April 30, 2020

Lake Shirley Improvement Corporation
Joanna Bilotta-Simeone
PO Box 567
Shirley, MA 01464

Dear Ms. Bilotta-Simeone,

During the process of acquiring permits for the Lake Shirley Aquatic Vegetation Management Plan, the Lunenburg Conservation Commission (Commission) requested an independent assessment of the plant data collected during the annual surveys. The Commission's concern is the loss of native species over time. The Order of Conditions requires a modification of the vegetation management program if there is a loss of ecologically important species.

Attached is the report which summarizes Aquatic Restoration Consulting's analysis of vegetation data dating back to 2002. The report concludes that there are changes over time, some changes can be attributed to natural variability and some are likely associated with either the winter water level drawdown and herbicide treatment or both. There was a reduction of two native species that could not be attributed to natural variability or the reduced clarity event that occurred in 2005 prior to treatments. One of the plants impacted is Robbins' pondweed (*Potamogeton robbinsii*). This plant is common in New England and grows in colonies formed by rhizomes (rootlike stem in sediment sending up shoots). It rarely produces fruit and does not produce vegetative turions (buds); the primary mode of reproduction is rhizomes which results in slow recovery once impacted. The second native plant that declined to a substantial degree is coontail (*Ceratophyllum demersum*). Coontail has no roots and is free-floating. It does produce turions to overwinter and can propagate vegetatively (forming new plants from fragments). It can rebound much faster than Robbins' pondweed and has been known to be aggressive and a non-desirable species in waterbodies in New England. It is quite common and is widely distributed within the aquarium industry. Both plants are susceptible to drawdown impacts, but published literature suggests that Robbins' pondweed has a low susceptibility to diquat.

I will consult with the SOLitude Lake Management (SOLitude), the licensed herbicide applicator, following their early season plant survey to evaluate alternatives for preservation/recovery for Robbins' pondweed and coontail. We will review the location and density of the targeted plants for treatment and assess if the desired natives are present. SOLitude will provide a treatment plan that excludes areas where Robbins' pondweed was once abundant that should be avoided to encourage growth and recovery. Similarly, avoiding areas to protect coontail against direct herbicide treatment will likely increase its frequency of abundance. But since this plant can reproduce vegetatively and is generally free floating, it will likely recover quicker than Robbins' pondweed requiring less restrictive treatment protocols.

Overall plant density and biomass have increased in recent years and coverage is enough to provide the function and values needed to support a healthy ecosystem, provided that the plant community does not get overly dominated by only a few species. Species richness has varied over time with a low value of 12 species observed, however evenness remained desirable suggesting that the plant community was not overly dominated by one species.

For these reasons, I see no substantial evidence to suggest that the changes in plant community would result in a major decline in macroinvertebrate, fish or waterfowl habitat. However, this cannot be definitively concluded since there are no other biological data for comparison. Documentation of absence of an impact to the system as whole is complex and difficult as trade-offs occur as variables in the system change, including variables of natural origin that are unquantifiable. Aquatic ecosystems are naturally diverse, and a habitat loss to one species is often a habitat gain to another: some fish prefer open water, some prefer dense vegetation and other need a mix of both. Habitat specialists are also seen in macroinvertebrates, waterfowl and mammals. The system should be managed to balance multiple habitat types and consider all uses including human.

Looking more closely at the pretreatment data and avoiding key areas should help Robbins' pondweed and coontail recover in abundance provided other conditions remain constant (e.g. water clarity) and there is not direct competition with more aggressive species at the same Observation location. This process will require continued monitoring as already outlined in the Order of Conditions and will require adaptive management, adjusting the treatment program in response to site data.

Please let me know if you have any questions or comments regarding this report. Thank you for the opportunity to assist with your continued assessment and management of Lake Shirley.

Sincerely,

W Gendron

Wendy C. Gendron, CLM
Aquatic Ecologist

Report For:

Lake Shirley Improvement Corporation
Lunenburg/Shirley, Massachusetts

Lake Shirley Long Term Macrophyte Monitoring Assessment Report – 2002-2019

Prepared by:
Aquatic Restoration Consulting, LLC
18 Sunset Drive
Ashburnham, MA 01430

April 2020

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Introduction

Lake Shirley Improvement Corporation (LSIC) contracted Aquatic Restoration Consulting, LLC (ARC) to prepare the Notice of Intent and acquire permits to continue with the Lake Shirley Aquatic Vegetation Management Plan (VMP). The VMP includes the use of State-approved aquatic herbicides, algaecides and implementation of a six-foot winter water level drawdown for the purposes of managing growth of non-desirable plant species and prevent noxious, potentially toxic, algal blooms. During the process of acquiring permits for the VMP, the Lunenburg Conservation Commission (Commission) requested an independent assessment of the macrophyte data collected during the annual surveys. The Commission is concerned about the loss of native species over time. The Order of Conditions requires a modification of the management program if the analysis concludes that there is a loss of ecologically important species. This report serves as the assessment of macrophyte data dating back to 2002 and provides management recommendations based on the findings.

Lake Shirley was a small natural waterbody of about 10 to 20 acres that was enhanced by damming the Catacunemaug Brook in 1852, creating the now 354-acre reservoir. The reservoir was used as a water supply replenishment to mill ponds downstream. As a water supply reservoir the impoundment was never intended for recreational purposes and water depths varied substantially. The dam has been repaired, replaced and improved over the years. Some form of water level manipulation has continued since the dam's creation. Today, water level manipulation is conducted primarily for spring flood and rooted plant control.

Lake Shirley is heavily used for swimming, boating and fishing as well as relaxation and wildlife viewing. The morphometry of the lake is shallow (average depth of 7.2 feet) and as a result, a large portion of its surface area is littoral zone where sunlight reaches the bottom sediment. Lake Shirley suffers from dense growths of aquatic macrophytes and occasional algal blooms fueled by nutrients coming from both internal recycling and the 14 square mile watershed. In 2006 there was a significant algal bloom that resulted in severe light limitation that may have reduced aquatic macrophyte density.

The LSIC and the Town of Shirley (Town) have been working with consultants and State agencies to recommend and implement management programs to control both rooted aquatic macrophytes and algae. Over the years, Lake Shirley has experienced dense growths of both native and non-native macrophytes. Two non-native macrophytes, fanwort (*Cabomba caroliniana*) and milfoil (*Myriophyllum spp*.) were first documented in the 1977 report prepared by the Massachusetts Division of Water Pollution Control. A diagnostic feasibility study conducted in 1986-1987 by Metcalf & Eddy also noted these species and recommended a winter water level drawdown program to reduce excessive growth and preserve the recreational value of the lake. Wild celery (*Vallisineria sp.*), although a native species, was also noted as excessively dense during this time. Milfoils are either non-existent or rare today, but fanwort and wild celery are still problematic. Two additional non-native species were identified in the 2002 survey: curlyleaf pondweed (*Potamogeton crispus*) and European naiad (*Najas minor*).

The LSIC and the Town continued with the water level drawdown (depths varied over the years but mostly consistent around 6 feet), but it wasn't until 2007 when the LSIC and the Town began treating the lake with aquatic herbicides and algaecides. Annual treatments (sometimes twice per year) consisting of primarily diquat and copper sulfate were applied to as much as 102 acres or as few as 30 acres depending on the need. Targeted macrophytes included all non-natives (milfoils, fanwort, curlyleaf pondweed and European naiad) but also included the native species, wild celery, also known as tapegrass. This report documents the changes in the macrophyte community over time (2002 through 2019), evaluates trends/correlations, attempts to detect any cause/effect relationship with drawdown and herbicide/algaecide treatment and provides recommendations for altering the existing vegetation management program to protect or increase desirable native species abundance.

Data Content

Survey Methods

Annual lake vegetation surveys were conducted by Geosyntec Consultants (Geosyntec) from 2002 through 2013. The timing of the surveys was generally July, August or early September. A biologist estimated aquatic plant density and biomass at 66 point locations throughout the lake using visual observation by boat (Figure 1). Observation locations were located using a Global Positioning System (GPS) device. A grappling hook was used to rake species that were submerged and not readily visible from the surface. Macrophyte species were recorded at each observation station and the dominant plant(s) were noted. Density and biomass ratings were categorized on a scale of zero to four. Plant density represents an estimate of aerial coverage; biomass represents the portion of the water column occupied by plants. Table 1 provides the rating system used for plant density and biomass.

Table 1. Macrophyte Survey Density and Biomass Ratings

Density Rating	Biomass Rating
1: Sparse - 0-25%	1: Scattered plant growth; or primarily at lake bottom
2: Moderate - 26-50%	2: Less abundant growth, or in less than half of the water column
3: Dense - 51-75%	3: Substantial growth through majority of water column
4: Very Dense - 76-100%	4: Abundant growth throughout water column to surface

In 2007 Geosyntec's survey was a pre- and post-treatment assessment conducted in June and did not utilize the 66 points used in other surveys. They used 19 pre-treatment locations and 20 post-treatment locations. Because the intent of this survey was not a whole lake assessment and the biologist did not use the same 66 points, these data were not included in this analysis.

Prior to 2014, Aquatic Control Technologies (ACT, now SOLitude) performed qualitative surveys to determine where treatment was needed and performed late summer surveys to estimate the efficacy of the treatment. Since these were qualitative and were performed for a specified purpose, these data were not included in this analysis. However, beginning in 2015 SOLitude utilized the same 66 observation points and density/biomass rating system established by Geosyntec to perform early season and late season surveys. SOLitude utilized an underwater video in addition to a grappling hook to identify the macrophytes present and relative abundance. The late season (September and October) SOLitude surveys from 2015 through 2019 were used in this analysis. Late season data were used as these were the most comparable in terms of expected plant density/biomass to data collected by Geosyntec. Table 2. summarizes the available macrophyte survey data available.

