AQUATIC ECOSYSTEM RESEARCH
A Freshwater Conservation Company

Little Island Pond

Aquatic Plant Community Assessment

Prepared for the
Little Island Pond Association
November 3, 2020

EXECUTIVE SUMMARY

Aquatic Ecosystem Research was engaged by The Little Island Pond Association to undertake a midsummer water quality assessment and a quantitative plant community study. Water quality will not be reported on here because The Association did not elect to have a report generated; however, the results of that assessment were used to support the plant community analysis, which is reported on here.

- Study Design:
    - A geogrid was established in GIS that contained 323 sample points that were visited during the plant survey that took place on July 30th, 2020.
    - Each point was visited; and, the plant community was assessed visually and by sampling with a grapple.
- Basic Plant Community Statistics:
    - A total of 21 plant species were detected.
        - 18 macrophytes
        - 2 lily-species
        - 1 macroalgae
    - The top 4 most abundant aquatic plant species were:
        - *Utricularia purpurea* (Purple Bladderwort)
        - *Najas flexilis* (Nodding Waternymph)
        - *Chara spp.* (Muskgrass)
        - *Potamogeton foliosus* (Leafy Pondweed)
    - Two-hundred and two of the 323 points contained plant species (65%).
        - No plants were found at depths greater than 8m.
        - No rare or endangered species were detected.
        - No non-native species were detected.
    - The average rank abundance, corrected abundance, richness, and diversity at points with plants (i.e. 202 points) were 1.97, 0.06, 3.61, and 1.27, respectively.
        - These data suggest that Little Island Pond's plant community was moderately productive, rich, and of moderate diversity.
        - AER's opinion of the plant community is that it is healthy and not in need of any major management activity.
            - Residential access to the lake was not limited by the plant community.
- Risk of Non-native Species Invasion:
    - The average conductivity, pH, and alkalinity for Little Island Pond were 197.6 us/cm, 7.1 SU, and 19 mg/L, respectively. Those values suggest that Little Island Pond is at risk for the MNP-group of the most common non-native species in New England.

    - M = *Myriophyllum spicatum* (Eurasian Milfoil)
    - N = *Najas minor* (Brittle Naiad)
    - P = *Potamogeton crispus* (Curly-leaf Pondweed)
- Aquatic Plant Community Management
  - AER's opinion of the plant community is that there is no need for large-scale management.
  - Residents experiencing conditions that are not preferential can deploy benthic barriers or have a local company execute Diver Assisted Suction Harvesting (DASH) in their swimming or docking areas.
  - The dense patches of *Potamogeton perfoliatus* (Clasping Pondweed), which ranked 7th in total abundance but is one of the most obvious species in the lake, can be managed around the island and other areas outlined in this report via mechanical harvesting.
    - It is AER's opinion that this is not imperative.
    - This species should be monitored and mapped at regular intervals to determine the trajectory of its population.
  - The plant community should be inspected yearly to map the population of *P. perfoliatus* and to look for non-native species invasions.
    - Early detection of non-native species is the most important part of plant management at Little Island Pond.
  - Quantitative plant studies should be undertaken at 3-year intervals to develop an understanding of the plant community's trajectory.

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INTRODUCTION

Purpose

Aquatic Ecosystem Research was engaged by the Little Island Pond Association to evaluate mid-summer water quality and to conduct a quantitative survey of the plant community. Those initiatives were undertaken to obtain a snapshot of the water quality, evaluate the structure of the pelagic algae community, to examine the structure of the plant community, to detect any non-native plant species, and to determine future lake management needs. Prior to AER's data collection initiative, there were no major concerns about water quality; but, portions of the lake were experiencing high plant community density conditions that affected recreational access. Therefore, the primary goal of this study was to develop a plant management plan that would enhance recreational access and support the overall health of the lake ecosystem.

Lake Characteristics and Residential Community

Little Island Pond is a 160acre lake located in Pelham, NH (42°43'35.82"N, 71°17'20.06"). The lake has a maximum depth of 13.2m (43.2ft), a mean depth of 5.1m (16.9ft), and it contains 9.11×10^8 gallons of water. The lake, which is part of the Merrimack River Basin, is situated at an elevation of 145ft above sea level with a watershed that is 764.9ac. The shoreline is about 2.6mi long and the lake has an estimated 40% water volume flushing rate per year. Furthermore, the lake has clear waters that are likely associated with the igneous bedrock geology of the local watershed and limited public access. The State of New Hampshire has conducted three assessments of the lake since 1978; each study (i.e. 1978, 1992, and 2001) contained at least one mid-summer sampling event and classified the lake as oligotrophic with sparse vegetation (www.nhdes.maps.arcgis.com).

Underlying Geological Conditions

Local geological conditions are important factors contributing to the baseline water quality conditions of all lakes. For example, lakes located in areas with slow weathering basaltic bedrock tend to be lower in total dissolved salts, have lower pH/buffering capacity, and specific assemblages of algae/plants that are metabolically efficient when carbon dioxide is the major form of carbon available for photosynthesis. Conversely, hard-water systems are normally found in areas with quick-weathering bedrock types that are sedimentary in nature; these lakes tend to have higher levels of total dissolved salts, higher pH/buffering capacity, and algae/plant assemblages that are metabolically efficient when bicarbonate is the major form of carbon available for photosynthesis.

Underlying the watershed of Little Island Pond are two major geological formations: 1) two-mica granite of northern and southeastern New Hampshire and 2) Merrimack Group/Berwick Formation. The former, which lies directly below the lake, is an igneous plutonic inclusion that was formed during the late Devonian period; the mineral type is granite. The latter formation, which skirts the southeastern side of the lake and encircles the entirety of the watershed, is a regional metamorphic formation of hornfels and schists. The minerals in both of these formations weather slowly and do not contribute ions to the local waters at a high rate. This feature of the local geology is likely the driving factor contributing to the relatively low concentrations of phosphorus and nitrogen; however, these rocks can contribute ions such sodium and silicate, which can result in relatively high specific conductivities of local surficial waters.

Specific Goals of 2020 Little Island Pond Initiative

The main goals of obtaining data associated with the water quality and plant community of Little Island Pond were:

- Establish a mid-season water quality baseline
- Evaluate the major midseason phytoplankton assemblage
- Inventory all species of the plant community
- Determine the presence of non-native aquatic macrophytes
- Determine the presence of rare or endangered macrophyte species
- Evaluate the impact of all macrophyte species on recreational access
- Statistically model the likelihood of encountering any macrophyte species as depth increases
- Examine the relationships among macrophyte richness, macrophyte diversity, depth, and other macrophyte species
- Identify species that dominate the community or negatively impact recreational access
- Create spatial distribution graphics associated with dominant species and/or problematic species
- Develop a management plan that addresses impeded recreational access due to plants
- Identify data gaps and provide guidance on ecosystem monitoring.

METHODOLOGY

Experimental Design (Plant Survey)

Due to the fact that Little Island Pond is a moderately large body of water, it was necessary to develop a comprehensive and feasible approach to surveying the aquatic plant community. Aquatic Ecosystem Research approached the issue of sampling effort and fiscal responsibility by developing a grid system for the lake. Using Geographic Information Systems (GIS) AER's geospatial analyst established a geogrid for the lake where the corners of each grid block would act as a sample point. For Little Island Pond, we established a 45mx45m grid that resulted in a total of 323 unique sampling points (Fig. 1).

Plant Sampling and Data Collection (Plant Survey)

Each grid point was located using a Garmin GPS unit with <3m accuracy. At each point the plant community was assessed visually and sampled using a grapple. The sample technique was composed of two individual grapple tosses – one to each side of the boat. Plants were identified visually using Crow and Hellquist (2000) and a *Potamogeton spp.* supplemental key, which was provided by C. Barre Hellquist. This supplement was used because there have been some significant changes to the taxonomic characteristics utilized in the identification of *Potamogeton* species. A representative sample of each species was retained and photographed using a high-resolution (i.e. 20Mpixel) digital camera. Those photos were stored in AER's digital herbarium. If rare species were found, a representative sample was frozen at -10C and retained at AER's office.

Data were logged in field notebooks by rank abundance where 1 was rare, 2 for present but not abundant, 3 for abundant but not dominant, 4 for dominant, or 5 for dense monoculture. Data were always logged with an identifier that coincided with the grid sample point. Those data were transferred to lake-specific Excel spreadsheets for further processing.

Data Processing and Analytical Techniques

Field data, as it related to individual sample points, was logged as an attribute table in the survey grids. Each sample point coincided with a series of variables, which included latitude, longitude, depth, and all of the species detected during the survey. The species data were logged in that attribute table with the rank order abundance and used in probability-of-occurrence calculations. If the species was absent, the species variable was given a value of 0. Species data were then used to calculate richness (i.e. total number of species at the point), diversity (the number of species corrected for the rank abundance of each), total abundance (sum of all rank abundances for all species), and corrected abundance (average of all rank abundances corrected for local richness and lake richness).

The data matrix was loaded into Geographic Information System (GIS) software to undertake a variety of analytical protocols. Firstly, we used the richness and diversity variables to develop spatial assessments of those plant community characteristics. Those data, which had the potential to range from zero to infinity, were interpolated to determine how richness and diversity are distributed throughout the lake and to identify areas of high species richness. Secondly, the individual species variables were used to develop a spatial assessment of all dominant species distributions. Those data were interpolated to determine the estimated coverage of each dominant species at any point throughout the lake. Coverage maps were created by assigning rank abundance vales to each point and interpolating data from adjacent points in an iterative fashion throughout the sample grid.

After conducting the spatial analyses, those matrices were used to calculate basic statistics (i.e. number of detections and percent of community). Finally, AER's statistician regressed depth vs. richness, diversity, and individual species abundances to examine those relationships. We also evaluated the relationships among the abundant species and the richness/diversity variables. During the development, we evaluated three different type of explanatory models: 1) Linear, 2) polynomial, and 3) logistic. The final model was chosen based on fit; the characteristic used in model selection was the coefficient of determination (r^2).

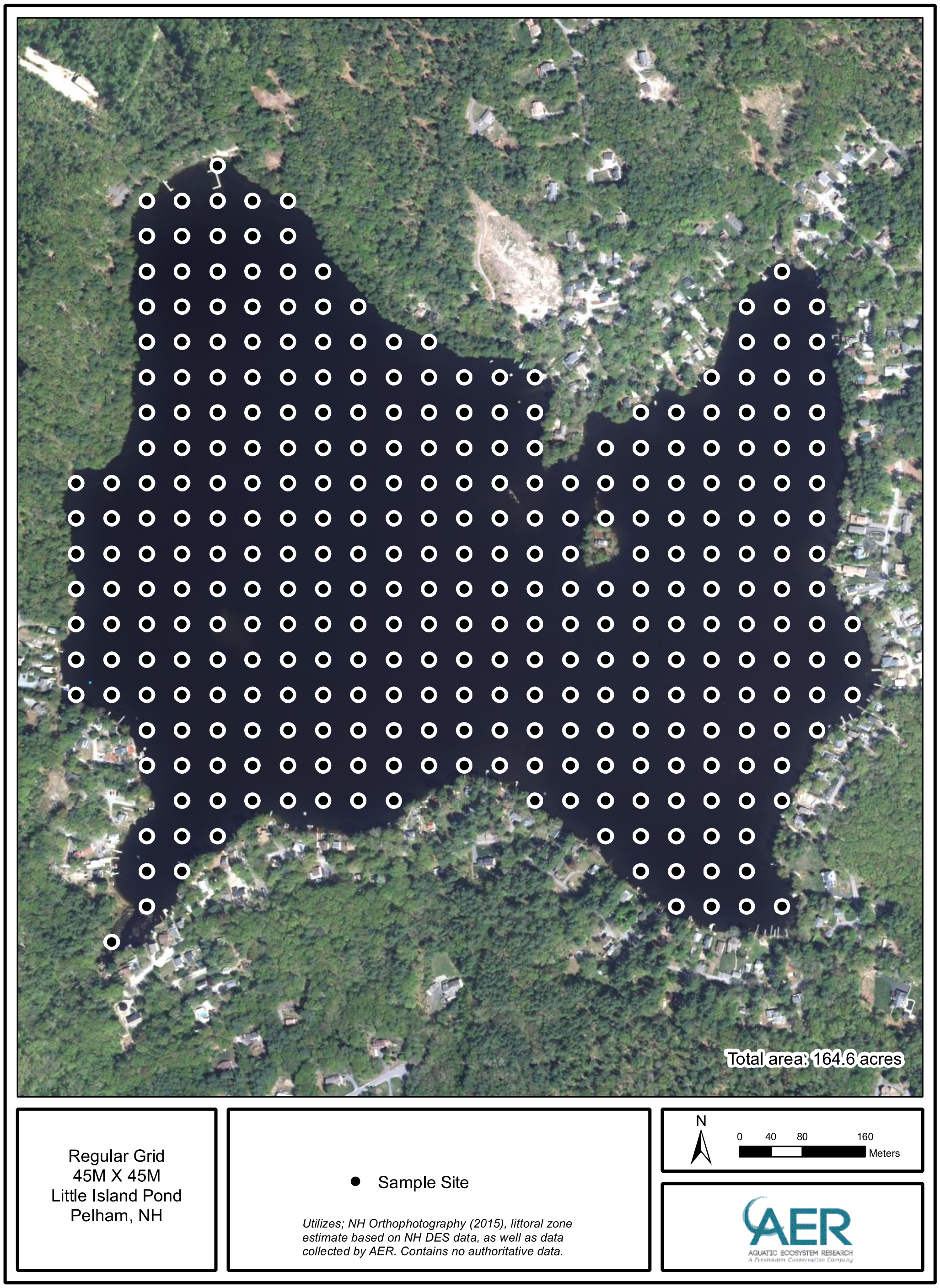

Figure 1. Little Island Pond sampling grid.

