfin Brook	810	2,003
Spuytenduivel Brook	3,004	7,424
Scout Camp	805	1,990

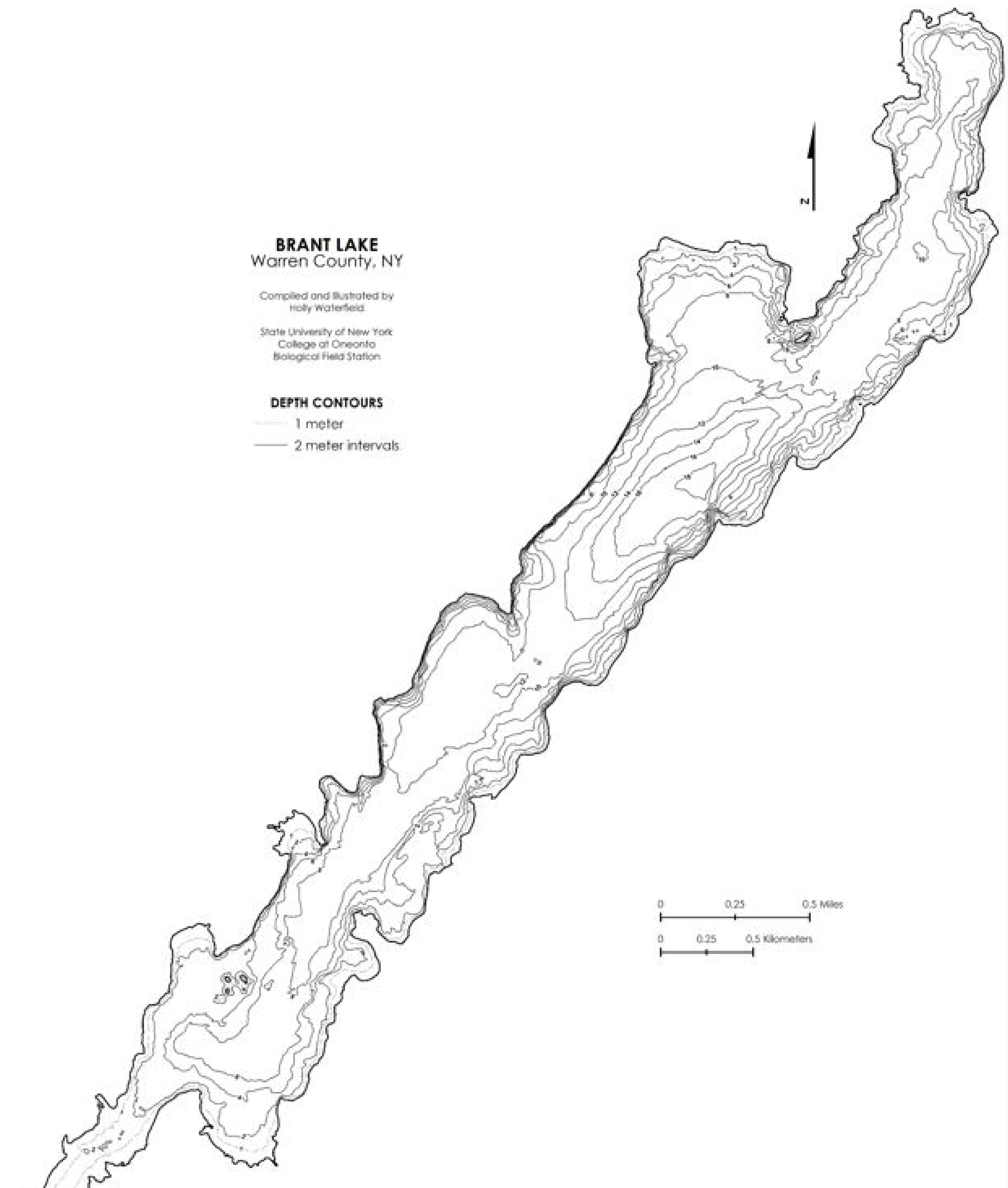

Figure 1. Bathymetric map of Brant Lake showing 2-m contour intervals (Waterfield 2016).

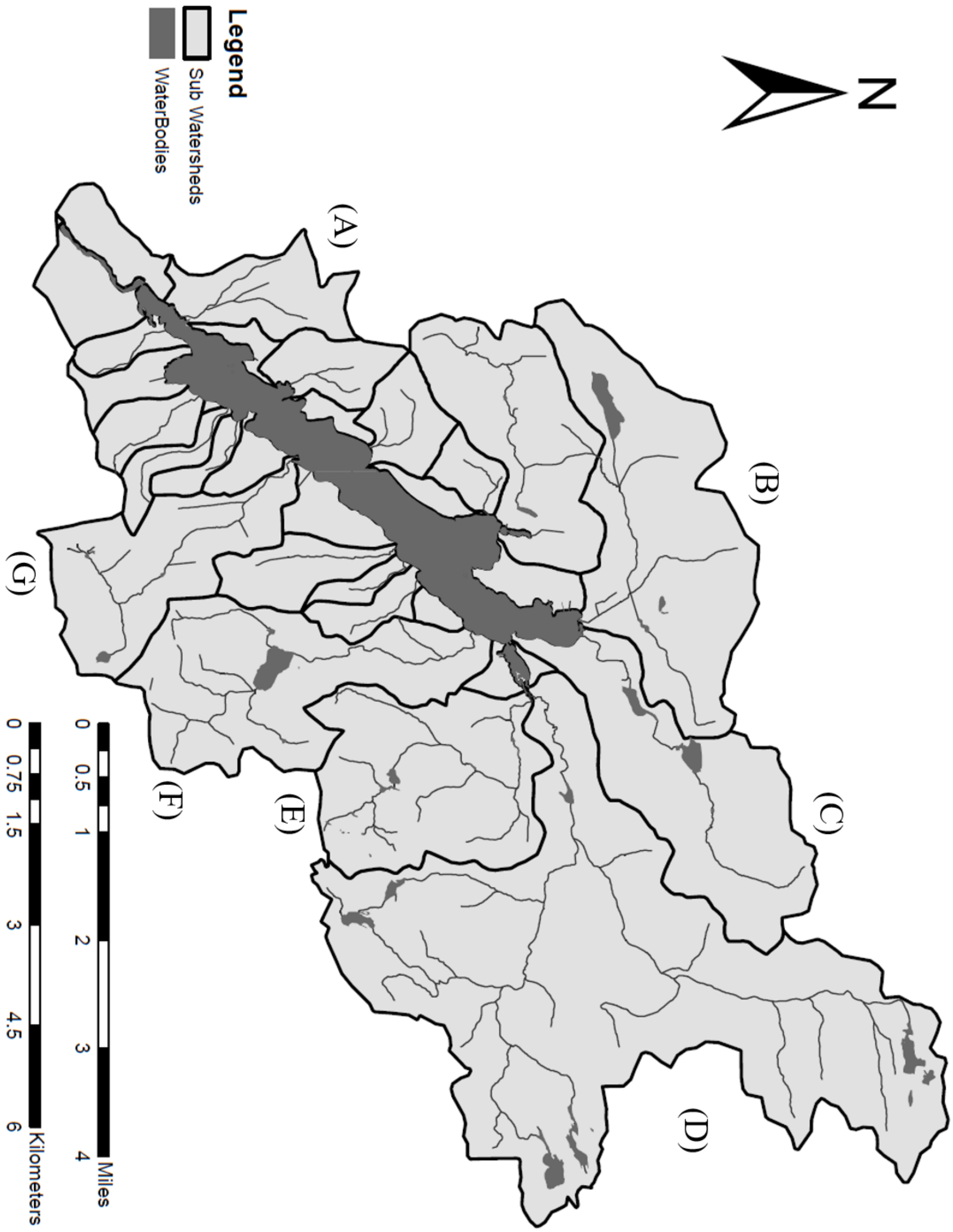

Figure 2. Sub basins of the Brant Lake drainage basin (Wick and Lieberum 2000). Letter designations indicate sub basins in Table 2: (A) Pine Hill, (B) Beaver Hill, (C) Scout Camp, (D) Spuytenduivel Brook, (E) Redfin Brook, (F) Lily Pond Brook, and (G) Bennett Pond.

Bedrock Geology and Soils–The majority of the bedrock in the Brant Lake basin is either a Charnockite granitic mixture or Biotite-quartz-plagiocase, with the rest of the geology mixed between metasedimentary rock, calcitic and dolomitic marble, and various other rock types (Figure 3). The soils in the basin primarily consist of Bice, Stowe, and Lyme-fine-sandy-loam with small areas having various mucks and outcrops (Figure 4). Bice and Stowe sandy loams are naturally well drained, but Lyme is poorly drained (NRCS 2015). Soils within the Town of Horicon have been rated as having severe limitations for septic system leach fields (Lamb 2010), with most of the shoreline containing these soils (Wick and Lieberum 2000). For a detailed discussion on soils within the drainage basin, refer to Wick and Lieberum (2000) and Lamb (2010).

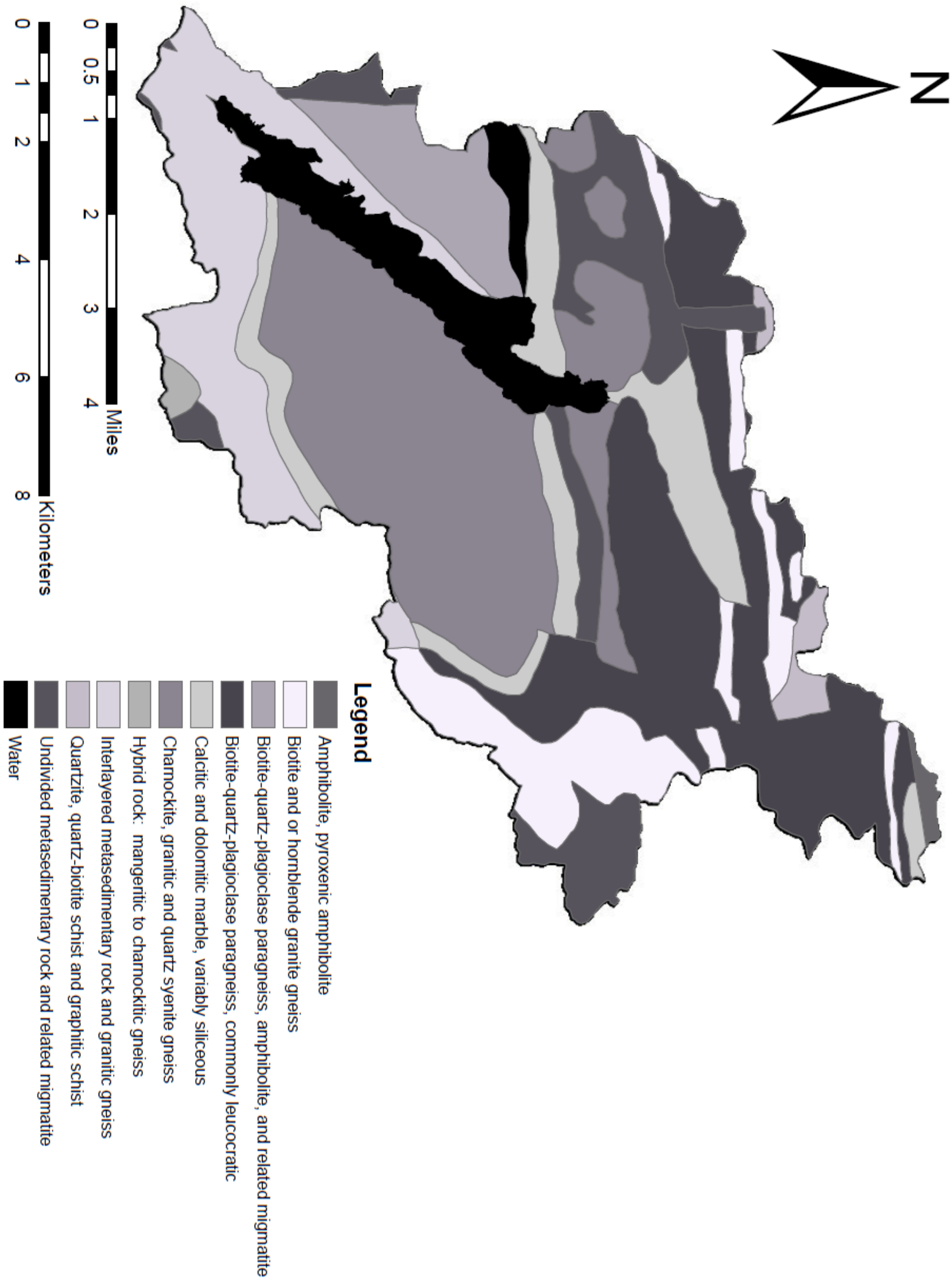

Figure 3. Bedrock geology of the Brant Lake drainage basin. Data from NYSDEC database (NYSDEC 2013).

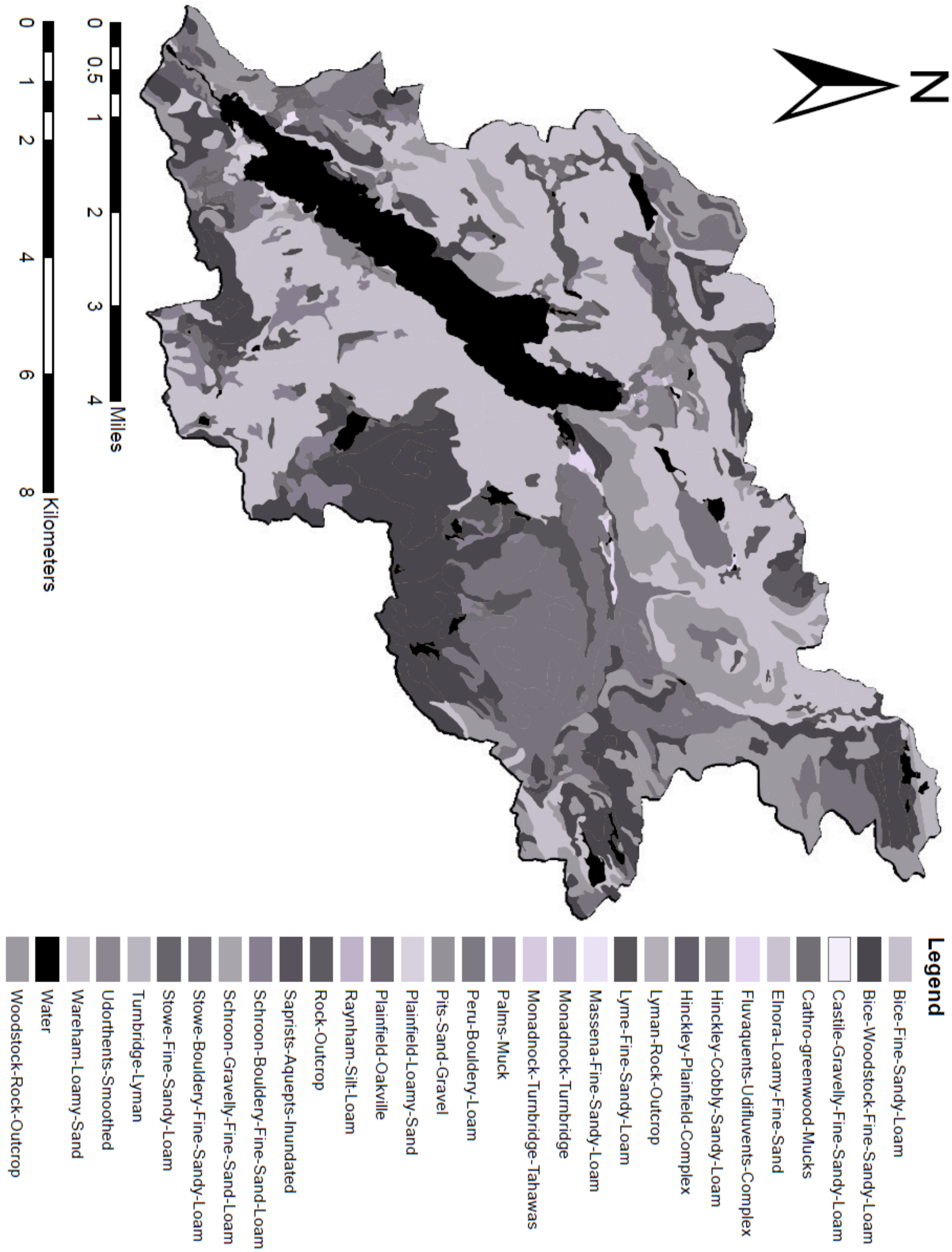

Figure 4. Soil types of the Brant Lake drainage basin. Data from the USDA web soil survey (NRCS 2015).

Land Use and Land Cover–The majority of the Brant Lake drainage basin is a combination of deciduous, evergreen, and mixed forest (91%, Figure 5). Most development in the basin is located in close proximity to the lake, with several camps, cottages and homes located on the shoreline. There are two roads that run parallel to the lake, State Route 8 on the eastern side and Palisades Road on the western side. There is an old cattle farm located in the northernmost bay on the lake that drains the Beaver Pond and Scout Camp sub drainages, but now it is used for horses (Wick and Lieberum 2000).

Early Lake History–Brant Lake originally resembled a large river, which was primarily used for floating logs and timber to the saw mill located at the southern end of the lake. Lake stakeholders were not happy with the condition of the lake, which was described as being shallow and dirty, with rocks, logs and debris on the banks. A committee consisting of fifteen members was formed to address improvements to the lake. This committee was one of the earliest iterations of the BLA. In the fall of 1907, repairs commenced on the upper and lower dams, with financial support coming from the stakeholders. These repairs raised the water to its current level today.

Water Quality–The first record of water quality sampling on Brant Lake came from 1933 with pH and alkalinity readings from three depths (9.1 m, 13.7 m and 18.3 m) (Eichler 1990). pH sampling continued sporadically on dates in the 40's and 60's into the 80's. In 1982 and 1987, in addition to pH and alkalinity, Secchi depth (SD) was measured along with total phosphorus (TP), total filterable phosphorus, total Kjehldahl nitrogen, soluble Kjehndahl nitrogen, nitrate, ammonium (NH_4^+), conductivity, total organic carbon (TOC) and turbidity (Kishbaugh, personal communication as cited in Eichler [1990]).

In 1987, Brant Lake joined the New York State Citizens Statewide Lakes Assessment Program (CSLAP). It is unclear if the previous sampling up to 1987 was done on behalf of NYS, or some other institution. The CSLAP sampling measured SD, TP, nitrate, total color, pH, specific conductivity, and chlorophyll *a* (Chl. *a*). Brant Lake had two five-year cycles of CSLAP sampling from 1987-1991 and from 1999-2003.

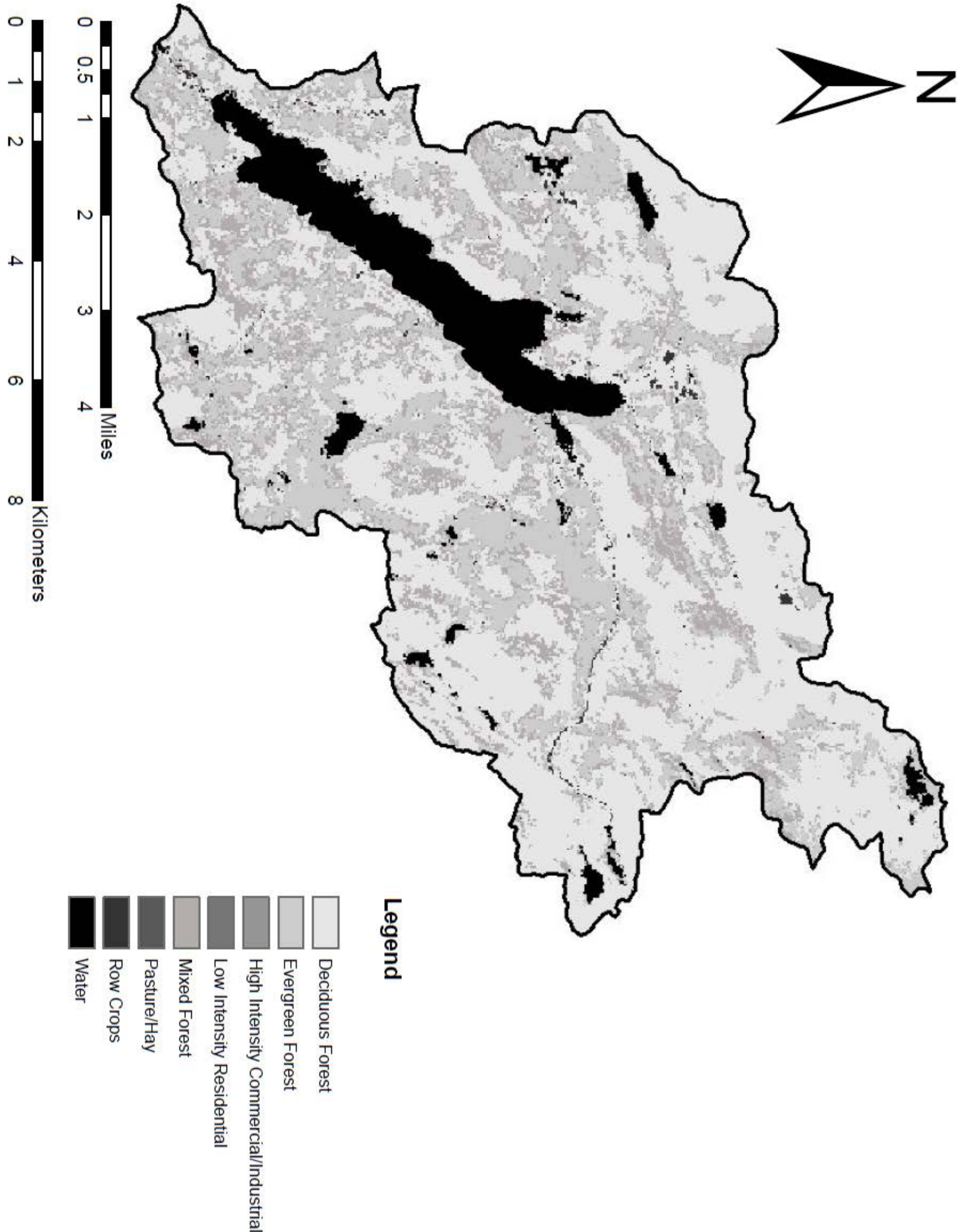

Figure 5. Land use and cover for the Brant Lake drainage area. Data from the national land cover database (Homer et al. 2015).

Macrophytes–Aquatic plant surveys were conducted in the 1990s to understand plant community composition and EWM population size. In total, 42 aquatic plant species have been observed in Brant Lake since 1990 (Table 3). The 1999 survey found 38 aquatic plant species, 31 of which were submersed plants. Although present at that time, Eurasian watermilfoil (*Myriophyllum spicatum*, "EWM") was not a large part of the plant community in 1990, and was the 26th most abundant species by relative percent cover, and was found at only 1 of 6 vegetation transects (Eichler 1990). The report documented one dense bed of EWM in the northeastern end of the lake, with scattered individuals in adjacent areas. Additionally, Eichler (1990) noted several areas that could support dense beds of EWM in the future. These areas included the southwestern bay and Pickerel Pond, between the main lake and the entrance of Spuytendival Creek. In 1999, EWM was the 18th most abundant aquatic plant species by relative percent cover and the 5th most abundant by frequency of occurrence, and was found at all survey sites (Eichler 1999). There was also a 1,000% increase in average percent cover from 1990 to 1999 that indicated expansion, although total percent cover changed from 0.1% to only 1.2% (Table 4.). At the time, EWM growth covered 0.5ha (1.3 acres) of the littoral zone of the lake. Once again, the report discussed the same two potential areas detailed in the 1990 report as places to monitor for EWM expansion.

Table 3. List of aquatic plant species found in Brant Lake during surveys in the 1990's. Data were collected via diving line transects (adapted from Eichler [1999]).

Scientific name	Common name	1990	1992	1999
Bidens beckii	Water marigold	X	X	X
Brasenia schreberi	Water shield	X	X	X
Ceratophyllum demersum	Coontail	X	X	
Chara/Nitella	Stonewort	X	X	X
Elatine minima	Little elatine		X	X
Eleocharis acicularis	Spike rush	X	X	X
Elodea canadensis	Waterweed	X	X	X
Eriocaulon septangulare	Pipewort	X	X	X
Fontinalis flos-aquae	Moss		X	
Heteranthera dubia	Water stargrass	X	X	X
Isoetes echinospora	Quillwort	X	X	X
Isoetes macrospora	Quillwort	X	X	X
Juncus pelocarpus	Bog rush	X	X	X
Myriophyllum alterniflorum	Little milfoil	X	X	
Myriophyllum sibiricum	Northern milfoil	X	X	X
Myriophyllum spicatum	Eurasian watermilfoil	X	X	X
Myriophyllum tenellum	Leafless milfoil		X	X
Najas flexilis	Water naiad	X	X	X
Najas guadalupensis	Southern naiad		X	X
Nuphar luteum	Yellow water lily	X	X	X
Nymphaea odorata	White water lily	X	X	X
Pontedaria cordata	Pickerelweed	X	X	X
Potamogeton amplifolius	Large-leaf pondweed	X	X	X
Potamogeton crispus	Curly-leaf pondweed	X		
Potamogeton epihydrus	Leafy pondweed	X	X	X
Potamogeton gramineus	Variable pondweed	X	X	X
Potamogeton natans	Floating-leaf pondweed	X		X
Potamogeton perfoliatus	Heart pondweed	X	X	X
Potamogeton praelongus	White-stem pondweed	X	X	X
Potamogeton pusillus	Small pondweed	X	X	X
Potamogeton robbinsii	Robbins' pondweed	X	X	X
Potamogeton spirillus	Spiral pondweed	X	X	X
Potamogeton vaseyii	Vasey's pondweed	X	X	X
Ranunculus longirostris	Buttercup		X	X
Sagittaria graminea	Arrowhead	X	X	X
Scirpus subterminalis	Water bulrush	X	X	X
Sparganium sp.	Bur-reed	X	X	X
Typha sp.	Cattail	X		X
Utricularia purpurea	Purple bladderwort	X	X	X
Utricularia resupinata	Lavender bladderwort	X	X	X
Utricularia vulgaris	Giant bladderwort	X	X	
Vallisneria americana	Duck celery	X	X	X

Table 4. Average percent cover of select aquatic plant species (adapted from Eichler [1999]). N.d means that the species was not detected.

Species	Average Percent Cover		
	1990	1992	1999
Eriocaulon septangulare	3.9	9.3	4.6
Myriophyllum sibiricum	1.4	1.5	2.7
Myriophyllum spicatum	0.1	0.2	1.1
Najas flexilis	17.7	6.5	2.1
Najas guadalupensis	nd	nd	7.6
Potamogeton robbinsii	12	3.1	6.4
Scirpus subterminalis	9.7	7.3	7.1
Vallisneria americana	9.8	5.6	4.6

Zooplankton–Newtown and Reyes (2016) surveyed the zooplankton community of Brant Lake during the summer of 2015. That survey found that the community was dominated by small-bodied rotifers throughout the season, with the highest abundance observed in June. The authors postulated that predation pressure by phantom midge (*Chaoborus* spp.) and rainbow smelt (*Osmerus mordax*) may have shifted the zooplankton community to smaller bodied individuals.

Chapter 2. Physical and Chemical Limnology

Introduction

The physical and chemical characteristics of a lake affects its ecology and recreational uses. A shift from lower to higher productivity, caused primarily by increases in nutrients from anthropogenic sources, can alter algal, macroinvertebrate, and fish communities (Gannon and Stemberger 1978; Wetzel 2001; Olin et al. 2002; Sutela et al. 2010). The effects of these changes may be perceived as positive or negative with respect to desired lake uses. For example, increased fish production is likely to be perceived as a positive change whereas harmful algal blooms are likely to be perceived as negative change. Therefore, an understanding of the basic physical and chemical limnology of a lake can help explain realized or potential impediments to desired uses.

Aspects of Brant Lake's limnology have been monitored through participation in CSLAP from 1987 to 1991 and from 1999 to 2003. Total phosphorus, SD, and Chl. *a* were measured approximately every 2 weeks during the ice-free season during this monitoring (NYSDEC 2003). Eichler (1990) provided the first temperature and oxygen profile for the lake in July 1990. These early studies indicated that water quality in Brant Lake was suitable for all desired uses. There has been no water quality monitoring in Brant Lake since 2003, which presents challenges to maintenance of desired uses. Similarly, the historical absence of accurate bathymetric information about the lake has prevented in-depth understanding of basic limnological processes. Freshwater lake ecosystems are subject to a variety of stressors such as cultural eutrophication, increasing salinity due to road salt application, invasive species and climate change. Regular limnological monitoring is needed for early detection of these stressors.

The goal of this study was to (1) characterize the current state of Brant Lake's physical and chemical limnology and (2) determine if any changes have occurred within the lake since the CSLAP data were collected. Understanding the current status of Brant Lake's limnology will provide insight into the relative impacts of the aforementioned stressors on the system and guide future management.

Methods

Field Data Collection–Physical and chemical parameters of Brant Lake were measured at least bi-weekly during the open-water season and at least monthly during ice cover from October 2014 to October 2015. All limnological data were collected in the deepest part of the basin (Figure 6) as estimated by using a Speedtech ® Depthmate portable sounder. Measurements of physicochemical parameters [pH, temperature, dissolved oxygen (DO) and specific conductivity] were recorded at 1 m intervals from 1 m below the surface [depth (z) = 1 m] to 18 m deep (z = 18 m, bottom). All parameters were measured with a YSI® 650 MDS with a 6-Series multiparameter sonde, calibrated according to manufacturer's instructions (YSI 2009). Water transparency was measured using a Secchi disk. The disk was lowered slowly over the shaded side of the boat until it disappeared, then raised until the disk reappeared. Depths at both the disappearance and reappearance of the disk were recorded to the nearest 0.25 m. The average of these depths was recorded as the final Secchi depth (Wetzel and Likens 2000).

