



Status of Kettle Pond Plant Communities of Cape Cod National Seashore

Report on 2016 Surveys and Analyses of Temporal Change Since 1995

Natural Resource Report NPS/CACO/NRR—2018/1668



ON THE COVER

Aerial photograph of Wellfleet kettle ponds

Photograph by: Stephen Smith, Cape Cod National Seashore (2007))

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June 2018

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Smith, S. M. 2018. Status of kettle pond plant communities of Cape Cod National Seashore: Report on 2016 surveys and analyses of temporal change since 1995. Natural Resource Report NPS/CACO/NRR—2018/1668. National Park Service, Fort Collins, Colorado.

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Executive Summary

- In numerous ponds, species richness and plant cover has decreased over time
- The presence of *Phragmites* in Herring and Horseleech ponds is of concern, since this species has a propensity to proliferate and displace native vegetation. The other two invasive species were the *Cambomba caroliniana* (fanwort) and *Elodea nuttallii* (Nuttall's waterweed), which were found in Herring and Higgins ponds, respectively
- One state-listed species, *Drosera filiformis* (thread-leaf sundew; Special Concern) was recorded in 2016 (Great-W pond)
- Because littoral zone macrophytes appear to be under some stress, as evidenced by their reduced abundance in many cases, it is important that CACO continues to support current efforts to restore/rehabilitate denuded pond shorelines where visitors have trampled the vegetation
- By frequency (% occurrence), the five most abundant species along transects in 2016 were *Lobelia dortmanna* (Dortmann's Cardinalflower), *Eriocaulon septangulare* (pipewort), *N. odorata* (white waterlily), *Nymphoides cordata* (little floating-hearts), and *Pontederia cordata* (pickerelweed)
- By frequency, the five most abundant species in the 2016 box plots were *Eriocaulon septangulare*, *L. dortmanna*, *Isoetes* spp. (quillworts), *Myriophyllum* spp. (milfoil), and *N. odorata*

Acknowledgments

Many thanks to the many seasonal employees and interns who collected this data for CACO, whose contribution to this long-term monitoring program are invaluable.

Introduction

Background and Objectives of Kettle Pond Vegetation Monitoring

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. Today, there are 16 discrete kettle ponds within CACO in the towns of Truro and Wellfleet (Figure 1).

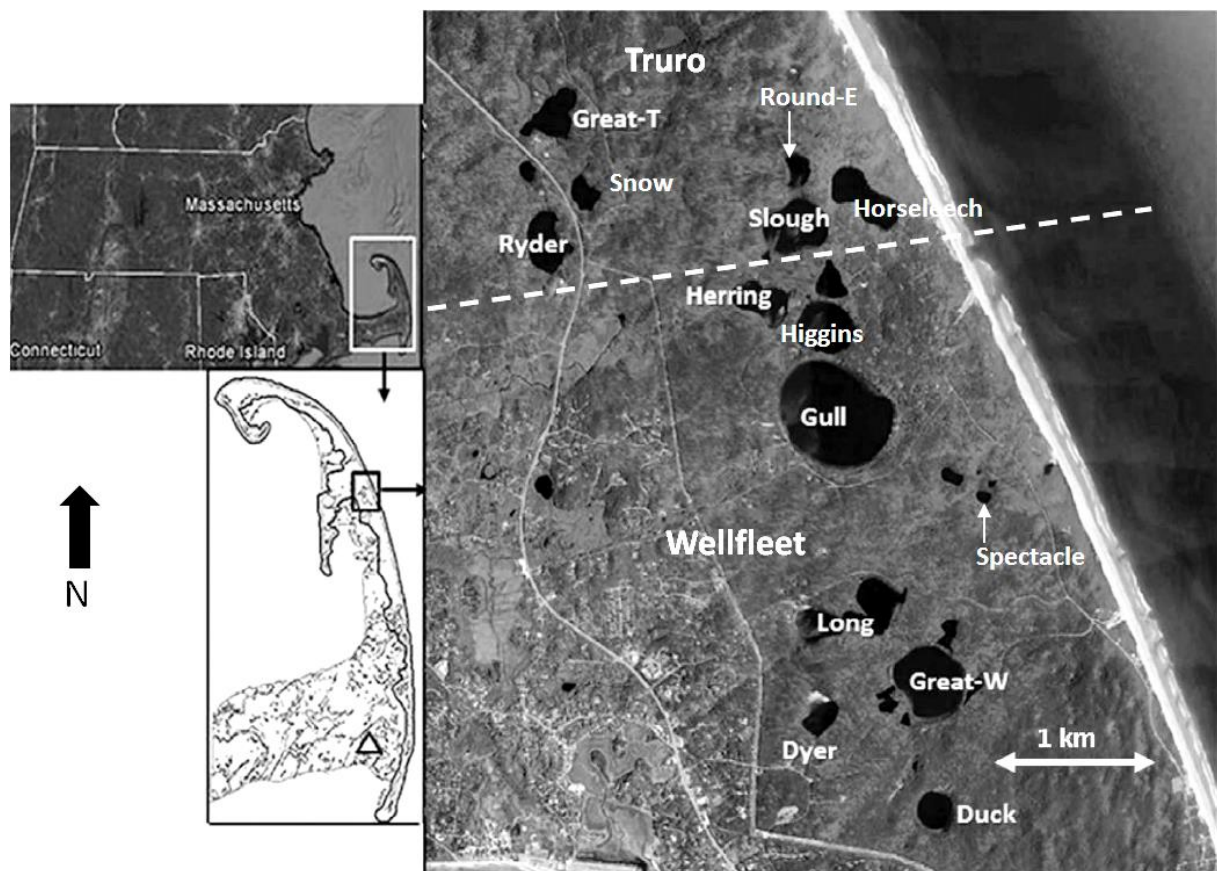


Figure 1. Map of Massachusetts (upper left), outer Cape Cod (lower left; polygon represents boundary of CACO), and CACO kettle ponds where plant communities are being monitored (dashed line represents boundary between the towns of Wellfleet and Truro).

This report is focused on the current (2016) status of kettle pond aquatic vegetation and changes that have occurred over time since the first survey by Roman et al. (2001) in 1995. The data collection is part of CACO’s long term Inventory & Monitoring Program to document the status and temporal changes in vegetation in several important ecosystems within the park. Detailed descriptions of Cape

Cod National Seashore (CACO) kettle ponds (Figure 1) can be found in Portnoy et al. (2001), Roman et al (2001) and Smith (2012). Kettle ponds provide critical habitat for a variety of plant and animal life (Henning and Remsburg 2009). A number of 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.

Macrophyte vegetation integrates a variety of physical, chemical, and biological factors over time and is therefore a good indicator of long term changes in pond physico-chemistry and hydrology. Aquatic plants are a critical link between top-down (e.g. trophically controlled) and bottom-up (e.g. water chemistry-driven) processes, which makes them an important element to assess overall ecosystem integrity. Roman et al. (2001) developed a preliminary protocol to assess vegetation changes in five kettle ponds (Duck, Herring, Great-T, Gull, Ryder) based on surveys conducted in 1995. This report compares that data to additional surveys conducted in 2005, 2010, and 2016, which were monitored according to a protocol published in 2012 (Smith 2012). Although some of the methods have changed slightly over this time period in an effort to improve the scope and techniques of sampling, various subsets of the data are directly comparable.

Study Objectives

Management Objectives

CACO has not yet developed specific management objectives for kettle pond vegetation; however, the ponds potentially can be managed in very tangible ways. For example, human access and foot traffic can be controlled, and development in the watershed could be limited or managed in various ways. In general, the preservation of native pondshore plant communities, particularly as it relates to state-listed rare species and infestations of invasive species, is a high priority. In addition, any shifts in plant communities that indicate rapid changes in trophic status would provide valuable information for determining whether human-related impacts on hydrology and/or nutrient cycles are occurring and whether certain management actions might be needed to ameliorate the effects.

Monitoring Objectives

The original sampling objectives of the report on kettle pond aquatic vegetation by Roman et al. (2001) in 1995 were based upon characterizing the attributes of plant communities in five specific kettle ponds relative to their trophic status. These ponds were selected non-randomly and were five of 10 ponds, known as the “primary ponds,” for which CACO has extensive water quality monitoring

data. A subsequent report in 2005 focused on analyzing changes in vegetation between 1995 and 2005, re-evaluating the original methods used to assess the vegetation, and testing several newly added components of monitoring. In addition, the other five primary ponds were added to the monitoring network. As such, this initial protocol will only be able to make inferences about these individual ponds, rather than all the kettle ponds in general. In a statistical context, the desirable level of power for the monitoring protocol is 80% to detect a 20% change in important kettle pond vegetation variables.

Methods

Plant cover has been monitored along transects in five ponds since 1995 (Duck, Great-T, Gull, Herring, Ryder), in ten ponds since 2005 (Duck, Dyer, Great-T, Great-W, Gull, Herring, Long, Ryder, Snow, Spectacle) and in 14 ponds since 2010 (Duck, Dyer, Great-T, Great-W, Gull, Herring, Higgins, Horseleech, Long, Round-E, Ryder, Slough, Snow, Spectacle) (Figure 1). The data collected thus far allows for comparisons of 1995-2016 for transects and 2010-2015 for box plots. These discrepancies are the result of 1) further development of the monitoring protocol (post-1995) and 2) adding more pond sites to the monitoring program over time. Percent cover of species along 1-m transect segments are estimated based on cover class categories. These were: 1=0-1%, 2=2-5%, 3=6-10%, 4=11-25%, 5=26-50%, 6=51-75%, 7=76-100%. In 1995, the transect start points were located several meters upslope from the pond edge within wetland and/or upland shrub zones. They extended pondward to where vegetation was no longer present determined by SCUBA. In 2010, these same start points were used, but shoreline vegetation regrowth made it very difficult and hazardous (unsafe where poison ivy was present) to work within the bordering shrub zone. Accordingly, the start point for transects was shifted pond-ward at specific distances from the original start points (Figure 2). In this way, different years of data could still be compared by making distance adjustments to the data. For example, the 0-1 m segment of transect 1 in 2016 would corresponded to the 3-4 m segment of the same transect in 1995 if the start point was moved pond-ward by a distance of 3 m, etc. Furthermore, transects were limited to 20 m into the ponds, given that the very low feasibility of using SCUBA to document deep submerged vegetation for each survey.

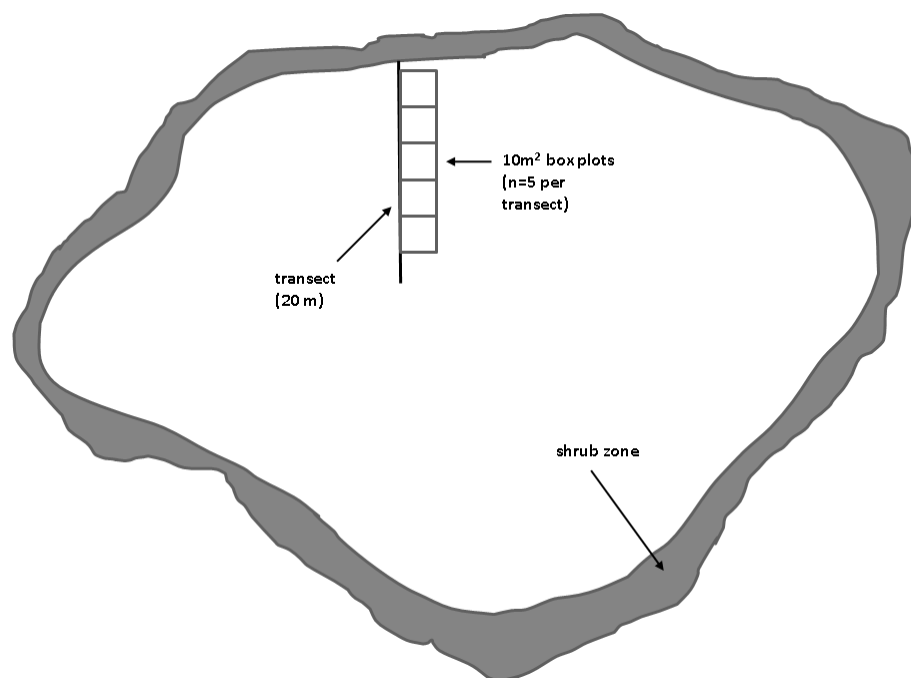


Figure 2. Diagram of current line transect and box plot (five contiguous 3.3 x 3.3 m plots; 10 m²) each) configuration. There are five transects (20 m each) and therefore 25 box plots per pond.

Two-dimensional box plots measuring 5 m (base) x 10 m (pond-ward) were added to the protocol in 2005 in order to document species that fell outside the scope of the line transects. However, crews encountered the same difficulties working in the shrub zone (Figure 2). In 2010, therefore, the box plots were also moved pond-ward into the open littoral zone and expanded in total area to five 3.3 m x 3.3 m (10 m²) plots along each transect for better spatial coverage (Figure 2). As a result, however, only box plots from 2010 and 2016 are directly comparable at this time.

Data Management and Statistical Analyses

All data files can be found on North Atlantic Coastal Laboratory server and the final report containing the data presented below will be posted to the NPS Integrated Resource Management Applications (IRMA) website for others to access.

The vegetation data, recorded as scores within cover class categories, was analyzed by first transforming these values into percentages based on the mid-point of ranges that each cover class represents (e.g., Gehlhausen and Augspurger 2000). For example, a score of 3 representing the 6-10% cover class category would be transformed to 8.5%. Subsequently, the sums of these percentages by transect (i.e., sum of the percentage mid-point values for the 20 plots along each transect) and pond (all 100 plots along 5 transects totaled) were calculated for analysis.

Various components of plant community composition and structure were compared in 1995, 2005, 2010, and 2016. Transect data from five ponds that were surveyed in 1995 could be compared with 2016 data, while ten ponds surveyed in 2005 could be compared with 2016. Box plots, yielded cover information for 2010 vs. 2016 comparisons in 14 ponds. Comparisons of transect data between 2010 and 2016 are not included in this report due the short time interval. Note that in some cases, a number of taxa could only be identified to genus, although these are treated statistically as a single (unidentified) taxon). Since many non-vascular bryophytes could not be reliably identified, even to genus, these data were excluded from the analyses. As mentioned above, only the matching portions of transect data from 1995 and 2016 or 2005 and 2016 were used in temporal analysis of change. Species richness was calculated as the total number of species recorded along a transect or pond, depending upon the analysis being conducted.

All statistical analyses were conducted in JMPTM ver. 10.02. Changes in taxonomic composition were assessed using Analysis of Similarities (ANOSIM), based on Bray-Curtis similarity matrices of the mid-point percentages of cover score categories (Clarke and Warwick 2001, Roman et al. 2002). Similarities Percentages (SIMPER) was used to assess which species contributed most (up to 70%) to disparities in ordinal space. Non-metric multidimensional scaling (NMDS), also derived from Bray-Curtis similarity matrices, was used to visualize similarities/dissimilarities in species composition by sum % cover values between various years of surveying. Stress values, a measure of the goodness of fit of the configuration, are given in the upper right hand corner of all MDS plots. Stress values < 0.2 are acceptable from the standpoint of making interpretation of the spatial array of points (Quinn and Keough 2002).

Results

General Characteristics of Kettle Pond Plant Communities in 2016

Transects – Sum % Cover by Pond (2016)

By frequency (% occurrence), the five most abundant species were *Lobelia dortmanna* (Dortmann's Cardinalflower), *Eriocaulon septangulare* (pipewort), *N. odorata* (white waterlily), *Nymphoides cordata* (little floating-hearts), and *Pontederia cordata* (pickerelweed) (Table 1). A fairly large number of species were present in just one or two ponds (Table 1). Species richness among ponds ranged between 3 in Duck and Dyer ponds and 23 in Herring Pond.

Table 1. Total frequency of occurrences for aquatic plant taxa in 2016 (all 14 ponds) at Cape Cod National Seashore.