RESULTS

Basic Plant Community Findings

Aquatic macrophytes were found at 202 of the 323 grid points, which suggests that 63% of the waterbody houses one or more plant species. In total, eighteen submerged/rooted aquatic macrophytes, 2 lily-pad species, and 1 macroalgae were encountered among the 323 points visited in Little Island Pond on July 30th, 2020. The most common species detected during this survey was *Utricularia purpurea* (Purple Bladderwort) with a total rank abundance of 246. Furthermore, it was found at 121 points, which accounts for 59.9% of all points where plants were found (202 points). Its average rank abundance among all points was 0.76; and, its average rank abundance among points where it was found was 2.03.

The second most common species found was *Najas flexilis* (Nodding Waternymph). It was found at 115 of the 323 points with a total rank abundance of 244. Fifty-six and nine-tenths percent of the points where plant species were found housed *Najas flexilis.* The average lake-wide rank abundance was 0.76 and the average rank abundance among points where it was detected was 2.12.

The third most common species detected in Little Island Pond was the microalgae *Chara spp.* (Muskgrass)*;* it was detected at 98 of the 323 lake-wide points (30.3%) and had a total rank abundance of 207. *Chara spp.* exhibited an average lake-wide rank abundance of 0.64 and an average rank abundance among points where it was present of 2.11.

The fourth most common species was *Potamogeton foliosus* (Leafy Pondweed). That species was detected at 57 of the 323 grid points (17.7%) and was found to have a total rank abundance of 90. Furthermore, its average abundance lake-wide was 0.28 and had an average total rank abundance of 1.58 where it was present.

Normally, we limit our species descriptions to the four most abundant; however, members of association indicated that there were concerns about the distribution of *Potamogeton perfoliatus* (Clasping Pondweed). It was found to be the 7th most abundant species in Little Island Pond with 37 point-encounters (18.4% of all points), a total abundance of 83, and average abundance of 2.24 where it was present. For a complete list of species detections and associated statistics, see Table 1.

Table 1. Plant species inventory at Little Island Pond on July 30, 2020 and associated statistics

Species Name	Common Name	Point Encounters	Percent of Points with Plants	Total Rank Abundance	Average Lake Rank Abundance	Average Abundance Where Present
Ceratophyllum demersum	Coontail	1	0.50	2	0.01	2.00
Chara spp.	Musk Grass	98	48.51	207	0.64	2.11
Eleocharis acicularis	Dwarf Hair Grass	31	15.35	87	0.27	2.81
Eriocaulon aquaticum	Common Pipewort	22	10.89	61	0.19	2.77
Elatine minima	Small Waterwort	7	3.47	18	0.06	2.57
Myriophyllum tenellum	Slender Watermilfoil	1	0.50	1	0.00	1.00
Najas flexilis	Nodding Waternymph	115	56.93	244	0.76	2.12
Nymphaea odorata	White Waterlily	34	16.83	84	0.26	2.47
Nuphar variegata	Yellow Pondlily	4	1.98	7	0.02	1.75
Potamogeton amplifolius	Large Leaf Pondweed	20	9.90	39	0.12	1.95
Pontederia cordata	Pickerelweed	10	4.95	17	0.05	1.70
Potamogeton epihydrus	Ribbonleaf Pondweed	1	0.50	3	0.01	3.00
Potamogeton foliosus	Leafy Pondweed	57	28.22	90	0.28	1.58
Potamogeton perfoliatus	Clasping Pondweed	37	18.32	83	0.26	2.24
Potamogeton robbinsii	Robbin's Pondweed	42	20.79	61	0.19	1.45
Sparganium spp.	Burreed	6	2.97	12	0.04	2.00
Sagittaria graminea	Grassy Arrowhead	9	4.46	21	0.07	2.33
Utricularia gibba	Floating Bladderwort	47	23.27	78	0.24	1.66
Utricularia macrorhyza	Common Bladderwort	30	14.85	55	0.17	1.83
Utricularia purpurea	Purple Bladderwort	121	59.90	246	0.76	2.03
Utricularia radiata	Floating Bladderwort	37	18.32	50	0.15	1.35

Spatial Distributions of Plant Community Characteristics

Mapping of the corrected rank abundance variable (Fig. 2) suggests that the majority of the lake is too deep for productive plant communities; and that where plants are present, the community is on the lower end of the rank abundance spectrum (i.e. Average Abundance per point = 1.9). The corrected abundance variable accounts for average of all species abundances, the number of species at any given point, and the total number of species within the lake. For Little Island Pond, this variable ranges from 0 to 0.10; the lowest values were found to be isolated to the deepest areas of the lake and are represented by a dark brown color in the Figure 2. The dark purple color present within the surface area of the lake map are the areas with the greatest abundance of plant material; the highest values for corrected abundance, which in comparison to other lakes is quite low, exist in the near shoreline areas or in shallow portions of the central reaches of the lake. The majority of the lake houses corrected plant abundances between 0.00 and 0.05, which are represented by colors ranging dark brown to grey (Fig.2). Overall, the plant community exhibited an average value of 0.05 for the variable of corrected abundance among points where plants were detected.

Richness, which is the total number of species detected at any given point, was mapped using GIS and spatial statistics. The richness variable – when overlaid with the geogrid – ranged from 0 to 10; and, the average number of species per point where plants were found was 3.6 (Fig. 3). Effectively, that means that there is an average of 4 unique plant species at any given point; however, any given point's number of species was distinctly related to location. There were no species found in the central portions of the lake where the depth of water was greatest (i.e. darkest green color, Fig. 3). The average of 3.6 species per point is higher than most recreational lakes, which is a positive ecological feature when one considers that the lake is also free of non-native species. The richest areas are distributed in a patchy manner throughout the lake; the largest patches of high richness are located around the small northeastern island extending along the western shoreline of the northernmost cove, along the western shoreline of the southeastern cove, and along the western shoreline of the lake. The majority of the lake houses between 3 and 4 species; but, the near-shoreline areas generally house more species than deeper waters, which is a common feature of aquatic macrophyte communities.

Diversity, which describes the evenness of the plant community, was projected across the sampling grid. That endeavor resulted in a map that shows a distinct transition from low diversity deep water areas to more diverse shallow water areas (Fig. 4). Where plants were present, the average diversity was 1.27 (0.8 lake-wide), which suggests that the majority of the lake is dominated by a few species; but that is not a fair description of the lake's diversity characteristics because much of the basin has a depth where the majority macrophyte species become limited by light.

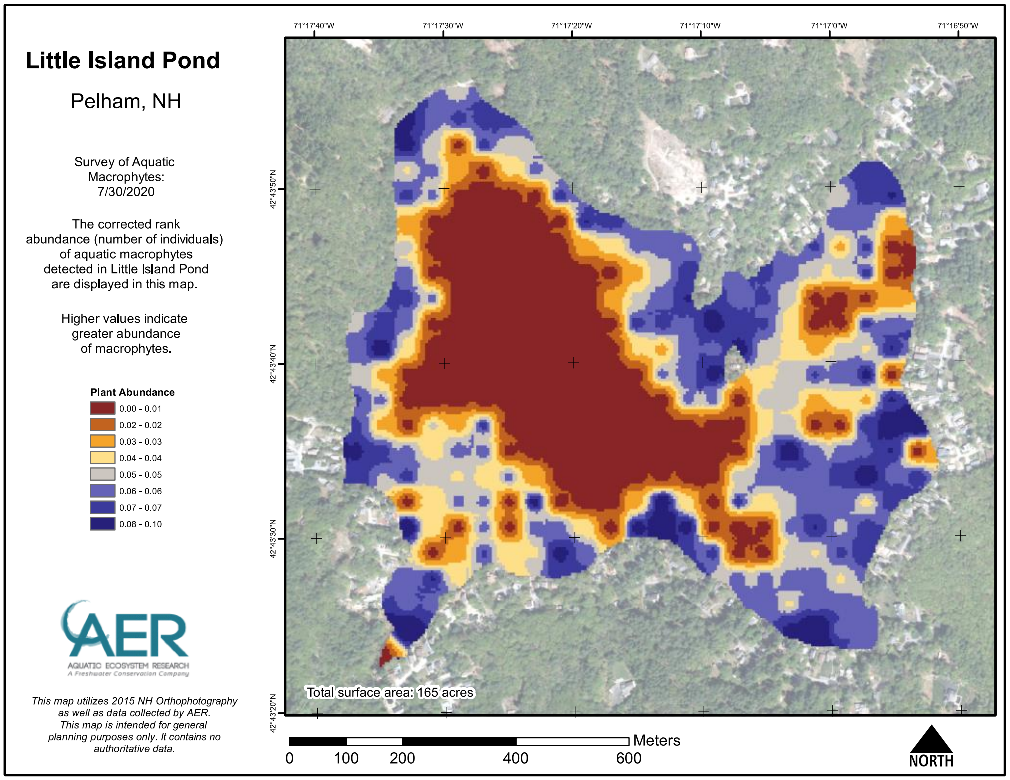

Figure 2. Spatial Distribution Map of Corrected Plant Community Abundance

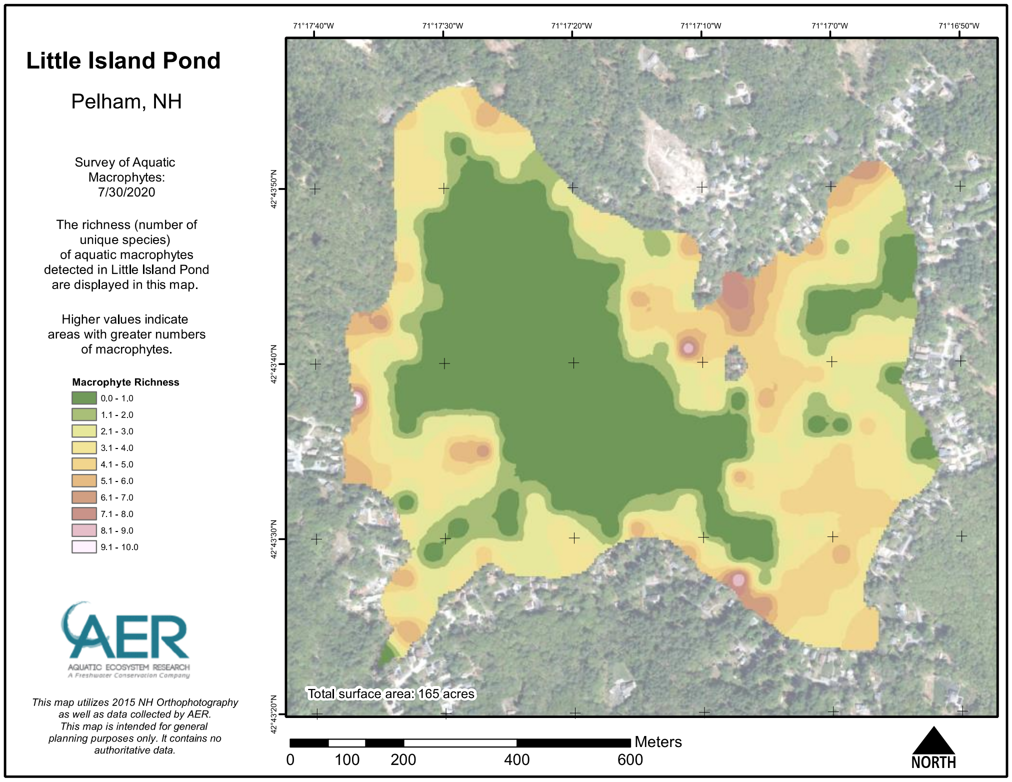

Figure 3. Spatial Distribution Map of Plant Species Richness.