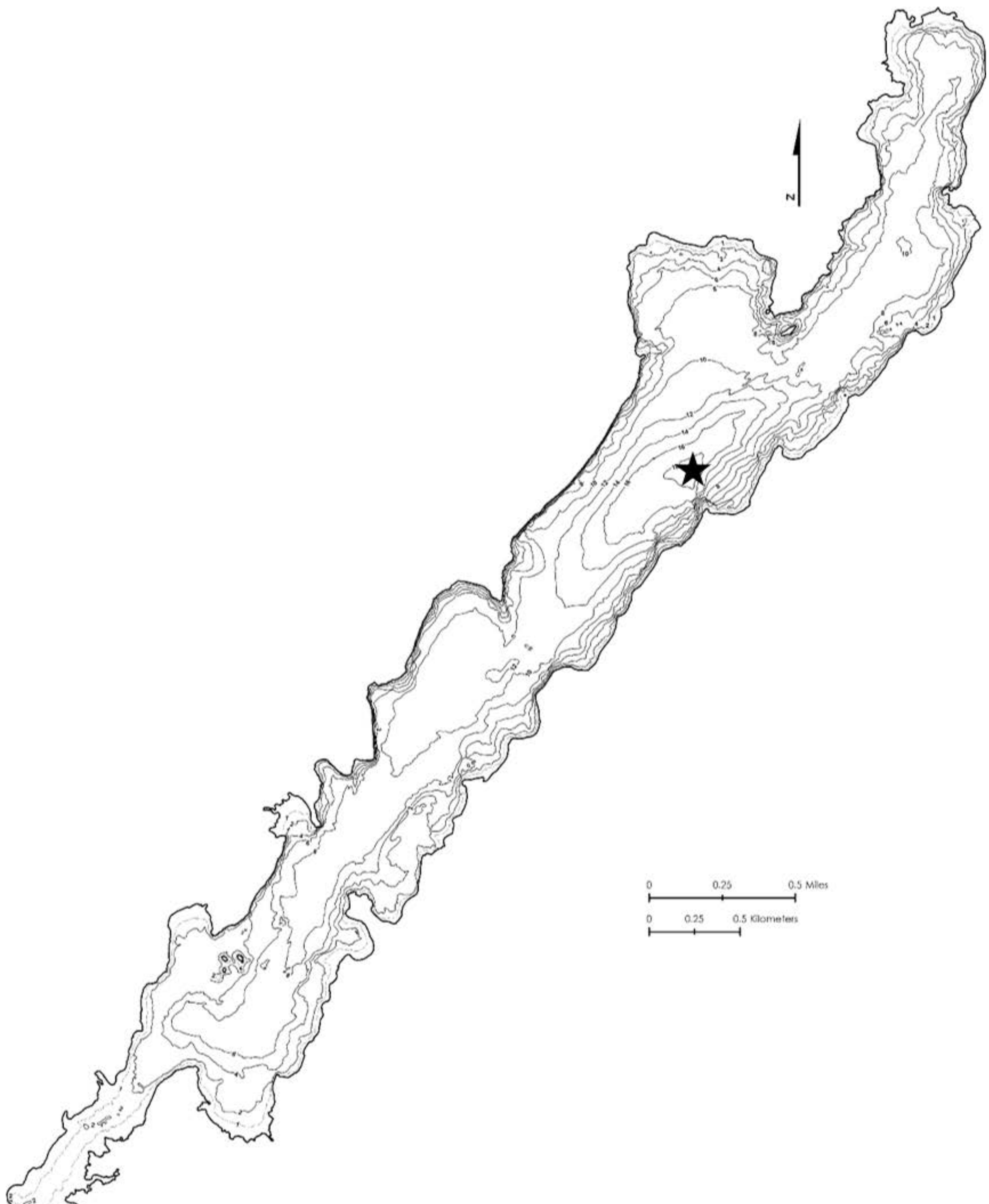

Figure 6. Sampling location (z = 18 m) for physical and chemical limnology (Waterfield 2015). Note sampling location was determined prior to development of this bathymetric map. Each contour line represents 2m in depth.

Water samples for chemical analyses were collected using a Kemmerer sampler. Nutrient samples for TP, total nitrogen (TN) and nitrate and nitrite combined (nitrate + nitrite) were collected at 5 depths from 1 to 18 m. The 5 depths were adjusted for each sampling event so that during stratification there always was one sample in the middle of the epilimnion and one in the middle of the hypolimnion along with a surface, thermocline and bottom sample. When no thermocline was present, samples were taken at 4.5 m intervals starting at 1 m (1 m, 4.5 m, 9 m, 13.5 m and 18 m). Samples for the remaining analyses (alkalinity, calcium, chloride and Chl. *a*) were taken at 1 m intervals.

Sample Storage and Preparation–Nutrient samples were collected and stored in acid-washed, translucent 125 ml polyethylene bottles. Samples for alkalinity, calcium, Chl. *a* and chloride were stored in brown, opaque 1 l polyethylene bottles to limit additional photosynthesis. Samples were kept on ice for up to 24 hours until they could be processed for storage. Sulfuric acid was added to all nutrient samples to acidify them to $pH < 2$ in order to stop adsorption to seston and biological activities (section 4500-P B, Way 2012) then stored at room temperature for up to 2 months before analysis. Chl.*a* samples were prepared by filtering 500 ml of lake water through a 47 mm Whatman® GF/A glass fiber filter using a low pressure vacuum pump. Filters were folded in quarters, patted dry, wrapped in aluminum foil and stored at -20 °C. The remaining unfiltered lake water samples were stored at 4°C for up to two months for alkalinity, calcium and chloride analyses.

Sample Processing–TP was determined by persulfate digestion followed by single reagent ascorbic acid (Liao and Marten 2001). TN and nitrate + nitrite were both determined by the cadmium reduction method, except that TN samples were digested first with peroxodisulfate (Ebina et al. 1983; Pritzlaff 2003). All nutrient analyses were conducted using a Lachat QuickChem FIA 8000 series auto analyzer. Chlorophyll *a* samples on GF/A filters were cut into small pieces over a 15 ml grinding tube with approximately 4 ml of buffered acetone (90% C_3H_6O, 10% $MgCO_3$). Samples were ground down to a homogenous slurry using a drill with a Teflon pestle drill bit. The slurry was transferred to a 15 ml centrifuge tube and brought to a final volume of 10 ml with buffered acetone. The centrifuge tubes were then transferred to a Thermo Scientific Sorvall Legend XI centrifuge and spun for 10 minutes at 10,000 × *g*. Once centrifugation was complete, samples were transferred into a clean 12 ml cylindrical cuvette and analyzed using a Turner Design TD-700 fluorometer. Chlorophyll *a* concentrations were determined using the method of Arar and Collins (1997):

Chlorophyll *a* (µg/l) = concentrated Chl. *a* × final volume/ml sample filtered

Alkalinity was determined using titrimetric methods (section 2320 B, Way 2012). One hundred ml of sample was added to a glass beaker and titrated to an endpoint of pH 4.6 using a 0.020 N HCl solution. Alkalinity (as mg/l of $CaCO_3$) was calculated as:

Alkalinity = ml of titrant × 0.020 × 50,000/ml sample

Calcium concentration was determined using the ethylenediaminetetraacetic (EDTA) titrimetric method (section 3500-Ca D, Way 2012). Fifty ml of sample was added to a glass beaker along with 1 ml of 2 N NaOH and ~ 0.2 g of murexide indicator. The sample was titrated to end point (color change from light pink to magenta) using 0.01 M EDTA. Calcium (as mg/L of Ca^{2+}) was calculated as follows:

Calcium = ml 0.001 N EDTA titrant × (400.8/ml sample), where N = normality of EDTA

Chloride concentration was determined using the titrimetric mercuric nitrate method (section 4500-CL^- C, Way 2012). One-hundred ml of sample was added to a glass beaker along with 1.0 ml of indicator acidifier reagent (section 4500-CL^- C, way 2012). A "blank" value (0.2 ml of titrant) was determined by adding 1.0 ml of the indicator acidifier reagent to 100 ml of deionized water and titrated to end point (from teal to deep purple). The sample was then titrated to the end point using 0.0141 N mercuric nitrate. Chloride (as mg/l of Cl^-) was calculated as follows:

Chloride = (sample value – blank value) × 0.0141 N × (35,450/sample volume (ml)

Trophic Status–To determine the trophic status of Brant Lake, the Carlson's trophic status index (TSI) (Carlson 1977) was calculated for each separate sampling occasion during the open water season. The TSI was calculated separately using CSLAP data and data collected in the present study. TSI uses SD, TP and Chl. *a* concentrations to determine values. TSI < 30 often indicates oligotrophy, 50–70 eutrophy, and > 70 hypereutrophy (Wetzel 2001). The equation for each parameter is as follows:

$$\text{TSI (SD)} = 60 - 14.41 \times \ln(\text{SD})$$
$$\text{TSI (Chl. } a) = 9.81 \times \ln(\text{Chl } a) + 30.6$$
$$\text{TSI (TP)} = 14.42 \times \ln(\text{TP}) + 4.15$$

Isopleth–Isopleths were generated using the 'akima' package (Akima et al. 2015) in R (R Core Team 2016), which interpolated parameter values (temperature, DO, pH, specific conductivity, TP, TN and nitrate + nitrite) across sampling dates and depths.

Statistical analysis–To compare mean open water surface values of Chl. *a* (n = 12), pH (n = 15), TP (n = 15), Secchi depth (n = 12), and TSI between CSLAP years (1987-1991, 1999-2003) and data collected during the open water season for 2015, a Wilcoxon rank sum test with continuity correction (Wilcoxon 1945) was performed with $\alpha = 0.05$. All CSLAP years were pooled (n: TSI (Chl. *a*) = 76; TSI (TP) = 80; TSI (SD) = 76). All statistical analyses were run in R (R Core Team 2016).

Results

Temperature–Brant Lake is dimictic with sustained summer and winter stratification punctuated by the spring and the fall mixing events. Thermal stratification in 2015 started in late May and continued until the end of October (Figure 7). The thermocline was at z = 6–8 m during the open-water season. Inverse stratification occurred during the ice-covered period (January to the end of March). The maximum water temperature observed was 25.3°C on August 26, 2015.

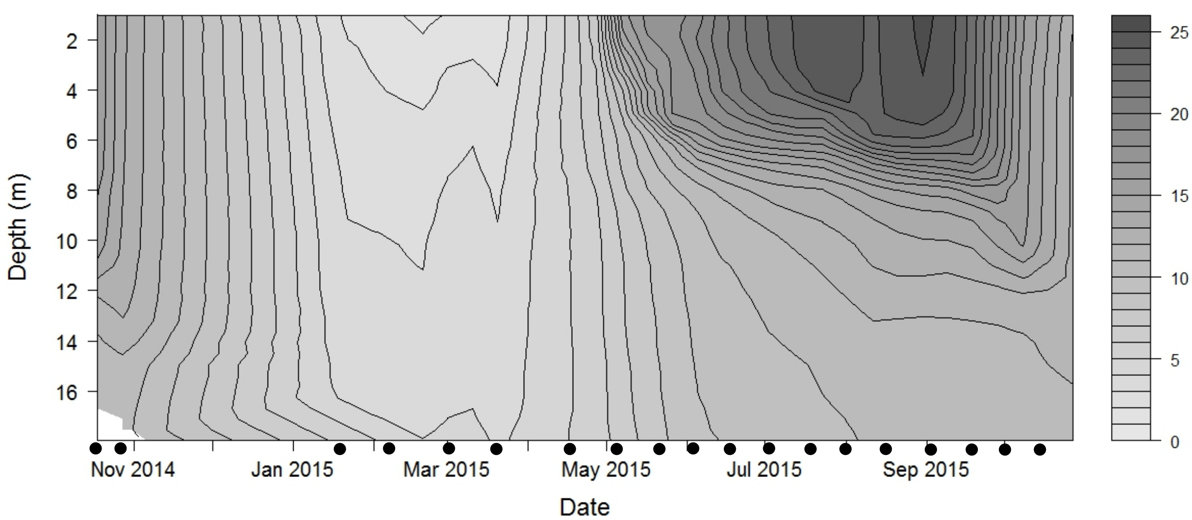

Figure 7. Temperature isopleth (°C) detailing stratification for Brant Lake (October 2014 to October 2015). Black dots below x axis indicate sampling dates.

DO– Prior to the onset of summer stratification, DO concentrations were uniform throughout the water column ranging from 11.52 mg/l at the surface to 10.95 mg/l at the bottom (Figure 8). Early during summer stratification (May 10, 2015 to July 8, 2015) DO was highest at z = 6–8 m. DO at the bottom declined from 10.07 mg/l on May 19, 2015 to 2.16 mg/l on July 8, 2015. During late summer, the water at the bottom of the lake became anoxic (< 1 mg/l) and remained so through October. Anoxia was most severe on September 22, 2015, reaching 9 m off the bottom, and persisted until the fall mixing. Surface DO was highest (14.26 mg/l) on January 18, 2015 under the ice. DO gradually decreased during ice cover, and a brief period of anoxia occurred on March 30, 2015; however, it was restricted to the bottom 1 m of the water column.

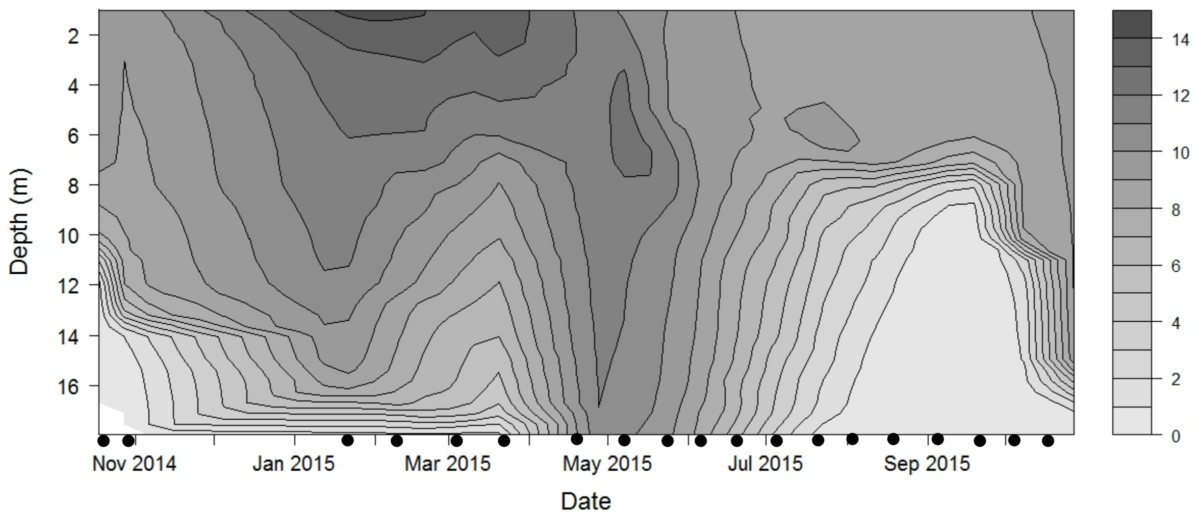

Figure 8. Dissolved Oxygen (DO) isopleth (mg/l) for Brant Lake (October 2014 to October 2015).

Total Phosphorus– Mean surface TP was 7.17 µg/l P, which is lower than the New York State standard for eutrophic waterbodies (20 µg/l; NYSDEC 2015) (Table 6). Mean surface TP measured during the current study was higher than that from the CSLAP data set but not significantly (Wilcoxon rank sum test: W = 454, df = 1, p = 0.2671) (Figure 9). Compared to nearby lakes, TP in Brant Lake was lower than all but the north basin of Schroon Lake (Table 7.) Elevated TP at the lake bottom was observed on October 18 and 29, 2014, August 26, October 6 and 27, 2015 (Figure 10). All aforementioned dates were coincident with anoxia at the sediment water interface.

Table 6. Summary of water quality parameters measured in Brant Lake during the present study (October 2014 to October 2015). All data shown are surface values. Total phosphorus, total nitrogen, nitrate + nitrite, specific conductivity and pH were all measured bi-weekly. Alkalinity, calcium, chloride, chlorophyll *a*, and Secchi depth were all measured at least monthly.

Parameter	Mean	Standard deviation	Range
Total phosphorus (µg/l P)	7.17	4.256	2-14
Total nitrogen (mg/l N)	0.10	0.073	0.02-0.22
Nitrate + nitrite (mg/l)	0.01	0.007	0.01-0.04
Calcium (mg/l)	8.37	0.469	7.62-8.82
Alkalinity (mg/l)	19.53	1.047	18.05-21.85
Chlorophyll *a* (µg/l)	1.42	1.318	0.001-4.91
Secchi Depth (m)	5.38	1.074	3.75-7.00
Specific conductivity (µS/cm)	0.09	0.003	0.080-0.093
pH	7.79	0.620	6.02-8.53

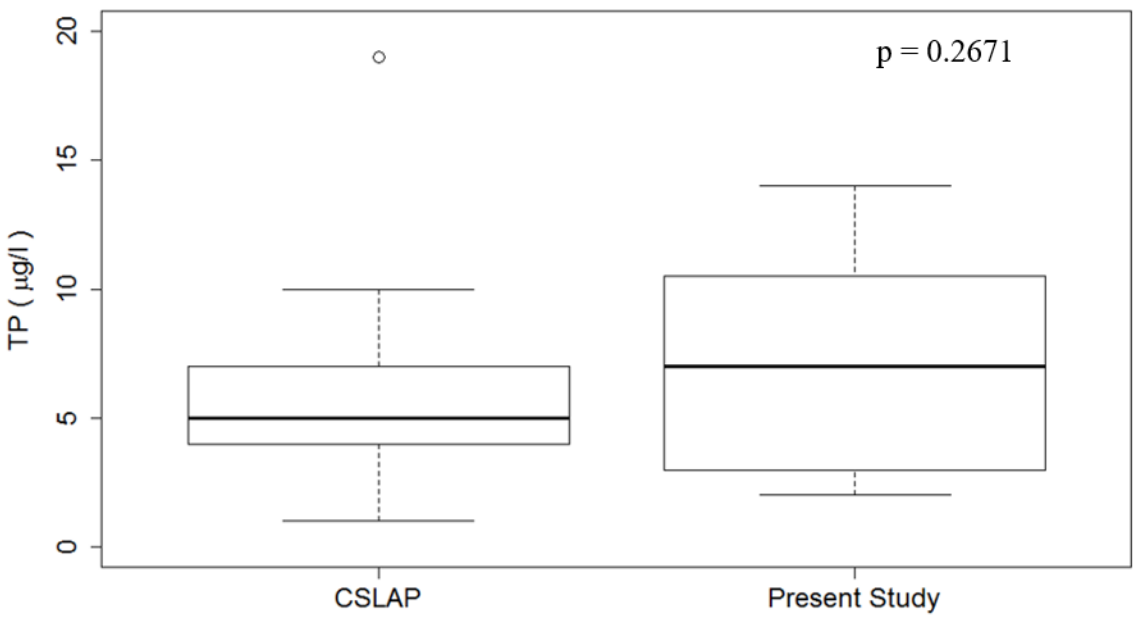

Figure 9. Comparison of surface total phosphorus (TP) (µg/l) measured in Brant Lake during CSLAP monitoring and the present study.

Table 7. Mean total phosphorus, Secchi depth, chlorophyll *a*, pH and calcium measured during the open-water season in other lakes near Brant Lake, as well as years of measurement.

Lake	CSLAP Years	TP (µg/l)	SD (m)	Chl *a* (µg/l)	pH	Ca^{2+} (mg/l)
Friends Lake	1991-1995, 2001-2010	10	4.71	3.19	7.5	7
Glen Lake	1986-1990, 1993-1995, 1997-2011	9	4.82	3.02	7.89	31.5
Schroon Lake (North)	1987-1995, 1997-2011	7	4.18	2.97	7.43	6.2
Schroon Lake (South)	2003-2011	9	4.12	1.37	7.46	5.9
Paradox Lake	2003, 2005, 2007-2011	9	4.85	2.37	8	8.2
Brant Lake (CSLAP)	1987-1991, 1999-2003	6	5.31	2.15	7.36	n/a
Brant Lake (Current)	N/A	7	5.38	1.42	7.79	8.37

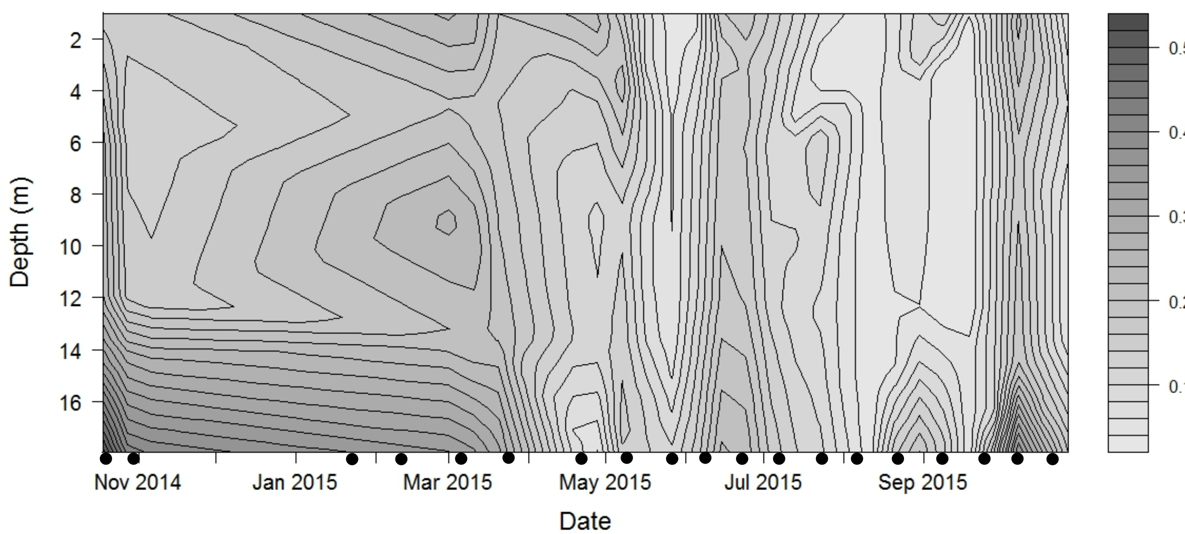

Figure 10. Total phosphorus (TP) concentration (µg/l) at depth in Brant Lake from October 2014 through October 2015.

Water Transparency– Mean Secchi depth during the open water season was 5.38 m, and ranked higher than those of nearby lakes (Table 7). We failed to detect a significant difference between the present study and historical CSLAP data (Wilcoxon rank sum test: $W = 479$, $df = 1$, $p = 0.9579$) (Figure 11).

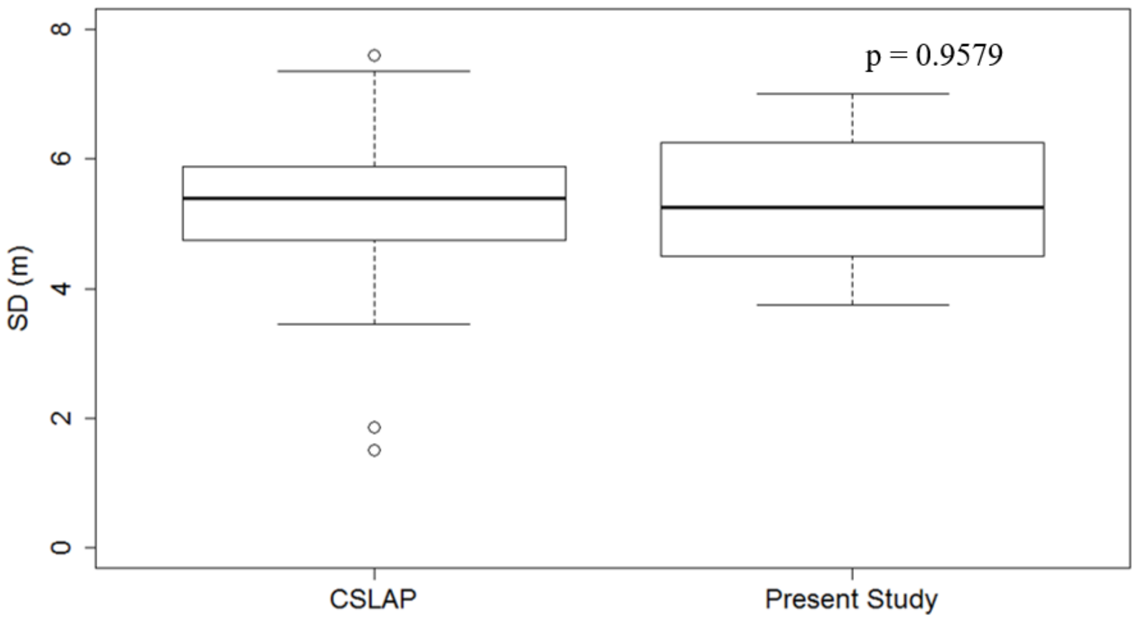

Figure 11. Comparison of Secchi depth (SD) in Brant Lake measured during CSLAP monitoring and the present study.

Chlorophyll a– Mean surface chlorophyll *a* concentration during the open water season was 1.42 µg/l (Table 6), which is lower than NY State standards for eutrophic waterbodies (10 µg/l). Chlorophyll *a* concentrations were lower in the present study than those measured in CSLAP monitoring in previous years (Wilcoxon rank sum test: W = 651.5, df = 1, p = 0.0177; Figure 12). Compared to nearby lakes, only the southern basin of Schroon lake had a lower Chl. *a* concentration than the present study (Table 7).

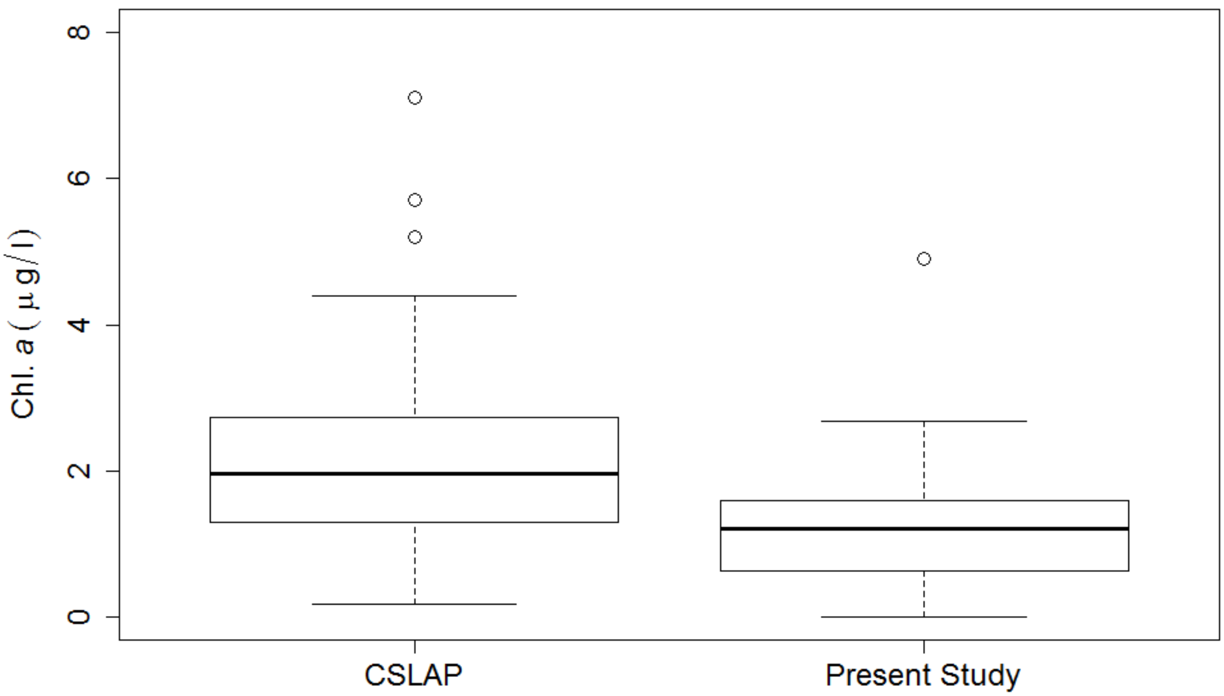

Figure 12. Comparison of chlorophyll *a* concentrations in Brant Lake measured during CSLAP monitoring and the present study.

pH– Mean surface pH was 7.79, within the range for NY state standard (6.5 to 8.5; Table 6). Compared to historical CSLAP data, pH measured in the present study was higher (Wilcoxon rank sum test: W = 271.5, df = 1, p = 0.0012; Figure 13). Glen Lake was the only regional lake that had a higher surface pH than Brant Lake (Table 7).

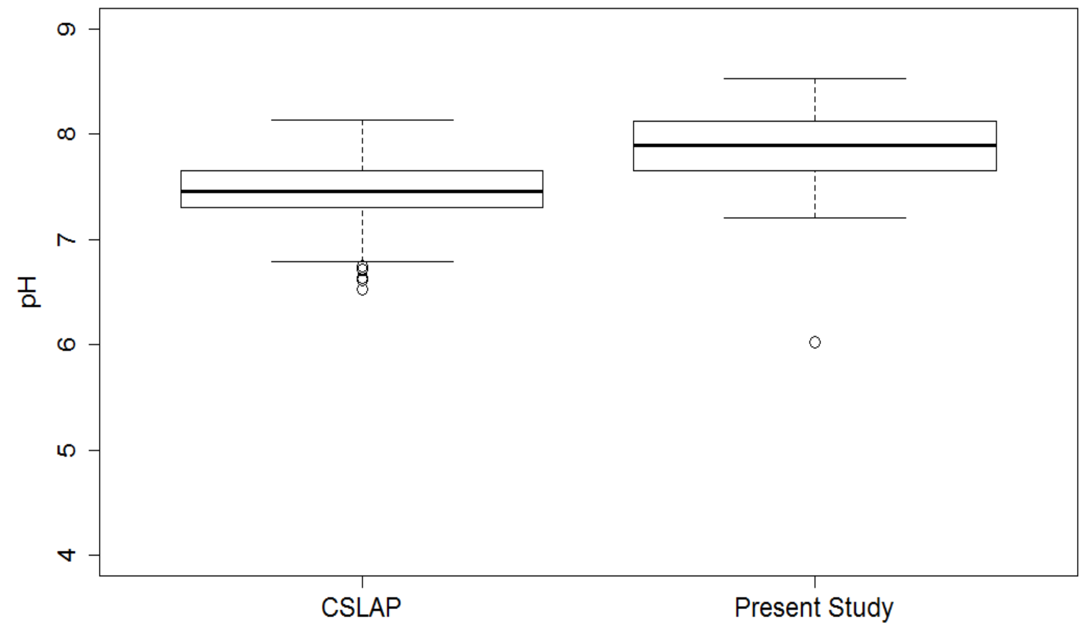

Figure 13. Comparison of pH values in Brant Lake measured during CSLAP monitoring and the present study.

Trophic State Index– Current TSI (SD) and TSI (TP) values were not statistically different from CSLAP values (Wilcoxon rank sum test: W = 405, W = 655.5 df = 1, df = 1, p = 0.7208, 0.3528 respectively; Figure 14). Current TSI (Chl. *a*) values were statistically lower than those measured during CSLAP monitoring (Wilcoxon rank sum test: W = 648.5, df = 1, p = 0.0196). Means for all TSI values from both data sets, except for TSI (TP) from CSLAP, were within the expected range for mesotrophic lakes.

