



Assessment of Vegetation Changes between 2007 and 2017 in Permanent Freshwater Ponds of the Province Lands, Cape Cod National Seashore

Natural Resource Report NPS/CACO/NRR—2020/2058



ON THE COVER

Pond in the Province Lands region of Cape Cod National Seashore (Provincetown)

Photo by Stephen Smith

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Contents

	Page
Figures.....	vi
Tables.....	ix
Executive Summary	xi
Acknowledgments.....	xii
Introduction.....	1
Description of resource.....	1
Threats and rationale for long term monitoring.....	1
Objectives of monitoring.....	2
Methods.....	3
Study area	3
Establishment of transects and box-plots for assessment if vegetation.....	3
Transect and box-plot vegetation surveys	4
Transect depth profiles	4
Sediment properties	4
Water quality	4
Statistical analysis	5
Results.....	6
Transects.....	6
Species richness – all ponds	6
Box plots – all ponds	6
Transects by pond.....	10
Bennett Pond plant cover by species	10
Bennett Pond species frequencies	11
Clapps-Round cover by species.....	12
Clapps-Round species frequencies.....	13
Clapps Pond cover by species	13

Contents (continued)

	Page
Clapps Pond species frequencies.....	14
Clapps-Round3 cover by species.....	15
Clapps-Round3 species frequencies.....	15
Grassy1 cover by species.....	16
Grassy1 species frequencies.....	17
Grassy4 species by cover.....	18
Grassy4 species frequencies.....	18
Grassy6 cover by species.....	19
Grassy6 species frequencies.....	20
Great Pond cover by species.....	20
Great Pond species frequencies.....	21
Lily1 cover by species.....	22
Lily1 species frequencies.....	22
Lily2 cover by species.....	23
Lily2 species frequencies.....	24
Little Bennett cover by species.....	24
Little Bennett species frequencies.....	25
P26 cover by species.....	25
P26 species frequencies.....	26
Pasture1 cover by species.....	26
Pasture1 species frequencies.....	27
Pasture3 cover by species.....	27
Pasture3 species frequencies.....	28
Pasture4 cover by species.....	29
Pasture4 species frequencies.....	29
Box Plots.....	30

Contents (continued)

	Page
Bennett pond.....	30
Clapps-Round Pond.....	31
Clapps Pond.....	32
Clapps-Round3 Pond.....	32
Grassy1 Pond.....	33
Grassy4 Pond.....	34
Grassy6 Pond.....	35
Great Pond.....	35
Lily1 Pond	36
Lily2 Pond	37
Little Bennett Pond.....	37
P26 Pond.....	38
Pasture1 Pond	38
Pasture3 Pond	39
Pasture4 Pond	40
Rare and exotic species	40
Environmental variables.....	40
Soil properties.....	40
Surface water quality.....	42
Water depth	44
Relationships among variables	44
Discussion.....	46
Conclusions.....	49
References.....	50

Figures

	Page
Figure 1. Map of Province Lands ponds (April 2001 aerial photo from MassGIS).	3
Figure 2. Diagram of transect and box-plot setup in Province Lands ponds.	4
Figure 3. nMDS of species cover in box-plots by pond in 2007 vs. 2017.	7
Figure 4. nMDS of species cover by plot in Bennett pond; 2007 vs. 2017.	10
Figure 5. nMDS of species frequencies by transect in Bennett pond in 2007 vs. 2017.	11
Figure 6. nMDS of species cover by plot in Clapps-Round Pond in 2007 vs. 2017.	12
Figure 7. nMDS of species frequencies by transect in Clapps-Round pond in 2007 vs. 2017.	13
Figure 8. nMDS of species cover by plot in Clapps pond in 2007 vs. 2017.	14
Figure 9. nMDS of species frequencies by transect in Clapps pond in 2007 vs. 2017.	14
Figure 10. nMDS of species cover by plot in Clapps-Round3 pond, 2007 vs. 2017.	15
Figure 11. nMDS of species frequencies by transect in Clapps-Round3 pond; 2007 vs. 2017.	16
Figure 12. nMDS of species cover by plot in Grassy1 pond in 2007 vs. 2017.	17
Figure 13. nMDS of species frequencies by transect in Grassy1 pond in 2007 vs. 2017.	17
Figure 14. nMDS of species cover by plot in Grassy4 pond in 2007 vs. 2017.	18
Figure 15. nMDS of species frequencies by transect in Grassy4 pond; 2007 vs. 2017.	19
Figure 16. nMDS of species cover by plot in Grassy6 pond in 2007 vs. 2017.	19
Figure 17. nMDS of species frequencies by transect in Grassy6 pond in 2007 vs. 2017.	20
Figure 18. nMDS of species cover by plot in Great pond in 2007 vs. 2017.	21
Figure 19. nMDS of species frequencies by transect in Great pond in 2007 vs. 2017.	21
Figure 20. nMDS of species cover by plot in Lily1 pond in 2007 vs. 2017.	22
Figure 21. nMDS of species frequencies by transect in Lily1 pond in 2007 vs. 2017.	23
Figure 22. nMDS of species cover by pond in 2007 vs. 2017.	23
Figure 23. nMDS of species cover by pond in 2007 vs. 2017.	24
Figure 24. nMDS of species cover by plot in Little Bennett pond; 2007 vs. 2017.	25

Figures (continued)

	Page
Figure 25. nMDS of species cover by plot in P26 pond; 2007 vs. 2017.....	25
Figure 26. nMDS of species frequencies by transect in P26 pond; 2007 vs. 2017.	26
Figure 27. nMDS of species cover by plot in Pasture1 pond in 2007 vs. 2017.	26
Figure 28. nMDS of species frequencies by pond in 2007 vs. 2017.....	27
Figure 29. nMDS of species cover by pond in 2007 vs. 2017.	28
Figure 30. nMDS of species frequencies by transect in Pasture3 pond in 2007 vs. 2017.	28
Figure 31. nMDS of species cover by plot in Pasture4 in 2007 vs. 2017.	29
Figure 32. nMDS of species frequencies by transect in Pasture4 pond; 2007 vs. 2017.	30
Figure 33. nMDS of species cover by transect in Bennett pond in 2007 vs. 2017.	31
Figure 34. nMDS of species cover by transect in Clapps-Round pond in 2007 vs. 2017.....	32
Figure 35. nMDS of species cover by transect in Clapps pond in 2007 vs. 2017.....	32
Figure 36. nMDS of species cover by transect in Clapps-Round3 pond in 2007 vs. 2017.....	33
Figure 37. nMDS of species cover by transect in Grassy1 pond in 2007 vs. 2017.....	34
Figure 38. nMDS of species cover by transect in Grassy4 pond in 2007 vs. 2017.....	34
Figure 39. nMDS of species cover by transect in Grassy6 pond in 2007 vs. 2017.....	35
Figure 40. nMDS of species cover by transect in Great pond in 2007 vs. 2017.....	36
Figure 41. nMDS of species cover by in Lily1 pond in 2007 vs. 2017.	36
Figure 42. nMDS of species cover by transect in Lily1 pond 2007 vs. 2017.	37
Figure 43. nMDS of species cover by transect in Little Bennett pond in 2007 vs. 2017.....	38
Figure 44. nMDS of species cover by transect in P26 pond in 2007 vs. 2017.....	38
Figure 45. nMDS of species cover by transect in Pasture1 pond in 2007 vs. 2017.....	39
Figure 46. nMDS of species cover by transect in Pasture3 pond in 2007 vs. 2017.....	39
Figure 47. nMDS of species cover by transect Pasture4 pond in 2007 vs. 2017.	40
Figure 48. Percent organic matter by weight (%OM) by pond in 2017.....	41
Figure 49. Soil organic matter content (%) by pond and year.	41
Figure 50. Percent nitrogen by weight in soil cores collected from the ponds.	42

Figures (continued)

	Page
Figure 51. Total phosphorus (P) by weight in soil cores collected from transect locations in 2017.	42
Figure 52. Surface water pH in 2007 vs. 2017 by pond.....	43
Figure 53. Surface water conductivity in 2007 vs. 2017 by pond.....	43
Figure 54. Surface water temperature in 2017 by pond (error bars are standard errors of the means).	44
Figure 55. Water depths in 2007 vs. 2017 by pond (error bars are standard errors of the means).	44
Figure 56. Principle Components Analysis (PCA) of select environmental variables among ponds.	45
Figure 57. Relationships between a) soil organic matter and total phosphorus, b) soil organic matter and total nitrogen, c) soil organic matter and surface water pH, and c) mean water depth and surface water conductivity.	45
Figure 58. Map of ponds in close proximity to the Provincetown landfill.	47
Figure 59. Average relative water depths in USGS Provincetown well between 1975 and 2017.....	48

Tables

	Page
Table 1. Species richness by pond in 2007 vs. 2017.....	6
Table 2. SIMPER results for species cover change in box-plots (all ponds pooled) between 2007 and 2017.	7
Table 3. Average percent cover (determined from mid-point % values of cover class scores) of all recorded species in 2007 vs. 2017 from box plots.	8
Table 4. SIMPER results for species cover change in Bennett Pond between 2007 and 2017.....	11
Table 5. SIMPER results for species frequencies in Bennett Pond between 2007 and 2017.....	12
Table 6. SIMPER results for species cover change between 2007 and 2017.....	12
Table 7. SIMPER results for species frequencies in Clapps-Round pond between 2007 and 2017.....	13
Table 8. SIMPER results for species cover change between 2007 and 2017.....	14
Table 9. SIMPER results for species cover change in Clapps-Round3 pond between 2007 and 2017.....	15
Table 10. SIMPER results for species frequencies in Clapps-Round3 pond between 2007 and 2017.....	16
Table 11. SIMPER results for species cover change in Grassy1 pond between 2007 and 2017.....	17
Table 12. SIMPER results for species cover change in Grassy4 pond between 2007 and 2017.....	18
Table 13. SIMPER results for species frequencies between 2007 and 2017.	19
Table 14. SIMPER results for species cover change between 2007 and 2017.....	20
Table 15. SIMPER results for species cover change in Great pond between 2007 and 2017.....	21
Table 16. SIMPER results for species frequencies in Great pond between 2007 and 2017.	22
Table 17. SIMPER results for species cover change between 2007 and 2017.....	22
Table 18. SIMPER results for species frequencies between 2007 and 2017.	23
Table 19. SIMPER results for species cover change between 2007 and 2017.....	24

Tables (continued)

	Page
Table 20. SIMPER results for species cover change in Little Bennett pond between 2007 and 2017.....	25
Table 21. SIMPER results for species cover change in Pasture1 between 2007 and 2017.....	27
Table 22. SIMPER results for species cover change between 2007 and 2017.....	28
Table 23. SIMPER results for species frequencies in Pasture3 between 2007 and 2017.	29
Table 24. SIMPER results for species cover change in Pasture4 between 2007 and 2017.....	29
Table 25. SIMPER results for species frequencies in Pasture4 pond between 2007 and 2017.....	30
Table 26. SIMPER results for species cover change in Bennett pond between 2007 and 2017.....	31
Table 27. SIMPER results for species cover change in Clapps-Round3 pond between 2007 and 2017.....	33
Table 28. SIMPER results for species cover change in Grassy4 pond between 2007 and 2017.....	35
Table 29. SIMPER results for species cover change in Grassy6 pond between 2007 and 2017.....	35
Table 30. SIMPER results for species cover change in box plots between 2007 and 2017.....	37
Table 31. SIMPER results for species cover change in Pasture3 pond between 2007 and 2017.....	39
Table 32. SIMPER results for species cover change in Pasture4 pond between 2007 and 2017.....	40

Executive Summary

Aquatic vegetation in the permanent ponds within the Province Lands region of Cape Cod National Seashore was surveyed from July-August of 2017 based on the previous sampling design and methods of Smith et al. (2008). This long-term monitoring protocol was designed for repeated sampling along permanent transects and 10 x 10 m plots within 15 ponds. Vegetation cover, soil organic matter surface water pH, conductivity, temperature, and water depths were measured and analyzed from these locations.

Two state-threatened species noted in 2007, *Orontium aquaticum* (golden club) and *Carex oligosperma*, were also present in 2017. Three exotic species, *Phragmites australis* (common reed), *Lythrum salicaria* (purple loosestrife), and *Salix cinerea* (gray willow), were also detected. Both *Phragmites* and *Salix* increased in cover, while *Lythrum* much was reduced – likely due to the introduction of *Galerucella* spp. beetles in 2005 as a method of biological control for this species. More generally, plant community composition among ponds differed primarily based on the relative abundances and distributions of three dominant species – *Nymphaea odorata* (white waterlily, increased), *Juncus militaris* (military rush, increased), and *Decodon verticillatus* (water willow, decreased), although on a broader scale most species (66%) exhibited an increase in abundance.

Although highly variable among ponds, species richness increased substantially between 2007 and 2017 and was correlated with the standard error values of water depth means (i.e., higher species richness associated with larger variations in water depths along transects). The large difference (25 cm) in average water levels between 2007 (wetter) and 2017 (drier) is likely one of, if not the, most important factors driving observed changes in plant communities. However, other processes such as natural succession are also continuously forcing vegetation change.

One other aspect of the Province Lands ponds that was investigated was the potential impact of the Provincetown landfill. In this regard, two of the ponds in close proximity and hydrologically down-gradient from the landfill had the two highest concentrations of soil nitrogen (Figures 50, 58). The same pattern was observed for soil TP (Figure 51). The other pond (Bennett) is the closest site to the landfill, but it is unclear how water may be moving in/out of this pond since it appears to largely in the groundwater flow path from a natural, open area to the north (Figure 58). Consequently, whether the landfill has leached nutrients into adjacent ponds is still questionable, but the elevated concentrations of TN and TP in Little Bennet and Duck ponds seem to indicate that there may be at least some nutrient enrichment, and this warrants further investigation.

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Introduction

Description of resource

Much of the northern tip of Cape Cod is a vast system of sand dunes known as the Province Lands. This region of the Cape Cod peninsula began forming ~6,000 years ago as eroding sediments from the Atlantic-facing coastal bluffs were transported north and re-deposited by longshore currents. Sand from the elongating spit was then blown inland to widen the spit and form the characteristic hook of Provincetown. Topographic depressions were carved out by wind scour over time and subsequent sea level rise, which forced the fresh ground water table upwards, has resulted in the seasonal or permanent flooding of some of these depressions. Human activities, including the construction of roads which can impede horizontal flow may have also contributed to the ponding in this area (Winkler 1990).

The permanently flooded ponds in this region of CACO differ from kettle ponds on the glacial outwash plain that arose from depressions made by blocks of glacial ice. Kettle ponds are very deep compared with the Province Lands ponds. In fact, Province Lands ponds are true ponds (in the sense that they are shallow enough to support rooted vegetation throughout their extent) while most of the kettle ponds are technically lakes. Like kettle ponds, however, the Province Lands ponds are an important natural resource at CACO. They contribute to the aesthetic beauty of the region and are, of course, important ecologically. Within these waterbodies, aquatic plant communities thrive in an otherwise desert-like environment. They are one of the last refuges on the outer Cape for several uncommon plant species such as carnivorous pitcher plants and sundews. In addition, they are critical habitat for the reproduction and survival of invertebrates, amphibians (including the state-threatened Eastern Spadefoot Toad and Fowler's toads), and other wildlife. Thus, it is important to understand the structure and function of these ponds and how they are developing over time in order to better predict the future of this resource and to guide management decisions.

Threats and rationale for long term monitoring

Any major change in hydrology could have a significant impact on these ponds, particularly if the town of Provincetown ever decided to extract ground water from town-owned parcels of land within the park boundary. Continued development is also a concern, bringing with it various threats to water quality. In fact, Winkler (1990) reported that Duck and Bennett Ponds may have already been affected by leachate from the nearby Provincetown landfill. Broader threats include many aspects of global warming, especially changes in temperature (and therefore evaporation) and precipitation quantity and quality.

Biological threats include invasions of exotic species. *Lythrum salicaria* (purple loosestrife) has already invaded Great Pond - it was not present in 1977 according to Benedict (1977). The exotic strain of *Phragmites australis* (common reed) also occurs in several ponds and has the potential to spread. Another biological threat includes herbivory by Canada geese, which is thought to be the reason for the long term decline in *Orontium aquaticum* (golden club), a state-threatened species.

Objectives of monitoring

In accordance with the National Park Service's Inventory & Monitoring program to develop species inventories and implement monitoring protocols for all ecosystem types within Park units, the main objectives of this work were to survey and quantitatively assess plant communities in Province

Lands ponds within CACO for the purpose of analyzing long term temporal trends. The work summarized in this report provides a baseline assessment of vegetation, a model for subsequent surveys, and a template for future analysis of change.

Methods

Study area

The area of study for this project was within the Beech Forest area of the Province Lands (Provincetown). Within this forested community there are numerous permanently-flooded, but relatively shallow ponds that support rooted aquatic vegetation throughout their extent. Figure 1 below shows the location and form of these sites.

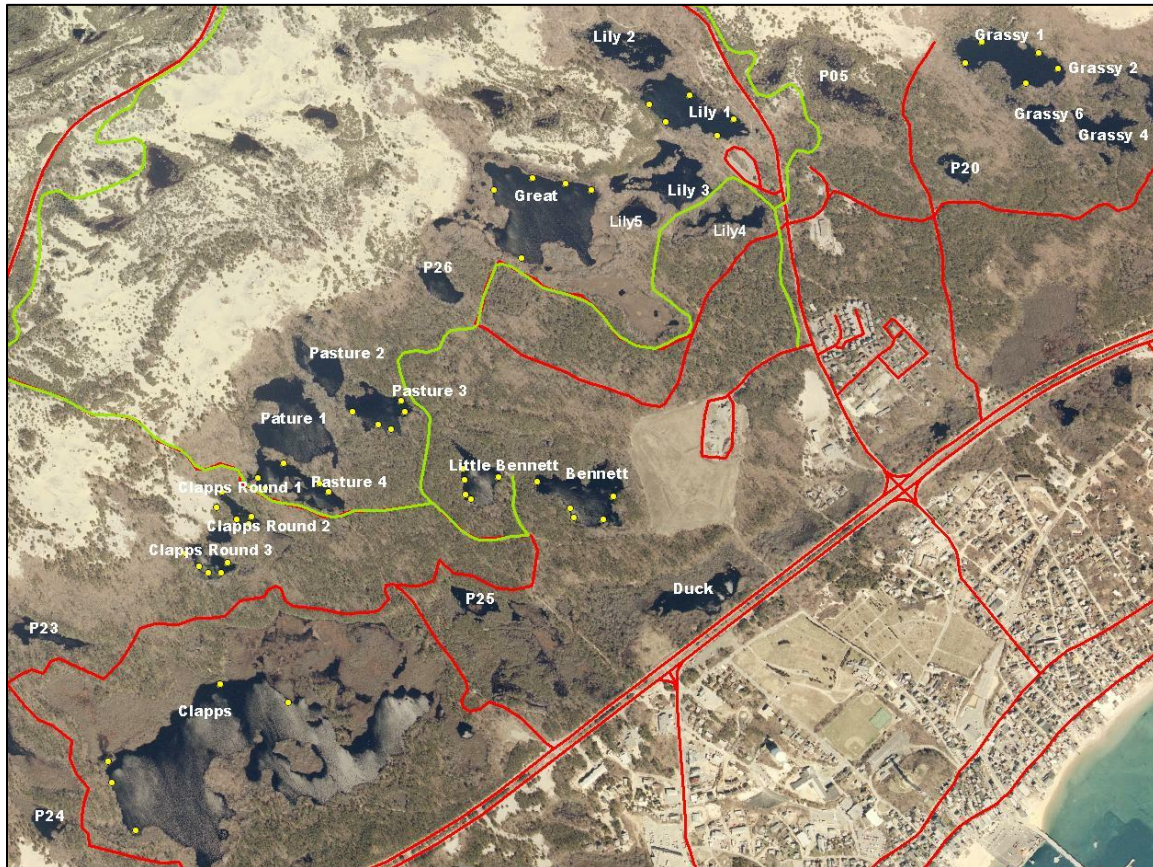


Figure 1. Map of Province Lands ponds (April 2001 aerial photo from MassGIS).