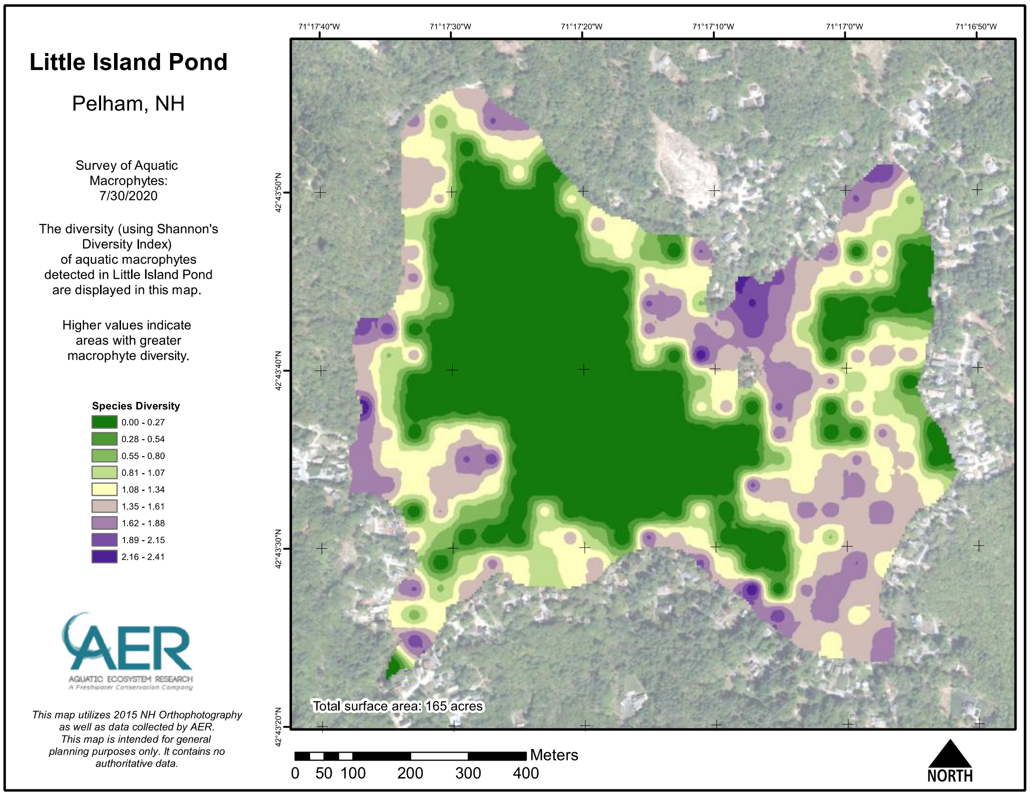

Figure 4. Spatial Distribution Map of Plant Community Diversity.

Shannon's Diversity Index (H'), which is the most commonly used diversity index, has a range of 0 to 5 and typically is found to have values between 1.5 and 3.5; however, that range of values is generally calculated in areas where light conditions are consistent. That is not the case with lakes because water depth and clarity are variable in their effects on light availability. In Little Island Pond, Shannon's H' never reaches that common range of values; that suggests that the plant community as a whole is dominated by a few species. However, there are numerous diversity hotspots distributed throughout the lake. A notable proportion of the near-shore areas are diverse in nature; furthermore, the areas surrounding the island in the northeast quadrant of the lake – where the water is shallow – also exhibit high diversity. That is also true of the small island located southwest quadrant of the lake. The largest patches of high diversity are 1) around the northeastern island extending northeast along the western shoreline of the northeastern bay, 2) the southeastern bay, and 3) the western shoreline.

Utricularia purpurea (Purple bladderwort) was found to be present throughout most of the littoral zone of the lake (Fig. 5); and, its abundance correlated with the most diverse areas of the lake. In areas where depth was greater than 5.0m (16ft) *U. purpurea* was rare; but, in areas that were shallower it was often present in high abundance. Overall, *U. purpurea* was found to be the most common plant both numerically and spatially. Upon the application of spatial statistics to those point data that were collected on July 30th, 2020, it becomes clear that the probability of encountering *U. purpurea* at any given point that is shallower than 5.0m (16ft) is high (Fig. 5).

Najas flexilis (Nodding waternymph) exhibited a spatial pattern similar to that of *U. purpurea* (Fig. 6). Its abundance coincided with areas of high diversity and richness (Fig. 6). It was the second most abundant aquatic macrophyte encountered in Little Island Pond during the July 30th, 2020 survey; *N. flexilis* also rank second in terms of point encounters. It was found to be distributed in the majority of near-shore areas and those areas surrounding the two small islands within the lake.

Chara spp. (Muskgrass) was found to be distributed – principally – in the eastern and southern areas of Little Island Pond. It was also found in areas of high diversity and favored the near shore regions. It was largely absent in the north western cove where it was found in a few small patches of low to moderate abundance (Fig. 7). *Chara spp.* was the third most abundant species in Little Island Pond numerically and spatially.

Potamogeton foliosus (Leafy pondweed) was the fourth most abundant aquatic macrophyte species encountered during the July 30th survey. Its spatial distribution does not strongly coincide with the spatial distributions of diversity or richness. *P. foliosus* was found to be distributed in a patchy manner throughout the body of the lake. It favored near shore areas and was largely absent in deep water areas (i.e. >5m) but was found in all quadrants of lake where water was relatively shallow (Fig. 8).

Potamogeton perfoliatus (Clasping pondweed) was found to be the 7th most common species in Little Island Pond. Generally, a species that ranks below the top 4 species is not discussed in our reports. However, it was indicated that it was a species of concern by members of the Association due to its presence in certain recreationally important areas of the lake. *Potamogeton perfoliatus* is a relatively large species of pondweed, which can create a situation where recreational users of the lake might interpret its presence as a nuisance. The survey that occurred on July 30th, 2020 found that its distribution was patchy in nature and that large patches were asymmetrically distributed throughout the lake (Fig. 9). The largest patches of this species were found adjacent to the northeastern island, near the eastern shoreline, and along the northern shoreline near the camp.

Statistical Features of the Plant Community

Aquatic Ecosystem Research deployed GLM (General Linear Models) to explore how a variety of abiotic and biotic variables are related. Firstly, total rank abundance was regressed against depth and we found that a 2nd order polynomial model best explained those data interactions (r^2=0.38, Fig. 10).

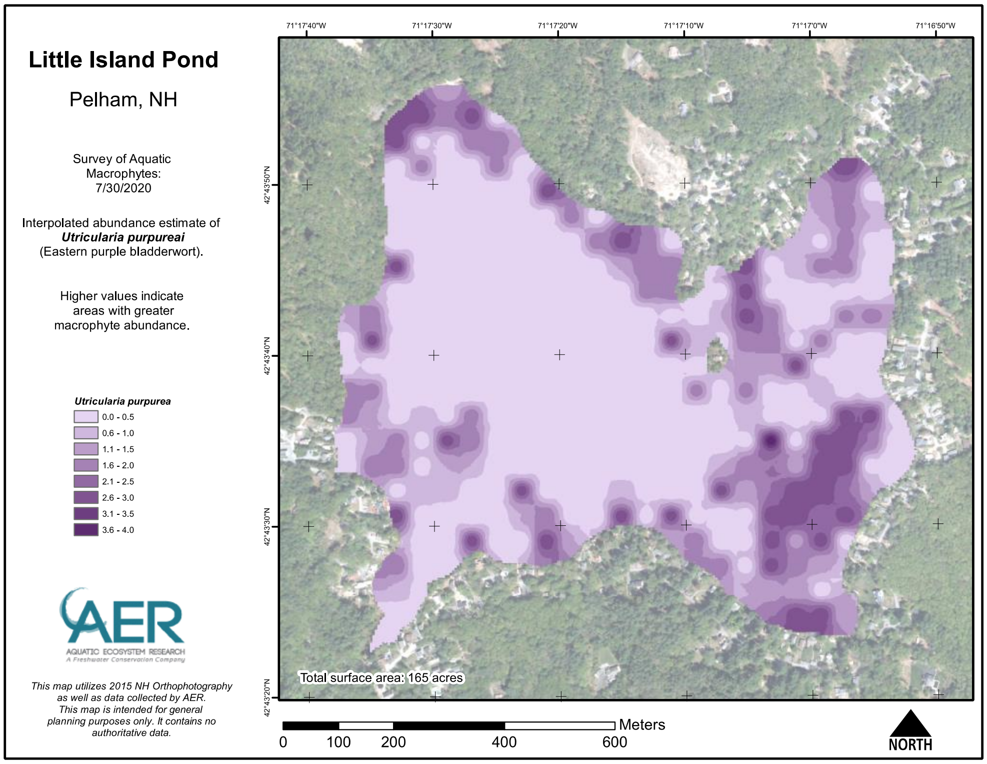

Figure 5. Spatial Distribution Map of *Utricularia purpurea* (Purple Bladderwort).

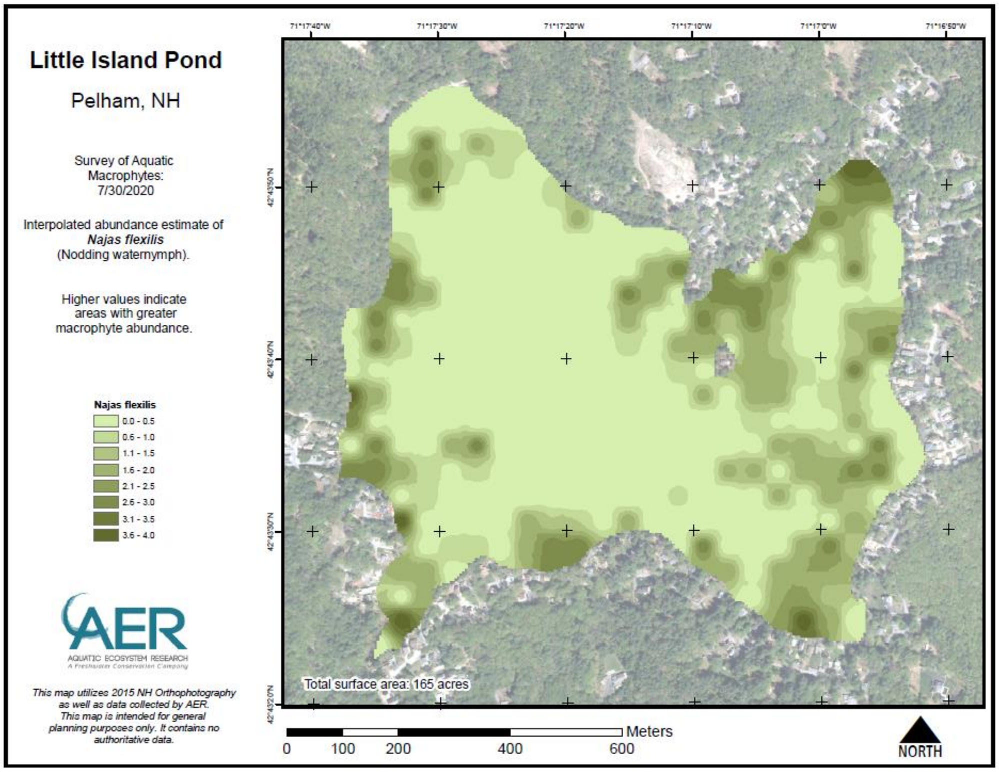

Figure 6. Spatial Distribution Map of *Najas flexilis* (Nodding Waternymph).

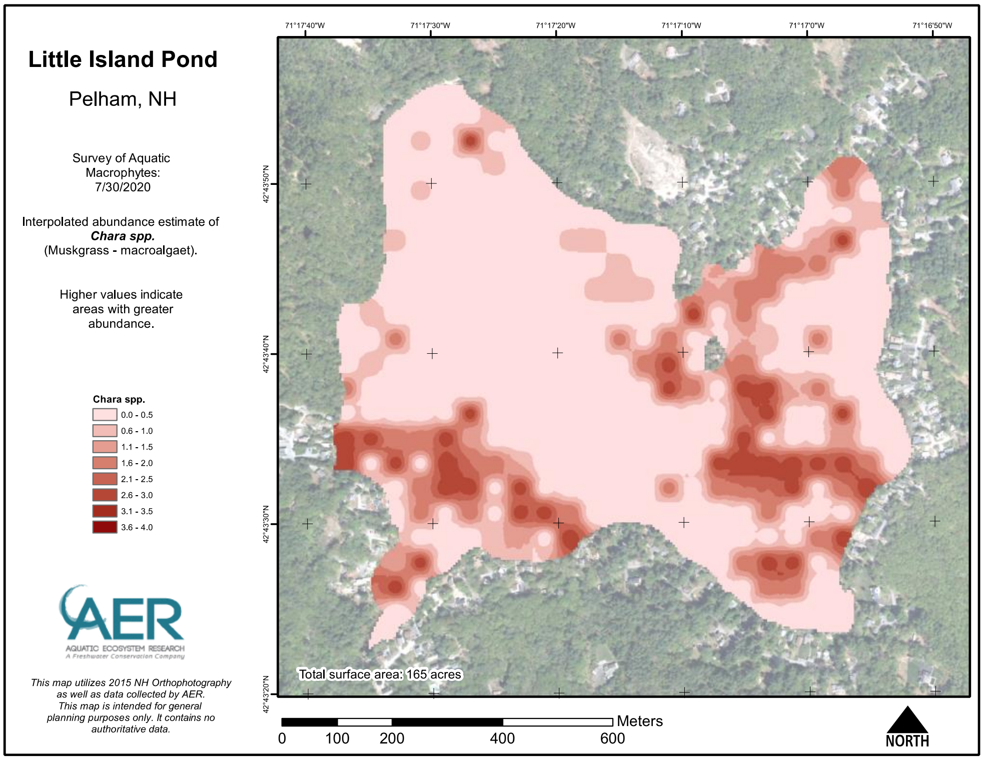

Figure 7. Spatial Distribution Map of *Chara spp.* (Muskgrass).