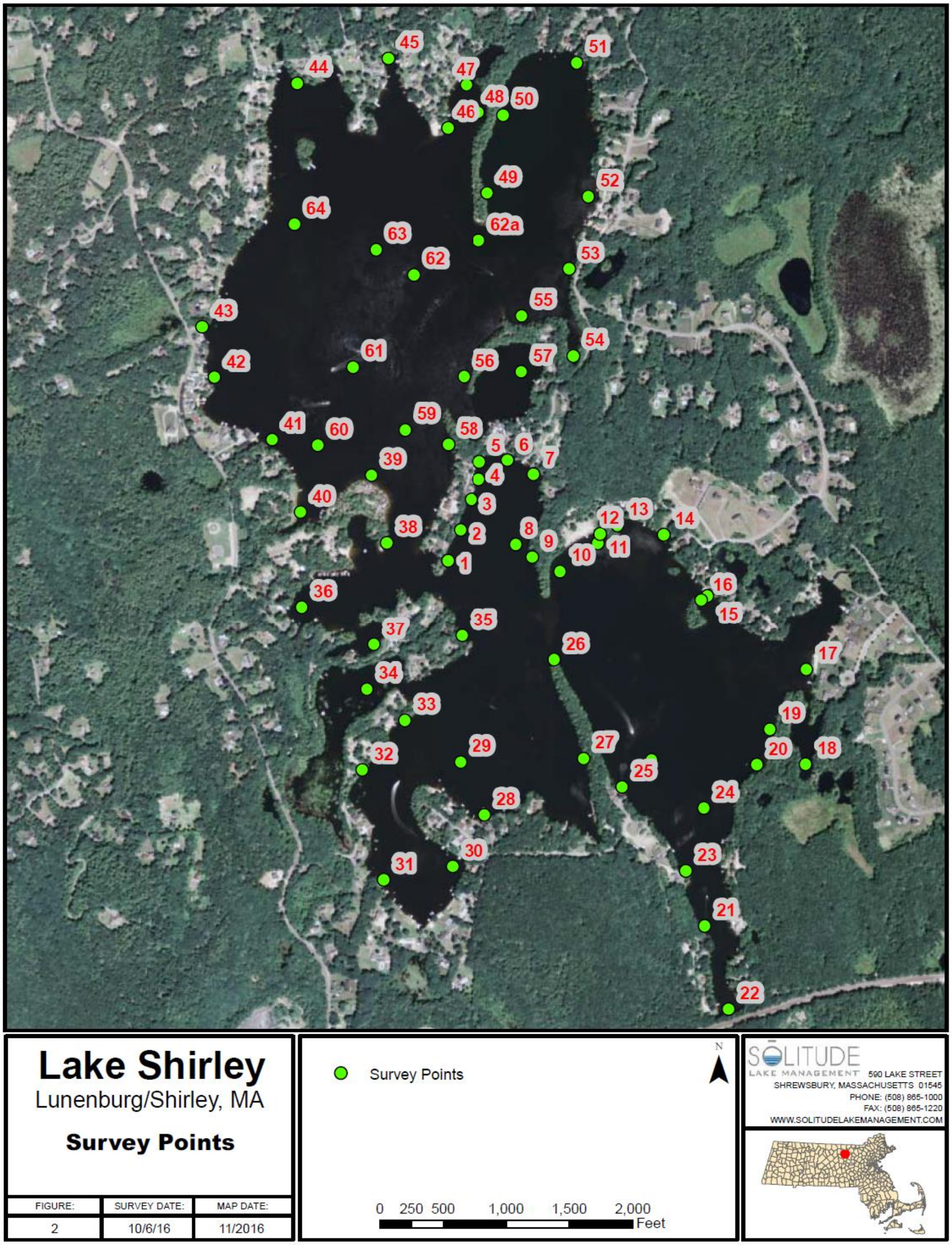


Figure 1. Lake Survey Macrophyte Survey Observation Locations (SOLitude 2016)

Table 2. Macrophyte Surveys Dates and Sampler

Month	Day	Year	Methodology	Biologists
August	12	2002*	Grappling hook	Bob Hartzel/J. Rogers
July	16	2003*	Grappling hook	Bob Hartzel/J. Rogers
July	29	2004*	Grappling hook	Bob Hartzel/B. Heald
July	27	2005*	Grappling hook	Bob Hartzel/Dan Bourdeau
August	18	2006*	Grappling hook	Bob Hartzel/Dan Bourdeau
June	25	2007	Grappling hook	Bob Hartzel/Nate Choquette
August	13	2008*	Grappling hook	Chad Yaindl
September	2	2009*	Grappling hook	Bob Hartzel
June	5	2010		ACT - qualitative
August	26	2010*	Grappling hook	Bob Hartzel
June	4	2011		ACT - qualitative
September	26	2011*	Grappling hook	Bob Hartzel
May	19	2012		ACT - qualitative
September	7	2012*	Grappling hook	Bob Hartzel
May	27	2013		ACT - qualitative
August	30	2013*	Grappling hook	Bob Hartzel
June	14	2014		ACT - qualitative
October	6	2014		ACT - qualitative
July	2	2015		ACT - qualitative
October	2	2015*	Camera/Rake toss	ACT
May	23	2016	Camera/Rake toss	SOLitude
October	6	2016*	Camera/Rake toss	SOLitude
July	5	2017	Camera/Rake toss	SOLitude
October	4	2017*	Camera/Rake toss	SOLitude
July	3	2018	Camera/Rake toss	SOLitude
September	21	2018*	Camera/Rake toss	SOLitude
June	17	2019	Camera/Rake toss	SOLitude
September	19	2019*	Camera/Rake toss	SOLitude

* Indicates data were used in this analysis

Standardization of Data

There is a variability associated with the biologists performing surveys. Some biologists tend to be lumpers or splitters – a natural tendency to lump species into a genus or those that take the extra effort to speciate all plants observed. The choice to lump or split can be due to the purpose and need of the survey, experience level of the surveyor and/or ease of identification. Some genera are exceedingly difficult to speciate, such as pondweeds (*Potamogeton*). There are over 60 species of pondweeds, many of which cannot be identified to the species level without reproductive structures such as seeds and flowers. Plant scientific names can also change over time as DNA sequencing has become more prevalent for identification. To reduce the effect of skewing data based on naming or differing levels of classification, the entire list of species observed was first reviewed to ensure there was no duplication based on best professional judgement. Data were left as reported if there was any uncertainty on whether modification was justified. Below is a bulleted list of modifications to the data prior to finalizing the database.

- *Eleocharis robbinsii* was identified in 2009 but *Eleocharis* was identified as *sp*. for 2015 & 2016; modified 2009 to *sp*.
- *Chara* was speciated to *vulgaris*, *aspera* and *sp*. Early years 2002-2004 only *vulgaris* was identified. In 2005 both *vulgaris* and *sp*. were used; 2006 only *vulgaris*; 2008 both *vulgaris* & *aspera*; only *sp*. or *spp*. was used from 2009 on. There was only one instance where *aspera* and *vulgaris* were found together (2008 at point 31). Since the majority of these data did not separate species, all *Chara* was lumped as *sp*.
- Mosses were either identified as *Musci* (which is a subdivision of Phylum/Division Bryophyte [moss, liverwort of hornwort]) or *Aulacomnium palustre* (bog moss), which is identification down to genus level. *Aulacomnium* was used 2002, 2005, 2008 & 2010. *Musci* was used 2009, 2015-2018. Changed all data to *Musci*.
- *Elodea canadensis* vs. *nuttallii*; *canadensis* was reported 2002 and 2019 whereas *nuttallii* was reported 2003-2005. These are both native similar species differing by the broadness of leaves and bluntness of ends. These species were not recorded together in any given year. It is suspected that only one is present, therefore *sp*. was used. All reports used the same common name.
- *Najas flexilis* was mostly identified as Bushy Pondweed in all years but 2019. Changed 2019 from Slender naiad to Bushy pondweed.
- Sept 2018 Chara/Nitella were lumped. Could not separate - left as reported.
- Question *spirodela* vs. *lemna* in 2006, but no change made.
- *Utricularia* were lumped as *sp.* or split into species. No change but this could artificially raise richness value for years this was split.

Summary of Database and Quality Control/Quality Assurance

The final database consists of 16 years of macrophyte survey data, containing 47 macrophyte species at 66 points, resulting in 24,546 records. Quality control review of data entry was conducted on all species presence data. This control review ensured that the frequency of each species was correct for every survey year. A 10% quality check was conducted on individual point data to ensure the species was documented at the correct observation point. During this process, some errors were discovered in previous survey reports. Most were insignificant except for 2006 where Geosyntec reported 26 species observed when data by observation point only totaled 23, an over estimation of richness by three species.

Data Analysis

Comparisons, Statistical Tests and Analysis

The purpose of this analysis was to evaluate if there were any undesirable negative impacts associated with the lake VMP, specifically any loss of non-target native species as a result of winter water level drawdown and/or herbicide/algaecide treatments. To explore this, several questions were postulated:

- Is there a difference in density, biomass, whole lake species richness, average richness at observation points, diversity & evenness of plant community over time?
- If there are differences, can these be attributed to:
    - The survey methodology (biologist)?

- The reduced clarity event occurring in summer of 2006 due to algal bloom (2002-2005 vs. 2006)?
- Herbicide/algaecide treatments (2002-2006 vs. 2008-2019)?
- Winter water level drawdown (data at observation points ≤6 feet vs. data >6 feet)?
- Natural variability

- How has the macrophyte community changed?
  - What species are less abundant?
  - What observation points changed the most?

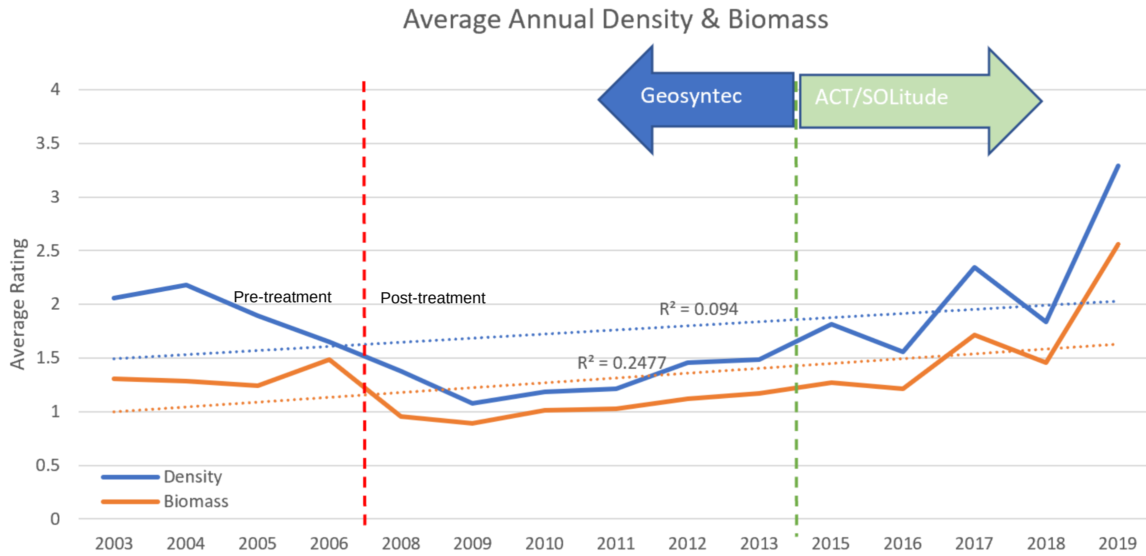
To evaluate data over time, simple time series plots were generated, and a linear regression was fit to these data. A coefficient of determination was calculated to determine the percent of variation can be explained by time.

To evaluate the differences between groups (e.g. pre-treatment vs. post-treatment) a standard t-Test was used assuming unequal variances and a one-tailed significance at $P<0.05$. While it is common to utilize non-parametric statistics for biological data, the macrophyte data did exhibit a normal distribution in more cases than not and the directional component of comparing means was desirable. A sensitivity analysis was conducted on a subset of data comparing conclusions drawn from the t-Test to conclusions using the non-parametric Mann-Whitney test to ensure that using a parametric test would not result in Type I or Type II statistical errors. The conclusions drawn were not different between the two tests. It was therefore assumed that the t-Test was sufficient for this analysis.

Density and Biomass

The average annual plant density and biomass data were plotted verses time (Figure 2). Average density ranged from 1.1 to 3.3, with the lowest found in 2009 and highest in 2019. Average biomass showed a similar pattern and range, a range of 0.9 to 2.6 (low in 2009 and high in 2019). The coefficient of determination (R^2) was low for both density and biomass, concluding that time could only account for 9 to 25% of the variation in density and biomass. Both density and biomass were on the decline prior to herbicide treatments which started around the time of the 2006 algal bloom. Data in the last four years are significantly greater than the first four years ($P<0.05$). Density in 2002-2006 averaged 1.9 whereas density 2016-2019 averaged 2.3. Biomass results averaged 1.3 vs. 1.7 in the first and last four years, respectively.