Establishment of transects and box-plots for assessment of vegetation

Fifteen ponds were randomly selected from among the 30+ permanent ponds that occur in the Province Lands Beech Forest Area. These included Lily1, Lily2, Grassy1, Grassy4, Grassy6, Bennett, Little Bennett, Pasture1, Pasture3, Pasture4, P26, Clapps, Clapps-Round1, Clapps-Round-3, and Great. Within each pond in this subset, 5 permanent 20-m transects and 100 m² (10 x 10 m) box-plots were established. To do this, locations were randomly selected from around the perimeter of the pond using ArcGIS 9.1 software. In the field, two PVC pipes were hammered into the pond bottom 10 m apart and roughly parallel with the shoreline at each location. The pipe was placed in emergent vegetation a few meters pondward of the shrub zone due to safety concerns related to the difficulty of working in dense woody vegetation. Looking out pondward, the poles on the observer's left side are

designated the start points for each transect, while both the left and right poles mark the bottom corners for the first box-plot. See Figure 2 for a diagram of the set up.

Transect and box-plot vegetation surveys

Cover by species was estimated visually in contiguous 1-m² plots along the length of the 20-m transects. Cover classes were based on a modified Braun-Blanquet scale (1=0-1%, 2=1-5%, 3=5-10%, 4=10-25%, 5=25-50%, 6=50-75%, 7=75-100%). Plant cover by species was assessed in the same manner in the 10 x 10 m box-plots (Smith et al. 2008).

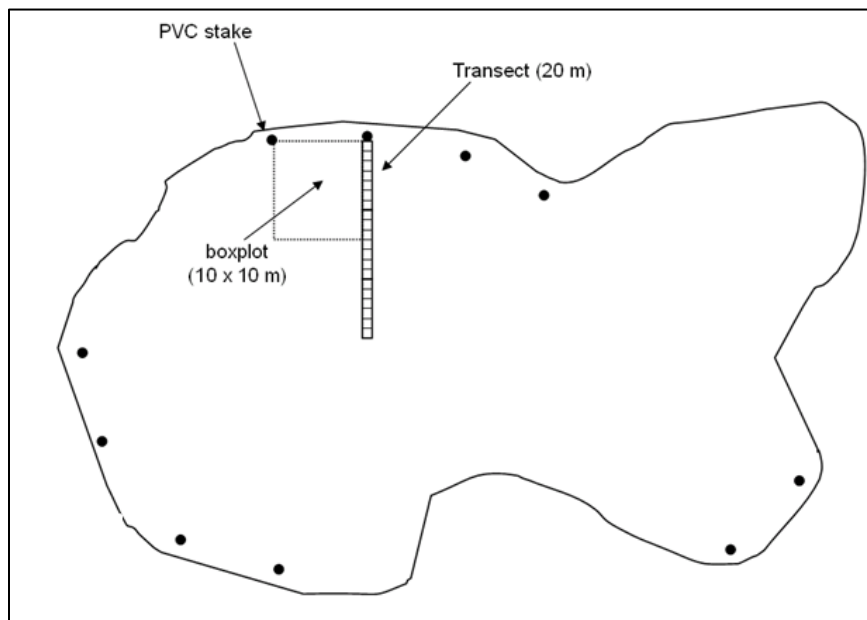


Figure 2. Diagram of transect and box-plot setup in Province Lands ponds.

Transect depth profiles

Water depths (recorded to the nearest cm) were taken manually (using a marked PVC pole) at each meter interval along each 20-m transect in June (as in Smith et al. 2008).

Sediment properties

Sediment cores were extracted from along each of the 20 m transects. Three cores were taken (10 cm depth) at each 5-m transect point along each of the five vegetation transects using a 4.8-cm diameter butyrate cylinder with a sharpened edge. The cores were then transported back to the lab and dried at 80°C to a constant weight. Sub-samples of the homogenized samples (< 2 mm) were then analyzed for organic matter content by weight-loss after ignition in a muffle furnace for 4 hrs. at 500°C. A subset of these samples was then sent to Brookside Laboratories, Inc. (New Bremen, Ohio) for analysis of total nitrogen (TN) and total phosphorus.

Water quality

Surface water pH and conductivity were measured once in August along the mid-points of each transect using calibrated hand-held digital meters (Oakton™).

Statistical analysis

Non-metric multidimensional non-metric scaling (nMDS) of summed cover class values was frequently used to illustrate taxonomic differences among ponds (Clarke 1993). Similarity Percentages Analysis (SIMPER) quantified the contribution of individual species to Bray-Curtis dissimilarities among groups (Primer™ ver. 6). Frequency of occurrence of individual species were also calculated and analyzed in the same way. Mid-point percentage values were calculated from the cover scores in order to calculate total percent cover and changes between surveys. Principle Components Analysis (PCA) was used to illustrate disparities in select environmental variables among ponds. For univariate data, simple linear and non-linear regression analyses were applied.

Results

Transects

Species richness – all ponds

Along the transects, species richness was highly variable among ponds in both years. Generally speaking, there were more positive gains in species than losses. In fact, the only losses occurred in Grassy4, Lily1, and P26 – where species richness declined by 1 taxon. ClasspsRound1, Clapps-Round3, and Bennett had, by far, the most number of species and Little Bennet and P26 the fewest. In total, 36 and 50 species were recorded (all plots, all transects) in 2007 and 2017, respectively.

Table 1. Species richness by pond in 2007 vs. 2017.

Pond	spp. 2007	spp. 2017	Diff
Bennett	10	21	11
Clapps	7	8	1
Clapps-Round1	20	21	1
Clapps-Round3	9	23	14
Grassy1	8	12	4
Grassy4	7	6	-1
Grassy6	2	8	6
Great	11	16	5
Lily1	8	7	-1
Lily2	4	12	8
Little Bennett	1	1	0
P26	2	1	-1
Pasture1	4	10	6
Pasture3	2	6	4
Pasture4	2	5	3
Totals	36	58	22
Means	6.5	10.5	4.0
SE	1.3	1.8	1.2

Box plots – all ponds

According to the box plot surveys, plant species composition changed significantly between 2007 and 2017 overall (ANOSIM: $R=0.20$, $p=0.003$) (Figure 3). The taxa contributing most to the dissimilarities in plant communities between years were: *Eleocharis quadrangulata*, *Dulichium arundinaceum*, *Decadon verticillatus*, *Pontederia cordata*, and *Utricularia cornuta* (Table 2). The total number of taxa observed (all box plots, all ponds) in box plots in 2007 was 42, but this number increased to 64 in 2017.

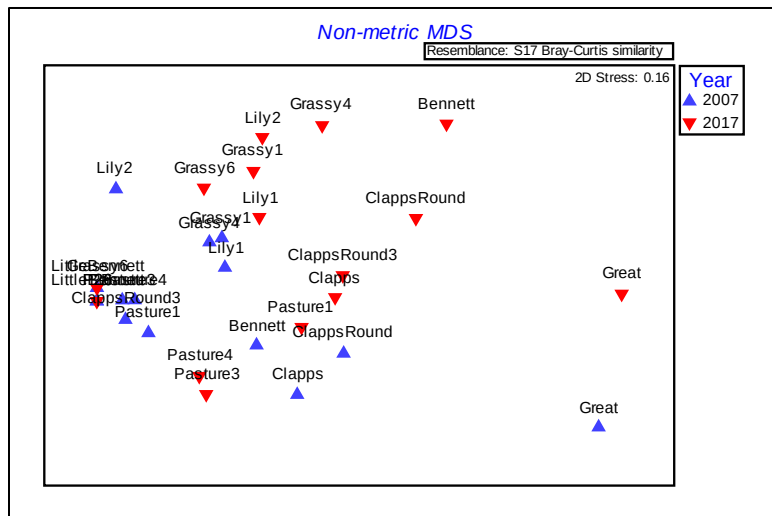


Figure 3. nMDS of species cover in box-plots by pond in 2007 vs. 2017.

Table 2. SIMPER results for species cover change in box-plots (all ponds pooled) between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Eleocharis quadrangulata</i>	0.7	2.7	9.5
<i>Dulichium arundinaceum</i>	0.9	1.9	16.2
<i>Decadon verticillatus</i>	0.7	1.3	21.5
<i>Pontederia cordata</i>	0.5	1.1	26.0
<i>Utricularia cornuta</i>	0.1	0.9	30.4
<i>Triadenum virginicum</i>	0.0	1.5	34.7
<i>Juncus militaris</i>	0.6	0.9	38.8
<i>Brasenia schreberi</i>	0.0	1.0	42.7
<i>Vaccinium corymbosum</i>	0.1	0.8	45.8
<i>Ilex verticillata</i>	0.1	0.7	48.8
<i>Eleocharis palustris</i>	0.3	0.6	51.6
<i>Eleocharis acicularis</i>	0.3	0.7	54.3
<i>Scirpus cyperinus</i>	0.3	0.7	56.7
<i>Hypericum perforatum</i>	0.7	0.0	59.1
<i>Nymphaea odorata</i>	4.6	4.7	61.4
<i>Potamogeton epihydrus</i>	0.1	0.5	63.4
<i>Phragmites australis</i>	0.1	0.3	65.3
<i>Hypericum boreale</i>	0.0	0.5	67.2
<i>Scirpis subterminalis</i>	0.3	0.2	68.9
<i>Typha angustifolia</i>	0.3	0.3	70.6

When analyzed by individual taxa, it become apparent that percent cover changed dramatically for a number of species. For example, *Brasenia schreberi*, *Ruppia maritima*, *Eleocharis acicularis*,

Calamagrostis canadensis, and *Phragmites australis* exhibited the largest increases (many time from zero in 2007) between survey years, while *Lythrum salicaria*, *Rhynchospora alba*, *Juncus militaris*, *Decadon verticillatus*, and *Typha angustifolia* decreased the most (Table 3). In total, 37 new species were recorded in 2017 and 15 species that were present in 2007 were not observed in 2017.

Table 3. Average percent cover (determined from mid-point % values of cover class scores) of all recorded species in 2007 vs. 2017 from box plots.

Species	2007	2017	Diff	new record	not found
<i>Brasenia schreberi</i>	0.0	40.0	40.0	X	–
<i>Ruppia maritima</i>	0.0	17.5	17.5	X	–
<i>Eleocharis acicularis</i>	2.5	18.5	16.0	–	–
<i>Calamagrostis canadensis</i>	0.0	13.5	13.5	X	–
<i>Phragmites australis</i>	3.6	15.2	11.6	–	–
<i>Pontedaria cordata</i>	0.0	8.4	8.4	X	–
<i>Spiraea tomentosa</i>	0.0	8.0	8.0	X	–
<i>Nymphaea odorata</i>	45.0	51.8	6.9	–	–
<i>Juncus pelocarpus</i>	0.0	6.4	6.4	X	–
<i>Potamogeton pusillus</i>	0.0	6.2	6.2	X	–
<i>Thelypteris palustris</i>	0.0	6.2	6.2	X	–
<i>Juncus</i> sp.	0.0	4.8	4.8	X	–
<i>Triadenum virginicum</i>	0.0	4.5	4.5	X	–
<i>Eleocharis robbinsii</i>	6.4	9.0	2.6	–	–
<i>Eleocharis</i> sp.	0.5	2.5	2.0	–	–
<i>Scirpus cyperinus</i>	0.0	2.0	2.0	X	–
<i>Cladium mariscoides</i>	0.0	1.8	1.8	X	–
<i>Isoetes</i> sp.	0.0	1.8	1.8	X	–
<i>Utricularia</i> sp.	0.0	1.8	1.8	X	–
<i>Juncus acuminatus</i>	0.5	1.8	1.3	–	–
<i>Clethra alnifolia</i>	0.0	1.0	1.0	X	–
<i>Xyris difformis</i>	0.5	1.3	0.8	–	–
<i>Potamogeton epihydrus</i>	3.0	3.6	0.6	–	–
<i>Agrostis</i> sp.	0.0	0.5	0.5	X	–
<i>Bidens connata</i>	0.0	0.5	0.5	X	–
<i>Boehmeria cylindrica</i>	0.0	0.5	0.5	X	–
<i>Ceratophyllum demersum</i>	0.0	0.5	0.5	X	–
<i>Eleocharis parvula</i>	0.0	0.5	0.5	X	–
<i>Euthamia graminifolia</i>	0.0	0.5	0.5	X	–
<i>Galium trifidum</i>	0.0	0.5	0.5	X	–

Table 3 (continued). Average percent cover (determined from mid-point % values of cover class scores) of all recorded species in 2007 vs. 2017 from box plots.

Species	2007	2017	Diff	new record	not found
<i>Hypericum boreale</i>	0.0	0.5	0.5	X	–
<i>Hypericum mutilum</i>	0.0	0.5	0.5	X	–
<i>Ilex glabra</i>	0.0	0.5	0.5	X	–
<i>Isoetes lacustris</i>	0.0	0.5	0.5	X	–
<i>Kalmia angustifolia</i>	0.0	0.5	0.5	X	–
<i>Myriophyllum humile</i>	0.0	0.5	0.5	X	–
<i>Orontium aquaticum</i>	0.0	0.5	0.5	X	–
<i>Osmunda regalis</i>	0.0	0.5	0.5	X	–
<i>Panicum</i> sp.	0.0	0.5	0.5	X	–
<i>Poa palustris</i>	0.0	0.5	0.5	X	–
<i>Polygonum hydropiperoides</i>	0.0	0.5	0.5	X	–
<i>Salix cinerea</i>	0.0	0.5	0.5	X	–
<i>Scutellaria galericulata</i>	0.0	0.5	0.5	X	–
<i>Smilax rotundifolia</i>	0.0	0.5	0.5	X	–
<i>Spiraea alba</i>	0.0	0.5	0.5	X	–
<i>Drosera intermedia</i>	1.8	2.2	0.4	–	–
<i>Acer rubrum</i>	0.5	0.5	0.0	–	–
<i>Carex</i> sp.	0.5	0.5	0.0	–	–
<i>Gratiola aurea</i>	0.5	0.5	0.0	–	–
<i>Rhynchospora capitellata</i>	3.0	3.0	0.0	–	–
<i>Sparganium americanum</i>	0.5	0.5	0.0	–	–
<i>Vaccinium macrocarpon</i>	0.5	0.5	0.0	–	–
<i>Vaccinium corymbosum</i>	1.8	1.5	-0.2	–	–
<i>Eleocharis pauciflora</i>	0.5	0.0	-0.5	–	X
<i>Juncus debilis</i>	0.5	0.0	-0.5	–	X
<i>Rhododendron viscosum</i>	0.5	0.0	-0.5	–	X
<i>Sium suave</i>	0.5	0.0	-0.5	–	X
<i>Spirea tomentosa</i>	0.5	0.0	-0.5	–	X
<i>Woodwardia virginica</i>	1.3	0.5	-0.8	–	–
<i>Euthamia</i> sp.	0.9	0.0	-0.9	–	X
<i>Carex oligosperma</i>	1.8	0.0	-1.8	–	X
<i>Clethra tomentosa</i>	1.8	0.0	-1.8	–	X
<i>Scirpis subterminalis</i>	1.8	0.0	-1.8	–	X
<i>Eriocaulon aquaticum</i>	2.2	0.0	-2.2	–	X
<i>Juncus bufonius</i>	2.2	0.0	-2.2	–	X

Table 3 (continued). Average percent cover (determined from mid-point % values of cover class scores) of all recorded species in 2007 vs. 2017 from box plots.

Species	2007	2017	Diff	new record	not found
<i>Scirpis cyperinus</i>	2.5	0.0	-2.5	–	X
<i>Lysimachia terrestris</i>	3.0	0.5	-2.5	–	–
<i>Scirpus subterminalis</i>	3.0	0.5	-2.5	–	–
<i>Utricularia cornuta</i>	3.0	0.0	-3.0	–	X
<i>Dulichium arundinaceum</i>	4.3	0.8	-3.5	–	–
<i>Ilex verticillata</i>	4.7	0.7	-3.9	–	–
<i>Pontederia cordata</i>	4.4	0.0	-4.4	–	X
<i>Eleocharis palustris</i>	7.9	2.9	-5.0	–	–
<i>Lythrum salicaria</i>	6.6	1.3	-5.3	–	–
<i>Rhynchospora alba</i>	5.5	0.0	-5.5	–	X
<i>Juncus militaris</i>	15.3	9.3	-6.0	–	–
<i>Decadon verticillatus</i>	15.8	8.3	-7.6	–	–
<i>Typha angustifolia</i>	51.3	38.4	-12.9	–	–
Totals	42	64	–	37	15

Transects by pond

Bennett Pond plant cover by species

The vegetation community of Bennett’s Pond exhibited a significant shift between 2007 and 2017 (ANOSIM: $R=0.21$, $p=0.001$) (Figure 4). Changes in *Nymphaea odorata*, *Decadon verticillatus*, and *Triadenum virginicum* abundance and distribution accounted for the most variance between years.