Species	Frequency (%)
<i>Lobelia dortmanna</i>	86%
<i>Eriocaulon septangulare</i>	79%
<i>Nymphaea odorata</i>	64%
<i>Nymphoides cordatum</i>	50%
<i>Pontederia cordata</i>	50%
<i>Juncus militaris</i>	50%
<i>Carex</i> spp.	50%
<i>Elatine minima</i>	43%
<i>Utricularia</i> spp.	36%
<i>Nuphar variegatum</i>	29%
<i>Decodon verticillatus</i>	29%
<i>Triadenum virginicum</i>	29%
<i>Isoetes</i> spp.	29%
<i>Myriophyllum humile</i>	29%
<i>Scirpus pungens</i>	29%
<i>Utricularia macrorhiza</i>	21%
<i>Utricularia radiata</i>	21%
<i>Lysimachia terrestris</i>	21%
<i>Euthamia tenuifolia</i>	21%
<i>Potamogeton epiphydrus</i>	21%
<i>Najas</i> spp.	21%

Table 1 (continued). Total frequency of occurrences for aquatic plant taxa in 2016 (all 14 ponds) at Cape Cod National Seashore.

Species	Frequency (%)
<i>Lycopus virginicus</i>	21%
<i>Eleocharis</i> spp.	21%
<i>Euthamia tenuifolia</i>	21%
<i>Isoetes lacustris</i>	21%
<i>Hydrocotyle umbellata</i>	14%
<i>Scirpus pungens</i>	14%
<i>Elodea nuttallii</i>	14%
<i>Phragmites australis</i>	14%
<i>Lycopus</i> spp.	14%
<i>Myriophyllum</i> spp.	14%
<i>Eleocharis palustris</i>	14%
<i>Galium</i> spp.	14%
<i>Brasenia schreberi</i>	7%
<i>Eleocharis parvula</i>	7%
<i>Sagittaria latifolia</i>	7%
<i>Decadon verticillatus</i>	7%
<i>Gratiola aurea</i>	7%
<i>Callitriche palustris</i>	7%
<i>Drosera filiformis</i>	7%
<i>Drosera intermedia</i>	7%
<i>Justicia americana</i>	7%
<i>Woodwardia virginica</i>	7%
<i>Cicuta bulbifera</i>	7%
<i>Elatine</i> spp.	7%
<i>Najas flexilis</i>	7%
<i>Potamogeton amplifolious</i>	7%
<i>Thelypteris palustris</i>	7%
<i>Viola lanceolata</i>	7%

The ponds separate out considerably from each other in NMDS ordinal space (Figure 3). Differences among ponds were due primarily to differences in the abundances of the most abundant species listed above. For example, *N. odorata* was very abundant in Herring Pond but non-existent in Long Pond (Table 1). Dyer Pond was spatially separated from the rest of the ponds due to its small number of species.

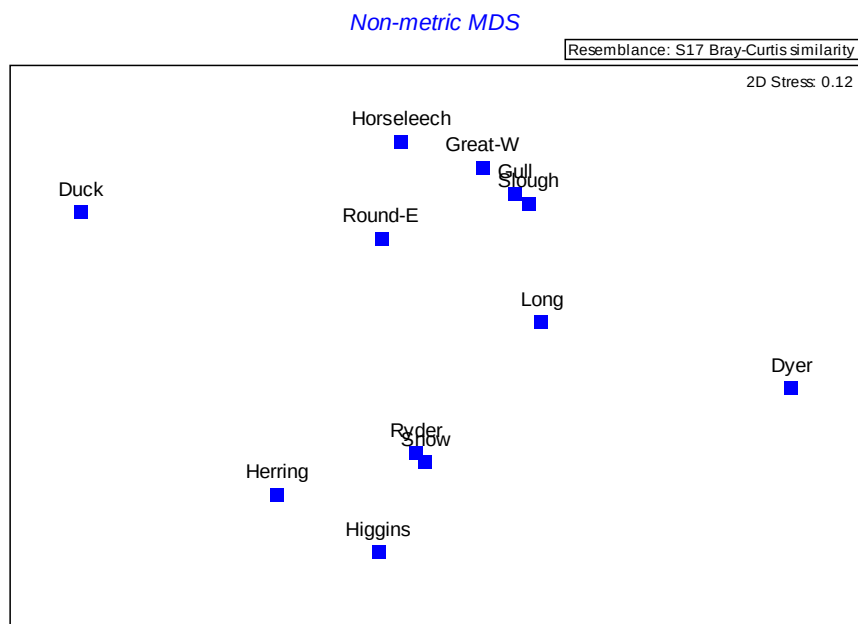


Figure 3. NMDS of species composition among ponds in 2016 by sum % cover at Cape Cod National Seashore.

Box Plots – Sum % Cover by Pond (2016)

By frequency, the five most abundant species in the 2016 box plots were *Eriocaulon septangulare*, *L. dortmanna*, *Isoetes* spp. (quillworts), *Myriophyllum* spp. (milfoil), and *N. odorata* (Table 2). Seventeen species were tied for the least abundant (Table 2). Species richness among ponds was lowest in Duck Pond (3 spp.) and highest in Herring Pond (30 spp.).

Table 2. Frequencies of aquatic plant taxa in box plots 2016 (all 14 ponds) at Cape Cod National Seashore.

Species	Frequency (%)
<i>Eriocaulon septangulare</i>	86%
<i>Lobelia dortmanna</i>	86%
<i>Isoetes</i> sp.	71%
<i>Myriophyllum</i> sp.	64%
<i>Nymphaea odorata</i>	64%

Table 2 (continued). Frequencies of aquatic plant taxa in box plots 2016 (all 14 ponds) at Cape Cod National Seashore.

Species	Frequency (%)
<i>Elatine minima</i>	57%
<i>Eleocharis</i> spp.	57%
<i>Euthamia tenuifolia</i>	57%
<i>Pontederia cordata</i>	57%
<i>Utricularia</i> spp.	57%
<i>Carex</i> sp.	50%
<i>Juncus militaris</i>	50%
<i>Lysimachia terrestris</i>	50%
<i>Nymphoides cordata</i>	50%
<i>Triadenum virginicum</i>	50%
<i>Lycopus</i> spp.	43%
<i>Najas</i> spp.	36%
<i>Nuphar variegatum</i>	36%
<i>Scirpus pungens</i>	36%
<i>Utricularia radiata</i>	36%
<i>Decodon verticillatus</i>	29%
<i>Utricularia macrorhiza</i>	29%
<i>Galium</i> spp.	21%
<i>Gratiola aurea</i>	21%
<i>Hydrocotyle umbellata</i>	21%
<i>Potamogeton epiphydrus</i>	21%
<i>Woodwardia virginica</i>	21%
<i>Brasenia schreberi</i>	14%
<i>Calamagrostis canadensis</i>	14%
<i>Phragmites australis</i>	14%
<i>Callitriche palustris</i>	7%
<i>Cambomba caroliniana</i>	7%
<i>Cicuta bulbifera</i>	7%
<i>Daucus carota</i>	7%

Table 2 (continued). Frequencies of aquatic plant taxa in box plots 2016 (all 14 ponds) at Cape Cod National Seashore.

Species	Frequency (%)
<i>Drosera filiformis</i>	7%
<i>Drosera intermedia</i>	7%
<i>Elodea nuttallii</i>	7%
<i>Juncus acuminatus</i>	7%
<i>Osmunda regalis</i>	7%
<i>Sagittaria latifolia</i>	7%
<i>Salix glauca</i>	7%
<i>Scirpus cyperinus</i>	7%
<i>Sium suave</i>	7%
<i>Thelypteris palustris</i>	7%
<i>Utricularia cornuta</i>	7%
<i>Utricularia purpurea</i>	7%
<i>Viola lanceolata</i>	7%

For the 2016 box plot data, the 14 ponds again separated out into a wide scatter in NMDS, with few distinct groupings (Figure 4). Dyer and Duck Ponds were separated based on their low numbers of species, while Spectacle Pond was distinct in the high abundance of *U. macrorhiza*.

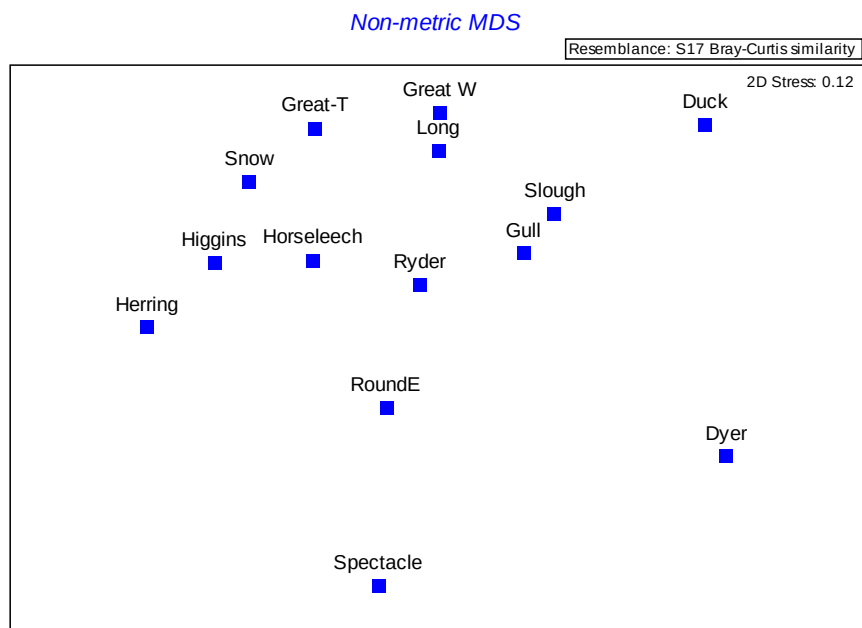


Figure 4. NMDS of ponds based on sum % cover from box plots (2016 data only) at Cape Cod National Seashore.

A total of 55 species were recorded in the transects and box plots combined (Table 3). As noted in the table below, some of these taxa were only identified to genus. Three exotic and one state-listed species were observed in 2016. The three invasive, exotics were *P. australis*, *Cambomba caroliniana* (fanwort, Herring Pond), and *Elodea nuttallii* (Nuttall's waterweed, Higgins Pond). The rare taxon was *Drosera filiformis* (thread-leaf sundew; Special Concern), found in Great-W pond. No federally listed species were encountered in any of the ponds in any year.

Table 3. Total number of wetland species recorded along transects transect and box plot surveys (combined) in 2016 at Cape Cod National Seashore. (I) indicates invasive taxa.

Species	Common Name
<i>Brasenia schreberi</i>	water shield
<i>Calamagrostis canadensis</i>	bluejoint
<i>Callitriche palustris</i>	water star-wort
<i>Cambomba caroliniana</i>	fanwort (I)
<i>Carex</i> spp.	Carex sedges
<i>Cicuta bulbifera</i>	water-hemlock
<i>Clethra alnifolia</i>	pepperbush
<i>Daucus carota</i>	wild carrot
<i>Decadon verticillatus</i>	water-willow
<i>Drosera filiformis</i>	threadleaf sundew

Table 3 (continued). Total number of wetland species recorded along transects transect and box plot surveys (combined) in 2016 at Cape Cod National Seashore. (I) indicates invasive taxa.

Species	Common Name
<i>Drosera intermedia</i>	spatulaleaf sundew
<i>Elatine minima</i>	small waterwort
<i>Elatine</i> spp.	waterworts
<i>Eleocharis palustris</i>	common spikerush
<i>Eleocharis parvula</i>	dwarf hairgrass
<i>Eleocharis</i> sp.	spikerushhes
<i>Elodea nuttallii</i>	Nuttall's waterweed (I)
<i>Eriocaulon septangulare</i>	pipewort
<i>Euthamia tenuifolia</i>	Slenderleaf goldentop
<i>Galium</i> spp.	bedstraws
<i>Gratiola aurea</i>	golden hedgehyssop
<i>Hydrocotyle umbellata</i>	marshpennywort
<i>Isoetes lacustris</i>	boreal quillwort
<i>Isoetes</i> spp.	quillworts
<i>Juncus acuminatus</i>	tapertip rush
<i>Juncus militaris</i>	bayonet rush
<i>Justicia americana</i>	American water-willow
<i>Lycopus</i> spp.	waterhorehounds
<i>Lycopus virginicus</i>	Virginia waterhorehound
<i>Lysimachia terrestris</i>	Swamp candles
<i>Myriophyllum humile</i>	low watermilfoil
<i>Myriophyllum</i> sp.	watermilfoils
<i>Najas flexilis</i>	nodding waternymph
<i>Najas</i> sp.	waternymphs
<i>Nuphar variegatum</i>	Yellow pondlily
<i>Nymphaea odorata</i>	White waterlily
<i>Nymphoides cordata</i>	Little floating hearts
<i>Osmunda regalis</i>	Royal fern
<i>Phragmites australis</i> (I)	Common reed
<i>Pontederia cordata</i>	Pickerelweed
<i>Potamogeton amplifolius</i>	largeleaf pondweed

Table 3 (continued). Total number of wetland species recorded along transects transect and box plot surveys (combined) in 2016 at Cape Cod National Seashore. (I) indicates invasive taxa.

Species	Common Name
<i>Potamogeton epiphydrus</i>	ribbonleaf pondwee
<i>Sagittaria latifolia</i>	broadleaf arrowhead
<i>Scirpus cyperinus</i>	woolgrass
<i>Schoenoplectus pungens</i>	three-square
<i>Sium suave</i>	hemlock waterparsnip
<i>Thelypteris palustris</i>	marsh fern
<i>Triadenum virginicum</i>	Virginia marsh St. Johnswort
<i>Utricularia cornuta</i>	horned bladderwort
<i>Utricularia macrorhiza</i>	common bladderwort
<i>Utricularia purpurea</i>	eastern purple bladderwort
<i>Utricularia radiata</i>	floating bladderwort
<i>Utricularia</i> sp.	bladderworts
<i>Viola lanceolata</i>	bog white violet
<i>Woodwardia virginica</i>	Virginia Chain Fern

Changes in Plant Community Composition along Transects in the 5 Original Ponds between 1995 and 2016

Duck Pond

Significant plant community change was observed in Duck Pond between 1995 and 2016 based on ANOSIM results (Table 4). *Cyperus dentatus* (toothed flatsedge), an unidentified species of *Juncus*, *E. acicularis* (dwarf hairgrass) and *Juncus pelocarpus* (brownfruit rush) were all present in 1995, but absent in 2016. These differences accounted for the most change in Duck Pond over time (Table 4). Most notably, species richness declined from 13 to 3 from 1995-2016. NMDS showed that transects 2 and 4 exhibited the largest disparities as no taxa were recorded along both transects in 2016 (Figure 5).

Table 4. ANOSIM (R=goodness of fit, p=significance level) and SIMPER results from comparisons of Duck Pond 1995 vs. 2016 transect percent cover data (SIMPER numeric values represent mean sum % cover; Cum %=percent contribution to dissimilarity between years) at Cape Cod National Seashore.