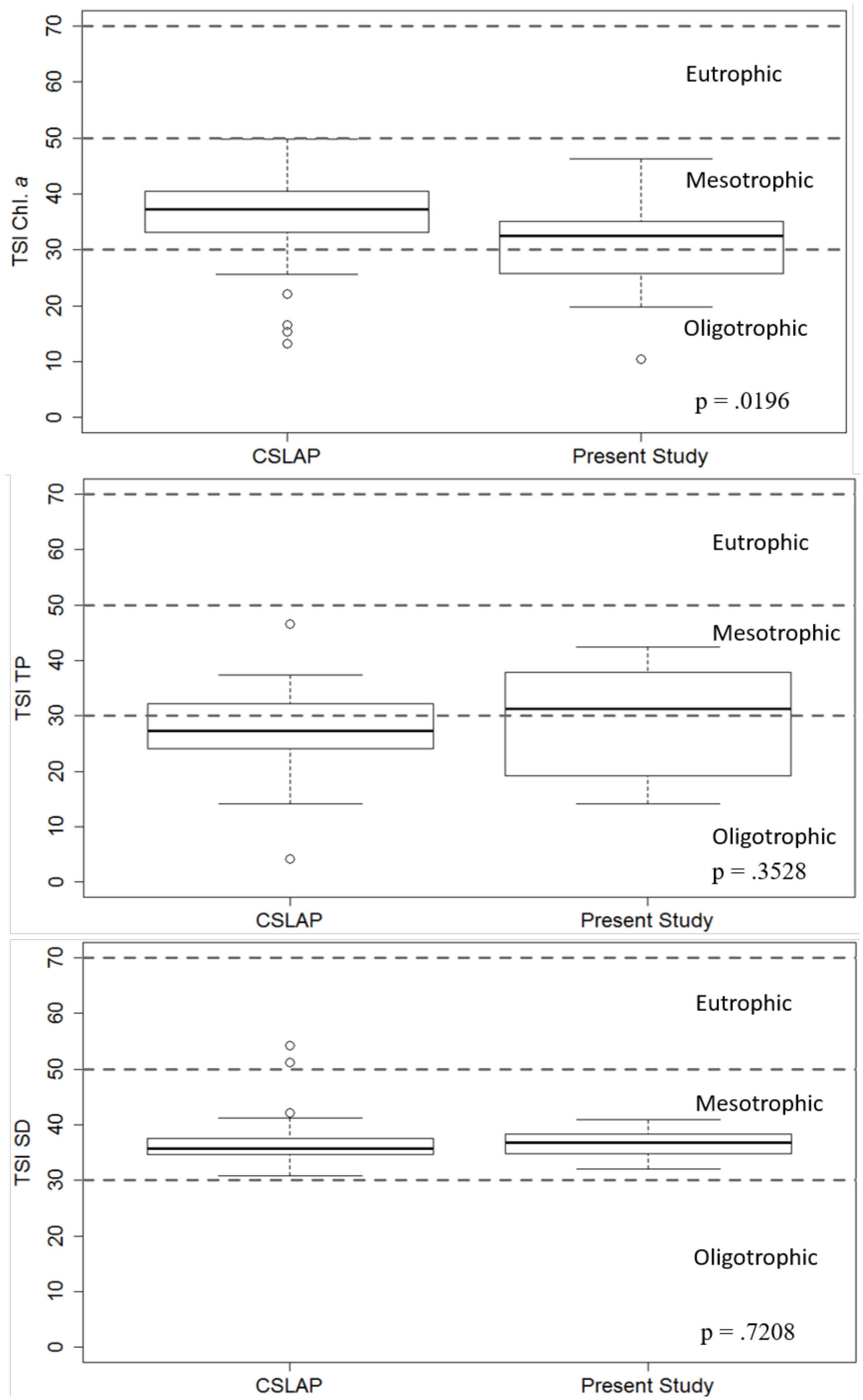

Figure 14. Comparison of mean TSI (Chl. *a*), TSI (TP) and TSI (SD) values from CSLAP monitoring and the present study. Dashed lines indicate boundaries for trophic states (Wetzel 2001).

Discussion

The limnology of Brant Lake indicates that there has historically been minimal anthropogenic impact on this system. SD, TP and Chl. *a* concentrations were all below the New York State standard for “eutrophic conditions” (NYSDEC 2015) and comparable to values measured in other local lakes (Table 2). There was a gap in limnological monitoring in Brant Lake from 2004 to 2014, but the similarities between data collected during historical CSLAP monitoring and the present study suggest that the trophic status of the lake has not changed measurably in the past decade. While the mean TSI (Chl. *a*) was significantly lower in this study than that calculated from CSLAP data, the value was still within the mesotrophic range (Wetzel 2001). Taken together, these results suggest that Brant Lake has been mesotrophic since the late 1980s.

Anoxic conditions (<1 mg/l DO) occurred in the deepest area of the lake basin starting in mid-July of 2015 and continuing until the end of October 2015. This was associated with internal P loading (evidenced by high TP near the bottom) on October 18 and 29, 2014 and August 26, October 6 and 27, 2015. Interestingly, internal P loading was not observed during September 2015. TP was more uniformly distributed in the water column during July and August 2015 but not in Sept 2015. Until the end of 2015, there was no accurate bathymetric map with which to reference the deepest point in the lake, which may have led to not sampling over the exact deepest point. This may be why internal loading was not detected during September.

There appears to be no evidence that internal loading has had an impact on TP in the epilimnion. Low oxygen levels in the deepest point of the lake were reported by Eichler (1990). This observation was associated with higher nitrate (surface: 0.014 mg N/l, bottom: 0.053 mg N/l) and ammonia (NH_4) (surface: < 0.010 mg N/l, bottom: 0.060 mg N/l). TP was higher near the sediment as well, but not to the degree of the other parameters (surface: 0.004 mg/l P, bottom: 0.008 mg P/l). While data from Eichler (1990) were snapshots and lacked follow-up monitoring, annual fluctuations in DO concentrations in deep water have most likely followed similar patterns from 1990 to present. This inference is supported by similar observations in TSI and other limnological parameters.

Surface pH on Brant Lake is circumneutral to basic and is similar to pH in nearby lakes (Table 2). The higher pH values observed during this study, compared to the CSLAP years (1987-2003), may indicate that Brant Lake has been recovering from atmospheric acid depositions. Eichler (1990) reported a mean pH from the 1930’s to the 1980’s as 6.92 (Standard deviation: 0.33, range: 6.3-7.5). A steady increase in pH over this time period has been associated with recovery from atmospheric acid deposition in other Adirondack lakes (Driscoll et al. 2003). Alkalinity measurements indicated that Brant Lake has low capacity to buffer changes in pH compared to nearby Lake George which, from 2002 to 2010, had an overall mean alkalinity of about 30 mg/l $CaCO_3^-$ (Boylen et al. 2014). Comparisons with other Adirondack lakes were not possible due to differing methodologies in determining alkalinity. Our study did not filter water samples before preforming analysis, where Baker et al. (1990) did. However, the reduced alkalinity in Brant Lake does have the potential to increase its susceptibility to large fluctuations in pH and increases uncertainty associated with temporally restricted monitoring of pH. If pH sampling does not occur on a consistent basis, detection of these fluctuations may be too late for mitigative strategies to be implemented.

Low calcium concentration has been hypothesized to limit successful zebra mussel (*Dreissena polymorpha*) colonization (Hincks and Mackie 1997, Cohen and Weinstein 2001, Jones and Riccardi 2005, Whittier et al. 2008) and has been used to predict zebra mussel distribution (Neary and Leach 1992). While there is no universally applicable calcium concentration threshold below which zebra mussels cannot occur, 8.5 mg/l Ca^{2+} was reported to be the threshold for positive growth (Hinks and Mackie 1997) and was the lowest calcium concentration at which zebra mussel populations were found in a recent study (Jones and Riccardi 2005). Jones and Riccardi (2005) also found very low zebra mussel biomass (3.4 gm^{-2}) in sites with the lowest calcium concentrations (8 mg/l Ca^{2+}). The mean surface concentration of calcium in Brant Lake was 8.60 mg/l, close to both of the published thresholds. This indicates that Brant Lake may have enough calcium to support slightly positive growth of successful individual mussels but not exponential growth of an introduced zebra mussel population to the point at which significant harm is done to the rest of the ecosystem within a short period after introduction.

The chloride concentrations recorded in this study were more than two times higher than the values reported in Eichler (1990). These concentrations, however are well within the range reported in Kelting et al. (2012), which studied 82 lakes with paved roads within their watersheds in the Adirondack Park (lake water Cl^-: 0.1 to 58.4 mg/l). Other lakes also have documented increases in chloride concentrations, including Lake George (Swinton et al. 2015) and Otsego Lake (Albright 2005). Mean chloride concentrations tripled in Lake George from 1980 to 2009 (Swinton et al. 2015), and concentrations doubled in Otsego lake, NY from 1994 to 2005, with variable readings thereafter (Waterfield and Albright 2013). The increase in chlorides in these lakes has been attributed partially to road salts. The highest concentrations of chlorides were present in streams that ran through areas of high urbanization. Swinton et al. (2015) found a significant correlation between chloride concentrations and the amount of roadway surface within sub watersheds. Albright (1996) found chloride concentrations in a tributary located within the village of Cooperstown feeding Otsego Lake to be over 1,000 mg/l during a winter thaw event. No area within the Brant Lake watershed has close proximity to high density of paved roads as the Otsego Lake and Lake George watersheds do, reducing the intensity of direct inputs from major roadways. This may explain why Brant Lake's chloride levels have only doubled over a 25 year period while chloride concentrations in Lake George and Otsego have seen larger increases in shorter time periods. It is also pertinent to emphasize that chloride data have been collected for Lake George and Otsego Lake over multiple years, while Brant Lake lacks such long-term chloride data sets. While chloride concentrations are likely to increase in the future, the magnitude and rate of increase can only be predicted through continued monitoring.

Increased chloride concentration has the potential to affect the biota of Brant Lake in the future. Blasius and Merrit (2002) found that the amphipod *Gammarus pseudolimnaeus* exhibited increased drift (avoidance behavior for macroinvertebrates under stressful conditions) at chloride concentrations of 606 mg/l, and the LC_{50} of *Hexagenia limbata* (a burrowing mayfly) was 3,800 mg/l at 18°C. These concentrations are well above the current chloride concentration in Brant Lake; however, if anthropogenic inputs of chloride remain unchecked for a long time, they can potentially alter the lake fauna.

The current chemical and physical limnology of Brant Lake is overall conducive to proper ecological functioning and commonly desired recreational uses. Comparisons with past data indicated that the trophic state of the lake has most likely been stable within the mesotrophic range over the last two decades. Increases in chloride concentrations may indicate that there are some anthropogenic stressors that have the potential to affect desired lake uses in the future. An effective management plan should include strategies for the prevention of potential problems caused by these anthropogenic stressors in the future.

Chapter 3. Brant Lake Fisheries Surveys

Introduction

Understanding the dynamics of fisheries within a lake is a key component of any comprehensive lake management plan. Understanding the status of sport fish populations and structure of the fish community assemblage can help detect changes and evaluate current management practices. Fish can have measured impacts on food web structure and water quality (Jeppesen et al. 2000, Harman et al. 2002), underlining their importance in lake management.

Anglers fishing on Brant Lake commonly target black bass (*Micropterus* spp.) and yellow perch (*Perca flavences*). Yellow perch are also especially popular through the ice. The New York State Department of Environmental Conservation (DEC) stocks brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) annually in the spring (Table A1: Appendix) to provide additional angling opportunity.

The NYSDEC has conducted 4 fisheries surveys on the lake since 1997. There has only been one survey aimed at understanding the status of recreationally relevant species (2005 gill netting survey) and no survey has assessed near shore fish communities (Table 5).

Table 5. Past NYSDEC fisheries surveys of Brant Lake.

Year	Survey purpose	Gear used
1997	Rare/endangered species	Backpack electrofishing/seining
2000	TSMP collection	Boat electrofishing
2005	General biological survey	Gill-netting
2008	General biological survey	Backpack electrofishing/seining

The 2005 gill netting survey was assessed the status of stocked brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*). Sixteen brown trout and 4 rainbow trout were caught in 8 overnight gill net sets. Mean total length for brown trout and rainbow trout were both 306 mm. Brown trout length ranged from 226 mm to 558 mm. Rainbow trout length ranged from 296 mm to 321 mm. A majority of these trout were either within or just slightly longer than the length at which they were stocked (216–241 mm).

The goal of this study was to assess the status of both near-shore and pelagic fish communities with respect to populations of recreationally valuable species. In order to achieve this goal, we conducted both gill netting and electrofishing surveys to quantify species richness, estimate catch per unit effort (CPUE) and population size structure using proportional stock density (PSD) (Anderson et al. 1996). We anticipate that the information derived from this study will inform lake stakeholders about the current status of the Brant Lake fishery and provide managers a baseline from which to implement sound management decisions.

Methods

Gill netting–Experimental gill nets were used to sample the cold water fish community. Each experimental gill net contained 6 25-ft panels. Stretch mesh sizes for the panels were 1.5'', 2.0'', 2.375'', 2.5'', 3", 3.5" for all but one net which had bar mesh sizes of .025", 0.31", 0.40", 0.50", 0.60" and 0.74". All nets were deployed on the bottom horizontally. Soak time was approximately 20 hrs, lasting from June 18, 2015 through June 19, 2015. All fish sampled were identified to the lowest possible taxonomic level, total length was measured (mm) and each fish was weighed (g).

Electrofishing–Boat electrofishing was used to assess near shore fish communities at randomly generated sites. Sixteen sites were generated around the lake using a stratified random sampling design. Sampling sites were broken down into "game fish" and "all fish" collections (Green 1989) prior to randomly selecting a starting location from a pre-determined set of possible starting locations that provided complete shoreline coverage around the lake in 0.5-mile reaches. During game-fish collections, only black bass and chain pickerel were collected. During all-fish collections, all species were collected. All electrofishing runs lasted for 15 minutes with pre-determined start/stop locations that were used to demarcate sites, moving from north to south within each site. For example, if a run started on the west shoreline of the lake, the boat would sample south on the shoreline until 15 minutes expired. If a run started on the east side of the lake, the boat would sample south on the shoreline. Because of time constraints, two electrofishing boats were used: one on the east shoreline and one on the west. Similarly, two game-fish collections were dropped from the sampling effort due to time constraints.

Electrofishing boats were equipped with a 3500 watt generator with a Type VI-A variable pulsator (Cornwell 2005). Two netters were positioned on the front of the bow, one on either side. Fish were netted and placed into 284-liter tanks and processed at the end of each collection. Fish were identified to lowest possible taxonomic level and total length was measured. All fish were released uninjured, except for 10 yellow perch and one smallmouth bass that were kept for DEC contaminant analysis.

Water quality measurements were taken to ascertain conditions prior to sampling (Table A3: Appendix). Physicochemical data were collected in the deepest part of the basin. Measurements of physicochemical parameters (pH, temperature, dissolved oxygen , percent oxygen saturation and specific conductivity) were recorded at 1 m intervals from 1 m below the surface to 18 m deep (bottom). Water quality parameters were measured with a YSI® 650 MDS with a 6-Series multiparameter sonde, calibrated according to manufacturer's instructions (YSI 2009).

Data analysis–We used catch per unit effort (CPUE) to examine relative abundance of fishes sampled. CPUE for fishes other than black bass and chain pickerel was calculated using combined shock times from the all-fish collections. Black bass and chain pickerel CPUE was calculated using the combined shock times from both all- and game-fish collections. For select fishes for which sufficient data were collected, length frequency histograms were generated to examine population size structure along with proportional stock density (PSD). PSD was calculated as (Anderson et al. 1996):

$$PSD = (\text{Number of fish} \geq \text{quality length}/\text{Number of fish} \geq \text{stock length}) \times 100$$

Construction of length frequency histograms and calculation of PSD was done using the FSA package (Ogle 2016) in R (R Core Team 2016). Data from angling, gill nets and electrofishing were combined to obtain more accurate estimates of size structure (Beamesderfer and Rieman 1988; Willis et al. 1993).

Results

Species Richness and Relative Abundance–A total of 21 species were sampled between gill netting and electrofishing representing 11 families (Table 8). Gill netting resulted in the collection of 354 fish and electrofishing yielded 813 fish (239 fish/hr; Table 9). There were five brown trout and zero rainbow trout caught during the gill net survey, and zero trout of either species caught in electrofishing.

The most abundant species by CPUE was yellow perch (102 fish/hr) followed by pumpkinseed (66 fish/hr) and golden shiner (44 fish/hr). Yellow perch CPUE was comparable to state suggested perch abundances (Low: 15 fish/hr, High: 50 fish/hr; Forney et al. 1994). Compared to other lakes in the state, CPUE of yellow perch > 100 mm (94 fish/hr), was higher than most lakes reported (Figure 15). Largemouth and smallmouth bass CPUE were comparable to state standards (state largemouth and smallmouth bass mean CPUE: 17 +/- 19 and 4 +/-8 fish/hr, respectively; Perry et al. 2014).

Table 8. Species list of fish found in Brant Lake during 2015 sampling efforts. Asterisk indicates species that were previously collected in the lake, but not detected in electrofishing or gill netting during 2015.

Family	Common name	Scientific name
Catostomidae	White sucker	*Catostomus commersonii*
Centrarchidae	Black crappie	*Pomoxis nigromaculatus*
Centrarchidae	Bluegill	*Lepomis macrochirus*
Centrarchidae	Largemouth bass	*Micropterus salmoides*
Centrarchidae	Pumpkinseed	*Lepomis gibbosus*
Centrarchidae	Red breasted sunfish	*Lepomis auritus*
Centrarchidae	Rock bass	*Ambloplites rupestris*
Centrarchidae	Smallmouth bass	*Micropterus dolomieu*
Cottidae	Slimy sculpin	*Cottus cognatus*
Cyprinidae	Bridle shiner*	*Notropis bifrenatus*
Cyprinidiae	Bluntnose minnow	*Pimephales notatus*
Cyprinidiae	Emerald shiner	*Notropis atherinoides*
Cyprinidiae	Golden shiner	*Notemigonus crysoleucas*
Esocidae	Chain pickerel	*Esox niger*
Fundulidae	Banded killifish	*Fundulus diaphanus*
Ictaluridae	Brown bullhead	*Ictalurus nebulosus*
Ictaluridae	Yellow bullhead	*Ameiurus natalis*
Osmeridae	Rainbow smelt	*Osmerus mordax*
Percidae	Yellow perch	*Perca flavescens*
Salmonidae	Brown trout	*Salmo trutta*
Salmonidae	Rainbow trout*	*Oncorhynchus mykiss*
Umbridae	Central mudminnow	*Umbra limi*

Table 9. Total number of fish and CPUE during 2015 fall electrofishing survey (pooled among boats).

Common Name	Total Caught	CPUE (Fish/Hr)
White sucker	1	0.53
Black crappie	9	4.74
Bluegill	18	9.47
Largemouth bass	144	42.35
Pumpkinseed	126	66.32
Redbreast sunfish	40	21.05
Rock bass	13	6.84
Smallmouth bass	37	10.88
Bluntnose minnow	6	3.16
Emerald shiner	14	7.37
Golden shiner	84	44.21
Chain pickerel	63	18.53
Banded killifish	2	1.05
Brown bullhead	21	11.05
Yellow bullhead	5	2.63
Rainbow smelt	30	15.79
Yellow perch	194	102.11
Central mudminnow	6	3.16

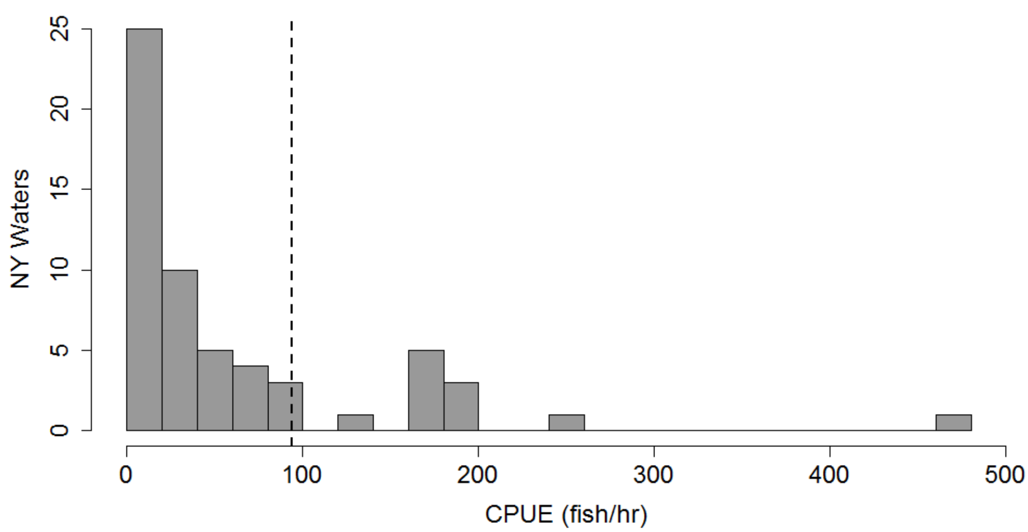

Figure 15. Yellow perch >100 mm CPUE for select NYS waters (Forney et al. 1994). Dashed line indicates 2015 Brant Lake CPUE for yellow perch >100 mm.

Population Size Structure–Yellow perch length frequency distribution indicates at least three distinct age classes. The first age class is evident around 60-80 mm. Two other potential age classes occur at 160-190 mm and at 270-290 mm (Figure 16). There may be a fourth age class between the latter two, but too few fish were collected in that range to make a definitive determination.

Largemouth bass length frequency distribution shows three potential year classes at 80-100 mm, 200-260 mm and 400-440 mm (Figure 17). Smallmouth bass length distribution shows potential age classes at 80-190 mm and 360-430 mm (Figure 18). PSD values for largemouth and smallmouth bass (Table 10) are comparable to state standards (Perry et al. 2014; Table 10).

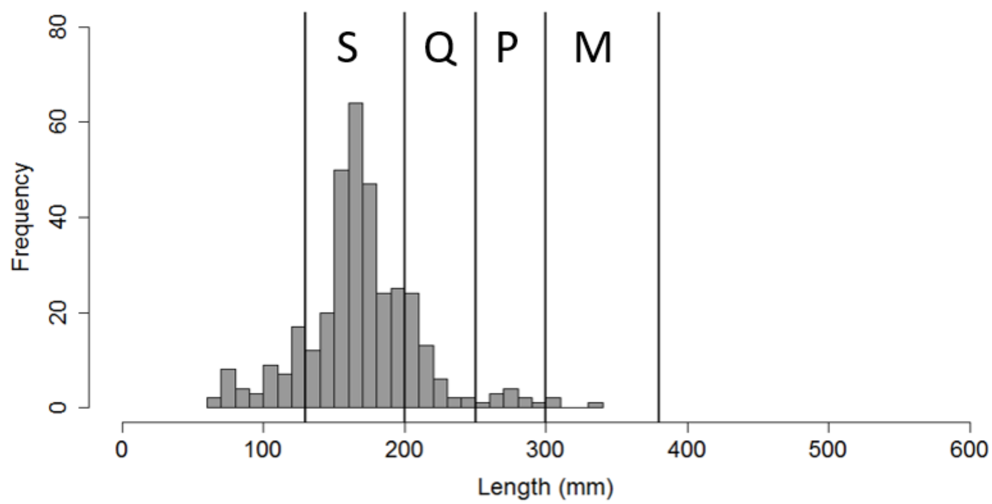

Figure 16. Length-frequency histogram for yellow perch collected in Brant Lake during 2015 (n = 353). Letters indicate ranges for Stock (S), Quality (Q), Preferred (P) and Memorable (M) size ranges (Gabelhouse 1984).

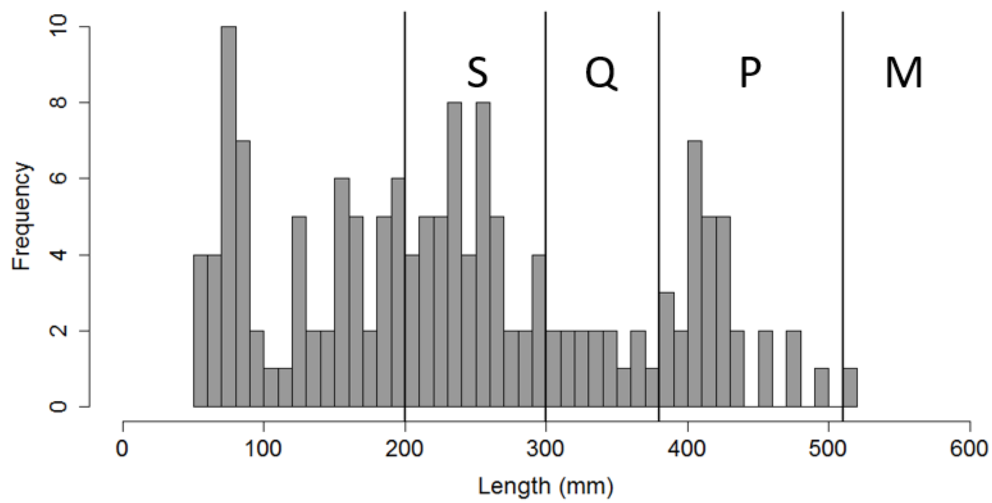

Figure 17. Length-frequency histogram for largemouth bass collected in Brant Lake during 2015 (n = 153). Letters indicate ranges for Stock (S), Quality (Q), Preferred (P) and Memorable (M) size ranges (Gabelhouse 1984).

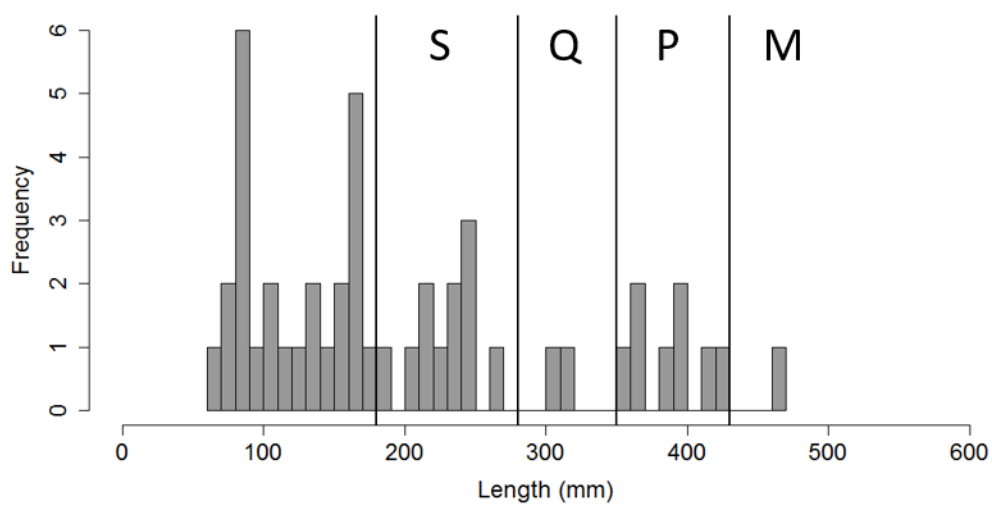

Figure 18. Length-frequency histogram for smallmouth bass collected in Brant Lake during 2015 (n = 47). Letters indicate ranges for Stock (S), Quality (Q), Preferred (P) and Memorable (M) size ranges (Gabelhouse 1984).

Table 10. Proportional stock densities (PSD) for select species. Numbers in parenthesis indicate standard deviations.

Common Name	PSD (State standard)
Largemouth Bass	48.4 (55 +/- 24)
Pumpkinseed	16.8
Smallmouth Bass	50.0 (56 +/-24)
Chain Pickerel	40.0
Yellow Perch	21.4

Discussion

Brant Lake provides a number of warm-water fishing options for its stakeholders based on CPUE for largemouth bass, chain pickerel and yellow perch. The presence of multiple age classes for largemouth bass, smallmouth bass and yellow perch implies that successful recruitment has been occurring for these species in past years and future year classes may be similar to 2015 in terms of abundance. Largemouth and Smallmouth bass have a significant prey source represented by the abundance of small yellow perch (<150 mm). This supply of prey should help sustain largemouth and smallmouth bass populations at their current proportional stock densities.

The cold-water fishery in Brant Lake also provides opportunities for recreation angling. The low number of brown trout caught during our fisheries surveys alone does not necessarily indicate that there is a small population. Our gill nets were only set on the bottom, where we could have missed trout suspended in the water column. Brown trout can inhabit near-surface waters (Langeland et al. 1991; Langeland and L'Abée-Lund 1996), which may have reduced the effectiveness of our gear deployment. However, available habitat in Brant Lake may also limit the potential abundance of both brown and rainbow trout in this system.

It seems likely that the trout populations in Brant Lake are under stress due to habitat availability in the lake. Water temperature in Brant Lake reached a maximum of 25 °C at the surface and was consistently above 20 °C in the epilimnion during summer stratification (Physical and Chemical Limnology). Forseth and Jonsson (1994) found that optimal growth of brown trout occurs at 16 °C, and Haraldstad and Jonsson (1983) found brown trout living in 15-20 °C waters. Black et al. (1953) found the upper lethal limit for rainbow trout to be 23-25 °C and Eaton et al. (1995) reported upper thermal tolerance of 22-24 °C. In Brant Lake, trout may be stressed during summer stratification and move lower in the water column. But, the deep water in Brant Lake may also be uninhabitable for trout due to other habitat requirements such as dissolved oxygen.

As water temperature increased in the epilimnion during summer stratification, dissolved oxygen decreased in the hypolimnion due to abiotic and biotic demands for oxygen (Chapter 2). By the end of summer stratification in Brant Lake in 2015, a reasonably large proportion of the hypolimnion was completely anoxic, and dissolved oxygen concentration was below 5 mg/l during the majority of the stratification period. Brown trout are sensitive to dissolved oxygen concentrations lower than 5 mg/l (Mills 1971; Davis 1975) and the incipit lethal level for dissolved oxygen for rainbow trout is 3 mg/l (Raleigh et al. 1984). With thermal stress in the epilimnion and oxygen stress in the hypolimnion, trout may be effectively “squeezed” into the metalimnion during late summer. For example, on 8 September 2015, there was only 1 m of the vertical habitat that was below 20 °C and above 5 mg/l of dissolved oxygen. Based on these data, we infer that the trout population is under considerable stress during most of the open-water season.