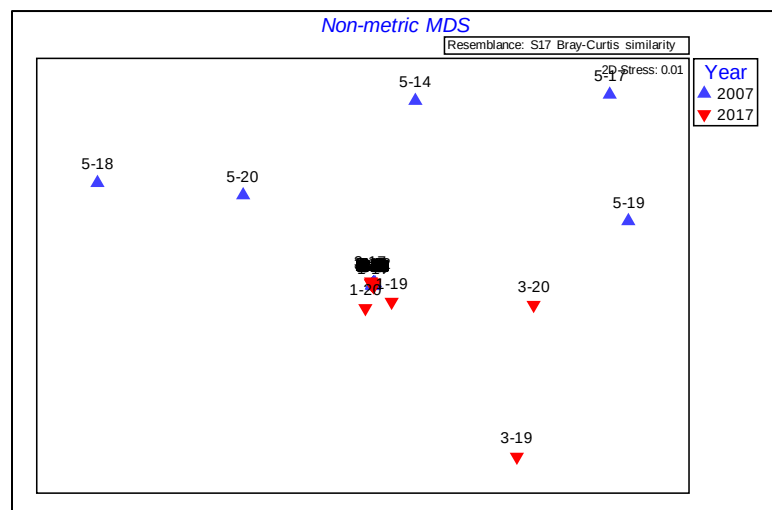


Figure 4. nMDS of species cover by plot in Bennett pond; 2007 vs. 2017.

Table 4. SIMPER results for species cover change in Bennett Pond between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Nymphaea odorata</i>	5.4	4.2	26.4
<i>Decadon verticillatus</i>	1.1	1.3	40.4
<i>Triadenum virginicum</i>	0.0	1.4	49.6
<i>Eleocharis acicularis</i>	0.2	1.1	57.5
<i>Hypericum perforatum</i>	0.5	0.4	63.1
<i>Juncus pelocarpus</i>	0.0	0.8	68.6
<i>Eleocharis robbinsii</i>	0.0	0.9	74.1

Bennett Pond species frequencies

Bennett pond species frequencies also exhibited a significant shift in taxonomic composition (ANOSIM: $R=0.70$, $p=0.008$) (Figure 5, Table 5). This was due mainly to changes in the abundance/distribution of *Triadenum virginicum*, *Juncus pelocarpus*, and *Eleocharis acicularis*, although a number of other species contributed only slightly less to the dissimilarities between 2007 and 2017 (Table 5).

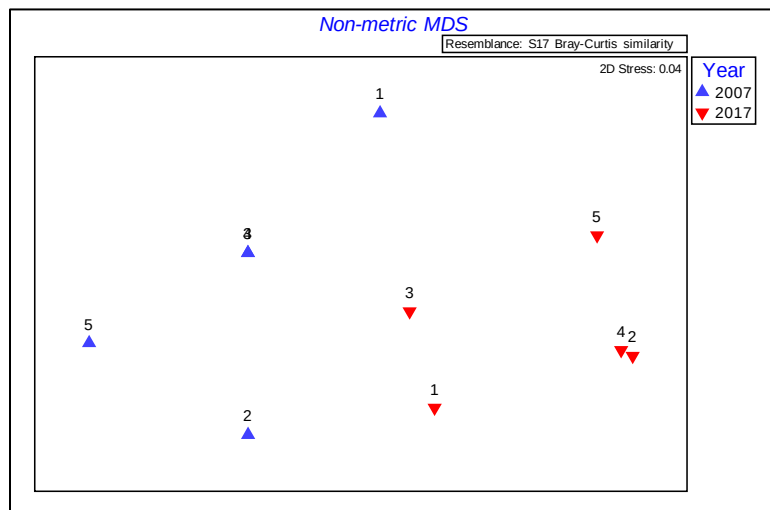


Figure 5. nMDS of species frequencies by transect in Bennett pond in 2007 vs. 2017.

Table 5. SIMPER results for species frequencies in Bennett Pond between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Triadenum virginicum</i>	0.0	0.6	11.8
<i>Juncus pelocarpus</i>	0.0	0.6	23.4
<i>Eleocharis acicularis</i>	0.1	0.5	32.4
<i>Decadon verticillatus</i>	0.2	0.4	41.0
<i>Drosera intermedia</i>	0.0	0.4	48.5
<i>Dulichium arundinaceum</i>	0.0	0.4	55.3
<i>Eleocharis robbinsii</i>	0.0	0.3	60.7
<i>Hypericum perforatum</i>	0.2	0.0	66.1
<i>Eleocharis</i> spp.	0.0	0.2	71.1

Clapps-Round cover by species

Clapps-Round pond vegetation in 2017 was substantially different from 2007 as assessed by ANOSIM (ANOSIM: $R=0.146$, $p=0.00$). SIMPER results showed that *Nymphaea odorata*, *Decadon verticillatus*, and *Brasenia schreberi* contributed most to the dissimilarity between years.

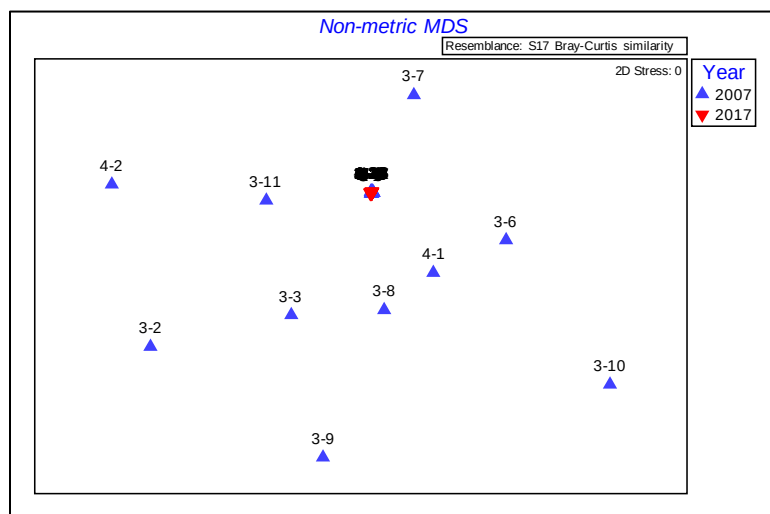


Figure 6. nMDS of species cover by plot in Clapps-Round Pond in 2007 vs. 2017.

Table 6. SIMPER results for species cover change between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Nymphaea odorata</i>	3.9	3.9	23.5
<i>Decadon verticillatus</i>	1.6	1.0	37.7
<i>Brasenia schreberi</i>	0.0	1.7	51.3
<i>Pontedaria cordata</i>	0.0	1.2	60.1
<i>Eleocharis robbinsii</i>	0.0	1.2	68.9
<i>Eleocharis acicularis</i>	0.5	0.2	73.2

Clapps-Round species frequencies

Species frequencies also exhibited significant change over time (ANOSIM: $R=0.62$, $p=0.008$). However, the species most responsible for this shift were different than for cover and included *Eleocharis robbinsii*, *Pontedaria cordata*, and *Brasenia schreberi*.

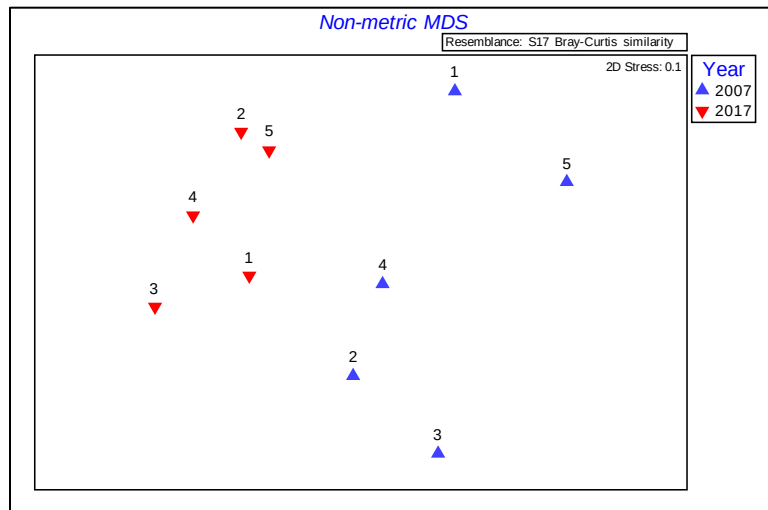


Figure 7. nMDS of species frequencies by transect in Clapps-Round pond in 2007 vs. 2017.

Table 7. SIMPER results for species frequencies in Clapps-Round pond between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Eleocharis robbinsii</i>	0.0	0.6	15.9
<i>Pontedaria cordata</i>	0.0	0.5	30.3
<i>Brasenia schreberi</i>	0.0	0.3	39.8
<i>Decadon verticillatus</i>	0.3	0.3	47.2
<i>Dulichium arundinaceum</i>	0.1	0.3	54.3
<i>Nymphaea odorata</i>	0.7	0.9	59.9
<i>Scirpis cyperninis</i>	0.1	0.2	64.7
<i>Eleocharis acicularis</i>	0.1	0.1	69.1
<i>Eleocharis palustris</i>	0.0	0.2	73.4

Clapps Pond cover by species

A significant difference was found in the plant community of Clapps Pond between 2007 and 2017 (ANOSIM: $R=0.031$, $p=0.002$) (Figure 8). This was almost entirely the result of shifts in *N. odorata* and *B. schreberi* abundance/distribution (Table 8).

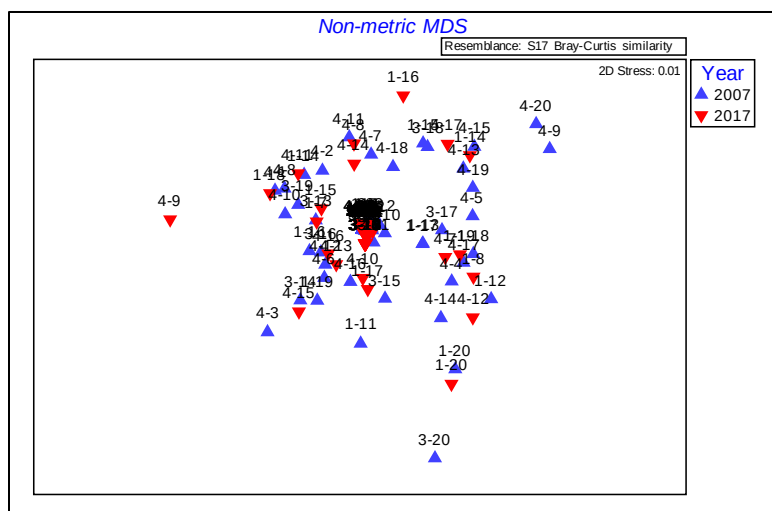


Figure 8. nMDS of species cover by plot in Clapps pond in 2007 vs. 2017.

Table 8. SIMPER results for species cover change between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Nymphaea odorata</i>	2.9	3.5	63.8
<i>Brasenia schreberi</i>	0.00	0.8	76.1

Clapps Pond species frequencies

Unlike species cover, the frequency of occurrences of Clapps Pond taxa did not exhibit significant change over time (ANOSIM: $R=-0.008$, $p=0.44$) (Figure 9).

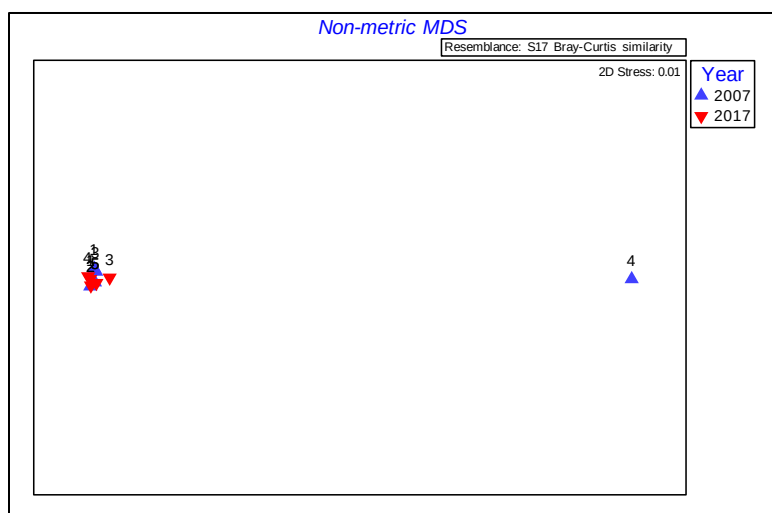


Figure 9. nMDS of species frequencies by transect in Clapps pond in 2007 vs. 2017.

Clapps-Round3 cover by species

The plant community in Clapps-Round3 Pond in 2017 was vastly different than in 2017 – at least along the transects (ANOSIM: $R=0.075$, $p=0.001$) (Figure 10, Table 9). SIMPER analysis revealed that it was changes in *N. odorata*, *B. schreberi*, and *D. verticillatus* that contributed most to the difference between surveys (Table 9).

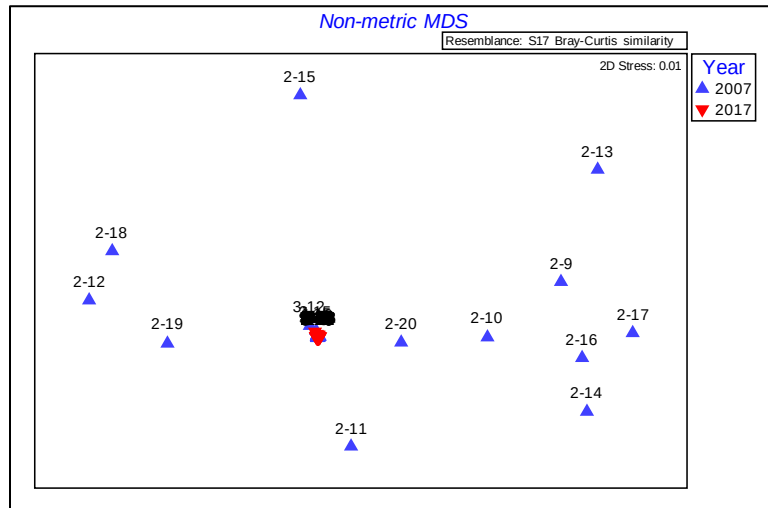


Figure 10. nMDS of species cover by plot in Clapps-Round3 pond, 2007 vs. 2017.

Table 9. SIMPER results for species cover change in Clapps-Round3 pond between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Nymphaea odorata</i>	5.1	4.6	39.7
<i>Brasenia schreberi</i>	0.0	1.3	57.5
<i>Decadon verticillatus</i>	0.4	0.5	63.8
<i>Eleocharis acicularis</i>	0.2	0.4	69.7
<i>Eleocharis robbinsii</i>	0.0	0.6	75.6

Clapps-Round3 species frequencies

Species frequencies similarly exhibited significant shift between 2007 and 2017 (ANOSIM: $R=0.254$, $p=0.04$) (Figure 11), with *Eleocharis robbinsii*, *Brasenia schreberi*, and *Nymphaea odorata* being the main components of this change (Table 10).

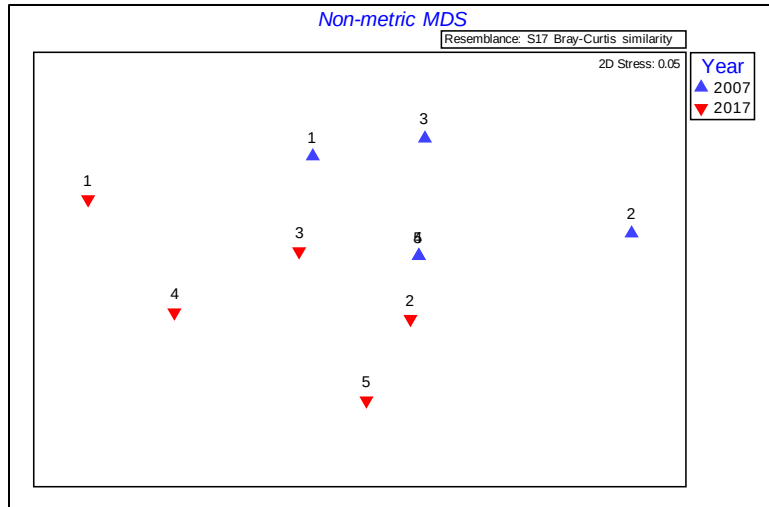


Figure 11. nMDS of species frequencies by transect in Clapps-Round3 pond; 2007 vs. 2017.

Table 10. SIMPER results for species frequencies in Clapps-Round3 pond between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Eleocharis robbinsii</i>	0.0	0.3	13.9
<i>Brasenia schreberi</i>	0.0	0.3	27.7
<i>Nymphaea odorata</i>	0.9	1.0	36.4
<i>Eleocharis acicularis</i>	0.1	0.2	44.9
<i>Decadon verticillatus</i>	0.1	0.2	52.2
<i>Utricularia</i> sp.	0.0	0.1	59.3
<i>Eleocharis quadrangulata</i>	0.1	0.0	64.3
<i>Tridenum virginicum</i>	0.0	0.2	69.2
<i>Dulichium arundinaceum</i>	0.0	0.1	73.9

Grassy1 cover by species

Grassy1 pond, like most of the others, exhibited an apparent shift in plant communities that met the criteria for statistical significance (ANOSIM: $R=0.168$, $p=0.001$) (Figure 12, Table 11). This change was driven by increases in both *N. odorata* and *Phragmites australis* according to SIMPER analysis.

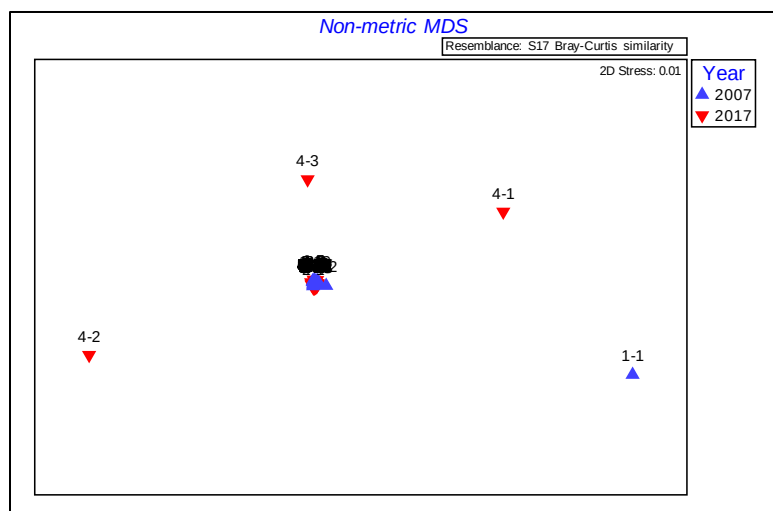


Figure 12. nMDS of species cover by plot in Grassy1 pond in 2007 vs. 2017.