Species	1995	2016	Cum %
<i>Cyperus dentaum</i>	9.9	0.0	37.1
<i>Eleocharis acicularis</i>	34.5	0.0	58.5
<i>Juncus</i> spp.	0.8	0.0	72.9
Total spp	13	3	–

ANOSIM R=0.365, p<0.01

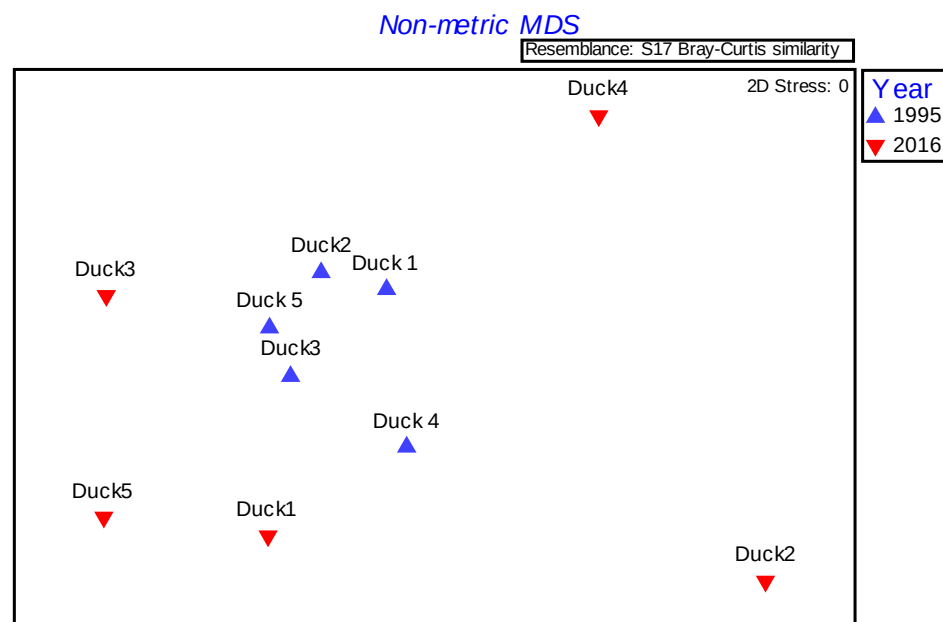


Figure 5. NMDS of percent cover (right) for Duck Pond by transect in 1995 and 2016 at Cape Cod National Seashore.

Great-T (Truro) Pond

In Great-T, ANOSIM also showed significant changes ($p = 0.01$) with year of sampling (Table 5). In terms of sum % cover, the species contributing most to variation in the communities between surveys were *Utricularia* sp., *N. odorata* (decreased), and *Gratiola aurea* (golden hedgehyssop; not observed in 2016). NMDS of frequency values illustrates the separation by transect between 1995 and 2016, with transects 2, 3, and 4 exhibiting the largest divergence in ordinal space (Figure 6). The transect 2 shift was mainly due to increases in *J. militaris* and *N. variegatum*. Along transects 3 and 4, a dramatic increase in *Utricularia* caused the spatial shifts.

Table 5. ANOSIM (R=goodness of fit, p=significance level) and SIMPER results from comparisons of Great-T (Truro) Pond 1995 vs. 2016 transect percent cover data (SIMPER numeric values represent mean sum % cover; Cum %=percent contribution to dissimilarity between years) at Cape Cod National Seashore.

Species	1995	2016	Cum %
<i>Utricularia</i> spp.	135.1	505.2	39.2
<i>Nymphaea odorata</i>	143.1	20.0	52.3
<i>Gratiola aurea</i>	89.7	0.0	61.9
<i>Myriophyllum humilis</i>	73.5	35.4	70.2
Total spp	31	9	–

ANOSIM R=0.132, p=0.18

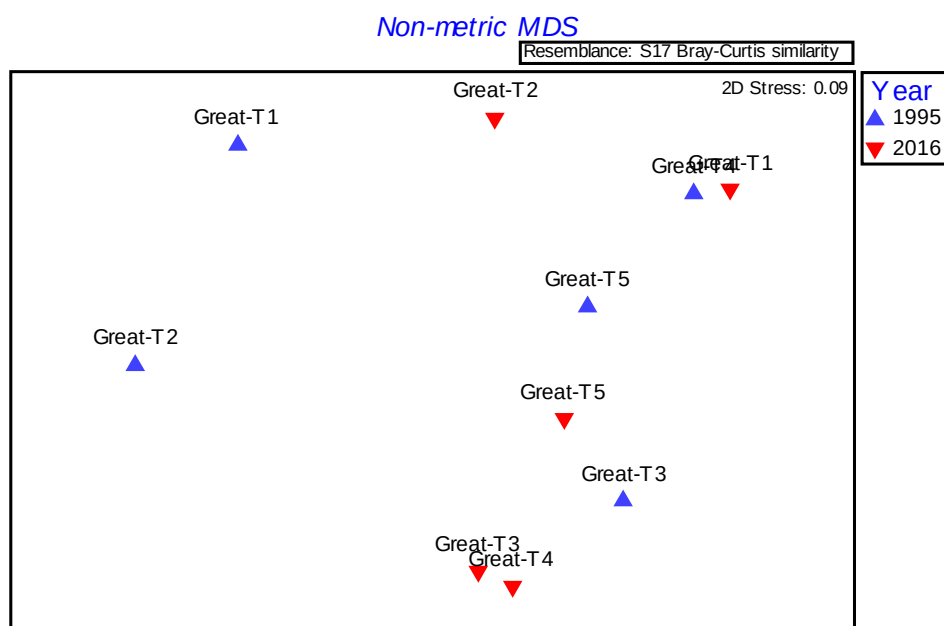


Figure 6. NMDS of percent cover (right) for Great-T (Truro) Pond by transect in 1995 and 2016 at Cape Cod National Seashore.

Gull Pond

Gull pond also underwent a statistically significant change in species composition over time (Table 6). For sum % cover, *L. dortmanna* was reduced and, as stated above, *E. acicularis* and *G. aurea* were not observed in 2016. In the NMDS plots, the changes in community composition by transect and year are obvious (Figure 7). Transects 1 and 2 exhibited the largest changes in NMDS for sum % cover, mainly due to a dramatic reduction in *E. acicularis*.

Table 6. ANOSIM (R=goodness of fit, p=significance level) and SIMPER results from comparisons of Gull Pond 1995 vs. 2016 transect percent cover data (SIMPER numeric values represent mean sum % cover; Cum %=percent contribution to dissimilarity between years) at Cape Cod National Seashore.

Species	1995	2016	Cum %
<i>Lobelia dortmanna</i>	152.4	62.3	30.4
<i>Eleocharis acicularis</i>	68.1	0.0	56.2
<i>Gratiola aurea</i>	108.2	0.0	76.9
Total spp	11	13	–

ANOSIM R=0.312, p=0.02

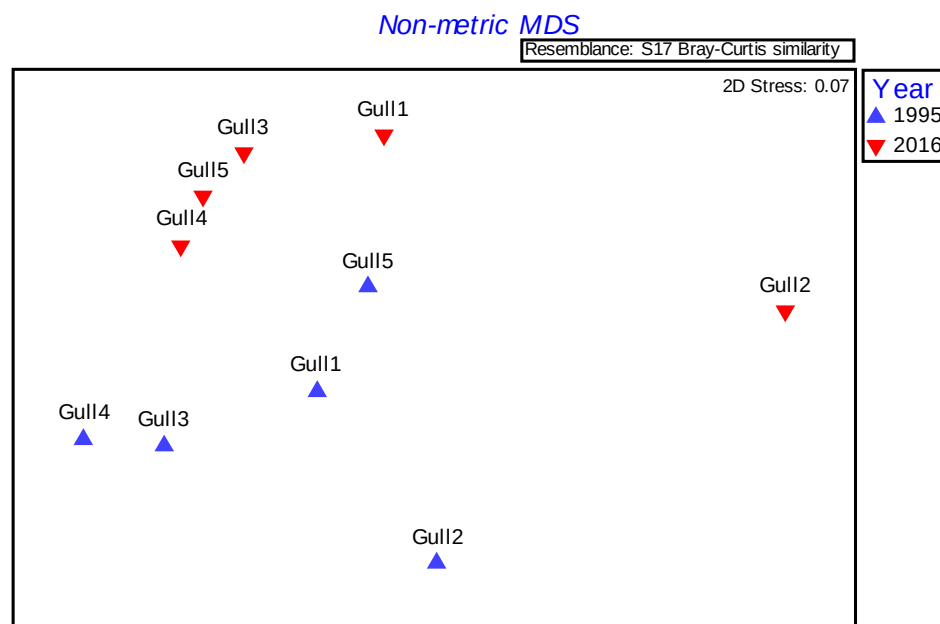


Figure 7. NMDS of percent cover for Gull Pond by transect in 1995 and 2016 at Cape Cod National Seashore.

Herring Pond

In Herring Pond, ANOSIM suggested that there were no statistically significant taxonomic differences between 1995 and 2016 based on % cover values (Table 7). Notwithstanding, *N. odorata* (increased), *Decodon verticillatus* (water willow) (decreased), *N. flexilis* (increased), *T. palustris* (disappeared), and *Brasenia schreberia* (water shield) (disappeared) accounted for the highest amount of dissimilarity between years. Species richness declined slightly from 28 to 23 species between 1995 and 2016. NMDS analysis of this pond's vegetation illustrates how transects 2, 3, and 5 shifted in ordinal space between the two years of survey (Figure 8). Both *Najas* spp. and *N. odorata* exhibited higher % cover along transects 2 and 3, whereas increases in *Lycopus* spp. and *H. umbellata* produced the spatial shift in transect 5.

Table 7. ANOSIM (R=goodness of fit, p=significance level) and SIMPER results from comparisons of Herring Pond 1995 vs. 2016 transect percent cover data (SIMPER numeric values represent mean sum % cover; Cum %=percent contribution to dissimilarity between years) at Cape Cod National Seashore.

Species	1995	2016	Cum %
<i>Nymphaea odorata</i>	143.6	292.5	28.7
<i>Decodon verticillatus</i>	116.7	42.6	50.6
<i>Najas flexilis</i>	0.6	68.7	58.6
<i>Thelypteris palustris</i>	54.2	0.0	65.2
<i>Brasenia schreberia</i>	46.2	0.0	71.7
Total spp	28	23	–

ANOSIM R=0.106, p=0.15

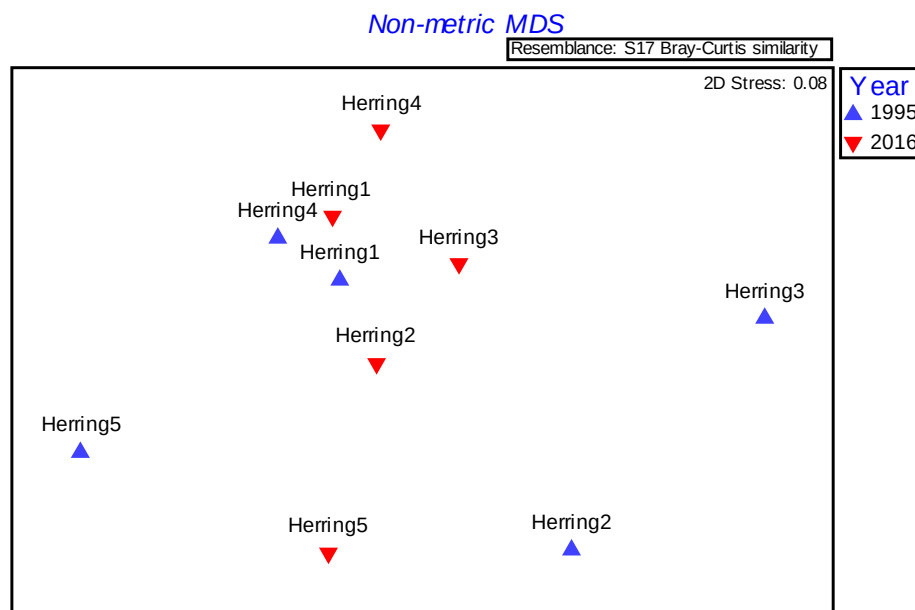


Figure 8. NMDS of percent cover (right) for Herring Pond by transect in 1995 and 2016 at Cape Cod National Seashore.

Ryder Pond

Ryder Pond also did not show any significant difference in community composition for either metric between years (Table 8). Similar to Herring Pond, *N. odorata*, *L. dortmanna*, and *J. militaris* accounted for the large proportion of change between years. The total number of species recorded along the transects for this pond remained relatively unchanged between years of survey (7 to 8 total species). NMDS shows the disparity between vegetation communities between years was relatively minor (Figure 9).

Table 8. ANOSIM (R=goodness of fit, p=significance level) and SIMPER results from comparisons of Ryder Pond 1995 vs. 2016 transect percent cover data (SIMPER numeric values represent mean sum % cover; Cum %=percent contribution to dissimilarity between years) at Cape Cod National Seashore.

Species	1995	2016	Cum %
<i>Nymphaea odorata</i>	57.1	53.0	41.7
<i>Lobelia dortmanna</i>	0.0	23.2	59.2
<i>Juncus militaris</i>	25.7	3.2	73.5
Total spp	7	8	–

ANOSIM R=-0.011, p=0.54

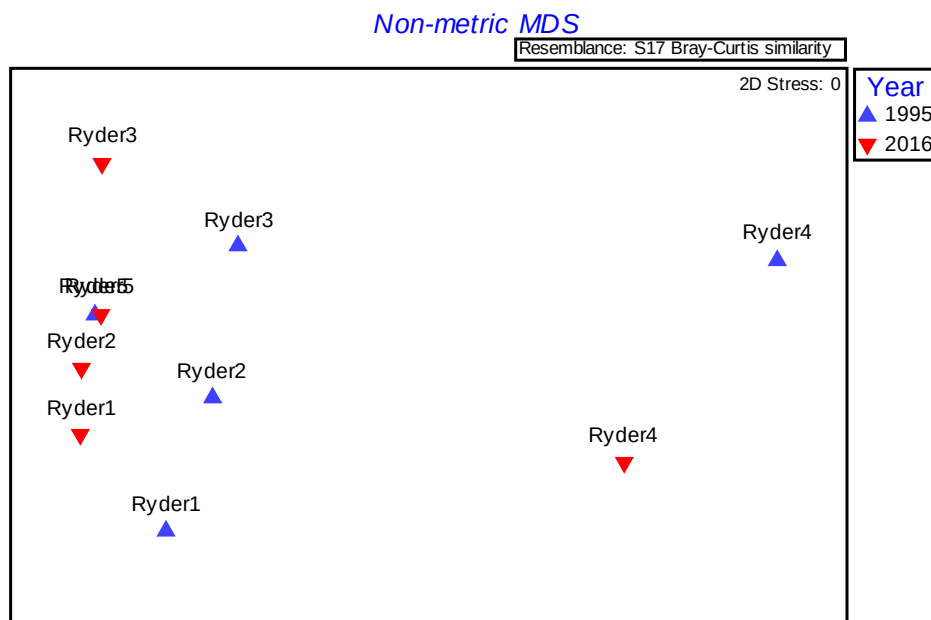


Figure 9. NMDS of percent cover (right) for Ryder Pond by transect in 1995 and 2016 at Cape Cod National Seashore.

All ponds combined

When all transect data for all ponds were combined, ANOSIM indicated that the overall plant communities have not changed significantly since 1995 – even though Duck and Gull Pond did as individual systems (Table 9). The main species discussed above with regard to shifts in individual ponds were also responsible for the largest dissimilarities among survey years for all ponds combined. Total species richness, declined from 47 to 29. NMDS illustrates that Duck Pond separated most in ordinal space between years (Figure 10). This was mainly due to the disappearance of *E. acicularis*, which was abundant in 1995.

Table 9. ANOSIM (R=goodness of fit, p=significance level) and SIMPER results from comparisons of 1995 vs. 2016 transect percent cover data for all ponds (SIMPER numeric values represent mean sum % cover; Cum %=percent contribution to dissimilarity between years) at Cape Cod National Seashore.

