



Analysis of Kettle Pond Plant Communities of Cape Cod National Seashore (1995–2020)

Natural Resource Report NPS/CACO/NRR—2023/2601



ON THE COVER

Aerial view of Wellfleet kettle ponds

NPS / STEPHEN SMITH

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Stephen M. Smith

Cape Cod National Seashore
99 Marconi Site Road
Wellfleet, MA 02631

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Executive Summary

Along transects and within boxplots, several ponds have experienced significant changes in macrophyte species composition since 1995, while others have remained relatively unchanged.

In 2020 new occurrences of *Phragmites australis* (common reed) were documented in Duck (a single plant, which was immediately removed), Gull, and Higgins ponds.

Three state-listed rare species that occur in CACO kettle ponds were not found in 2020. These included *Sabatia kennedyanna* (Plymouth rose gentian) (found in 2016 at Great-T), *Drosera filiformis* (threadleaf sundew) (found in 2016 at Great-W) and *Sagittaria teres* (quill-leaved arrowhead), which was once abundant but has now been absent for decades.

Reductions in the cover of *N. odorata* (white waterlily) along transects was observed in Great-T, Ryder, Higgins, and Snow ponds, although this trend was apparent in boxplots only in Herring Pond. *E. acicularis* (dwarf harigrass) also diminished in cover in several ponds, including along Duck, Dyer, Gull, Long, Round-E, and Slough ponds. *J. militaris* (bayonette rush) appears to have undergone a variety of short-term changes including reductions along transects in Great-T, Higgins, Long, and Snow ponds. Boxplots only exhibited a reduction in Higgins Pond, however. *L. dortmanna* (Cardinal flower) is another taxon common to most CACO ponds. Its abundance along the Gull Pond transects decreased, contrasted by an increase in Long Pond transects, and in Great-W and Round-E boxplots. The proliferation of *Utricularia* spp. in Great-T Pond is one of the most conspicuous changes that has occurred over the last decade. The plant community shifts reported here are likely the result of both short-term (e.g., trampling, geese grazing, extreme drought or high water, etc.) and long-term (e.g., climate warming, diminishing acidity, increasing alkalinity).

That said, many of the statistically significant increases or decreases in cover were restricted to just one or two transects, and sometimes the changes in individual taxa contrasted each other among the different transects. One-dimensional line-intercept transects are likely detecting changes that are not real on any meaningful spatial scale. On the other hand, the number of boxplot sites should be increased to obtain much better spatial resolution. Accordingly, we propose increasing the number of box plot sites in each pond from five to ten for all future monitoring.

Background and Objectives

Scattered throughout Cape Cod National Seashore (CACO) (Massachusetts, USA) are numerous freshwater lakes and ponds of glacial origin. Collectively known as “kettle ponds” due to their roughly circular shapes, these waterbodies were created by melting blocks of glacial ice that left depressions on the outwash plain nearly 18,000 years ago. As sea level rose and pushed the groundwater table upward, these depressions became flooded. Depending on land surface elevation relative to groundwater elevation, seasonally (vernal ponds) or permanently (kettle ponds) flooded ponds developed. There are 16 discrete kettle ponds within CACO in the towns of Truro and Wellfleet (Figure 1).



Figure 1. Aerial photo of several kettle ponds in Wellfleet (left) and map of all CACO ponds where plant communities are being monitored (right).

Detailed descriptions of Cape Cod National Seashore (CACO) kettle ponds can be found in Portnoy et al. (2001), Roman et al (2002) and Smith (2012). The following text provides a brief synopsis of their characteristics and importance to CACO as a natural resource that is part of our Cape Cod Ecosystem Monitoring Program (excerpted from Smith 2012):

“Kettle ponds provide critical habitat for a variety of plant and animal life. Several aquatic plant species designated by the State of Massachusetts as Endangered, Threatened, Special Concern, and Watch Listed occur around pond edges (LeBlond 1989). The ponds are also major attraction for humans. With this brings a number of concerns including trampling and denudation of shoreline and littoral zone vegetation, erosion, bather urination, and septic effluent from houses surrounding the ponds that add nitrogen and phosphorus to the system (Roman et al. 2001). More broadly, the water quality of rainfall can influence pond pH and nutrient status (Portnoy et al. 2001). Toxic metals in precipitation and groundwater can also be potential problems. Finally, there are biotic threats to pond communities—especially exotic plant species such as *Phragmites australis* (common reed) and *Lythrum salicaria* (purple loosestrife). In Massachusetts there are many species of invasive

submerged aquatic vegetation (SAV), which have not yet been found in the kettle ponds but are an ongoing concern. These and other invasive taxa have the potential to seriously compromise biological diversity and habitat structure as they have in many other wetland systems.”

Methods

Aquatic macrophytes are an important habitat within the littoral zones of lakes and can be some of the most productive communities in the world (Ondiviela et al., 2014). They are a critical link between top-down (e.g. trophically-controlled) and bottom-up (e.g. physico-chemically-driven) processes which makes them an important element to assess overall ecosystem integrity. Macrophyte vegetation in the littoral zone integrates a variety of physical, chemical, and biological factors over time and is therefore a good indicator of long-term changes in pond conditions. For lakes, the littoral zone is defined as the nearshore habitat where photosynthetically active radiation penetrates to the lake bottom in sufficient quantities to support growth and it is this habitat upon which the monitoring is focused.

A detailed description of methods and the evolution of monitoring can be found in Smith et al. (2012, 2018). Vegetation surveys along five line transects placed in each of five kettle ponds (Great-T, Gull, Ryder, Herring, Duck) were conducted by Roman et al. (2001). This was repeated in 2005 and expanded to include five more ponds (Dyer, Great-W, Long, Snow, Spectacle), bringing the total to ten. In 2010, four more (Horseleeche, Higgins, Round-E, Slough) ponds were added to the monitoring network bringing the total to 14. Line cover by species was assessed along each 1-m interval along the five 20-m transects in each pond. To do this the linear distance each species covered along each 1-m transect segment was assessed visually and recorded as a categorical value based on a modified Braun-Blanquet cover scale (<1% = 1; 1–5 % = 2; 5–10 % = 3; 10–25% = 4; 25–50 % = 5; 50–75 % = 6; and 75–100 % cover = 7).

Two-dimensional 5m x 10 m rectangular box plots were added in 2005 to obtain better spatial coverage than line transects afford. However, it proved too difficult to assess substantial portions of them given that they encompassed the transition zone from shoreline to upland, which often consisted of very dense woody shrubs, and thorny vines. In addition to being extremely difficult to penetrate without cutting, this presented several safety issues for field crews. Thus, a decision was made to focus on the “open-water” vegetation pondward of this zone in 2010, when newly positioned 10-m² boxplots (pondward of the shrub zone) were established with one side of each boxplot consisting of ~3.33 m of the line transect (see Figure 2).

As in previous surveys number of taxa (particularly graminoids and submerged species) could only be identified to genus (e.g., *Eriocaulon*, *Utricularia*, *Potamogeton*, *Juncus*, *Carex*, *Eleocharis*). Moreover, the identification of these plants in the past to the species level is somewhat questionable given the level of expertise of field crews. Accordingly, some of the data is best treated as groups of very similar species.

Another identification issue that has arisen relates to submerged, non-vascular, plant-like algae and moss (Figure 3 below). Besides being difficult to identify, these species are typically covered with periphyton, which makes them even more difficult to examine. It is also material that is unrooted, so it tends to move around with wind waves, etc. As such, these non-vascular, non-rooted species were not included in the analyses below.

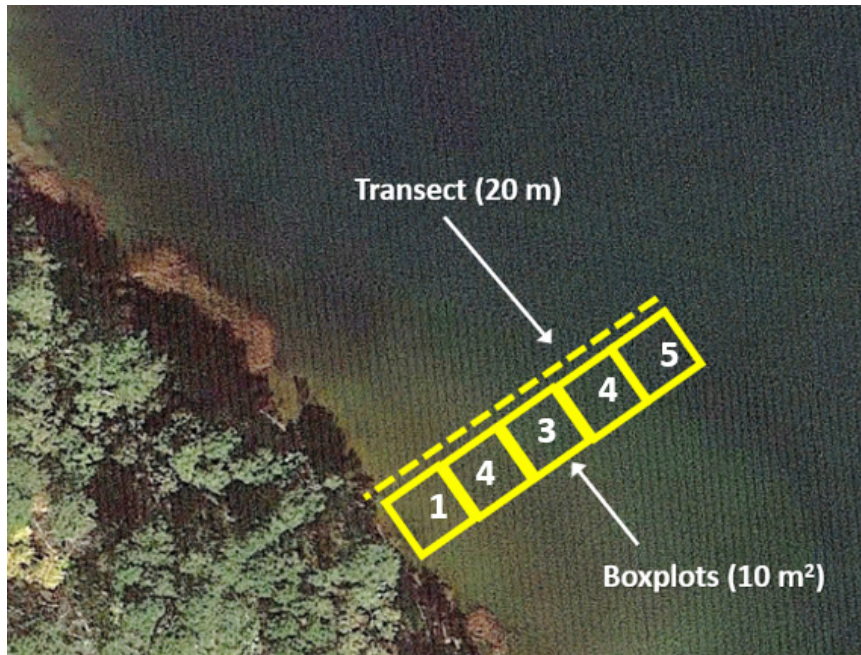


Figure 2. Diagram of line transect and box plots.



Figure 3. Photos of plant-like algae (top row; from left to right: *Chara* sp., *Nitella* sp., *Najas* sp.) and aquatic mosses (bottom row, left to right: *Drapanocladus* and *Sphagnum*).

Data analysis

Cover data were converted to their mid-point percentages (cite) and then analyzed using non-parametric Bray-Curtis Analysis of Similarities (ANOSIM) (Clarke and Warwick 2001, Roman et al. 2002). Similarities percentages (SIMPER; Primer ver. 7) was used to examine individual species contributions to disparities in plant communities among surveys – even where changes were not statistically significant (only species contributing to at least 70% of the observed dissimilarity are listed).

Non-metric multidimensional scaling (NMDS) helped illustrate similarities/dissimilarities in species composition among transects and survey years (note that NMDS figures are included only where ANOSIMs met the criteria for statistical significance at $\alpha=0.05$). NMDS allows one to visualize, based on relative distances in ordinal space, how closely or not multivariate datasets resemble one another. This depends upon both abundance and distribution (the latter pertaining to where along transects) of each species. When the abundance values for species that are key contributors to significant community change are similar, it's an indication that their distributions along the transects is very different.

Temporal trends in a select groups of individual species that are common to most ponds and a dominant component of their plant communities, were analyzed by linear regression. Unfortunately, regression analysis is of limited value when the number of data points is so low – for example, there are only four data points in the case of ponds which have been monitored since 1995).

Trends in functional groups (tree, shrub, graminoid, etc., as per USDA PLANTS, 2022) and wetland indicator status (obligate, facultative-wet, facultative, etc., as per ACOE 1988) were also analyzed but not presented here due to the lack of any significant or meaningful patterns.

This report focusses on comparisons between initial (variable by pond) and the most recent (2020) data. The 10 m x 10 m boxplots that were established in 2010 and surveyed in 2016 and 2020 were analyzed as well, as were corresponding transect data from this time frame for direct comparison of transect vs. boxplots trends (Table 1).

Table 1. Summary of the various data analyses that were conducted on kettle pond vegetation monitoring data. All data are kept in Y:\IM_Projects\Vegetation_Monitoring\Kettle_Ponds.

Method	Monitoring period	Ponds
Transects	1995–2020	Duck, Herring, Gull, Great-T, Ryder
	2005–2020	Dyer, Great-W, Higgins, Long, Snow, Spectacle
	2010–2020	Horseleech, Round-E, Slough
Boxplots	2010–2020	All

Results

Summary of Changes in Plant Community Composition by Pond and Monitoring Period

Along the permanent transects, 5 out of 14 ponds exhibited a statistically significant shift in plant community composition during the maximum duration of monitoring, the starting date of which differs among ponds (Table 2). These were Great-T, Gull, Long, Ryder, and Spectacle ponds. Duck pond has also changed but the magnitude of its shift was slightly outside the criterion for statistical significance.

Table 2. Results of ANOSIM to detect statistically significant (boldface) changes in plant communities based on transect survey data collected in 2005 and 2020.

Pond	P value	Period
Duck	0.06	1995 vs. 2020
Dyer	0.57	2005 vs. 2020
Great-T	<0.01 ^a	1995 vs. 2020
Great-W	0.94	2005 vs. 2020
Gull	0.01 ^a	1995 vs. 2020
Herring	0.19	1995 vs. 2020
Higgins	0.14	2005 vs. 2020
Horseleech	0.85	2010 vs. 2020
Long	0.01 ^a	2005 vs. 2020
Round-E	0.64	2010 vs. 2020
Ryder	0.04 ^a	1995 vs. 2020
Slough	0.73	2010 vs. 2020
Snow	0.93	2005 vs. 2020
Spectacle	<0.01 ^a	2005 vs. 2020

^a Statistically significant results (also shown with bold text).

When the time frame for analysis of transect data is truncated to 2010–2020, which allows comparisons among all ponds, Great-T, Gull, Ryder, and Spectacle ponds still exhibited a significant change. For the boxplot data, however, only the changes in Great-T and Higgins ponds vegetation exhibited statistical significance, although Herring Pond approached the threshold for significance with a p-value of 0.6 (Table 3).

Table 3. Results of ANOSIM to detect statistically significant (boldface) changes in plant communities based on transect and boxplot survey data collected in 2010 and 2020.

Pond	2010–2020		No. shared taxa in SIMPER analyses
	Transects	Boxplots	
Duck	0.72	0.25	0 (n=2)
Dyer	0.40	0.84	1 (n=2)
Great-T	<0.01^a	<0.01^a	2(n=2)
Great-W	0.99	0.94	2/(n=2)
Gull	<0.01^a	0.12	2(n=3)
Herring	0.19	0.06	2 (n=3)
Higgins	0.15	0.02^a	2 (n=3)
Horseleech	0.85	0.67	3 (n=4)
Long	0.52	0.29	1 (n=2)
Round-E	0.64	0.21	3 (n=3)
Ryder	0.04^a	0.28	1 (n=3)
Slough	0.73	0.74	2 (n=2)
Snow	0.14	0.50	1 (n=5)
Spectacle	<0.01^a	0.74	1 (n=2)

^a Significantly significant results (also shown with bold text).