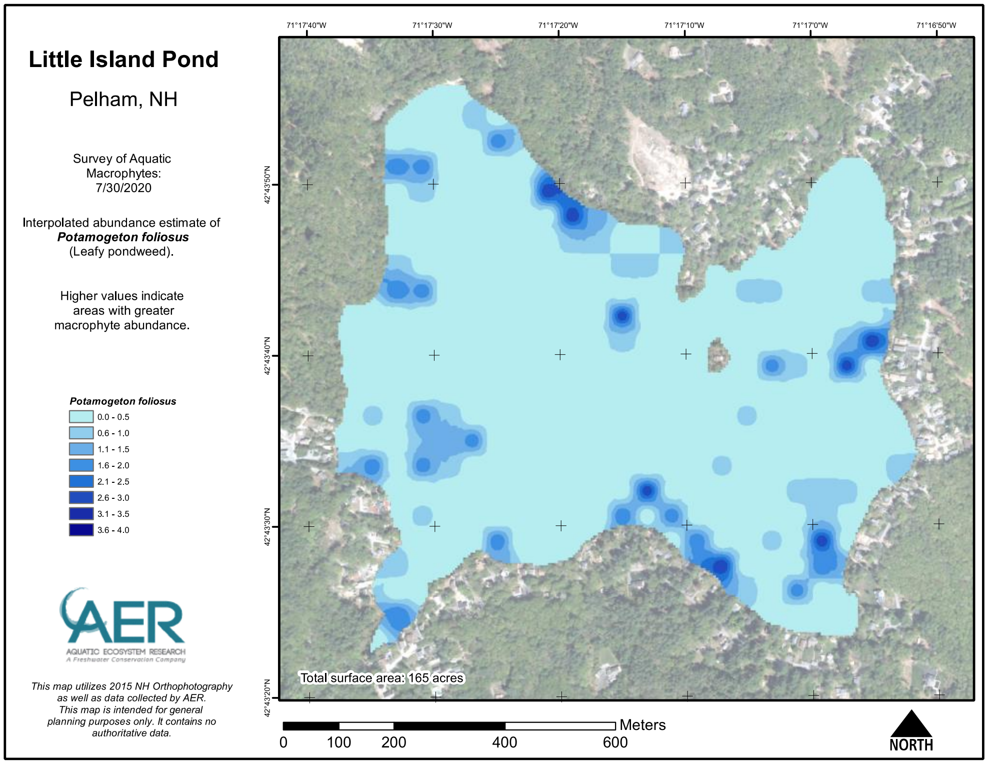

Figure 8. Spatial Distribution Map of *Potamogeton foliosus* (Leafy Pondweed).

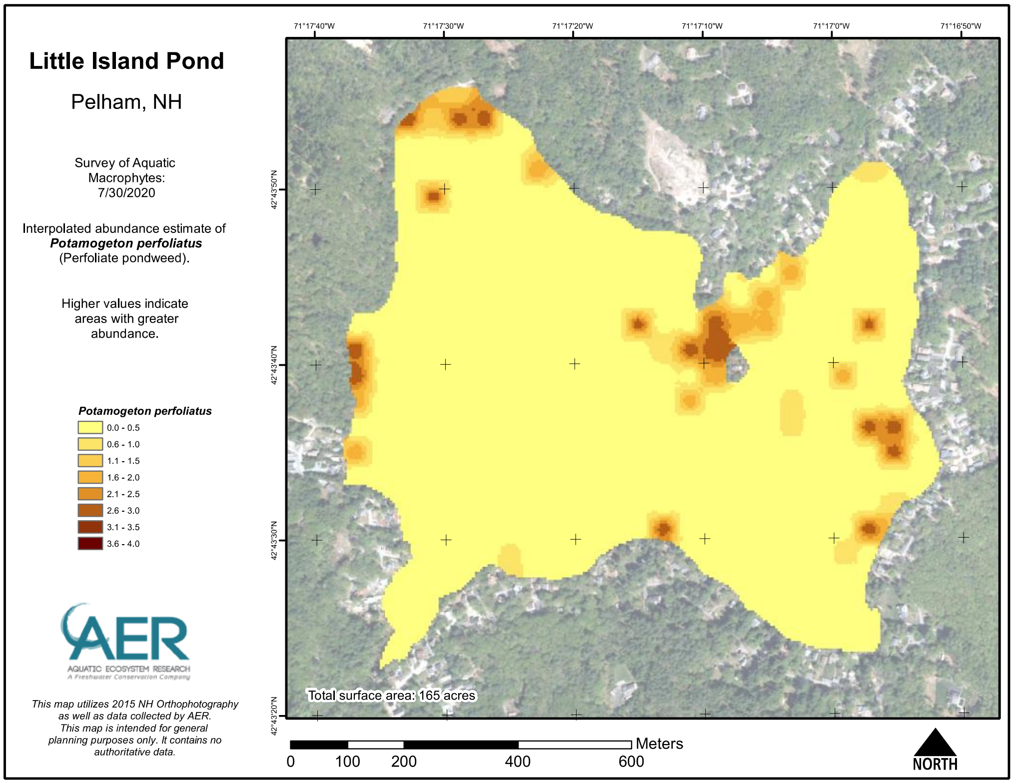

Figure 9. Spatial Distribution Map of *Potamogeton perfoliatus* (Clasping Pondweed).

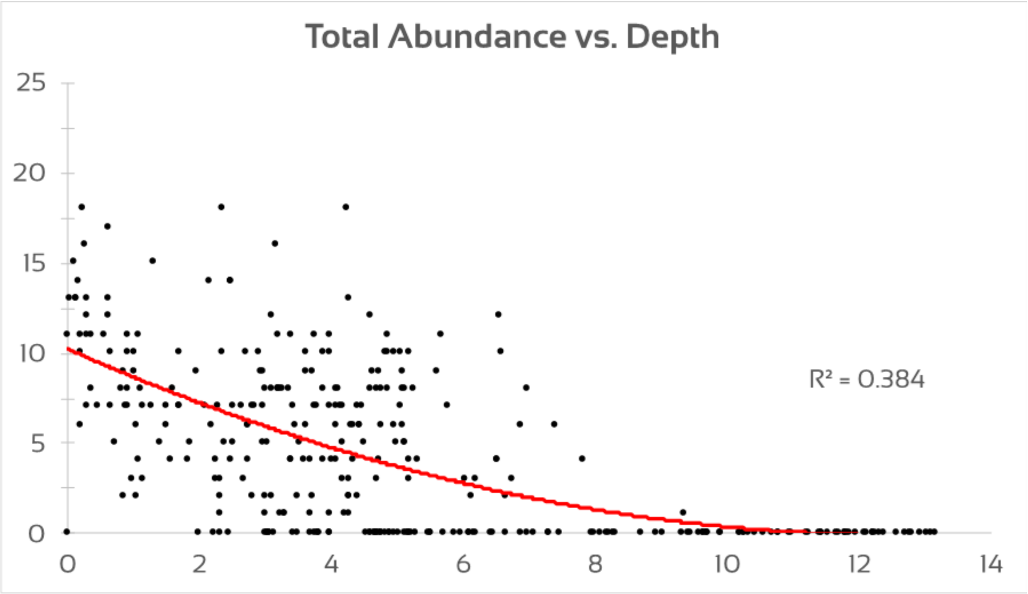

Figure 10. Polynomial Regression Model of Total Abundance (y-axis) vs. depth (x-axis). The red line indicates the model's estimation.

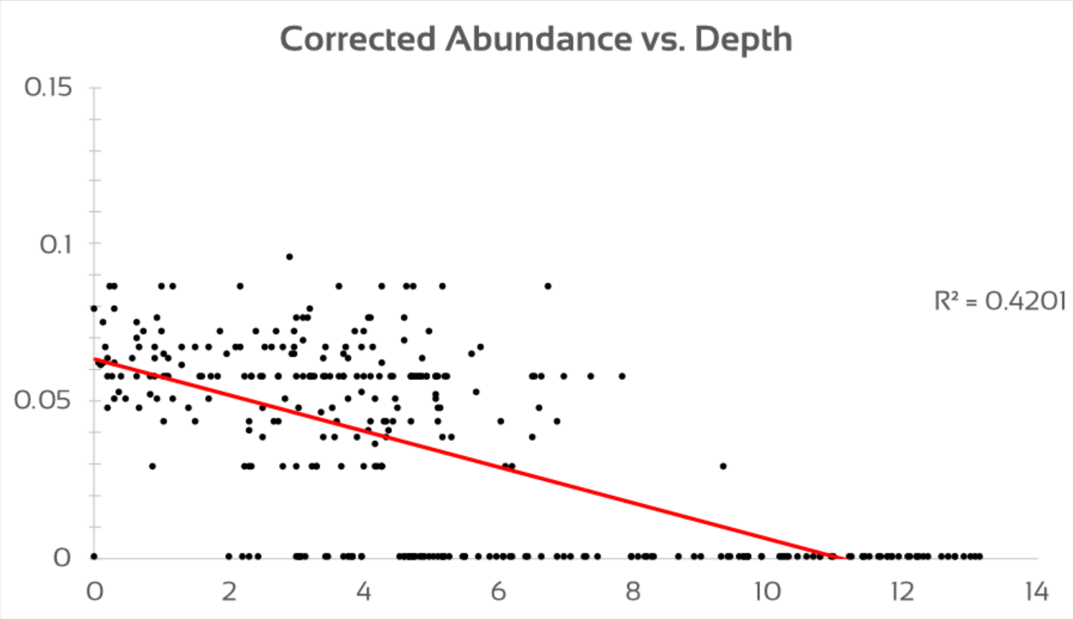

Figure 11. Linear Regression Model of Corrected Abundance (y-axis) vs. depth (x-axis). The red line indicates the model's estimation.

However, when we regressed corrected abundance vs. depth, we found that a linear model best explained the distribution of plant abundance (r^2=0.42, Fig. 11). Both models of abundance vs. depth suggest that the majority of plant abundance is present in the shallowest reaches of the lake; the area between 0.50m and 1.5m house the majority of the plant community biomass. The reason for the difference between the models' outcomes is the way that the abundance variable is calculated; total plant abundance is a raw sum of individual rank abundances and corrected rank abundance determines the abundance variable by correcting for the number of species and the average abundance of all species. However, both models are in agreement in regard to the area of highest abundance; those models suggest that the area between 0.5 and 1.5m contains the majority of the plant community's biomass.

The examination of diversity vs depth suggested that the distribution of community evenness (diversity) followed a polynomial model (r^2=0.35, Fig. 12). Diversity was found to decrease with depth and the most diverse areas were between 0.10 (0.33ft) and 1.0m (3.28ft). That finding was further supported by the results of AER's regression of richness vs. depth. When those two variables were examined together, a polynomial model was found to best explain that relationship (r^2=0.37, Fig. 13). Richness was greatest in shallow waters and decreased in a linear fashion as depth increased. The 0.10 to 1.0m of depth range was found to house the greatest number of individual plant species.

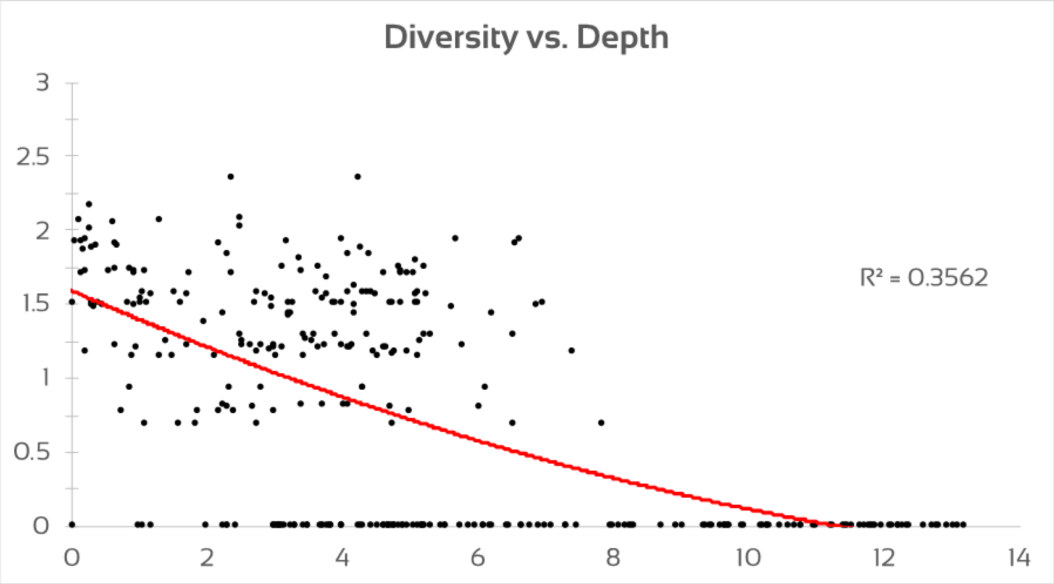

Figure 12. Polynomial Regression Model of Community Diversity (y-axis) vs. depth (x-axis). The red line indicates the model's estimation.