Species	1995	2016	Cum %
Nymphaea odorata	343.8	365.5	19.7
Utricularia spp.	142.2	530.2	35.8
Lobelia dortmanna	195.5	88.4	47.2
Eleocharis acicularis	112.4	1.6	54.8
Gratiola aurea	197.9	0.0	61.6
Decodon verticillatus	116.7	42.6	66.3
Juncus militaris	64.1	37.6	70.5
Total spp.	47	29	–

ANOSIM R=-0.004, p=0.49

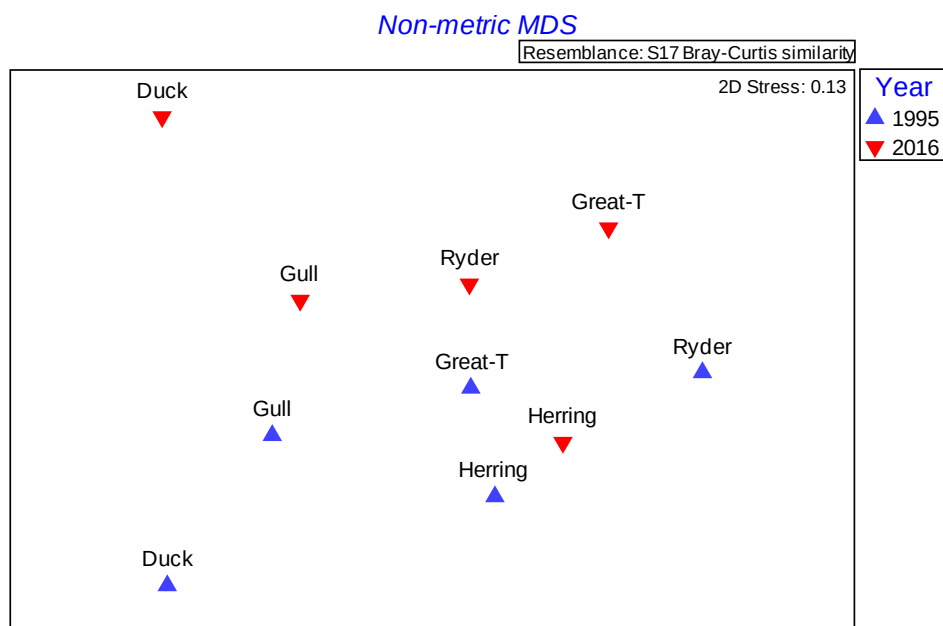


Figure 10. NMDS of sum % cover (right) for all ponds pooled 1995 and 2016 at Cape Cod National Seashore.

When the sum % cover values of all species from all plots, transects, and ponds were examined, it was revealed that *G. aurea*, *E. acicularis*, *L. dortmanna*, *Decodon verticillatus*, and *T. palustris* exhibited the largest declines between 1995 and 2016 (Table 10). In contrast, *Euthamia tenuifolia*, *Potamogeton epihydrous*, *Nuphar variegatum*, *Najas flexilis*, *Utricularia spp.* increased the most in abundance.

Table 10. Aquatic plant species recorded along transects and their total summed percentage values (all plots, transects, and ponds) ranked from largest negative to positive change between 1995 and 2016 at Cape Cod National Seashore.

Species	Sum % cover 1995	Sum % cover 2016	Change (%)
<i>Gratiola aurea</i>	990	0	-990
<i>Eleocharis acicularis</i>	562	8	-554
<i>Lobelia dortmanna</i>	978	442	-536
<i>Decodon verticillatus</i>	584	213	-371
<i>Thelypteris palustris</i>	271	0	-271
<i>Brasenia schreberi</i>	231	0	-231
<i>Juncus spp.</i>	208	0	-208
<i>Myriophyllum humilis</i>	368	183	-185

Table 10 (continued). Aquatic plant species recorded along transects and their total summed percentage values (all plots, transects, and ponds) ranked from largest negative to positive change between 1995 and 2016 at Cape Cod National Seashore.

Species	Sum % cover 1995	Sum % cover 2016	Change (%)
<i>Calamagrostis canadensis</i>	176	0	-176
<i>Juncus militaris</i>	321	188	-133
<i>Myriophyllum tenellum</i>	126	0	-126
<i>Onoclea sensibilis</i>	94	0	-94
<i>Glyceria</i> spp.	56	0	-56
<i>Cyperus dentatus</i>	53	0	-53
<i>Vaccinium macrocarpon</i>	39	0	-39
<i>Agrostis alba</i>	26	0	-26
<i>Viola lanceolata</i>	20	0	-20
<i>Leersia oryzoides</i>	17	0	-17
<i>Hypericum canadensis</i>	17	0	-17
<i>Viola lanceolata</i>	14	0	-14
<i>Lysimachia terrestris</i>	15	2	-13
<i>Drosera intermedia</i>	12	0	-12
<i>Aster novii-belgi</i>	11	0	-11
<i>Bidens connata</i>	11	0	-11
<i>Cyperus</i> spp.	5	0	-5
<i>Agrostis alba</i>	4	0	-4
<i>Impatiens capensis</i>	3	0	-3
<i>Rhychospora corniculata</i>	3	0	-3
<i>Cicuta bulbosa</i>	5	3	-2
<i>Erechtites hiericifolia</i>	1	0	-1
<i>Nymphoides cordata</i>	173	172	-1
<i>Drosera filiformis</i>	0	0	0
<i>Galium</i> spp.	1	3	2
<i>Carex</i> spp.	1	4	3
<i>Elodea nuttalli</i>	0	3	3
<i>Lycopus virginicus</i>	3	9	6

Table 10 (continued). Aquatic plant species recorded along transects and their total summed percentage values (all plots, transects, and ponds) ranked from largest negative to positive change between 1995 and 2016 at Cape Cod National Seashore.

Species	Sum % cover 1995	Sum % cover 2016	Change (%)
<i>Eleocharis palustris</i>	0	21	21
<i>Sagittaria latifolia</i>	0	22	22
<i>Eriocaulon septangulare</i>	32	56	25
<i>Triadenum virginicum</i>	45	69	25
<i>Elatine minima</i>	0	29	29
<i>Isoetes</i> spp.	7	36	30
<i>Phragmites australis</i>	0	31	31
<i>Schoenoplectus pungens</i>	7	44	37
<i>Lycopus</i> spp.	4	106	102
<i>Pontederia cordata</i>	94	201	107
<i>Nymphaea odorata</i>	1719	1828	109
<i>Hydrocotyle umbellata</i>	25	151	126
<i>Euthamia tenuifolia</i>	23	168	145
<i>Potamogeton epihydrous</i>	0	157	157
<i>Nuphar variegatum</i>	53	304	251
<i>Najas flexilis</i>	3	344	341
<i>Utricularia</i> spp.	711	2651	1940

Changes in plant community composition along transects among the 10 ponds surveyed in 2005 and 2016

Duck Pond

Overall plant composition did not change statistically between 2005 and 2016, despite some major changes in certain species (Table 11). In this regard, *Calamagrostis canadensis* (bluejoint), *E. acicularis*, and *Euthamia tenuifolia* (slender goldentop) all decreased, while *L. dortmanna* increased in abundance – all four contributing to the most dissimilarity between years. Transects 3, 4, and 5 exhibited the largest shift in species abundance and distribution between 2005 and 2016 in this pond, as revealed by NMDS (Figure 11). The transect 3 divergence was caused by a loss of *Calamagrostis canadensis*, while transect 4 and 5 shifts were the result of the absence of species in 2016.

Table 11. ANOSIM (R=goodness of fit, p=significance level) and SIMPER results from comparisons of Duck Pond 2005 vs. 2016 transect percent cover data (SIMPER numeric values represent mean sum % cover; Cum %=percent contribution to dissimilarity between years) at Cape Cod National Seashore.

Species	2005	2016	Cum %
<i>Calamagrostis canadensis</i>	40.8	0.0	28.0
<i>Eleocharis acicularis</i>	7.8	0.0	47.2
<i>Euthamia tenuifolia</i>	3.6	0.1	59.6
<i>Lobelia dortmanna</i>	0.0	2.2	71.7
Total spp.	10	3	–

ANOSIM R=0.15, p=0.16

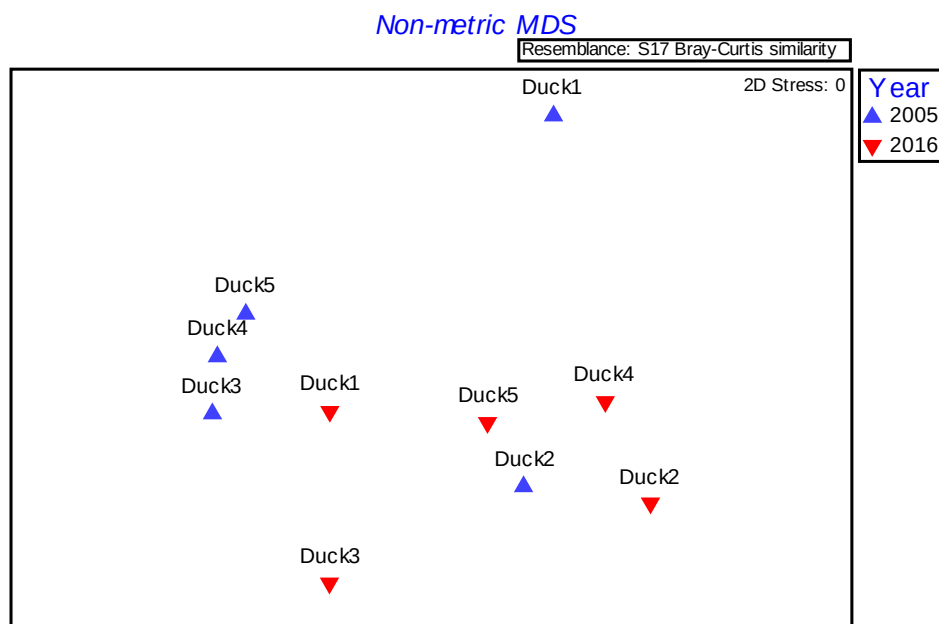


Figure 11. NMDS of percent cover for Duck Pond by transect in 2005 and 2016 at Cape Cod National Seashore.

Dyer Pond

ANOSIM results revealed that no significant community change occurred between 2005 and 2016 in Dyer Pond (Table 12). Nonetheless, it was *E. acicularis*, *Eriocaulon* sp. (pipewort), and *C. dentatus* that exhibited the largest dissimilarities in abundance, with *E. acicularis* and *C. dentatus* not recorded in 2016. However, total species richness actually increased slightly from 4 to 6 between 2005 and 2016. Clearly, transect 4 (disappearance of *E. acicularis*) shifted in considerably between 2005 and 2016 (Figure 12). This change, however, was insufficient to influence the overall plant community (all transects) over time.

Table 12. ANOSIM (R=goodness of fit, p=significance level) and SIMPER results from comparisons of Dyer Pond 2005 vs. 2016 transect percent cover data (SIMPER numeric values represent mean sum % cover; Cum %=percent contribution to dissimilarity between years) at Cape Cod National Seashore.

Species	2005	2016	Cum %
<i>Eleocharis acicularis</i>	167.5	0.0	42.8
<i>Eriocaulon</i> spp.	227.5	3.4	69.2
<i>Cyperus dentatus</i>	7.5	0.0	88.5
Total spp.	4	6	–

ANOSIM R=0.066, p=0.26

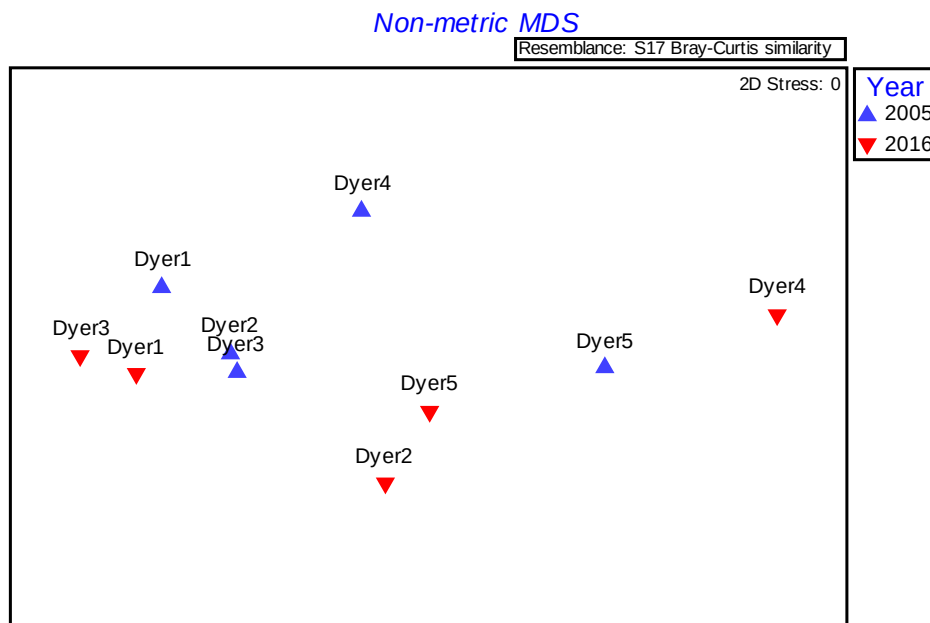


Figure 12. NMDS of percent cover for Dyer Pond by transect in 2005 and 2016 at Cape Cod National Seashore.

Great-T (Truro) Pond

Transect vegetation in Great-T pond did exhibit a significant change in composition between 2005 and 2016, with *U. radiata*, *J. militaris*, and *N. odorata* contributing to the highest dissimilarity, the latter two decreasing substantially (Table 13). Moreover, total species richness fell from 14 in 2005 to 9 in 2016. Ordination of the vegetation data shows the obvious reason for the disparity in plant communities between 2005 and 2016, with transect 1 and 2 exhibiting large changes in the three taxa indicated below as well as *E. acicularis* (Figure 13).

Table 13. ANOSIM (R=goodness of fit, p=significance level) and SIMPER results from comparisons of Great-T (Truro) Pond 2005 vs. 2016 transect percent cover data (SIMPER numeric values represent mean sum % cover; Cum %=percent contribution to dissimilarity between years) at Cape Cod National Seashore.

Species	2005	2016	Cum %
<i>Utricularia radiata</i>	586.2	505.2	37.9
<i>Juncus militaris</i>	368.3	34.4	61.6
<i>Nymphaea odorata</i>	190.6	20.0	74.3
Total spp.	14	9	–

ANOSIM R=0.352, p<0.01

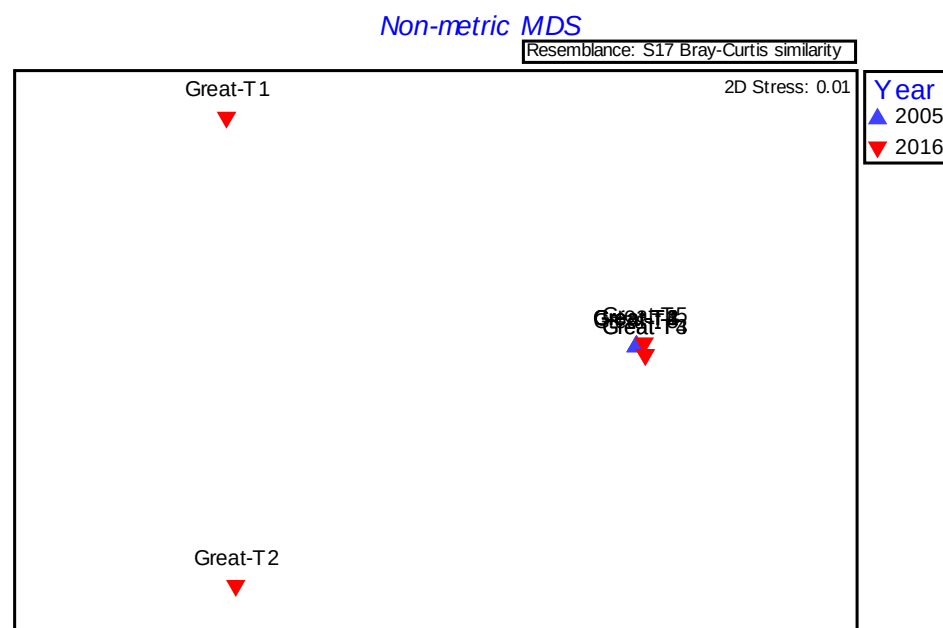


Figure 13. NMDS of percent cover for Great-T Pond by transect in 2005 and 2016 at Cape Cod National Seashore.

Great-W (Wellfleet) Pond

Great-W did not exhibit a significant community-level change in transect vegetation between survey years (Table 14). The differences that manifested themselves were based on the abundance and distribution of *L. dortmanna* and *J. militaris*. Species richness remained basically unchanged (10 in 2005, and 11 in 2016). Despite the large change along transect 4 due to the absence of any species in 2016, plant community structure as a whole did not change appreciably over the 2006-2016 time period (Figure 14).