Table 11. SIMPER results for species cover change in Grassy1 pond between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Nymphaea odorata</i>	4.3	5.3	66.4
<i>Phragmites australis</i>	0.2	0.2	77.3

Grassy1 species frequencies

In contrast to species cover, the frequency of occurrence of plant taxa demonstrated no significant disparities between survey years (ANOSIM: $R=-0.064$, $p=0.77$) (Figure 13)

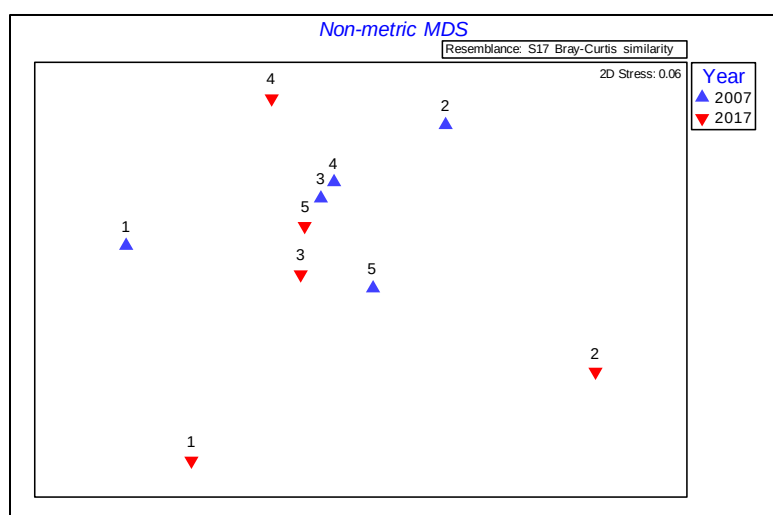


Figure 13. nMDS of species frequencies by transect in Grassy1 pond in 2007 vs. 2017.

Grassy4 species by cover

There was a significant change in aquatic vegetation along the transects in this pond, largely driven by increases in *N. odorata* and *E. robbinsii* (ANOSIM: $R=0.15$, $p=0.001$) (Figure 14, Table 12).

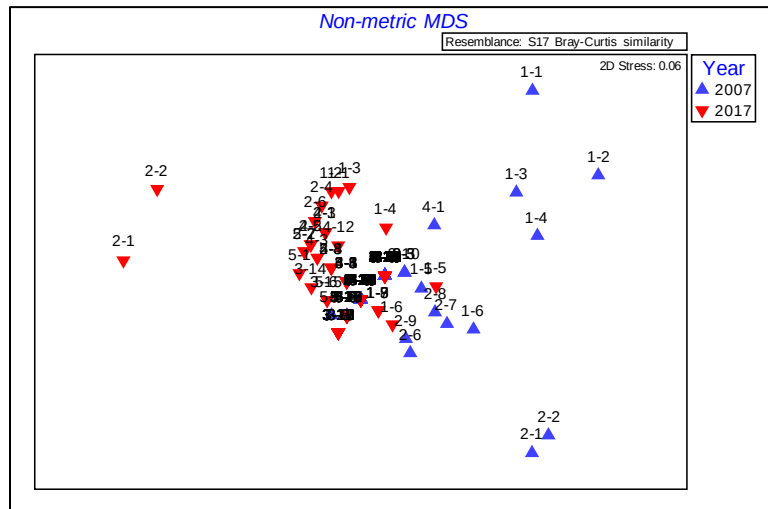


Figure 14. nMDS of species cover by plot in Grassy4 pond in 2007 vs. 2017.

Table 12. SIMPER results for species cover change in Grassy4 pond between 2007 and 2017.

Species	2007	2017	Cum. %
<i>Nymphaea odorata</i>	4.2	5.1	49.5
<i>Eleocharis robbinsii</i>	0.0	0.7	72.8

Grassy4 species frequencies

The frequency of occurrence data for Grassy4 pond aquatic plant taxa also exhibited significant shift between 2007 and 2017 (ANOSIM: $R=0.39$, $p=0.008$) (Figure 15, Table 13). However, this time it was *Eleocharis robbinsii*, *Juncus militaris*, and *Juncus acuminatus* that played the largest role in compositional dissimilarities among surveys.

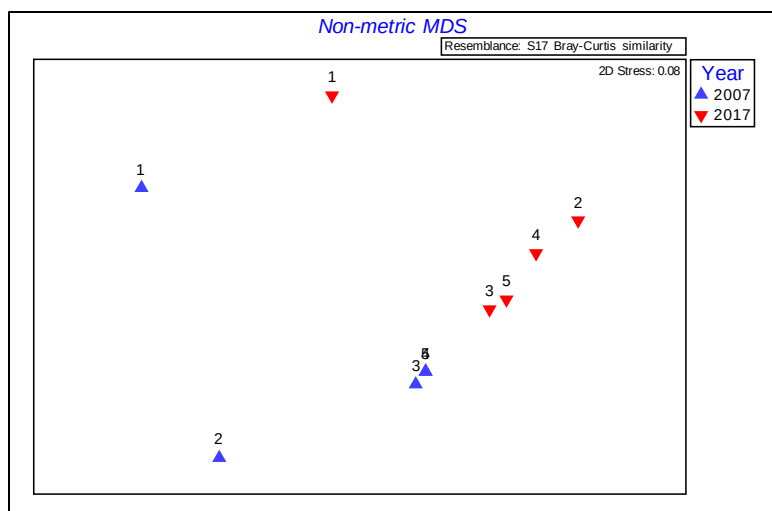


Figure 15. nMDS of species frequencies by transect in Grassy4 pond; 2007 vs. 2017.

Table 13. SIMPER results for species frequencies between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Eleocharis robbinsii</i>	0.0	0.3	45.1
<i>Juncus militaris</i>	0.1	0.1	64.7
<i>Juncus acuminatus</i>	0.0	0.1	77.7

Grassy6 cover by species

The change in aquatic vegetation cover for Grassy6 pond was due solely to an increase in *N. odorata* (ANOSIM: $R=0.211$, $p=0.001$) (Figure 16, Table 14).

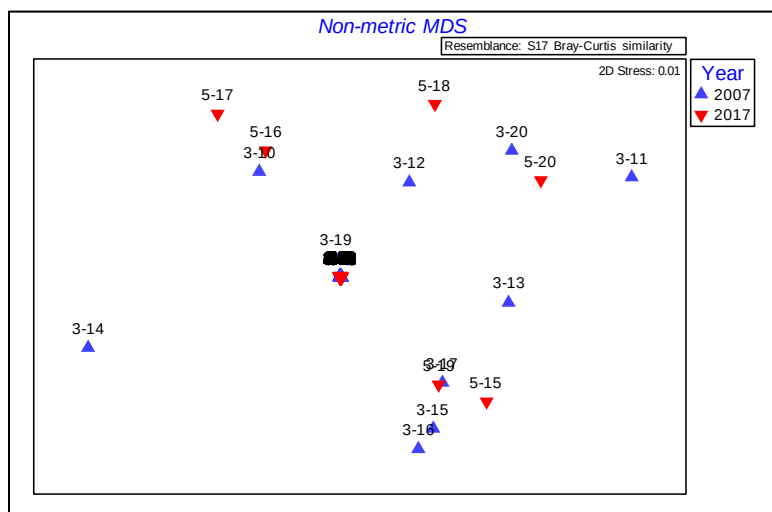


Figure 16. nMDS of species cover by plot in Grassy6 pond in 2007 vs. 2017.

Table 14. SIMPER results for species cover change between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Nymphaea odorata</i>	4.1	5.5	82.9

Grassy6 species frequencies

In contrast to % cover, frequency of occurrence values did not indicate that any significant change occurred between 2007 and 2017 in Grassy6 pond (ANOSIM: $R=-0.06$, $p=1.0$) (Figure 17).

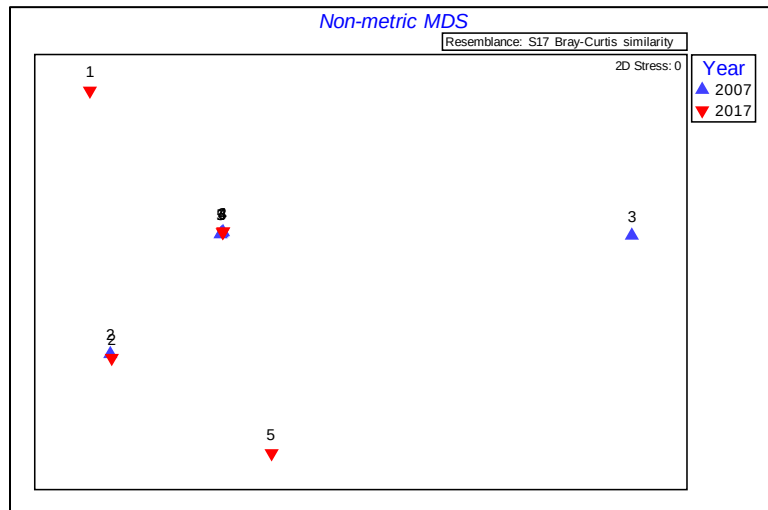


Figure 17. nMDS of species frequencies by transect in Grassy6 pond in 2007 vs. 2017.

Great Pond cover by species

Species composition along the transects differed significantly between the 2007 and 2017 surveys (ANOSIM: $R=0.33$, $p<0.01$). The taxa contributing most to this difference were *Eleocharis* sp., *Typha angustifolia*, *D. verticillatus*, and *Lythrum salicaria* (*)

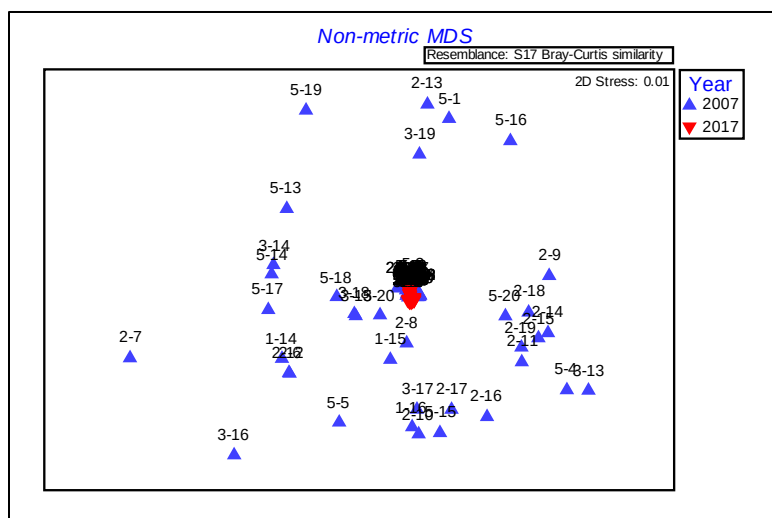


Figure 18. nMDS of species cover by plot in Great pond in 2007 vs. 2017.

Table 15. SIMPER results for species cover change in Great pond between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Eleocharis</i> sp.	0.0	2.9	39.1
<i>Typha angustifolia</i>	2.3	1.6	57.4
<i>Decadon verticillatus</i>	1.4	0.7	68.0
<i>Lythrum salicaria</i>	1.0	0.1	73.9

Great Pond species frequencies

Species frequencies in Great pond did not change significantly between 2007 and 2017, although the probability value was very close to the alpha level of 0.05 (ANOSIM: $R=0.17$, $p=0.06$).

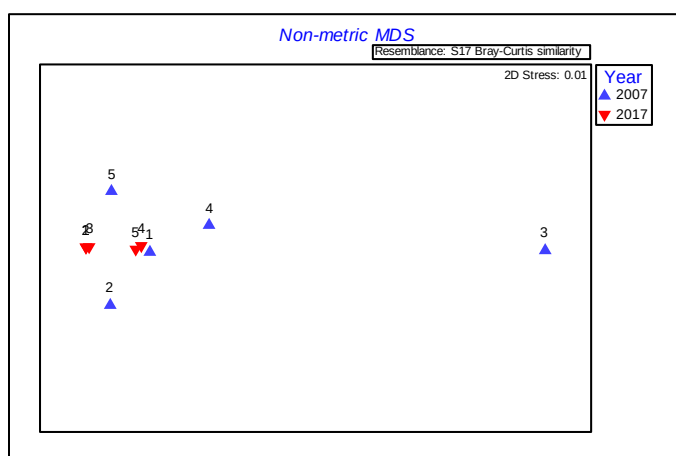


Figure 19. nMDS of species frequencies by transect in Great pond in 2007 vs. 2017.

Table 16. SIMPER results for species frequencies in Great pond between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Eleocharis palustris</i>	0.0	0.7	46.7
<i>Typha angustifolia</i>	0.1	0.3	56.3
<i>Triadenum virginicum</i>	0.0	0.3	63.8
<i>Decadon verticillatus</i>	0.1	0.2	69.5
<i>Calamagrostis canadensis</i>	0.0	0.2	75.0

Lily1 cover by species

Plant cover by species shifted substantially in Lily1 Pond between 2007 and 2017 (ANOSIM: $R=0.47$, $p=0.001$) (Figure 20, Table 17), with *B. schreberi* and *N. odorata* comprising the majority of change.

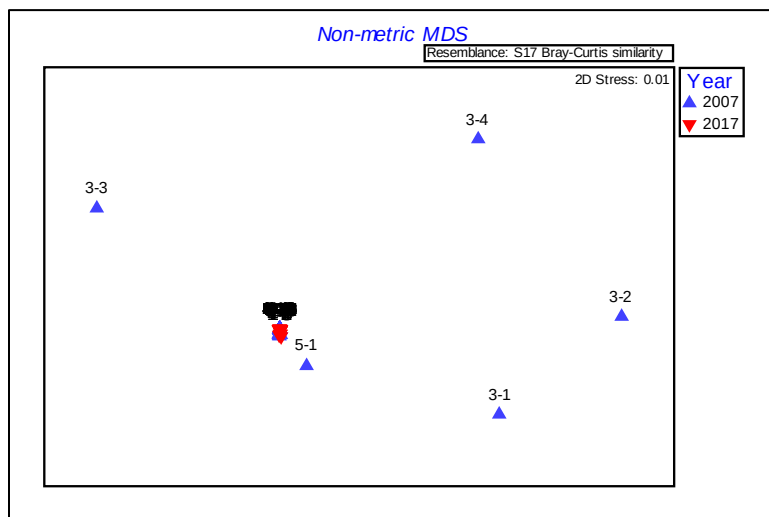


Figure 20. nMDS of species cover by plot in Lily1 pond in 2007 vs. 2017.

Table 17. SIMPER results for species cover change between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Brasenia schreberi</i>	0.0	4.6	52.9
<i>Nymphaea odorata</i>	4.8	3.0	86.6

Lily1 species frequencies

With respect to species frequencies, a different group of plant taxa were responsible for significant change between surveys (ANOSIM: $R=1$, $p=0.008$) (Figure 21). These included *Scirpus cyperinus*, *Scirpus subterminalis*, and *Pontederia cordata* – all of which disappeared between 2007 and 2017 (Table 18).

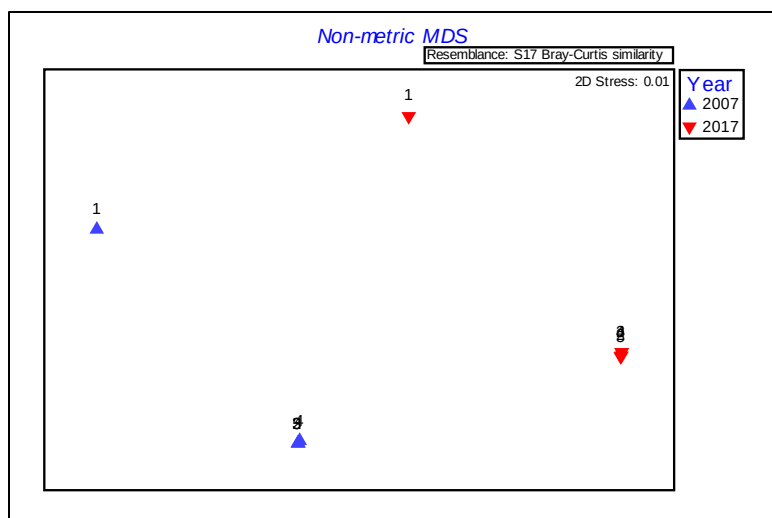


Figure 21. nMDS of species frequencies by transect in Lily1 pond in 2007 vs. 2017.

Table 18. SIMPER results for species frequencies between 2007 and 2017.

Species	2007	2017	Cum. %
<i>Scirpus cyperinus</i>	1.0	0.0	22.0
<i>Scirpus subterminalis</i>	1.0	0.0	43.9
<i>Pontederia cordata</i>	1.0	0.0	65.7
<i>Eleocharis Robbinsii</i>	0.0	0.9	86.1

Lily2 cover by species

Once again, plant communities demonstrated a shift in composition between survey years (ANOSIM: $R=0.029$, $p=0.002$) (Figure 22, Table 19), with *Nymphaea odorata* and *Ilex verticillata* exhibiting the biggest differences in abundance/distribution.

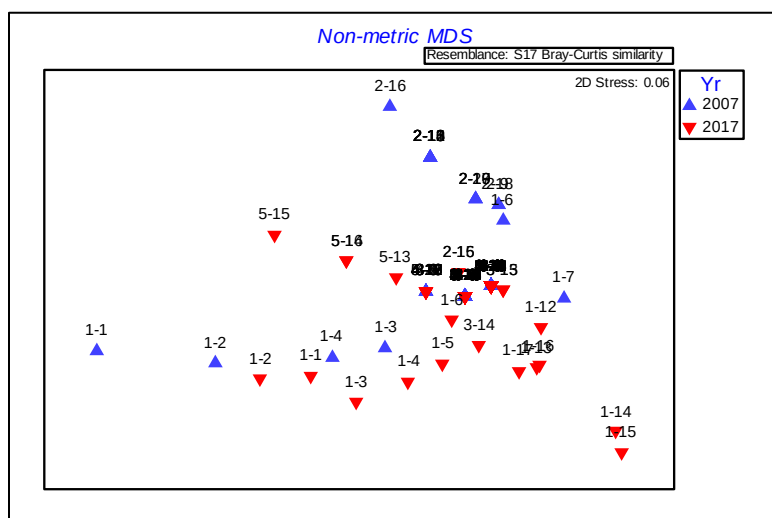


Figure 22. nMDS of species cover by pond in 2007 vs. 2017.

Table 19. SIMPER results for species cover change between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Nymphaea odorata</i>	6.0	6.3	50.6
<i>Ilex verticillata</i>	0.5	0.0	70.1

Lily2 species frequencies

Unlike cover, species frequencies did not exhibit any statistically significant change between 2007 and 2017 (ANOSIM: $R=-0.028$, $p=0.68$) (Figure 23). In other words, the presence/absence of species within the plant communities did not shift appreciably during this period.