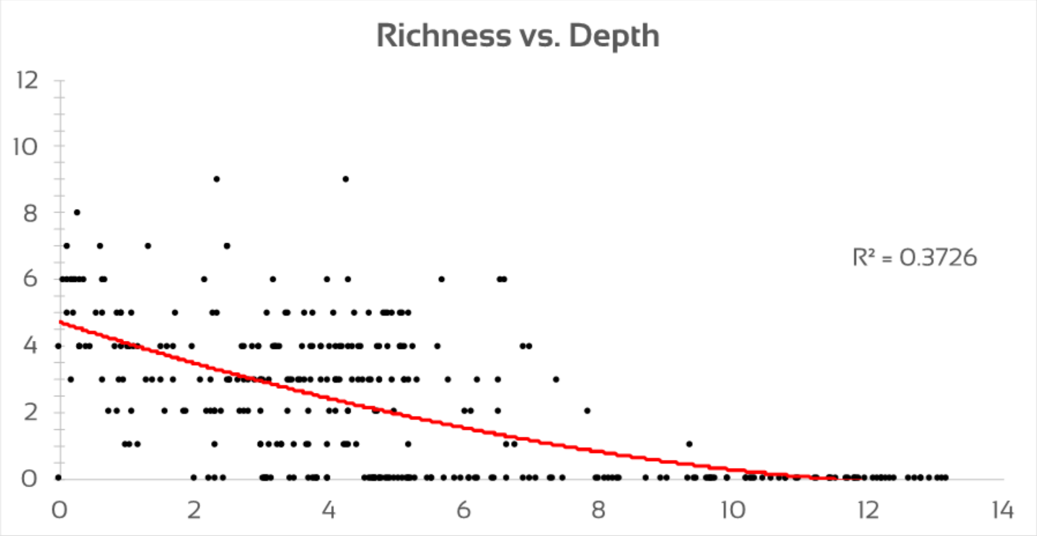

Figure 13. Polynomial Regression Model of Community Richness (y-axis) vs. depth (x-axis). The red line indicates the model's estimation.

To understand individual species relationships with abiotic and biotic factors, the four most abundant species – and *P. perfoliatus* - were regressed against depth, richness, and diversity variables. *Utricularia purpurea* was found to be the most abundant species in Little Island Pond; when its abundance was regressed against depth, it was found to follow a linear model (r^2=0.12, see Appendix 1). The amount of variance explained in that species' data was relatively low (i.e. 12%), which suggests that more than depth is dictating the abundance distribution of *U. purpurea.* However, the linear model suggests that *U. purpurea* has an average abundance of 1.25 in areas that are shallower than 1m deep.

When *Najas flexilis* (Nodding waternymph) was regressed against depth it was found that a weak linear relationship existed (r^2=0.15, Appendix 1). That suggests that the abundance of *N. flexilis* was not strongly tied to the availability of light and that other factors are contributing to the distribution of that species' abundance. *Najas flexilis* is often found in the shallow and middle depth strata in lakes; therefore, we assert that community competition phenomena are probably more important in determining the distribution of *N. flexilis* in Little Island Pond.

When *Chara spp.* (Muskgrass) was regressed against depth, a very weak linear relationship was found to best described its abundance distribution within the lake's depth profile (r^2=0.04, Appendix 1). That model suggests that *Chara spp.* requires light but that light availability is not the primary driving factor determining its distribution; instead, its distribution is more likely a result of interspecies relationships and the availability of open area within the littoral zone of Little Island Pond.

Potamogeton foliosus (Leafy pondweed) was found to follow a similar statistical pattern (r^2=0.03, Appendix 1). Those data suggest that *P. foliosus* exhibits an abundance distribution where it is equally probable to encounter it throughout the littoral zone. However, the points housing the greatest abundance of *P. foliosus* are clustered in the between the 2 and 5m zone of Little Island Pond.

Potamogeton perfoliatus (Clasping pondweed) also exhibited a weak linear relationship with depth (r^2=0.06, Appendix 1). While its presence was obvious to residents in a few areas of the lake, it ranked as the 7th most abundant species in the lake and exhibited a patchy distribution in certain areas of the Little Island Pond. It was found to be most common in areas between 1 and 4m of depth.

To further understand relationships among the most abundant aquatic macrophyte/macroalgae species in Little Island Pond, the total abundance variable of each species was regressed against both diversity and richness. When the richness was regressed against *Utricularia purpurea* total abundance, the analysis suggested that a polynomial relationship was the best explanatory model (r^2=0.41, Appendix 1). Furthermore, that model suggests that richness peaks in areas where there is a moderate abundance of *U. purpurea* (i.e. abundance = 2.25, Appendix 1). When that species was used in the regression of diversity vs. its abundance a slightly stronger polynomial model was developed (r^2=0.44, Appendix 1). That model suggested that the abundance of *U. purpurea* explained 44.28% of the variance in diversity data; and that as *U. purpurea* (Purple bladderwort) increased in abundance, diversity also increased.

When diversity and richness were regressed against the abundance of *Najas flexilis,* two polynomial relationships were resolved with variance accountings of 44.75 and 42.34%, respectively. The relationship between diversity and *N. flexilis* abundance was strong in nature (r^2=0.45, Appendix 1) and suggests that when *N. flexilis* abundance is between 2.5 and 3 that plant community diversity is at its greatest. When richness was regressed against the abundance of *N. flexilis*, it was found that there was a strong relationship between the two variables (r^2=0.42). That model suggests that where *N. flexilis* exhibits an abundance between 2.5 and 3 that there are more unique species present (Appendix 1).

Diversity and richness were also regressed against the abundance of *Chara spp.* (Muskgrass); the resulting models were both linear in nature and they explained 19.47 and 18.32% of the variance of the datasets. The diversity model was moderate in its explanatory value and suggested that as the abundance of *Chara spp.* increased so did the diversity of the local area; however, *Chara spp.* was never found to exceed and abundance of 3, which could limit the model's explanatory value and mask its impact on the structure of Little Island Pond's plant community (Appendix 1). That pattern was also found when richness was regressed against its abundance. The relationship was marginally weaker (r^2=0.18, Appendix 1).

The relationship between *Potamogeton foliosus'* abundance and community diversity was found to be positive in nature and best explained by a linear model (r^2=0.14, Appendix 1). That relationship was weak to moderate in nature but does suggest that as its abundance increases so too does diversity. When richness was regressed against the abundance of that species, a positive linear relationship was detected (r^2=0.13, Appendix 1). The relationship was weak to moderate in strength and suggested that where *P. foliosus* is most abundant that the plant community richness is also greatest.

Potamogeton perfoliatus was regressed again diversity and richness; the resulting models both exhibited weak explanatory values with r^2-values of 0.07 (Appendix 1) and 0.08 (Appendix 1), respectively. Those models suggest that the abundance of *P. perfoliatus* is not promoting or limiting community diversity or richness; instead, that this species may be invading areas that are not beneficial to other species. The true trajectory of this species is currently unknown and future studies should be undertaken to understand the plant community impacts that this species may have.

Finally, the savvy reader might have noticed that the relationships developed for richness and diversity were similar independent of the species in questions. To understand why diversity and richness models were always similar, we regressed diversity against richness and found that a 6th order polynomial model exhibited a 99% relationship between those two variables (Fig. 14). While a strong relationship between richness and diversity is to be expected, an explanatory value of 99% is extremely high. Therefore, we assert that the plant community is maturing – for reasons currently unknown – and that competition is increasing. It is impossible to know what the outcome will be regarding plant community status; future studies will elucidate the community's trajectory.

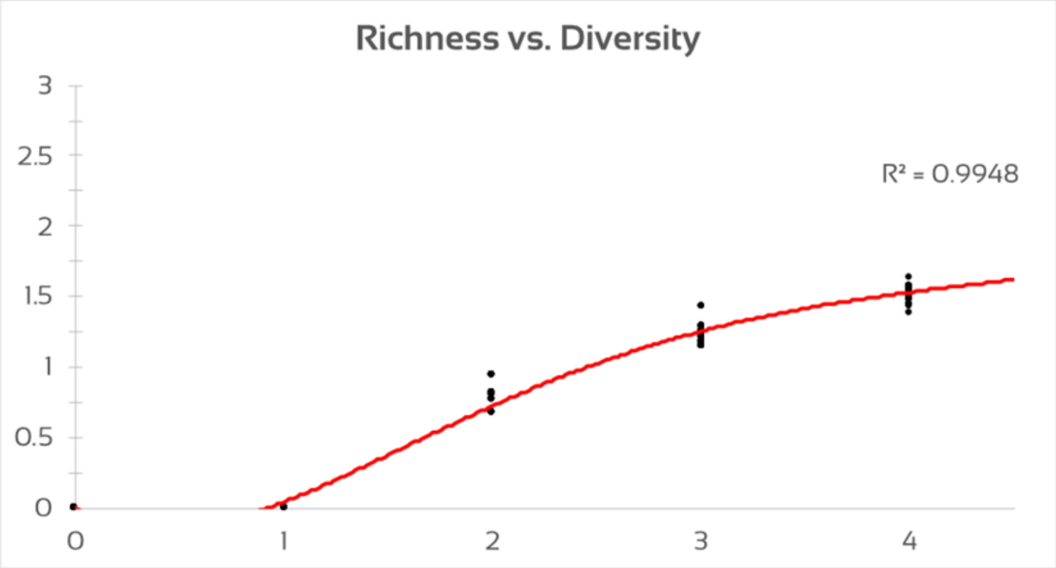

Figure 14. Polynomial Regression Model of Diversity (y-axis) vs. Richness (x-axis). The red line indicates the model's estimation.

DISCUSSION

Overall, the Little Island Pond plant community exhibits low to moderate productivity and moderate diversity; the plant community was also not found to house any non-native or rare/endangered species. The residents have noted that some species of aquatic macrophytes are becoming more abundant; however, there were no signs that aquatic macrophytes were impinging upon recreational access. This section will briefly discuss the ecological benefits of aspects of the current plant community and provide information about localized management strategies that may be deployed to manage areas of high plant abundance.

The analysis of the plant community suggests that the most productive areas of the plant community exist between 0.5 and 2.0m. Additionally, the depth ranges between 0.5 to 3.5m house the greatest species richness and community diversity. We also found that the dominant species of the community are most productive in that same depth range. Our findings also suggest that there are strong relationships among the richness and diversity variables and the two most abundant species (i.e. *Utricularia purpurea* and *Najas flexilis*). Ultimately, these findings create a situation where balancing any need for management and ecosystem conservation is of the utmost importance.

In short, Little Island Pond contains a total richness that is greater than the regional average of 13 species, is a community that has resisted invasion from non-native species, and has high average diversity. All of the aforementioned characteristics suggest that the plant community is healthy and ecologically functional. However, anecdotal data from residents suggest that the plant community composition may be shifting from smaller obscure species to larger rooted species. Therefore, it is important to ask the following questions as they apply to management: 1) What do we – as residents – expect out of our lake? and 2) What does our lake expect out of us?

Management Approach

Little Island Pond houses a diverse and rich plant community that has resisted invasion by non-native species. Therefore, it is our opinion that any major disturbance to that community could have adverse impacts over the long term. So, what do we expect out of our lake? Most people living the "lake-life" expect to have access to their water body to swim or boat, enjoyment of the scenery during the spring/summer/fall, and to experience increasing property values over time. To meet those expectations, it is sometimes necessary to take some management action.

But, what does the lake expect out of its residents? This esoteric question is difficult to answer because the natural world does not speak to us directly; instead, we as managers need to anticipate the outcomes of our actions and how those actions might impact the recreational asset. Therefore, lakes expect us to be good stewards and to keep them in good health where natural diversity is maintained, and communities are managed with a tempered hand.

For those reasons – including the current healthy state of Little Island Pond – we would only recommend localized, subtle mechanical management. We believe that the status of the lake is "healthy" due to the water quality conditions and the native diversity of the plant community; additionally, we believe that any heavy-handed approach to managing the plant community will result in short-term benefits (i.e. limited plant community) but long-term negative impacts (i.e. diminished water quality/non-native plant invasion).

Overall, we do not see a need for large scale management of Little Island Pond's aquatic macrophyte community; however, some steps can be taken to manage local boating/swimming areas and areas of high *P. perfoliatus* productivity.