Table 14. ANOSIM (R=goodness of fit, p=significance level) and SIMPER results from comparisons of Great-W (Wellfleet) Pond 2005 vs. 2016 transect percent cover data (SIMPER numeric values represent mean sum % cover; Cum %=percent contribution to dissimilarity between years) at Cape Cod National Seashore.

Species	2005	2016	Cum %
<i>Lobelia dortmanna</i>	221.2	87.5	60.7
<i>Juncus militaris</i>	82.5	24.2	77.2
Total spp.	10	11	–

ANOSIM R=0.048, p=0.29

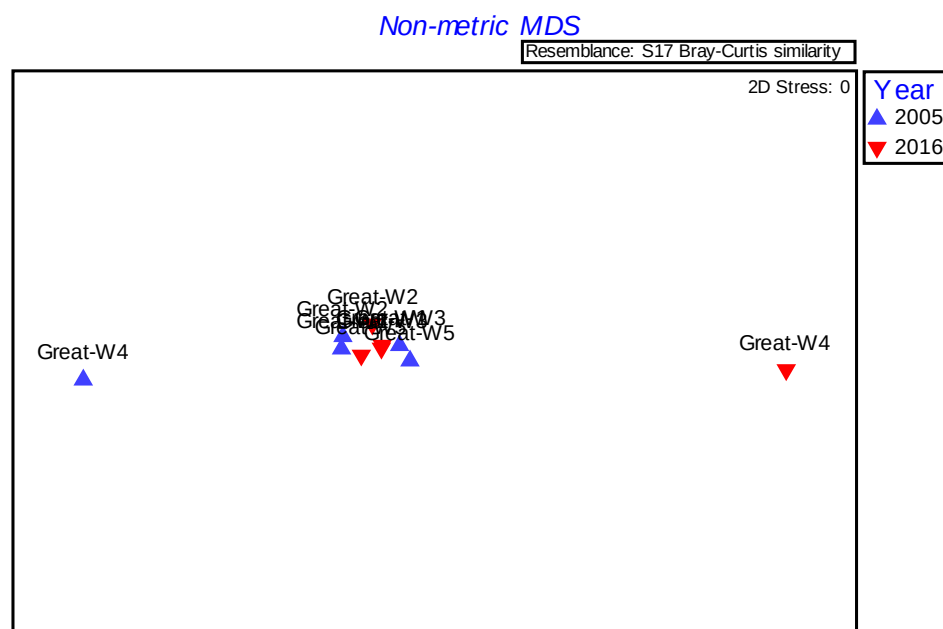


Figure 14. NMDS of sum % cover for Great-W (Wellfleet) Pond by transect in 2005 and 2016 at Cape Cod National Seashore.

Gull Pond

ANOSIM indicated a significant taxonomic change in the vegetation communities of 2005 vs. 2016, with *L. dortmanna*, *E. acicularis*, *Gratiola aurea*, and *Schoenoplectus pungens* (threesquare) exhibiting the largest changes in abundance and distribution (Table 15). *E. acicularis* and *G. aurea* were present in 2005 but not recorded in 2016. The total number of species recorded in 2005 and 2016 was 14 and 13, respectively. As illustrated by NMDS, the large change in vegetation along transect 2 (disappearance of *L. dortmanna*) was enough to produce a significant alteration in the overall plant community between years, although this was a result of a dramatic reduction in *Pontederia cordata* (pickerel weed) (Figure 15)

Table 15. ANOSIM (R=goodness of fit, p=significance level) and SIMPER results from comparisons of Gull Pond 2005 vs. 2016 transect percent cover data (SIMPER numeric values represent mean sum % cover; Cum %=percent contribution to dissimilarity between years) at Cape Cod National Seashore.

Species	2005	2016	Cum %
<i>Lobelia dortmanna</i>	536.9	62.3	39.4
<i>Eleocharis acicularis</i>	103.4	0.0	52.1
<i>Gratiola aurea</i>	156.1	0.0	63.5
<i>Schoenoplectus pungens</i>	93.2	8.1	70.9
Total spp.	14	13	–

ANOSIM R=0.566, p<0.01

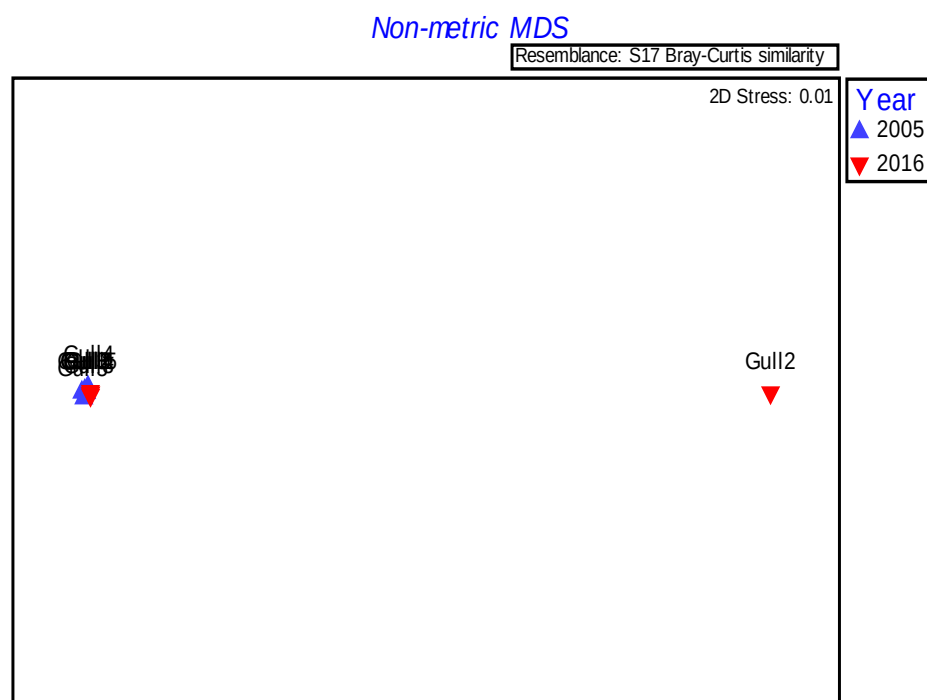


Figure 15. NMDS of sum % cover for Gull Pond by transect in 2005 and 2016 at Cape Cod National Seashore.

Herring Pond

Herring Pond exhibited no significant shift in species composition between 2005 and 2016, despite considerable changes in the abundance of *N. odorata* (increased), *D. veticillatus* (decreased), *N. flexilis* (increased), *T. palustris* (disappeared), and *B. schreberi* (disappeared) (Table 16). Transects 3 and 5 exhibited the most obvious shifts in species abundance and distribution between 2005 and 2016 as revealed by NMDS (Figure 16). These changes were due to large declines in *N. cordata* and *N. flexilis*, respectively.

Table 16. ANOSIM (R=goodness of fit, p=significance level) and SIMPER results from comparisons of Herring Pond 2005 vs. 2016 transect percent cover data (SIMPER numeric values represent mean sum % cover; Cum %=percent contribution to dissimilarity between years) at Cape Cod National Seashore.

Species	2005	2016	Cum %
<i>Nymphaea cordata</i>	351.3	31.4	27.2
<i>Nymphaea odorata</i>	261.1	292.5	49.6
<i>Decodon verticillatus</i>	171.7	42.6	59.9
<i>Najas flexilis</i>	122.5	0.0	69.1
<i>Najas</i> sp.	53.1	68.7	76.3
Total spp.	5	4	–

ANOSIM R=0.192, p=0.10

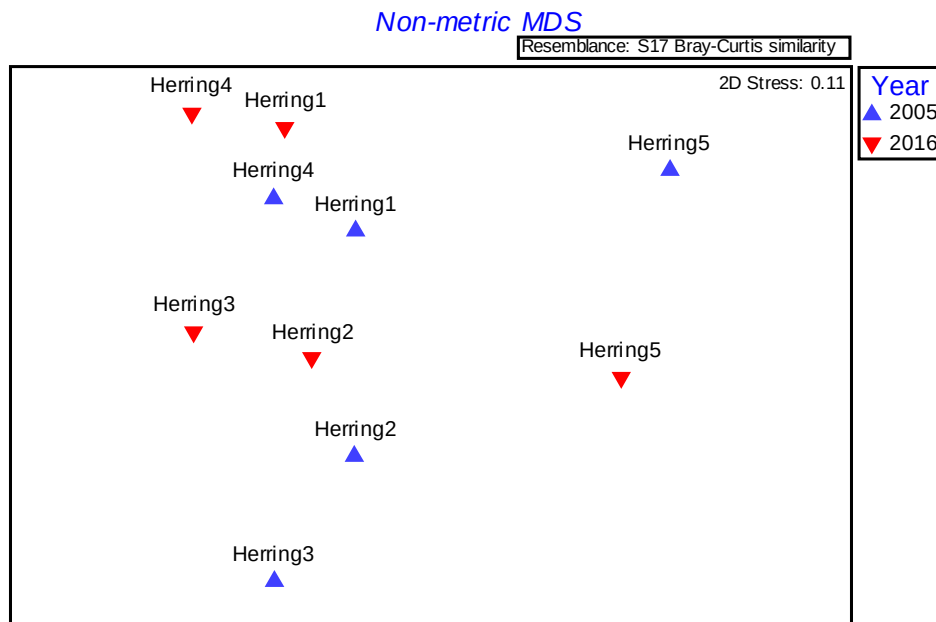


Figure 16. NMDS of sum % cover for Herring Pond by transect in 2005 and 2016 at Cape Cod National Seashore.

Long Pond

Long Pond plant community changed significantly between 2005 and 2016 (Table 17). However, the sole reason for this result was the dramatic reduction in one species – *E. acicularis*, as revealed by SIMPER analysis. In addition, species richness decreased slightly from 13 to 8 between surveys. The significant shift in plant community between years was primarily the result of transect 2, as portrayed in the NMDS plot (Figure 17), where *E. acicularis* – abundant in 2005 – was not recorded (or any other species) in 2016.

Table 17. ANOSIM (R=goodness of fit, p=significance level) and SIMPER results from comparisons of Long Pond 2005 vs. 2016 transect percent cover data (SIMPER numeric values represent mean sum % cover; Cum %=percent contribution to dissimilarity between years) at Cape Cod National Seashore.

Species	2005	2016	Cum %
<i>Eleocharis acicularis</i>	953.2	38.7	75.4
Total spp.	13	8	–

ANOSIM R=0.426, p<0.01

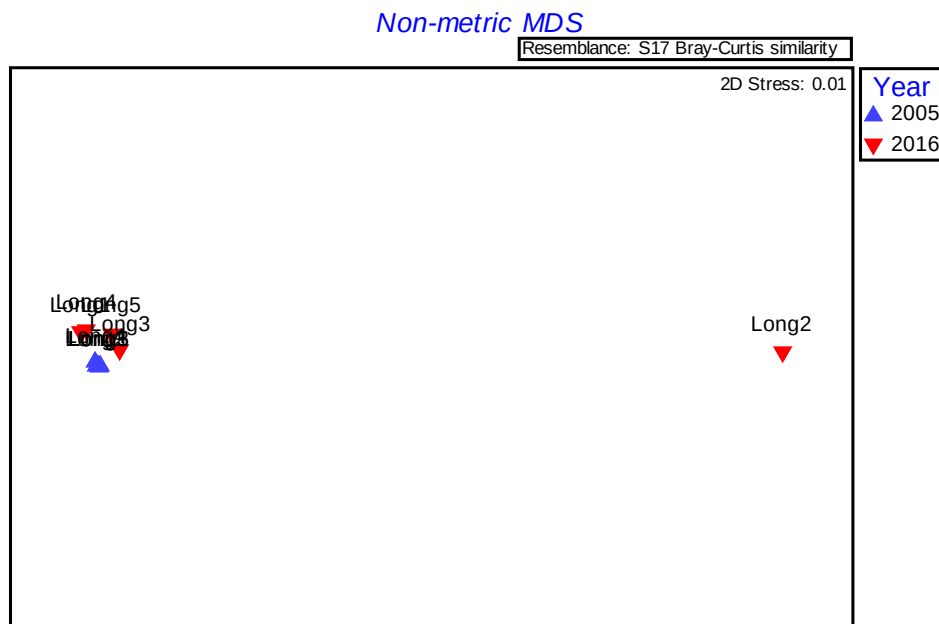


Figure 17. NMDS of sum % cover for Long Pond by transect in 2005 and 2016 at Cape Cod National Seashore.

Ryder Pond

There was no significant change in plant communities in Ryder Pond between 2005 and 2016 along the transects (Table 18). Regardless, SIMPER indicates that *N. odorata*, *J. militaris*, *E. acicularis*, and *L. dortmanna* accounted for the largest shifts in plant communities during this time. All decreased (*E. acicularis* disappeared) except *L. dortmanna*, which increased. Species richness declined slightly from 10 to 8 between surveys. Despite the large change in transect 4 (Figure 18) – the result of no species being recorded in 2016, the plant community as a whole failed to show a statistically significant shift.

Table 18. ANOSIM (R=goodness of fit, p=significance level) and SIMPER results from comparisons of Ryder Pond 2005 vs. 2016 transect percent cover data (SIMPER numeric values represent mean sum % cover; Cum %=percent contribution to dissimilarity between years) at Cape Cod National Seashore.

Species	2005	2016	Cum %
<i>Nymphaea odorata</i>	186.1	53.0	31.4
<i>Juncus militaris</i>	123.2	3.2	57.8
<i>Eleocharis acicularis</i>	20.2	0.0	67.6
<i>Lobelia dortmanna</i>	0.1	23.2	77.0
Total spp.	10	8	–

ANOSIM R=0.084, p=0.21

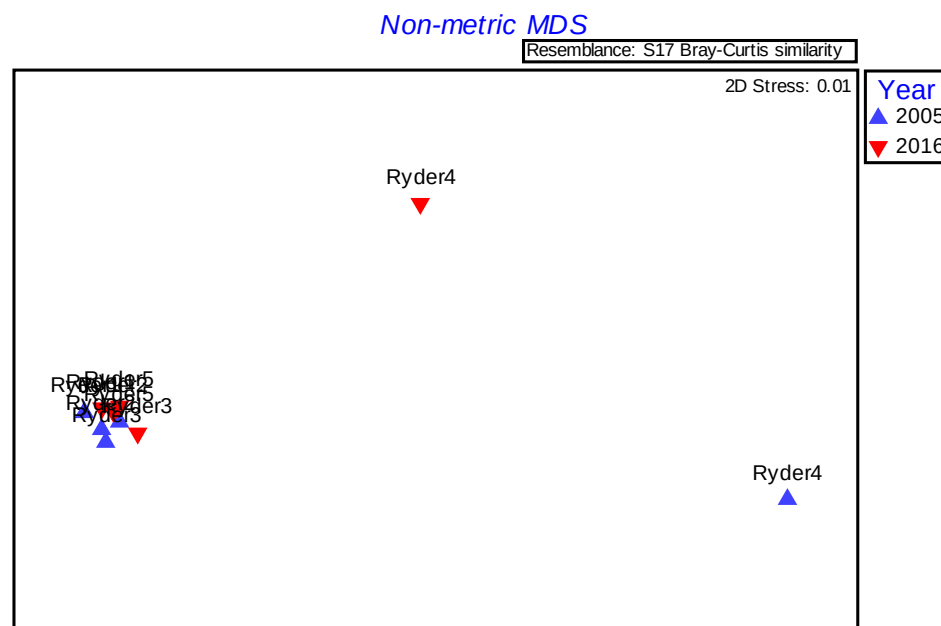


Figure 18. NMDS of sum % cover for Ryder Pond by transect in 2005 and 2016 at Cape Cod National Seashore.