Transect Species Richness

Along transects, two ponds displayed statistically significant trends in species richness (Figure 4). It should be noted, however, that these regressions consist of only three to five data points (one value per pond per survey year for 1995, 2005, 2010, 2016, 2020). Thus, any statistically significant regressions must be interpreted with an abundance of caution as a limited sample size can greatly skew trend direction and magnitude. Notwithstanding, the total number of species recorded along the transects in both Duck and Great-T ponds declined but no other obvious trends were apparent.

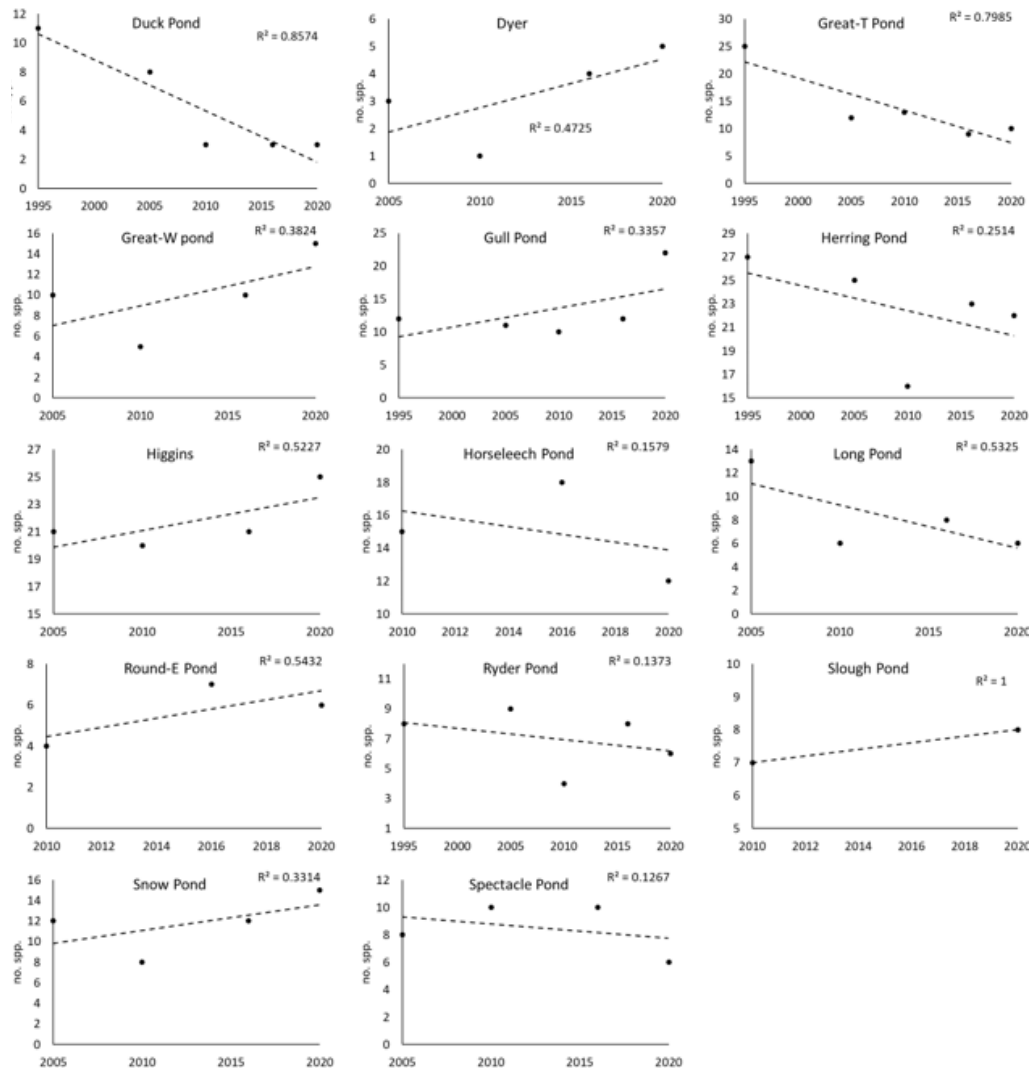


Figure 4. Species richness by survey year along transects by pond.

Box Plot Species Richness (2010–2020)

Because the 10-m² contiguous box plots were not established until 2010, note that more surveys are needed for valid interpretation of trends. Below are figures showing total species richness (all plots pooled) by year like those above for the transects. Regressions are shown for context (dashed line) (Figure 5).

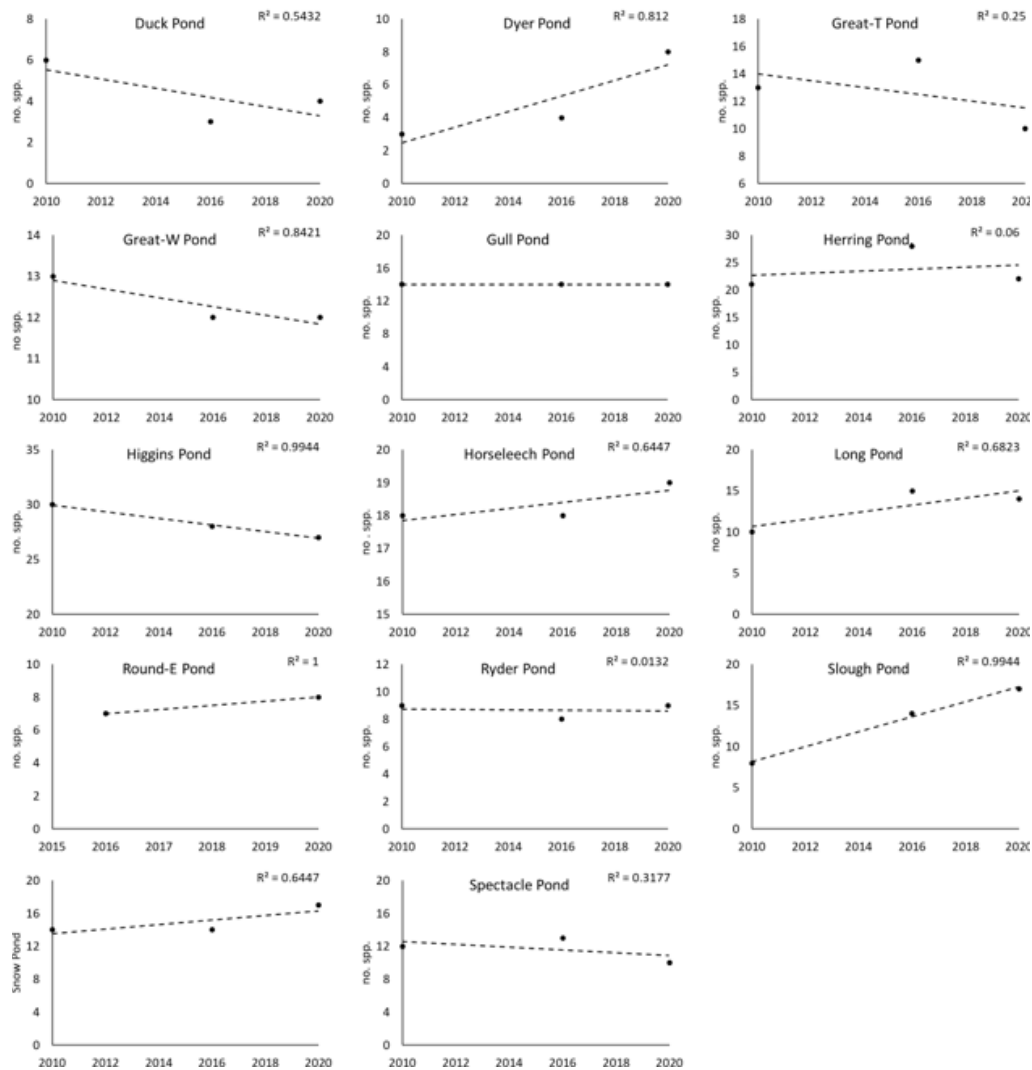


Figure 5. Species richness by survey year in box plots between 2010 and 2020.

Individual ponds

Duck Pond

Duck Pond transect and Boxplot start points are illustrated below (Figure 6).

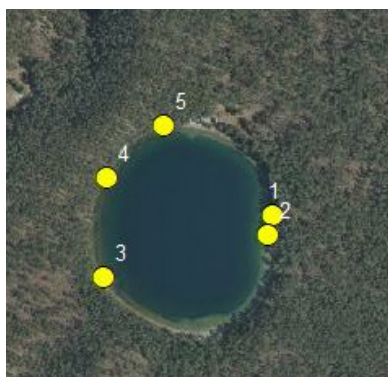


Figure 6. Duck Pond transect and boxplot shoreline locations.

Transects (1995–2020)

The extent of vegetation change between 1995 and 2020 fell just outside the criteria for statistical significance (ANOSIM $p=0.06$). Notwithstanding the disappearance of *Cyperus dentatus* (toothed flatsedge) and *Eleocharis acicularis* (needle spikerush), concurrent with an increase in *Lobelia dortmanna* (water lobelia) accounted for the largest proportion of variance between surveys (Table 4).

Table 4. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Duck Pond along transects between 2010 and 2020 (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Transects (1995–2020)	1995	2020	Cum.%	Trend ^a
<i>Cyperus dentatus</i>	0.5	0.01	36.0	↓
<i>Eleocharis acicularis</i>	1.7	0.0	55.9	↓
<i>Lobelia dortmanna</i>	0.01	1.3	71.0	↑

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

Transects & Boxplots (2010–2020)

Transect vegetation in Duck Pond did not exhibit any significant change between 2010 and 2020 (ANOSIM $p=0.72$). An increase in *L. dortmanna* cover, concurrent with a reduction in *Elatine minima* (small waterwort) accounted for most of the observed shifts in plant communities (Tables 5 and 6). It is noteworthy that *L. dortmanna* exhibited the opposite trend in the transects between 1995 and 2020 vs. between 2010 and 2020.

Species composition in the Duck Pond boxplots also failed to exhibit any statistically significant change between 2010 and 2020 (ANOSIM $p=0.25$). Observed dissimilarities between survey years indicated that minor shifts in the abundance and distribution of *Eriocaulon septangulare* (pipewort; decreased) and *Myriophyllum* spp. (watermilfoil; increased).

Table 5. SIMPER analysis showing the abundance values of taxa accounting for the largest proportion of aquatic vegetation change in Duck Pond along transects between 2010 and 2020 (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Transects (2010–2020) ns			
	2010	2020	Cum.%	Trend ^a
<i>Lobelia dortmanna</i>	2.4	1.3	57.2	↓
<i>Elatine minima</i>	0.5	0.0	79.3	↓

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

Table 6. SIMPER analysis showing the abundance values of taxa accounting for the largest proportion of aquatic vegetation change in Duck Pond within boxplots between 2010 and 2020 (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Boxplots (2010–2020) ns			
	2010	2020	Cum.%	Trend ^a
<i>Eriocaulon septangulare</i>	1.52	0.5	42.59	↓
<i>Myriophyllum</i> sp.	0.02	0.3	77.35	~

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

Dyer Pond

Dyer Pond transect and Boxplot start points are illustrated below (Figure 7).



Figure 7. Dyer Pond transect and boxplot shoreline locations.

Transects 2005–2020

The transect vegetation in this pond has not exhibited a significant shift during the monitoring period (ANOSIM $p=0.57$). In reality, the vegetation in this pond has long been very sparse so there was not much to lose to begin with. Regardless, the transects in Dyer have experienced losses of *E. septangulare* and *E. acicularis* (Table 7).

Table 7. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Dyer Pond along transects between 2005 and 2020. (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Transects (2005–2020)			
	2005	2020	Cum.%	Trend ^a
<i>Eleocharis acicularis</i>	8.4	0.2	47.9	↓
<i>Eriocaulon septangulare</i>	11.4	0.1	70.6	↓

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

Transects & Boxplots (2010–2020)

Between 2010 and 2020, Dyer Pond vegetation along the transects underwent no significant change (ANOSIM $p=0.40$). *J. militaris* (bayonet rush) and *E. acicularis* accounted for most of the observed variation between surveys, with both exhibiting increases in cover from zero values recorded in 2010 (the species was detected in transects in 2005 however, so it is not a new appearance to the pond) (Table 8).

Plant communities in the Dyer Pond boxplots also exhibited no significant alterations between 2010 and 2020 (ANOSIM $p=0.84$) (Table 9). Like the transects during this time, *J. militaris* appeared in 2020. *E. septangulare* underwent a reduction in cover.

Table 8. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Dyer Pond along transects between 2010 and 2020. Values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5 .

Species	Transects (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Juncus militaris</i> ^b	0.0	0.4	42.0	~
<i>Eleocharis acicularis</i>	0.0	0.2	69.6	~

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Table 9. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Dyer Pond within boxplots between 2010 and 2020. Values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5.

Species	Boxplots (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Eriocaulon septangulare</i>	1.52	0.76	36.3	↓
<i>Juncus militaris</i> ^b	0.02	1.52	70.1	↑

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Great-T Pond

Great-T Pond transect and boxplot start points are illustrated below (Figure 8).

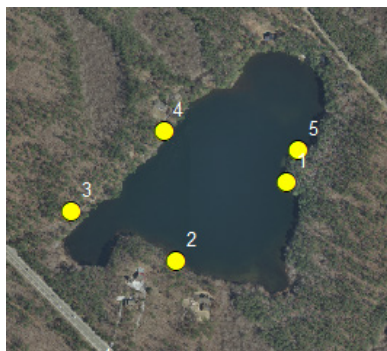


Figure 8. Great-T Pond transect and boxplot shoreline locations.

Transects (1995–2020)

Community composition along transects was significantly different between 1995 and 2020 (ANOSIM $p < 0.01$; Figure 9). A more than twofold increase in *Utricularia* spp. (bladderworts) accounted for ~ 70% of the dissimilarity between the 1995 and 2020 surveys, with transects 1–3 exhibiting the most change (Figure 9, Table 10).