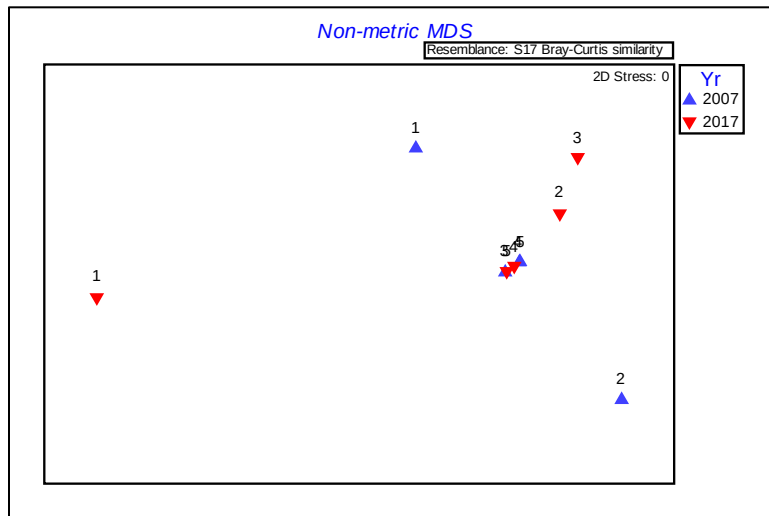


Figure 23. nMDS of species cover by pond in 2007 vs. 2017.

Little Bennett cover by species

N. odorata dominated in this pond and variations in the abundance/distribution of this specific taxon suggested a statistical change between survey years ANOSIM: $R=0.094$, $p=0.001$) (Figure 24).

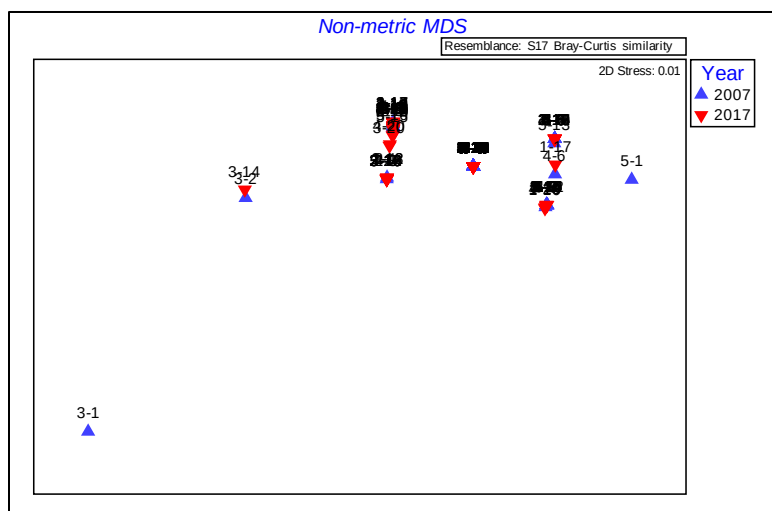


Figure 24. nMDS of species cover by plot in Little Bennett pond; 2007 vs. 2017.

Table 20. SIMPER results for species cover change in Little Bennett pond between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Nymphaea odorata</i>	5.2	4.7	100

Little Bennett species frequencies

Since the only species recorded in both survey years was *N. odorata*, no figure is presented as there was no alteration in plant community.

P26 cover by species

No significant plant composition changes were detected in P26 (ANOSIM: $R=-0.001$, $p=0.43$) for both cover and frequency data.

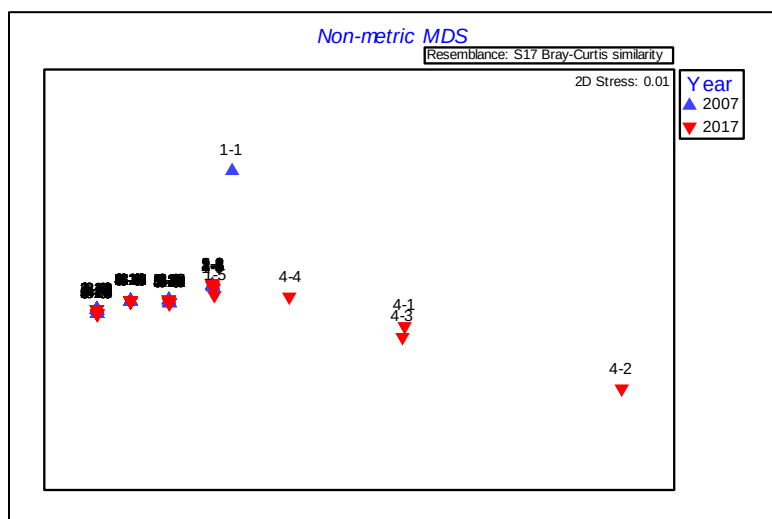


Figure 25. nMDS of species cover by plot in P26 pond; 2007 vs. 2017.

P26 species frequencies

No change in transect species frequencies occurred in P26 between 2007 and 2017. While *N. odorata* continued to dominate the vegetation in both years, *Scirpus subterminalis* disappeared in 2017.

ANOSIM: $R=-0.5$, $p=1.0$

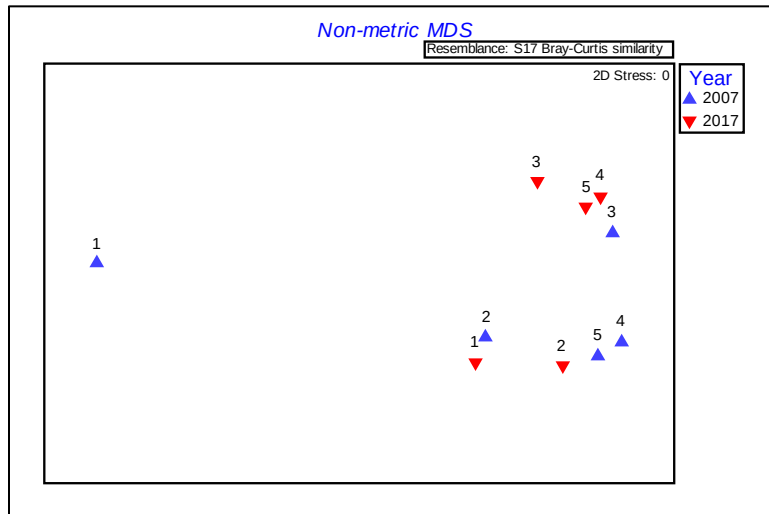


Figure 26. nMDS of species frequencies by transect in P26 pond; 2007 vs. 2017.

Pasture1 cover by species

Shifts in the distributions/cover of *N. odorata*, *Brasenia schreberi*, and *Juncus militaris* accounted for the largest portion of taxonomic dissimilarity between 2007 and 2017 plant communities (ANOSIM: $R=0.09$, $p=0.001$) (Figure 27, Table 22).

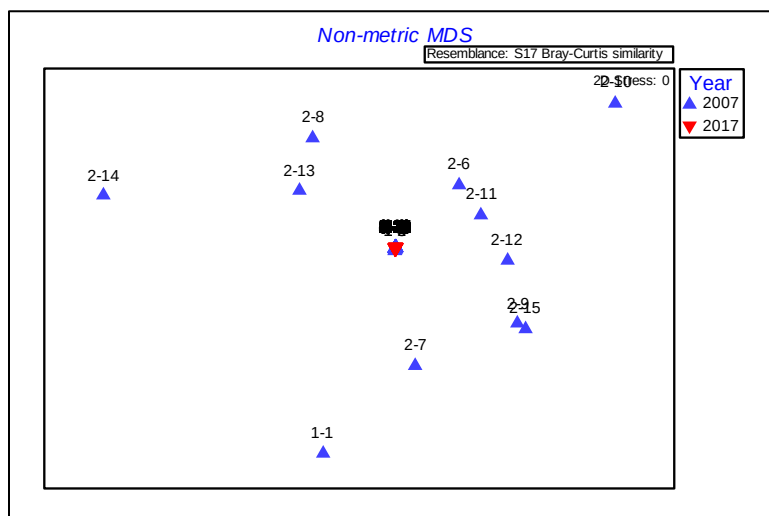


Figure 27. nMDS of species cover by plot in Pasture1 pond in 2007 vs. 2017.

Table 21. SIMPER results for species cover change in Pasture1 between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Nymphaea odorata</i>	3.8	3.7	40.8
<i>Brasenia schreberi</i>	0.0	2.0	66.5
<i>Juncus militaris</i>	0.4	1.1	79.6

Pasture1 species frequencies

Species frequencies remained statistically unchanged in Pasture1 box plots between 2007 and 2017 (ANOSIM: $R=-0.016$, $p=0.49$) (Figure 28).

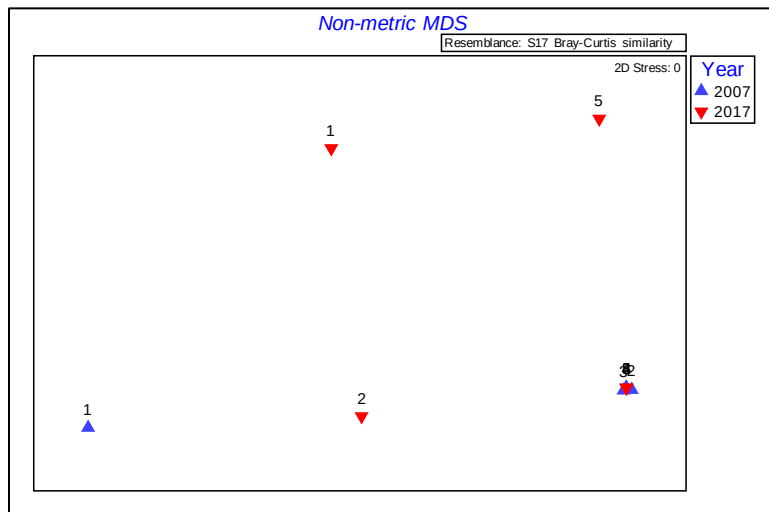


Figure 28. nMDS of species frequencies by pond in 2007 vs. 2017.

Pasture3 cover by species

A substantial reduction in *N. odorata* (the dominant species in this pond) resulted in a statistically significant shift in Pasture3 vegetation between 2007 and 2017 (ANOSIM: $R=0.25$, $p=0.001$) (Figure 29, Table 23).

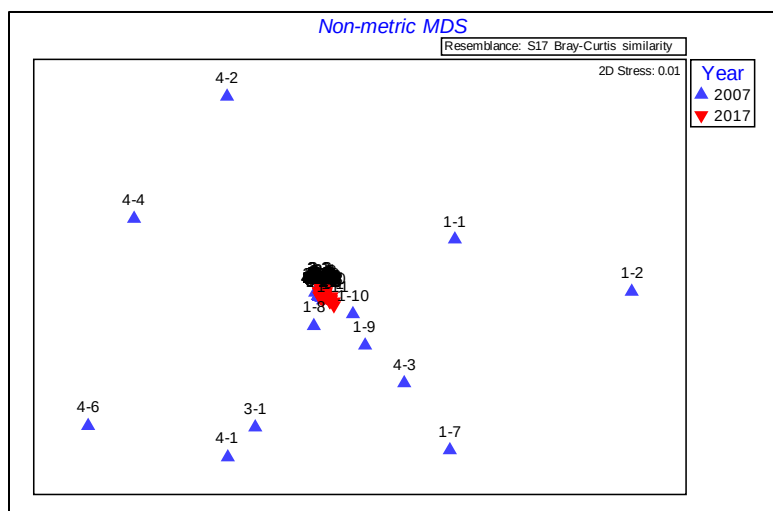


Figure 29. nMDS of species cover by pond in 2007 vs. 2017.

Table 22. SIMPER results for species cover change between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Nymphaea odorata</i>	4.0	2.9	48.9
<i>Utricularia</i> sp.	0.0	1.0	70.3

Pasture3 species frequencies

Species frequencies also demonstrated a significant change over the 10 years between surveys (Figure 30), with *Utricularia* spp. and *Eleocharis robbinsii* accounting for the majority of change (Table 24).

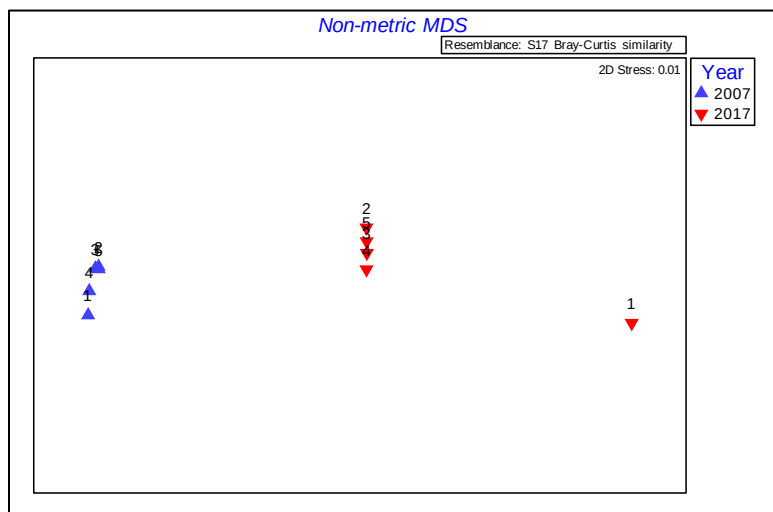


Figure 30. nMDS of species frequencies by transect in Pasture3 pond in 2007 vs. 2017.

Table 23. SIMPER results for species frequencies in Pasture3 between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Utricularia</i> sp.	0.0	0.7	49.6
<i>Eleocharis robbinsii</i>	0.0	0.3	70.2

Pasture4 cover by species

The vegetation along transects in Pasture4 pond underwent fairly dramatic change from 2007 to 2017, as *N. odorata* declined and *Potamogeton* spp., *Utricularia* spp., and *E. robbinsii* all appeared in 2017 despite being absent in the 2007 survey (ANOSIM: $R=0.35$, $p=0.001$) (Figure 31, Table 25).

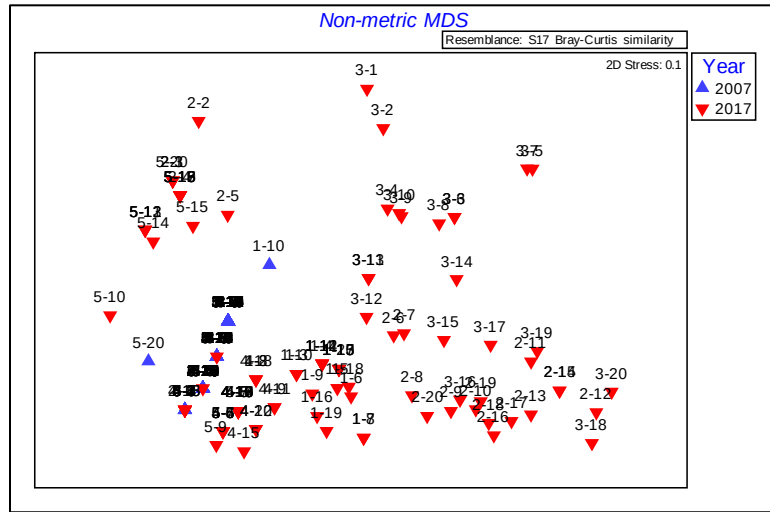


Figure 31. nMDS of species cover by plot in Pasture4 in 2007 vs. 2017.

Table 24. SIMPER results for species cover change in Pasture4 between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Nymphaea odorata</i>	5.1	4.4	33.0
<i>Potamogeton</i> spp.	0.0	1.1	53.3
<i>Utricularia</i> spp.	0.0	0.9	69.7
<i>Eleocharis robbinsii</i>	0.0	1.0	85.8

Pasture4 species frequencies

The detection of *Utricularia* and *Potamogeton* spp. in 2017 (previously absent) contributed substantially to significant differences in species frequencies between 2007 and 2017, while *Eleocharis quadrangulata* exhibited a large increase in abundance (ANOSIM: $R=0.66$, $p=0.008$) (Figure 32, Table 26).

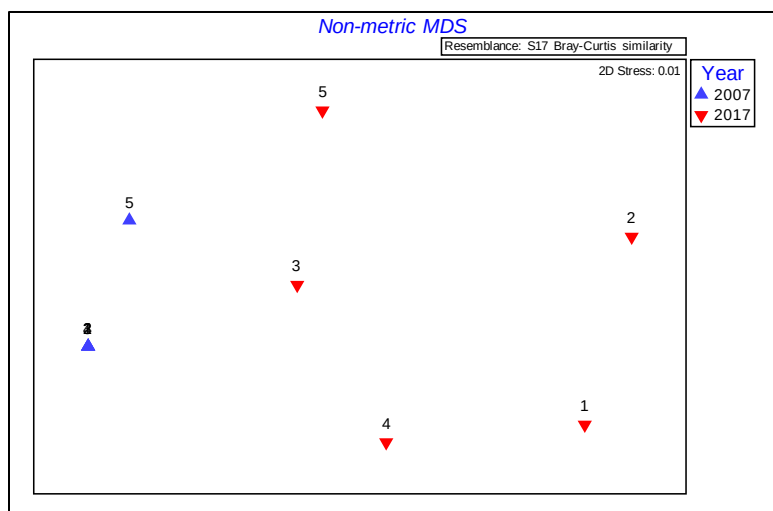


Figure 32. nMDS of species frequencies by transect in Pasture4 pond; 2007 vs. 2017.

Table 25. SIMPER results for species frequencies in Pasture4 pond between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Utricularia</i> sp.	0.0	0.6	48.8
<i>Potamogeton</i> spp.	0.0	0.3	69.2
<i>Eleocharis quadrangulata</i>	0.01	0.2	86.2

Box Plots

Bennett pond

The taxonomic composition of Bennett pond shifted dramatically over the decade between survey years. This was due to changes in abundance/distribution of numerous species, with *Triadenum virginicum*, *Eleocharis acicularis*, and *Juncus pelocarpus* contributing most to dissimilarity between 2007 and 2017 (ANOSIM: $R=0.71$, $p=0.02$) (Figure 33, Table 27).

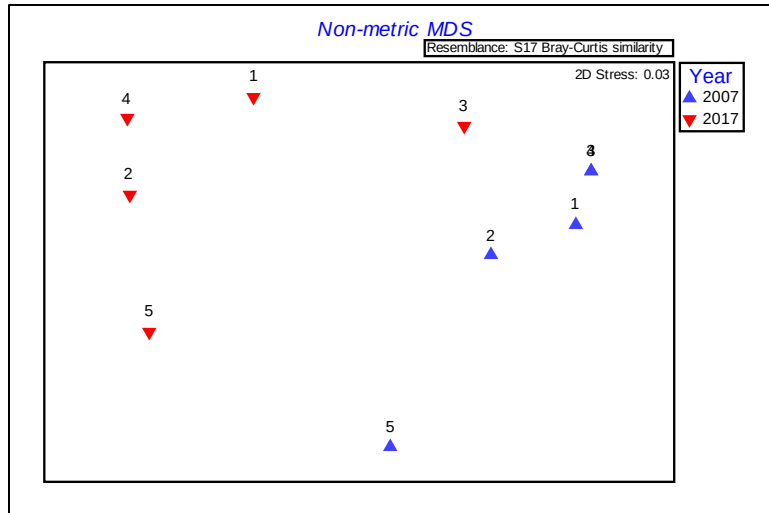


Figure 33. nMDS of species cover by transect in Bennett pond in 2007 vs. 2017.