Despite these habitat limitations, we know that brown trout are surviving at some level high enough to be detected in our sampling, so there may be small patches of suitable cold-water habitat during late summer that allows some fish to survive from year to year. Those fish that do survive appear to grow fast enough to recruit to harvestable size during their life-time. While survival and growth in cold-water fish populations is unknown, the steady stocking of trout and current growth and survival rates continue to support cold-water angling opportunities in Brant Lake.

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Appendix A

Supplemental Limnological data

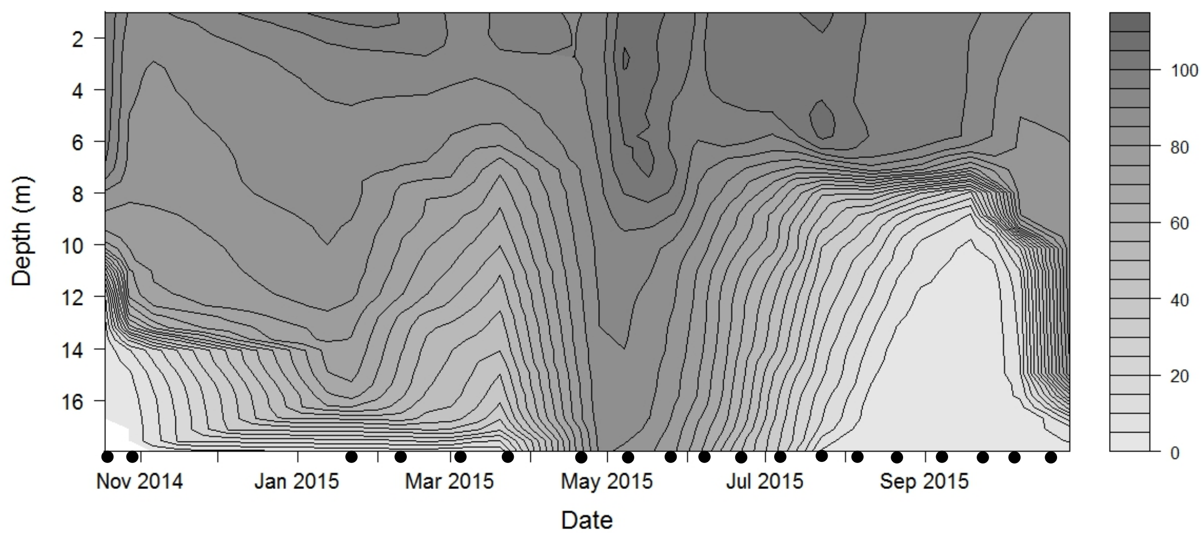

Figure A1: Percent oxygen saturation (%) isopleth for Brant Lake (October 2014 to October 2015).

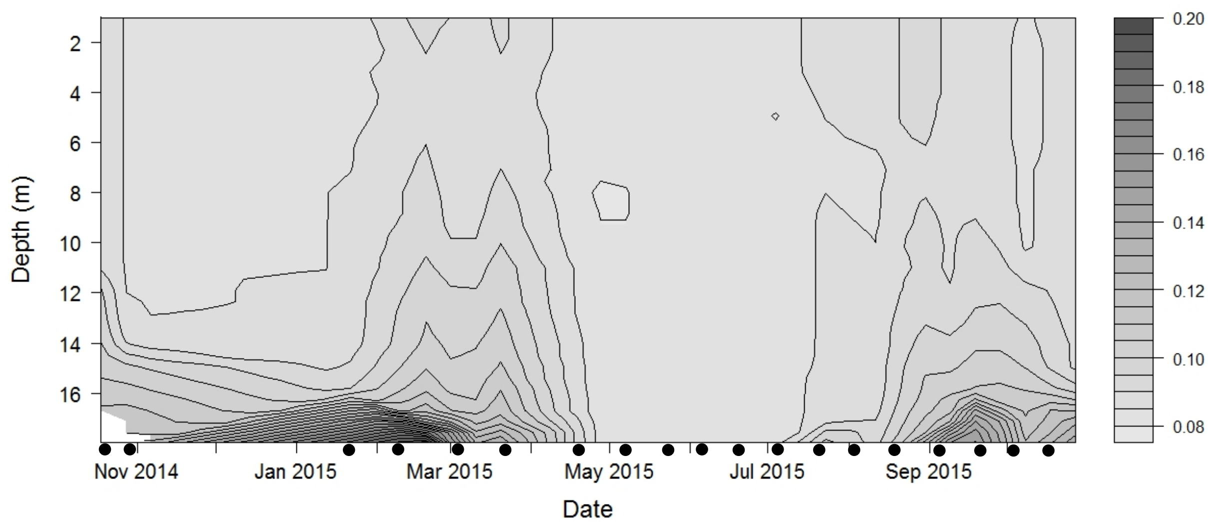

Figure A2: Specific conductivity (mS/cm^3) isopleth for Brant Lake (October 2014 to October 2015).

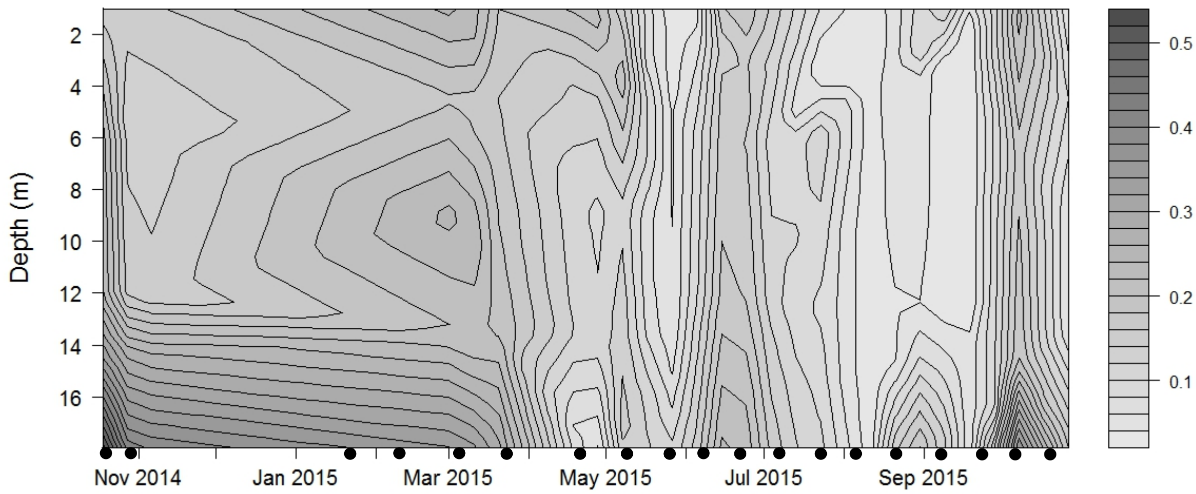

Figure A3: Total Nitrogen (mg/l) isopleth for Brant Lake (October 2014 to October 2015).

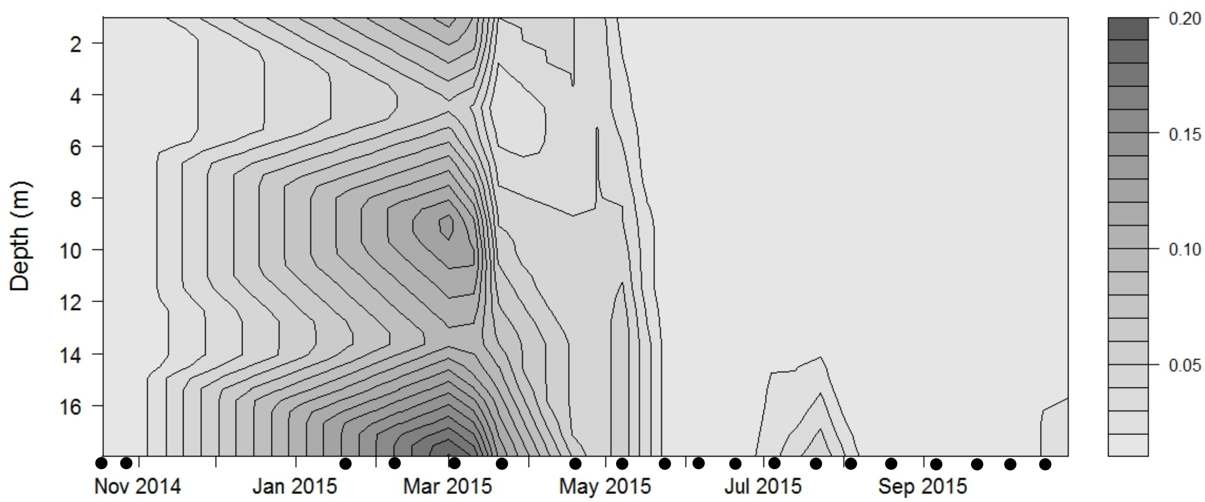

Figure A4: Nitrate + Nitrite (mg/l) isopleth for Brant Lake (October 2014 to October 2015).

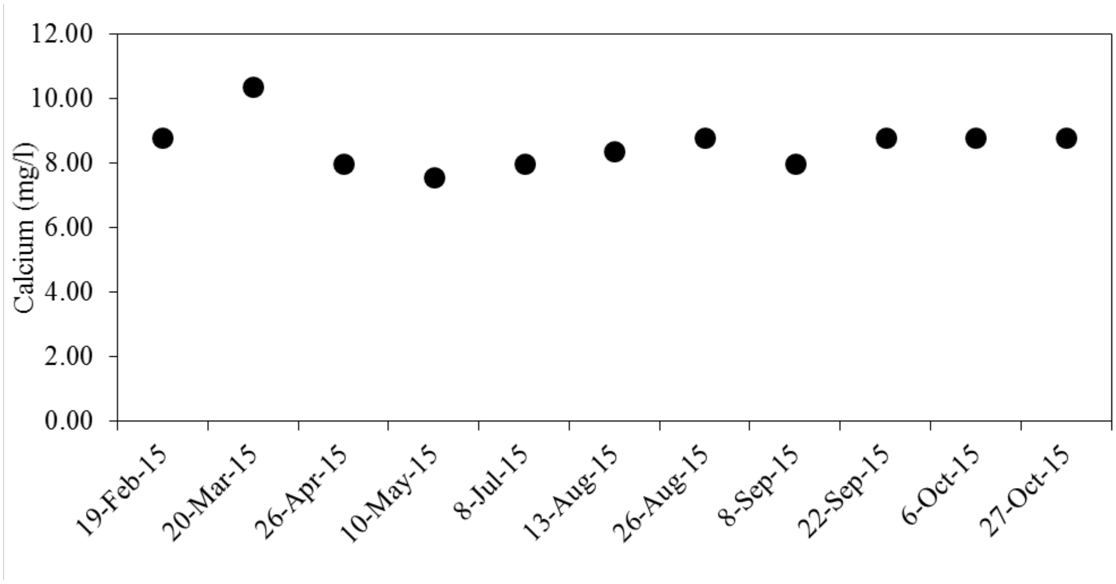

Figure A5: Surface calcium concentrations for Brant Lake

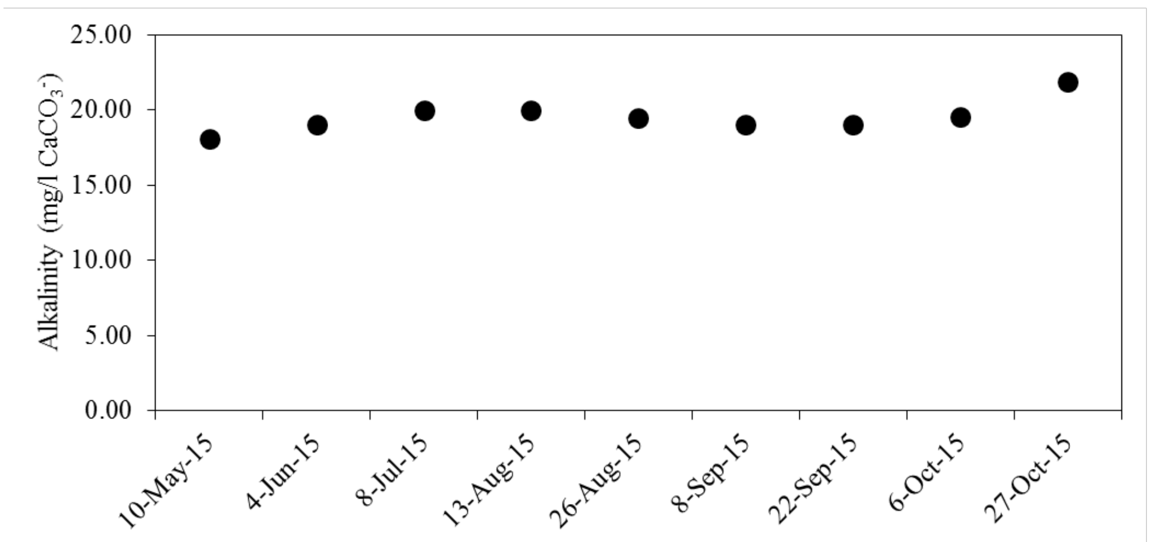

Figure A6: Surface alkalinity concentrations for Brant Lake.

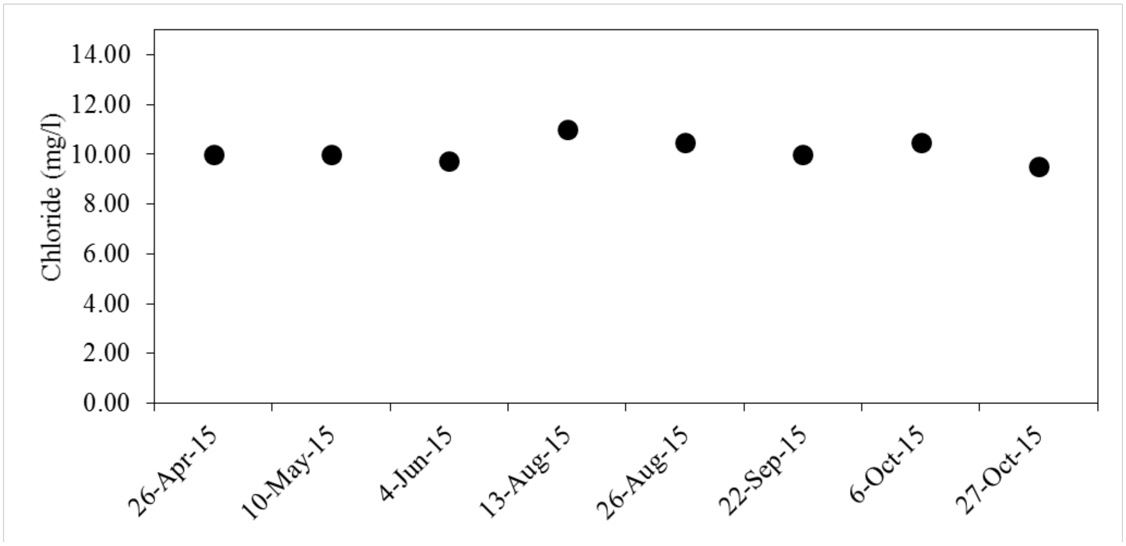

Figure A7: Surface chloride concentrations for Brant Lake.

Appendix B

Supplemental Fisheries Information

Table B1. History of fish stocking in Brant Lake.

Year Stocked	Species	Length (in)	Number of Fish Stocked
2016	*Salmo trutta*	8.5-9.5	2850
2016	*Oncorhynchus mykiss*	8.5-9.5	3300
2015	*Salmo trutta*	8.0	2820
2015	*Oncorhynchus mykiss*	9.0	3300
2014	*Salmo trutta*	9.0	2840
2014	*Oncorhynchus mykiss*	9.2	2610
2013	*Salmo trutta*	9.1	2400
2013	*Oncorhynchus mykiss*	9.0	3300
2012	*Salmo trutta*	9.0	2930
2012	*Oncorhynchus mykiss*	8.8	3300
2011	*Salmo trutta*	9.1	2780
2011	*Oncorhynchus mykiss*	8.8	3300
2010	*Salmo trutta*	8.8	2750
2010	*Oncorhynchus mykiss*	9.0	3200
2009	*Salmo trutta*	8.8	2760
2009	*Oncorhynchus mykiss*	3.4	1963
2009	*Oncorhynchus mykiss*	8.8	3120
2008	*Salmo trutta*	8.8	2750
2008	*Oncorhynchus mykiss*	8.8	3000
2007	*Salmo trutta*	8.8	2750
2007	*Oncorhynchus mykiss*	9.3	3010
2006	*Salmo trutta*	8.8	2750
2006	*Oncorhynchus mykiss*	6.0	2000
2006	*Oncorhynchus mykiss*	9.4	3300
2005	*Salmo trutta*	8.9	2750
2005	*Oncorhynchus mykiss*	8.9	3300
2004	*Salmo trutta*	8.8	2640
2004	*Oncorhynchus mykiss*	9.2	3170
2003	*Salmo trutta*	8.8	2910
2003	*Oncorhynchus mykiss*	9.1	3300
2002	*Salmo trutta*	8.9	3300
2002	*Oncorhynchus mykiss*	9.3	3000
2001	*Salmo trutta*	8.9	2800

2001	*Oncorhynchus mykiss*	8.9	3300
2001	*Oncorhynchus mykiss*	10.3	1220
2001	*Oncorhynchus mykiss*	5.7	7000
2000	*Salmo trutta*	8.8	3140
2000	*Oncorhynchus mykiss*	8.9	3300
1999	*Salmo trutta*	8.0	2390
1999	*Oncorhynchus mykiss*	9.0	3300
1999	*Oncorhynchus mykiss*	12.0	2500
1998	*Salmo trutta*	9.2	6180
1997	*Salmo trutta*	8.9	6180
1996	*Salmo trutta*	8.9	5520
1991	*Salmo trutta*	8.5	5330
1990	*Salmo trutta*	8.0	5680
1989	*Salmo trutta*	8.0	4940
1987	*Salmo trutta*	8.0	5400
1986	*Salmo trutta*	8.0	5150
1985	*Salmo trutta*	8.0	5375
1984	*Salmo trutta*	7.5	4965
1983	*Salmo trutta*	9.0	5935
1982	*Salmo trutta*	7.5	6500
1982	*Esox lucius × masquinongy*	6.0	3000
1982	*Esox lucius × masquinongy*	6.3	5500
1981	*Salmo trutta*	7.0	4460
1981	*Esox lucius × masquinongy*	5.5	5000
1980	*Salmo trutta*	8.7	1980
1980	*Esox lucius × masquinongy*	5.5	8200
1970	*Salvelinus namaycush X Salvelinus fontinalis*	6.0	3000
1969	*Salvelinus namaycush X Salvelinus fontinalis*	5.0	1190
1969	*Salvelinus namaycush X Salvelinus fontinalis*	5.0	5400
1969	*Salvelinus namaycush X Salvelinus fontinalis*	6.3	1265
1968	*Salmo trutta*	8.0	425
1968	*Salvelinus namaycush X Salvelinus fontinalis*	4.5	1500
1968	*Salvelinus namaycush X Salvelinus fontinalis*	6.0	1500
1967	*Salmo trutta*	7.8	425
1967	*Salvelinus namaycush X Salvelinus fontinalis*	5.5	1500

1967	*Salvelinus namaycush X Salvelinus fontinalis*	4.3	1500
1966	*Salvelinus namaycush X Salvelinus fontinalis*	4.8	1110
1966	*Salvelinus namaycush X Salvelinus fontinalis*	6.0	1335
1965	*Salmo trutta*	2.8	10000
1965	*Salmo trutta*	5.5	10000
1964	*Salmo trutta*	4.8	10000
1963	*Salmo trutta*	4.0	310
1962	*Salmo trutta*	4.0	525
1961	*Salmo trutta*	4.3	500
1960	*Salmo trutta*	3.5	310
1959	*Salmo trutta*	4.5	270
1958	*Salmo trutta*	4.5	500
1957	*Salmo trutta*	3.7	700
1956	*Salmo trutta*	4.0	500
1955	*Salmo trutta*	3.5	200
1954	*Salmo trutta*	3.7	340
1954	*Salmo salar*	5.8	3970
1953	*Salmo trutta*	3.5	340
1953	*Oncorhynchus nerka*	1.3	55000
1953	*Oncorhynchus nerka*	2.5	11600
1951	*Salmo trutta*	1.7	700
1951	*Oncorhynchus nerka*	1.3	82907
1950	*Salmo trutta*	1.7	200
1950	*Oncorhynchus nerka*	2.0	39500
1950	*Micropterus salmoides*		184
1949	*Salmo trutta*	3.0	150
1949	*Micropterus salmoides*		802
1948	*Salmo trutta*	3.0	125
1947	*Micropterus dolomieu*	2.5	2000
1946	*Pickerel*	14.0	142
1946	*Pickerel*	14.0	71
1946	*Micropterus dolomieu*	2.2	1000
1946	*Micropterus dolomieu*	1.5	3000
1944	*Micropterus dolomieu*	8.0	39
1942	*Micropterus dolomieu*	2.8	2000

Table B2. Electrofishing catch rate of adult yellow perch (>100mm) from New York waters. Data are from the NYSDEC data base and from the Cornell Warm water Fisheries Unit. Ranges in parenthesis are for the years indicated. Adapted from Forney et al. (1994).

Date	Waterbody	CPUE (fish/hr)
May, 78-80	Amawalk Reservoir	0.3
May, 91	Amawalk Reservoir	3
May, 78-80	Ballston Lake	19
Sep, 88	Belmont Lake	4.9
Sep, 89	Blind Sodus Bay	7.81
Sep-Oct, 73-76	Canadarago Lake	161 (60-287)
May, 81-85	Canadarago Lake	200 (107-266)
Oct, 81-82	Canadarago Lake	169-199
Oct, 86-93	Canadarago Lake	27 (10-52)
May, 89	Canadarago Lake	52.7
May, 84-90	Canopus Lake, Lower	63 (24-147)
Apr, 85-87	Canopus Lake, Upper	26 (11-36)
Sep, 90	Carry Falls Reservoir	2.3
Jun, 91	Carry Falls Reservoir	16
Jun, 89	Cassadaga Lake	13
Aug-Oct, 90-93	Cayuta Lake	7.6 (6-9.7)
May, 78-80	Copake Lake	22
May, 91	Cross River Resevoir	20
Jun, 90	Deer River Flow	4
Oct, 66-69	Dryden Lake	46 (27-81)
Sep, 90	Dyken Pond	199
Oct, 91-93	Eaton Brook Reservoir	37 (25-44)
Oct, 92-93	Findley Lake	79.2, 162.5
Jun, 91	Flat Rock Reservoir	62.7
May, 82-90	Fort Pond	1.9 (0-2.3)
May, 90	Greenwood Lake	19.6
Jul, 90	Jamesville Reservoir	13
May, 90	Kensico Reservoir	180
May, 79-90	Lake Ronkonkoma	40 (9-83)
May, 78-80	Lamoka Lake	124
May, 91	Long Pond	44
May, 85-90	Loon Lake	92 (21-132)
May, 78-80	Mariaville Lake	60
Sep, 90	Mill Pond	64
Apr, 90, Jun, 91	Millsite Lake	1, 1.6

1979-83	Mohawk River	(0.0-40.6)
Jun, 90	Mud Lake	40
Jul, 91	Newton Falls Reservoir., Upper	17
Jun, 91	Norwood Reservoir	16
Jun, 88	Otsego Lake	81
May, 90	Panther Lake	4
Jul, 85	Paradox Lake	13.9
Oct, 89-93	Port Bay, Lake Ontario	4.3 (0-11)
Apr, 90	Rudd Pond	30
Sep, 90	Schenevus Lake	14
Sep, 92, Oct, 93	Sixtown Pond	473, 260
Sep, 88	Snyders Lake	28
Sep, 91	Tomhannock Reservoir	30
May, 78-80	Tully Lake	91
May, 78-80	Waneta Lake	27
May, 78-80	White Lake	4.5
Jun, 90	Whitney Point Reservoir	13
May, 90	Wildwood Lake	178

Table B3. Water quality measurements on evening of electrofishing (October 6 2015).

Depth	Temperature (°C)	Percent oxygen saturation (%)	Dissolved oxygen (mg/l)	Specific conductivity (µs/cm^3)	pH
1	16.53	91	8.88	0.084	8.27
2	16.5	89.9	8.78	0.083	7.94
3	16.07	88	8.66	0.083	7.85
4	15.94	86	8.49	0.083	7.76
5	15.91	85	8.4	0.083	7.68
6	15.88	84.3	8.34	0.083	7.56
7	15.82	83.6	8.26	0.084	7.52
8	15.74	82.1	8.14	0.084	7.45
9	15.69	79	8.14	0.084	7.42
10	15.54	19.3	7.86	0.084	7.37
11	14.02	8.1	1.87	0.087	7.08
12	12.03	5.2	0.84	0.093	6.78
13	11.23	4.5	0.58	0.095	6.69
14	10.82	3.6	0.49	0.098	6.6
15	10.59	3.1	0.39	0.101	6.54
16	10.34	2.8	0.34	0.106	6.51
17	10.2	2.6	0.31	0.109	6.47
18	10.1	2	0.29	0.114	6.45

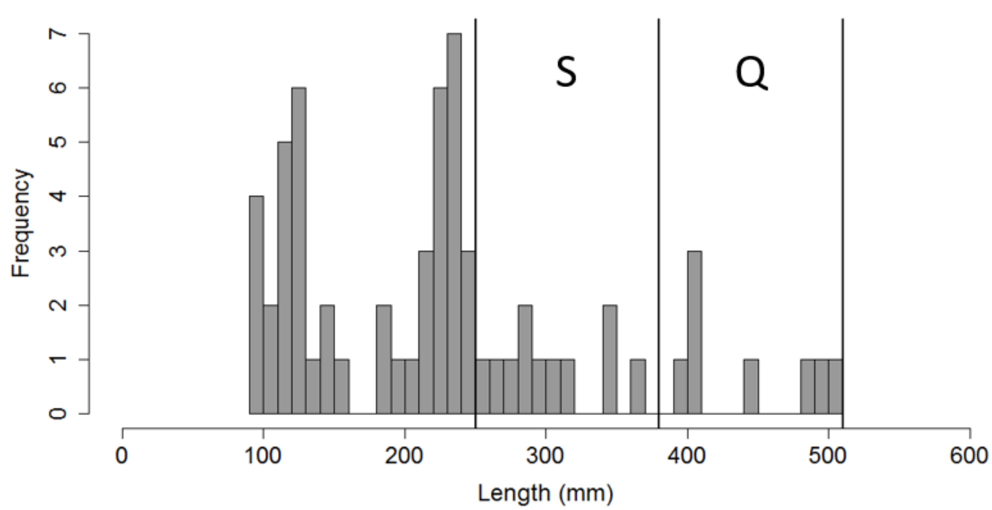

Figure B1. Length-frequency histogram for chain pickerel collected in Brant Lake during 2015 (n = 67). Letters indicate ranges for Stock (S) and Quality (Q) size ranges (Gabelhouse 1984).

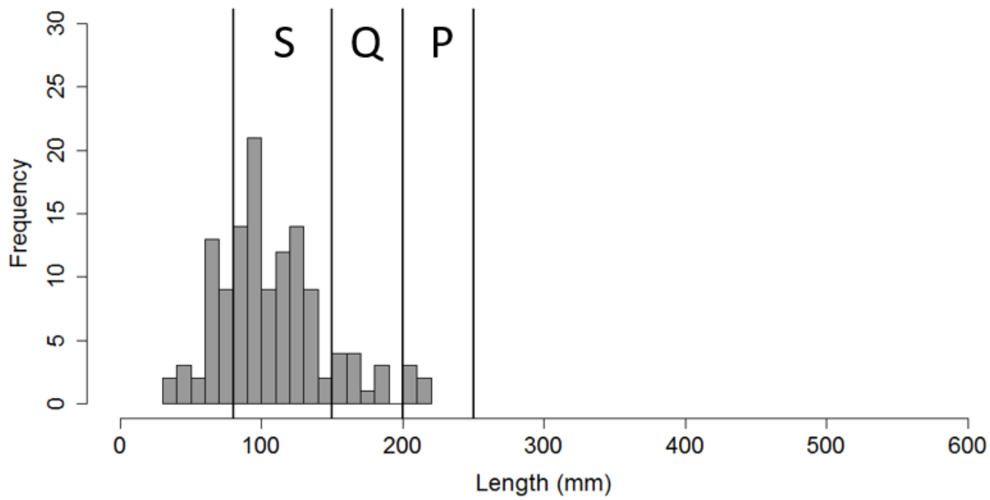

Figure B2. Length-frequency histogram for pumpkinseed collected in Brant Lake during 2015 (n = 127). Letters indicate ranges for Stock (S), Quality (Q) and Preferred (P) size ranges (Gabelhouse 1984).

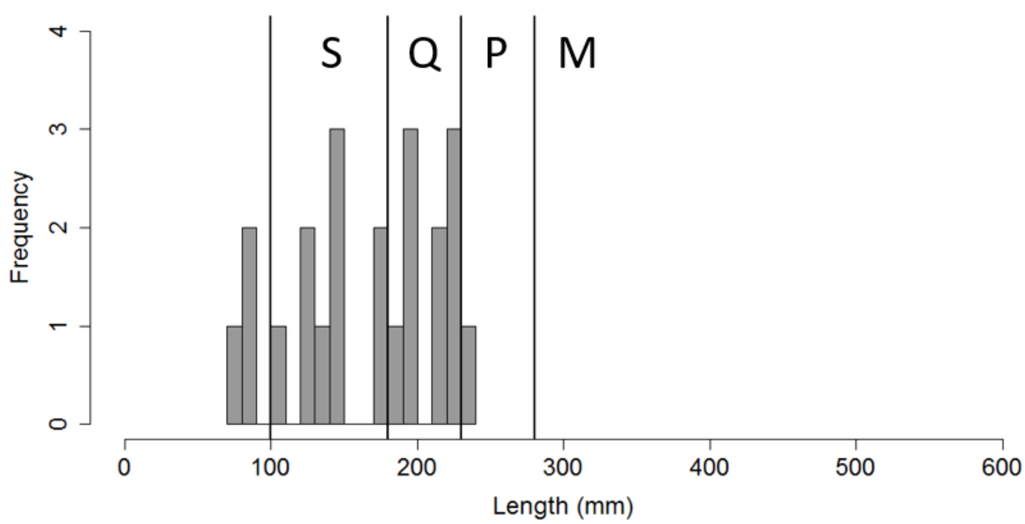

Figure B3. Length-frequency histogram for rock bass collected in Brant Lake during 2015 (n = 353) Letters indicate ranges for Stock (S), Quality (Q) and Preferred (P) and (M) Memorable size ranges (Gabelhouse 1984).