- General Plant Management
    - Property Adjacent Swim Areas and Docking Areas
        - Benthic Barriers:

            - Aquatic Ecosystem Research recommends that homeowners deploy benthic barriers within their swim and docking areas to manage plants that are compromising their access.
        - Timing:
            - Benthic barriers can be installed at the end of May. They can then be removed during at the beginning of July.
                - The approach is still under review, but the preliminary results suggest that full control can be achieved with just four weeks of barrier deployment.
                - This will have to be done yearly to maintain results.
                - Over time, this process will result in a less productive local plant community due to the exhaustion of rhizome material and removal of roots.
- Potamogeton perfoliatus
    - Clasping pondweed (*P. perfoliatus*) has become a notable member of the plant community according to local residents.
    - It ranked as the 7th most abundant species during the July 30th survey; its presence did not appear to be impacting recreational access in a significant way.
    - *P. perfoliatus* was found in some dense patches:
        - Circa the northern most island
        - North near the camp
        - Western shoreline (42°43’40”N)
        - Eastern shoreline, southeast of the northern island
    - This species should be monitored.
        - Yearly inspections focused on mapping its distribution throughout the lake
            - Estimated Cost/yr. = $1,500.00
    - Mechanical Harvesting, Diver Assisted Suction Harvesting, or Benthic Barriers
        - For the non-residential areas of the lake, a mechanical harvester can be deployed to manage the populations around the northern island.
        - For residential swimming areas:
            - Diver Assisted Suction Harvesting:
                - Timing – Early July
            - Benthic Barriers:
                - See previous description of application.

- Surveys
    - The plant community should be inspected yearly to determine the trajectory of the *P. perfoliatus'* population and to detect non-native species invasions early – should they be introduced.
    - A quantitative plant survey should be undertaken at 3 to 5-year intervals.

DESCRIPTION OF RECOMMENDED MANAGEMENT OPTIONS

Diver Assisted Suction Harvesting

Diver Assisted Suction Harvesting (DASH) is a mechanical harvesting technique that involves the use of a barge-supported pump and a diver on the lake bottom who hand picks plant stems and feeds them into the inlet hose of the pump system. The harvested material is sucked from the lake bottom, up to the barge where it is collected and bagged and later disposed of.

On a per acre basis, this method is slow and expensive. It is generally not a practical approach to manage large-scale infestations of aquatic plants. However, it is well suited for managing residential swim areas and public beach access.

Mechanical Harvesting

Harvesters are essentially large boat driven mowers. These large machines scrape the top of the lake-bottom sediment and cut the target plants from the base. The plant material is then fed "top-side" on a conveyor and disposed of.

Mechanical harvesters come in many shapes and sizes. The largest of them range in price from $200,000.00 to $300,000.00 but there are smaller systems that range from $60,000.00 to $80,000.00. Additionally, there are companies throughout New England that can be hired to do harvesting work. The major risk associated with harvesting is the fragmentation of stem-plants, which could further spread species of that type.

Benthic Barriers

Benthic barriers are portable panels of porous synthetic fabric. These panels can be placed on the bottom of ponds and lakes to control aquatic plant growth. Benthic barriers are usually used to control small infestations. The panels remain out of sight throughout the control period. They are useful in water too deep for harvesting or where chemical application is not acceptable.

Once benthic barriers are installed, an immediate open area of water is created. This could be desirable for areas around boat docks, swimming areas, and public beaches. Benthic barriers also create a maintenance issue because they often require re-positioning, additional weight placement, and can sometimes trap air bubbles underneath them, which allows sunlight to reach the plants and subsequently allows growth to continue. This approach is not commonly used to control large infestations.

CONCLUSIONS

Overall, the plant community of Little Island Pond is healthy and rich; it does not contain any rare/endangered or non-native species. The lake's water chemistry suggests that it is at risk for *Myriophyllum spicatum, Najas minor,* and *Potamogeton crispus* (June-Wells, et. al. 2013). We recommend physical approaches to managing the plant community where necessary. Finally, we recommend that individual residences experiencing nuisance plant populations in their swim/docking area deploy benthic barriers or hire a company to execute DASH within those small areas.

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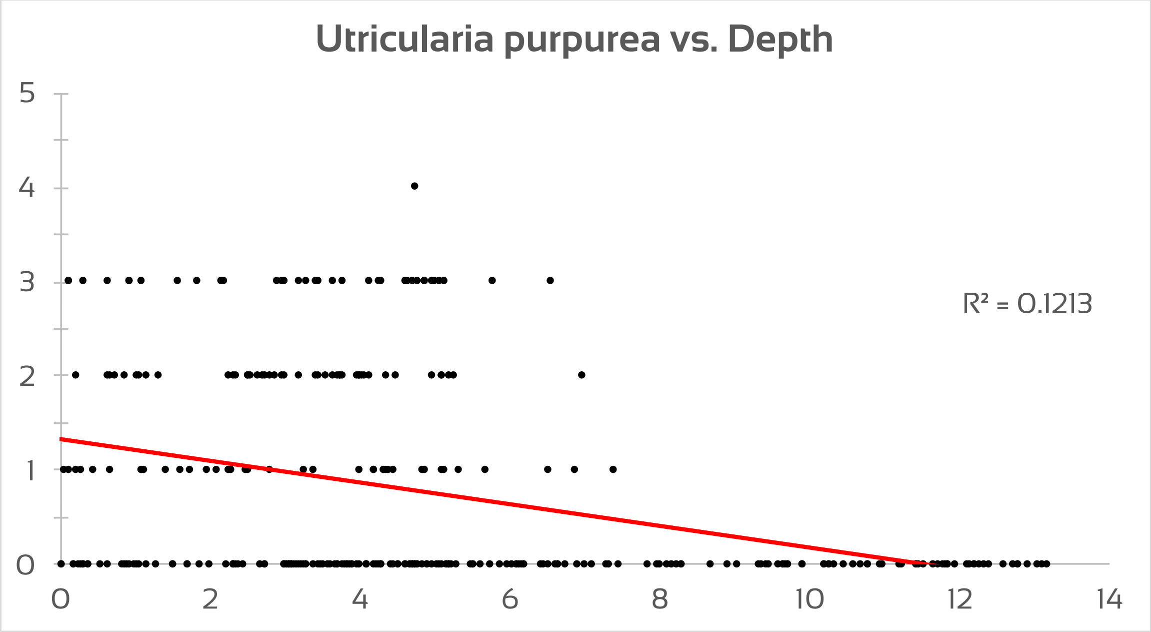
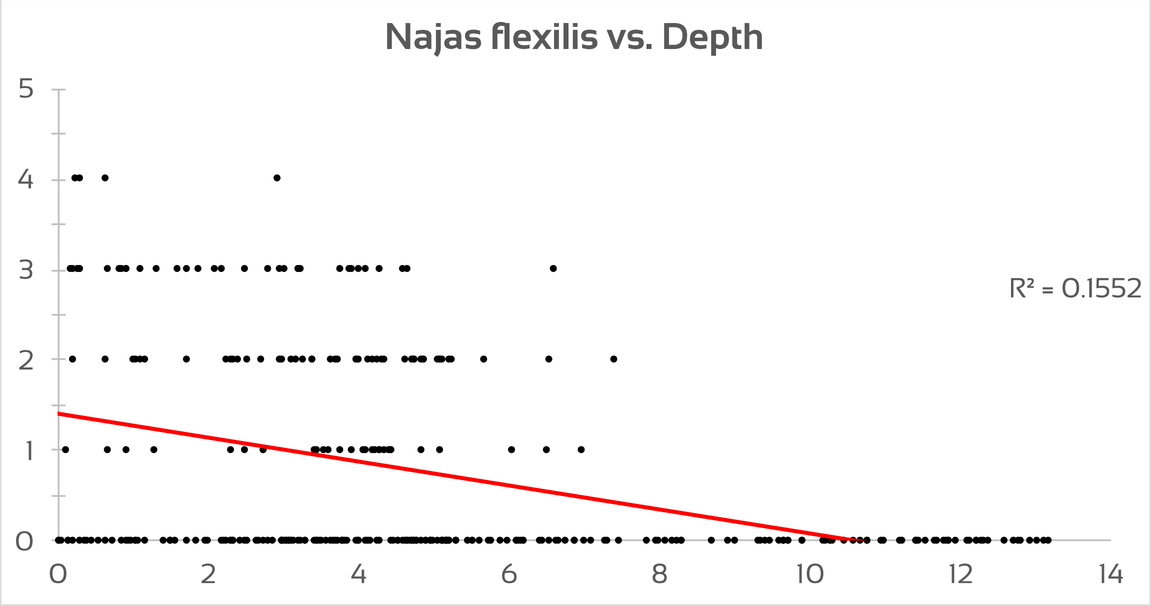
Mark June-Wells, Frank Gallagher, Jordan Gibbons & Gregory Bugbee (2013) Water chemistry preferences of five nonnative aquatic macrophyte species in Connecticut: a preliminary risk assessment tool, Lake and Reservoir Management, 29:4, 303-316

APPENDIX 1. STATISTICAL MODELLING OF THE MOST ABUNDANT LITTLE ISLAND POND AQUATIC PLANT SPECIES

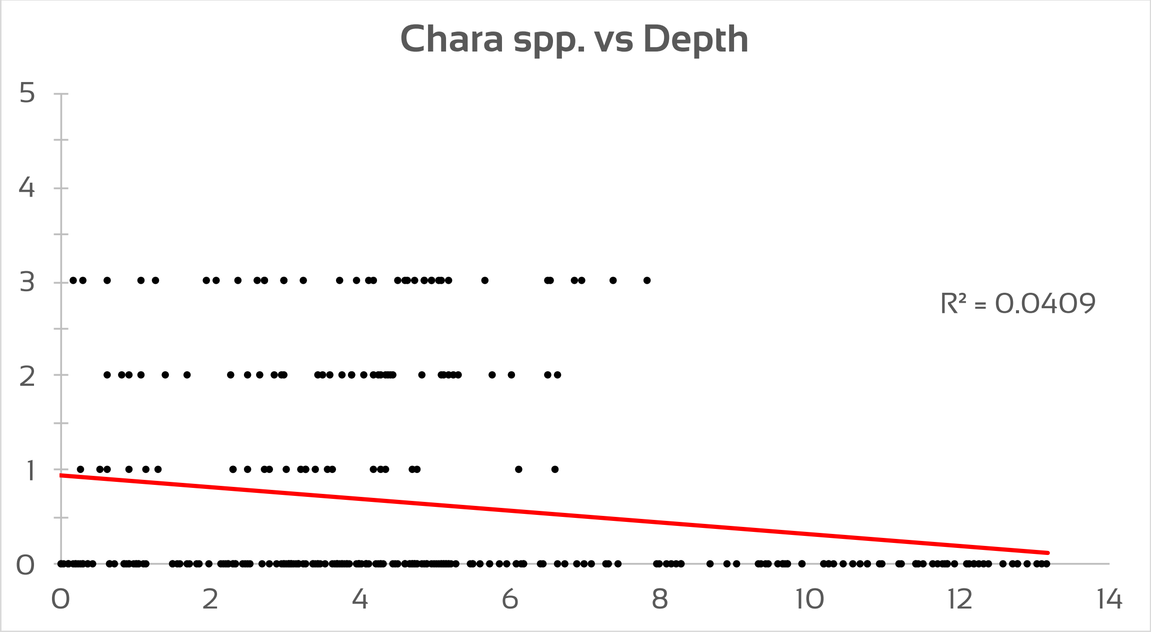
Polynomial Regression Model of Utricularia purpureas (Purple Bladderwort) abundance (y-axis) vs. depth (x-axis). The red line indicates the model's estimation.



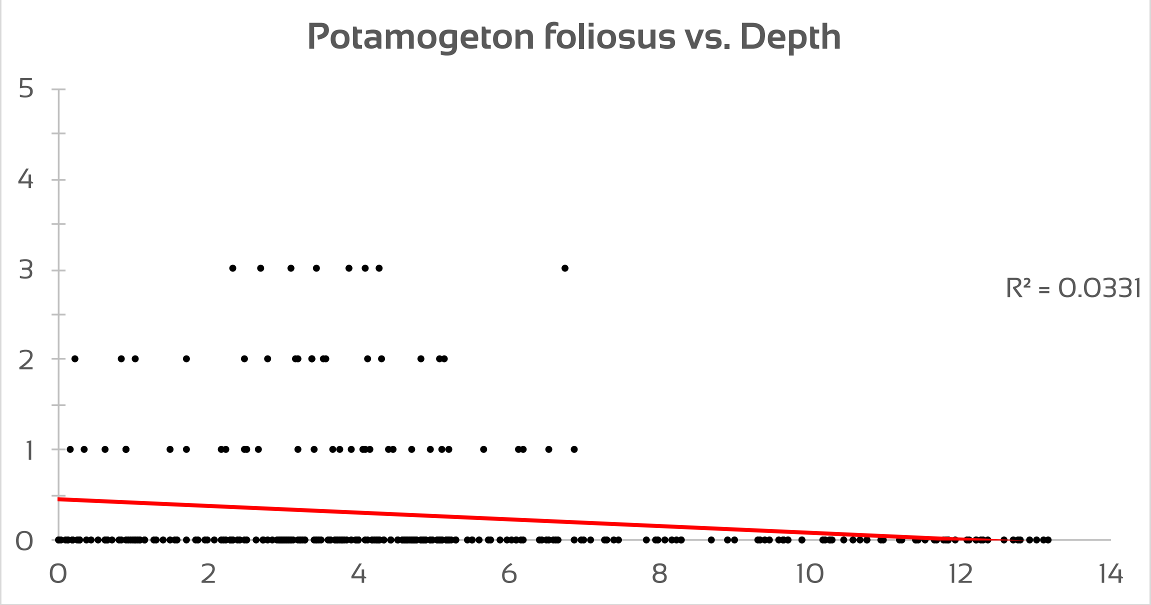
Linear Regression Model of Najas flexilis (Nodding Waternymph) abundance (y-axis) vs. depth (x-axis). The red line indicates the model's estimation.