Table 26. SIMPER results for species cover change in Bennett pond between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Triadenum virginicum</i>	0.0	3.0	12.1
<i>Eleocharis acicularis</i>	0.4	2.8	23.1
<i>Juncus pelocarpus</i>	0.0	2.4	33.8
<i>Decadon verticillatus</i>	1.0	1.8	42.2
<i>Eleocharis robbinsii</i>	0.0	1.8	48.6
<i>Nymphaea odorata</i>	6.2	5.4	54.9
<i>Dulichium arundinaceum</i>	0.2	1.4	60.3
<i>Drosera intermedia</i>	0.0	1.4	65.6
<i>Juncus acuminatus</i>	0.0	1.2	70.3

Clapps-Round Pond

In Clapps-Round pond, ANOSIM revealed no statistically significant difference between the plant communities in 2007 vs. 2017, although the p value was very close to the cutoff of 0.05 for significance (ANOSIM: R=0.35, p=0.06) (Figure 34).

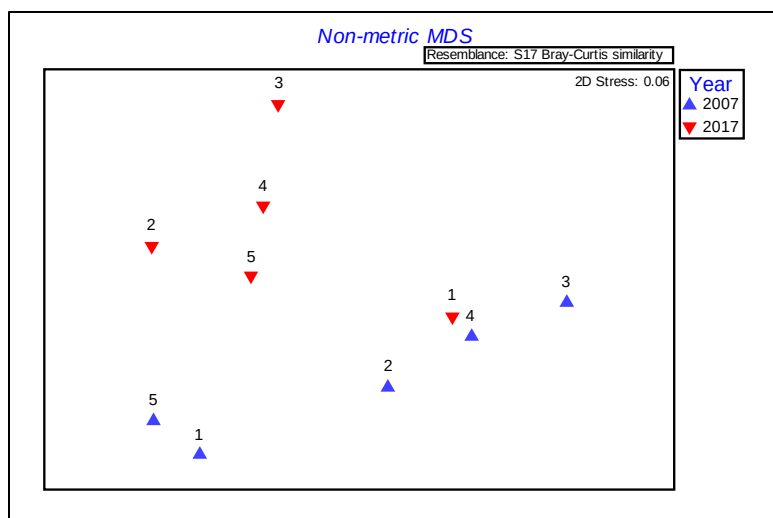


Figure 34. nMDS of species cover by transect in Clapps-Round pond in 2007 vs. 2017.

Clapps Pond

No vegetation shifts were observed in Clapps Pond between 2007 and 2017 based on species cover in the box plots (ANOSIM: $R=0.11$, $p=0.16$) (Figure 35).

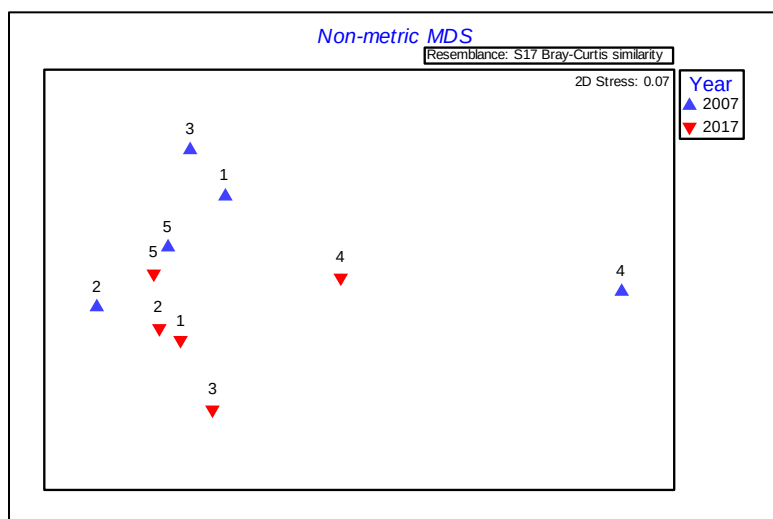


Figure 35. nMDS of species cover by transect in Clapps pond in 2007 vs. 2017.

Clapps-Round3 Pond

Changes in the abundance/distribution of *B. schreberi*, *D. verticillatus*, and *N. odorata* were responsible for the statistically significant difference in plant community in 2007 vs. 2017 (ANOSIM: $R=0.48$, $p=0.008$) (Figure 36, Table 28).

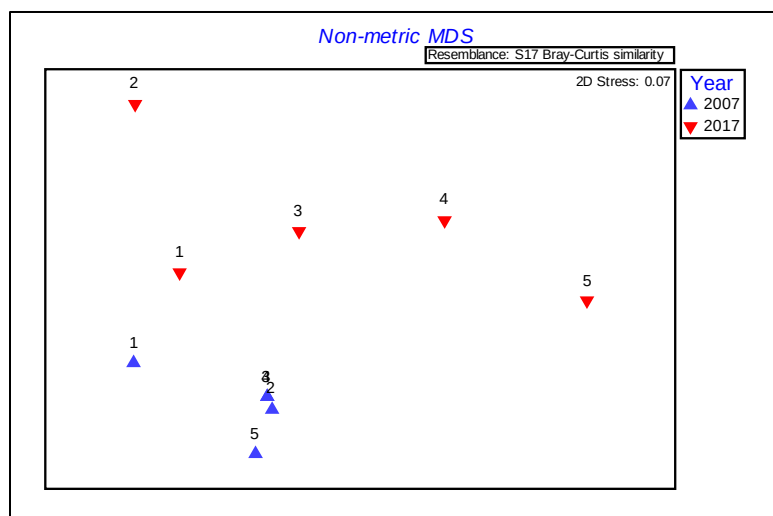


Figure 36. nMDS of species cover by transect in Clapps-Round3 pond in 2007 vs. 2017.

Table 27. SIMPER results for species cover change in Clapps-Round3 pond between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Brasenia schreberi</i>	0.0	2.0	21.1
<i>Decadon verticillatus</i>	0.8	1.0	34.8
<i>Nymphaea odorata</i>	6.4	5.8	47.3
<i>Pontedaria cordata</i>	0.0	1.0	57.2
<i>Utricularia</i> spp.	0.0	0.8	65.4
<i>Eleocharis robbinsii</i>	0.0	0.8	73.4

Grassy1 Pond

Even though there was a minor shift in plant communities within the box plots as illustrated in Figure 37, the change was no statistically significant (ANOSIM: $R=0.11$, $p=0.23$)

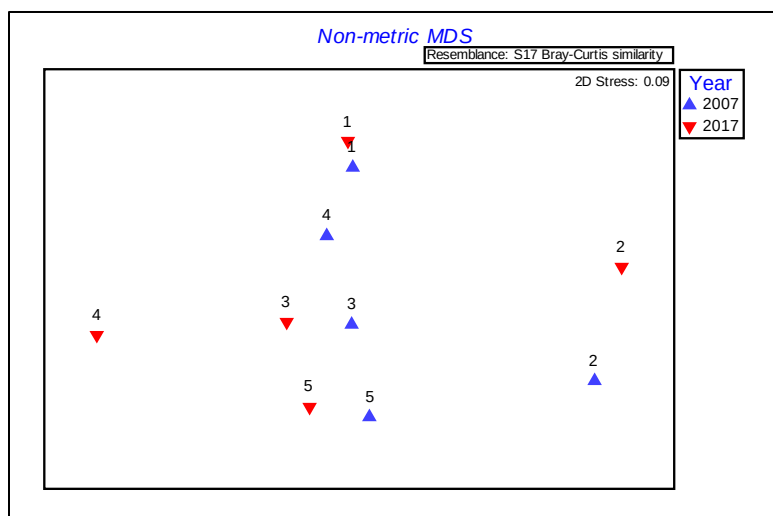


Figure 37. nMDS of species cover by transect in Grassy1 pond in 2007 vs. 2017.

Grassy4 Pond

Grassy4 pond showed a wide divergence in plant species composition between 2007 and 2017 (ANOSIM: $R=0.65$, $p=0.02$) (Figure 38). This was primarily due to increasing abundances of *E. robbinsii*, *Vaccinium corymbosum*, and *N. odorata* (Table 29).

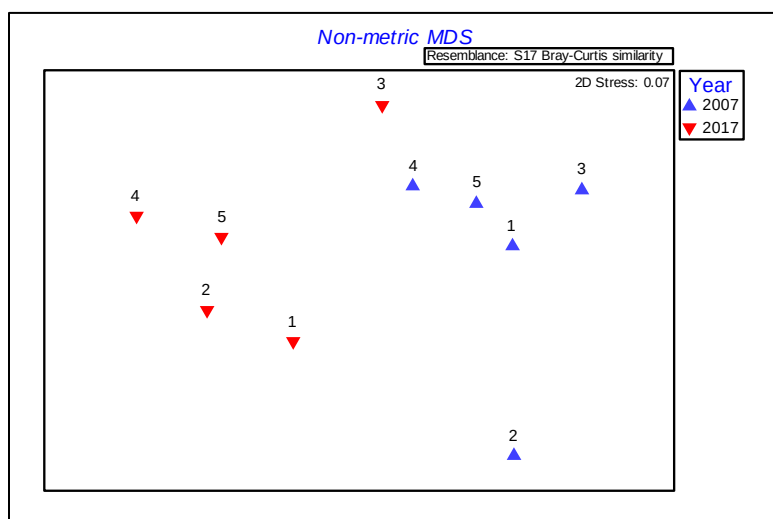


Figure 38. nMDS of species cover by transect in Grassy4 pond in 2007 vs. 2017.

Table 28. SIMPER results for species cover change in Grassy4 pond between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Eleocharis robbinsii</i>	0.0	3.8	29.6
<i>Vaccinium corymbosum</i>	0.4	1.6	41.3
<i>Nymphaea odorata</i>	4.4	5.4	51.2
<i>Juncus militaris</i>	0.8	0.6	60.0
<i>Juncus acuminatus</i>	0.2	1.0	68.1
<i>Dulichium arundinaceum</i>	1.2	0.8	74.1

Grassy6 Pond

The vegetation in box plots within Grassy6 pond was significantly different in 2017 than in 2007 (Figure 39). *N. odorata*, *P. australis*, and *E. robbinsii* contributed to the majority of dissimilarity between sampling years (ANOSIM: $R=0.32$, $p=0.008$) (Table 39).

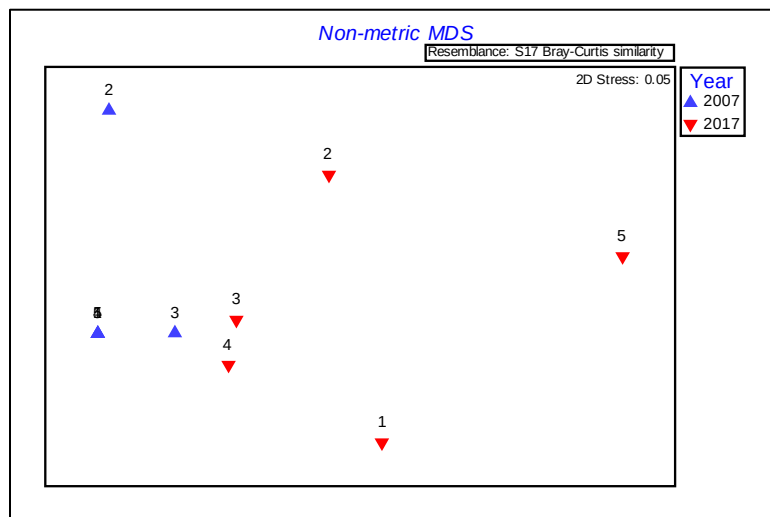


Figure 39. nMDS of species cover by transect in Grassy6 pond in 2007 vs. 2017.

Table 29. SIMPER results for species cover change in Grassy6 pond between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Nymphaea odorata</i>	5.0	6.8	32.3
<i>Phragmites australis</i>	0.4	1.8	58.9
<i>Eleocharis robbinsii</i>	0.0	0.8	70.3

Great Pond

Variations in the plant community between 2007 and 2017 within Great pond closely approached statistical significance but did not reach the threshold p value of 0.05 (ANOSIM: $R=0.28$, $p=0.06$).

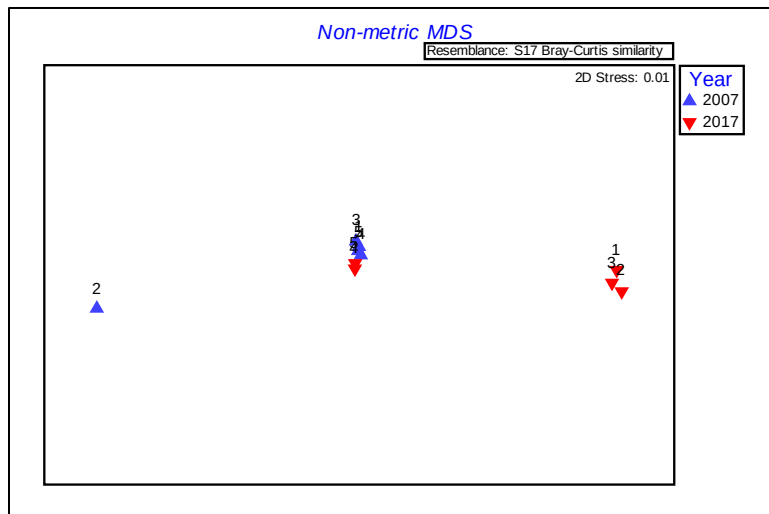


Figure 40. nMDS of species cover by transect in Great pond in 2007 vs. 2017.

Lily1 Pond

Shifts in the abundance of *B. schreberi* (not detected in 2007), *N. odorata*, and *E. palustris* accounted for most of the dissimilarities between plant communities in 2007 vs. 2017 (ANOSIM: $R=0.47$, $p=0.008$) (Figure 41, Table 31).

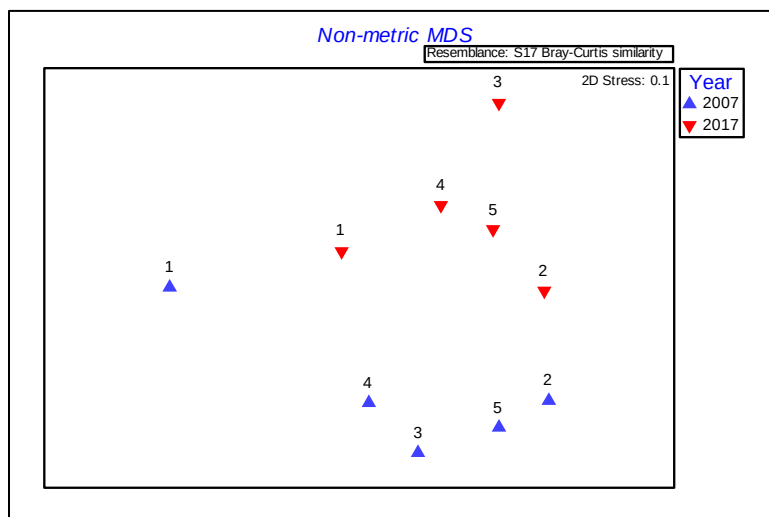


Figure 41. nMDS of species cover by in Lily1 pond in 2007 vs. 2017.

Table 30. SIMPER results for species cover change in box plots between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Brasenia schreberi</i>	0.0	4.6	37.2
<i>Nymphaea odorata</i>	4.2	3.8	48.4
<i>Eleocharis palustris</i>	1.4	0.6	58.7
<i>Dulichium arundinaceum</i>	1.4	0.8	69.0
<i>Juncus militaris</i>	1.0	0.6	77.4

Lily2 Pond

In Lily2 pond, ANOSIM suggested that no significant changes in plant species occurred within the box plots between 2007 and 2017 (ANOSIM: $R=0.08$, $p=0.22$) (Figure 42).

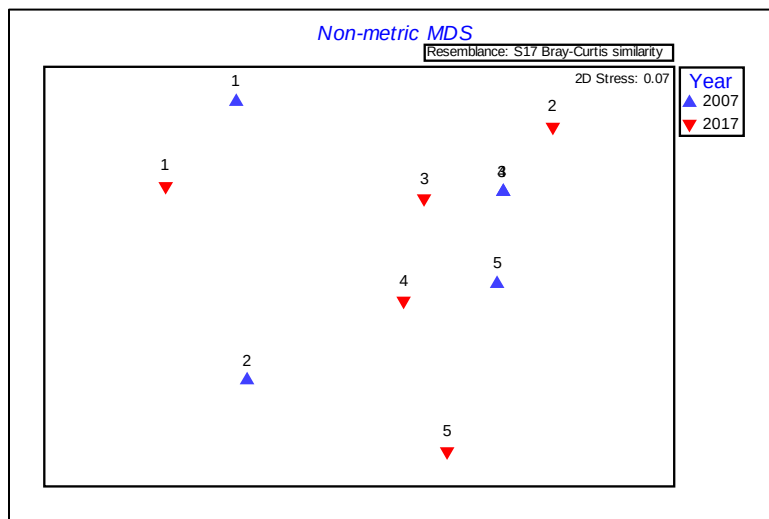


Figure 42. nMDS of species cover by transect in Lily1 pond 2007 vs. 2017.

Little Bennett Pond

In Little Bennett pond, there was no significant shift in taxonomic composition of the plant communities in 2007 and 2017 (ANOSIM: $R=-0.06$, $p=0.52$) (Figure 43)

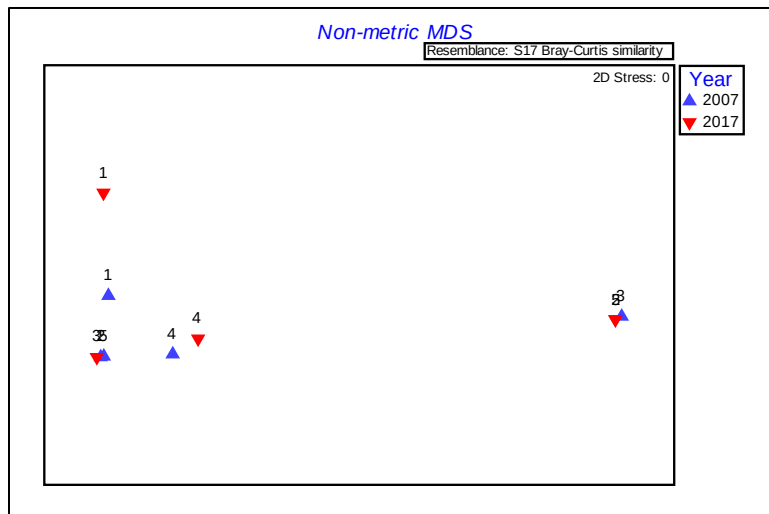


Figure 43. nMDS of species cover by transect in Little Bennett pond in 2007 vs. 2017.