Using all point data (not an annual average), density was significantly higher pre-treatment ($P=2.17\times10^{-5}$). However, biomass was not significantly different pre- vs. post-treatment ($P=0.33$)(Figure 3). Biomass results were sensitive to the 2019 data, which was the highest biomass reported over the period of record. When 2019 biomass data were removed from the dataset, biomass pre-treatment was significantly higher than post treatment ($P=6.83\times10^{-4}$) and followed a similar pattern to density. While the 2019 data are statistical outliers (deviates from the body of other observations), there was no indication that these data were erroneous and are included to represent the range of random variation.



* Plant density and biomass were not reported in 2002

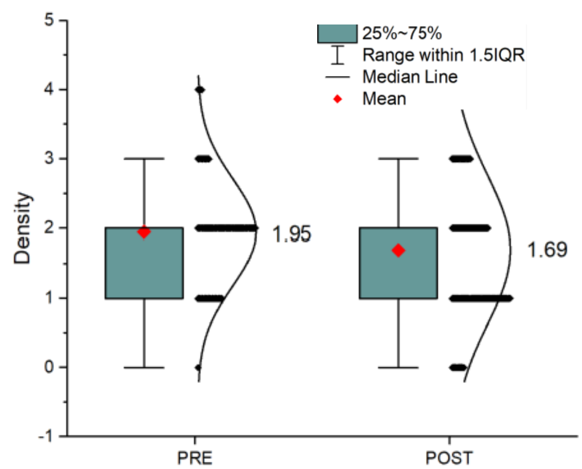
Figure 2. Average Annual Macrophyte Density and Biomass over Time

Plant Density t-Test including 2019 data

t-Test: Two-Sample Assuming Unequal Variances

	PRE	POST
Mean	1.94697	1.69421
Variance	0.57512	1.15602
Observations	264	726
Hypothesized Mean Difference	0	
df	660	
t Stat	4.11606	
P(T<=t) one-tail	2.2E-05	
t Critical one-tail	1.64717	
P(T<=t) two-tail	4.3E-05	
t Critical two-tail	1.96356	

Conclusion:
Reject the H_0: There is insufficient evidence to conclude that plant density in the four year prior to herbicide treatments is equal to the plant density in the 11 years after herbicide treatments began
Accept the H_a: There is sufficient evidence to conclude that plant density in the four years prior to herbicide treatments is greater than the plant density in the 11 years after herbicide treatments began



Plant Biomass t-Test including 2019 data

t-Test: Two-Sample Assuming Unequal Variances

	PRE	POST
Mean	1.329545	1.30854
Variance	0.358667	0.655017
Observations	264	726
Hypothesized Mean Difference	0	
df	628	
t Stat	0.441775	
P(T<=t) one-tail	0.329402	
t Critical one-tail	1.647284	
P(T<=t) two-tail	0.658804	
t Critical two-tail	1.963749	

Conclusion:
Reject the H_0: There is sufficient evidence to accept the null hypothesis and conclude that plant biomass in the four years prior to herbicide treatments is equal to the plant biomass in the 11 years after herbicide treatments began

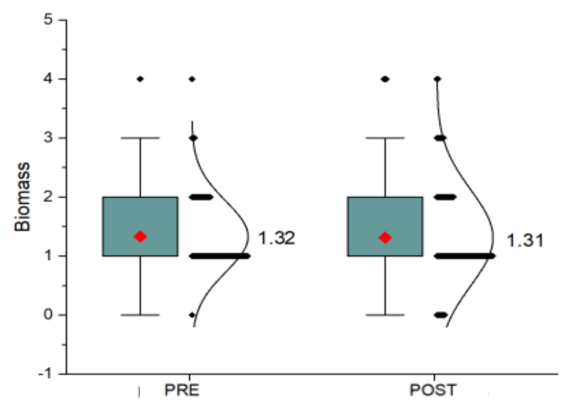


Figure 3. Plant Density and Biomass Pre and Post Treatment

Separating out the influence of biologist (Geosyntec vs. ACT/SOLitude) revealed that plant density and biomass surveyed by Geosyntec was significantly lower than that surveyed by ACT/SOLitude ($P<0.05$ with and without 2019 data). Density and biomass in the last four years has increased but it is undetermined if this naturally occurring or a sampling effect; time (year surveyed) and surveyor variables cannot be separated in this instance because there are no early year (pre-treatment) quantitative data collected by ACT/SOLitude to compare.

Similar analyses were performed to evaluate if drawdown has influenced plant density and biomass. In order to analyze data within and outside the drawdown zone, water depths from the 2019 survey were used. Any data derived from points where water depths were less than or equal to six feet were considered to be within the drawdown zone. Similarly, points where depths were greater than six were outside the drawdown zone. Both plant density and biomass were significantly higher within the drawdown zone than outside (Figure 4).

It is not surprising that density and biomass are higher within the drawdown zone as these areas are expected to have substantial plant coverage and biomass by the end of the summer as this area receives ample light to support growth. The drawdown likely prevents extreme density and biomass by killing aggressive non-natives or slowing regrowth. Plant densities and biomass often decline as the water gets deeper due to diminished light to sediments. Deeper areas favor light tolerant tall growing species like the non-native invasive milfoils and fanwort.

DENSITY Within vs Outside DD including 2019
t-Test: Two-Sample Assuming Unequal Variances

	Within	*Outside*
Mean	2	1.553435
Variance	1.043103	0.890065
Observations	465	524
Hypothesized Mean Difference	0	
df	950	
t Stat	7.112719	
P(T<=t) one-tail	1.12E-12	
t Critical one-tail	1.646459	
P(T<=t) two-tail	2.24E-12	
t Critical two-tail	1.962464	

BIOMASS Within vs Outside DD including 2019
t-Test: Two-Sample Assuming Unequal Variances

	Within	*Outside*
Mean	1.494624	1.156489
Variance	0.664303	0.442004
Observations	465	524
Hypothesized Mean Difference	0	
df	896	
t Stat	7.093719	
P(T<=t) one-tail	1.33E-12	
t Critical one-tail	1.646556	
P(T<=t) two-tail	2.65E-12	
t Critical two-tail	1.962615	

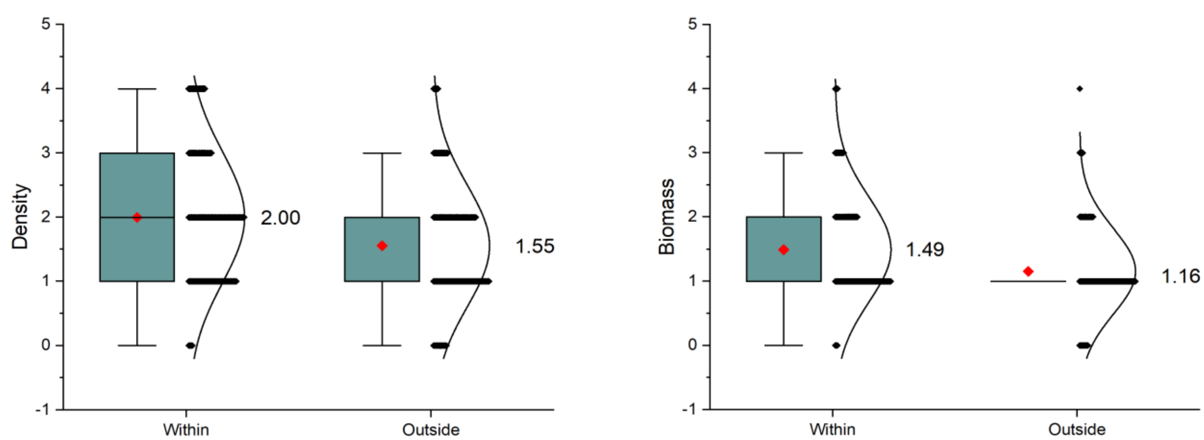


Figure 4. Density and Biomass within and outside the Drawdown Zone

Richness, Diversity and Evenness

Biodiversity is difficult to quantify and assess changes between systems and over time. There are a multitude of indices available for this purpose. In this evaluation we used some of the most common indices to assess change. No one index was mined to produce the most significant results. The use of multiple indices provides a greater understanding of the interactions within the ecosystem. Analysis of biodiversity measures are shown with and without the treatment target plants (milfoils, fanwort, curlyleaf pondweed, European naiad and wild celery) since the objective of the treatment is to reduce the frequency of, or perhaps eliminate, the target species. It is not applicable to count reductions in these species when assessing impacts as the reduction is the desired outcome.

Richness (S) – richness is simply a count of the number of different species present. Richness is extremely sensitive to the classification of individuals present, so if two individual species are lumped into one taxon in one year but not another, this will represent a change in richness that does not exist. For this very reason, species data were reviewed and consolidated where appropriate prior to conducting the analysis. Although an effort was made to correct taxonomic inconsistences (see Standardization of Data Section of this report) modification to these data were minimized in order to not introduce error.

Richness places equal weight of the presence of rare or less abundant species with species that are abundant, so the disappearance/appearance of single plants even when rare can result in measurable changes in richness. For example, in this dataset it appears that in early surveys conducted by Geosyntec, the biologist reported one observation of several emergent wetland species (e.g. arrow arum, pickerel weed, etc.) but these species have not been reported in many years since. It is unclear if biologist shifted focus to reporting only submerged aquatic species or if these plants are truly no longer present. Richness data from 2002 through 2019 are provided in Table 3.

Table 3. Richness 2002-2019

				Drawdown Zone		Excluding target spp Drawdown Zone		Avg at Observation Pts	
	Year	S	Excluding target spp	Within (S)	Outside (S)	Within (S)	Outside (S)	S	Excluding Target Spp
Pre-Treatment	2002	27	22	26	16	21	12	4.3	2.3
	2003	18	13	18	16	13	11	5.5	3.2
	2004	20	15	20	14	15	9	5.2	2.9
	2005	24	18	24	19	18	13	6.4	3.6
	2006	22	17	21	9	16	4	3.3	1.7
Post-Treatment	2008	24	18	22	17	16	12	2.9	1.7
	2009	22	17	22	14	17	11	2.8	1.6
	2010	21	16	21	14	16	10	2.9	1.7
	2011	19	14	19	12	14	9	2.9	1.2
	2012	20	15	20	10	15	7	3.3	1.6
	2013	19	14	19	11	14	8	3.2	1.7
	2015	16	12	16	8	12	5	2.5	1.4
	2016	16	12	15	10	12	6	3.0	1.3
	2017	12	10	12	8	10	6	2.0	1.4
	2018	14	11	14	9	11	6	2.8	1.4
	2019	17	14	15	13	12	10	4.7	2.3
	Minimum	12	10	12	8	10	4	2.0	1.2
	Maximum	27	22	26	19	21	13	6.4	3.6
	Average	19.4	14.9	19.0	12.5	14.5	8.7	3.6	1.9
	Avg Pre	22.2	17.0	21.8	14.8	16.6	9.8	5.0	2.7
	Avg Post	18.2	13.9	17.7	11.5	13.5	8.2	3.0	1.5
	Diff Pre-Post	4.0	3.1	4.1	3.3	3.1	1.6	2.0	1.2

Macrophyte richness (S) ranged from 12 to 27 species [10 to 22 without target species (S*)]. The lowest number of species encountered occurred in 2017 while the highest was reported in 2002, the first year (Table 3). Within the pre-treatment years but excluding target species, richness varied between a loss of nine species to a gain (or return) of three species in year by year comparison (Figure 5). This large delta suggests high variability in species presence/absence between sampling years even without any herbicide treatments. Between 52 to 60% of the variation in richness at Lake Shirley is explained by time.