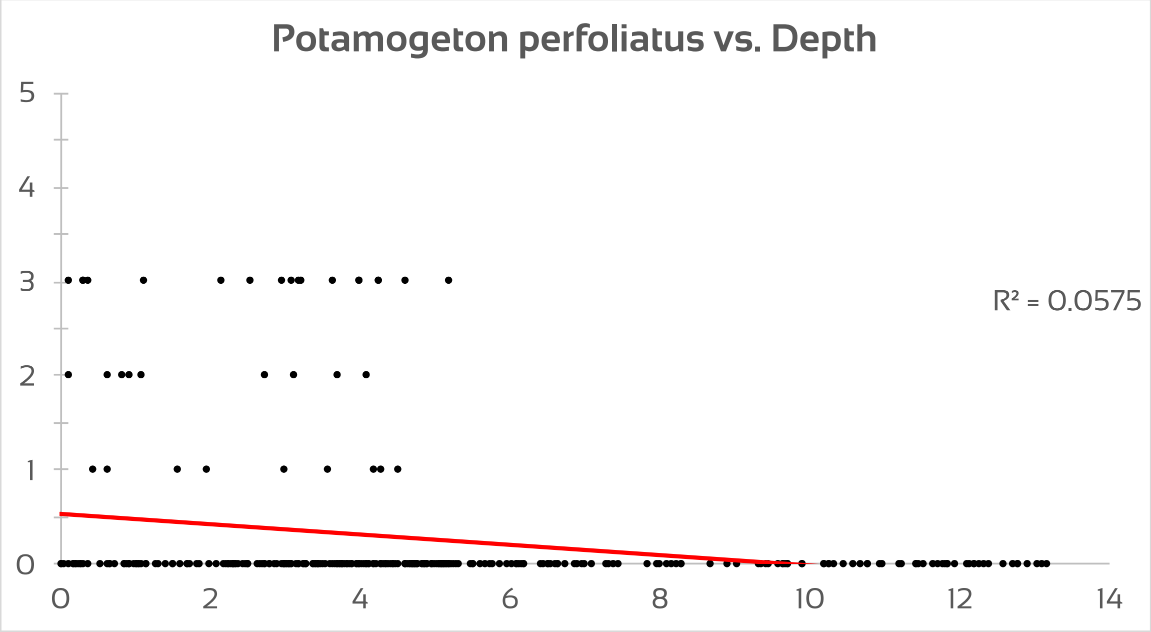
Linear Regression Model of Chara spp. (Muskgrass) abundance (y-axis) vs. depth (x-axis). The red line indicates the model's estimation.



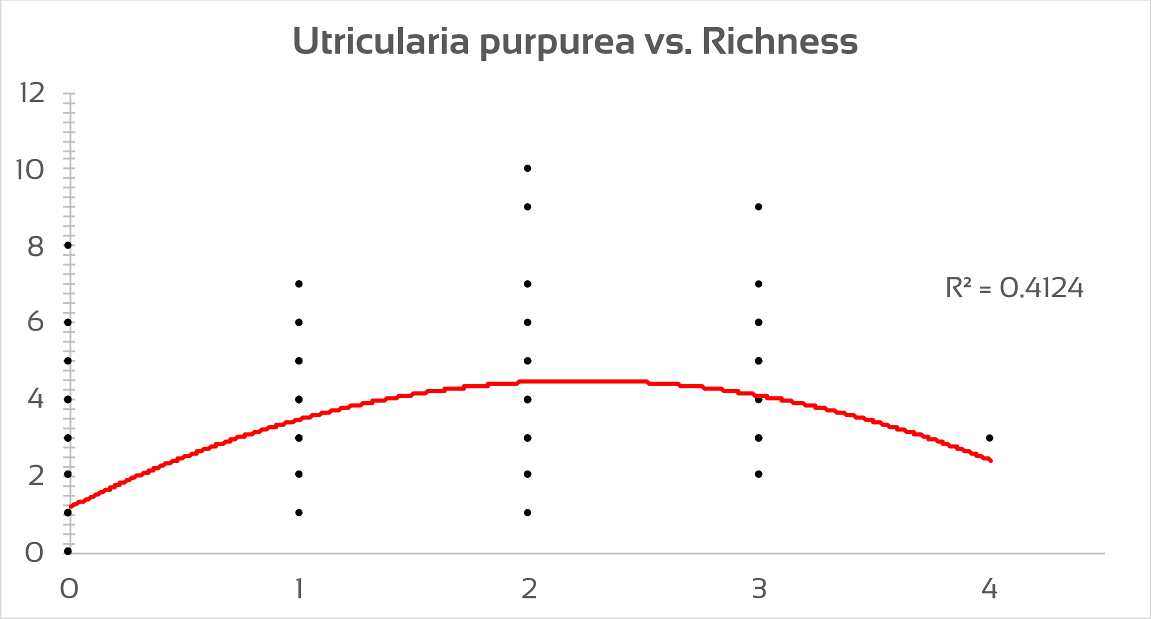
Linear Regression Model of Potamogeton foliosus (Leafy Pondweed) abundance (y-axis) vs. depth (x-axis). The red line indicates the model's estimation.



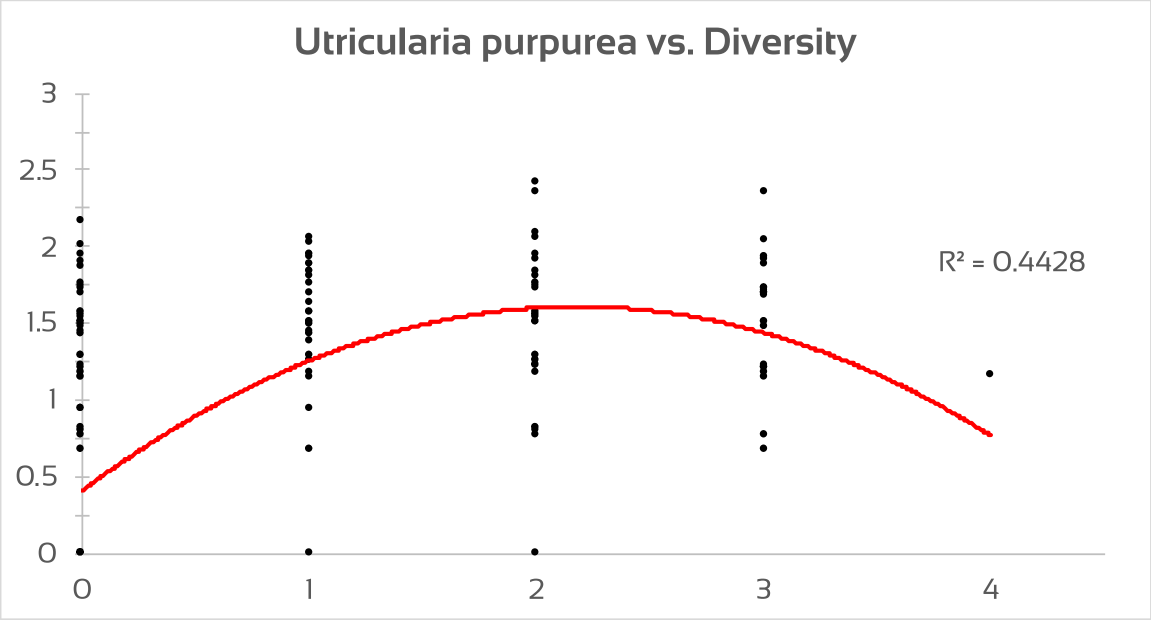
Linear Regression Model of Potamogeton perfoliatus (Clasping Pondweed) abundance (y-axis) vs. depth (x-axis). The red line indicates the model's estimation.



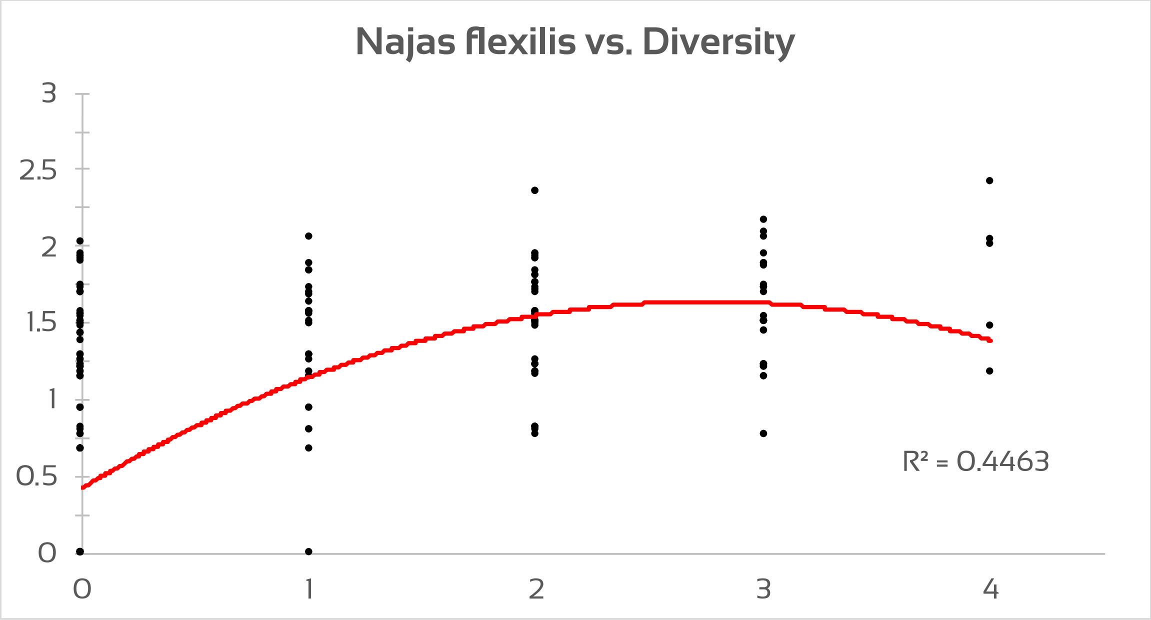
Polynomial Regression Model of Richness (y-axis) vs. Utricularia purpurea abundance (x-axis). The red line indicates the model's estimation.



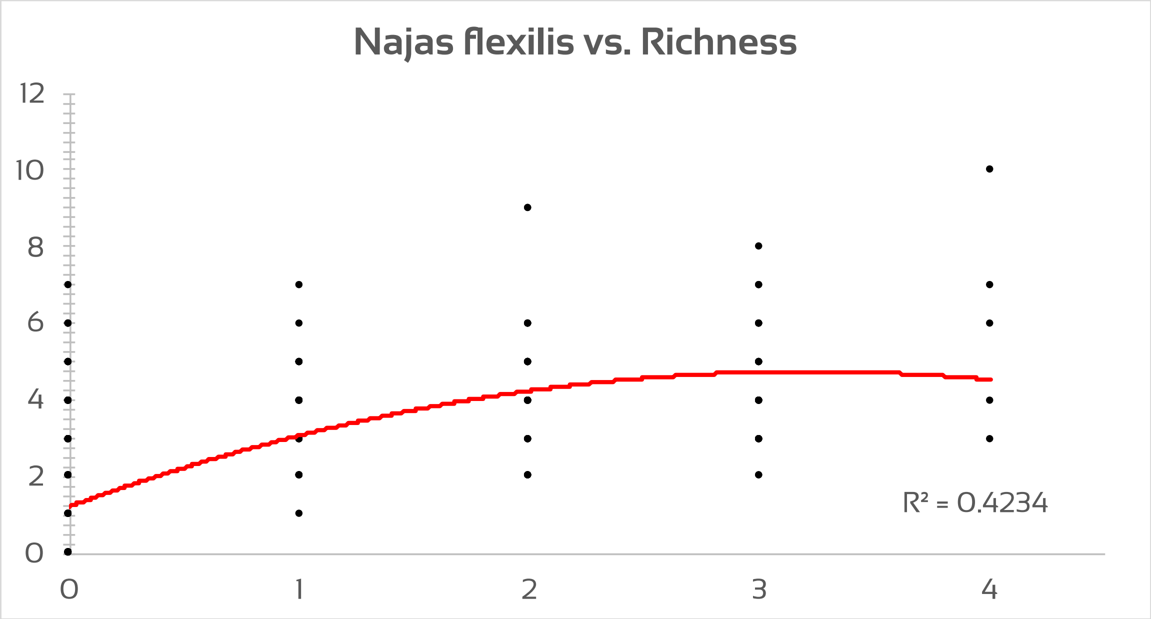
Polynomial Regression Model of Diversity (y-axis) vs. Utricularia purpurea abundance (x-axis). The red line indicates the model's estimation.