Brant Lake Management Plan

Alejandro Reyes

Submitted to the Brant Lake Association and the Town of Horicon

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Management Plan Structure

The Brant Lake Management Plan is designed to guide the current and future management of Brant Lake toward sustainable ecological and recreational goals. This document firstly identifies the current ecological and recreational issues that affect the ecology of Brant Lake and the desired uses of stakeholders. As no single plan can address all of them perfectly, our strategy is to focus on three main issues: 1) Eurasian watermilfoil (EWM) management, 2) Prevention and early detection of aquatic invasive species 3) Management of nutrients. This plan is based on the current state of Brant Lake, as reported in the previous chapter, and relevant information from peer reviewed literature. We hope that by focusing on three topics in detail, the reader will come away with a strong understanding of these issues, their basic scientific underpinnings and the strategies used for management.

Chapter 4. Summary of Management Concerns

Introduction

Development of a comprehensive lake management plan requires the inputs of the stakeholders. Opinions and perceptions regarding the lake and its watershed are important when management goals and priorities are set. In order to obtain this information, a lake watershed survey was distributed to the members of the Brant Lake Association (BLA) and the Town of Horicon (TOH).

Survey Details

The survey consisted of 19 questions (Appendix A), many of which were taken from a previous Brant Lake watershed survey in 1999. Due to financial considerations, the survey was administered in an online form using www.surveymonkey.com. Only one response was allowed per web browser to reduce the chance of multiple responses from one source. To advertise the survey, a postcard was sent out to residents of the TOH, and an email was sent to members of the BLA, both of which contained the survey link. The survey was made available on March 16, 2016 and closed on April 30, 2016. Survey data were analyzed and results were interpreted by this author.

Survey results

Demographics–A total of 307 surveys were completed out of 1,900, resulting in a response rate of 16%. The majority of the respondents (78%) were seasonal residents (Figure 1), and most (75%) owned either shoreline property or property within0.5 miles of Brant Lake (Figure 2). The average age of respondents was 61 years and most (62%) had been living in or visiting the Brant Lake area for more than 30 years (Figure 3).

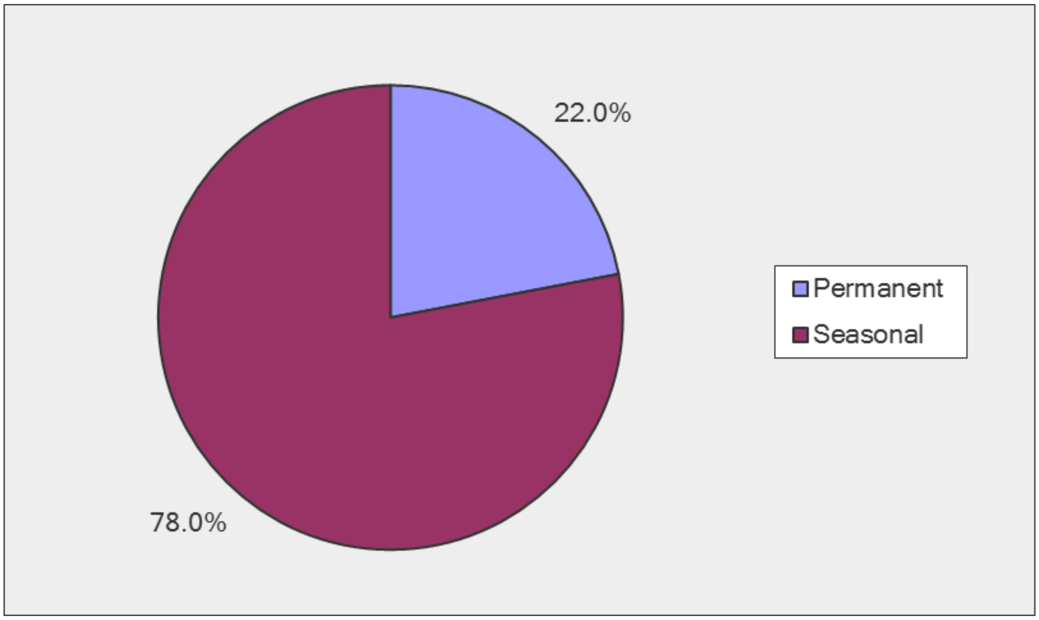

Figure 1. Responses to 2015 Brant Lake watershed survey question: Are you a permanent or seasonal resident of the Brant Lake Watershed Area?

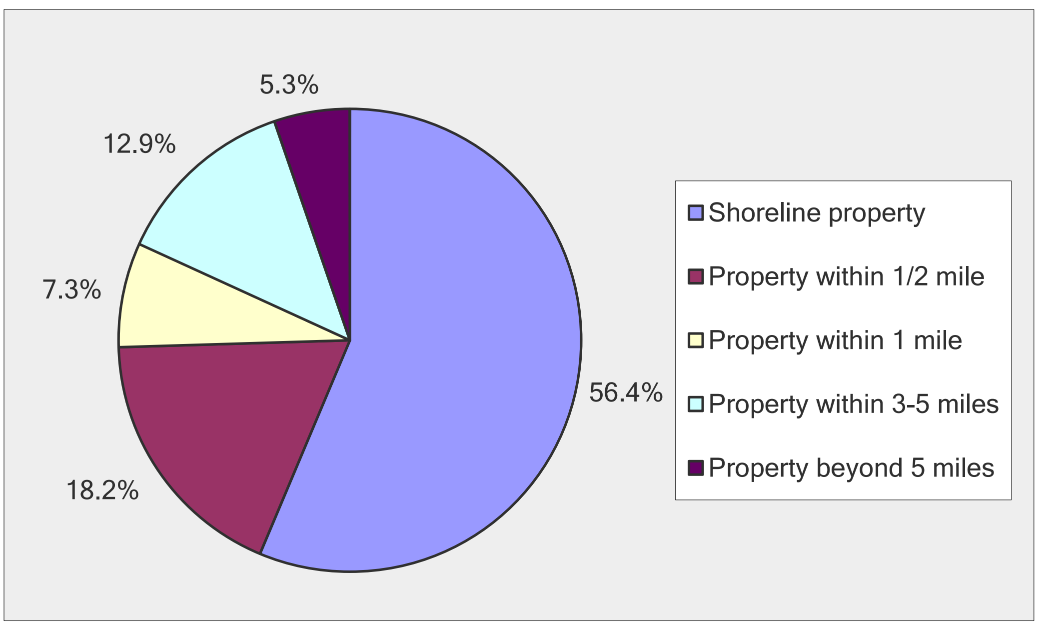

Figure 2. Responses to 2015 Brant Lake watershed survey question: What is the proximity of your residence to Brant Lake?

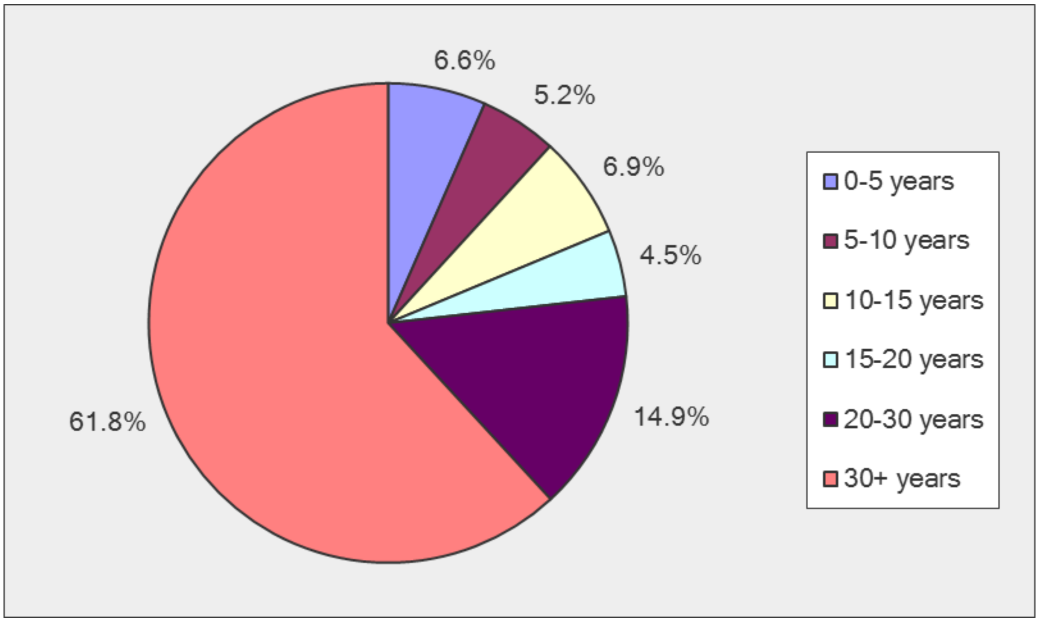

Figure 3. Responses to 2015 Brant Lake watershed survey question: How long have you been coming to Brant Lake or living in the area?

Lake and watershed use–During the summer, swimming, nature hiking, boat cruising and fishing were the most frequent activities for survey respondents (Figure 4). The boat cruising option for many respondents may mean watercraft other than personal water craft based on the lack of response from that category. There were numerous comments concerning the lack of a public beach on the lake.

Overall usage of the lake is much lower in the winter (Figure 5), presumably due to the seasonal residence of many respondents. For respondents who did use the lake and its watershed during winter, snowshoeing was the most common activity, followed by cross country skiing and ice skating (Figure 5). Both cross country skiing and ice skating also were popular responses in 1999.

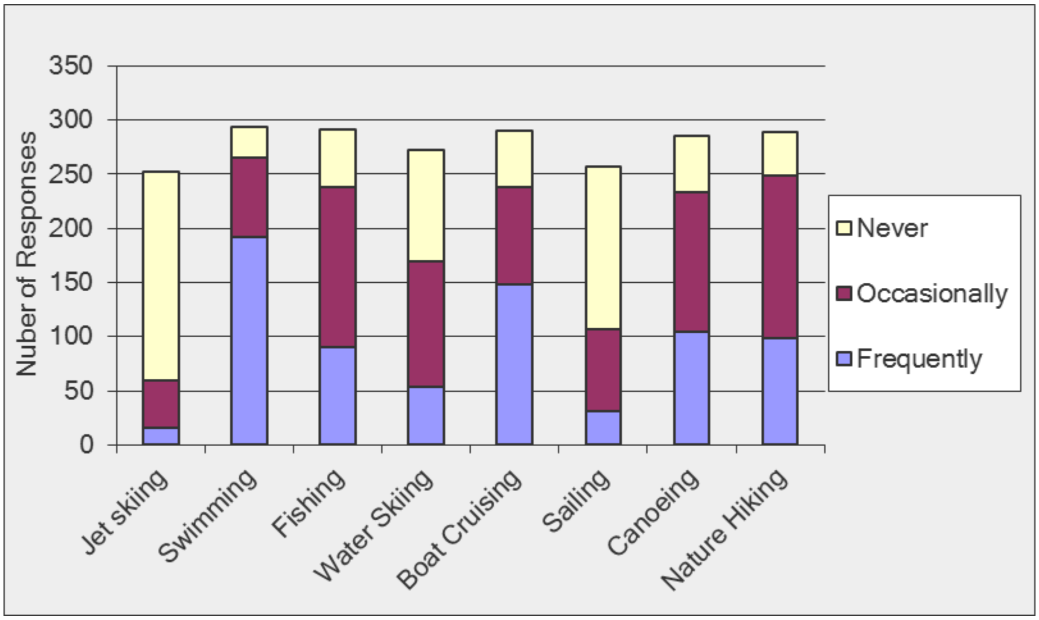

Figure 4. Responses to 2015 Brant Lake watershed survey question: What best describes your family's SUMMER usage of Brant Lake and its watershed?

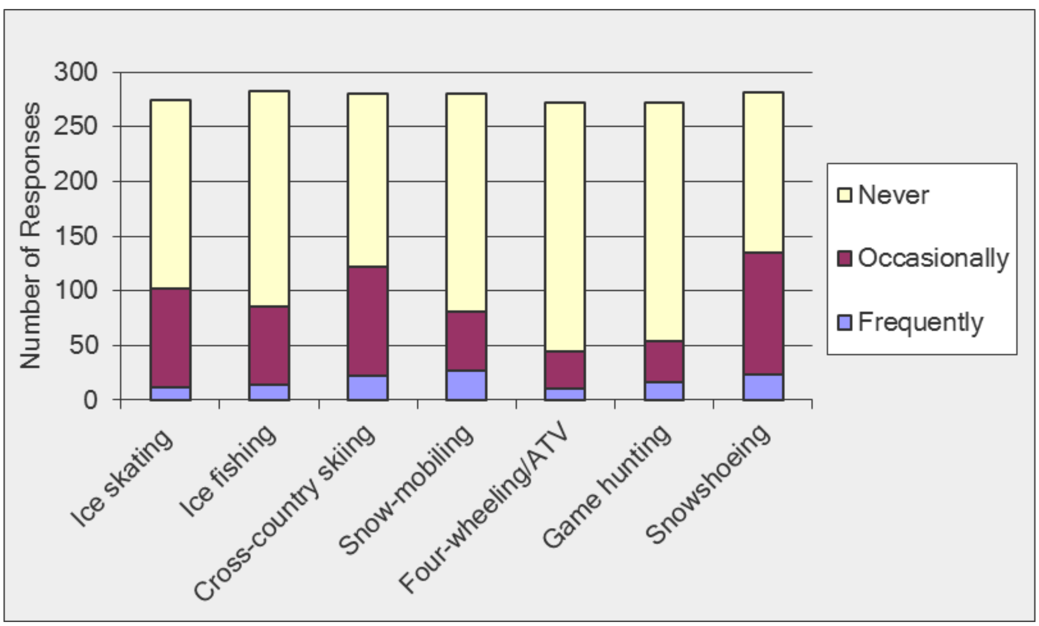

Figure 5. Responses to 2015 Brant Lake watershed survey question: What best describes your family's WINTER usage of Brant Lake and its watershed?

Stakeholder perceptions of problems–Fifty-nine percent of respondents had not noticed any deterioration in water quality. Most respondents who did notice a deterioration, noticed it either 5 to 10 years ago (41%) or in the last 5 years (33%; Figure 6). This was similar to the survey conducted in 1999, in which most respondents noticed water quality deterioration in the 5 years previous to that survey. The most commonly mentioned ecological problems that affected desired uses of the lake were 1) excessive weed growth, 2) invasive species, and 3) buildup of muck on the bottom (Figure 7). Loss of water quality and unpleasant water quality were mentioned less frequently than other problems, consistent with responses related to the deterioration of water quality.

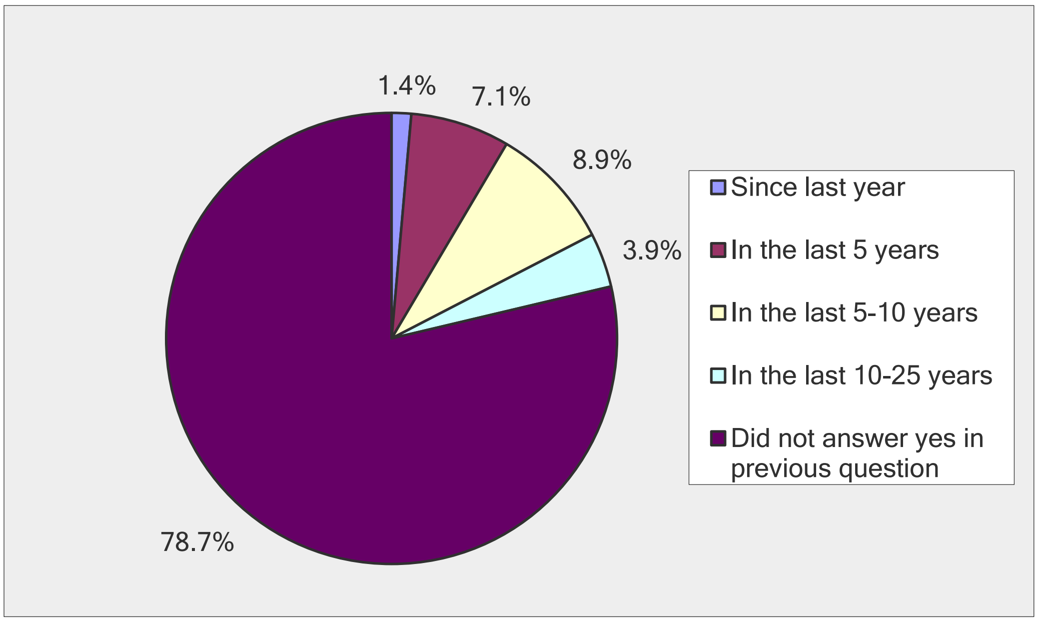

Figure 6. Responses to 2015 Brant Lake watershed survey question: If you HAVE noticed deterioration in the water quality of the lake (answered yes to previous), since when?

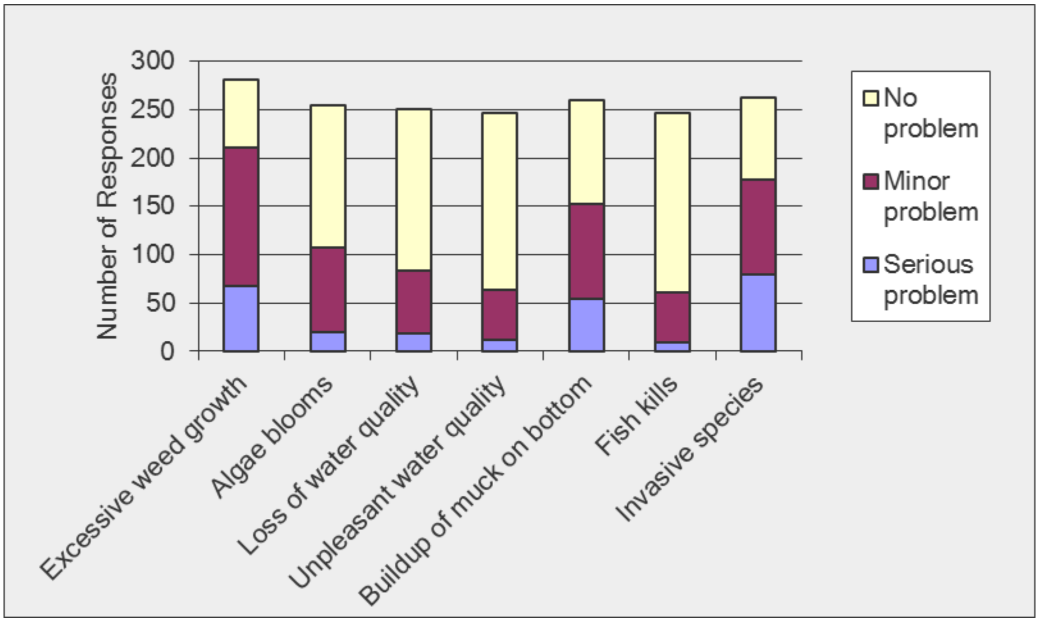

Figure 7. Responses to 2015 Brant Lake watershed survey question: To what degree have the following ecological problems affected your use of the lake?

EWM Management–Most respondents thought that the diver assisted hand harvesting program for EWM management was either highly or moderately effective (70%) (Figure 8). When asked which techniques other than hand harvesting might be effective in controlling EWM, mechanical harvesting (22%) and biological control (18%) were the most common techniques mentioned (Figure 9). In the comments section, boat inspections and use of benthic mats were common alternatives put forth for weed control.

Invasive species– Most respondents did not know which invasive species had the potential to pose threats to the desired uses of Brant Lake or ecosystem function therein (Figure 10). Among those respondents who were able to identify potential invasive threats, zebra mussels (*Dreissena polymorpha*) and quagga mussels (*Dreissena bugensis*) were the most commonly identified species, followed by Asian clam (*Corbicula fluminea*). In the comments section, most respondents mentioned EWM as the greatest threat. This may have been because respondents believed the question was asking about all invasive species, and not just those invasive species that were not yet in the lake.

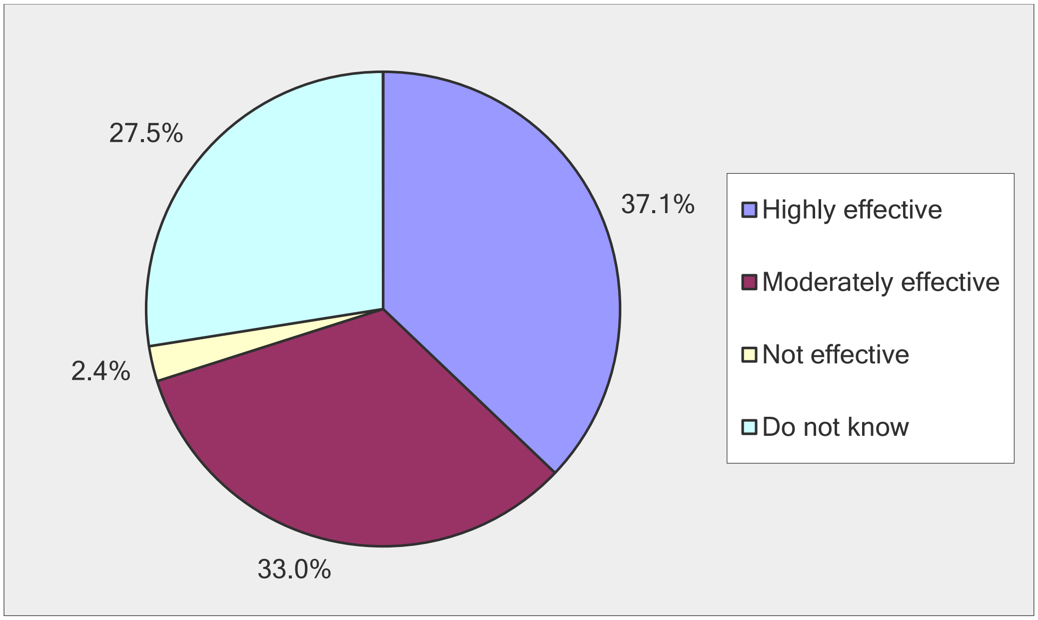

Figure 8. Responses to 2015 Brant Lake watershed survey question: How would you rate the effectiveness of the hand harvesting program for Eurasian watermilfoil conducted by Aquatic Invasive Management and the Brant Lake Association?

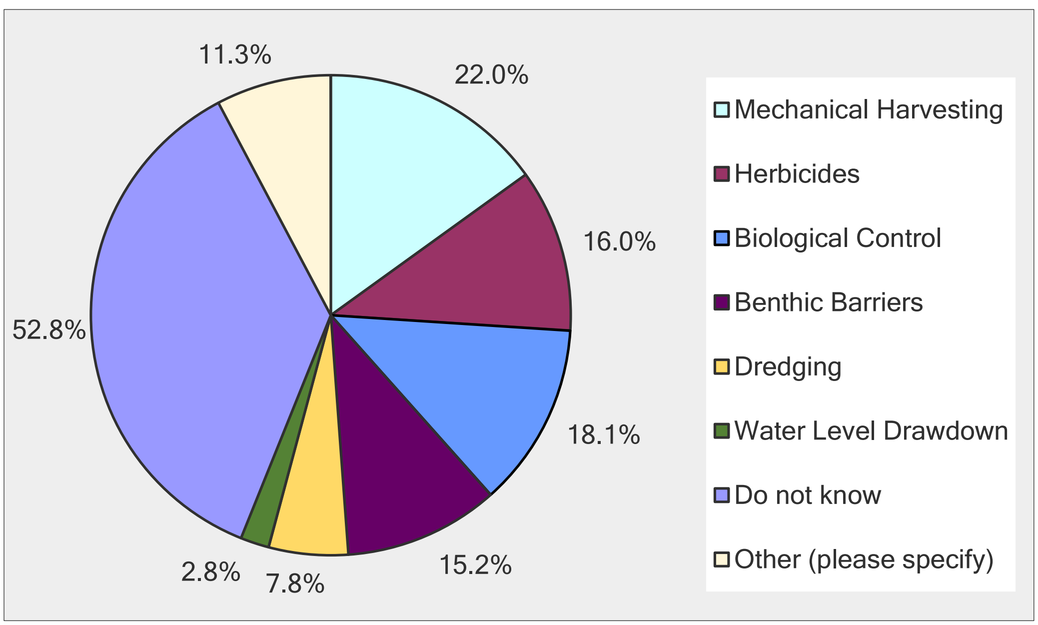

Figure 9. Responses to 2015 Brant Lake watershed survey question: Besides hand harvesting, which management tools do you feel would be effective in controlling Eurasian watermilfoil in Brant Lake?

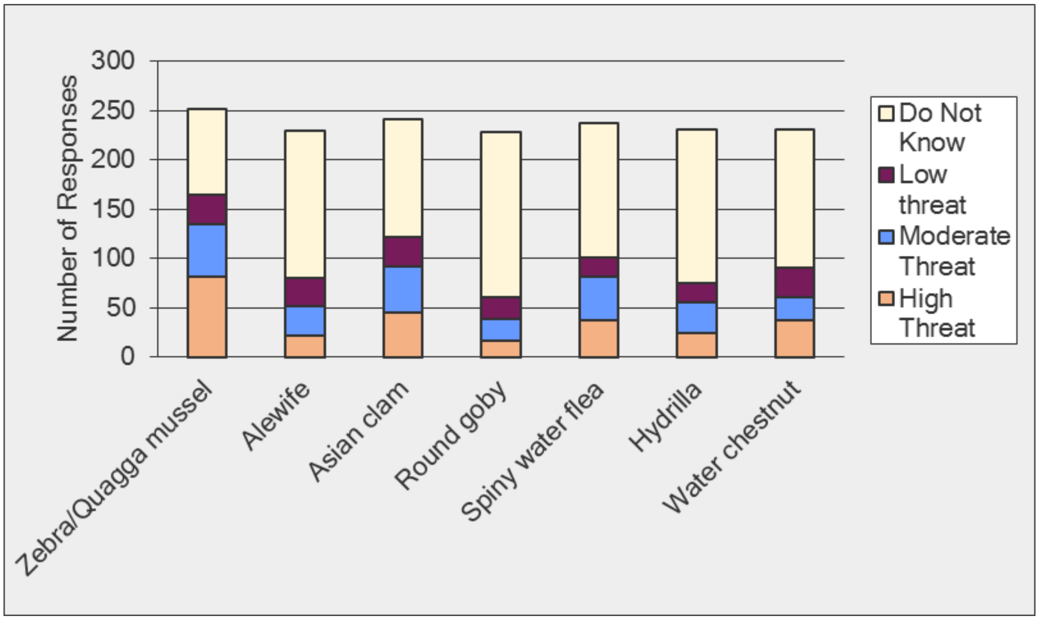

Figure 10. Responses to 2015 Brant Lake watershed survey question: Which invasive species do you perceive to be the greatest threat to Brant Lake if found?

Fisheries–Most respondents did not know the status of the fisheries in Brant Lake. A majority of respondents who did comment on the fisheries thought that sunfish and were great (Figure 11). Largemouth bass (*Micropterus salmoides*), smallmouth bass (*Micropterus dolomieu*), brown bullhead (*Ameiurus nebulosus*) and yellow perch (*Perca flavences*) were thought to be fair. Rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) were perceived to be the poorest fisheries.

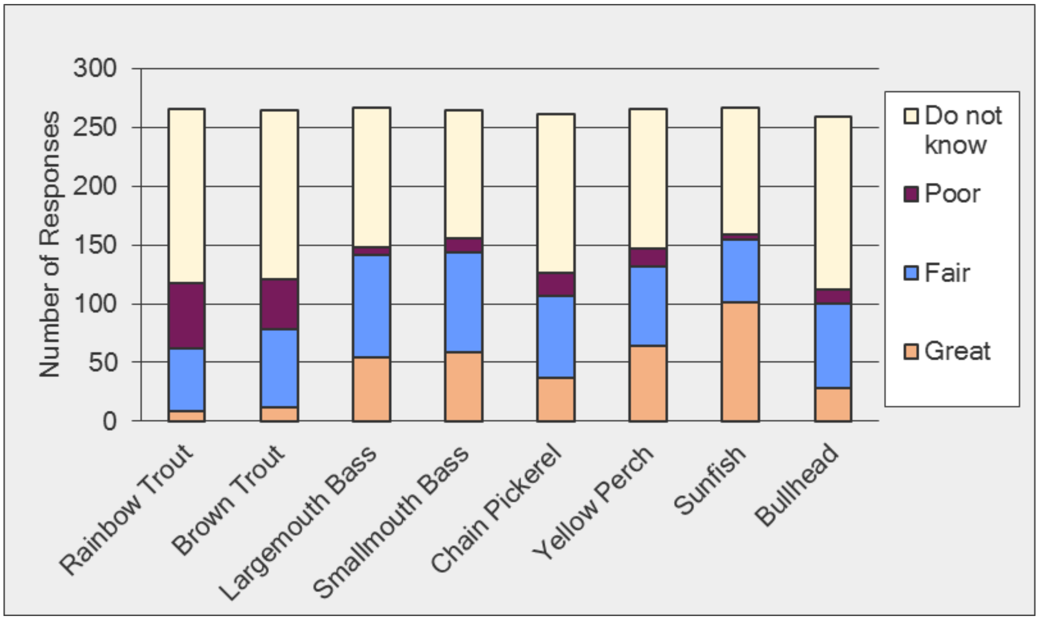

Figure 11. Responses to 2015 Brant Lake watershed survey question: How would you rate fishing quality for the species in Brant Lake listed below?

Public vs private access–Fifty–seven percent of respondents believed that Brant Lake should be a publically accessible waterbody. This was one of the most voiced opinions in the comments section, with strong viewpoints on both sides. When given a choice between twenty–four hour access all week long and restricted access hours, respondents were split with 55% of people favoring an hour restriction.

Other Issues- Excessive boat speed, unsafe watercraft operation, and excessive noise on the lake were the most frequently mentioned issues related to recreational uses of Brant Lake (Figure 12). There also were numerous comments concerning unsafe operation of personal water craft on the lake, reinforcing watercraft use as an important recreational issue. The most commonly mentioned land use issues were an overdeveloped shoreline, highway storm water runoff and septic system failures (Figure 13).