Snow Pond

No significant taxonomic shift occurred in Snow Pond between 2005 and 2016 according to ANOSIM (Table 19). Individual species that did show substantial changes were *N. odorata* (decreased), *P. cordata* (decreased), *J. militaris* (decreased), *Utricularia* spp. (not recorded in 2005 but present in 2016), and *E. acicularis* (present in 2005 but absent in 2016). Total species richness was identical in both years. Despite the complete loss of *E. acicularis*, the transects shifted very little in ordinal space and the central orientation showed little spatial movement between years (Figure 19).

Table 19. ANOSIM (R=goodness of fit, p=significance level) and SIMPER results from comparisons of Snow Pond 2005 vs. 2016 transect percent cover data (SIMPER numeric values represent mean sum % cover; Cum %=percent contribution to dissimilarity between years) at Cape Cod National Seashore.

Species	2005	2016	Cum %
<i>Nymphaea odorata</i>	204.7	65.9	23.3
<i>Pontederia cordata</i>	87.2	43.2	41.3
<i>Juncus militaris</i>	116.1	31.8	56.9
<i>Eleocharis acicularis</i>	148.9	0.0	77.6
Total spp.	13	13	–

ANOSIM R=-0.026, p=0.35

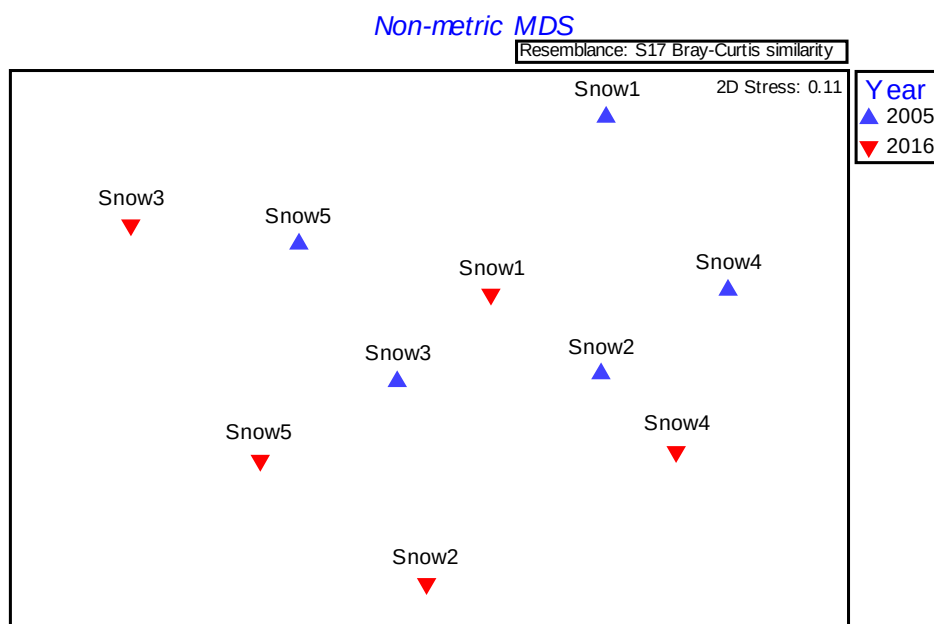


Figure 19. NMDS of sum % cover for Snow Pond by transect in 2005 and 2016 at Cape Cod National Seashore.

Spectacle Pond

A significant plant community shift occurred in Snow Pond between 2005 and 2016 along the transects (Table 20). However, the change was based almost solely on the proliferation of *Utricularia* spp. And total species richness actually increased from 9 to 11. The significant ANOSIM result was almost completely due to the large changes in transects 1 and 4 (Figure 20), which exhibited very large increases in *Utricularia* spp.

Table 20. ANOSIM (R=goodness of fit, p=significance level) and SIMPER results from comparisons of Spectacle Pond 2005 vs. 2016 transect percent cover data (SIMPER numeric values represent mean sum % cover; Cum %=percent contribution to dissimilarity between years) at Cape Cod National Seashore.

Species	2005	2016	Cum %
<i>Utricularia</i> spp.	214.1	1002.5	75.8
Total spp.	9	11	–

ANOSIM R=0.484, p<0.01

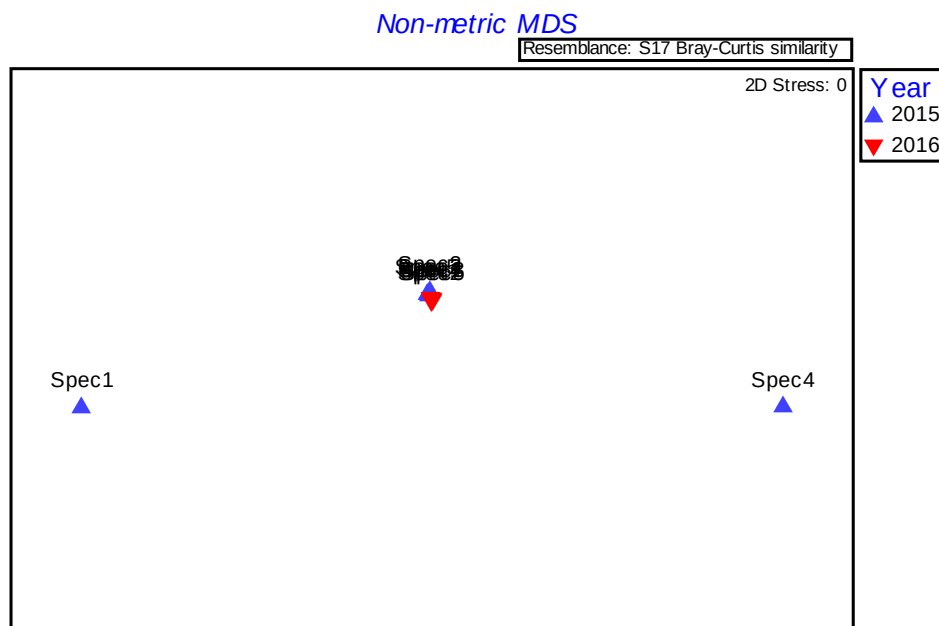


Figure 20. NMDS of sum % cover for Spectacle Pond by transect in 2005 and 2016 at Cape Cod National Seashore.

All ponds

When the transect data for all ponds was combined and analyzed for temporal change between 2005 and 2016, a significant difference was found (Table 21). *Utricularia* spp., *E. acicularis*, *N. odorata*, *L. dortmanna*, *J. militaris*, and *N. cordata* contributed most to dissimilarity among the two year groups and all declines substantially. There was enough change in several individual ponds (e.g., Duck and Dyer ponds, which exhibit a dramatic loss of species) to result in a statistically significant shift in plant communities of the entire group of kettle ponds as a whole (Figure 21). Moreover, species richness decreased from 43 in 2005 to 31 in 2016.

Table 21. ANOSIM (R=goodness of fit, p=significance level) and SIMPER results from comparisons of 2005 vs. 2016 transect percent cover data from all ponds (SIMPER numeric values represent mean sum % cover; Cum %=percent contribution to dissimilarity between years) at Cape Cod National Seashore.

Species	2005	2016	Cum %
<i>Utricularia</i> sp.	401.2	768.9	16.4
<i>Eleocharis acicularis</i>	733.9	19.6	30.4
<i>Nymphaea odorata</i>	425.3	216.0	42.4
<i>Lobelia dortmanna</i>	401.7	105.8	53.8
<i>Juncus militaris</i>	485.7	61.9	64.4
<i>Nymphoides cordata</i>	327.7	75.3	71.7
Total spp.	43	31	–

ANOSIM R=0.196, p=0.01

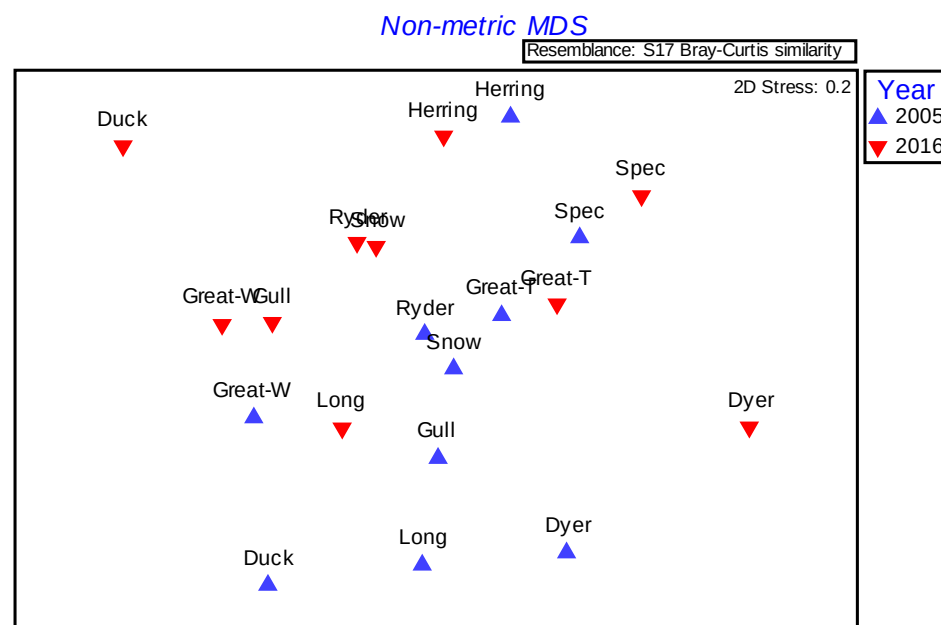


Figure 21. NMDS of sum % cover (right) for all ponds pooled 2005 and 2016 at Cape Cod National Seashore.

Between 2005 and 2016, the five taxa that declined most in abundance along transects (all plots, transects, and ponds) were *E. acicularis*, *J. militaris*, *N. cordata*, *L. dortmanna*, and *N. odorata* (Table 22). Species exhibiting the largest increases (which were of much lower magnitude than increases) were *E. minima*, *Lycopus* spp., *Hydrocotyle umbellata*, *Carex* spp., and *N. variegatum*. In general, total aquatic plant cover was reduced by ~fourfold, from 37,714 to 9,546 summed percent values.

Table 22. Aquatic plant species recorded along transects and their total summed percentage values (all plots, transects, and ponds) ranked from largest negative to positive change between 2005 and 2016 at Cape Cod National Seashore.

Species	Sum % cover 1995	Sum % cover 2016	Change (%)
<i>Eleocharis acicularis</i>	7340	194	-7146
<i>Juncus militaris</i>	4857	620	-4237
<i>Nymphoides cordata</i>	3277	172	-3105
<i>Lobelia dortmanna</i>	4017	1055	-2962
<i>Nymphaea odorata</i>	4253	2160	-2093
<i>Eriocaulon</i> spp.	2014	109	-1906
<i>Utricularia</i> spp.	4012	2676	-1336
<i>Decodon verticillatus</i>	1412	221	-1191
<i>Gratiola aurea</i>	820	0	-820
<i>Najas flexilis</i>	894	347	-548
<i>Pontederia cordata</i>	957	417	-541
<i>Isoetes</i> spp.	576	39	-537
<i>Schoenoplectus pungens</i>	466	44	-423
<i>Calamagrostis canadensis</i>	420	0	-420
<i>Cyperus dentatus</i>	231	0	-231
<i>Woodwardia virginica</i>	213	0	-213
<i>Eleocharis robbinsii</i>	205	0	-205
<i>Thelypteris palustris</i>	153	0	-153
<i>Myriophyllum</i> spp.	331	192	-139
<i>Euthamia tenuifolia</i>	302	174	-128
<i>Triadenum virginicum</i>	158	69	-89
<i>Onoclea sensibilis</i>	65	0	-65

Table 22 (continued). Aquatic plant species recorded along transects and their total summed percentage values (all plots, transects, and ponds) ranked from largest negative to positive change between 2005 and 2016 at Cape Cod National Seashore.

Species	Sum % cover 1995	Sum % cover 2016	Change (%)
<i>Lysimachia terrestris</i>	63	2	-61
<i>Phragmites australis</i>	92	31	-61
<i>Potamogeton epihydrous</i>	270	213	-57
<i>Cicuta bulbosa</i>	44	3	-41
<i>Vaccinium macrocarpon</i>	38	0	-38
<i>Sium suave</i>	29	0	-29
<i>Leersia oryzoides</i>	25	0	-25
<i>Impatiens capensis</i>	3	0	-3
<i>Juncus pelocarpus</i>	19	0	-19
<i>Bidens connata</i>	10	0	-10
<i>Juncus canadensis</i>	8	0	-8
<i>Dulichium arundinacea</i>	6	0	-6
<i>Viola lanceolata</i>	3	0	-3
<i>Drosera intermedia</i>	2	0	-2
<i>Hypericum canadensis</i>	1	0	-1
<i>Hypericum mutilum</i>	0	0	0
<i>Scirpus cyperinus</i>	0	0	0
<i>Elatine</i> spp.	0	1	1
<i>Galium</i> spp.	1	3	3
<i>Eleodea nutalli</i>	0	3	3
<i>Juncus acuminatus</i>	0	4	4
<i>Eleocharis palustris</i>	16	21	5
<i>Eleocharis</i> spp.	0	16	16
<i>Sagittaria latifolia</i>	0	22	22
<i>Elatine minima</i>	0	32	32
<i>Lycopus</i> spp.	1	115	115
<i>Hydrocotyle umbellata</i>	20	151	131
<i>Carex</i> spp.	0	138	138

Table 22 (continued). Aquatic plant species recorded along transects and their total summed percentage values (all plots, transects, and ponds) ranked from largest negative to positive change between 2005 and 2016 at Cape Cod National Seashore.

Species	Sum % cover 1995	Sum % cover 2016	Change (%)
<i>Nuphar variegatum</i>	99	307	208
Grand sums	37714	9546	–

Change in box plot vegetation between 2010 and 2016

Duck Pond

ANOSIM suggests that plant community composition did not change significantly between 2010 and 2016 (Table 23). *L. dortmannia* and *Isoetes lacustris* (boreal quillwort) exhibited the most change of all species, of which there were a total of 4 in 2010 and 3 in 2016. NMDS illustrates the divergence of transects 1 and 5 between years (Figure 22).

Table 23. ANOSIM (R=goodness of fit, p=significance level) and SIMPER (Cum %=percent contribution to dissimilarity between years) results from comparisons of Duck Pond % cover in 2010 vs. 2016 within box plots at Cape Cod National Seashore.

Species	2010	2016	Cum %
<i>Lobelia dortmannia</i>	15.6	3.7	38.3
<i>Isoetes lacustris</i>	3.8	0.0	71.9
Total spp.	4	3	–

ANOSIM R=0.144, p=0.127

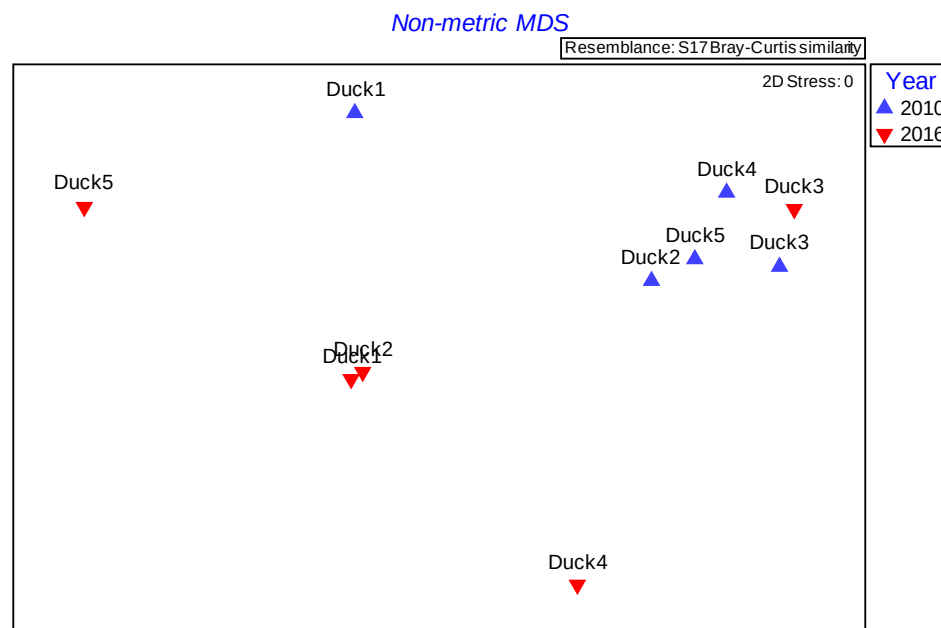


Figure 22. NMDS of sum % cover for Duck Pond by transect-box plots in 2010 and 2016 at Cape Cod National Seashore.