P26 Pond

Vegetation in the box plots of P26 pond also demonstrated no significant shift in species composition over the 10 year period between surveys (ANOSIM: $R=-0.054$, $p=1.0$, Figure 44).

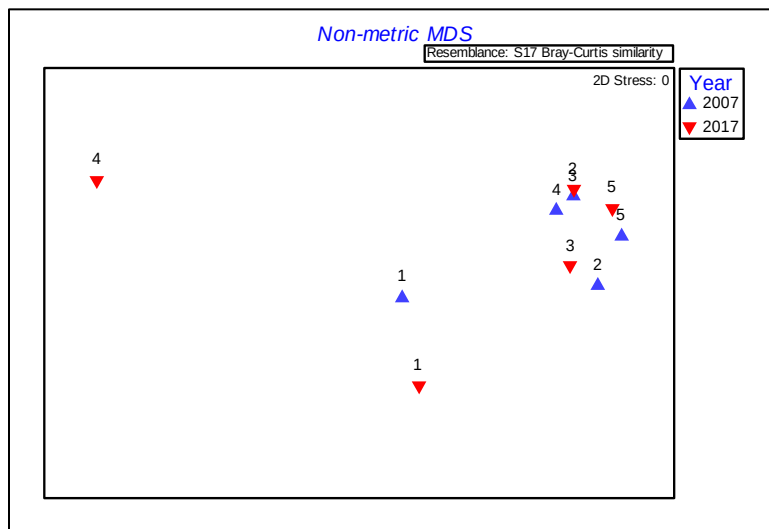


Figure 44. nMDS of species cover by transect in P26 pond in 2007 vs. 2017.

Pasture1 Pond

While minor changes in species composition of Pasture1 pond vegetation were apparent (Figure 45), ANOSIM suggested that these alterations were not statistically significant (ANOSIM: $R=0.16$, $p=0.15$)

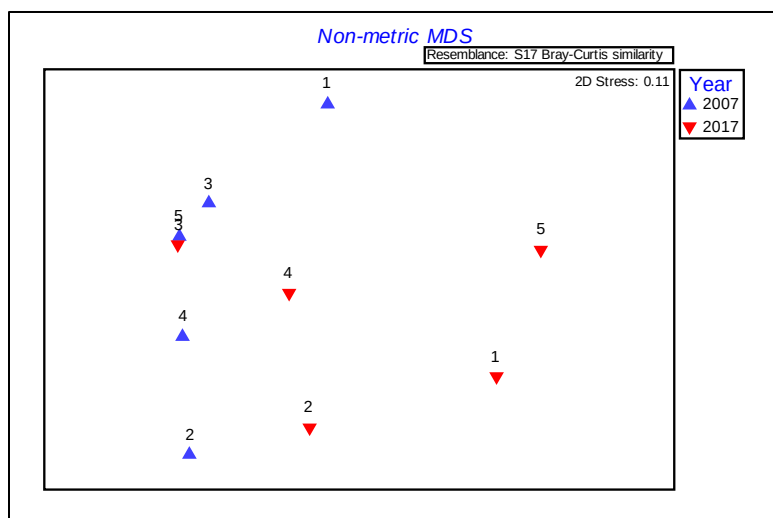


Figure 45. nMDS of species cover by transect in Pasture1 pond in 2007 vs. 2017.

Pasture3 Pond

In contrast to Pasture1, this pond did exhibit a significant change in vegetation between 2007 and 2017 (ANOSIM: $R=0.70$, $p=0.008$) (Figure 46, Table 32). The shift was due mainly due to changes in the abundance/distribution of *E. robbinsii*, *Utricularia* sp., and *N. odorata*.

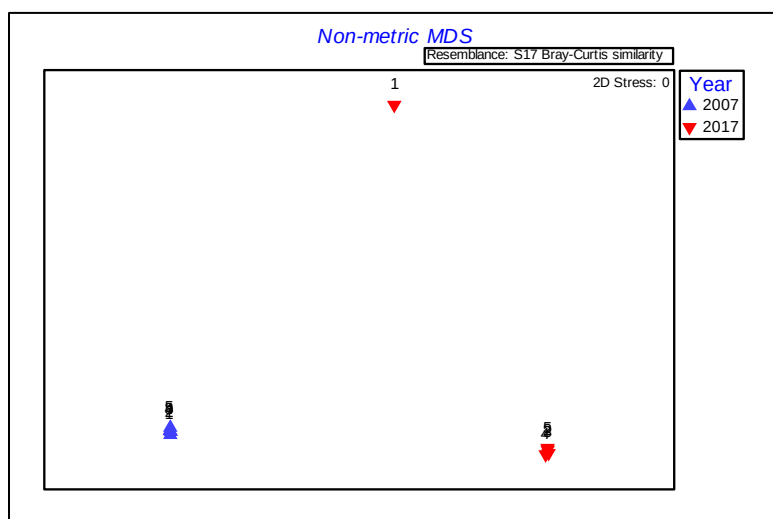


Figure 46. nMDS of species cover by transect in Pasture3 pond in 2007 vs. 2017.

Table 31. SIMPER results for species cover change in Pasture3 pond between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Eleocharis robbinsii</i>	00	2.6	31.2
<i>Utricularia</i> sp.	0.0	2.0	55.3
<i>Nymphaea odorata</i>	4.2	3.6	73.6

Pasture4 Pond

In Pasture4 pond, the plant community within box plots exhibited a significant change (ANOSIM: $R=0.47$, $p=0.008$) as a result of shifting abundances/distribution of *Eleocharis robbinsii*, *Nymphaea odorata*, *Utricularia* spp.

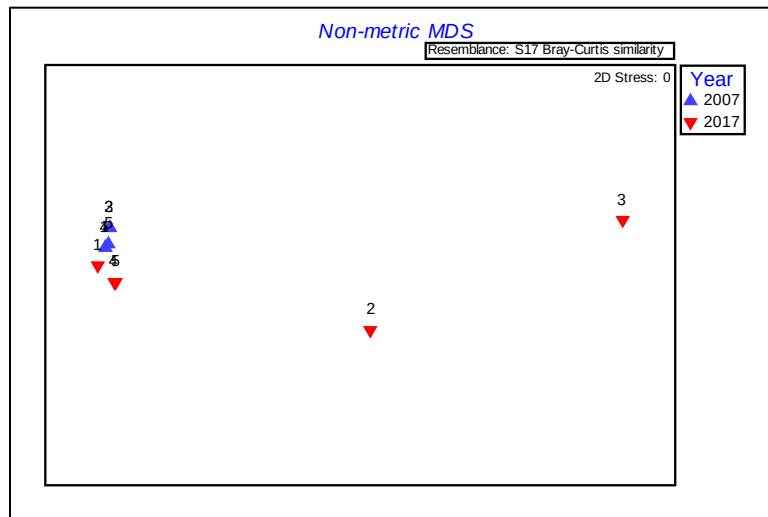


Figure 47. nMDS of species cover by transect Pasture4 pond in 2007 vs. 2017.

Table 32. SIMPER results for species cover change in Pasture4 pond between 2007 and 2017.

Species	2007	2017	Cum.%
<i>Eleocharis robbinsii</i>	0.0	2.0	26.6
<i>Nymphaea odorata</i>	5.6	5.4	48.3
<i>Utricularia</i> spp.	0.0	1.0	64.8
<i>Potamogeton epihydrus</i>	0.0	1.2	79.8

Rare and exotic species

Four non-native species were recorded. They were *Lythrum salicaria* (purple loosestrife), *Phragmites australis* (common reed), *Typha angustifolia* (narrowleaf cattail), and *Salix cinerea* (gray willow). The two state-threatened species, *Carex oligosperma* (few-fruited sedge) and *Orontium aquaticum* (golden club) were observed. The former was found in several additional ponds (Grassy 1, Bennett, Clapps Round 1) than what was documented in a previous rare-plant report (LeBlond 1989), while the later was found outside of the transects or box plots themselves.

Environmental variables

Soil properties

The organic matter (OM) content of soil cores was highly variable among ponds, ranging between 8% in Clapps-Round1 and 66% in Little Bennett (Figure 48).

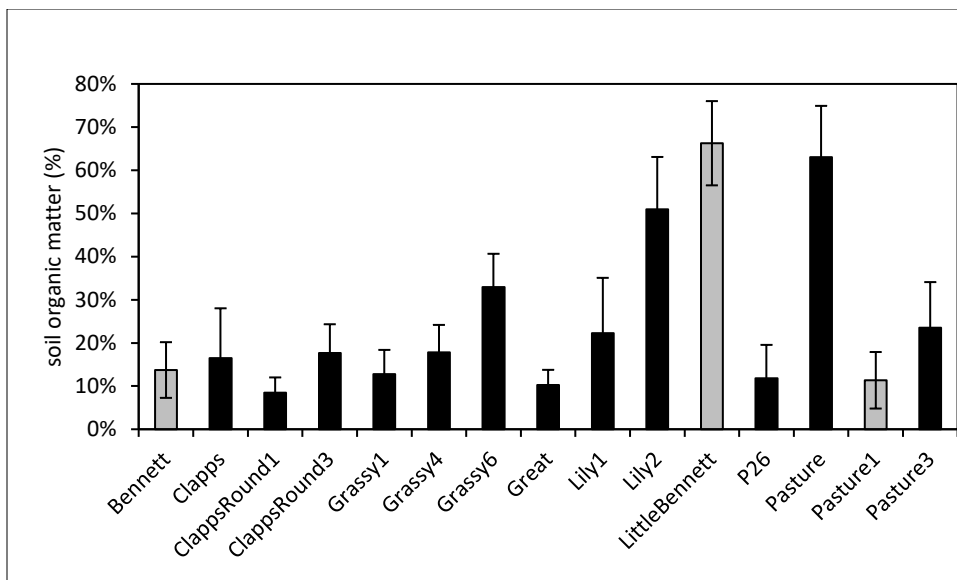


Figure 48. Percent organic matter by weight (%OM) by pond in 2017.

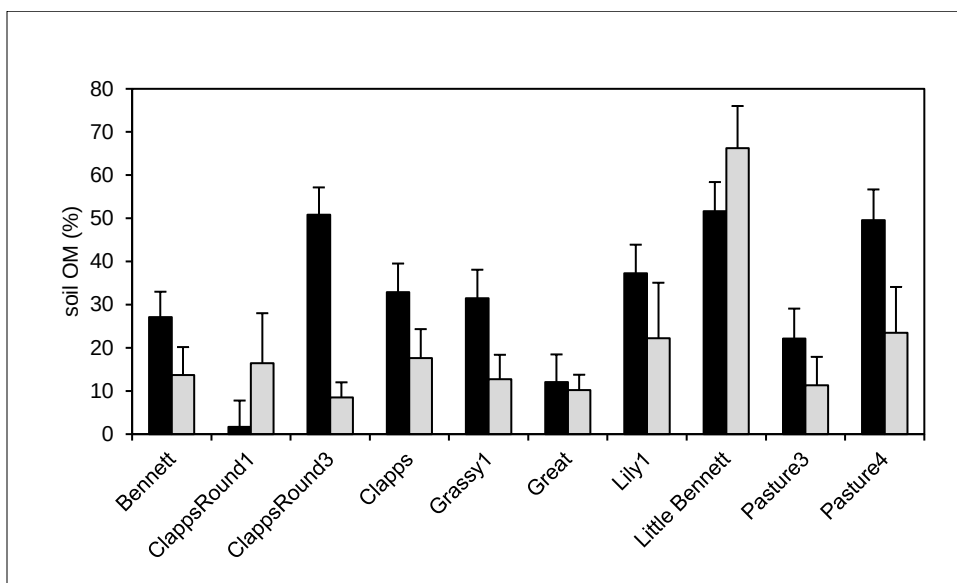


Figure 49. Soil organic matter content (%) by pond and year (errors bars are standard errors of the means).

The nitrogen content of pond soils was also highly variable, ranging between >2% in Pasture1 and Little Bennett, and <0.5% in Round1, Great, and P26 ponds.

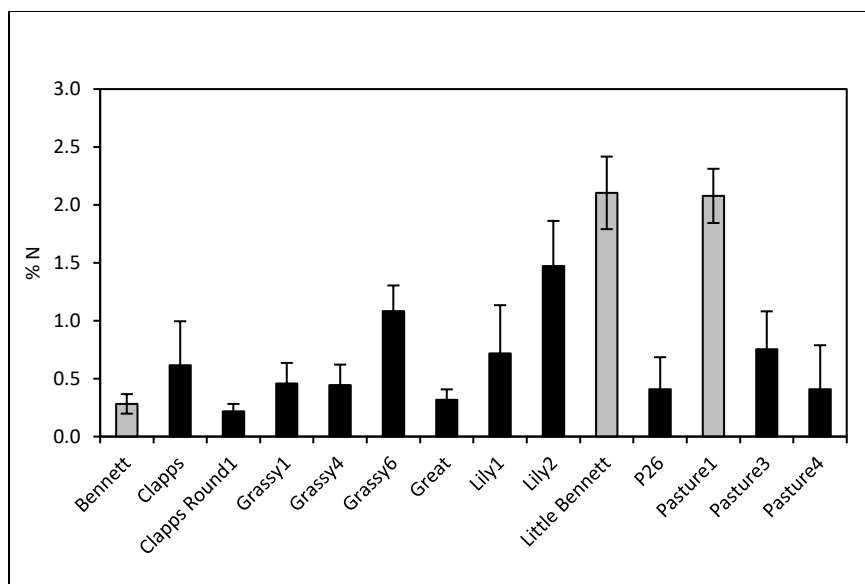


Figure 50. Percent nitrogen by weight in soil cores collected from the ponds.

Soil P followed a similar pattern to N, with Pasture1 and Little Bennett ponds having the highest concentrations (>390 mg/kg) and ClappsRound1, P26, and Bennett the lowest (<100 mg/kg).

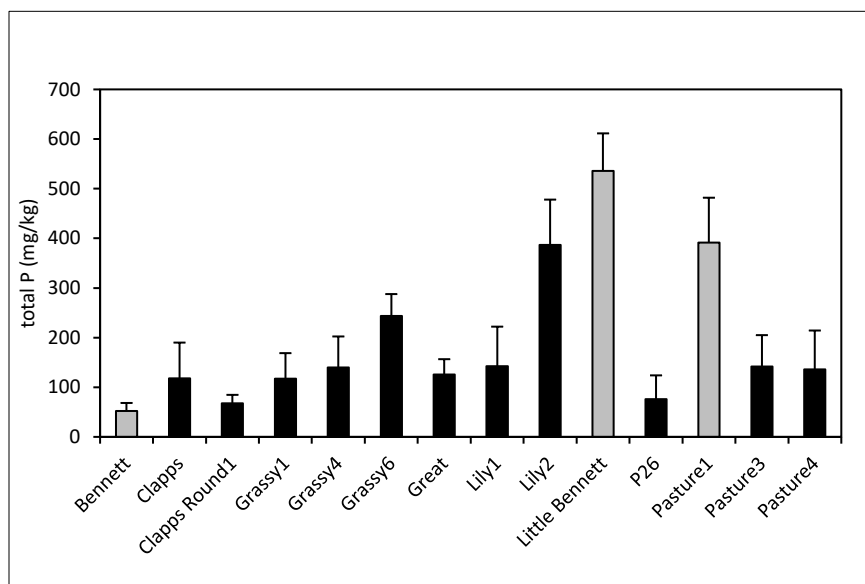


Figure 51. Total phosphorus (P) by weight in soil cores collected from transect locations in 2017.

Surface water quality

Surface water pH readings (average of 5 readings at each transect location, once during August) indicated in 2007 that the ponds were all very acidic with pH values < 6 (Figure 52). However, there was a substantial difference in pH between survey years

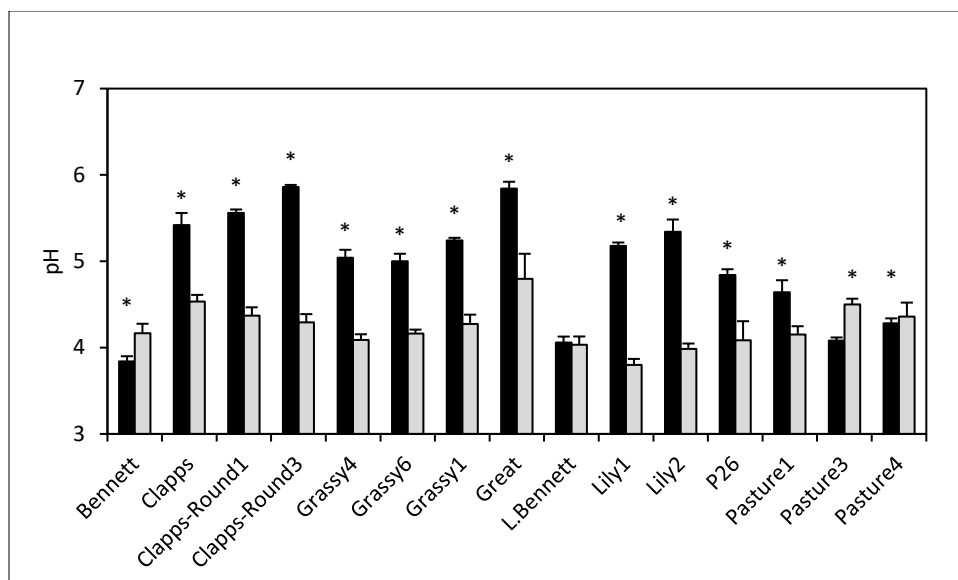


Figure 52. Surface water pH in 2007 vs. 2017 by pond (error bars are standard errors of the means).