Post-treatment richness varied between a loss of two species and gain (or return) of three species, excluding target species. These data suggest that non-treatment factors can result in a 33% change in species richness any given year. In addition, average pre vs. post-treatment richness was 17 vs. 14, a difference of three species. This is well within the natural variable of species richness even within Massachusetts lakes with no herbicide treatment. Species richness at three non-treated lakes, each with 7-10 years of survey data, varied between 10 and 15%. Richness changes could not be attributed to any herbicide/algaecide treatments in these lakes, but all lakes implement a small <5-foot drawdown for rooted plant control[1].

In addition to considering richness in the lake as whole, richness at each individual observation point was considered. The sum of richness (number of species) at each site divided by the total number of observations sites provides an average richness at observation points. This is the value prior reports refers to as the "richness index." Average richness at observation points over time is shown on Figure 6. These data differ slightly from prior reports based on the data standardization conducted prior to analysis and a few errors found in prior datasets. Average richness across observations points ranged from 2.0 to 6.4, where the lowest richness at points was recorded in 2017 and the highest in 2005. When removing the target species, the range dropped to 1.2 to 3.6, indicating that most points contained non-desirable species that are the target for treatments (milfoils, fanwort, curlyleaf pondweed, European naiad and wild celery). There was a drastic decline in average richness at observation points from 2005 to 2006, 53% decline in species richness (3.6 in 2005 vs. 1.7 in 2006); Geosyntec postulated that this was the result of light limitation caused by an extreme algal bloom the summer of 2006.

Analysis of richness pre-treatment vs. post-treatment resulted in a significant difference, with pre-treatment richness values higher on average than post ($P=0.03$; Figure 7). However, removing the target species from the dataset results in statistically similar richness pre- and post-treatment ($P=0.06$). The influence of biologists (Geosyntec vs. ACT/SOLitude) revealed similar results: richness documented by Geosyntec was significantly higher than that documented by ACT/SOLitude ($P<0.05$), but when excluding the target species, this difference was not significant. These data suggest that when non-native species and nuisance wild celery are not included, there is no difference in richness given the variability.

Species richness in the drawdown zone is significantly higher than species richness outside the drawdown zone with and without the target species (Figure 8). This suggests that the presence of non-target species is not influential in evaluating differences within and outside the drawdown zone. Richness is sensitive to the drawdown or another variable like water depth or light availability.

[1] Wagner, K. (2020). *Unpublished*. Current knowledge of herbicides relevant to projects in Massachusetts. Submitted to regulatory agencies for consideration to amend the Generic Environmental Impact Report for Eutrophication and Aquatic Plant Management in Massachusetts.

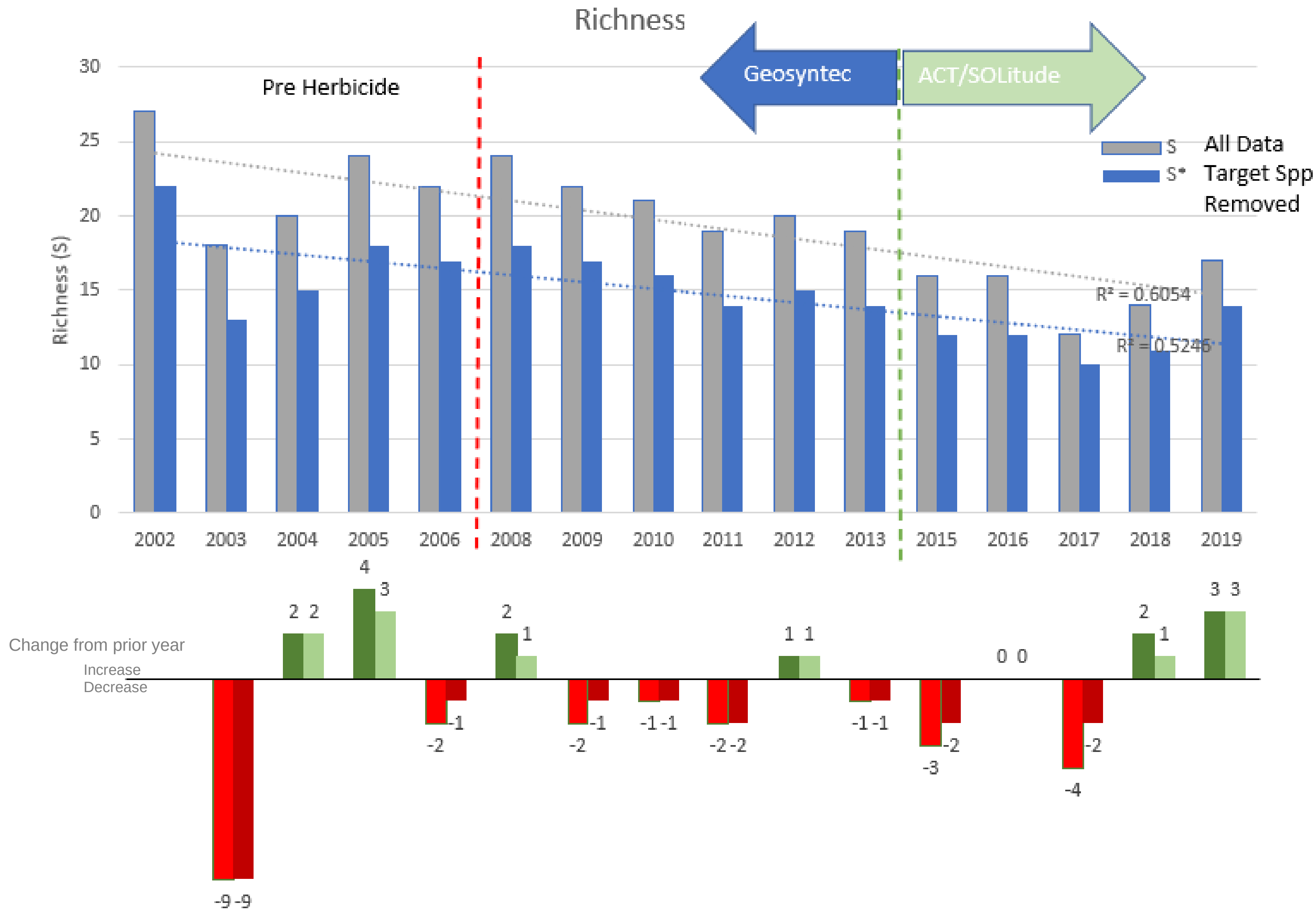


Figure 5. Richness with Previous Year Comparison

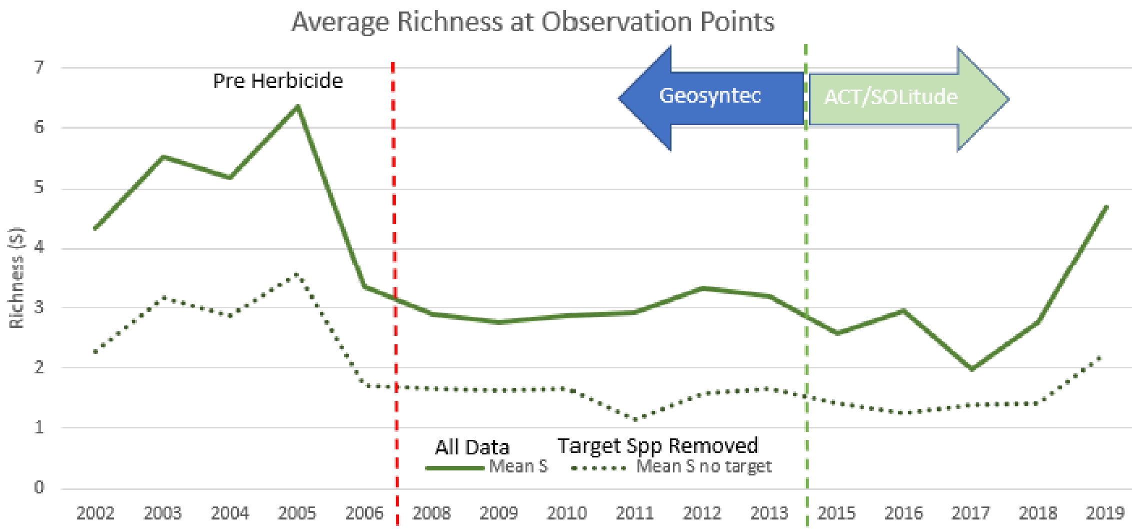


Figure 6. Average Richness at Observation Points

Pre- vs. Post-Treatment Richness

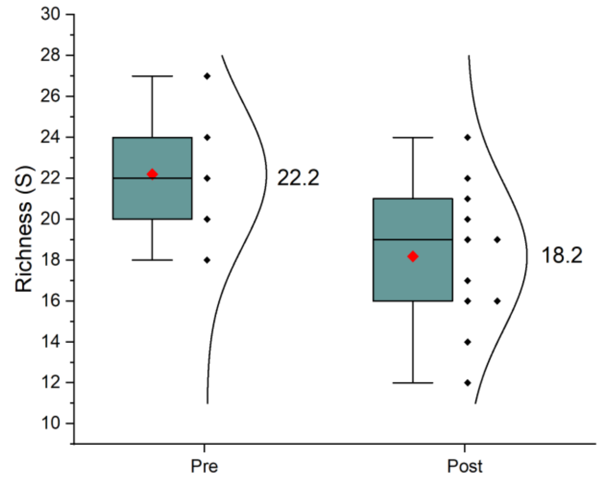
All richness data

Richness (S)		
t-Test: Two-Sample Assuming Unequal Variances		
	Pre	*Post*
Mean	22.2	18.182
Variance	12.2	12.764
Observations	5	11
Hypothesized Mean Differenc	0	
df	8	
t Stat	2.1177	
P(T<=t) one-tail	0.0335	
t Critical one-tail	1.8595	
P(T<=t) two-tail	0.0671	
t Critical two-tail	2.306	

Conclusion:

Reject the H_0: There is insufficient evicence to conclude that plant richness in the five years prior to herbicide treatments is equal to the plant richness in the 11 years after herbicide treatments began

Accept the H_a: There is sufficient evidence to conclude that plant richness in the five years prior to herbicide treatments is greater than plant richness in the 11 years after herbicide treatments began



Excluding treatment target species data

Richness (S)		
t-Test: Two-Sample Assuming Unequal Variances		
	Pre	*Post*
Mean	17	13.909
Variance	11.5	6.2909
Observations	5	11
Hypothesized Mean Differenc	0	
df	6	
t Stat	1.8239	
P(T<=t) one-tail	0.059	
t Critical one-tail	1.9432	
P(T<=t) two-tail	0.118	
t Critical two-tail	2.4469	

Conclusion:

Accept the H_0: There is sufficient evidence to conclude that species richness in the five years prior to herbicide treatments is equal to the species richness in the 11 years after herbicide treatments began, excluding target species data

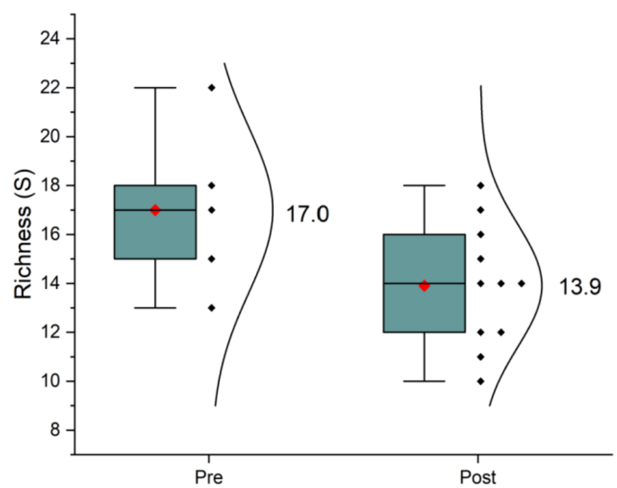


Figure 7. Richness Pre and Post Treatment.