Non-metric MDS

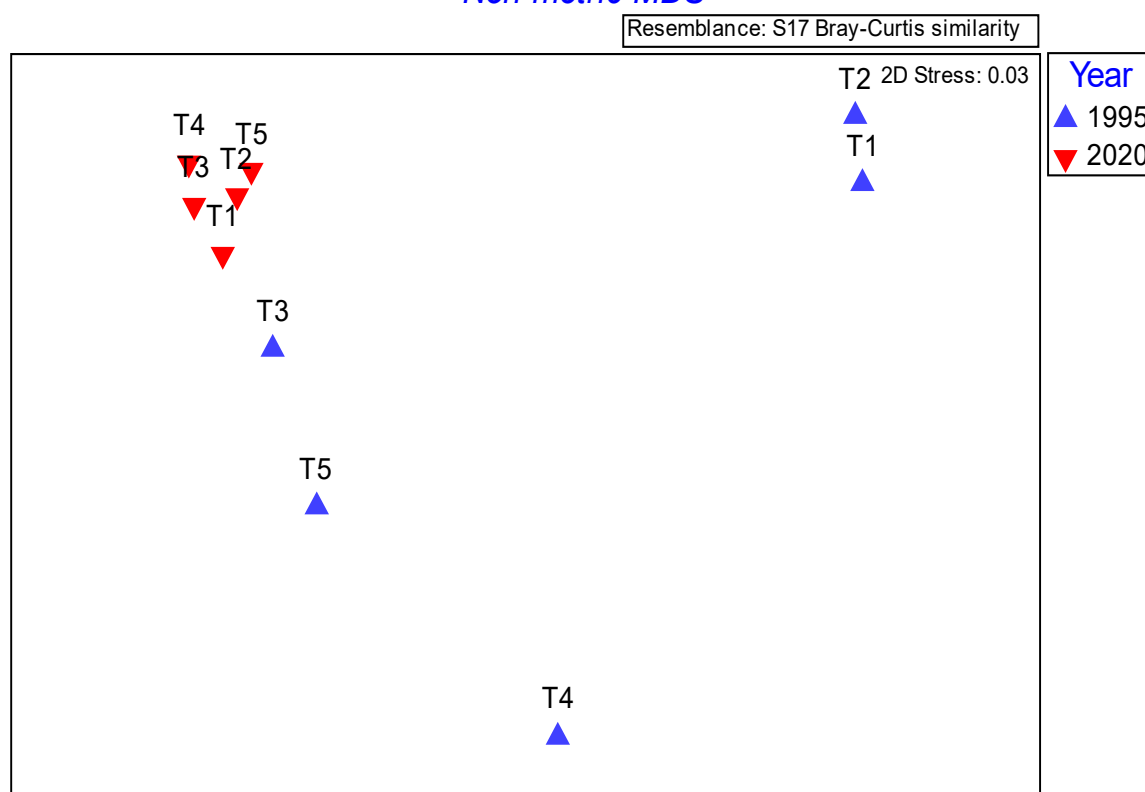


Figure 9. Species richness by survey year in transects between 1995 and 2020.

Table 10. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Great-T Pond along transects between 2010 and 2020. (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Transects (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Utricularia</i> spp.	6.8	62.1	70.2	↑

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

Transects & Boxplots (2010–2020)

The dramatic increase in *Utricularia* observed along transects since 1995 was also evident between 2010 and 2020 (ANOSIM $p < 0.01$) (Figure 10; Table 11). In contrast, *Myriophyllum* spp. almost disappeared. The boxplots also demonstrated significant change, particularly at sites 1, 2, and 4 ($p < 0.01$; Figure 15). Like the transects, a large increase in *Utricularia* spp. and a reduction in *Myriophyllum* spp. (*M. humile* and *M. tenellum*) was documented (Table 12).

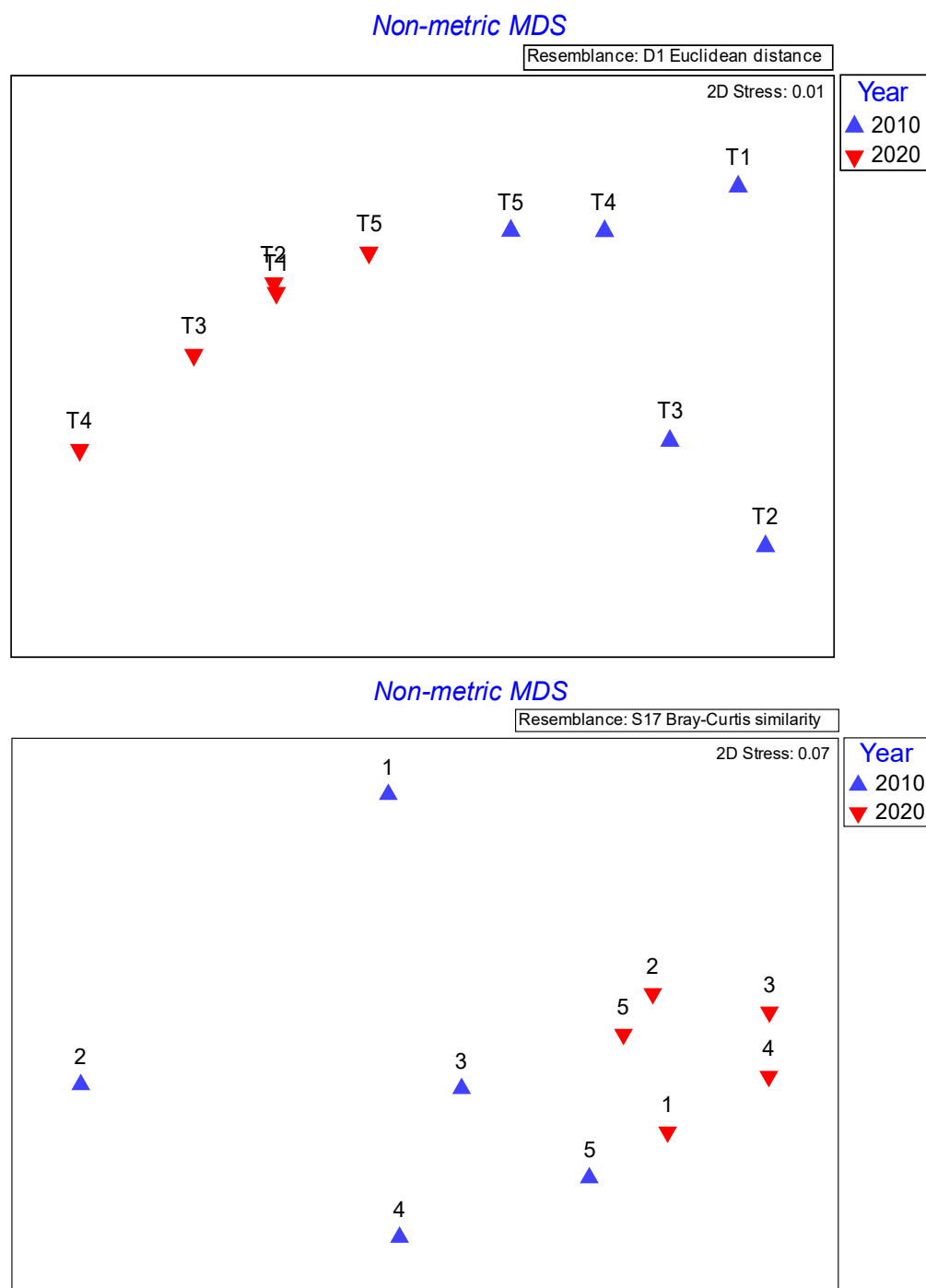


Figure 10. nMDS of pond species composition along Great-T Pond transects (left) in 1995 vs. 2020 and box plots (right) (2010–2020) (alpha-numeric and numeric labels indicate the specific transects or boxplot locations, respectively).

Table 11. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Great-T Pond along transects between 2010 and 2020. (shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Transects (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Utricularia</i> spp. ^b	15.2	62.1	66.8	↑
<i>Myriophyllum</i> spp. ^b	12.6	0.1	82.2	↓

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Table 12. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Great-T Pond within boxplots between 2010 and 2020. (shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Boxplots (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Utricularia</i> spp. ^b	20.4	65.0	55.4	↑
<i>Myriophyllum</i> spp. ^b	12.8	1.6	70.3	↓

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Great-W Pond

Great-W Pond transect and Boxplot start points are illustrated below (Figure 11).

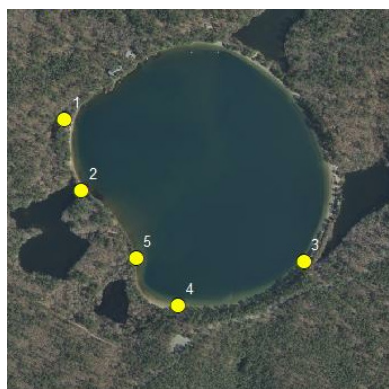


Figure 11. Great-W Pond transect and boxplot shoreline locations.

Transects (2005–2020)

In Great-W, no statistically significant vegetation changes along the transects were evident between 2005 and 2020 (ANOSIM $p=0.94$). Minor changes in the abundance and distribution of *L. dortmanna* and *J. militaris* were largely responsible for the shifts in plant communities (Table 13).

Table 13. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Great-W Pond along transects between 2010 and 2020. (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Transects (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Lobelia dortmanna</i>	11.1	11.3	50.5	~
<i>Juncus militaris</i>	4.1	4.5	67.0	~

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

Transects & Boxplots (2010–2020)

Like the above, no vegetation change was observed along the transects during the shortened time period of analysis (ANOSIM $p=0.99$). The boxplots also remained unchanged between 2010 and 2020 (ANOSIM $p=0.94$) (Tables 14 and 15).

Table 14. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Great-W Pond along transects between 2010 and 2020. (shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Transects (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Lobelia dortmanna</i> ^b	11.1	11.3	61.2	~
<i>Juncus militaris</i> ^b	1.0	4.5	72.5	↑

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Table 15. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Great-W Pond within boxplots between 2010 and 2020. (shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Boxplots (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Lobelia dortmanna</i> ^b	11.1	11.3	50.5	~
<i>Juncus militaris</i> ^b	4.1	4.5	67.0	~

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Gull Pond

Gull Pond transect and Boxplot start points are illustrated below (Figure 12).

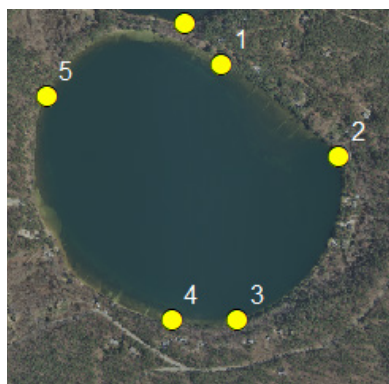


Figure 12. Gull Pond transect and boxplot shoreline locations.

Transects (1995–2020)

Vegetation shifted significantly ($p=0.01$) along Gull Pond transects, primarily due to changes in five taxa (Figure 13; Table 16). *Potamogeton* spp. (pondweed) and *Decodon verticillatus* (waterwillow) were not recorded along the transects in 1995 but were present in significant amounts in 2020, especially along transect 4. Conversely, *Lobelia dortmanna*, *E. acicularis*, and *Gratiola aurea* (golden hedge-hyssop) disappeared from the transects between 1995 and 2020 – most of these changes occurring along transects 3 and 4.

Non-metric MDS

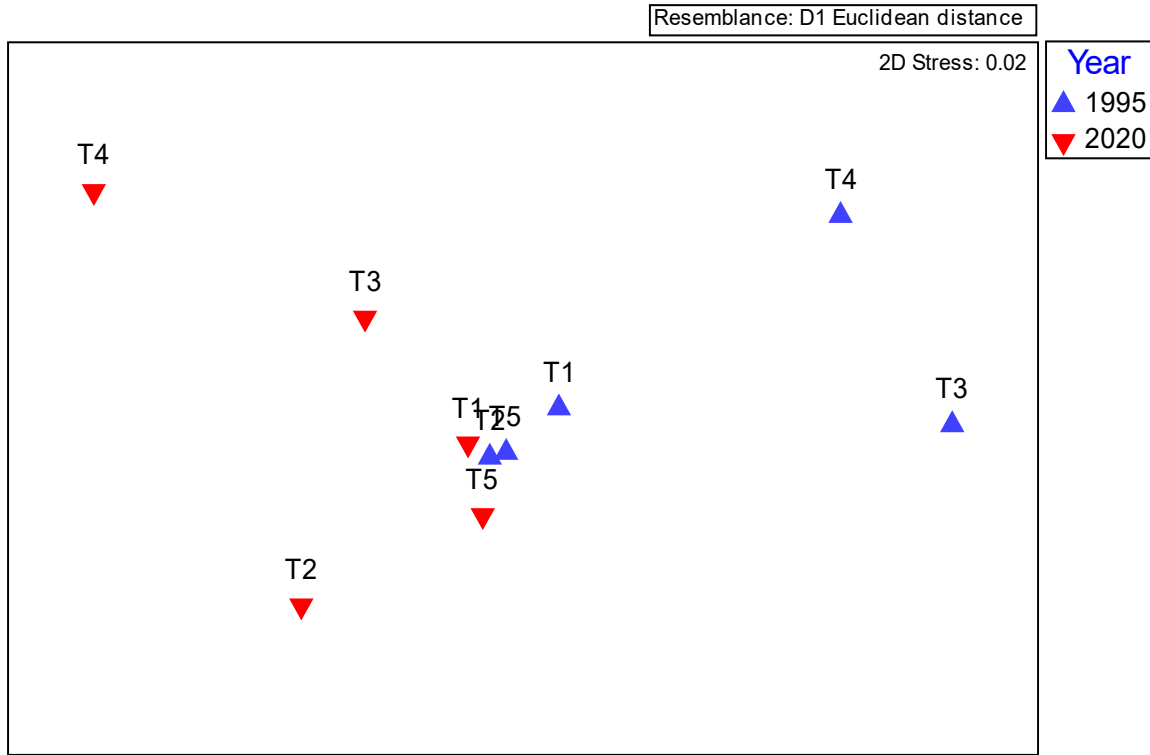


Figure 13. nMDS of pond species composition along Gull Pond transects (left) in 1995 vs. 2020 (alpha-numeric and numeric labels indicate the specific transects).