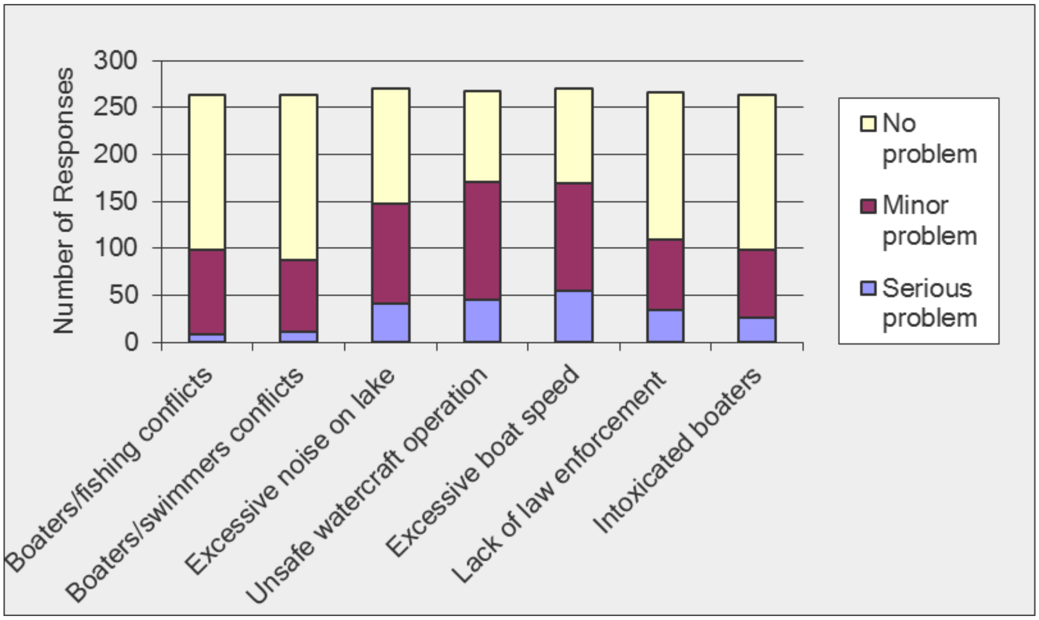

Figure 12. Responses to 2015 Brant Lake watershed survey question: To what extent are the following competing recreational issues a problem on the lake?

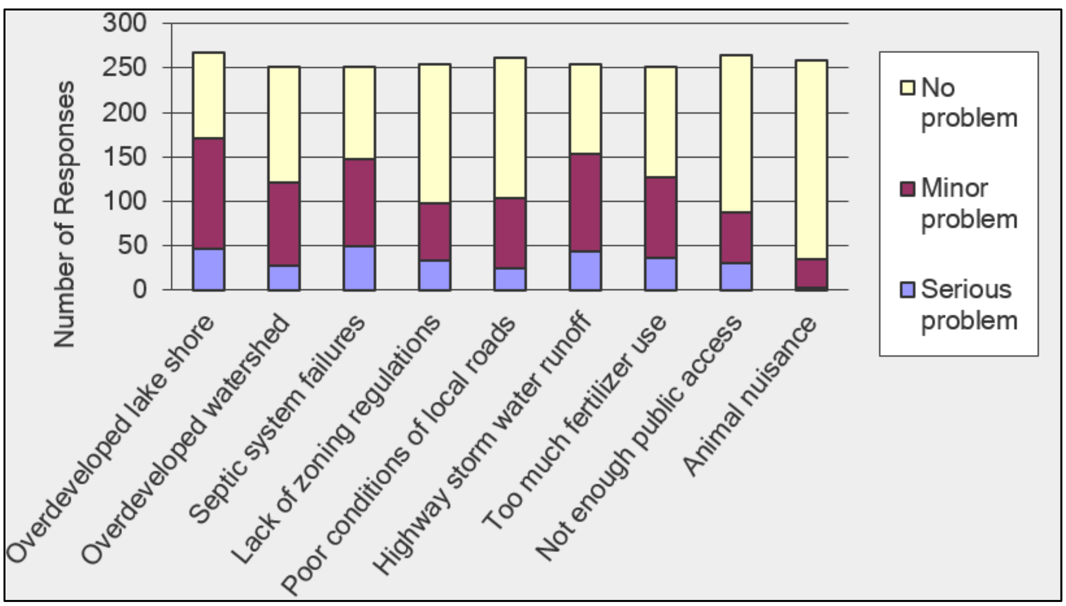

Figure 13. Responses to 2015 Brant Lake watershed survey question: To what extent are the following competing recreational issues a problem on the lake?

Issues facing the Stakeholders of Brant Lake

The most cited responses for the issue based questions (Figures 7, 12, 13) were excessive weed growth, invasive species, unsafe watercraft operation, overdeveloped lakeshore and highway storm water runoff. We have structured our management plan to be able to address these concerns by including sections on Eurasian watermilfoil management, invasive species and nutrient management with smaller sections on fisheries and boating conflicts. Addressing these issues within these three sections should lead to a mitigation of impacts on desired uses for all lake stakeholders.

Chapter 5. Eurasian watermilfoil (EWM) management

Introduction

Aquatic plants serve a variety of ecological functions. They provide habitat for aquatic organisms, food for waterfowl, and nursery areas for fishes and amphibians. Plants also play a critical role in maintaining good water quality by holding sediment in place, which limits particulate and nutrient re-suspension from winds and bottom-feeding fish. Most people who use or recreate on lakes do not become concerned about aquatic plants until those plants interfere with a desired use. Often, the plants that cause the greatest number of conflicts with desired uses are also invasive species.

The federal executive order 13112 defines an invasive species as: “an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health” (Federal Register 1999). Invasive aquatic plants are very often the focus of aquatic plant management because of the wide variety of problems they cause. In high abundance, some invasive plants can create dense canopies that shade out native species and can potentially interfere with lake ecology (e.g. fish, native plants, and nutrients), in addition to human uses including boating, swimming, and angling. In Brant Lake, there are currently two non-native (invasive) plants: EWM, and curly leaf pondweed (*Potamogeton crispus* L.). Currently, EWM is considered to be a nuisance plant in Brant Lake. Curly leaf pondweed is not perceived to be a nuisance, but has the potential to become one based on its history of invasions in many other northeastern lakes. Because of these current perceptions, the primary focus of this management plan will be on EWM.

EWM ecology and biology

Eurasian watermilfoil is a submersed aquatic plant native to Europe, Asia and northern Africa (Couch and Nelson 1985). It was first introduced into North America sometime before 1950, and by 1985 was found in 33 states and parts of Canada (Couch and Nelson 1985). EWM is a perennial plant (lives for more than two years) with finely dissected leaves. It can occur from 1 to 10 m water depth, but is more often found in 1 to 4 m water depth (Smith and Barko 1990). Growth from shoots begins in spring, when water temperatures reach approximately 15 °C (Smith and Barko 1990). Canopies of EWM can alter the ecology of a lake system by reducing native plant diversity (Madsen et al. 1991; Boylen et al. 1999) and influencing water chemistry (Unmuth et al. 2000).

In order to manage any species, a basic understanding of its ecology is needed. Understanding the conditions that might influence the success of establishment or invasion potential of invasive species can aid in their management. Two factors that may influence the persistence and ability of EWM to thrive in Brant Lake are disturbance and biodiversity. Limiting anthropogenic disturbance will reduce the chance that EWM will find suitable, open habitats to colonize. Limited disturbance will also help protect the biodiversity of native aquatic plants in Brant Lake which will help to resist further EWM expansion.

Role of Disturbance in EWM Management

Disturbance, as defined by Barnes and Mann (2009) is "any relatively discrete event in time that removes organisms and opens up space which can be colonized by individuals of the same or different species". Disturbance in lakes can be either natural (storms, rapid changes in weather, etc.) or anthropogenic (increased sedimentation, nutrient addition, construction, invasive species etc.). A community affected by disturbance, depending on a number of factors, may react in different ways. A community may be able to resist such a disturbance, with the community structure and function remaining intact. If the disturbance is significant enough, it can shift structure and function away from the normal "stable state" or baseline condition, to an alternate stable state. Invasive species are unique in this sense as they can capitalize on previous disturbances and induce disturbance themselves, resulting in positive feedback loops that allow them to dominate in novel systems. Many successful, impactful biological invasions shift communities to an alternate state, which is often times undesirable. It has been presumed that as effective "colonizers" due to adaptations such as variable reproductive strategies and generalized physiological tolerances, invasive species that become established are able to capitalize on the available habitat and outcompete native species (Hobbs and Huenneke 1992; Lake and Leishman 2004).

Eurasian watermilfoil is an effective colonizer due to its ability to reproduce through fragmentation, which is thought to be its primary means of dispersal within and among lakes (Madsen et al. 1988; Hartleb et al. 1993). A fragment (or propagule) can be broken off from a parent plant, and relocated throughout a lake by a number of mechanisms including water movement, bird dispersal or human dispersal (Smith and Barko 1990). This gives EWM a competitive advantage over native plants lacking this ability. Some in-lake plant management techniques such as mechanical harvesting of EWM can actually increase rates of fragmentation (Madsen et al. 1989). If high fragmentation occurs in a lake, there will be an increased probability that EWM will spread to new, uninhabited (or disturbed) areas, which may eventually lead to the formation of dense beds. As an example of this process, disturbance was implicated in the re-introduction and spread of a EWM population in Idaho (Wersal et al. 2010). Once EWM has established in a new area, the formation of dense beds can lead to the localized elimination of other plants through competitive exclusion, resulting in biological disturbance favoring local monocultures of EWM and promotes further spread through fragmentation.

In addition to affecting fragmentation rates, certain aquatic plant management techniques can create open habitats suitable for EWM colonization. Benthic barriers, designed to smother aquatic plants, can create such conditions. These barriers, if installed correctly, will eventually result in complete senescence of all plants beneath them. While this may be a desirable outcome for complete aquatic plant control locally, it creates a localized area of barren substrate (i.e. a disturbance) open for colonization, leading to an increased chance of EWM establishing a bed. In Lake George, recolonization rates of EWM after benthic barriers were removed were a function of how close the benthic mat area was to existing unmanaged EWM plants (Eichler et al. 1995). Since EWM management began on Brant Lake, there have been numerous benthic mats placed around the lake, perhaps as many as 100 (Doug Paton, personal communication.). The open habitats created by the mats may be part of the reason why there was a perceived increase in milfoil abundance from 2000 (post Eichler 1999 survey) to 2008 (beginning of Aquatic Invasive Management hand harvesting).

Given the above considerations, it is essential to keep the role of disturbance in mind, along with re-colonization potential, when selecting a management technique for EWM in Brant Lake. Long-term management objectives cannot be achieved if short-term management techniques create favorable future conditions for EWM population growth. Choosing alternate techniques with limited disturbance potential or mitigating disturbance after the techniques are implemented can greatly improve long term management.

Linking Disturbance to Biodiversity

Biodiversity, defined by the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment 2005) is the “variability among living organisms from all sources, including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part”. While biodiversity is often thought of on a global scale, there are important applications of this topic locally. There are many reasons to promote biodiversity in local settings. Most notably, high biodiversity has been linked to maintenance of essential ecosystem functions (Hooper et al. 2005). Biodiversity has also been related to invasion resistance in multiple studies (Stachowicz et al. 1999; Kennedy et al. 2002). As the number of species increases in an area, the chance that one of these species will be an excellent competitor with an invasive species also increases. The increased competition from this “niche overlap” has the potential to create a community that is balanced, and more resilient to the introduction of non-native species.

Relationships between increased biodiversity and increased resistance to invasion have been derived largely through deductive reasoning and logic, and these relationships can be realized in natural ecosystems; however, in practice this is often not the case (Naeem et al. 2000). Specifically, this theoretical framework fails to take into account the role of disturbance in structuring communities. Without disturbance, ecological communities are regulated by competition and predation which often lead to localized dominance by one or two taxa via competitive exclusion (Hardin 1960). With too much disturbance, all species are negatively affected and many can eventually be driven to local extinction. The intermediate disturbance hypothesis predicts that biodiversity should be highest given a moderate level of disturbance (Connell 1978).

So how do both biodiversity and the intermediate disturbance hypothesis relate to the management of EWM in Brant Lake? Biota living in aquatic settings are constantly exposed to natural disturbance at some intensity (the force of the disturbance), frequency (the number of disturbances during a set time period), and duration (the length of individual disturbances). When natural disturbance is exacerbated by anthropogenic disturbances, biological communities experience additional “stress”. Disturbances from multiple pathways can create opportunities for new, often invasive species to establish. Following moderate and extreme disturbances, invasive species often exclude native species as available habitats are re-colonized. Limiting the amount of anthropogenic disturbance in Brant Lake will promote native biodiversity locally, increasing competitive interactions faced by non-native species, and helping to prevent dominant monocultures of EWM.

Reducing Disturbance in Brant Lake

Due to the ability of EWM to capitalize on disturbance, it is essential that the number and size of disturbed areas around the lake be kept at a minimum. Much of this responsibility lies with the shoreline homeowners, because they have the most influence on the littoral zone adjoining their property. Shoreline property can be a source of significant disturbance through addition of excessive nutrients via excess lawn fertilizer use (Law et al. 2004; Lehman et al. 2009), septic systems (Jones and Lee 1979; Gilliom and Patmont 1983; Chen 1988) and storm water runoff from impervious surfaces (Arnold et al. 1982; Bannerman et al. 1993). Strategies for shoreline homeowners to reduce disturbance near their property include but are not limited to: proper monitoring and maintenance of septic systems, construction of rain gardens to trap storm water entering the lake, and planting vegetation both in the water and on the shoreline to reduce erosion (see Nutrient Management section of this document). On a lake-wide scale, enforcement of the NYS Navigation Law that prohibits reckless boat operation, specifically operating with no wake within 100 feet of the shoreline will also help to protect littoral zone habitats from erosion. Protecting these habitats will benefit native plant communities and help maintain local biodiversity.

History of EWM Management in Brant Lake

Eurasian watermilfoil was first discovered in Brant Lake in the late 1980s by local stakeholders (Doug Paton, personal communication). In 1994 lake stakeholders raised USD $10,000 to put a 5,000 ft^2 benthic mat on a recently discovered EWM bed. This marked the first management effort aimed at reducing the EWM population in the lake. In 2005, the BLA used local divers to harvest dense EWM growth by hand in the Grassville Road area. Local divers were used for the next two years, until the growth became impossible to control with this technique. Aquatic Invasive Management (AIM) was hired in 2008 to assume harvesting duties. Since 2008, the TOH and the BLA have spent over $500,000 on harvesting efforts. In 2011, a shoreline monitoring program was initiated, with the goal of locating EWM beds to inform divers where to harvest in the lake.

Current EWM Management in Brant Lake

Hand Harvesting.—Hand harvesting is a common technique for aquatic plant control. It can be performed by wading, snorkeling, SCUBA or by boat. The appeal of this technique is its selectiveness; plants that are the target of management are the only ones removed, leaving desirable plants in place. Hand pulling is most effective on small infestations, where plants have not spread too far from the initial bed (Gettys et al. 2009). On larger lakes, hand pulling can also be effective, but not without a substantial investment of time and money (Boylen et al. 1996).

In the Adirondacks, hand harvesting of EWM is a common technique for all lake sizes. One of the most notable examples of a hand harvesting program is Upper Saranac Lake, NY. Upper Saranac Lake is a large oligotrophic lake located in Franklin County, NY within the Adirondack Park. It has a surface area of 1,912 ha (4,725 acres) with a littoral zone of 483 ha (1,194 acres). From 2004 to 2006, EWM was intensively managed by diver assisted hand harvesting. Divers harvested the entire littoral zone of the lake twice per summer during the intensive phase. EWM was reduced to 5% cover over more than 90% of the littoral zone during the first three years of management, and the biomass of plants harvested was reduced from 16,640 kg in 2004 to 460 kg in 2006 (Kelting and Laxson 2010). After this reduction, management was scaled down to a maintenance phase. The total cost associated with the program was $1,055,244 during the first three years, with maintenance management costing $292,951 for years 2007 and 2008 (Kelting and Laxson 2010). Management of EWM on Upper Saranac Lake has been successful in reducing the population size to a fraction of what it was in 2004. However, this reduction was costly, a total investment of $1.5 million from 1999 to 2008.

Since 2008, AIM has been harvesting EWM from Brant Lake, however bag count data (number of bags of EWM harvested annually) were not available until 2010. Total bags harvested was initially high in 2008 with decreasing bag counts until 2011, after which bag counts were low until 2014 (Figure 14), when increased EWM growth was observed in the southern end of the lake. Because harvesting efforts were focused on that portion of the lake, the northern end of the lake experienced limited harvest intensity, leading to relatively unimpeded growth (Andrew Lewis, personal communication). This may explain the increase in bag counts observed in 2015. Kelting (2010) observed a similar increase in EWM growth in Saranac Lake in 2009, after a few years of maintenance management.

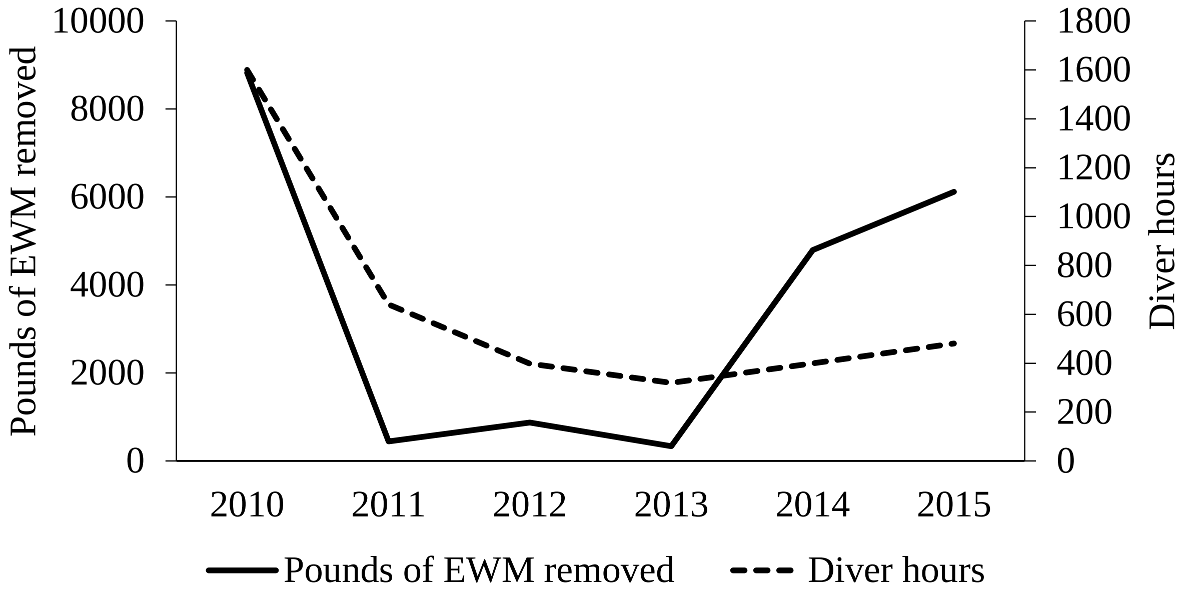

Figure 14. Summary of bag counts harvested by AIM each year since 2010. Note that harvesting began in 2008, but no bag count data were available until 2010.

There is no reason to believe that fluctuations in bag counts will not continue for the foreseeable future with the current level of harvesting effort. During years in which there are high bag counts, divers are busy pulling EWM and not surveying the entire lake for new growth. Low bag count years provide more lake-wide coverage, but because of the size of the lake, not all spots can be checked thoroughly. Increasing the harvesting effort (diver hours) on the lake would help reduce the EWM population further, however it may be cost prohibitive. The goal of the divers should be to manage EWM in the most cost-efficient way possible, which means spending less time searching for new EWM beds and more time harvesting. This issue was recognized by the divers and the BLA; and a shoreline monitoring program was adopted to address this issue.

Shoreline monitoring program–The shoreline monitoring program uses volunteers to provide locations of EWM beds to the divers. The lake is divided into sections, with one local resident assigned a section to monitor. The volunteers search for milfoil in their section. If a plant is found, they record the GPS location and deliver that information to a central controller (individual who receives all locations of potential EWM beds spotted by the monitors). The controller then visits the location to verify presence of EWM and delivers that information to the divers if confirmed.

Currently, the shoreline monitors visually inspect the littoral zone of their assigned section for EWM. This means that they can only monitor when conditions are suitable for spotting, usually early in the morning, on a clear day with no rain and when wave action is minimal. Using a viewing tube or bucket could help monitors spot EWM even when some weather conditions are less than ideal. Viewing devices can be as simple as a PVC pipe or bucket with cut out bottom that has a thermal plastic (e.g. Plexiglass) circle glued to the end of it. The end of the tube covered with thermal plastic is placed into the water, just below the surface, to allow clear underwater vision regardless of glare or wave action. The field of vision using a viewing tube or bucket is limited to the immediate area and will not work in turbid conditions.. Viewing tubes and buckets are sold by various outlets online such as Walmart and amazon.com. Costs for a viewing tube can range from $25 for simple tubes to $130 for the larger, tilted-lense versions. These more advanced versions of the viewing tube are sold at: http://www.watermonitoringequip.com/pages/lake.html.

A plant rake can be used to sample a greater area of water than a viewing tube, and does not require sight into the water. As a result, this technique is not affected by weather conditions, time of day or turbidity. The rake is made of two metal garden rake heads welded or otherwise secured together, with a rope attached to the top (Figure 15), so the user can toss it out a pre-measured distance. The rake is tossed into the water from a dock or a boat, allowed to settle on the bottom, retrieved slowly so plants are caught on the rake, and brought to the surface. This technique can cause some fragmentation, so spotting and collecting loose plant fragments is advised.

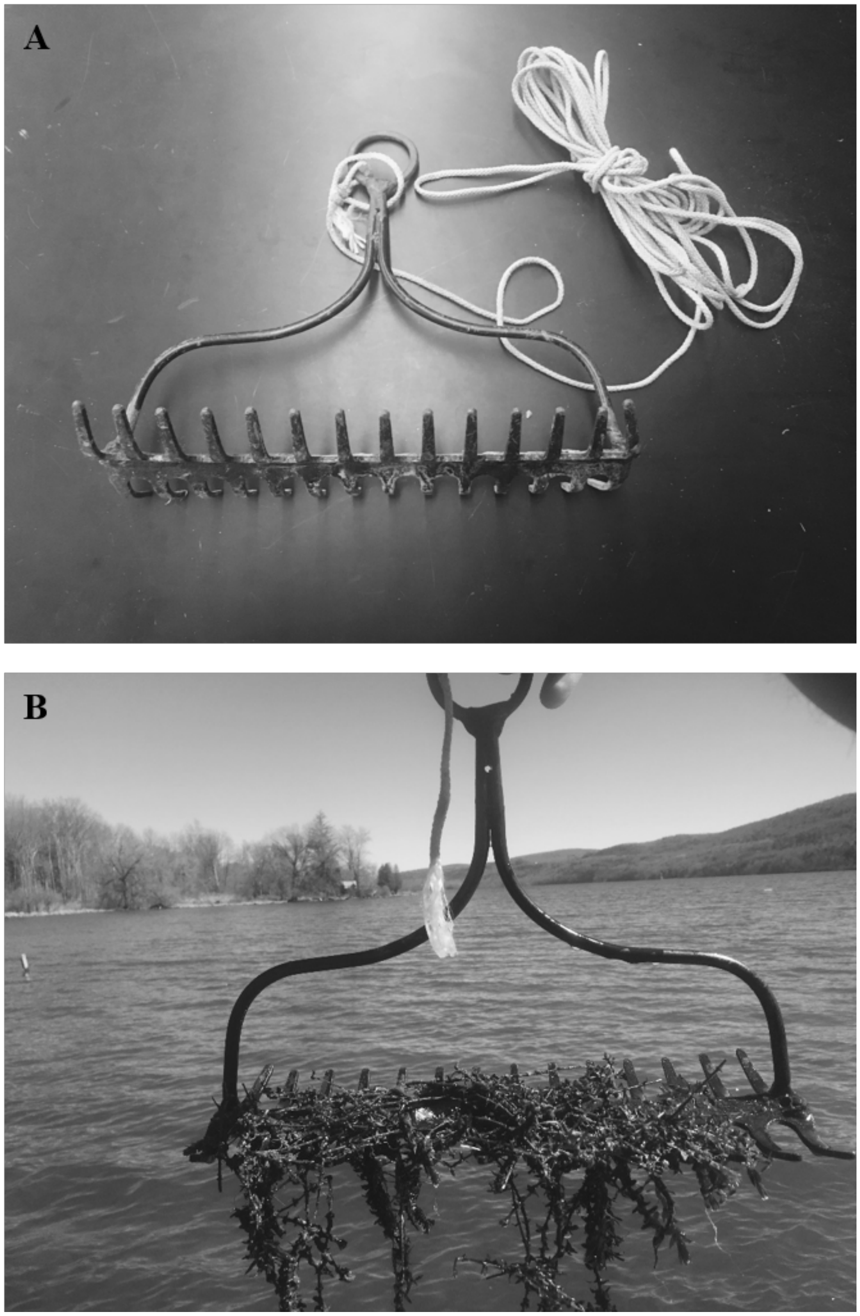

Figure 15. Plant rake used to sample aquatic plants. The rake is made of the heads of two garden rakes welded together with the tines facing the outside (A). Plants get caught between the tines of the rake and are brought to the surface (B).

Tools such as visual spotting, viewing tubes, plant rakes, and snorkeling/SCUBA diving can be used in an integrated fashion to provide lake-wide monitoring for invasive species, if only during punctuated surveys. Greater detection rate should result from the use of a suite of tools for

EWM spotting that can be integrated into the existing shoreline monitoring program and public search days. This higher detection rate could assist the divers when EWM abundance in the lake is low, leading to more cost efficient management of EWM.

On a whole-lake scale, a "public EWM search day" might allow volunteers to cover a large lake area and gather a large amount of data about EWM locations within a short time frame. The search day could also be a way to involve stakeholders in the management of their resource, increasing public awareness of EWM and its management in Brant Lake. Starting in the morning, there should be a number of crews dispersed to various parts of the lake. At least one member of the crew should be in charge of a GPS unit used to record locations. One or more members of the crew should be trained in basic aquatic plant identification, and be able to distinguish between species that are present in the lake as well as potential invaders. Similar to the regular shoreline monitoring, GPS locations should be sent to the AIM divers as soon as possible after the search day to maximize cost-effectiveness of these efforts (less time for growth between discovery and harvesting means fewer diver hours). The use of a mobile data collection application (for example the app Epicollect.net) can help speed up the transfer on information from the monitors to the divers. These applications allow for the user to input the data into a mobile device, save the data and then upload it to a private server. The data is then displayed on an interactive map that can be accessible to the divers.

Alternate Techniques

Currently, hand harvesting appears to be the most (if not only) appropriate technique for controlling EWM populations at a desirable level for Brant Lake. It is believed to have limited non-target impacts on native flora compared to other aquatic plant management techniques (Cooke et al. 2005; Gettys et al. 2009). Selectively harvesting EWM plants creates a small local disturbance, however, because native plants are not being affected, they may recolonize harvested areas before EWM can re-establish. Furthermore, the current regulatory climate within the Adirondack Park is not conducive to herbicides, biological control or other techniques believed to have detrimental non-target impacts especially to wetland habitats.

Assessment of alternate techniques to hand harvesting for EWM management and their feasibility will be helpful for long-term management of EWM despite the current availability of these techniques for use. The regulatory climate of the Adirondacks may not be the same 10 years from now, and may allow for new, more effective techniques to be used. If the EWM population in Brant Lake increases to an abundance at which hand harvesting becomes cost prohibitive, alternate techniques may also be more cost effective. In recognition of the need to evaluate alternative techniques, we have provided a guideline to aquatic plant management techniques in the context of EWM biology and ecology and their potential utility for Brant Lake.

Knowledge of these techniques will aid Brant Lake with future management concerns. A detailed discussion of alternate techniques that may be suitable under different scenarios is presented in appendix B.

Goal-oriented Management

The EWM management program on Brant Lake currently lacks a clear goal, and measureable objectives by which success can be gauged. Goals for aquatic plant management often involve either eradication of a population or suppression to a desired level where ecological and recreational uses are minimally affected. Because of the ability of EWM to colonize new habitats through fragmentation, combined with the size of Brant Lake, it is unlikely that the population will ever be eradicated. So setting a desired population size at zero would not be effective; the goal may not be met without exorbitant capital investment, even in years with excellent control. If suppression is the goal, stakeholders must determine to what level of abundance they wish to suppress EWM so as to minimize effects on desired uses for the lake. It will be important to recognize that different stakeholders will view EWM control differently based on their desired uses for Brant Lake, so consideration must be given to potential conflicts between various uses of the lake during this process.

A goal for the desired population size of EWM is fundamental for guiding the management of this species, and without it management techniques will have little basis in a measureable endpoint. Taking action without a goal in mind will invariably lead to capricious allocation of resources and approaches to control, and will likely fail to achieve a level of EWM abundance that is satisfying to the users of Brant Lake. By guiding management through formation of goals and objectives based on stakeholder values and desired uses, EWM control will undoubtedly be more successful than in the absence of a clear end point. Furthermore, the management of many submerged aquatic plants is an iterative, indefinite process if eradication cannot be achieved. By defining goals and objectives for the management of EWM, stakeholders will be able to maximize the efficiency of management, and drastically reduce the cost of management over the course of decades. As such, a small investment in clarifying goals now has the potential to save stakeholders much time, effort, and money in the future. Similarly, having clearly stated goals and objectives in the plan will make stakeholders more competitive for grants related to aquatic plant management, which could further reduce financial costs incurred directly by the TOH and the BLA.

A standardized aquatic plant survey repeated at certain intervals (either annually or biannually) is necessary to benchmark the current population size of EWM and to track the progress of management actions in the future. Without some method of measuring EWM abundance or an index thereof, the success of management actions cannot be reliably evaluated.

This has the potential to result in inefficient allocation of resources available for the management of Brant Lake, and could result in stakeholder dissatisfaction with the management program, leading to reduced financial and political support for this important issue.

The Warren County Soil and Water Conservation District (WCSWCD) is working with the Darrin Freshwater Institute to conduct an aquatic plant survey of Brant Lake in August of 2016. This survey should be able to detail the EWM population and give a baseline population size needed to establish goals. If stakeholders are in agreement that the current population size meets ecological and recreational needs, then this should be the standard Brant Lake should hope to achieve each year. Otherwise, management objectives should be adjusted accordingly. The survey should be repeated at least annually in a standardized manner to track EWM population size and ensure that management progresses toward this goal.

Eurasian Watermilfoil Management

Key Action Items

- Limit the number and area of disturbed sites in the lake to maximize local biodiversity and limit Eurasian watermilfoil expansion.
- Improve the effectiveness of the shoreline monitoring by integrating multiple survey techniques for Eurasian water milfoil detection.
- Establish a clear goal and measurable objectives for the management of Eurasian water milfoil.
    - Decide on a population size of Eurasian water milfoil that is acceptable for ecological and recreational desired uses.
    - Implement a standardized, scientifically robust monitoring program to assess the effects of management actions on Eurasian water milfoil abundance.