Within vs. Outside Drawdown Zone Richness

All richness data

Richness (S)

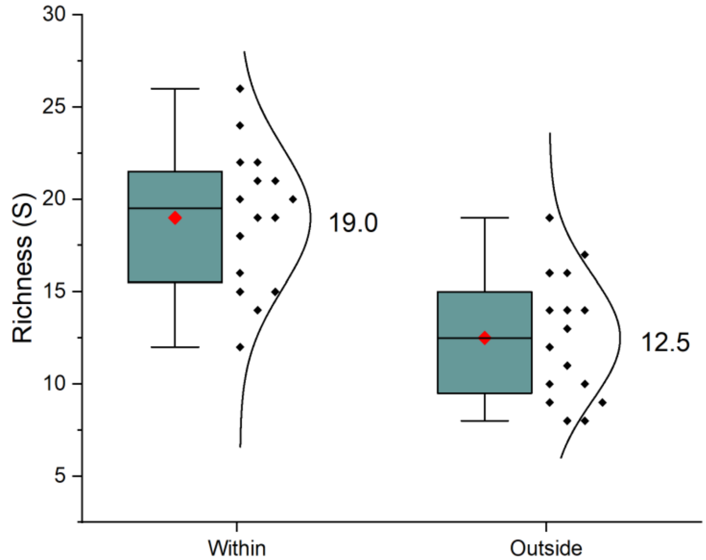
t-Test: Two-Sample Assuming Unequal Variances

	Within	*Outside*
Mean	19	12.5
Variance	14.53333	11.6
Observations	16	16
Hypothesized Mea	0	
df	30	
t Stat	5.085995	
P(T<=t) one-tail	9.14E-06	
t Critical one-tail	1.697261	
P(T<=t) two-tail	1.83E-05	
t Critical two-tail	2.042272	

Conclusion:

Reject the H_0: There is insufficient evidence to conclude that plant richness in the drawdown zone is equal to the plant richness outside the drawdown zone

Accept the H_a: There is sufficient evidence to conclude that plant richness in the drawdown zone is greater than plant richness outside the drawdown zone



Excluding treatment target species data

Richness (S)

t-Test: Two-Sample Assuming Unequal Variances

	Within	*Outside*
Mean	14.5	8.6875
Variance	8.133333	7.695833
Observations	16	16
Hypothesized Mea	0	
df	30	
t Stat	5.843781	
P(T<=t) one-tail	1.08E-06	
t Critical one-tail	1.697261	
P(T<=t) two-tail	2.16E-06	
t Critical two-tail	2.042272	

Conclusion:

Reject the H_0: There is insufficient evidence to conclude that plant richness in the drawdown zone is equal to the plant richness outside the drawdown zone

Accept the H_a: There is sufficient evidence to conclude that plant richness in the drawdown zone is greater than plant richness outside the drawdown zone

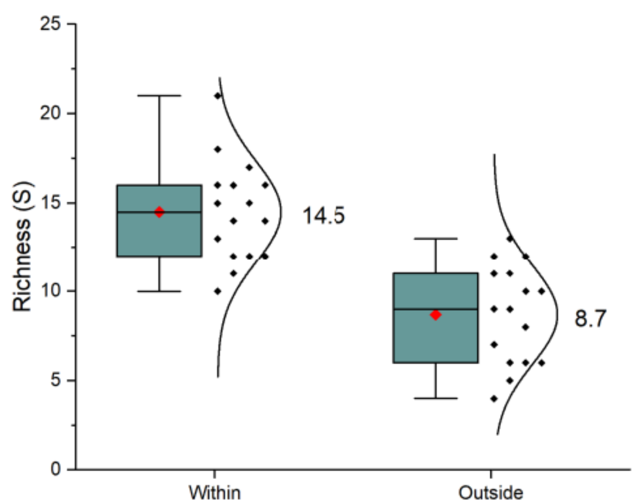


Figure 8. Richness within and outside the Drawdown Zone

Diversity (H') and Evenness – The Shannon Index (also known as the Shannon-Wiener Diversity Index) was used to assess the diversity of the community and evaluate if there has been significant changes over time, changes due to herbicide/algaecide treatment or differences in drawdown zone. The Shannon Index (H') considers both species richness and abundance (i.e., dominance). The higher the H' value the greater the diversity and evenness, or lack of dominance by a few species. Values closer to zero indicate that richness and low and the community is dominated by a few species. The index is calculated using the following formula:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

Where:

S = number of species in the sample (richness)
p_i = proportion of the sample belonging to the i^{th} species
ln p_i = natural logarithm of p_i

Shannon Index is often discussed along with an equitability (or evenness) index. Evenness is expressed on a scale of 0 to 1, where values closer to 1 indicated that species are evenly represented in the community. A value near 0 indicates dominance by few species. Evenness (E) is calculated by dividing H' by the maximum diversity possible (Hmax) in the community, calculated by taking the natural log of S-richness.

Diversity and evenness values are presented in Table 4. Diversity ranged from 1.9 to 2.8, with an average of 2.4. Diversity excluding the target species was 1.5 to 2.6, with an average of 2.1. Diversity was lowest in 2017 and 2016 (all data and excluding target species, respectively). However, evenness was lowest in 2006 and likely represents the fact that four species were found at over half the observation sites; Eurasian milfoil was observed at 52 or the 66 observation points, followed by coontail at 47 points. The other abundant species were Robbins' pondweed and wild celery. The presence and abundance of the two natives (pondweed and coontail) explains why evenness does not improve when the target species were excluded (Figure 9).

Diversity pre-treatment averaged 2.6 and post-treatment was 2.3 (Figure 10). These differences were statistically significant suggesting that diversity in the five years prior to treatment were greater than the 11 years after herbicide/algaecide treatments started. However, diversity was sensitive to the abundance of non-desirable species. When the target species were removed from the dataset, species diversity was similar pre- and post-treatment suggesting that the presence and abundance of non-native species (and wild celery) caused the increased species diversity. Evenness was similar pre- and post-treatment (0.83 vs. 0.78, pre-post respectively) and with and without target species (0.81 vs. 0.77, pre-post, respectively) (Figure 10).

Table 4. Diversity and Evenness 2002-2019

		All Data				Excluding Target Spp			
	Year	**S**	**H**	**Hmax**	**E**	**S**	**H**	**Hmax**	**E**
Pre-Treatment	2002	27	2.67	3.30	0.81	22	2.57	3.09	0.83
	2003	18	2.60	2.89	0.90	13	2.29	2.56	0.89
	2004	20	2.64	3.00	0.88	15	2.35	2.71	0.87
	2005	24	2.79	3.18	0.88	18	2.52	2.89	0.87
	2006	22	2.18	3.09	0.70	17	1.70	2.83	0.60
Post-Treatment	2008	24	2.69	3.18	0.85	18	2.53	2.89	0.87
	2009	22	2.64	3.09	0.85	17	2.53	2.83	0.89
	2010	21	2.39	3.04	0.79	16	2.14	2.77	0.77
	2011	19	2.29	2.94	0.78	14	2.29	2.64	0.87
	2012	20	2.35	3.00	0.78	15	2.21	2.71	0.82
	2013	19	2.21	2.94	0.75	14	1.84	2.64	0.70
	2015	16	2.08	2.77	0.75	12	1.65	2.48	0.66
	2016	16	1.96	2.77	0.71	12	1.53	2.48	0.62
	2017	12	1.89	2.48	0.76	10	1.62	2.30	0.70
	2018	14	2.19	2.64	0.83	11	1.91	2.40	0.79
	2019	17	2.22	2.83	0.78	14	1.99	2.64	0.75
Minimum		12	1.89	2.48	0.70	10	1.53	2.30	0.60
Maximum		27	2.79	3.30	0.90	22	2.57	3.09	0.89
Average		19.4	2.4	2.9	0.8	14.9	2.1	2.7	0.8
Avg Pre		22.2	2.6	3.1	0.8	17.0	2.3	2.8	0.8
Avg Post		18.2	2.3	2.9	0.8	13.9	2.0	2.6	0.8
Diff Pre-Post		4.0	0.3	0.2	0.1	3.1	0.3	0.2	0.0

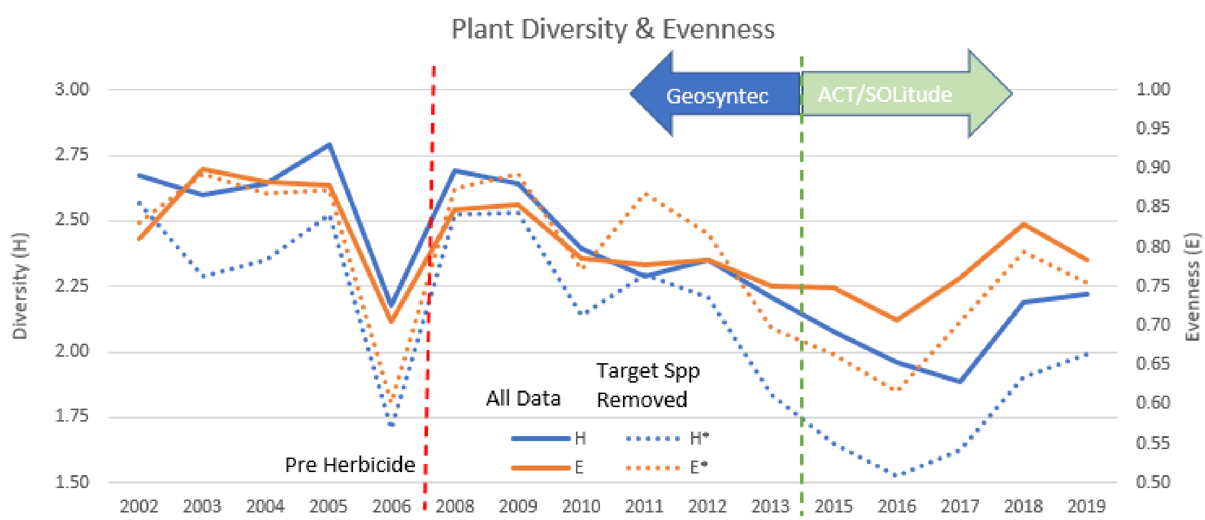


Figure 9. Diversity and Evenness over Time

Aquatic Restoration Consulting, LLC

Pre- vs. Post-Treatment Diversity and Evenness

All diversity data

Diversity (H)