Surface water conductivity varied between 0.08 (P26) and 1.5 (Grassy4) $\mu\text{S}/\text{cm}$, with an average of 0.11 $\mu\text{S}/\text{cm}$ in 2017 (Figure 53). In 2007, the average value was the same (0.11 $\mu\text{S}/\text{cm}$), ranging between 0.06 $\mu\text{S}/\text{cm}$ (ClappsRound1) and 0.18 $\mu\text{S}/\text{cm}$ (Grassy4). The average value in 2007 was 4.9 and 4.2 in 2017

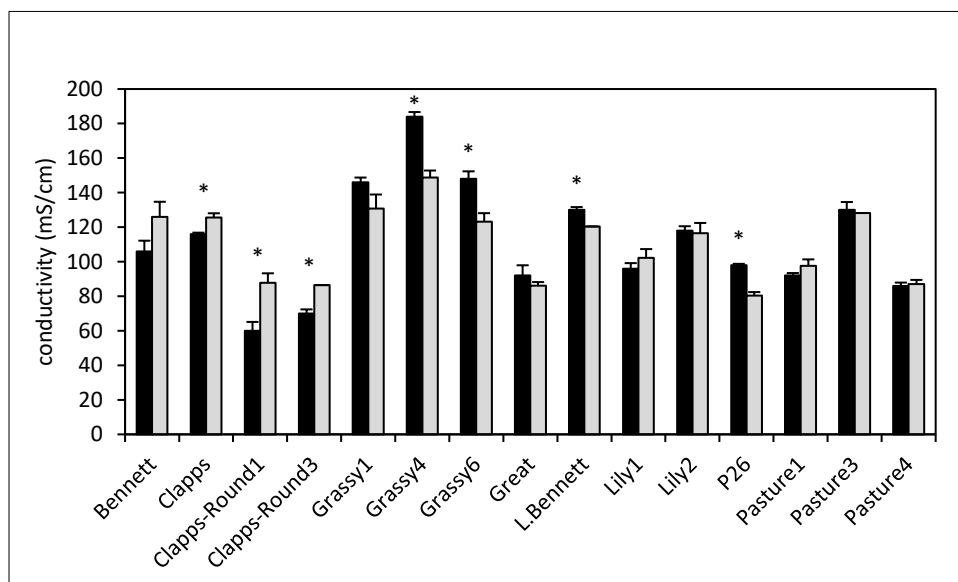


Figure 53. Surface water conductivity in 2007 vs. 2017 by pond (error bars are standard errors of the means).

Surface water temperatures were within a relatively narrow range between 21.9°C (Lily2) and 24.3°C (Clapps), averaging 21.9°C (Figure 54).

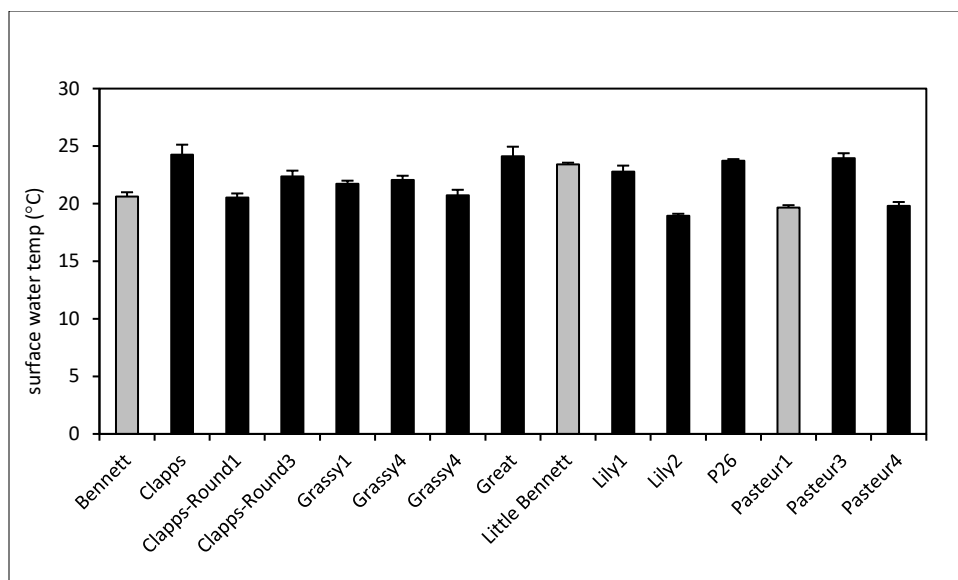


Figure 54. Surface water temperature in 2017 by pond (error bars are standard errors of the means).

Water depth

Water depths were considerably lower in 2017 compared with 2007, but the differences varied substantially among ponds, ranging between -69% (Bennett) and =2% (Little Bennett).

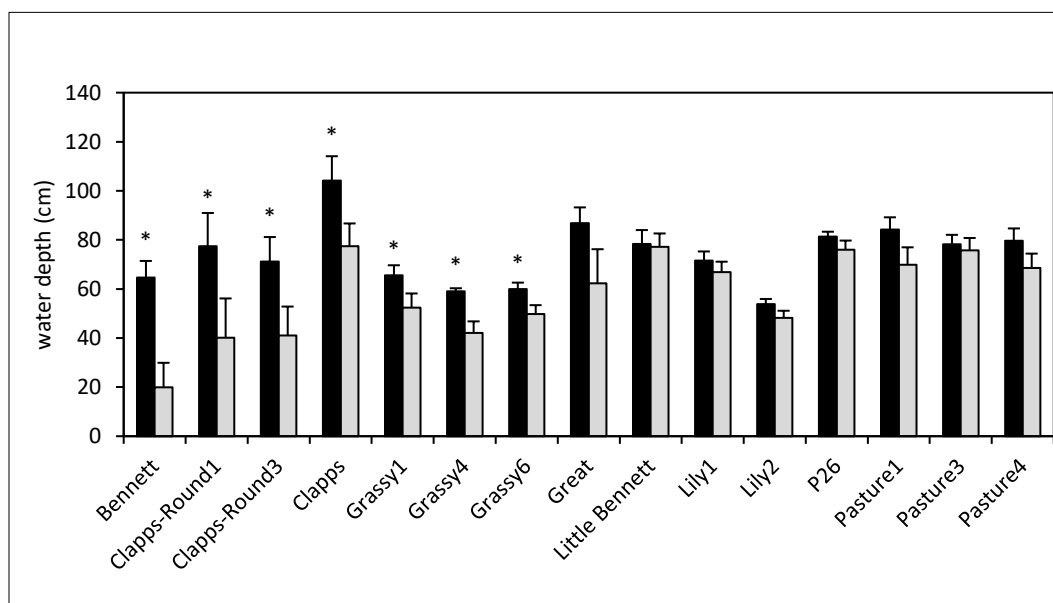


Figure 55. Water depths in 2007 vs. 2017 by pond (error bars are standard errors of the means).

Relationships among variables

In terms of physico-chemical properties, Principle Components Analysis (PCA) was run on the sediment and water quality data. From this analysis it appears that disparities among ponds is primarily the result of variations in pH and % organic matter (Figure 56).

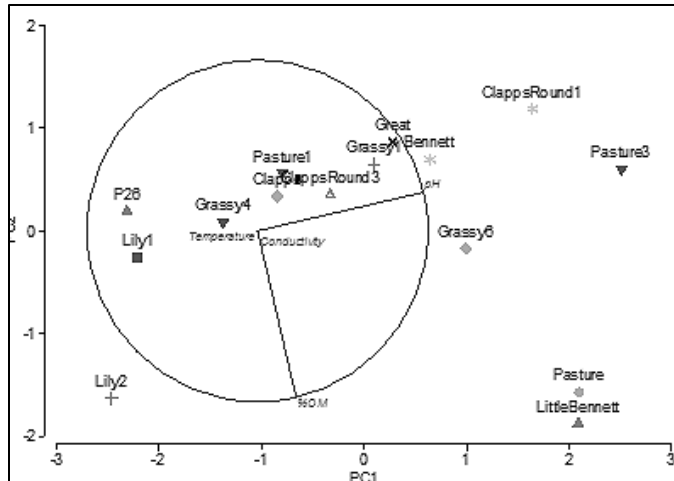


Figure 56. Principle Components Analysis (PCA) of select environmental variables among ponds.

In terms of soil nutrient content, TN and TP were closely related to each other ($R^2=0.92$, $p<0.01$). Nitrogen content was also positively related to %OM ($R^2=0.45$, $p<0.01$ for N vs. %OM; $R^2=0.50$, $p<0.01$ for P vs. %OM) (Figure 57). Moreover, surface water pH was reasonably well-correlated with percent soil organic matter and surface water conductivity was negatively related to mean water depth along the transects (Figure 57). Interestingly, species richness was positively and significantly correlated with the standard error (SE) of H₂O depths (Figure 57).

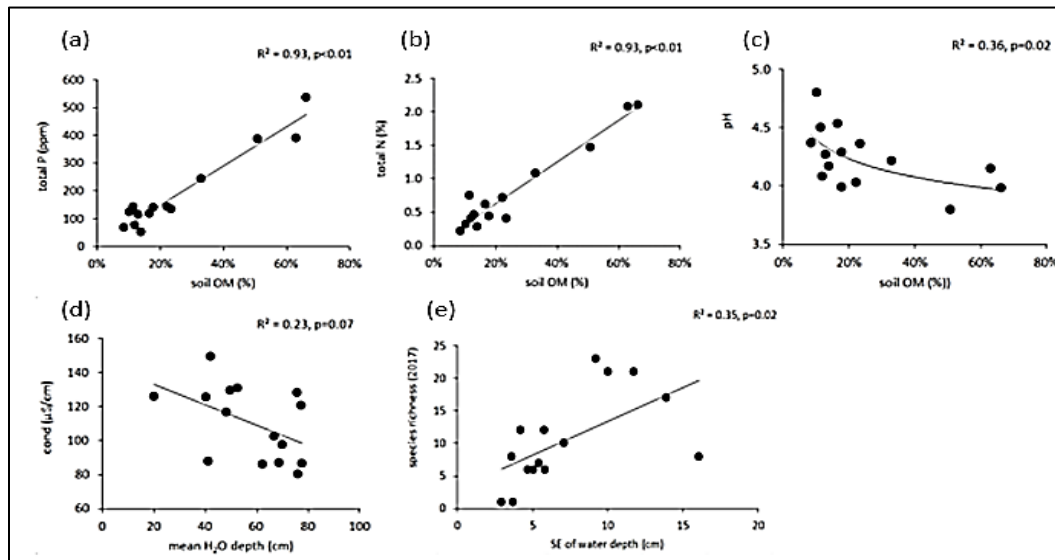


Figure 57. Relationships between a) soil organic matter and total phosphorus, b) soil organic matter and total nitrogen, c) soil organic matter and surface water pH, and c) mean water depth and surface water conductivity. Correlation coefficients indicated by R^2 values.

Discussion

There were a number of species cover and frequency changes in the Province Lands pond vegetation. A large part of this could be due to substantially lower water levels in 2017, given that wetland plant growth and inter-specific competition can respond within a single growing season. In this regard, the average number of species per pond increased from 6.5 in 2007 to 10.5 in 2017. Moreover, the total number of species recorded along transects in 2007 was 36, but increased to 58 in 2017. For box plots, the change was similar with total species numbering 42 in 2007 and 64 in 2017. The species accounting for the largest dissimilarity between 2007 and 2017 plant communities were *Eleocharis quadrangulata*, *Dulichium arundinaceum*, *Decadon verticillatus*, *Pontederia cordata*, and *Utricularia cornuta* – all of which are native species and do not suggest any undesirable trajectory. Four exotic species were observed in 2017 (as they were in 2007), including *P. australis* (unincreased) *L. salicaria*, *S. cinerea*, and *T. angustifolia*. *Phragmites* itself increased substantially between surveys.

One surprise was the appearance and abundance of *Brasenia schreberi* in 2017. This may be due to the shallower water depth in 2017 as this species grows best in water, 1-m in depth (cites). Additionally, *N. odorata* contributed substantially to dissimilarities between survey years for many ponds. This particular species, although it can grow in water > 2 m, exhibits reduced biomass under longer, deeper flooding conditions (Paillisson and Marion 2006). Many other aquatic taxa, including rushes and sedges, also respond to reduced water depths will elevated biomass (Edwards et al. 2003; Fraser and Karnezis 2005). Similarly, Hudon (1997) reported that during low water levels, marshland in the St. Lawrence River can support a high plant biomass, whereas the lake shifts to more open-water with much lower plant biomass when levels are high.

With respect to environmental variables, two of the ponds closest to the Provincetown landfill (Little Bennett) and directly down-gradient (hydrologically) had the two highest concentrations of soil nitrogen (Figures 50, 58). The same pattern was observed for soil TP (Figure 51). The other pond, Bennett, is the closest site to the landfill, but it is unclear how water may be moving in/out of this pond in relation to potential impacts since it appears to largely in the groundwater flow path from a natural, open area to the north (Figure 58). Consequently, whether the landfill has leached nutrients into adjacent ponds is still unclear, but the elevated concentrations of TN and TP in Little Bennet and Duck ponds seem to indicate that there may be some impact and warrants further investigation.

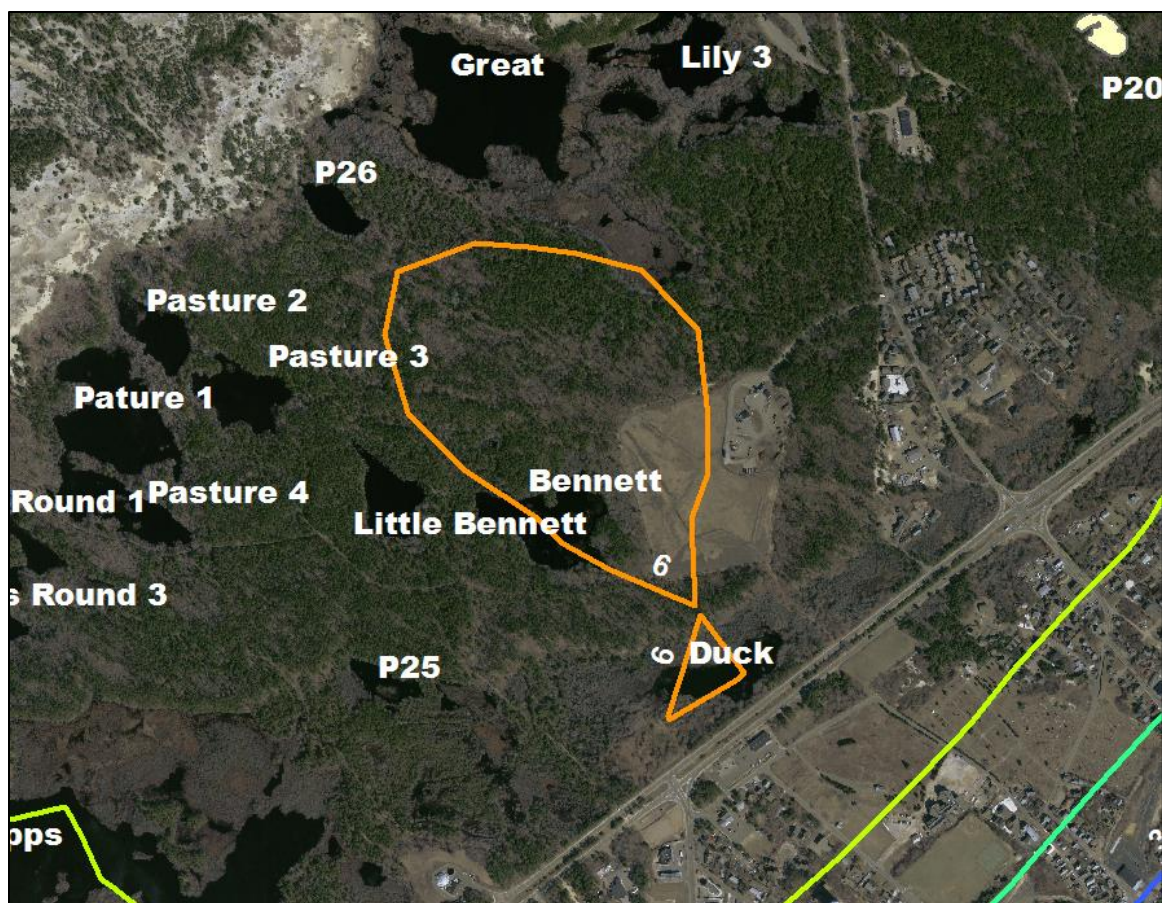


Figure 58. Map of ponds in close proximity to the Provincetown landfill.

In terms of OM changes between years, in most ponds the difference was not significant. Only Pasture4 and Clapps-Round3 exhibited significant change (decreases). The reason for this is not currently known, although this could be an artifact of sampling in relation to spatial heterogeneity. Alternatively, the time interval of 10 years between samplings is not enough time to capture substantial changes in OM from the methods of sampling here. Regardless, both TN and TP were significantly and positively related to % OM. In contrast, pH was negatively correlated with % OM, which is logical given that pH tends to decrease with OM accumulation during the process of succession (Berendse et al. 1998). With respect to the observed pH decline between 2007 and 2017, the 2016–2017 low water/drought conditions preceding the sampling may have caused pH to decrease in ponds (Yan et al. 1996, Faulkenham et al. 2003). In fact, relative groundwater levels (water depths in relation to the lowest depth recorded during the period of record) showed that values were 25 cm lower in 2017 than in 2007 (Figure 59).

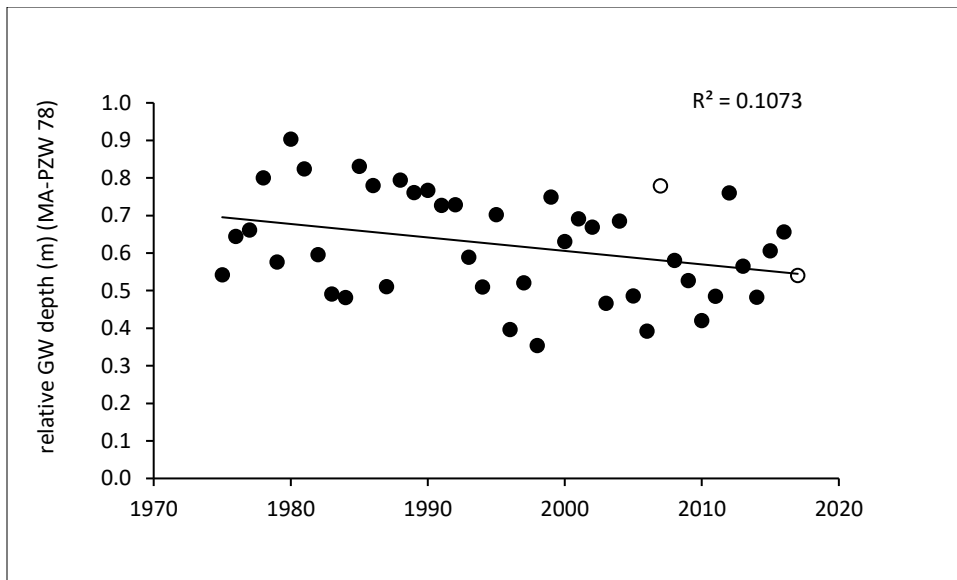


Figure 59. Average relative water depths in USGS Provincetown well between 1975 and 2017 (open circles denote 2007 and 2017 values).

Conclusions

Plant communities and certain environmental variables were significantly different between survey years. The low water levels in 2017 due to summer drought conditions almost certainly played a significant role in this change. Accordingly, more surveys are needed to discern whether the trends observed during this particular time period will continue, dissipate, or reverse itself. However, these and all other ecosystems on Cape Cod are continuously experiencing climate change, which has been shown to influence water temperatures and the decline in acid rain has elevated pH levels in permanent kettle ponds (Smith et al. 2016).

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