Table 16. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Gull Pond along transects between 2010 and 2020. (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Transects (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Potamogeton epiphydrous</i>	0.0	7.1	17.8	↑
<i>Lobelia dortmanna</i>	7.6	0.0	35.6	↓
<i>Eleocharis acicularis</i>	3.5	0.0	47.9	↑
<i>Decodon verticillatus</i>	0.0	4.1	60.1	↑
<i>Gratiola aurea</i>	5.41	0.0	71.5	↓

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

Transects & Boxplots (2010–2020)

Significant change was evident along the transects within the shortened timeframe of 2010–2020 (Figure 9) ($p < 0.01$). *Lobelia dortmanna* and *Eriocaulon septangulare* were lost between surveys

while *Potamogeton epihydrous* and *Decodon verticillatus* made new appearances (Table 17). Most of these changes occurred along transects 3, 4, and 5.

Table 17. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Gull Pond along transects between 2010 and 2020. (shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Transects (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Lobelia dortmanna</i> ^b	16.4	0.0	31.6	↓
<i>Eriocaulon septangulare</i> ^b	9.9	0.0	51.1	↓
<i>Potamogeton epihydrous</i>	0.0	7.1	65.0	↑

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

The vegetation in the boxplots also demonstrated a statistically significant shift in composition ($p=0.12$), owing primarily to reductions in *E. septangulare* and *Elatine minima* abundance along transects 2, 3, and 5 (Figure 14). Both positive and negative changes in *L. dortmanna* cover accounted for some of the variation between surveys as well (Table 18). For example, this species increased between surveys along transects 3, but declined along transects 2 and 5.

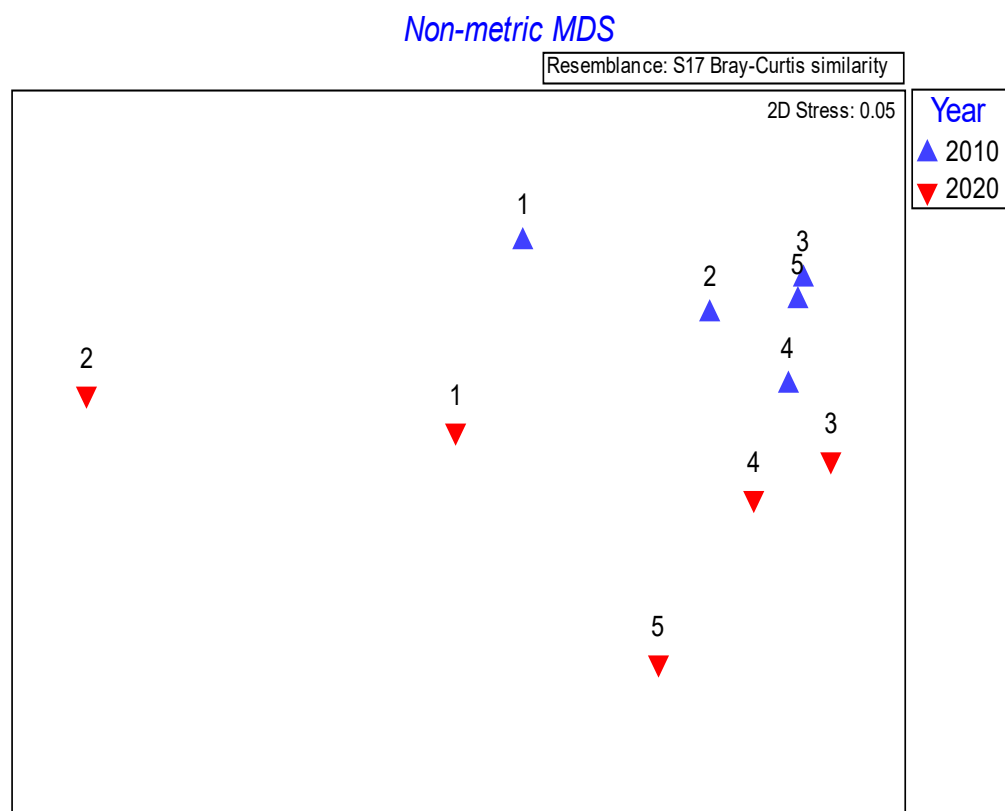
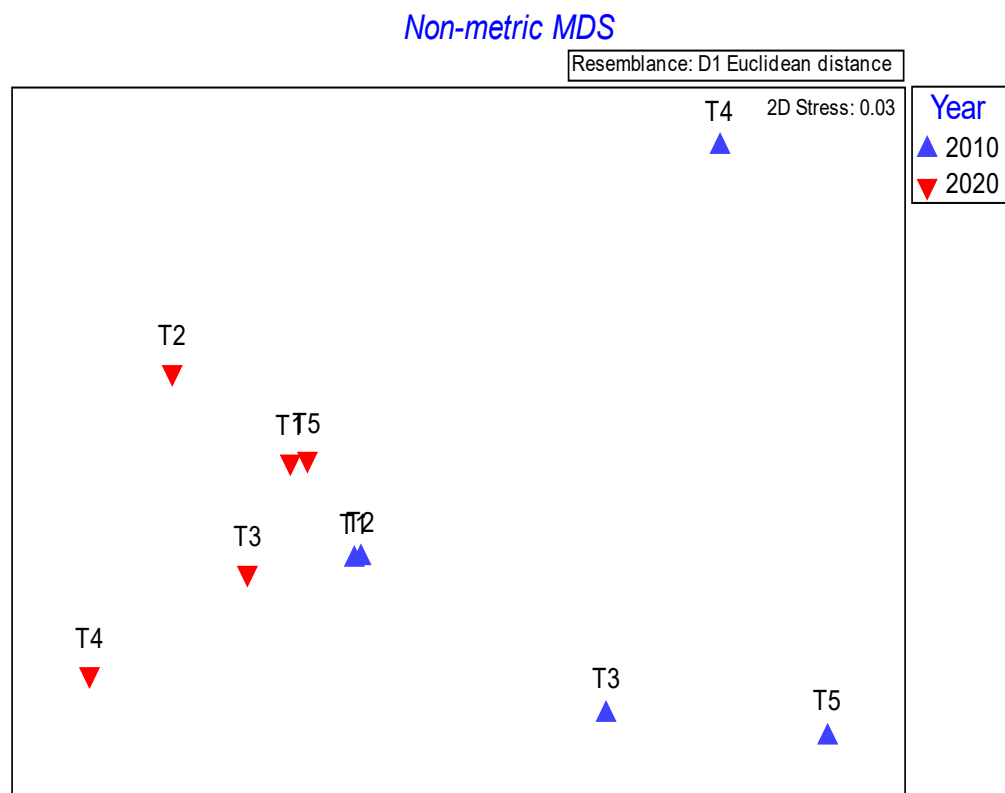


Figure 14. nMDS of species composition along Gull Pond transects (left) in 1995 vs. 2020 and box plots (right) (2010–2020) (alpha-numeric and numeric labels indicate the specific transects or boxplots, respectively).

Table 18. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Gull Pond within boxplots between 2010 and 2020. (shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Boxplots (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Eriocaulon septangulare</i> ^b	18.2	0.1	30.3	↓
<i>Lobelia dortmanna</i> ^b	20.6	20.8	58.5	~
<i>Elatine minima</i>	7.1	1.3	69.8	↓

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Herring Pond

Herring Pond transect and Boxplot start points are illustrated below (Figure 15).

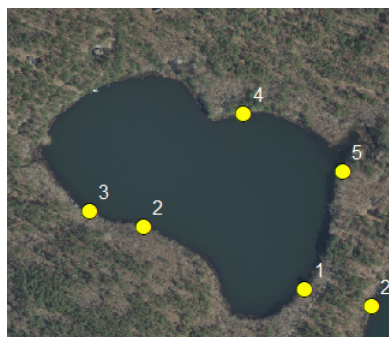


Figure 15. Herring Pond transect and boxplot shoreline locations.

Transects (1995–2020)

In 2012, *Phragmites* that had long established itself in the area encompassing transect 5 was treated with herbicide. Because its decline is a direct result of this activity, this taxon was excluded from the analyses below. Excluding the demise of *Phragmites*, vegetation shifts along Herring Pond transects between 1995 and 2020 were not statistically significant ($p=0.19$). Nonetheless, some notable taxonomic changes occurred (Table 19). Specifically, *N. odorata* was dramatically reduced while *Potamogeton epihydrous* increased in cover. *Decodon verticillata*, *Brasenia schreberi* (water shield), and *Thelypteris palustris* (marsh fern) distributional (more than abundance) shifts accounted for a smaller portion of change.

Table 19. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Herring Pond along transects between 1995 and 2020. (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Transects (1995–2020)			
	1995	2020	Cum.%	Trend ^a
<i>Potamogeton epihydrous</i>	0.0	7.0	19.1	↑
<i>Decodon verticillatus</i>	5.8	4.1	36.0	↓
<i>Nymphaea odorata</i>	7.2	0.4	52.4	↓
<i>Brasenia schreberi</i>	2.3	0.4	62.4	↓
<i>Thelypteris palustris</i>	2.8	0.0	71.3	↓

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

Transects & Boxplots (2010–2020)

Transect vegetation exhibited a significant shift between 2010 and 2020, despite the lack of any longer-term trend between 1995 and 2020 ($p < 0.01$) (Figure 16). *N. odorata* (white waterlily) exhibited a more dramatic reduction along transects 1–4 within the condensed timeframe. This was contrasted by the higher abundance of *P. epihydrous*, largely along transect 4.

Non-metric MDS

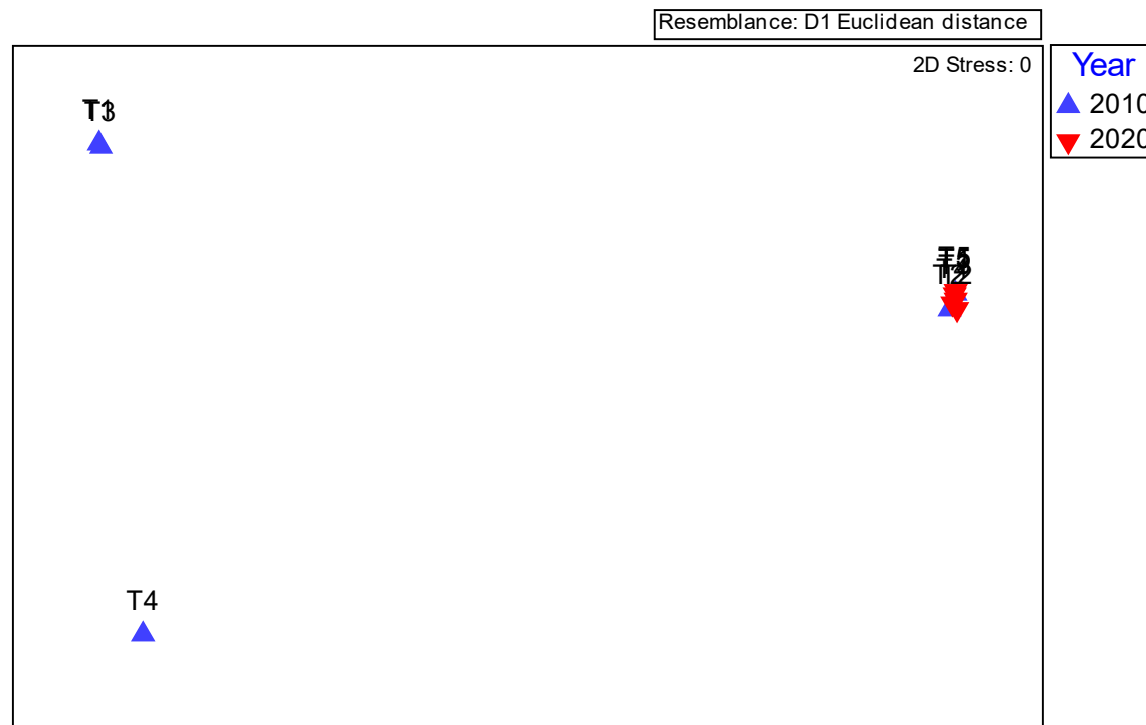


Figure 16. nMDS of species composition along Herring Pond transects in 2010 vs. 2020 (alpha-numeric and numeric labels indicate the specific transects).

In the boxplots, vegetation changes were not statistically significant ($p=0.60$). Nonetheless, the contrasting trends in *N. odorata* and *P. epiphydrus* mentioned above also manifested themselves in the boxplot data, primarily along transects 1–4 for the former and transects 3–4 for the latter (Tables 20 and 21).

Table 20. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Herring Pond along transects between 2010 and 2020. (shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Transects (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Nymphaea odorata</i> ^b	39.39	0.5	58.63	↓
<i>Potamogeton epiphydrus</i> ^b	2.06	7.1	72.85	↑

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Table 21. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Herring Pond within boxplots between 2010 and 2020. (shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Boxplots (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Nymphaea odorata</i> ^b	35.2	3.6	42.3	↓
<i>Potamogeton epiphydrus</i> ^b	2.9	14.3	60.9	↑
<i>Decodon verticillatus</i>	6.5	5.3	69.9	↓

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Higgins Pond

Higgins Pond transect and boxplot start points are illustrated below (Figure 17).

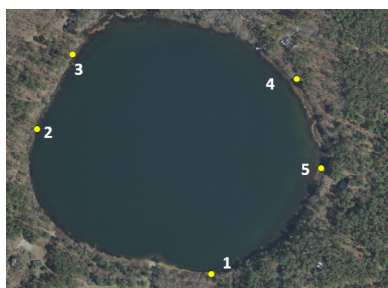


Figure 17. Higgins Pond transect and boxplot shoreline locations.