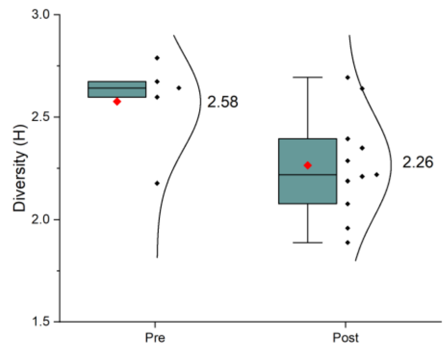
t-Test: Two-Sample Assuming Unequal Variances

	Pre	Post
Mean	2.57629	2.26426
Variance	0.05464	0.06304
Observations	5	11
Hypothesized Mean Difference	0	
df	8	
t Stat	2.41749	
P(T<=t) one-tail	0.02101	
t Critical one-tail	1.85955	
P(T<=t) two-tail	0.04201	
t Critical two-tail	2.306	

Conclusion:

Reject the H_0: There is insufficient evidence to conclude that plant diversity in the five years prior to herbicide treatments is equal to the plant diversity in the 11 years after herbicide treatments began

Accept the H_a: There is sufficient evidence to conclude that plant diversity in the five years prior to herbicide treatments is greater than plant diversity in the 11 years after herbicide treatments began



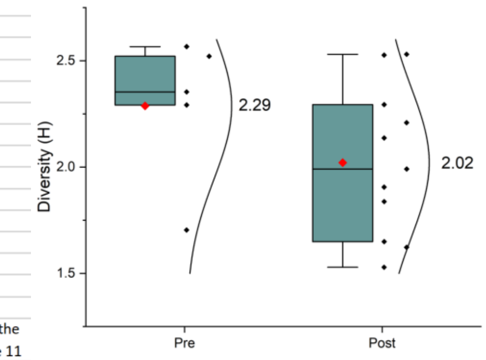
Excluding treatment target species data

Diversity (H)

t-Test: Two-Sample Assuming Unequal Variances

	Pre	Post
Mean	2.28718	2.02095
Variance	0.1193	0.12249
Observations	5	11
Hypothesized Mean Difference	0	
df	8	
t Stat	1.42318	
P(T<=t) one-tail	0.09625	
t Critical one-tail	1.85955	
P(T<=t) two-tail	0.19249	
t Critical two-tail	2.306	

Accept the H_0: There is sufficient evidence to conclude that plant diversity in the five years prior to herbicide treatments is equal to the species diversity in the 11



All Evenness data

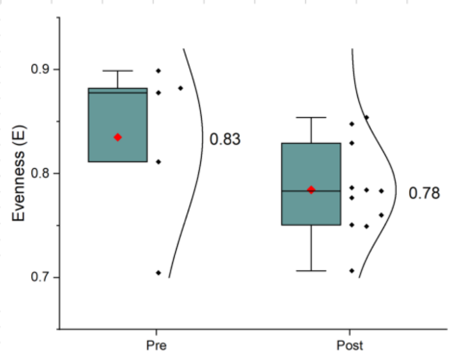
Evenness (E)

t-Test: Two-Sample Assuming Unequal Variances

	Pre	Post
Mean	0.83489	0.78436
Variance	0.00643	0.002
Observations	5	11
Hypothesized Mean Difference	0	
df	5	
t Stat	1.31915	
P(T<=t) one-tail	0.12215	
t Critical one-tail	2.01505	
P(T<=t) two-tail	0.2443	
t Critical two-tail	2.57058	

Conclusion:

Accept the H_0: There is sufficient evidence to conclude that species evennes in the five years prior to herbicide treatments is equal to the species evenness in the 11 years after herbicide treatments began



Excluding treatment target species data

Evenness (E)

t-Test: Two-Sample Assuming Unequal Variances

	Pre	Post
Mean	0.81324	0.76832
Variance	0.01454	0.00837
Observations	5	11
Hypothesized Mean Difference	0	
df	6	
t Stat	0.74155	
P(T<=t) one-tail	0.24318	
t Critical one-tail	1.94318	
P(T<=t) two-tail	0.48636	
t Critical two-tail	2.44691	

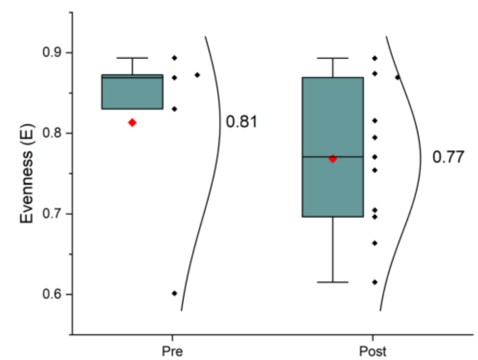


Figure 10. Diversity and Evenness Pre and Post Treatment

Diversity and evenness values within and outside the drawdown zone are presented in Table 5; Figure 11. Diversity within the drawdown zone ranged from 2.0 to 2.9, with an average of 2.5 and was significantly higher ($P=1.2 \times 10^{-4}$) than outside the drawdown zone (range 1.6 to 2.5, 2.1 average). While diversity decreased when the treatment target species were removed from the dataset, density still remained significantly higher in the drawdown zone vs. outside (average density 2.3 vs. 1.6, within and 1.6, respectively). Evenness was statistically similar within and outside the drawdown zone (0.84 vs. 0.82). However, evenness was sensitive to the presence of treatment targeted species and resulted in a significant lower evenness outside the drawdown (average 0.85 within and 0.76 outside; Figure 12), suggesting that non-native species and wild celery were more abundant in areas outside the drawdown zone.

Table 5. Diversity and Evenness within and outside the Drawdown Zone.

		All Data							
		Within Drawdown Zone (<= 6.0)				Outside Drawdown Zone (>6.0)			
	Year	S	H	Hmax	E	S	H	Hmax	E
Pre-Treatment	2002	26	2.81	3.26	0.86	16	2.32	2.77	0.84
	2003	18	2.67	2.89	0.92	16	2.40	2.77	0.87
	2004	20	2.71	3.00	0.90	14	2.39	2.64	0.91
	2005	24	2.87	3.18	0.90	19	2.52	2.94	0.86
	2006	21	2.39	3.04	0.78	9	1.65	2.20	0.75
Post-Treatment	2008	22	2.74	3.09	0.89	17	2.36	2.83	0.83
	2009	22	2.67	3.09	0.86	14	2.34	2.64	0.89
	2010	21	2.51	3.04	0.82	14	2.09	2.64	0.79
	2011	19	2.38	2.94	0.81	12	1.90	2.48	0.77
	2012	20	2.53	3.00	0.85	10	1.81	2.30	0.79
	2013	19	2.37	2.94	0.81	11	1.84	2.40	0.77
	2015	16	2.21	2.77	0.80	8	1.76	2.08	0.85
	2016	15	2.02	2.71	0.75	10	1.75	2.30	0.76
	2017	12	2.02	2.48	0.81	8	1.60	2.08	0.77
	2018	14	2.28	2.64	0.86	9	1.95	2.20	0.89
	2019	15	2.30	2.71	0.85	13	2.04	2.56	0.80
Minimum		12	2.02	2.48	0.75	8	1.60	2.08	0.75
Maximum		26	2.87	3.26	0.92	19	2.52	2.94	0.91
Average		19.0	2.47	2.92	0.84	12.5	2.05	2.49	0.82
Avg Pre		21.8	2.69	3.07	0.88	14.8	2.26	2.67	0.84
Avg Post		17.7	2.37	2.86	0.83	11.5	1.95	2.41	0.81
Diff Pre-Post		4.1	0.32	0.22	0.05	3.3	0.31	0.25	0.04

		Excluding Target Spp							
		Within Drawdown Zone (<= 6.0)				Outside Drawdown Zone (>6.0)			
	Year	S	H	Hmax	E	S	H	Hmax	E
Pre-Treatment	2002	21	2.67	3.04	0.88	12	2.07	2.48	0.83
	2003	13	2.36	2.56	0.92	11	2.05	2.40	0.85
	2004	15	2.43	2.71	0.90	9	1.97	2.20	0.90
	2005	18	2.59	2.89	0.90	13	2.16	2.56	0.84
	2006	16	2.08	2.77	0.75	4	0.89	1.39	0.64
Post-Treatment	2008	16	2.57	2.77	0.93	12	2.12	2.48	0.85
	2009	17	2.56	2.83	0.90	11	2.14	2.40	0.89
	2010	16	2.32	2.77	0.84	10	1.64	2.30	0.71
	2011	14	2.27	2.64	0.86	9	2.01	2.20	0.92
	2012	15	2.43	2.71	0.90	7	1.43	1.95	0.74
	2013	14	2.07	2.64	0.79	8	1.21	2.08	0.58
	2015	12	1.95	2.48	0.78	5	1.07	1.61	0.66
	2016	12	1.87	2.48	0.75	6	0.91	1.79	0.51
	2017	10	1.82	2.30	0.79	6	1.21	1.79	0.68
	2018	11	2.05	2.40	0.85	6	1.49	1.79	0.83
	2019	12	2.08	2.48	0.84	10	1.68	2.30	0.73
Minimum		10	1.82	2.30	0.75	4	0.89	1.39	0.51
Maximum		21	2.67	3.04	0.93	13	2.16	2.56	0.92
Average		14.5	2.26	2.66	0.85	8.7	1.63	2.11	0.76
Avg Pre		16.6	2.43	2.80	0.87	9.8	1.83	2.21	0.81
Avg Post		13.5	2.18	2.59	0.84	8.2	1.54	2.06	0.74
Diff Pre-Post		3.1	0.25	0.20	0.03	1.6	0.29	0.14	0.08

Diversity (H)

t-Test: Two-Sample Assuming Unequal Variances

	Within	*Outside*
Mean	2.46769	2.04614
Variance	0.07034	0.09284
Observations	16	16
Hypothesized Mean Difference	0	
df	29	
t Stat	4.17417	
P(T<=t) one-tail	0.00012	
t Critical one-tail	1.69913	
P(T<=t) two-tail	0.00025	
t Critical two-tail	2.04523	

Conclusion:

Reject the H_0: There is insufficient evidence to conclude that plant diversity in the drawdown zone is equal to the plant diversity outside the drawdown zone

Accept the H_a: There is sufficient evidence to conclude that plant diversity in the drawdown zone is greater than plant diversity outside the drawdown zone