Chapter 6. Prevention and Early Detection of Aquatic Invasive Species

Introduction

Invasive species cause serious ecological and economic problems worldwide. Their presence in an ecosystem can lead to population declines of native species and in some cases, local extirpations. Non-native species introductions are the primary threat faced by forty-two percent of biota listed on the threatened and endangered species list in the US (Pimentel et al. 2005). They also can have profound economic effects, especially if the native populations they affect are of commercial value or if ecosystem services are detrimentally affected. Invasive species cost the United States approximately $120 billion annually (Pimentel et al. 2005), with $7.5 billion of these costs attributed to invasive aquatic plants, fish and invertebrates.

Invasions in the United States are predicted to increase over time. Lovell et al. (2006) predicted that there would be an increase of about 15–24 % in the prevalence of non-native species from 2000 to 2020. These numbers do not account for species moved by means other than international trade, and as such represent a conservatively low estimate. Rahel and Olden (2008) argued that climate change will increase the spread of aquatic invasive species. They state that increases in fish culture facilities and water gardens along with the increased frequency of floods will aid invasive species dispersal.

Aquatic invasive species (AIS) follow a stepwise pattern in their geographic spread. General steps of any biological invasion are as follows: removal from native basin or source population, re-location to new basin, establishment of a reproducing population, and population growth to a size that negatively impacts ecological and recreational desired uses. There is a financial benefit to intervening in the invasion earlier in the process rather than later (Leung et al. 2002; Keller et al. 2008). Because of this benefit, preventing invasive species from becoming established has become a main focus of invasive species management strategies (Ruesink et al. 1995; Simberloff 2003). Furthermore, an emphasis on the early detection and rapid response of AIS in concert with prevention strategies can improve the ultimate success of a program (Vander Zanden et al. 2010).

Brant Lake is currently at high risk for aquatic invasive species introductions and subsequent establishments due to a close proximity to waterbodies with AIS populations. Management of this risk necessitates the creation of a plan for the prevention, early detection and management of these species. To accomplish this, we detail: 1) the risk of arrival of potential AIS, 2) strategies to prevent invasive species introductions and 3) early detection, implementation, and execution of a rapid response plan. A brief review of ecological and recreational impacts of certain AIS and strategies to eradicate/control their populations is given in appendix C.

Risk of arrival

There are numerous vectors for AIS transport into novel basins. Vectors can be exploited for either intentional reasons such as legal or illegal stocking, or unintentionally through boat hitchhiking, aquarium and bait bucket dumping. Vectors vary based on the organisms that are moved through them, the frequency and intensity with which they are used, and the strategies used to limit them. The importance of a specific AIS vector to a lake may vary with lake size and accessibility for the public, in addition to the abiotic and biotic characteristics of the lake.

All AIS vectors into a particular lake represent the total propagule pressure being exerted on the system. For our purposes, we define propagule pressure as the total number of individuals of a particular species that are introduced into a waterbody (Lockwood et al. 2005). As the spatial and temporal diversity of these introduction events increases, the chance of successful invasions increases (Drake et al. 2006). Spatial diversity represents all of the areas on a lake through which introductions can occur (public boat launches, private marinas, lakeside properties, tributaries) and temporal diversity represents all of the different times an introduction can occur (hours, days, weeks, seasons). Identification of which AIS vectors can contribute significantly to the total propagule pressure exerted on Brant Lake is critical for AIS prevention.

Boat Hitchhiking

Brant Lake, based on its geographic location, is susceptible to invasive species introductions via recreational boating, among other vectors. The lake is in close (Under 100 miles) proximity to a number of waterbodies with AIS populations (Table 1). Both Lake George (15 miles away) and Lake Champlain (27.2 miles away) contain populations of AIS not found in Brant Lake (Marsden and Hauser 2009; Leader et al. 2014). During open water seasons in 2014 and 2015, an average of 28 boats visited Brant Lake from Lake George, and an average of 6 boats came from Lake Champlain (Leidy et al. 2014; Leidy et al. 2015). These numbers are likely an underestimate due to staffing hours for boat stewards at the boat launch at Brant Lake. Furthermore, in 2015, data collection was switched from paper to an electronic version supported by Paul Smith's College, and June boat steward data were lost during the transition. Boat stewards also intercepted boats from waterbodies across New York that have AIS populations such as Canandaigua Lake, Cayuga Lake, Great Sacandaga Lake, the Mohawk River and Oneida Lake (Leidy et al. 2015). Because a large number of boats enters Brant Lake from a variety of lakes with AIS, it is reasonable to infer that this vector may constitute the greatest anthropogenic propagule pressure on the lake among those sources identified.

Table 1. List of notable waterbodies with AIS not present in Brant Lake (iMapinvasives 2016).

Waterbody	Distance to Brant (mi)	Zebra mussel	Quagga mussel	White perch	Rusty crayfish	alewife	Spiny water flea	Asian clam	Round goby	Water chestnut	Hydrilla
Cayuga Lake	200	X	X			X				X	X
Friends Lake	9.1										
Great Sacandaga Lake	36.8						X				
Hudson River (below Troy)	74.4	X		X	X	X				X	
Lake Champlain	27.2	X		X	X	X	X			X	
Lake Erie	298	X	X	X	X	X	X	X	X	X	
Lake George	15.5	X					X	X			
Lake Ontario	165	X	X	X	X	X	X	X	X		
Loon Lake	6.3									X	
Oneida Lake	128	X	X	X	X	X			X	X	
Saratoga Lake	54									X	
Schroon Lake	10										
Seneca Lake	199	X	X			X					
St. Lawrence River	154	X	X		X	X			X		

Bait bucket introductions

Bait bucket introductions are another way that people move species between waterbodies. In general, the introduction of invasive species by this vector occurs through unauthorized, illegal stocking activities of individuals whether intentional or unintentional. Intentional stockings are often caused by individuals trying to improve existing conditions for angling in a waterbody. Un-regulated introductions of fish to provide additional angling opportunity or plants to improve fish habitat fall into this category. Illegal fish stocking has been an issue in western states, where anglers want to “re-create” midwestern or eastern fisheries (Rahel 2004). In Wyoming, 50 percent of the unauthorized introductions of fish in the last three decades were illegal stockings (Rahel 2004) and Montana alone has had more than 500 illegal introductions in over 300 waterbodies (Tipton 2007). These introductions take place in ecosystems with relatively simple food webs, which may exacerbate invasion impacts (Rahel 2004). For example, lake trout (*Salvelinus namaycush*) was introduced into Yellowstone Lake from the Midwest, and has caused a large decline in the native Yellowstone cutthroat trout (*Oncorhynchus clarki* *bouvieri*) population (Koel et al. 2005). This effect also cascaded into the terrestrial ecosystem affecting bears, otters, pelicans and many other species (Koel et al. 2005).

Unintentional bait bucket releases generally occur as a result of anglers discarding unused (live) bait into a waterbody after fishing. This type of introduction has been implicated in the dispersal of small bodied fishes and invertebrates into nearby Lake Champlain (Marsden and Hauser 2012). Unintentional introductions such as these also occur as a result of individuals releasing plants or fish into local ponds as a method of disposal. The aquarium trade has also been a vector for the introduction and establishment of numerous non-native populations (Courtenay et al. 1990) and continues to be a significant source of propagule pressure in the US.

It is difficult to determine the relative importance of bait bucket introductions in Brant Lake as a vector of AIS spread because there is no cost-efficient method to quantify this source of propagule pressure. There is evidence, however, that bait bucket introductions may be an important vector on Brant Lake. Rainbow smelt (*Osmerus mordax*), for example, may have been introduced into Brant Lake via this method, as bait bucket introductions have been postulated to be a major vector for this species in the Great Lakes region (Evans and Loftus 1987).

Strategies to prevent AIS Introductions

New York and Local Laws–There are some NY State and local laws that are designed to curb AIS introductions. Regulation 6 NYCRR Part 575 prohibits the possession, purchase, sale, propagation, importation, and transport of invasive species without the proper permits. Most invasive species from the northeast and around the country that have the potential to be a threat are listed in the regulations on the NYSDEC website (http://www.dec.ny.gov/regulations/93848.html). Regulation 6 NYCRR Part 576 states that no person shall launch, or attempt to launch a watercraft or floating dock into a public waterbody unless the reasonable precautions of cleaning, draining, and treating have been taken. “Cleaning” refers to inspecting the watercraft and removing any animal or plant or parts thereof that are attached to either the hull of the boat, or present on any other part of the watercraft or trailer (live well, bilge, anchor, lines, lower unit). “Draining” refers to emptying out water from the watercraft's motor, bilge, live well, bait well, ballast tanks, and other areas of the watercraft capable of holding water. This is particularly important for reducing the spread of small bodied AIS such as spiny water flea (*Bythotrephes longimanus*) and zebra mussels. “Treating” involves either drying or rinsing a watercraft. Drying can be done outside during summer, during the winter in subfreezing temperatures or by manually drying the boat. Following treatment, rinsing should preferably use high pressure hot water spray on both the hull of the boat and in compartments where water can collect. If hot water is not available, the use of the warmest water to rinse is advised. Locally, Warren County passed an invasive species transport law of their own, prohibiting launching, leaving and/or entering a public highway with plant or animal or parts thereof attached to a watercraft or trailer.

Brant Lake's Boat Steward Program–Since 2012, the TOH and the BLA have supported a boat launch steward program to inspect boats for AIS and other aquatic organisms before they enter the lake. Until 2016, stewards worked six days a week from 08:00 to 16:00. This schedule left coverage gaps in the early morning and late afternoon, times of high boat launch traffic (Reyes, personal observation.). In 2016, the town plans to extend boat steward coverage to 11 hours a day, seven days a week. The town is in the process of obtaining a boat washing unit, which should help lake patrons keep their boats clean before and after they launch. The stewards should have access to a list of notable lakes that contain AIS infestations that Brant Lake does not have. This will help the boat stewards understand which boats present the greatest risk for AIS spread and may encourage them to examine boats from high-risk waterbodies more closely. It provides an opportunity to educate the boating and angling public about preventative protocols when moving their boats between waterbodies with AIS. In light of the proposed changes for 2016, and new state and local regulations, the boat steward program at Brant Lake should be well equipped to limit propagule pressure from the boat hitchhiking and bait bucket vectors at the boat launch.

Education– Education is widely recognized as a means of curbing AIS introductions (Kay and Hoyle 2001; McNeely 2001; Krasney and Lee 2002; Le Maitre et al. 2004; Pejchar and Mooney 2009). The goal of educational campaigns is to build an understanding in the public that encourages voluntary participation in practices that prevent the spread of AIS, rather than relying solely upon boat stewards to implement these practices. All educational campaigns focus on four points: 1) species identification, 2) impacts, 3) modes of transport, and 4) measures that can be taken to prevent the spread of AIS. These points may be conveyed to the public through a variety of materials such as brochures, pamphlets, stickers, and signage. Educational presentations and focused discussions with experts about invasive species can convey all of this information in an interactive fashion.

The boat steward program should continue to provide educational materials to boaters as they enter the lake. All of these educational materials, including invitations to educational seminars should be made available to all lakeshore property owners, especially those who own private launches. Private launches represent an additional, spatially separate vector for boat hitchhikers to enter the lake. Working with these private launches has the potential to reduce propagule pressure in a way that cannot be addressed by the boat stewards.

Early Detection and Rapid Response

While prevention is considered to be one of the best ways to curb economic and ecological problems related to species introductions, it is not a fail-proof strategy (Vander Zanden et al. 2010). Financial constraints prohibit all-day and night-time coverage of the Brant Lake boat launch during open water months, not all boats may be checked thoroughly, not all private launches can be regulated, and species could be introduced into a tributary of the lake and flow downstream. Education should help to mitigate these vectors, but will not eliminate them, especially in the short term. In light of these limitations to prevention, we propose to integrate an early detection/rapid response (EDRR) program into the AIS management plan for Brant Lake.

The goal of any EDRR program should be to detect new AIS early on in the invasion process. Detection of AIS at a low abundance can allow for eradication in some cases, and minimally will allow the BLA to implement protocols for suppression before these control strategies become cost prohibitive. The strength of the early detection program is in the speed and organization of the response. A slow response can decrease the likelihood of a cost effective eradication/control effort. A rapid response to an invasion of *Caulerpa taxifolia*, for example, enabled the eradication of this AIS in California (Anderson 2005). Steps for early detection should be clearly laid out, identifying key stakeholders and experts to be involved in the process. An example of the early detection process is given in Figure 16.

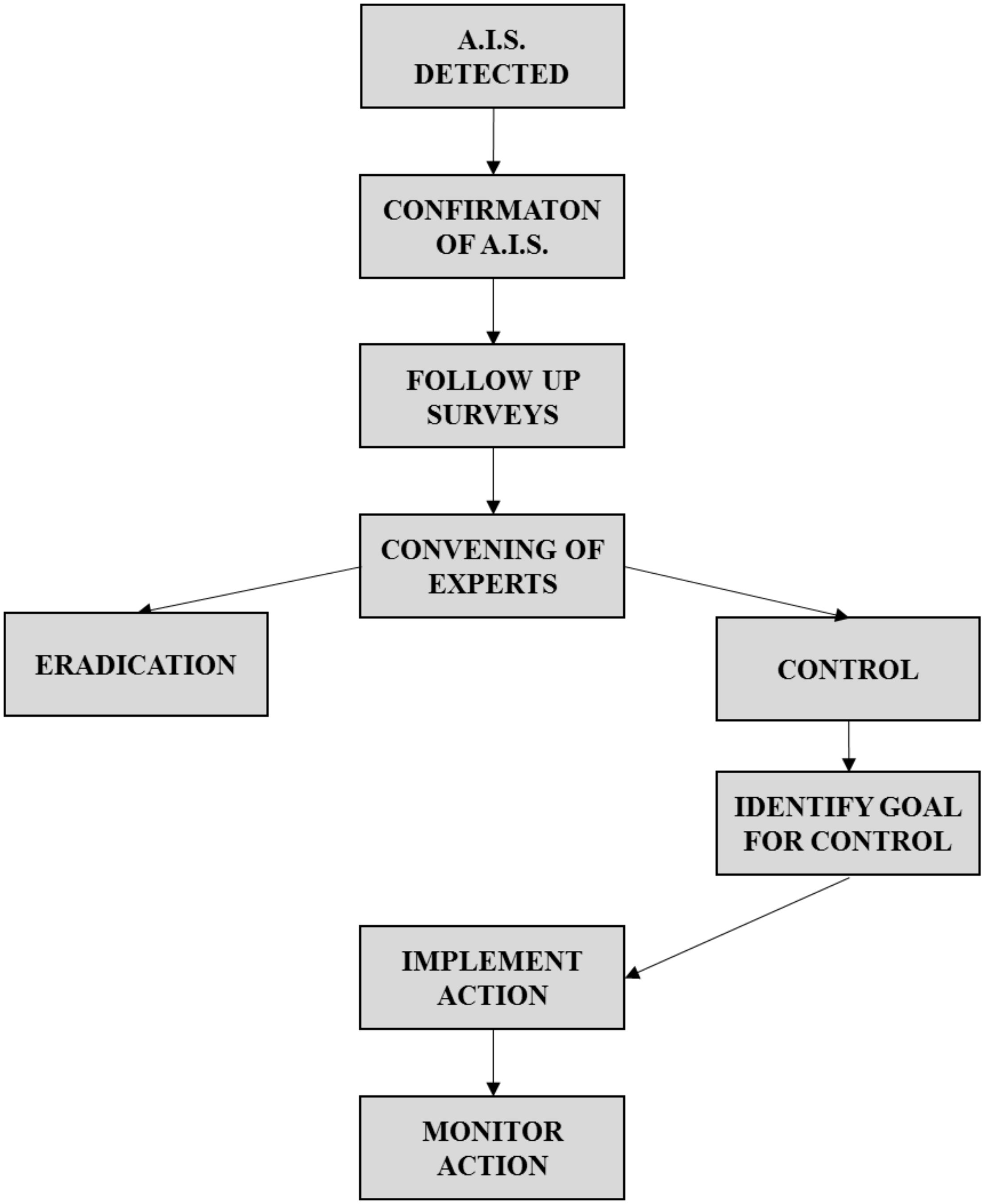

Figure 16. Template for early detection and rapid response of AIS for Brant Lake.

Implementing an early detection program on a lake can be a cost-intensive exercise, especially if an outside consulting firm is performing the bulk of the work. Therefore, lake stakeholders and volunteers should be used to offset these expenses. In its simplest form, early detection starts with recognizing an AIS, so stakeholders and volunteers should be trained to recognize AIS and to report them.

Detection of AIS– One of the challenges with early detection of AIS is that different techniques are needed to sample for different species. Monitoring for invasive plants will necessarily involve different techniques and tools than monitoring for invertebrates, which will be different than monitoring for fishes. For plants, Brant Lake could dovetail early detection with the existing EWM management and shoreline monitoring program. There is an opportunity to leverage both the divers and the shoreline monitors involved in these efforts to monitor for new. This has the potential to provide an effective method of early detection, and avoids additional expenses.

Techniques for detecting adult and larval stages of invertebrates differ from one another. Detection methods for adult zebra mussels and Asian clams (*Corbicula fluminea*) include both artificial substrates (Figure 17) and visual surveys (surface, diving and/or snorkeling). Similar to plant detection, adult invertebrate detection efforts can be dovetailed with the existing shoreline monitoring program in Brant Lake. Larval detection techniques for the aforementioned species and all stages of spiny water flea involve enumeration of zooplankton tows (State of the Lake: Zooplankton section). There are pros and cons for undertaking zooplankton tows (Table 2), and they should be considered when allocating resources for early detection.

Where early detection of introduced fish species is concerned, angler and stakeholder knowledge plays a major role, more so than any of the other groups. The DEC has only done four fish related surveys since 1997, the most recent of which was conducted in 2008. The fisheries survey conducted by SUNY Oneonta and SUNY Cobleskill in 2015 revealed the presence of a population of rainbow smelt not captured in past fisheries surveys (State of the Lake fisheries section). Some locals knew that this species occurred in the lake prior to 2015, however other fish species may go undetected if surveys are not conducted at more regular intervals.

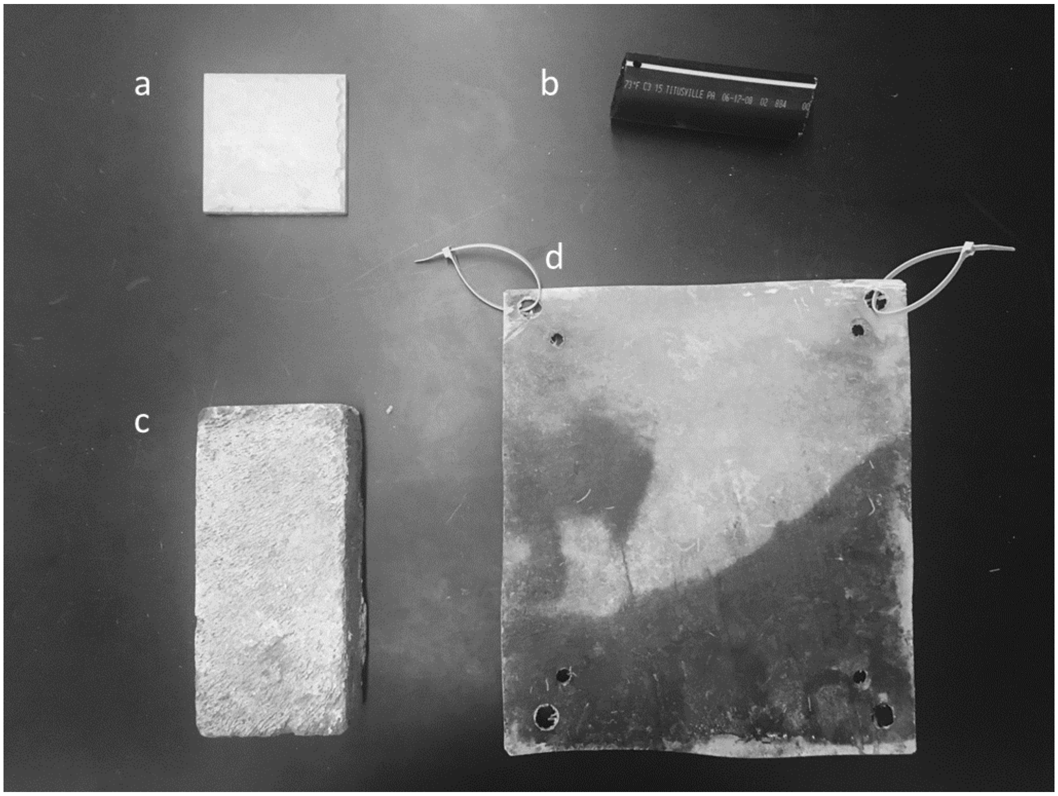

Figure 17. Artificial substrates that can be used for detecting zebra and quagga mussels: (a) Tile, (b) PVC Pipe, (c) Brick, (d) fiberglass sheet (from an old canoe).

Table 2. Pros and cons of conducting zooplankton surveys for early detection purposes.

Pros	Cons
Information regarding the current zooplankton community.	Needs to be analyzed using special equipment at a lab.
Information regarding the trophic state of the lake.	Can take time to analyze, possibly restricting rapid response potential.
Detection of AIS larval stages.	Can be cost intensive.
Easy to conduct in the field.	

When any AIS is detected, a voucher specimen or a picture (preferably a specimen) should be sent to an expert for verification. Samples should be accompanied by a date, GPS location, collector's name and any other pertinent information. Care should be taken to preserve specimens in such a manner that will allow for identification by regional experts. Regional institutions that are qualified to positively identify AIS include, but are not limited to, Lake Champlain Research Institute at SUNY Plattsburgh, The Darrin Freshwater Institute at the Rensselaer Polytechnic Institute, the Adirondack Watershed Institute at Paul Smith's College and the Adirondack Park Invasive Plant Program. These same institutions should also be contacted to perform follow up surveys. Those surveys should aim to establish the current population size.

The Adirondack Park Invasive Plant Program has a regional rapid response team that is equipped to handle small, pioneer aquatic plant populations utilizing hand harvesting. For each new invasion reported to their office, they perform a species evaluation questionnaire to determine if the risk is great enough for them to contribute available resources. Contacting them should be done as soon as an AIS is confirmed to ensure adequate time for the evaluation process to be completed. When experts convene, APIPP should have an idea of what resources they are able to allocate to respond the invasion.

Convening of Experts–Concurrent with or immediately following initial surveys for confirmed species introductions, regional experts and stakeholders should convene to decide what actions, if any, to take. Most likely, the first decisions this group will need to make will be related to the feasibility and costs of eradication. This decision should be based on the best available data, have the highest benefit to cost ratio, and should not be entered into lightly. If stakeholders opt to attempt eradication of introduced species, the existing AIS prevention program needs to be evaluated for shortcomings that have the potential to allow for re-invasion. If the species re-invades, the eradication program will have effectively failed, and other options might be re-evaluated. Vander Zanden et al. (2010) details some of the pertinent questions to ask before conducting an eradication program. Evaluating these questions with all of the relevant stakeholders at the table can take significant time, time that may allow for an invasion to spread beyond the point of eradication. Conversely, a poorly designed eradication program that is rushed can lead to failure, which would waste time and money. Finding a balance between thoroughness and timeliness is a key component of successful AIS management. If it is determined that eradication is not possible, due to financial or logistical constraints, and stakeholders decide that they will attempt to control the species at some abundance below that which causes nuisance problems, then a target population size that satisfies both ecological and recreational needs should be established.

Planning for Monitoring of Management Actions–Any monitoring of management actions, similarly to eradication, needs to strike a balance between thoroughness and timeliness. A monitoring program that is either rushed or delayed can lead to erroneous interpretations of the effectiveness of the implemented action. Depending on the specific biology and ecology of the species and the specifics of the management action, effects can take anywhere from days to years to be detectable. The same local experts who were convened to decide on the actions to be undertaken should be consulted concerning implementing an appropriate monitoring program for the specific species.

While monitoring needs to be strategically timed, results from the monitoring program should also be available as soon as possible so that the information can be used to adapt management where needed. This should be made clear prior to contracting a firm, state agency, or academic institute. If post action monitoring results come back and the action is deemed successful, the program resumes early detection for other species or the same species at a new time. If post action monitoring results indicate an unsuccessful action, experts should re-convene to discuss reasons for failure and appropriate steps moving forward.

Conclusion

Aquatic invasive species introduction into local waterbodies is an issue that is not going away. For as many species that are controlled, there are numerous others waiting in to invade. In light of this continuing struggle, proper AIS management plans should be put into place to maintain ecological and recreational desired uses. The current AIS prevention program in Brant Lake is in a strong position to reduce significant propagule pressure on the lake. With the integration of stronger educational programs, an effective EDRR in place, and continued support from the TOH and the BLA, Brant Lake should be well protected from AIS in the future.

Invasive Species Management

Key Action Items

- Continue boat steward program with increased daily coverage and use of boat decontamination station.
- Educate lake homeowners about vectors of invasive species spread other than boat hitchhikers.
    - Display educational materials at private boat launches.
- Integrate an early detection/rapid response plan with prevention to be able to respond to invasions before control/eradication strategies become cost prohibitive.

Chapter 7. Management of Nutrients

Introduction

Eutrophication, or increased productivity, in lakes is caused by excess nutrients entering the system either from the watershed or from within the lake. Cultural eutrophication occurs when this process is made more rapid and more extreme due to human influences from industry, agriculture, and residential development. In order to develop appropriate management strategies for these nutrients for Brant Lake, an estimation of the relative contribution of internal and external nutrient inputs to the overall lake nutrient concentration is necessary. These estimates should serve to establish management strategies that are cost effective. Establishing a nutrient budget for Brant Lake would serve this purpose and should be pursued in the future, especially if monitoring indicates increases in nutrient concentrations in future years. A nutrient budget was not constructed as a part of this study due to financial and logistical constraints, however we can make inferences concerning the potential contributions of internal and external inputs from our limnological sampling (State of the Lake Report: Physical and Chemical Section).

Excessive internal inputs of nutrients can occur during anoxic conditions present at the sediment water interface. These anoxic conditions occur on Brant Lake when the lake is thermally stratified from mid-July to October. In terms of internal inputs, there is evidence of phosphorus release from deep waters during periods of anoxia, however it does not seem to be translating into elevated water column phosphorus levels (State of the Lake Report: Physical and Chemical Section).

External inputs of nitrogen and phosphorus from point and non-point sources is one of the leading causes of cultural eutrophication (Schindler 2012). Point source pollution is defined as any clear individual source of contamination into a lake such as industrial discharge, landfills and sewage treatment plants (NYSFOLA 2015). Non-point source pollution refers to the culmination of smaller sources across an area that enters the lake (NYSFOLA 2015). Some examples of nonpoint source include urban storm water, agricultural inputs, lawn fertilizer and septic systems leaching. Since there are no large point source inputs located within the Brant Lake watershed, non-point sources are likely to be the dominant external pathway for nutrients entering Brant Lake.

Non-point nutrient sources can be located anywhere within the watershed, but are most often associated around areas of agriculture and development. Because the majority of the Brant Lake watershed is forested and most of the development occurs near the shoreline of the lake, non-point pollution should occur with the most intensity at or near the shoreline.

Management of shoreline non-point source pollution

Establishment of water quality thresholds-The EWM section discussed the value of establishing clear, measurable goals for proper management; the same applies for nutrients. Brant Lake currently has low phosphorus and nitrogen concentrations, low algal productivity and high water transparency; which is desirable from both a recreational and an ecological standpoint. Preservation of the current state of Brant Lake's water quality should be a goal of the Brant Lake stakeholder group. Continued monitoring of water quality is necessary to assess if the goal is being met each year and to detect changes early on that can minimize future management costs.

Monitoring of the lake should occur at least monthly during the open water season and should measure at a minimum: temperature, dissolved oxygen, specific conductivity, pH, total phosphorus, total nitrogen, calcium, chloride, chlorophyll a and water transparency. All of those parameters except for temperature and dissolved oxygen are measured through the Citizens Statewide Lakes Assessment Program (CSLAP) and the Adirondack Lakes Assessment Program (ALAP). Temperature and dissolved oxygen can be measured by using a multiprobe sonde which can cost anywhere from USD $700 dollars to more than ten thousand dollars. Professional lake management consultants or university professors can also monitor the lake and can provide invaluable knowledge and experience to the stakeholders of Brant Lake.

The stakeholders associated with Brant Lake should establish threshold levels for water quality parameters to serve as the acceptable limit for parameter fluctuation from year to year. Violation of these thresholds should indicate that some negative change is taking place within the lake, and that remedial action is needed. To assist in this process, we propose water quality thresholds for Brant Lake based on our limnological sampling as a starting point (Table 3). Each threshold is two standard deviations above the surface mean value, except for pH and water transparency. Because both low and high values for pH may indicate a negative situation, the threshold indicates two standard deviations both above and below the mean. The threshold for Secchi disk is two standard deviations below the mean because decreasing water transparency may indicate increasing algal productivity and/or increasing total suspended solids, which are often perceived as having negative impacts on desired uses. These threshold values are meant to be the annual mean from monthly or bimonthly sampling during the open water season (May to October). The averaging of these values over the season is meant to protect the threshold from being violated due to normal variation in the values that may just be due to chance and not an actual trend.

Table 3. Proposed water quality thresholds for Brant Lake based on limnological sampling of the lake during 2014 and 2015. All thresholds apply to surface measurements.

Parameter	Mean	Standard deviation	Proposed threshold
Calcium (mg/l)	8.37	0.47	9.31
Chloride (mg/l)	10.50	3.08	16.67
Chlorophyll *a* (µg/l)	1.33	1.30	3.93
pH	7.95	0.48	7-9
Total phosphorus (µg/l)	7.23	3.95	15.13
Secchi disk (m)	5.23	0.99	3.25

At the end of each year, members of the BLA and the TOH should meet to review the water quality data and assess if thresholds were exceeded or not. If a private consultant is monitoring the lake, he/she should be present at these meetings to defend and interpret their findings.

Best Management Practices

BMP's are any procedure that can limit the availability of nutrients and contaminants to be moved from the watershed to the lake. (NYSFOLA 2015). These practices vary from small changes inside lakeshore homes, to large watershed scale projects spanning multiple jurisdictional agencies. In terms of Brant Lake, we will discuss BMP's for lakeshore lawns, septic systems, and storm water runoff.