Transects (2005–2020)

ANOSIM suggested that no significant vegetation change occurred along Higgins Pond transects between 2005 and 2020 ($p=0.14$). The shifts that did occur were mainly due to a large increase in *B. schreberi* concurrent with reductions in *J. militaris* and *N. odorata* (Table 22).

Table 22. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Higgins Pond along transects between 2005 and 2020. (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Transects (2005–2020)			
	2005	2020	Cum.%	Trend ^a
<i>Brasenia schreberi</i>	4.4	24.0	37.6	↑
<i>Juncus militaris</i>	8.2	2.1	54.6	↓
<i>Nymphaea odorata</i>	6.5	0.1	67.9	↓
<i>Pontederia cordata</i>	2.4	0.1	73.5	↓

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

Transects & Boxplots (2010–2020)

Within the 2010–2020 timeframe, transect vegetation exhibited no change ($p=0.15$). Similar to the longer timeline above, *N. odorata* and *J. militaris* declined substantially, while the abundance of *B. schreberi* increased (Table 23) and these trends occurred along all transects.

Unlike the transects, Higgins Pond boxplots did show a statistically significant shift ($p=0.02$) (Figure 18). Moreover, different species were responsible for the variation between surveys. *Isoetes* spp. (quillwort) disappeared from plots along transects 1 through 4. *D. verticillatus* increased in boxplots along transect 4 but decreased along transect 5 (Tables 23 and 24). *E. minima* vanished in boxplots along transect 1 and *J. militaris* declined in plots along all transects.

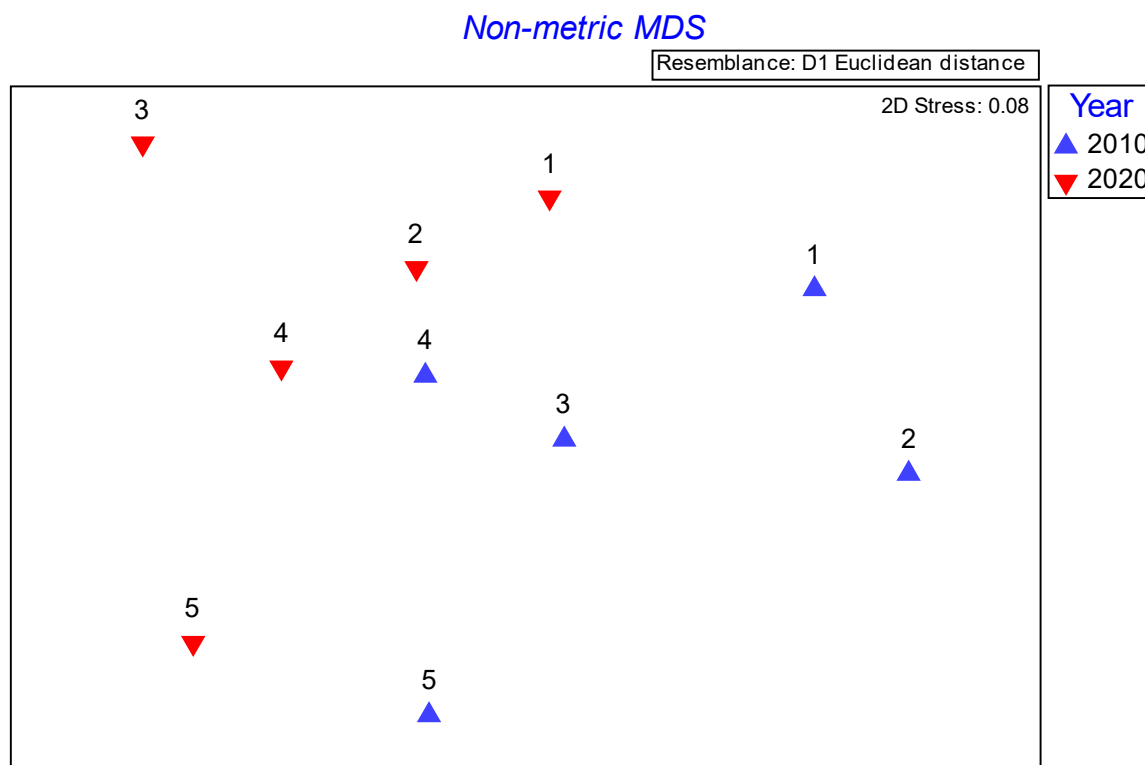


Figure 18. nMDS of species composition within Higgins Pond boxplots in 2010 vs. 2020 (numeric labels indicate the specific boxplots).

Table 23. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Higgins Pond along transects between 2010 and 2020. (shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Transects (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Brasenia schreberi</i> ^b	4.4	24.0	36.3	↑
<i>Nymphaea odorata</i>	6.5	0.1	50.8	↓
<i>Juncus militaris</i>	7.9	2.1	64.7	↓

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Table 24. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Higgins Pond within boxplots between 2010 and 2020. (shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Boxplots (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Elatine minima</i>	19.4	0.0	17.4	↓
<i>Juncus militaris</i>	11.1	0.5	34.4	↓
<i>Isoetes</i> sp.	10.9	0.0	49.8	↓
<i>Decodon verticillatus</i>	4.0	5.9	57.7	↑
<i>Brasenia schreberi</i> ^b	1.9	5.5	65.5	↑

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Horseleeche pond

Horseleeche Pond transect and Boxplot start points are illustrated below (Figure 19).

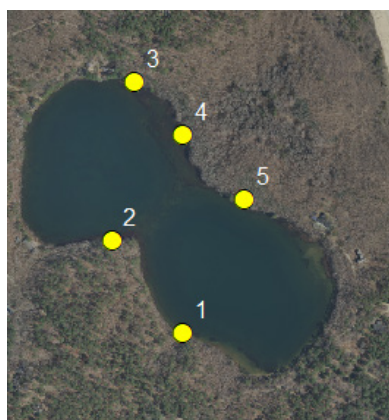


Figure 19. Horseleeche Pond transect and boxplot shoreline locations.

Transects & Boxplots (2010–2020)

Phragmites that occurred along one transect in Horseleeche Pond was treated with herbicide in 2016 – thus, it was excluded from these analyses. The rest of the transect vegetation in this pond has remained statistically unchanged since 2010 ($p=0.85$) *N. odorata*, *L. dortmanna*, *Nymphoides cordata* (little floatingheart) and *J. militaris* (Table 25). Boxplots also failed to show any significant change ($p=0.67$). SIMPER illustrates the species contributing most to the minor vegetation shifts that did occur (Table 26). *N. odorata*, *J. militaris*, and *L. dortmanna*, were important to both transect and boxplot variation between surveys.

Table 25. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Horseleeche Pond along transects between 2010 and 2020. (shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Transects (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Nymphaea odorata</i> ^b	16.5	22.5	29.7	↑
<i>Lobelia dortmanna</i> ^b	9.2	4.6	46.3	↓
<i>Nymphoides cordata</i>	6.8	8.1	59.6	↑
<i>Juncus militaris</i> ^b	9.8	6.6	71.2	↓

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Table 26. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Horseleeche Pond within boxplots between 2010 and 2020. (shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Boxplots (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Nymphaea odorata</i> ^b	17.9	29	25.9	↑
<i>Juncus militaris</i> ^b	15.0	19.7	41.9	↑
<i>Lobelia dortmanna</i> ^b	7.8	8.5	56.1	~
<i>Utricularia</i> sp.	14.8	0.9	68.3	↓

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Long Pond

Long Pond transect and Boxplot start points are illustrated below (Figure 20).



Figure 20. Long Pond transect and boxplot shoreline locations.

Transects (2005–2020)

Since 2005, Long Pond transect vegetation has undergone significant change ($p < 0.01$; Figure 21), mainly from dramatic reductions in the abundance of in *E. acicularis* along all transects, and *J. militaris* from transects 1, 4, and 5 (Table 27).

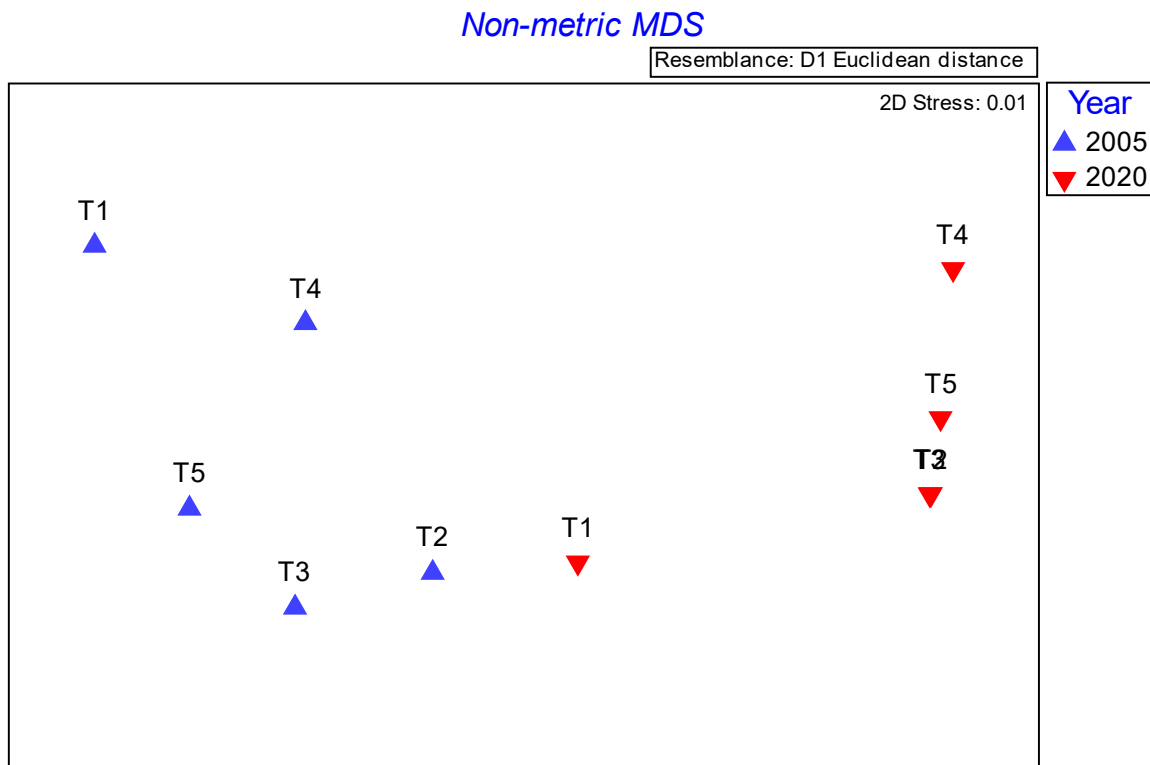


Figure 21. nMDS of species composition along Long Pond transects in 2005 vs. 2020 (alpha-numeric and numeric labels indicate the specific transects).

Table 27. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Long Pond along transects between 2005 and 2020. (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Transects (2005–2020)			
	2005	2020	Cum.%	Trend ^a
<i>Eleocharis acicularis</i>	47.7	5.6	69.4	↓
<i>Juncus militaris</i>	13.3	0.01	87.1	↓

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

Transects & Boxplots (2010–2020)

In the shortened timeframe, losses of the taxa listed above were still detectable along the transects, but not at a significant level ($p=0.52$). Similarly, community-level change in the boxplots was not evident ($p=0.29$). Moreover, the cover of *J. militaris* increased in the boxplots, which contrasts with declining trend along transects (Tables 28 and 29). On the other hand, *L. dortmanna* increased along transects and in boxplots. Reductions in *P. cordata* and *N. cordata* accounted for the other notable species shifts within boxplots.

Table 28. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Long Pond along transects between 2010 and 2020. (shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Transects (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Eleocharis acicularis</i> ^b	11.6	5.6	43.4	↓
<i>Lobelia dortmanna</i> ^b	0.2	5.8	81.4	↑

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Table 29. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Long Pond within boxplots between 2010 and 2020. (shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Boxplots (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Juncus militaris</i>	0.2	7.7	24.4	↑
<i>Pontaderia cordata</i>	4.2	0.02	40.0	↓
<i>Nymphoides cordata</i>	5.9	0.0	55.2	↓
<i>Lobelia dortmanna</i> ^b	0.8	1.8	69.8	↑

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Round-E Pond

Round-E Pond transect and boxplot start points are illustrated below (Figure 22).



Figure 22. Round Pond transect and boxplot shoreline locations.

Transects & Boxplots (2010–2020)

The permanent transects and boxplots have been surveyed for the same period (since 2010). Along the transects of this pond, no significant species composition shifts have occurred ($p=0.64$), although slight declines in the cover of *L. dortmanna*, *Utricularia* spp., and *N. cordata* contributed to some dissimilarity among surveys (Table 30).

Boxplot plant communities also remained relatively unchanged between 2010 and 2020 ($p=0.21$). Of note was the fact that although *Utricularia* declined in the boxplots like it did along transects, *L. dortmanna* and *N. cordata* both increased in cover, which is the opposite trend observed along transects (Table 31).

Table 30. SIMPER analysis showing the taxa accounting for the largest proportion of plant community change in Round-E Pond transects between 2016 and 2020. (shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Transects (2016–2020)			
	2016	2020	Cum.%	Trend ^a
<i>Lobelia dortmanna</i> ^b	17.8	15.8	33.6	↓
<i>Utricularia</i> spp. ^b	13.1	8.8	60.1	↓
<i>Nymphoides cordata</i> ^b	8.9	2.5	76.0	↓

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Table 31. SIMPER analysis showing the taxa accounting for the largest proportion of plant community change in Round-E Pond boxplots between 2016 and 2020. (shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Boxplots (2016–2020)			
	2016	2020	Cum.%	Trend ^a
<i>Lobelia dortmanna</i> ^b	12.9	23.6	34.1	↑
<i>Utricularia</i> spp. ^b	12.6	5.3	54.1	↓
<i>Nymphoides cordata</i> ^b	2.3	12.0	72.1	↑

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Ryder Pond

Ryder Pond transect and boxplot start points are illustrated below (Figure 23).