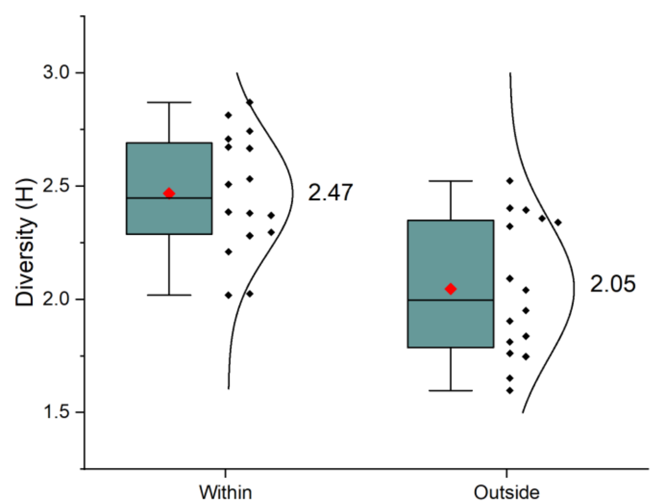


Figure 11. Diversity within and outside the Drawdown Zone

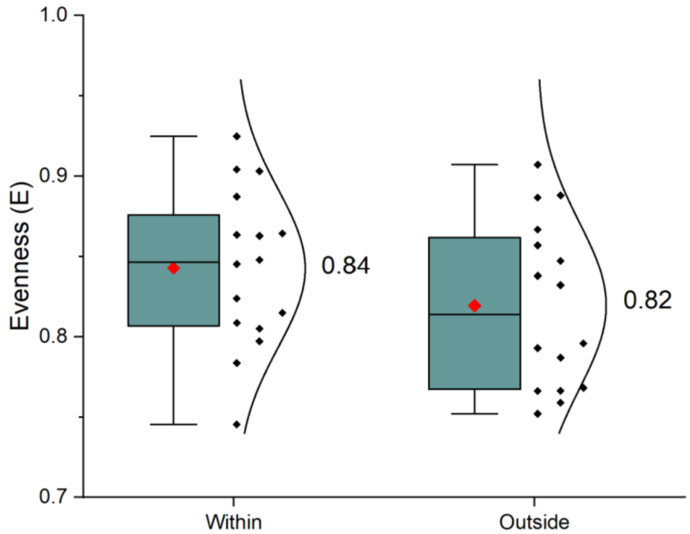
Within vs. Outside Drawdown Zone Evenness

All Evenness data

Evenness (E)		
t-Test: Two-Sample Assuming Unequal Variances		
	Within	*Outside*
Mean	0.84261	0.81938
Variance	0.00242	0.00271
Observations	16	16
Hypothesized Mean Difference	0	
df	30	
t Stat	1.2976	
P(T<=t) one-tail	0.10216	
t Critical one-tail	1.69726	
P(T<=t) two-tail	0.20432	
t Critical two-tail	2.04227	

Conclusion:

Accept the H_0: There is sufficient evidence to conclude that species evenness in the drawdown zone is equal to the species evenness outside the drawdown zone



Excluding treatment target species data

t-Test: Two-Sample Assuming Unequal Variances		
	Within	*Outside*
Mean	0.84795	0.76076
Variance	0.00351	0.0148
Observations	16	16
Hypothesized Mean Difference	0	
df	22	
t Stat	2.5777	
P(T<=t) one-tail	0.00859	
t Critical one-tail	1.71714	
P(T<=t) two-tail	0.01717	
t Critical two-tail	2.07387	

Reject the H_0: There is insufficient evidence to conclude that evenness in the drawdown zone is equal to evenness outside the drawdown zone

Accept the H_a: There is sufficient evidence to conclude that evenness in the drawdown zone is greater than evenness outside the drawdown zone

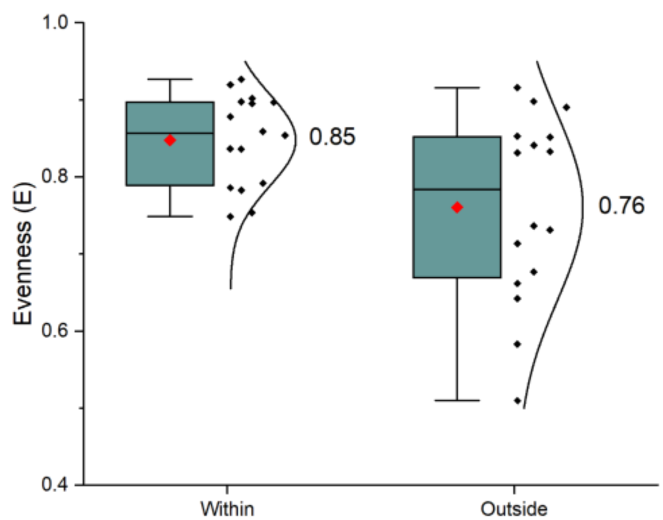


Figure 12. Evenness within and outside the Drawdown Zone

While all the statistical information is useful to see how density, biomass and community diversity and evenness changes, it does not tell us what has changed. Which species have come and gone or have been overly dominate in the lake? An assessment of individual species abundance over time and at each point is required. Table 6 provides a list of all species observed and their abundance by year. The table includes a color gradation to illustrate abundance where darker colors represent higher abundance. The right-hand columns provide a qualitative summary of the change pre- vs. post-treatment. Because there was a substantial decline in species richness and diversity between 2002-2005 and 2006, a qualitative comparison between these two periods is also provided. If species declined between this timeframe, it cannot be concluded that the decline is attributed to the herbicide/algaecide treatments. It was noted by Geosyntec that a significant algal bloom occurred in the summer of 2006 that likely impacted plant abundance and potentially richness. The macrophyte species that had a noticeable decline pre- vs. post- treatment that were not rare and did not vary greatly in abundance in 2006 were: Eurasian milfoil, Robbins' pondweed and coontail.

Table 7 provides average richness values by observation point and average pre- vs. post-treatment. Whether the points are located within or outside the drawdown zone is also indicated. For points where average richness declined by more than two, the species that were potentially impacted are listed. These are species that have not been observed at that point since 2006 (i.e., absent post-treatment). Most locations with changes greater than two were within the drawdown zone (11 locations within vs. 5 locations outside). Based on these data it is difficult to conclude that the cause of the decline, as both drawdown and herbicide/algaecide treatment are indicated.

The two natives that appear the most effected pre-post treatment are Robbins' pondweed and coontail. However, 10 of the 13 sites with the reduction were within the drawdown zone. Further, Robbins' pondweed is reported in the literature to have low susceptibility to the herbicides used but high susceptibility to drawdown. Coontail is susceptible to both. It is highly likely that both management measures play a role in the decline of species, but other variables such as water clarity, influenced by algae and non-algal turbidity (resuspension of sediments and watershed suspended solids loading) could also explain a decline. These factors were not assessed in this evaluation.

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Table 6. Species Abundance by Date

Pre Herbicide | Post Herbicide | Geosyntec | ACT/SOLitude

	Common Name	Genus species	Aug-02	Jul-03	Jul-04	Jul-05	Aug-06	Aug-08	Sep-09	Aug-10	Sep-11	Sep-12	Aug-13	Oct-15	May-16	Oct-16	Jul-17	Oct-17	Jul-18	Sep-18	Jun-19	Sep-19	Pre vs Post	<2005 vs 2006
Target Non-native Invasives	Eurasian milfoil	Myriophyllum spicatum	48	50	51	61	52	12	2	3	4	6											Decrease	
	Variable milfoil	Myriophyllum heterophyllum	38	36	10	15	5	1	1	1	1	1	1	1									Decrease	Decrease
	European Naiad	Najas minor		2	15	20	10	29	29	21	46	54	36	13		40	6		10	39		60	Increase	
	Fanwort	Cabomba caroliniana	32	39	34	40	7	4	10	12	18	13	25	19	7	18	17	7	23	19	27	50	Comparable	Decrease but rebounded
	Curlyleaf pondweed	Potamogeton crispus	1			4		3					1		11	2			3		7		Comparable	
Target Native	Wild celery	Valisneria americana	13	28	43	44	34	34	33	44	48	42	38	38	20	52	21	32	22	30	30	50	Comparable	
Emergent Wetland	Arrow arum	Peltandra virginica	1																				Decrease-Rare	
	Arrowhead	Sagittaria latifolia	1									3											Comparable-Rare	
	Bur-reed	Sparganium sp.				2	1	2															Decrease-Rare	
	Pickerel weed	Pontederia cordata	1																				Decrease-Rare	
	Spike rush	Eleocharis sp.							1					2		2							Increase-Rare	
	Wool grass	Scirpus cyperinus		1																			Decrease-Rare	
Macro Algae	Stonewort	Nitella sp.	3	4	14	10		6	22		1	20							13		4	3	Comparable	Decrease
	Musk grass	Chara sp.	12	17	14	16	1	15	9	39			20	12	3	1	7	11	14		2		Comparable	Decrease
	Stonewort/Musk grass	Nitella/Chara sp																		29			Grouped two plants	
	Filamentous green algae							1	1						23	5	3	6	6		7	16	Increase	
Similar Bladderworts	Bladderwort	Utricularia sp.	18	32	26	34	1	2	3	1	8	1	5	10	1	6	10	22	18	16	34	50	Comparable	Decrease but rebounded
	Eastern purple bladderwort	Utricularia purpurea						10	9	1	13	3	3										Increase	
	Little floating bladderwort	Utricularia radiata					1		3			1											Comparable-Rare	
Free floati	Watermeal	Wolffia sp.	1				1			2													Comparable-Rare	
	Giant duckweed	Spirodela polyrhiza					2																Decrease-Rare	
	Duckweed	Lemna minor						1			3												Increase-Rare	
Similar floating leaves	Watershield	Bresenia schreberi											1							2			Increase-Rare	
	White waterlily	Nymphaea odorata	4	6	5	4	3	3	5	3	2	2	2	2	1	3	1		1		2	4	Comparable-Rare	
	Yellow waterlily	Nuphar variegatum	11	6	5	7	2	6	4	6	2	6	6	2			1		1		6	6	Comparable	
Similar naiad	Bushy pondweed	Najas flexilis	14	14	25	26	1	23	11	16	14	24	51	48	46	50	58	40	10	10	12	30	Comparable-Increas	Decrease but rebounded
	Northern (Thread-like) naiad	Najas gracillima																	3	20	10		Increase	
Similar pondweeds	Clapsing pondweed	Potamogeton perfoliatus				2				1	1	3	1	4		8	2	3	2	7	8	12	Increase	
	Richardson's pondweed	Potamogeton richardsonii					1																Decrease-Rare	
Other Pondweeds	Grassy pondweed	Potamogeton gramineus	1	23	27	27	13	5	11	5	11	10	3										Decrease	Decrease
	Flatstem pondweed	Potamogeton zosterformis																	2	1		2	Increase-Rare	
	Big leaf (Large leaf) pondweed	Potamogeton amplifolius	2		1	1	2																Decrease-Rare	
	Floating (broad-leaf) pondweed	Potamogeton natans	5																				Decrease-Rare	
	Leafy pondweed	Potamogeton foliosus	3																		26	1	Increase	
	Thin-leaf (Small) pondweed	Potamogeton pusillus	7	7	5	11	1	8	4	15	5	20	7	9	1	2	4	1	11			17	Comparable	Decrease but rebounded
	Ribbonleaf pondweed	Potamogeton epihydrus	1		1	2		2		6	1	3	2	1	3	1		1	3	2	2	1	Comparable	
	Robbins' pondweed	Potamogeton robbinsii	8	22	25	32	34	3	1	2	1	1	1	1	1	2		1	1	1	1		Decrease	
	Sago pondweed	Potamogeton pectinatus	6	7	10	11									3	2	1						Decrease	Decrease
	Coontail	Ceratophyllum demersum	12	30	26	30	47	7	5	2	6	3	4	1		1	3	1	2	3	4	5	Decrease	
	Waterweed	Elodea sp.	33	36	4	13															1	1	Decrease	Decrease
	Hedge hyssop	Gratiola sp.					1																Decrease-Rare	
	Quilwort	Isoetes sp.							2													1	Increase-Rare	
	Small waterwort	Elantine minima	1		1	4		11	6	5	8	4	3										Comparable	
	Water marigold	Megalodonta beckii					1																Decrease-Rare	
	Water purslane	Ludwigia palustris						1		1													Increase-Rare	
	Water starwort	Callitriche sp.																	1				Increase-Rare	
	Bog moss	Musci sp.	1			4		3	10	4				1	2			6		3			Comparable	