Lakeshore Lawns–The improper fertilization of lawns can be a significant source of nutrients entering waterbodies (Law et al. 2004; Lehman et al. 2009). Using lake water that already contains phosphorus and nitrogen to water lawns can help provide grass with fertilization and not add any excess nutrients to the lake. New York State has passed legislation to regulate fertilization activities under the Dishwasher Detergent and Nutrient Runoff Law. Specifically, the law bans the use of lawn care fertilizer that contains phosphorus unless a new lawn is being established or a soil test finds that there is not enough phosphorus (NYSDEC 2012). Fertilizer cannot be applied within 20 feet of any surface water, unless there is a buffer of naturally occurring vegetation or some sort of spreader guard or deflector shield used. Planting of a vegetative strip along the shoreline can help with adsorption of nutrients before they reach the water (Yuan et al. 2009; Dosskey et al. 2010). This can include trees, shrubs, emergent and floating aquatic vegetation, the latter of which can reduce shoreline erosion from wave action (Coops et al. 1996; Comoss et al. 2002). Rain gardens can also be installed on a lawn, particularly at a point of depression, where runoff can collect. They have the potential to reduce runoff the lake (Dietz and Claussen 2005).

Septic Systems–Untreated wastewater constituents entering waterbodies from improperly functioning septic systems have been implicated in a wide array of water quality issues (Jones and Lee 1979; Gilliom and Patmont 1983; Chen 1988; Lapointe et al. 1990; Bannerman et al. 1993). The status of septic systems in the Brant Lake watershed was not addressed by the current study, however management of near shore septic maintenance should remain a priority for the BLA and the TOH. To mitigate possible adverse ecological effects from improperly functioning septic systems, homeowners should pump outs and inspect septic systems on a regular basis. Many factors can influence pump out frequency such as septic tank size, number of residents within the household, residence status (seasonal or year round) the current condition of the septic tank and drain field and what the actual use of the system is (use of a garbage disposal). Routine septic system maintenance can prevent the drain field from becoming impacted which reduces its ability to disperse water and may lead to untreated wastewater constituents leaching into nearby soils or waterbodies. There are a number of ways individual homeowners can limit the impact to the drain field such as using water efficiently, properly disposing of waste and avoiding drain field disturbance via compaction or increased water flow (Adirondack Park Agency 1996; USEPA 2015).

If a drain field is severely impacted by overuse, just pumping out the system may only give the homeowner a couple of days of proper septic system function. Based on this and because there may be no cost effective way to accurately assign specific pump out regimes to individual residences, there should be regular inspections of septic systems required by the TOH. These inspections should establish if a system needs either pumping out, reclamation/relocation of the drain field and/or upgrade of the treatment system. TOH should work with the lake homeowners in a collaborative way that preserves anonymity to address their septic needs.

Storm water runoff–Runoff from storm water can house a variety of pollutants such as phosphorus, nitrogen, chlorides, metals, and oils (USEPA 2007), all of which can have negative impacts on a lake's ecosystem. These impacts are magnified by the amount of impervious surfaces present in an area (Brabec et al. 2002). Impervious surfaces do not allow storm water to be absorbed into the ground where harmful pollutants can be bound to sediments or taken up by vegetation and can increase discharge of polluted storm water into the lake (Arnold et al. 1982; Bannerman et al. 1993; Arnold Jr. and Gibbons 1996). Any lake with human influences will have to manage for storm water inputs, so reduction of the volume of storm water entering a lake is advised.

The Warren County Soil and Water Conservation District (WCSWCD) identified 36 drop inlets leading into Brant Lake on the Route 8 side of the lake in 2000 (Wick and Lieberum 2000). Drop inlets are collection points of storm water from the road surface which can outlet either directly into the lake or into a drainage way and then into the lake. The drop inlets were categorized (high, moderate, and low priority) in terms of their individual catchment area and proximity to the lake. A high-priority drop inlet has a large catchment area and is within close proximity to the lake, making its potential to deliver large quantities of pollutants high. This categorization gives the BLA and the TOH a starting point for managing storm water. Re-examining these high priority sites to determine if any remediation actions can be taken to lessen their impact should be done. This should be a partnership between the state highway department, the WCSWCD, the TOH and the BLA. The same classification system should be developed for the western side of the lake along Palisades Road.

If any remediation effort is to be implemented, water quality should be monitored before and after implementation to assess the effectiveness of the action. This sampling should occur at the point lowest in the drop inlet basin leading into the lake. Sampling this area should give the best estimation of pollutants entering the lake. The same monitoring should occur for the lake tributaries at the lowest possible point before it enters the lake. Storm water can enter tributaries at road crossings or when in close proximity to driveways.

Conclusion

Brant Lake currently has desirable water quality in terms of ecological and recreational uses. In order to preserve this water quality, management of future sources of nutrients should be addressed. A monitoring program with clearly defined, measurable goals should be established to detect these changes. Impacts from external shoreline inputs may have the most potential to influence the lake's water quality long term. Based on this inference, implementation of BMP's for lakeshore lawns and septic systems along with identifying high priority drop inlet sites should have a positive effect on managing nutrient concentrations.

Management of Nutrients

Key Action Items

- Implement a monitoring program that can detect potential negative changes in water quality.
    - Join CSLAP or ALAP.
    - Bring in local institution/consultant.
- Encourage the adoption of best management practices for lakeshore lawns, septic systems and storm water runoff.
    - Promote responsible use of lawn fertilizer, planting of vegetative buffers, and installation of rain gardens.
    - Support adoption of local regulations for mandatory septic system inspections/pump outs.
    - Re-visit high priority drop inlet locations along Route 8 and work with WCSWCD to identify drop inlet locations along palisades road.

Chapter 8. Other potential management concerns

Fisheries

Brant Lake has a balanced fishery with opportunities to catch both warm, cool and cold water species. The diversity of the fishery should be kept intact to provide the best opportunity for the stakeholders. Because Brant Lake is a publically accessible lake, there likely is a large number of anglers who use the resource who were not included in our stakeholder survey. In order to better understand fishing use on the lake, a creel survey should be conducted. A creel survey can help include more of the public in the management of the resource and provide the NYSDEC fisheries unit with valuable information that will aid in future management. A repeat fishery survey should be completed every 3-5 years in order to ensure fish populations are providing opportunities that are in line with desired uses for anglers.

Key Action Items

- Maintain current quality of fishing on the lake.
- Inquire to the DEC fisheries unit about conducting a creel survey to gauge angler opinions.

Recreational conflicts

Excessive boat speed and unsafe watercraft operation were two of the most mentioned recreational issues for lake stakeholders. Increased law enforcement presence on Brant Lake can aid in reducing potentially dangerous situations. In particular, the NYS Navigational Law; specifically limiting boat speed to 5 mph when within 100 feet of the shoreline should be supported. BLA and the TOH should encourage stakeholders to take the New York State boaters safety course to increase awareness of boating safety and promote proper boating. Adding signage via buoys reminding lake stakeholders about the NYS law may curb some dangerous operation.

Key Action Items

- Lobby with local law enforcement to monitor and reduce reckless boat driving on the lake.

Hypothetical Timeline for Brant Lake Management

Winter/Spring 2017

- *EWM Management*
    - The BLA and the TOH review results of Darrin Freshwater Institute aquatic plant survey and summary of hand harvesting effort.
    - The BLA and the TOH bring stakeholders together to determine desirable population size for EWM.
        - Collaboration with the WCSWCD and the Darrin Freshwater Institute.
    - The BLA and the TOH invite bids from local institutions/consultants to monitor EWM population**.**
- *Invasive Species Management*
    - The BLA and the TOH reviews boat steward data from 2016.
    - The BLA plans out invasive species educational seminars.
    - The BLA distributes AIS educational materials to homeowners with private launches and encourages participation in seminars.
    - The BLA and the TOH establish protocols and chain of command for the early detection rapid response program.
        - Invite bids from outside institutions for species specific monitoring.
- *Nutrient Management*
    - The BLA and the TOH work with the local and state highway department to re-visit drop inlet sites.
        - Inquire about Palisades Road drop inlet classification.
    - The BLA plans educational seminars about best management practices for shoreline property and septic system maintenance.
    - The BLA and the TOH invite bids from local institutions/consultants to conduct nutrient monitoring.

Summer 2017

- *EWM Management*
    - The BLA and the TOH secure a monitoring program for EWM population.
    - The contracted institution/consultant implements monitoring of EWM population and of hand harvesting.
    - The BLA integrates additional detection techniques for shoreline monitors.
- *Invasive Species Management*
    - The BLA and the TOH continue supporting the boat steward program.
    - The BLA hosts planned educational seminars for invasive species identification and clean, drain dry procedures.
    - The BLA implements the early detection rapid response program.

- *Nutrient Management*
    - The BLA and the TOH secure a monitoring program for in-lake nutrients.
    - The BLA execute educational seminars about best management practices for shoreline property and septic system maintenance.
    - The BLA Plan out educational seminars about best management practices for shoreline property and septic system maintenance.
    - Drop inlet surveys are conducted on Palisades Road, and possible remedial action is discussed for high priority sites.

Winter/Spring 2018 and Beyond

- *EWM Management*
    - The BLA and the TOH review of 2017 EWM monitoring.
        - Determine if desired EWM population size was achieved.
            - If so, continue management and monitoring.
            - If not, determine cause of failure, review alternative management techniques, implement changes, and monitor changes.
- *Invasive Species Management*
    - The BLA and the TOH review boat steward data and early detection program.
        - Evaluate effectiveness, adjust as needed.
- *Nutrient Management*
    - Implement remediation measures on high priority drop inlet sites.
        - Monitor actions to assess effectiveness.

Appendix A. Original survey questions.

1. Question: Are you a permanent or seasonal resident of the Brant Lake Watershed Area?
2. Question: What is the proximity of your residence to Brant Lake?
3. Question: How long have you been coming to Brant Lake or living in the area?
4. Question: What best describes your family's SUMMER usage of Brant Lake and its watershed?
5. Question: How do you access the lake to enjoy these activities?
6. Question: What best describes your family's WINTER usage of Brant Lake and its watershed?
7. Question: Have you noticed any deterioration (reduction) in the water quality of the lake?
8. Question: If you HAVE noticed deterioration in the water quality of the lake (answered yes to previous), since when?
9. Question: To what degree have the following ecological problems affected your use of the lake?
10. Question: To what extent are the following competing recreational issues a problem on the lake?
11. Question: How would you rate the effectiveness of the hand harvesting program for Eurasian watermilfoil conducted by Aquatic Invasive Management and the Brant Lake Association?
12. Question: Besides hand harvesting, which management tools do you feel would be effective in controlling Eurasian watermilfoil in Brant Lake?
13. Question: Which invasive species do you perceive to be the greatest threat to Brant Lake if found?
14. Question: How would you rate fishing quality for the species in Brant Lake listed below?
15. Question: Do you believe that Brant Lake should be a publicly accessible water body?
16. Question: If yes, how should the access be managed?

Appendix B. Alternate techniques for EWM management

Alternate Techniques

Benthic barriers–Benthic barriers are mats made of material heavier than water such as PVC, nylon or fiberglass. They are placed on top of beds of undesirable plants, anchored to the bottom by rebar or some other anchoring material. Benthic barriers can usually be installed from the surface in less than three feet of water, with deeper deployments requiring SCUBA. Benthic barriers are effective at limiting plant growth with plant decay in about 30 days (Mayer 1978) and root decomposition in 60 days (Eichler et al. 1995).

Materials for benthic barrier fabrication should have a mesh size that is small enough to prevent plants from growing through them (Mayer 1978). Solid fabrics need to have a ventilation system to allow gases to escape and to prevent mats from billowing. Regular maintenance of the barrier is needed, due to the buildup of silt, which can promote plant growth on top of the mat. As discussed previously, benthic barriers can create open habitats available for colonization by EWM or other plants following this disturbance. To maximize recolonization of native plants after a mat is removed, Eichler et al. (1995) recommended harvesting EWM in adjacent locations to the benthic mat, reducing the chance of fragments of EWM reaching the newly opened habitat. Benthic barriers have been used in the past in Brant Lake to control EWM beds. Future use of benthic mats in the lake should incorporate hand harvesting of adjacent locations and regular maintenance of mats.

Mechanical Harvesting–The control of aquatic plants with power driven (mechanical) equipment has been used for decades in aquatic plant management. Mechanical control is most commonly used to clear high-use areas such as beaches and navigation channels. There are three main types of harvesters used in the management of EWM: cutter boats, rotovators, and harvesters. Cutter boats simply cut the top of topped out vegetation, allowing plants to float away from the area. Rotovators “till” the sediment, affecting submersed plants close to the roots. This technique works better in sand and gravel than silt and clay (Cooke et al. 2005). Harvesters bring plants on board after they are cut and deposit plants on shore once full. They are highly maneuverable and can work in shallow water.

Mechanical control techniques available for use in Brant Lake are not selective, especially in conditions of low plant abundance. Cutting EWM will only remove the top portions of the EWM, leaving the roots intact. Rotovators can cause short term turbidity (Cooke et al. 2005), and can cause significant disturbance to the sediment, potentially resulting in unintended influences on the local macroinvertebrate community. Harvesting EWM is probably the most environmentally benign, but the most expensive technique (Cooke et al. 2005). This technique does not remove roots, which can stimulate regrowth through the same mechanisms as cutting (Crowell et al. 1994).

The ultimate success of mechanical control of EWM in Brant Lake is dubious. All mechanical harvesting increases fragmentation, more so that any technique discussed in this plan. Also, non-target plants would be impacted as well, possibly giving EWM a competitive advantage locally. Finally, the Adirondack Park requires a permit for the use of a mechanical harvester because it is considered an activity that can potentially disrupt a wetland.

Lake Drawdown–Drawdown can be an effective technique for controlling abundance of a variety of submersed, emergent and floating leaved plant species. Drawdowns are common in NY State lakes that have water level control structures in place (Menninger 2011). Implementing a drawdown during the fall exposes sediments to freezing conditions in the winter, affecting both existing plants and their seed banks. Generally, all plants above the drawdown elevation are affected, however effects vary by species. For example, Turner et al. (2005) evaluated aquatic plants after experimental drawdown in Canada and found that initially all plants decreased in biomass, followed by differential responses. Pipewort (*Eriocaulon septangulare*) decreased in relative frequency, while spiral pondweed (*Potamogeton spirillus*) increased in that study.

It is important to note that EWM plants that live lower than the drawdown elevation are not affected, and can be a source for recolonization to shallower depths after the lake elevation is increased. Siver et al. (1986) evaluated two winter drawdown levels in consecutive years (2 m and 2.7 m) as a management technique for control of EWM on Candlewood Lake, CT. Eurasian watermilfoil was reduced at all sampling locations, with greater reductions observed at the 2.7 m drawdown level. Both brittle naiad (*Najas minor*) and slender waternymph (*Najas flexilis*) increased in abundance after drawdown, with the former becoming locally dominant. The authors speculated that because *Najas* spp. does not canopy, locally dominant populations should not interfere with lake recreation and aesthetics.

The TOH is able to draw down water levels in Brant Lake water level, and has been conducting annual drawdowns for dock repair for the past few decades. Flashboards at the Mill Pond Dam are removed in the fall after boating season and replaced sometime around Memorial Day. There are no data about how much the lake is lowered annually or by how much the lake could be lowered. Until this can be documented, it is difficult to determine if the annual drawdowns are extreme enough to promote EWM control. Also, drawdown can have short term effects on the local plant and invertebrate community. It should be noted that these effects are lake-wide and may open up potential habitat for EWM fragments from deeper, adjacent EWM populations to establish (Siver et al. 1986).

Biological control–Biological control (biocontrol), is defined as the use of one organism to control or suppress the growth of another organism. It is important to note that biocontrol is usually meant only to suppress exotic populations, because eradication of the target organism means eradication of the biocontrol agent. When implemented properly, biocontrols have the potential to provide long-term, lake-wide control at a relatively low cost. There are two kinds of biocontrols used in the U.S.: classical and augmentative. Classical biocontrol is the introduction of natural predators/pathogens from the exotic species' native range. In many cases, natural predators of exotic plants can provide selective control. An example is a flea beetle (*Agasicles hygrophila*) being used to control alligator weed (*Alternanthera philoxeroides*) in the southern US (Cooke et al. 2005, Gettys et al. 2009). This flea beetle is native to Argentina, as is alligator weed. Augmentative biocontrol occurs where a naturally occurring organism is identified, cultured and released back into its natural environment. The Milfoil weevil (*Euhrychiopsis lecontei*) is an example of an insect whose populations have been augmented to achieve control of EWM (Newman and Biesboer 2000). For management of EWM in the northeast, three herbivorous insects have potential to control the species, along with grass carp.

Herbivorous Insects–Currently, there are three insects that have been implicated in reductions of EWM. They are the aquatic macrophyte moth (*Acentria ephemerella*), milfoil midge (*Cricotopus myriophylli*) and the milfoil weevil (*Eurychiopsis lecontei*) (Newman and Biesboer 2000). The aquatic macrophyte moth larvae bury into the leaflets of EWM and feed on the tip of the plant (Johnson et al. 1998). Furthermore, the moth has been implicated in declines of EWM in New York (Johnson et al. 1998). The milfoil midge has been shown to affect EWM in British Columbia (Kangasniemi 1983). The milfoil weevil adults feed on the leaves, while the larvae bury into the stems and consume the tissue. The milfoil weevil larvae cause the most damage to the plant, being able to eat about 15 cm of the stem (Cooke et al. 2005). Residing in the stem seems to provide the larvae with protection against predators. All three insects occur naturally in many lakes across the northeast, often times co-occurring with EWM. Despite the insects' wide distributions, their potential for long-term control is not well understood. Newman (1998) implied that establishing and maintaining adequate population densities of herbivorous insects is necessary for long term biological control. Achieving adequate densities within a natural setting is difficult because of conflicting management strategies and other biological influences (e.g. competition and predation) on their populations.

For many parts of their life history, insects use EWM for protection from predators or as an overwintering site. Larvae of the aquatic macrophyte moth, for example, build small refugia (retreats) in EWM during summer and stay within the stem of the plant over winter (Johnson et al. 1998). Removal of refuge plants containing moth larvae can negatively impact moth survival and population density in future years. To minimize mortality, no other techniques that remove EWM from the lake should be used concurrently with an insect biocontrol.

Fish predation has been proposed as a limiting factor for insect populations (Mittelbach 1988). Specifically, it has been hypothesized that abundant sunfishes can suppress herbivorous insect populations (Lord 2004; Ward and Newman 2006). Certain life stages of these herbivores are more vulnerable to fish predation than others. For example, adult milfoil weevils are exposed to predation as they forage on the outside EWM plants, while larvae are often buried within the stem, shielded from predation.

Since the BLA uses hand harvesting currently, one can infer that there is significant mortality on insect herbivores within the lake. Halting the hand harvesting would undoubtedly increase insect survival, but it is not known if the insects would ever reach high enough densities to control EWM. There are sunfish present in the lake, but nothing is known of their density within EWM beds. Because of the uncertainty associated with the potential impacts of insect populations on EWM in Brant Lake, caution should be taken when considering this technique. Risk assessments should be conducted prior to any introduction or augmentation of existing insect populations. Those assessments should address the current distribution and population sizes of the insects, in addition to potential effects on EWM in the lake. If there is significant evidence that insects have the potential to control EWM in Brant Lake, then testing the technique should be considered because of the low cost, long-term control potential and selectivity of this tool.

Grass Carp–Grass Carp (*Ctenopharyngodon idella*) is an herbivorous fish that provides a relatively inexpensive (USD $10–$12 per fish), long-term alternative to chemical and mechanical control of aquatic weeds (Cooke et al. 2005). The species consumes a wide variety of aquatic weeds, but is known to have hierarchical preferences for certain species (Pine and Anderson 1991). Relevant to Brant Lake, EWM is among the least preferred plants (Pine and Anderson 1991).

Recommendations for stocking densities of grass carp vary widely due to variability in aquatic plant management objectives, environmental conditions, and post-stocking mortality rates (Chilton and Muoneke 1992). As a "rule of thumb", the NYS DEC recommends a three-leveled approach to grass carp stocking based on the average amount of vegetation in the lake; 5 fish per lake acre for low vegetation density, 10 fish per lake acre for medium vegetation density and 15 fish per lake acre for high vegetation density. For Brant Lake, this translates to 7,205 fish for low vegetation density, 14,410 fish for medium density and 21,615 fish for high vegetation density. At $12 per fish, a low stocking strategy would cost about $80,000. Note that the previous calculation serves to give stakeholders an idea of the amount of fish that may be needed if a grass carp stocking was approved. These estimates should not be used as the absolute numbers of fish and cost for the stocking.

Choice of stocking rate for grass carp is important for the success of the technique. A stocking rate that is too high can result in the eradication of all submerged aquatic plants (Betolli et al. 1993) leading to changes in water quality conditions (Bonar et al. 2002; Kirkagac and Demir 2006) and unintended changes to the ecosystem (Killgore et al. 1998; Dibble and Kovalenko 2009). A stocking rate that is too low can result in no control of the vegetation (Kirk 1992) or control of only the most preferred species (van Zon 1977), opening available habitat up for less preferred species. While the desired goal of many grass carp stocking programs is to reduce noxious aquatic plants to some level intermediate between eradication and no control, often times this is not realized or documented (Dibble and Kovalenko 2009). As a result, management efforts with objectives of achieving target plant densities using grass carp often produce ambiguous results or controversy in the management community (Stich et al. 2013). Bonar et al. (2002) found that 81% of surveyed lakes with grass carp either had vegetation completely eradicated or no control observed. In general, stocking of grass carp at low densities can be unpredictable (Hanlon et al. 2000), and as such an incremental approach to stocking at low densities has been used as a precautionary, long-term approach to aquatic plant management where intermediate control is desired (Chilton and Magnelia 2008; Stich et al. 2013).

Uncertainty in stocking rates and effectiveness of control, coupled with the low preference of grass carp for EWM in most systems suggests that there is considerable risk associated with stocking grass carp in Brant Lake. Grass carp would need to be stocked at a high enough density to affect EWM populations in the presence of more palatable plants. Because of Brant Lake's high plant diversity, specifically *Elodea* spp., *Najas* spp., *Nitella* spp., and *Potamogeton* spp., grass carp would have a bevy of palatable plants to choose from before EWM was considered. Stocking densities that would be high enough to control EWM, as a result, have the potential to result in the loss of ecologically valuable, native plant species before control is achieved, and could negatively affect human uses for this system.

Chemical control–Herbicides are used across the US to manage a variety of aquatic plant species. They can either burn the cells on contact (contact herbicides) or affect some aspect of the biochemistry of the plant (systemic herbicides). For a detailed explanation of the different herbicides available, mode of action and general treatment guidelines refer to Cooke et al. (2005) and Netherland (2009).

Over the past 10 years, there have only been two permits issued for the use of aquatic herbicides by the Adirondack Park Agency (APA). In both instances, the herbicide triclopyr (trade name Renovate®) was approved for use. triclopyr is a systemic herbicide that is highly selective toward dicotyledonous (dicot) plants. Examples of dicots are the watermilfoils (*Myriophyllum* spp.) and water chestnut (*Trapa natans*). triclopyr has been used to control EWM with minimal non-target impacts in a number of systems (Getsinger et al. 1997; Poovey et al. 2004; Glomski et al. 2010; Wersal et al. 2010). This selectivity is most likely the reason why triclopyr is allowed for use in the Park.

The APA has stringent guidelines for the use of herbicides, dictating that herbicides will only be used if the problem has been unsuccessfully managed through non-chemical means and all other techniques have been evaluated. Also, if the milfoil population has the potential to spread rapidly into new habitats and displace/eliminate native and/or protected plants. Currently there is no evidence to suggest that the Brant Lake milfoil population is large enough to necessitate an herbicide treatment.

Appendix C. Potential AIS and strategies for Eradication/Control

Introduction

Aquatic invasive species detected through the EDRR program or discovered by other means may necessitate control or eradication. These strategies may be species-specific or broadly non-selective, thus care should be taken when applying them to limit effects on non-target organisms (EWM section). We present a brief introduction to the biology and ecology of some common invasive species, why we believe they pose a risk for introduction to Brant Lake, and existing control and eradication strategies. This section is intended to provide a brief overview of each species; please contact local experts or refer to citations within the text for more detailed information.

Zebra mussel–Zebra mussels, native to Eurasia, were first reported in North America in the Great Lakes basin in 1988, more specifically, the Canadian waters of Lake St. Claire (Griffiths et al. 1991). Since then, zebra mussels have spread through all of the Great Lakes and into many notable waters in the eastern and central US (Johnson and Padilla 1996). Zebra mussels are efficient filter feeders, consuming phytoplankton throughout the water column (Roditi et al. 1996, Vanderploeg et al. 2001). This feeding has caused biotic and abiotic changes in freshwater systems where the mussels have reached high abundance (Holland 1993; Fahnenstiel et al. 1995; Padilla et al. 1996; MacIsaac 1996). Zebra mussels also can clog water intake systems and treatment plants by colonization of water pipes (MacIsaac 1996).

Zebra mussels have had a pronounced effect on the Hudson River ecosystem since reaching high biomass in 1992 (Strayer et al. 1996). Grazing by zebra mussels was associated with an 85% decline in phytoplankton biomass (Caraco et al. 1997). In the same study, chlorophyll *a* decreased, light availability increased, and phosphate concentrations doubled.

Currently, zebra mussels are present in many waters throughout New York State, notably the Hudson River, Lake George, Lake Champlain, Lake Erie and Lake Ontario. Calcium concentrations in Brant Lake may be high enough for zebra mussels to survive, but not high enough to establish a reproducing population (see State of the Lake Report). There are limited control options available for use in open waters of New York State, so prevention of this species may be where resources should be focused.

Spiny water flea–The spiny water flea is a small, planktonic crustacean native to Northern Europe and Asia, and was first found in North America in Lake Ontario in 1984 (Johannsson et al. 1991). By 2010, they were present in over 150 lakes and expanding their range (Yan at al. 2011). Spiny water fleas can consume zooplankton and may influence their vetical distribution within the water column, reducing their growth rates of zooplankton (Pangle et al. 2007). Effects on other zooplankton have the potential to cascade down the food chain, affecting zooplankton

(Hovius et al. 2006), phytoplankton (Strecker et al. 2011) and water quality (Walsh et al. 2016). Spiny water flea also compete directly with larger cladocerans such as *Leptodora* spp., which can affect small larval fish diets due to difficulty consuming the spines of the water flea (Foster and Sprules 2009).

The spiny water flea is spreading rapidly through the Adirondack region. The first population in the Adirondacks was discovered in Great Sacandaga Lake in 2008, a population was subsequently discovered in Lake George during 2012 (NYSDEC 2012), and the species was found in Lake Champlain by 2014 (Harris et al. 2014). There are probably many more lakes inhabited by spiny water flea, but the species' ecology and life-history result in low detection rates (Yan et al. 2011). Its small size makes individuals difficult to notice with the naked eye, along with the fact that most lakes do not have monitoring protocols in place to detect this species.

There are currently no recognized lake-wide eradication/control strategies for spiny water flea, justifying an increased focus on prevention strategies for this species. There are aspects of the limnology and ecology of Brant Lake, however that may limit the success of spiny water flea. Anoxic conditions extending from July to the end of October are unfavorable for spiny water flea (Grigorovich et al. 1998) and may force the species above the thermocline. The vertical migration may increase interaction with rainbow smelt, which are known to prey upon spiny water flea (Barnhisel and Harvey 1995).

Alewife–Alewife (*Alosa pseudoharengus*) is a member of the herring family, native to the Hudson, Delaware, and Susquehanna rivers in New York and much of the Atlantic coast. They have caused extensive ecological problems in inland systems such as Lake Champlain (Mihuc et al. 2012) and the Great lakes (Wells 1970) when introduced and 'landlocked' in fresh water. Alewife are efficient planktivores and shift plankton communities through grazing (Wells 1970). For example, after the introduction of alewife into Otsego Lake, NY the zooplankton community shifted from large crustaceans to smaller rotifers. The reduction of large zooplankton coincided with an increase in phytoplankton abundance, with dominance by smaller nano-plankton and cyanobacteria (Harman et al. 2002). Abiotic changes occurred with a decrease in mean Secchi depth and increase in the areal hypolimnetic oxygen deficits in the deep waters (Harman et al. 2002). Similar changes have been observed in Lake Champlain (Mihuc et al. 2012).

Alewife also can have adverse effects on inland fisheries. Landlocked populations outcompete a number of native pelagic species such as rainbow smelt (Urban and Brandt 1993) and bloaters (*Coregonus hoyi*) (Crowder and Crawford 1984) for plankton. They can also prey on the larval stages of these fish (Eck and Wells 1987). Populations of lake trout (*Salvelinus namaycusch*) and Atlantic salmon (*Salmo salar sebago*) in the Great Lakes and Finger Lakes exhibit thiamine deficiency leading to reproductive failure (Fisher et al. 1995), known to be caused by a high diet of alewives, which are rich in thiaminase (Fisher et al. 1996).

Alewife populations are present in Lake Champlain, the Hudson River, and in the Great Lakes (Leader et al. 2014). They are also present in most of the Finger Lakes and Oneida Lake (Leader et al. 2014). Eradication of alewife, once established, may not be feasible in larger lakes due to their high fecundity and early age of maturity (Bunnell et al. 2006Stocking walleye *Sander vitreus* fingerlings has been successful for trophic control of alewife in Otsego Lake, NY (Waterfield et al. 2014), whereas this strategy has not been as successful in other systems (Rudstam et al. 2011). Why this strategy of biocontrol worked for Otsego Lake and not for other lakes is currently not known, although it is suspected that the presence of a robust lake trout population in deep waters contributed. Control of alewife populations may also be attempted through netting, which has been proposed as an alternate strategy for Lake St. Catherine (Good and Cargnelli 2004). Physical removal of fishes with netting has been successful in other projects (Meronek et al. 1996), however there would be a significant cost associated with this technique, especially if the population reaches high abundance.

Water chestnut–Water Chestnut (*Trapa natans*) is a floating-leaved plant, with palmate, diamond shaped leaves with serrated edges growing in a rosette. It is capable of covering entire sections of waterbodies, impeding light penetration, which limits native plant growth. Water chestnut in the Hudson River has replaced water celery (*Vallisneria americana*), EWM, and other submergent plants in certain areas (Hummel and Kiviat 2004; Kishbaugh 2009). Reductions in dissolved oxygen under these mats can have a negative effect on invertebrates in some systems (Kishbaugh 2009). The dense mats created by water chestnut can also impede recreation my making channels impenetrable by canoe or kayak. The barbed spikes on the seed can puncture through a swimmer’s foot or even a wetsuit.

Water Chestnut populations are located in the Hudson River, Lake Champlain and the Mohawk River, along with numerous waterbodies in the capital region and the Lower Hudson Valley. Recently, a small population was discovered in Loon Lake, only 6 miles from Brant. Eradication of water chestnut populations is feasible provided the population is found early. Because nutlets can be viable in sediments for up to ten years (Muenscher 1944), management should occur before there is a significant seed bank. Physical harvesting of the plants should begin before the middle of July, when mature nutlets start to drop (Countryman 1978).

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