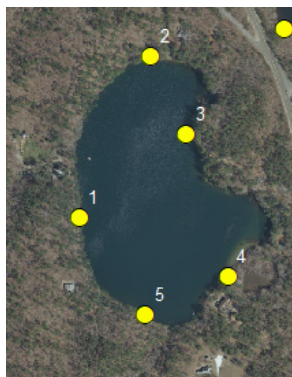


Figure 23. Ryder Pond transect and boxplot shoreline locations.

Transects (1995–2020)

The vegetation along Ryder Pond transects shifted significantly between 1995 and 2020 ($p=0.04$), principally due to changes occurring along transects 1 and 5 (Figure 24). Taxa making the largest contributions to these differences included *L. dortmanna* and *E. acicularis*, both of which increased in cover, although the latter species is only present along transect 5. *N. odorata* disappeared from along transect 5 (Table 32).

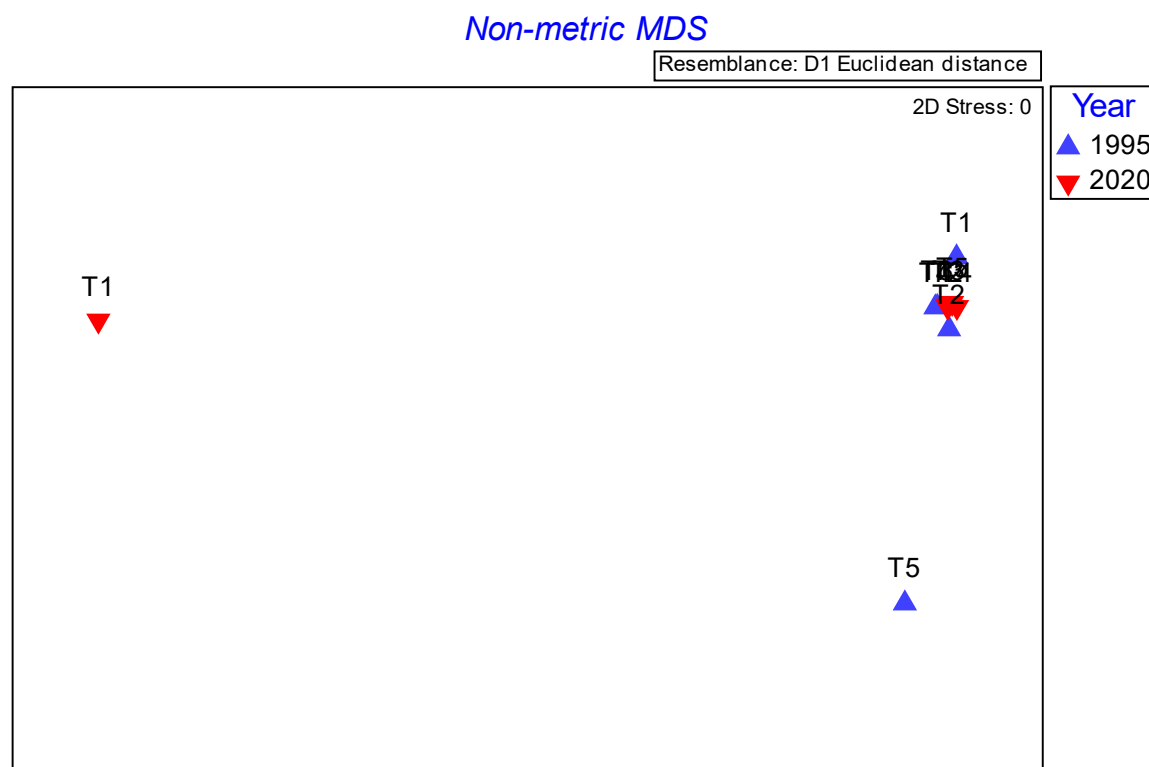


Figure 24. nMDS of species composition along Long Pond transects in 2005 vs. 2020 (T1 through T5 indicate the different transects) (alpha-numeric and numeric labels indicate the specific transects).

Table 32. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Ryder Pond along transects between 1995 and 2020. (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Transects (1995–2020)			
	1995	2020	Cum.%	Trend ^a
<i>Lobelia dortmanna</i>	0.0	0.2	32.8	~
<i>Nymphaea odorata</i>	2.9	0.0	53.1	↓
<i>Eleocharis acicularis</i>	0.01	5.6	70.4	↑

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

Transects & Boxplots (2010–2020)

The same trends captured in the longer time series above were also evident in Ryder Pond vegetation between 2010 and 2020 ($p=0.04$) (Figure 25, Table 33). Vegetation in this pond was different in 2020 than 2010 mainly due to an increase in *E. acicularis* along transect 1 and reduction in *N. odorata* along transect 5, while other changes were minor.

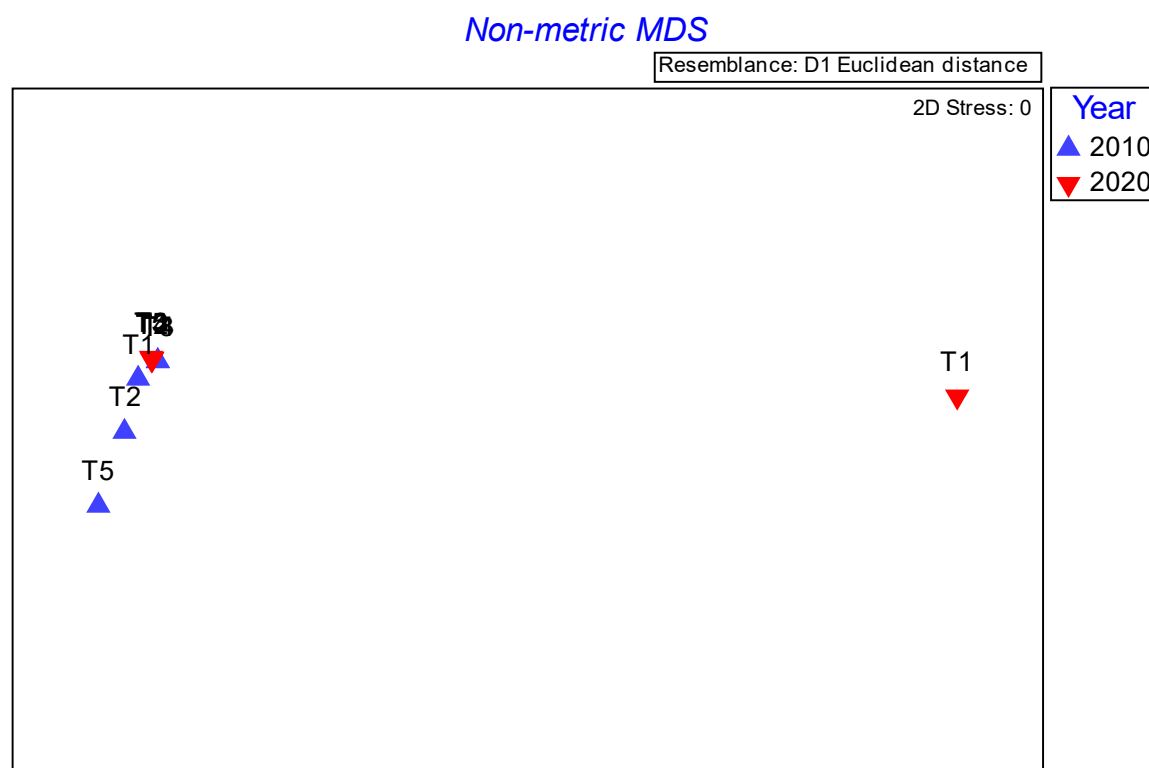


Figure 25. nMDS of species composition along Ryder Pond transects in 2010 vs. 2020 (alpha-numeric and numeric labels indicate the specific transects).

Table 33. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Ryder Pond along transects between 2010 and 2020. (shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Transects (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Lobelia dortmanna</i>	0.0	0.2	35.5	~
<i>Nymphaea odorata</i> ^b	5.7	0.0	60.7	↓
<i>Eleocharis acicularis</i>	0.0	5.6	78.4	↑

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

In the boxplots, however, no significant vegetation shifts were evident ($p=0.28$). *N. odorata* also declined in the boxplots as it did along the transects; however, other species such as *P. cordata*, *J. militaris*, and *Utricularia* spp. also contributed to plant community dissimilarities between surveys, but mainly from changing spatial patterns rather than altered abundance (Table 34).

Table 34. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Ryder Pond within boxplots between 2010 and 2020. (shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Boxplots (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Nymphaea odorata</i> ^b	3.7	0.3	32.1	↓
<i>Pontederia cordata</i>	0.4	0.4	47.6	~
<i>Juncus militaris</i>	0.5	0.3	61.0	~
<i>Utricularia</i> sp.	0.3	0.3	71.1	~

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Slough Pond

Slough Pond transect and toxplot start points are illustrated below (Figure 26).

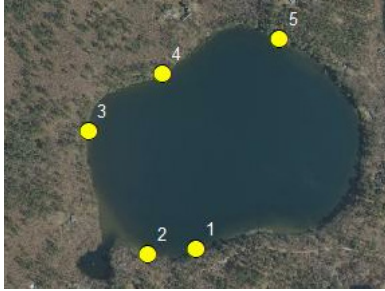


Figure 26. Slough Pond transect and boxplot shoreline locations.

Transects & Boxplots (2010–2020)

In Slough Pond, where transects and boxplots have been surveyed over the same timeframe, vegetation change was negligible ($p=0.73$ and 0.74 , respectively). Minor shifts were in the abundance and distribution of *L. dortmanna*, *Utricularia* spp., and *N. cordata* accounted for most of the dissimilarities between the 2010 and 2020 surveys.

There was similarly no significant change in boxplot vegetation ($p=0.74$). Notably, *Utricularia* spp. and *N. cordata* were listed in both SIMPER analyses as the main contributors to dissimilarities between surveys (Tables 35 and 36).

Table 35. SIMPER analysis showing the taxa accounting for the largest proportion of plant community change in Slough Pond transects between 2010 and 2020. (shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Transects (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Lobelia dortmanna</i>	17.6	15.8	33.6	↓
<i>Utricularia</i> spp. ^b	13.1	8.8	60.1	↓
<i>Nymphoides cordata</i> ^b	8.9	2.5	76.1	↓

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Table 36. SIMPER analysis showing the taxa accounting for the largest proportion of plant community change in Slough Pond boxplots between 2010 and 2020. (shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Boxplots (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Utricularia</i> spp. ^b	24.0	29.6	54.7	↑
<i>Nymphoides cordata</i> ^b	4.3	2.8	71.6	↓

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Snow Pond

Snow Pond transect and Boxplot start points are illustrated below (Figure 27)

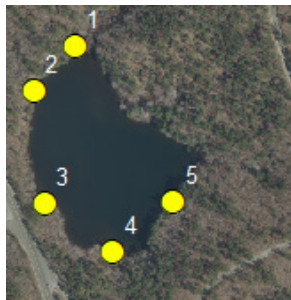


Figure 27. Snow Pond transect and boxplot shoreline locations.

Transects (2005–2020)

At Snow Pond, there has been virtually no change in transect vegetation ($p=0.93$). There were minor changes in the abundance and distribution of *E. acicularis*, *P. cordata*, and *D. verticillatus* (Table 37). *N. odorata* and *J. militaris* exhibited much larger dissimilarities (both declined) between surveys, although there were many discrepancies in trend direction with the longer time series (Table 37).

Table 37. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Snow Pond along transects between 2005 and 2020 (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Transects (2005–2020)			
	2005	2020	Cum.%	Trend ^a
<i>Nymphaea odorata</i>	10.2	5.4	20.5	↑
<i>Eleocharis acicularis</i>	7.4	7.9	40.2	~
<i>Pontederia cordata</i>	4.4	5.0	54.8	↑
<i>Decodon verticillatus</i>	5.4	5.3	67.7	~
<i>Juncus militaris</i>	5.8	1.4	79.9	↓

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

Transects & Boxplots (2010–2020)

Between 2010–2020, there was no significant change in transect vegetation ($p=0.14$). The same taxa (*N. odorata*, *E. acicularis*, *P. cordata*;) were responsible for most of the dissimilarities between surveys (Table 38).

Table 38. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Snow Pond along transects between 2010 and 2020. (shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Transects (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Nymphaea odorata</i>	5.32	5.39	22.91	~
<i>Eleocharis acicularis</i>	0.00	7.88	44.83	↑
<i>Pontederia cordata</i> ^b	0.67	5.04	61.24	↑

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

The same result was observed in the boxplots ($p=0.50$), with *P. cordata*, *Carex* spp., *Potamogeton* sp., *J. militaris*, and *Utricularia* spp. exhibiting the largest shifts in abundance and distribution, albeit these were only minor changes (Table 39). With the exception of *P. cordata*, different taxa accounted for the change between surveys in both transects vs. boxplots.

Table 39. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Snow Pond within boxplots between 2010 and 2020. (shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots (values are average percent cover; Cum.% is the cumulative percentage of community variation explained by the listed species; trend symbols indicate changes >0.5).

Species	Boxplots (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Pontederia cordata</i> ^b	7.1	1.9	22.2	↓
<i>Carex</i> sp.	2.2	7.8	36.6	↓
<i>Potamogeton</i> sp.	1.2	5.5	49.9	↑
<i>Juncus militaris</i>	0.9	0.1	59.7	~
<i>Utricularia</i> spp.	3.7	1.0	68.3	↓

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Spectacle Pond

Spectacle Pond transect and Boxplot start points are illustrated below (Figure 28).



Figure 28. Spectacle Pond transect and boxplot shoreline locations.

Transects (2005–2020)

Along the transects, ANOSIM showed a significant difference ($p < 0.01$) in vegetation between 2005 and 2020 (Figure 29), mainly due to a large increase in the abundance of *Utricularia* spp. along all transects, a trend that has been noticeable across much of this pond (Table 40).