Dyer Pond

Dyer Pond exhibited no significant alteration in taxonomic structure between survey years (Table 24). *Myriophyllum* spp. (watermilfoil) (increased), *Eleocharis parvula* (dwarf spikerush) (absent in 2010, present in 2016), and *Eriocaulon septangulare* (sevenangle pipewort) (present in 2010, absent in 2016) contributed most to the dissimilarities between years. Species richness remained low, increasing from 3 to 4 between 2005 and 2016. Box plots along transects 4 and 5 in particular exhibited the largest spatial separation between years based on NMDS (Figure 23).

Table 24. ANOSIM (R=goodness of fit, p=significance level) and SIMPER (Cum %=percent contribution to dissimilarity between years) results from comparisons of Dyer Pond % cover in 2010 vs. 2016 within box plots at Cape Cod National Seashore.

Species	2010	2016	Cum %
<i>Myriophyllum</i> spp.	0.1	1.5	34.1
<i>Eleocharis parvula</i>	0.0	2.3	57.1
<i>Eriocaulon septangulare</i>	7.6	0.0	77.8
Total spp.	3	4	–

ANOSIM R=0.131, p=0.103

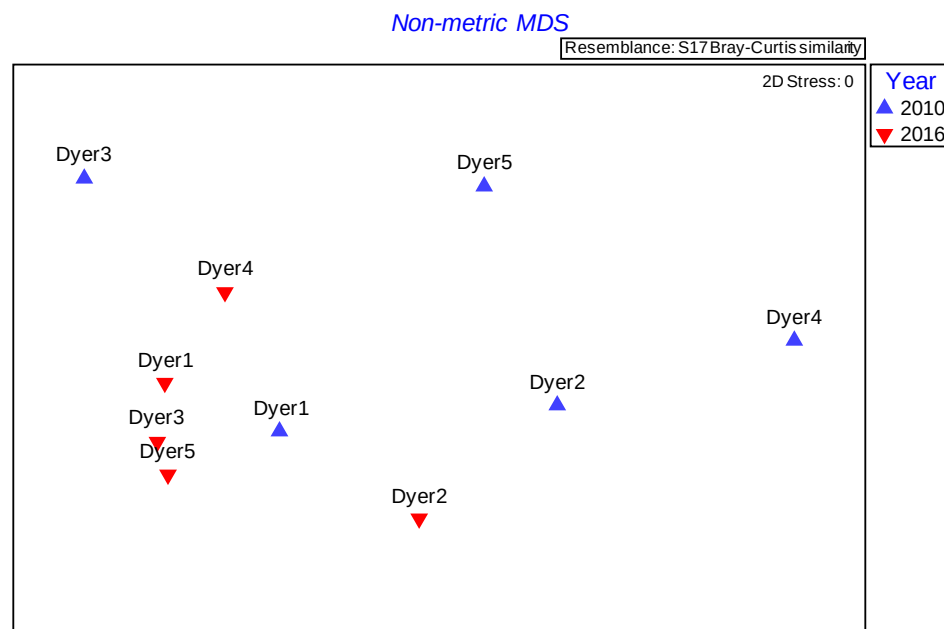


Figure 23. NMDS of sum % cover for Dyer Pond by transect-box plots in 2010 and 2016 at Cape Cod National Seashore.

Great-T (Truro) Pond

ANOSIM revealed no significant taxonomic shifts in Great-T Pond between 2010 and 2016 (Table 25). Notwithstanding, *Utricularia* spp., *Myriophyllum* spp., and *N. odorata*, all of which declined in abundance, contributed most to the dissimilarities between years. In terms of species richness, 12 taxa were recorded in 2010 and 14 in 2016. NMDS illustrates the disparities in box plot species composition between years, with those along transects 2 and 5 exhibiting the most change.

Table 25. ANOSIM (R=goodness of fit, p=significance level) and SIMPER (Cum %=percent contribution to dissimilarity between years) results from comparisons of Great-T (Truro) Pond % cover in 2010 vs. 2016 within box plots at Cape Cod National Seashore.

Species	2010	2016	Cum %
<i>Utricularia</i> spp.	204.4	127.1	35.4
<i>Myriophyllum</i> spp.	127.8	7.9	60.9
<i>Nymphaea odorata</i>	81	50.8	72.9
Total spp.	12	14	–

ANOSIM R=0.176, p=0.159

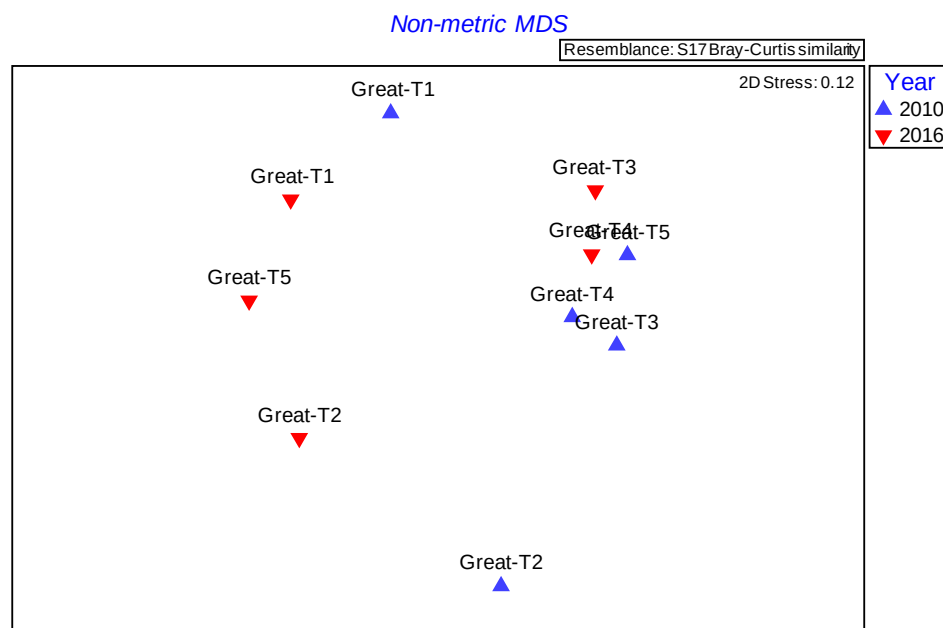


Figure 24. NMDS of sum % cover for Great-T (Truro) Pond by transect-box plots in 2010 and 2016 at Cape Cod National Seashore.

Great-W (Wellfleet) Pond

While a decrease in *L. dortmanna* and an increase in *J. militaris* accounted for the largest amount of community change between surveys, the overall plant community along Great-W box plots did not shift appreciably (Table 26). In addition, total species richness declined by 2 taxa, from 13 to 11, between years. Box plots along transect 4 changed substantially between years, while the rest were very tightly clustered in the NMDS plot (Figure 25).

Table 26. ANOSIM (R=goodness of fit, p=significance level) and SIMPER (Cum %=percent contribution to dissimilarity between years) results from comparisons of Great-W (Wellfleet) Pond % cover in 2010 vs. 2016 within box plots at Cape Cod National Seashore.

Species	2010	2016	Cum %
<i>Lobelia dortmanna</i>	73.5	27.2	59.1
<i>Juncus militaris</i>	1.7	22.4	73.4
Total spp.	13	11	–

ANOSIM R=-0.092, p=0.762

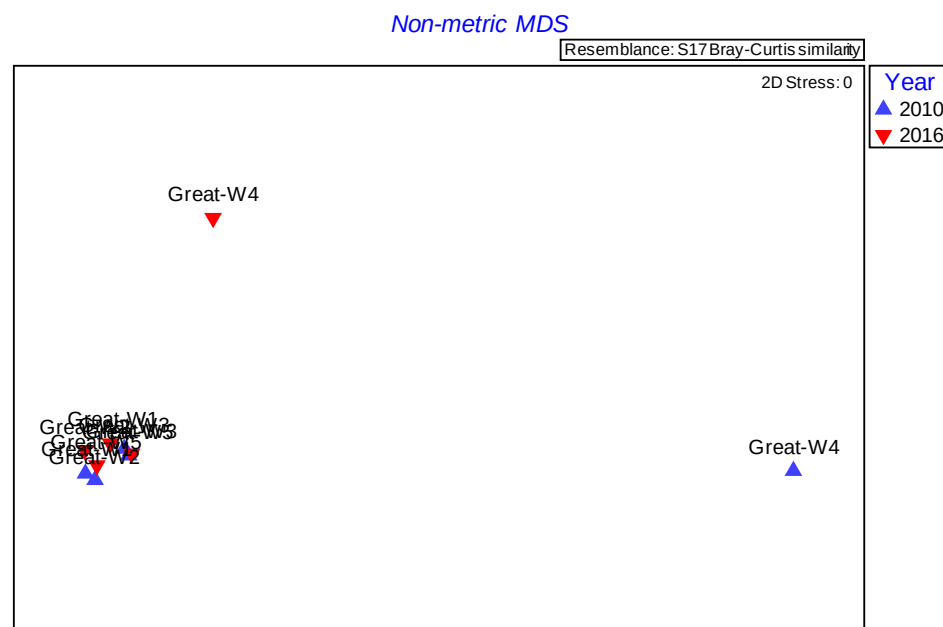


Figure 25. NMDS of sum % cover for Great-W (Wellfleet) Pond by transect-box plots in 2010 and 2016 at Cape Cod National Seashore.

Gull Pond

Gull pond species composition was statistically different in 2016 compared to 2010 (Table 27). *L. dortmanna*, *E. septangulare* and *E. minima*, all of which declined considerably, exhibited the most variability in abundance and distribution. Transects 2 and 4 exhibited the largest changes (reductions) in the above species as indicated in the NMDS (Figure 26). Species richness, however, remained the same (14 taxa) between survey years.

Table 27. ANOSIM (R=goodness of fit, p=significance level) and SIMPER (Cum %=percent contribution to dissimilarity between years) results from comparisons of Gull Pond % cover in 2010 vs. 2016 within box plots at Cape Cod National Seashore.

Species	2010	2016	Cum %
<i>Lobelia dortmanna</i>	102.9	17	32.9
<i>Eriocaulon septangulare</i>	91.2	0	64.9
<i>Elatine minima</i>	39	1.8	79.1
Total spp.	14	14	–

ANOSIM R=0.732, p=0.008

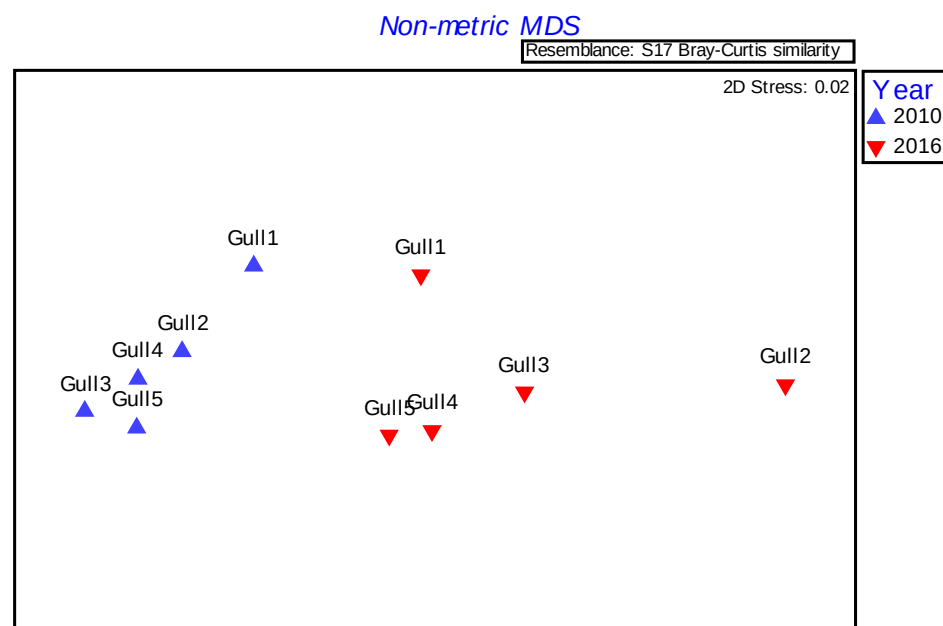


Figure 26. NMDS of sum % cover for Gull Pond by transect-box plots in 2010 and 2016 at Cape Cod National Seashore.

Herring Pond

No statistical change was detected for Herring Pond plant communities between 2010 and 2016 (Table 28). *N. odorata*, *Najas* spp., *D. verticillatus*, and *Potamogeton epihydrus* (ribbonleaf pondweed) all declined in abundance, as did *P. australis*. The latter change is due to herbicide treatment in 2007. Trends in these species, although not enough to significantly influence the overall plant community, contributed most to dissimilarities between years. Box plots along transects 3 and 5 stood out as being most spatially separated in ordinal space between years (Figure 27). The total number of species recorded along the box plots in this pond rose from 22 in 2010 to 28 in 2016.

Table 28. ANOSIM (R=goodness of fit, p=significance level) and SIMPER (Cum %=percent contribution to dissimilarity between years) results from comparisons of Herring Pond % cover in 2010 vs. 2016 within box plots at Cape Cod National Seashore.

Species	2010	2016	Cum %
<i>Nymphaea odorata</i>	175.9	114	35.1
<i>Najas</i> spp.	65.8	26	50.1
<i>Phragmites australis</i>	43.5	3.4	60.8
<i>Decodon verticillatus</i>	32.4	24.1	67.6
<i>Potamogeton epihydrus</i>	14.8	17	72.3
Total spp.	22	28	–

ANOSIM R=-0.096, p=0.778

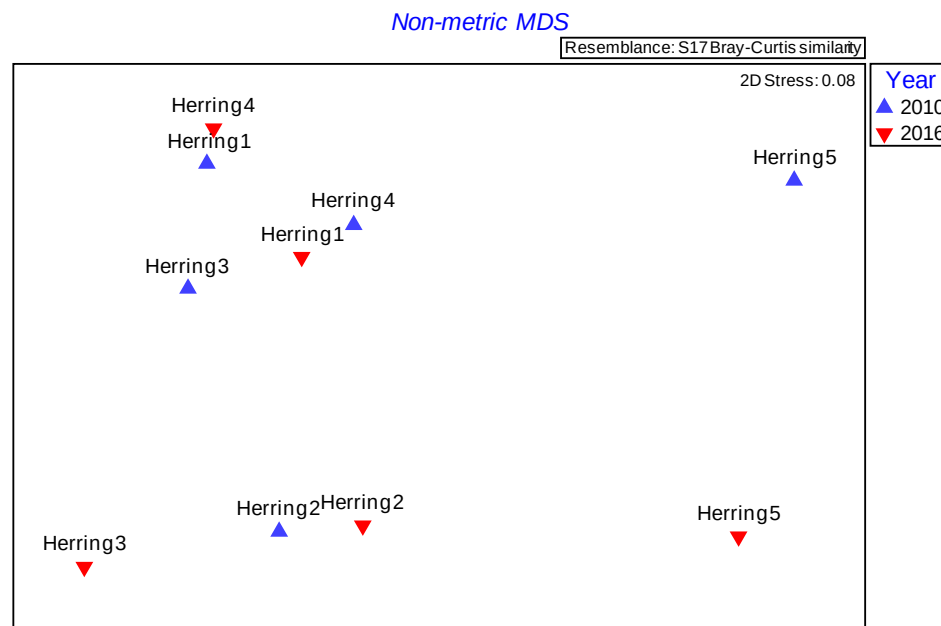


Figure 27. NMDS of sum % cover for Herring Pond by transect-box plots in 2010 and 2016 at Cape Cod National Seashore.