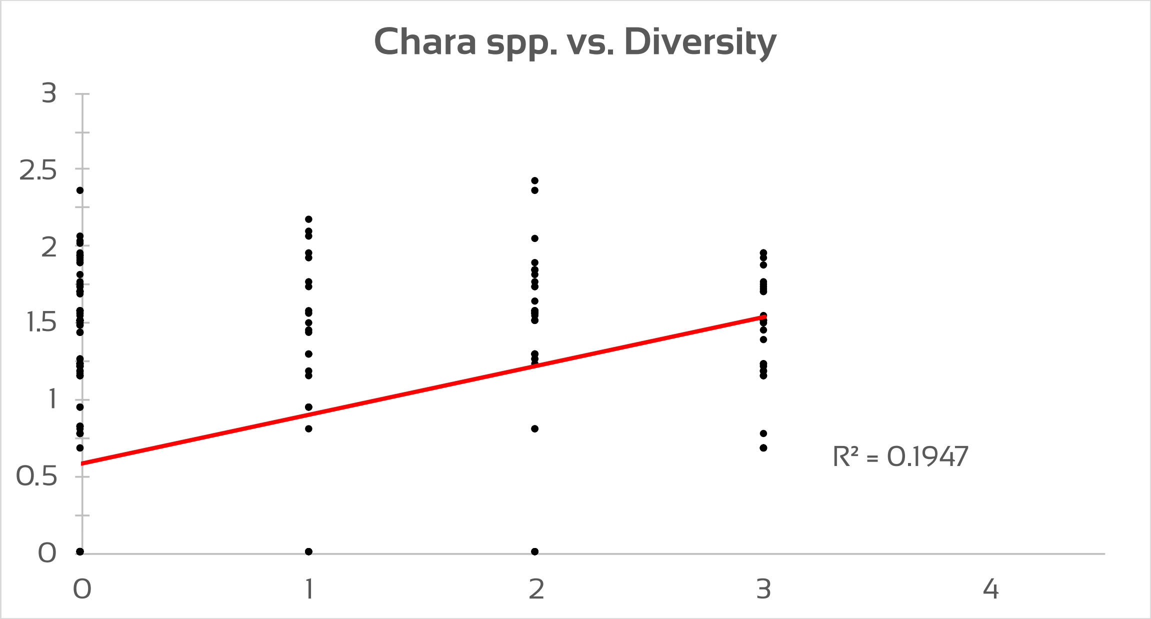
Polynomial Regression Model of Diversity (y-axis) vs. Najas flexilis abundance (x-axis). The red line indicates the model's estimation.



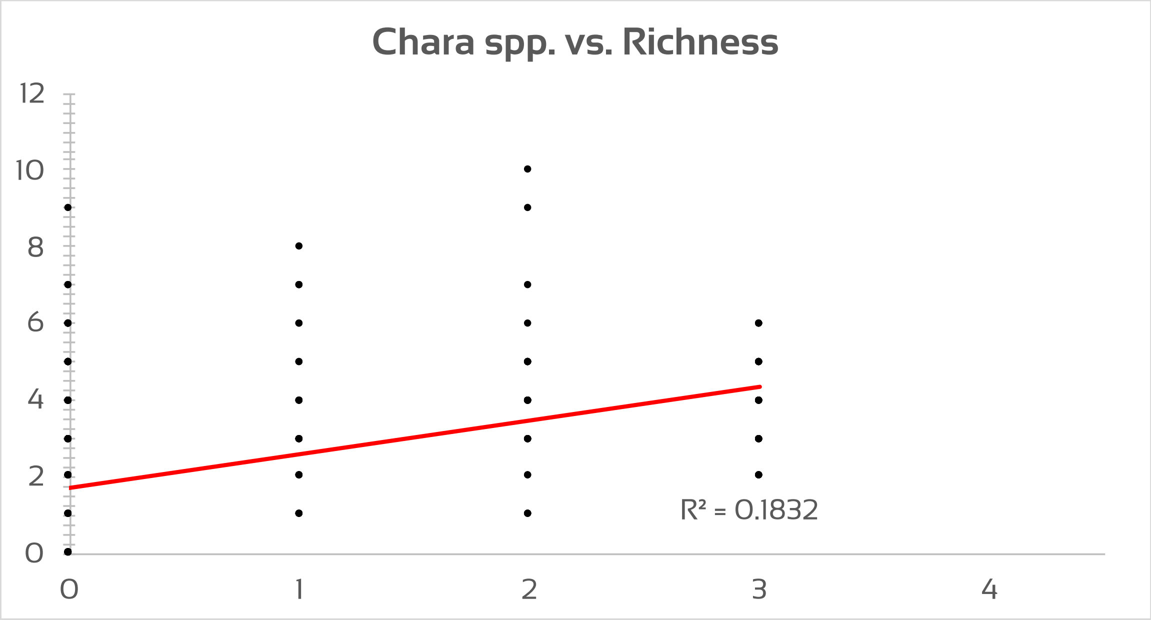
Polynomial Regression Model of Richness (y-axis) vs. Najas flexilis abundance (x-axis). The red line indicates the model's estimation.



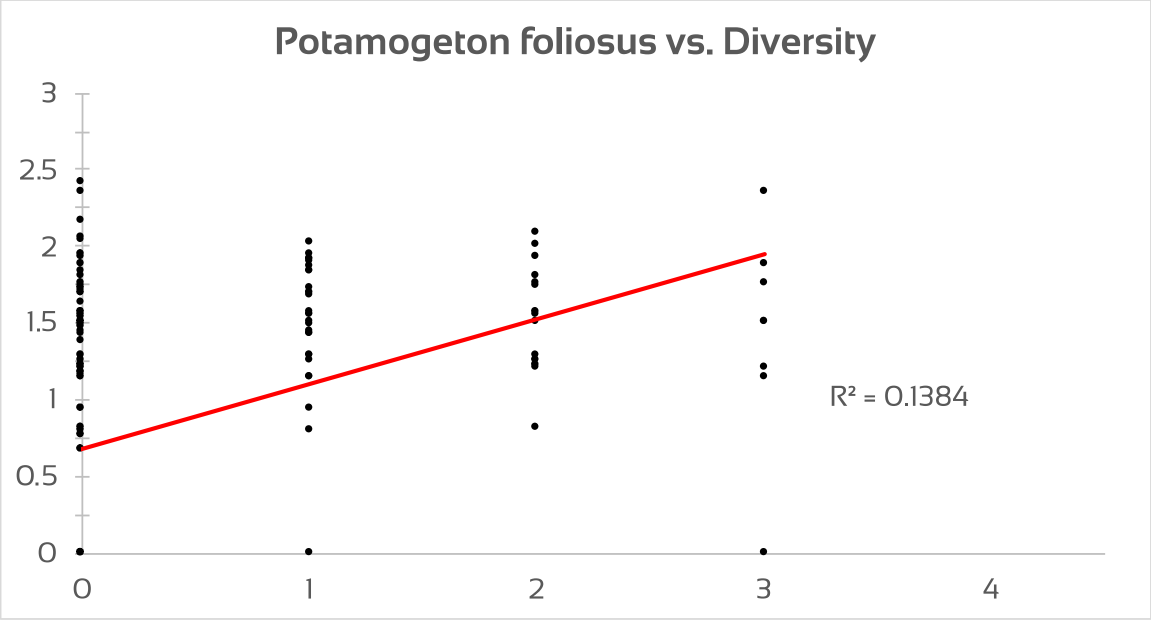
Linear Regression Model of Diversity (y-axis) vs. Chara spp. abundance (x-axis). The red line indicates the model's estimation.



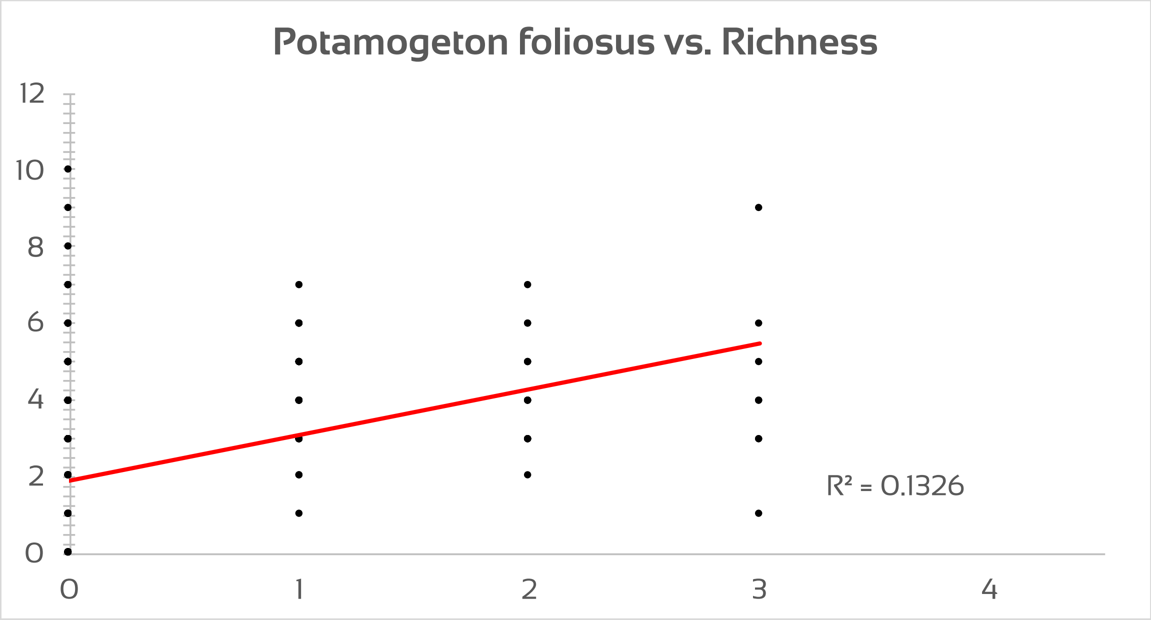
Linear Regression Model of Richness (y-axis) vs. Chara spp. abundance (x-axis). The red line indicates the model's estimation.



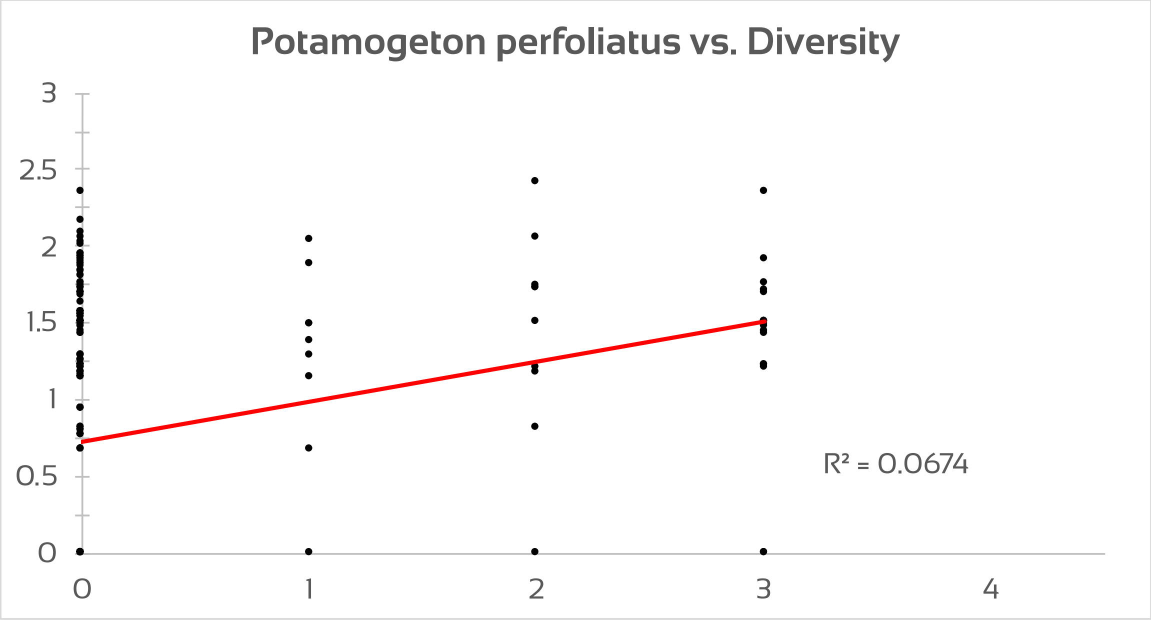
Linear Regression Model of Diversity (y-axis) vs. Potamogeton foliosus abundance (x-axis). The red line indicates the model's estimation.



Linear Regression Model of Richness (y-axis) vs. Potamogeton foliosus abundance (x-axis). The red line indicates the model's estimation.



Linear Regression Model of Diversity (y-axis) vs. Potamogeton perfoliatus abundance (x-axis). The red line indicates the model's estimation.



Linear Regression Model of Richness (y-axis) vs. Potamogeton perfoliatus abundance (x-axis). The red line indicates the model's estimation.