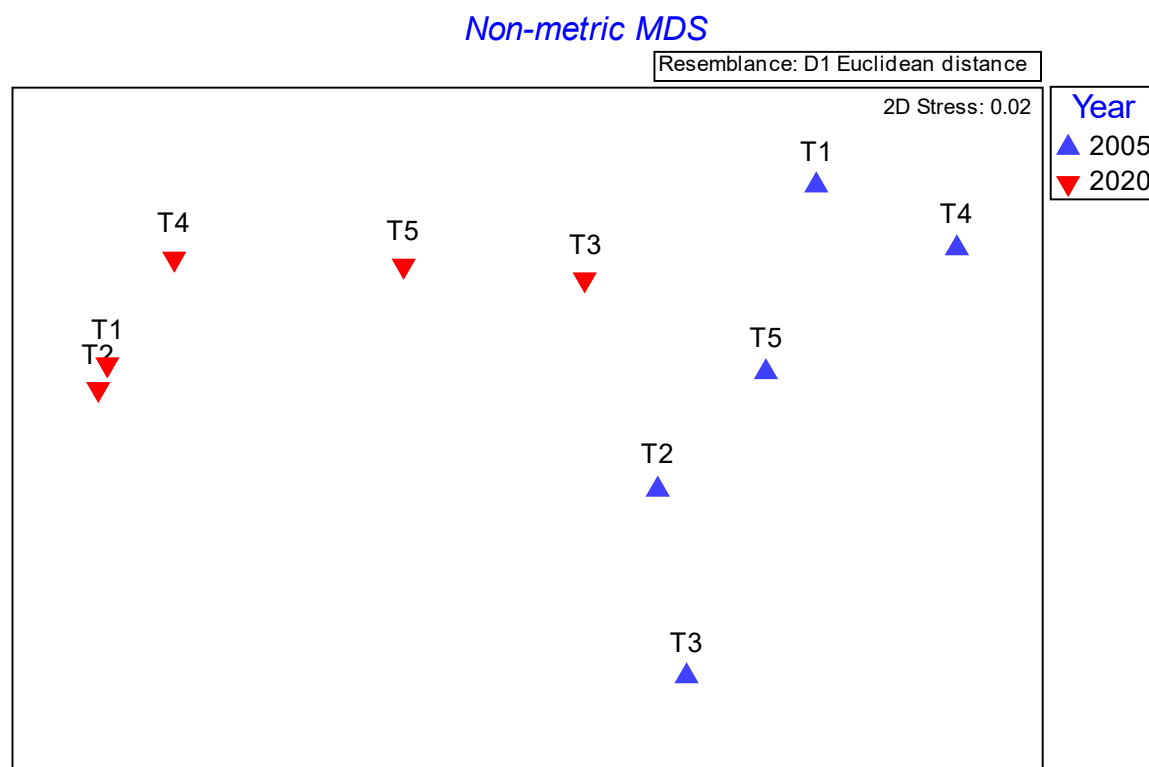


Figure 29. nMDS of species composition along Spectacle Pond transects in 2010 vs. 2020 (alpha-numeric and numeric labels indicate the specific transects).

Table 40. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Spectacle Pond along transects between 2005 and 2020.

Species	Transects (2005–2020)			
	2005	2020	Cum.%	Trend ^a
<i>Utricularia</i> spp.	10.7	41.0	72.7	↑

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

Transects & Boxplots (2010–2020)

Along the shortened timeline the increase in *Utricularia* spp. along all transects similarly produced a significant ANOSIM result ($p < 0.01$) (Figure 30). The boxplots also detected a shift in *Utricularia* spp., although the changes were not statistically significant ($p = 0.74$) (Table 41). A 50% loss of *N. cordata* also contributed to the changes in boxplot vegetation, although this was not enough to influence the statistical significance of overall community change (Table 42).

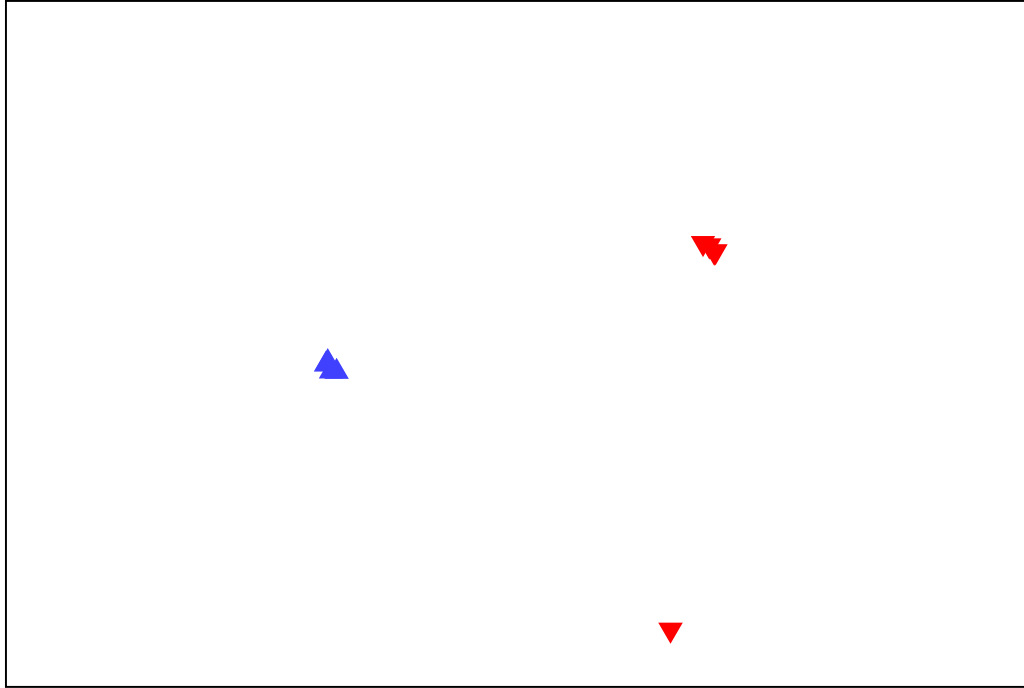


Figure 30. nMDS of species composition along Spectacle Pond transects (left) in 2010 vs. 2020 (alpha-numeric and numeric labels indicate the specific transects).

Table 41. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Spectacle Pond along transects between 2010 and 2020. Shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots.

Species	Transects (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Utricularia</i> sp. ^b	0.0	20.39	70.61	↑

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Table 42. SIMPER analysis showing the taxa accounting for the largest proportion of aquatic vegetation change in Spectacle Pond within boxplots between 2010 and 2020. Shaded rows indicate taxa contributing most to plant community change that were common to both the transects and boxplots.

Species	Transects (2010–2020)			
	2010	2020	Cum.%	Trend ^a
<i>Utricularia</i> sp. ^b	24.02	29.56	54.67	↑
<i>Nymphoides cordata</i>	4.3	2.82	71.63	↓

^a ↑ = trend is increasing, ~ = trend is unknown or the same, and ↓ = trend is decreasing.

^b Indicates taxa contributing most to plant community change that were common to both the transects and boxplots (cells also shaded in gray).

Trends in Key Species

Discussed below are taxa that are relatively abundant and widely distributed across CACO kettle ponds (Tables 43 and 44). These species include emergent forbs (*L. dortmanna*) and graminoids (*E. acicularis*, *J. militaris*), and submerged types (*N. odorata*, *Utricularia* spp.).

- Reductions in the cover of *N. odorata* (white waterlily) along transects was observed in Great-T, Ryder, Higgins, and Snow ponds. In the two-dimensional boxplots, this trend was only observed in Herring Pond.
- Large increases in *Utricularia* spp. were observed in Great-T transects and boxplots, and Spectacle Pond transects.
- *E. acicularis* along transects also diminished in several ponds, including along Duck Dyer Gull Long Round and Slough ponds. In boxplots, it was lost at both Higgins and Slough ponds.
- *J. militaris* has undergone a variety of short-term changes. There have been reductions along transects in Great-T, Higgins, Long, and Snow ponds. However, the boxplots only exhibited a reduction in Higgins Pond. Moreover, it increased in coverage in Great-T and Long boxplots.
- *L. dortmanna* cover along the transects in Gull Pond has decreased, contrasted by an increase in Long Pond transects and in Great-W and Round-E boxplots.

Table 43. Average mid-point percentage values of select individual taxa along transects by pond and survey year.

Species	Survey Year	Duck	Dyer	Gr-T	Gr-W	Gull	Herr	Hig	HL	Long	Rnd-E	Ryd	Slough	Snow	Spec
N. odo	1995	0.00	–	7.20	–	0.00	7.20	–	–	–	–	2.90	–	–	–
	2005	0.00	0.00	9.50	0.00	0.00	13.10	6.50	–	0.00	–	10.20	–	10.20	0.30
	2010	0.00	0.00	6.40	0.00	0.00	39.40	6.50	16.50	0.00	0.00	5.70	0.00	5.30	0.00
	2016	0.00	0.00	1.00	0.00	0.00	14.60	2.30	2.20	0.00	1.70	0.00	0.00	3.30	0.00
	2020	0.00	0.00	1.80	0.30	0.30	0.40	0.10	22.60	0.00	1.60	0.00	0.00	5.40	0.50
E.acic	2005	0.00	0.00	18.40	4.10	0.00	0.00	8.20	–	13.30	–	6.20	–	5.80	0.00
	2010	0.00	0.00	0.10	1.00	0.00	0.00	7.90	9.80	0.90	0.00	0.40	0.00	0.20	0.00
	2016	0.00	0.00	1.70	0.30	0.00	0.00	4.40	1.80	1.50	0.00	1.50	0.00	1.60	0.00
	2020	0.00	0.40	0.80	4.50	0.00	0.00	2.10	6.60	0.00	0.00	0.00	0.00	1.40	0.00
J. mil	1995	0.00	–	6.80	–	0.00	0.40	–	–	–	–	0.00	–	–	–
	2005	0.00	0.00	29.30	0.00	0.00	0.00	0.70	–	0.00	–	0.00	–	0.00	8.90
	2010	0.00	0.00	15.20	0.00	0.00	0.40	0.00	9.80	0.00	–	0.00	0.00	7.60	3.30
	2016	0.00	0.00	25.30	0.00	0.00	0.00	0.70	0.00	0.10	16.00	0.10	0.00	4.50	21.70
	2020	0.00	0.00	62.10	0.00	0.00	0.00	0.00	1.20	0.00	5.30	0.00	0.10	2.00	20.40
Utric	1995	0.00	–	2.20	–	7.60	0.00	–	–	–	–	0.00	–	–	–
	2005	0.00	–	2.20	11.10	26.80	0.00	–	–	0.00	–	0.00	–	0.00	0.10
	2010	2.40	–	1.70	11.10	16.40	0.00	–	9.20	0.20	17.60	0.00	2.20	0.00	0.30
	2016	0.10	–	0.00	4.40	3.10	0.00	–	6.30	1.40	8.60	1.40	2.10	0.40	0.30
	2020	1.30	–	0.70	11.30	0.00	0.00	–	4.60	5.80	15.80	0.20	3.40	0.00	0.00
L. dort	1995	0.01	–	2.15	–	7.58	0.00	–	–	–	–	0.00	–	–	–
	2005	0.00	–	2.18	11.06	26.85	0.00	–	–	0.00	–	0.01	–	0.00	0.07

Table 43 (continued). Average mid-point percentage values of select individual taxa along transects by pond and survey year.

Species	Survey Year	Duck	Dyer	Gr-T	Gr-W	Gull	Herr	Hig	HL	Long	Rnd-E	Ryd	Slough	Snow	Spec
L. dort (cont.)	2010	2.36	–	1.72	11.07	16.41	0.00	–	9.21	0.17	17.57	0.00	2.18	0.00	0.29
	2016	0.11	–	0.03	4.41	3.12	0.03	–	6.30	1.35	8.58	1.35	2.12	0.38	0.29
	2020	1.26	–	0.70	11.33	0.00	0.00	–	4.59	5.82	15.78	0.20	3.37	0.01	0.00

Table 44. Average mid-point percentages of select individual taxa within boxplots by pond and survey year.

Species	Survey Year	Duck	Dyer	Gr-T	Gr-W	Gull	Herr	Hig	HL	Long	R-E	Ryder	Slough	Snow	Spec
N. odo	2010	0.0	0.0	8.1	1.7	0.0	35.2	0.1	18.0	0.0	–	3.7	3.7	0.2	0.0
	2016	0.0	0.0	10.2	0.0	0.0	22.8	0.3	11.4	0.1	2.7	3.7	3.7	4.1	0.0
	2020	0.0	0.0	7.5	0.0	0.0	3.6	0.1	29.0	0.0	2.0	0.3	0.3	0.4	0.8
E. acic	2010	0.2	0.0	0.6	0.0	0.0	0.0	19.4	0.0	0.0	–	0.2	6.3	0.1	0.6
	2016	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	3.0	0.0	0.1	1.4	0.0	0.0
	2020	0.0	0.0	0.0	0.1	1.4	0.0	0.0	0.0	0.1	9.9	0.4	0.0	0.4	0.0
J. mil	2010	0.0	0.0	2.9	0.0	0.0	0.0	11.1	15.0	0.2	–	0.5	0.0	0.9	0.0
	2016	0.0	0.0	3.9	0.0	0.0	0.0	0.7	14.9	0.1	0.0	1.7	0.0	2.7	0.0
	2020	0.0	1.5	9.7	0.0	0.0	0.0	0.5	19.7	7.7	0.0	0.3	0.0	0.1	0.0
Utric.	2010	0.0	0.0	20.4	0.2	0.0	0.4	0.5	14.8	2.3	–	0.3	0.0	3.7	24.0
	2016	0.0	0.0	24.6	0.0	0.2	0.3	0.0	10.2	0.6	12.6	2.3	0.1	0.6	49.9
	2020	0.0	0.0	65.0	0.9	0.7	0.0	0.0	0.9	0.0	5.3	0.3	0.8	1.0	29.6
L. dort	2010	0.3	0.0	5.1	1.7	20.6	0.0	0.0	7.8	0.8	–	0.0	4.0	0.1	0.1
	2016	1.6	0.0	3.1	1.3	3.4	0.0	0.0	9.1	1.7	12.9	1.0	1.9	0.0	0.4
	2020	1.6	0.0	1.9	8.8	20.8	0.0	0.2	8.5	1.8	23.6	0.4	8.1	1.4	0.0

Exotic Species

In 2020 new occurrences of *Phragmites australis* (common reed) were documented in Duck (a single plant, which was immediately removed), Gull, and Higgins ponds. *Phragmites* has previously been treated with herbicide at Herring, Long, Horseleeche, Great-T, Snow, and Ryder – a small portion of which has grown back in certain ponds but will be retreated in September 2022. No state-listed species were observed during 2020. Figure 31 below shows dead *Phragmites* in Horseleeche Pond.