Table 7. Richness by Observation Point

			Richness excluding target spp			
			Pre-Treatment	Post-Treatment		
Drawdown Zone	Observation Point	Average Richness	Avg S	Avg S	Difference	Species Not Observered at Point Since 2006 (post-treatment)
OUT	1	1.3	1.4	1.2	0.2	
IN	2	1.4	1.4	1.4	0.0	
OUT	3	1.1	1.2	1.0	0.2	
OUT	4	1.5	2.0	1.3	0.7	
OUT	5	2.1	2.8	1.7	1.1	
OUT	6	1.6	2.4	1.2	1.2	
IN	7	2.0	2.0	2.0	0.0	
OUT	8	0.8	0.8	0.8	0.0	
OUT	9	0.9	1.4	0.7	0.7	
OUT	10	1.6	1.8	1.5	0.3	
IN	11	2.2	2.6	2.0	0.6	
IN	12	2.3	2.6	2.2	0.4	
IN	13	2.4	3.2	2.1	1.1	
IN	14	2.2	2.6	2.0	0.6	
IN	15	2.3	3.2	1.9	1.3	
IN	16	1.9	2.6	1.5	1.1	
OUT	17	1.8	2.6	1.4	1.2	
IN	18	4.1	5.2	3.5	1.7	
OUT	19	1.3	2.0	0.9	1.1	
OUT	20	1.4	1.8	1.2	0.6	
OUT	21	2.4	4.2	1.6	2.6	Coontail, Robbins' pondweed, Grassy pondweed & Waterweed
IN	22	2.2	3.0	1.8	1.2	
OUT	23	1.4	2.2	1.1	1.1	
OUT	24	1.6	2.0	1.4	0.6	
OUT	24a	1.2	1.3	1.2	0.1	
OUT	25	1.1	1.6	0.9	0.7	
OUT	26	1.1	1.2	1.1	0.1	
OUT	27	1.0	1.2	0.9	0.3	
IN	28	2.4	3.2	2.1	1.1	
OUT	29	1.0	1.2	0.9	0.3	
IN	30	2.8	3.4	2.5	0.9	
IN	31	2.9	3.6	2.5	1.1	
IN	32	2.3	3.6	1.6	2.0	Coontail, Sago pondweed & Waterweed
IN	33	2.1	3.8	1.3	2.5	Robbins' pondweed, Sago pondweed & Waterweed
IN	34	3.1	5.0	2.3	2.7	Sago pondweed, Waterweed & Bur-reed

Table 5 Continued. Richness by Observation Point

			Richness excluding target spp			
Drawdown Zone	Observation Point	Average Richness	Pre-Treatment Avg S	Post-Treatment Avg S	Difference	Species Not Observed at Point Since 2006 (post-treatment)
OUT	35	1.3	1.8	1.0	0.8	
OUT	36	1.8	2.6	1.4	1.2	
IN	37	3.1	4.4	2.5	1.9	
IN	38	1.0	2.2	0.5	1.7	
IN	39	2.1	3.0	1.6	1.4	
IN	40	3.1	4.8	2.4	2.4	Coontail, Robbins' pondweed, Bur-reed,
IN	41	2.5	4.4	1.6	2.8	Robbins' pondweed, Big leaf (Large leaf)
IN	42	2.6	3.8	2.0	1.8	
IN	43	4.4	5.4	4.0	1.4	
IN	44	2.8	4.8	1.9	2.9	Robbins' pondweed, Stonewort,
IN	45	2.4	3.2	2.0	1.2	
IN	46	1.4	2.6	0.9	1.7	
IN	47	2.6	3.8	2.1	1.7	
IN	48	2.1	3.8	1.4	2.4	Robbins' pondweed, Coontail, Big leaf
OUT	49	2.1	3.2	1.5	1.7	
IN	50	2.1	2.8	1.8	1.0	
IN	51	2.3	3.6	1.7	1.9	
OUT	52	1.9	3.2	1.4	1.8	
OUT	53	1.9	3.4	1.2	2.2	Grassy pondweed, Waterweed
IN	54	3.1	3.2	3.1	0.1	
OUT	55	1.5	2.6	1.0	1.6	
OUT	56	1.3	2.2	0.9	1.3	
OUT	57	2.1	2.8	1.8	1.0	
OUT	58	1.5	3.0	0.8	2.2	Robbins' pondweed, Coontail, Grassy
OUT	59	0.9	1.0	0.8	0.2	
OUT	60	1.2	1.8	0.9	0.9	
OUT	61	0.9	1.0	0.8	0.2	
OUT	62	1.4	2.0	1.1	0.9	
OUT	62a	1.3	2.0	1.1	0.9	
OUT	63	1.4	2.2	1.0	1.2	
OUT	64	1.5	2.2	1.2	1.0	

Within Drawdown Zone (light blue)

Outside Drawdown Zone (dark blue)

Color gradient - Darker red indicates larger change in richness

At points where richness change is >2.0, species not present after 2006 are listed

Conclusion

It is extremely valuable to have consistent annual macrophyte data in order to make assessments and draw conclusions from those data. There were enough data to answer, at least partially, the questions postulated to assess if there is a loss of ecologically important species associated with the rooted plant management techniques employed by LSIC.

Diversity and biomass have varied over the years. Density declined sharply between 2004 and 2009, since the decline started prior to herbicide/algaecide treatments, no cause and effect relationship is concluded. Biomass was higher in pre-treatment years but has been increasing since the low point in 2009. Overall density and biomass in the last four years is higher than pre-treatment. The influence of biologists performing the sampling could not be determined because only one firm collected quantitative data early on. Drawdowns appear to influence macrophyte cover and biomass. Density and biomass are higher within in the drawdown zone, but the extent of the influence is inconclusive since there are no pre-drawdown data and water depth itself is a known limiting factor for density and biomass due to light limitations. These data suggest there is still ample plant cover and biomass to provide the necessary functions and values for other aquatic life. It is highly likely that both cover and biomass would be excessive if management activities were not undertaken given the species present and the shallow morphometry of the lake.

Total lake richness was highest in the first survey year and declined sharply in the second year (dropping by nine species; a 33% reduction). There was some recovery, but richness dropped again in 2006. Post-treatment richness was variable but overall lower than pre-treatment, by about three species. This is within the range of natural variability. Some of the loss, especially the emergent wetland species, may be a function of the biologist deciding not to record emergents and focus on submerged and floating species. Average richness at observation points exhibited that nearly half of the richness at most points was attributable to non-desirable species (non-natives and water celery). The average richness at observation points declined more than 50% between 2005 and 2006, so the loss in average richness at points cannot be solely attributable to treatment. In addition, point richness was not significantly different pre- vs. post-treatment. Richness, like density and biomass, is greater within the drawdown zone and the difference is not influenced by non-desirable species.

Diversity was lowest in post-treatment, but evenness was lowest pre-treatment. The low evenness was the result of four species that were found at over half the observation sites: Eurasian milfoil, coontail, Robbins' pondweed and wild celery. Both diversity and evenness were similar pre- and post-treatment. Again, following the same pattern as the other metrics, diversity was higher in the drawdown zone and this difference is not attributable to non-desirable species. Evenness, however, was higher in the drawdown zone but evenness within and outside is sensitive to non-desirable species.

The macrophyte species that had a noticeable decline pre- vs. post- treatment that were not rare and did not vary greatly in abundance in 2006 were: Eurasian milfoil, Robbins' pondweed and coontail. Most locations with noticeable changes were within the drawdown zone. Therefore, it is difficult to conclude the cause of the decline, as both drawdown and herbicide/algaecide treatment are indicated. Robbins' pondweed is reported in the literature to have low susceptibility to the herbicides used at Lake Shirley, but this plant is high susceptibility to drawdown. This plant is common in New England and grows in colonies formed by rhizomes (rootlike stem in sediment sending up shoots). It rarely produces fruit and does not produce vegetative turions (buds); the primary mode of reproduction is rhizomes which results in slow recovery once impacted.

Coontail is susceptible to both. Coontail has no roots and is free-floating. It does produce turions to overwinter and can propagate vegetatively (forming new plants from fragments). It can rebound much faster than Robbins' pondweed and has been known to be aggressive and a non-desirable species in waterbodies in New England. It is quite common and is widely distributed within the aquarium industry.

It is highly likely that both management measures play a role in the decline of two native species, but other variables such as water clarity, influenced by algae and non-algal turbidity (resuspension of sediments and watershed suspended solids loading) could also explain a decline. These factors were not assessed in this evaluation.

Based on the fact that density and biomass remain at levels that are appropriate to support multiple habitat types throughout the lake and the plant assemblage is moderately diverse, I see no substantial evidence to suggest that the changes in plant community would result in a major decline in macroinvertebrate, fish or waterfowl habitat. However, this cannot be definitively concluded since there are no other biological data for comparison. Documentation of absence of an impact to the system is complex and difficult as trade-offs occur as variables in the system change, including variables of natural origin that are unquantifiable. Aquatic ecosystems are naturally diverse, and a habitat loss to one species is often a habitat gain to another; some fish prefer open water, some prefer dense vegetation and other need a mix of both. Variation in habitat preference is also seen with macroinvertebrates, waterfowl and mammals. The system should be managed to balance multiple habitat types and consider all uses, including human.

Although the aquatic habitat has not likely been significantly impacted, it is prudent to examine opportunities to prevent further loss and attempt the recovery of the two native species found with the most significant impacts over time. A recommended approach is described in the next section.

Recommendation

ARC will consult with the SOLitude Lake Management (SOLitude), the licensed herbicide applicator, following their early season plant survey to evaluate alternatives for preservation/recovery for Robbins' pondweed and coontail. We will review the location and density of the targeted plants for treatment and assess if the desired natives are present. SOLitude will provide a treatment plan that excludes areas where Robbins' pondweed was once abundant that should be avoided to encourage growth and recovery. Similarly, avoiding areas to protect coontail against direct herbicide treatment will likely increase its frequency and abundance. But since this plant can reproduce vegetatively and is generally free floating, it will likely recover quicker than Robbins' pondweed requiring less restrictive treatment protocols.

Looking more closely at the pre-treatment survey data and avoiding key areas should help Robbins' pondweed and coontail recover in abundance provided other conditions remain constant (e.g. water clarity) and there is not direct competition with more aggressive species at the same observation location. This process will require continued monitoring as already outlined in the Order of Conditions and will require adaptive management, adjusting the treatment program in response to site data.