Figure 31. Dead *Phragmites* stems in Horseleeche Pond in 2020 after herbicide treatment in 2018.

Rare Species

Three state-listed rare species that occur in CACO kettle ponds were not found in 2020. These included *Sabatia kennedyanna* (found in 2016 at Great-T), *Drosera filiformis* (found in 2016 at Great-W) and *Sagittaria teres* (quill-leaved arrowhead), which was once abundant but has now been absent for decades (LeBlond 1989).

Discussion of Results and Recommendations for Future Monitoring

There are a wide variety of natural and anthropogenic factors to consider in interpreting the aquatic vegetation data of CACO ponds. Plant communities exhibit natural shifts with variations in growing season conditions (e.g., temperature, solar radiation, pond depth, etc.) from year-to-year (cite). Furthermore, these kinds of short-term responses occur against a backdrop of much larger-scale processes involving regional and global climate change. With respect to the latter, both air quality regulation and air temperatures have probably had the biggest influence on these ponds in recent decades, but it is not clear how these water quality changes may influence macrophyte vegetation.

Trampling of shoreline vegetation is an issue in parts of some ponds, and the main access points have become completely devoid of vegetation. It has been suggested that trampling in sparsely vegetated Duck and Dyer ponds has eliminated much of the littoral zone vegetation. However, many of the monitoring locations are distant from swimming areas and some of these species are considered to be quite tolerant to physical disturbance and even proliferate on disturbed sites, including *Cyperus dentatus*, *Gratiola aurea* and *Eriocaulon aquaticum* (Koning 2005). As a group, isoetid plants are known to be high stress tolerators due to low competitive ability (Europe cites). In Dyer Pond *E. acicularis* was abundant along transects 2 and 3 in 1995 but has since disappeared and these transects are far from the main beach area point and difficult to access. Thus, the decline of taxa such as *E. acicularis* may be due to other factors such as changing acidity, although there is little doubt that in specific locations (access points primarily), there is significant trampling during low water levels (Figure 32).



Figure 32. Abundant footprints in the littoral zone of Horseleeche Pond in 2020 during low water conditions.

As summarized above, there were no trends in key species that were common to more than 2 or 3 ponds. This highlights the idea that, while connected to each other from a landscape perspective, each pond is its own unique entity with its own water chemistry, hydrology, and aquatic biota (references; Smith et al., 2016, Smith and Medeiros 2018, Smith et al., 2018b, Portnoy et al., 2001).

Pond water pH and alkalinity, both of which have increased steadily over recent decades due to improved air quality across the northeastern US (Smith et al., 2016), may also be contributing to vegetation changes. Alkalinity increases the availability of inorganic carbon for photosynthesis and there is evidence that at least some species of *Utricularia* are stress-tolerators in acidic waterbodies but actually grow better at higher pHs (cites). Pondweeds like *Potamogeton* spp. may also increase in response to rising pH (Chmara et al., 2015; Brandrud, 2002).

For obvious reasons, hydrology is a key factor regulating the composition and zonation of pond vegetation. The seasonal and interannual fluctuations in water level that shoreline vegetation experiences depends upon precipitation, evaporation, and evapotranspiration. It also depends upon elevation profiles of the littoral zone and adjacent upland. In places with gentler slopes, changes in vegetation are likely to be more widespread across the littoral zone in response to water level fluctuations. Where plant communities are confined to narrow bands along shorelines with steep subsurface slopes, horizontal changes in plant distributions are less conspicuous.

Plant communities respond to the fluctuations quite rapidly and extreme high water or drought events can have lasting effects. For example, when water levels are low, visitors are able to walk around the littoral zone and a significant amount of trampling occurs (staff observations). In contrast, during very high water years, growth of many species will be suppressed (Van der Valk 1994) and the beds of water lilies will change in shape and spatial pattern (Richards et al., 2011). In addition, CACO kettle ponds do not exhibit the same hydrologic fluctuations although most are getting deeper over the long term despite recent summer droughts (Smith and Medeiros, 2018), although the latter seem to be occurring more frequently. Thus, significant changes can be detected from one survey to another but be confounded by large water-level differences during those particular survey years. From an ecological standpoint, this is precisely why long time series of data are necessary to properly assess which changes are temporary and biologically unimportant, vs. continuous and impactful.

Interpretation of changes in common species

Unlike community-level multivariate analysis, there are insufficient data with which to base any statements about trajectories. The rule of thumb for time-series regression analyses is that a minimum of ten samples should be used when assessing trends. Of course, this criterion is a purely statistical one, not necessarily a biological one. Certain statistically insignificant changes may be very important in a management context – such as rare or invasive species. The interaction between people and water levels is also important for certain sections of shoreline (note that we generally located the vegetation transects away from pond access points where trampling occurs). More littoral zone vegetation tends to be trampled when pond water levels are low since people can walk around much easier. However, such exposure also allows for more seed germination, coupled with accelerated growth of some taxa due to the relief from flooding stress. Notwithstanding, there are some patterns that bear watching:

Reductions in the cover of *N. odorata* along transects was observed in Great-T, Ryder, Higgins, and Snow ponds, although this trend was apparent in boxplots only in Herring Pond. Whether this is a real phenomenon cannot be determined at present. However, field crews have noticed substantial grazing pressure on waterlilies over the course of the summer by various insects (Kouki 1991; Wallace et al., 1991) (Figure 33). This grazing pressure may be changing over time with respect to intensity and/or duration, given the warming air and water temperatures (Smith et al., 2016).



Figure 33. Herbivory on white waterlily (Herring Pond).

E. acicularis also diminished in cover in several ponds, including along Duck, Dyer, Gull, Long, Round-E, and Slough ponds. In the boxplots, it was lost at Higgins and Slough. This taxon is generally found in slightly acidic waterbodies and has been observed growing in waters with pH as low as 2.8 (Morton and Keeley, 1990). However, pond pH and alkalinity values have steadily risen as the acidity of rainwater has decreased (Smith et al., 2016). Accordingly, this species (along with other acid-tolerant species) is likely being lost to those with competitive superiority under less acidic, high alkalinity conditions (Rothrock and Wagner, 1975; Vestergaard, O. and Sand-Jensen, K., 2000a, b). *E. acicularis* and other similarly statured plants also experience physical disturbance from wind waves, which can uproot large beds at times (Figure 34).



Figure 34. *E. acicularis* that has been uprooted and pushed up along the shoreline of Snow pond (2010) following a storm event.

J. militaris appears to have undergone a variety of short-term changes including reductions along transects in Great-T, Higgins, Long, and Snow ponds. Boxplots only exhibited a reduction in Higgins pond, however. Increased coverage was observed in Great-T, and Long boxplots. Reasons for these fluctuations are not clear, nor are the contrasting trends. In past years, however, resident Canada geese have grazed this species so heavily that only damaged, necrotic stems remain (Figure 35).



Figure 35. Photo showing *J. militaris* stand heavily damaged by Canada geese (2016).

L. dortmanna is another taxon common to most CACO ponds. Its abundance along the Gull Pond transects decreased, contrasted by an increase in Long Pond transects, and in Great-W and Round-E boxplots. While these contrasting and inconsuistent trends are somewhat confusing, this species may also be benefitting from reduced acidity (Lazarek, 1986, Lucassen et al., 2016, Larsson 1995, Brouwer 2002).

The proliferation of *Utricularia* spp. in Great-T pond is one of the most conspicuous changes that has occurred over the last decade (Figure 36). In fact, homeowners around this pond have been quite vocal about its abundance in recent years. The change may be due to increased light penetration as underwater transmissivity has increased substantially in Great-T pond (Smith et al. 2018a). Pond water pH and alaklinity, both of which have increased steadily over recent decades (Smith et al., 2016), may further be contributing to the apparent proliferation of bladderwort. Increased alkalinity increases the availability of inorganic carbon for photosynthesis. Moreover, a wide variety of macrophytes can obtain carbon from bicarbonate, which is present in higher concentrations in higher alkalinity lakes. In Europe, increased alkalinity and water transparency (like CACO) resulted in a reduction of isoetids, which include *E. acicularis*, and similar in CACO ponds) and an increase in elodeid (a stem plant that completes its entire life cycle submerged, or with only its flowers above the waterline) species (Vestergaard et al. 2000). The floating-leaved and emergent species are not as strongly affected by alkalinity because they can utilize CO₂ from the atmosphere once above the water surface (Alexander et al. 2008).



Figure 36. Photos showing dense stands of *Utricularia* that have proliferated across Great-T Pond (2020).

Water temperature is another key variable influencing aquatic macrophytes. Submerged and emergent macrophytes commonly increase growth in response to warming temps – presumably since they are immersed in it, unlike many emergent species that experience much more variable air temperatures (Dar et al., 2014; Zhang et al., 2019). Warming has increased the strength and duration of thermal stratification (Smith et al., 2018), which itself can have consequences on phosphorus release from sediments, and thus plant and algae growth.

Recommended Changes to Monitoring Methodology

CACO has engaged in some form of kettle pond vegetation monitoring for 27 years, since the first iteration of a monitoring scheme was developed by Roman et al. (2001). Over this time, much has been learned. Listed below are several recommendations based on the collective experience of both field crews and the results of data analyses and interpretation.

Line-intercept Monitoring

The line intercept method of collecting data along transects is likely documenting changes/trends that are either the result of inconsistent line placement and/or minor, unimportant spatial shifts in vegetation distribution. In addition, there are shifts in the distributions of plants along elevation gradients in response to water level during the growing season. In addition, more species were generally detected in the boxplots as shown in Table 45. Accordingly, it is this author's recommendation that the monitoring should focus on the existing boxplots while adding more sampling sites along the shorelines of each pond for better spatial coverage. The existing line-transect data is still useful because they can always be re-surveyed at any point in the future.

Table 45. Number of taxa by survey method recorded between 2010 and 2020 (note that some "taxa" refers to some groups species collectively by genus such as *Utricularia* spp.).

Pond	Transects	Boxplots	Difference
Duck	5	7	+2
Dyer	8	10	+2
Great-T	15	19	+4
Great-W	15	22	+7
Gull	25	20	-5
Herring	24	34	+10
Higgins	28	40	+12
Horseleech	19	24	+5
Long	8	17	+9
Round-E	6	9	+3
Ryder	8	13	+5
Slough	12	21	+9
Snow	17	17	-
Spectacle	12	16	+4

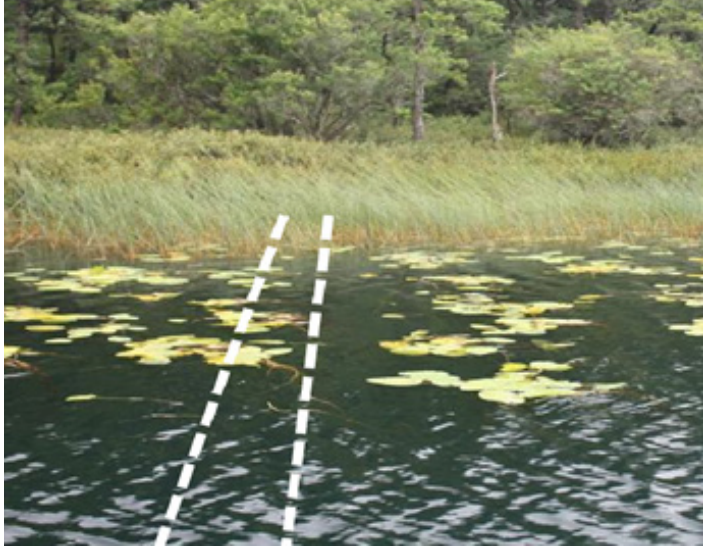


Figure 37. Illustration showing how a slight shift in transect bearing for line transects could significantly alter the abundance of certain vegetation due to spatial variability. In this photo, for example, a slight angle in the line transect can translate into a large or small cover value for the floating waterlily (*Nuphar luteum* in this case).

Non-vascular, Unrooted Primary Producers

While aquatic mosses and plant-like algae are important components of the aquatic biota in ponds, they are highly variable in spatial distributions because they are unrooted and easily disturbed by wind waves, etc. Accordingly, it is the recommendation of this author to confine analyses to macrophyte vegetation

Assessments of Benthic Vegetation in Deep Water

It is very difficult to accurately identify and estimate the cover of submerged vegetation in deeper water. For example, differentiating between *Utricularia* and *Myriophyllum* when visibility is low, the plants are covered with epiphytic algae as in Figure 38 below. In addition, it is extremely difficult to figure out whether the vegetation one is assessing on the bottom is actually right underneath the line transect floating on the surface. Moreover, the bottom gets stirred up as one works impairing visibility. Furthermore, the ends of some transects are quite deep and it is very difficult to get down to the bottom and, while holding one's breath, make visual assessments of cover. Accordingly, it is recommended that transects be monitored out to a maximum depth of 2 m or 15 m of horizontal transect, whichever comes first.



Figure 38. Underwater photo showing *Utricularia* spp. and other vegetation covered with periphytic algae.

Conclusions

Certain ponds have undergone significant alterations in macrophyte species composition over the last several decades or less, while others have remained relatively stable. This may be the result of both short- and long-term bottom-up/top-down pressures including human disturbance. Over longer time scales, CACO kettle pond vegetation is probably responding to atmospheric warming, dimensioned acidity, increasing alkalinity, and changing hydrology

Many of the significant increases or decreases in cover are restricted to just one or two transects, and sometimes the changes in individual taxa contrast each other among the different transects.

One-dimensional line-intercept transects are likely detecting changes that are not real on any meaningful spatial scale. On the other hand, the number of boxplot sites should be increased to obtain much better spatial resolution. Accordingly, we propose increasing the number of box plot sites in each pond from five to ten.

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1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525