Higgins Pond

Plant community composition along box plots in Higgins Pond was similar in 2010 and 2016 (Table 29). Many of the same taxa responsible for disparities between years in other ponds showed up in the SIMPER analysis for Higgins Pond as well. Specifically, these were *N. odorata*, *J. militaris*, *B. schreberi*, *Najas* spp., *P. eiphydrous*, and *D. verticillatus*. All decreased except, *B. schreberi*, which shifted in distribution, and *D. verticillatus*, which increased. Total species richness changed very little, decreasing from 27 taxa to 26 between years. The NMDS plot shows a rather cohesive clustering of transects between 2010 and 2016 (Figure 28).

Table 29. ANOSIM (R=goodness of fit, p=significance level) and SIMPER (Cum %=percent contribution to dissimilarity between years) results from comparisons of Higgins Pond % cover in 2010 vs. 2016 within box plots at Cape Cod National Seashore.

Species	2010	2016	Cum %
<i>Nymphaea odorata</i>	50.4	6.1	17.3
<i>Juncus militaris</i>	65.3	24.1	32.0
<i>Brasenia schreberi</i>	26.4	26.9	44.6
<i>Najas</i> spp.	38.3	0.2	56.3
<i>Potamogeton epihydus</i>	31.7	5.6	67.3
Total spp.	27	26	–

ANOSIM R=0.248, p=0.24

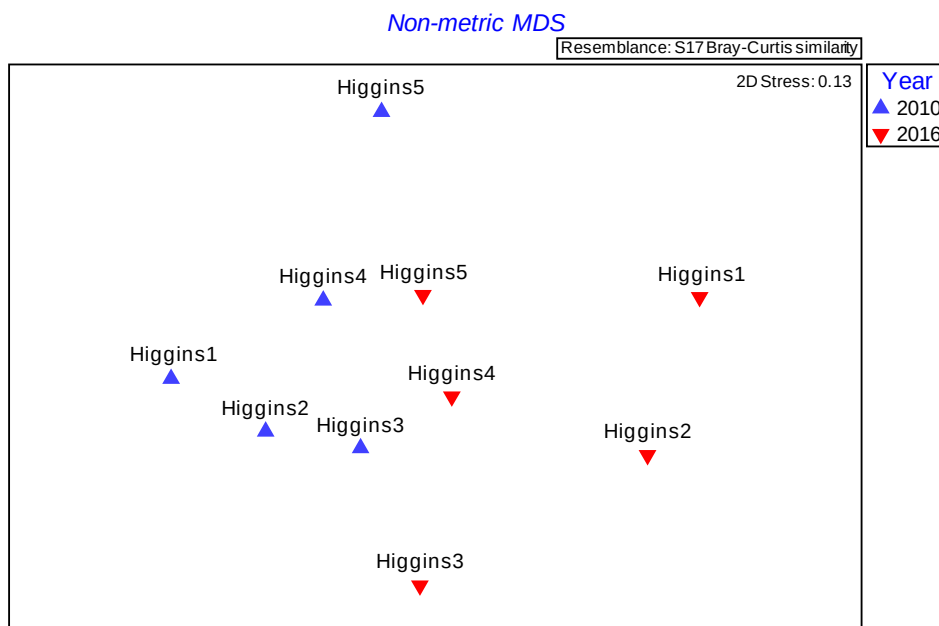


Figure 28. NMDS of sum % cover for Higgins Pond by transect-box plots in 2010 and 2016 at Cape Cod National Seashore.

Horseleech Pond

Horseleech Pond similarly exhibited no statistically significant plant community change (Table 30). *N. odorata*, *J. militaris* played prominently in dissimilarities between survey years, while *Utricularia* spp., *L. dortmanna*, and *N. cordata* were somewhat less important. There was only one additional species recorded in 2016 compared with 2010. While NMDS shows that transects were spatially separate from each other, there was little change in the position of each between years (Figure 29).

Table 30. ANOSIM (R=goodness of fit, p=significance level) and SIMPER (Cum %=percent contribution to dissimilarity between years) results from comparisons of Horseleech Pond % cover in 2010 vs. 2016 within box plots at Cape Cod National Seashore.

Species	2010	2016	Cum %
<i>Nymphaea odorata</i>	89.8	56.8	20.3
<i>Juncus militaris</i>	75.2	74.5	37.1
<i>Utricularia</i> spp.	74.1	50.8	52.9
<i>Lobelia dortmanna</i>	39	45.5	68.6
<i>Nymphoides cordata</i>	47.8	2.4	78.3
Total spp.	18	19	–

ANOSIM R=-0.072, p=0.619

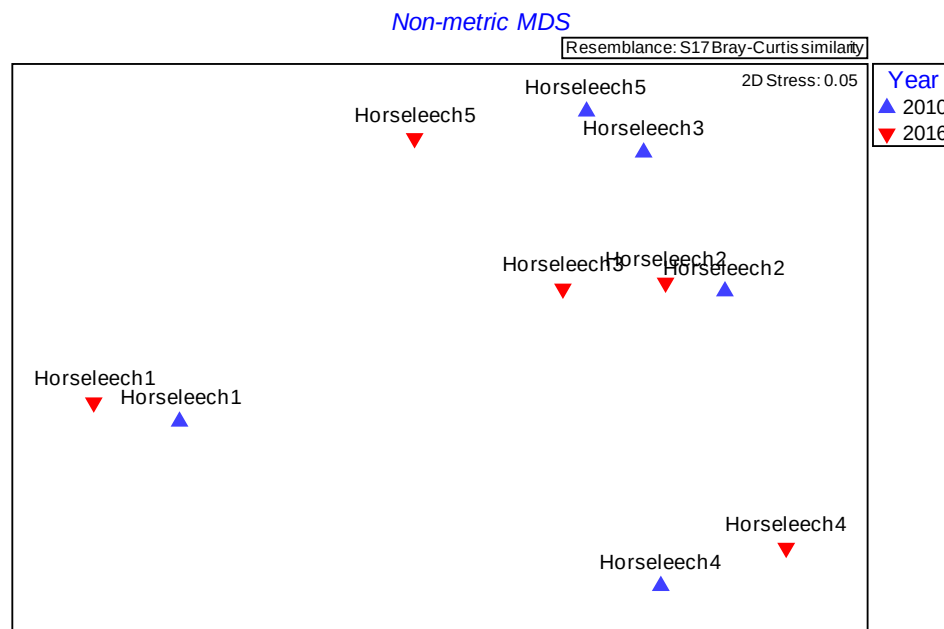


Figure 29. NMDS of sum % cover for Horseleech Pond by transect-box plots in 2010 and 2016 at Cape Cod National Seashore.

Long Pond

While *E. parvula* decreased substantially, *J. militaris* shifted its distribution, and *Elatine* spp. appeared in 2016 (although not recorded in 2010) (Table 31). However, overall taxonomic composition remained statistically unchanged and species richness remained the same at 13 taxa, even though plots along transect 2 were substantially different in 2010 than in 2016 (Figure 30).

Table 31. ANOSIM (R=goodness of fit, p=significance level) and SIMPER (Cum %=percent contribution to dissimilarity between years) results from comparisons of Long Pond % cover in 2010 vs. 2016 within box plots at Cape Cod National Seashore.

Species	2010	2016	Cum %
<i>Eleocharis parvula</i>	46.2	0.7	30.5
<i>Juncus militaris</i>	28.6	22.3	59.6
<i>Elatine</i> spp.	0	30.2	77.7
Total spp.	13	13	–

ANOSIM R=0.188, p=0.63

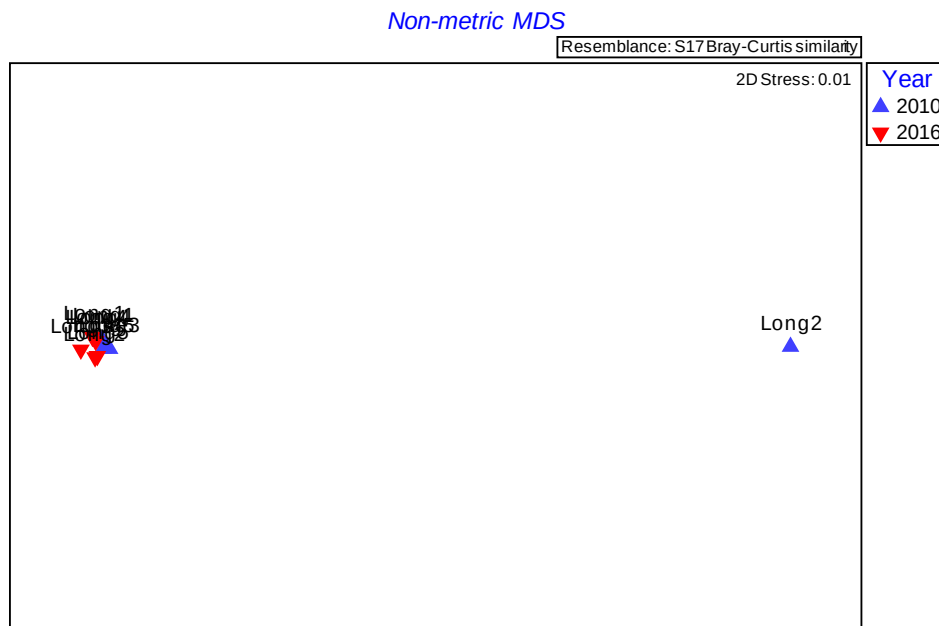


Figure 30. NMDS of sum % cover for Long Pond by transect-box plots in 2010 and 2016 at Cape Cod National Seashore.

Round-E Pond

Once again, plant community composition of the box plots in Round-E Pond exhibited no significant change between surveys conducted in 2010 and 2016 (Table 32). *Utricularia* spp., *L. dortmanna*, and *N. cordata*. There was a slight decline of one taxon from 2010-2016. The box plots along Round-E Pond transects exhibited only slight separations in ordinal space between years (Figure 31).

Table 32. ANOSIM (R=goodness of fit, p=significance level) and SIMPER (Cum %=percent contribution to dissimilarity between years) results from comparisons of Round-E Pond % cover in 2010 vs. 2016 within box plots at Cape Cod National Seashore.

Species	2010	2016	Cum %
<i>Utricularia</i> sp.	90.0	79.9	34.3
<i>Lobelia dortmanna</i>	93.1	64.4	67.4
<i>Nymphoides cordata</i>	35.4	11.4	76.4
Total spp.	8	7	–

ANOSIM R=-0.104, p=0.738

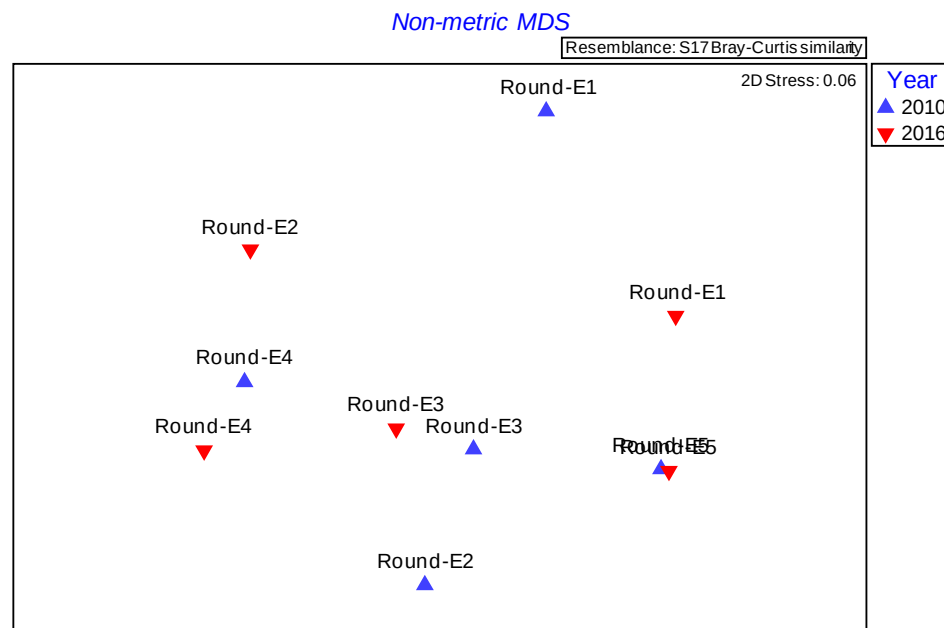


Figure 31. NMDS of sum % cover for Round-E Pond by transect-box plots in 2010 and 2016 at Cape Cod National Seashore.

Ryder Pond

Between 2010 and 2016, *N. odorata* shifted its distribution, while *Utricularia* spp., *J. militaris*, and *P. cordata* all increased in abundance. These changes, however, did not appreciably influence overall plant species composition (Table 33). In both surveys, a total of 9 species were recorded. NMDS shows a fairly cohesive cluster of transects between years (Figure 32).

Table 33. ANOSIM (R=goodness of fit, p=significance level) and SIMPER (Cum %=percent contribution to dissimilarity between years) results from comparisons of Ryder Pond % cover in 2010 vs. 2016 within box plots at Cape Cod National Seashore.

Species	2010	2016	Cum %
<i>Nymphaea odorata</i>	18.5	18.3	33.1
<i>Utricularia</i> spp.	1.6	18.6	53.3
<i>Juncus militaris</i>	2.5	8.4	67.6
<i>Pontedaria cordata</i>	1.9	5.9	78.9
Total spp.	9	9	–

ANOSIM R=-0.028, p=0.532

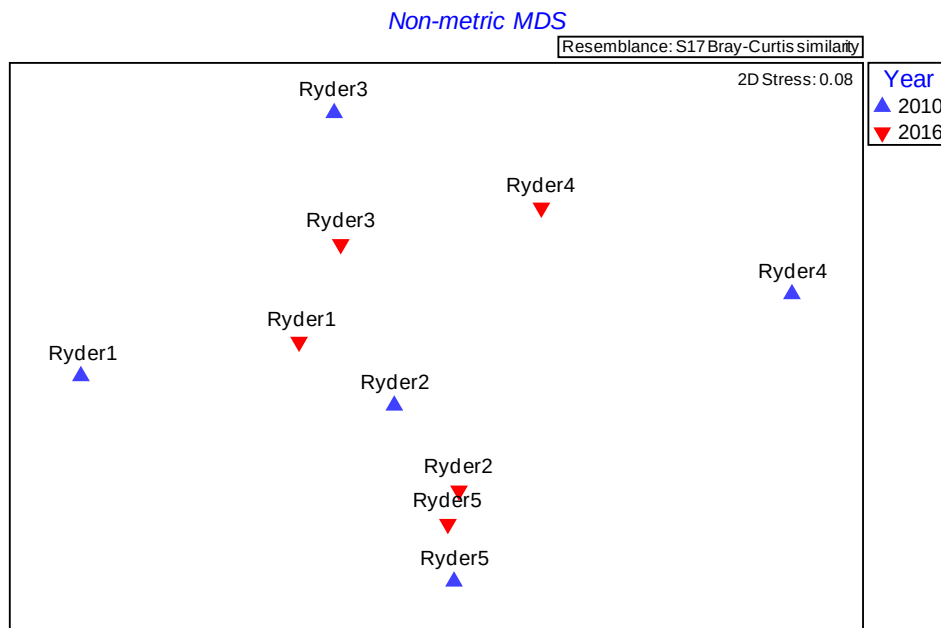


Figure 32. NMDS of sum % cover for Ryder Pond by transect-box plots in 2010 and 2016 at Cape Cod National Seashore.

Slough Pond

Slough Pond exhibited no significant alteration in plant communities between 2010 and 2016 (Table 34). *L. dortmanna* (decreased), *Elatine minima* (decreased), *E. parvula* (decreased), and *Isoetes* spp. (increased) all had the most change between surveys. There was an increase in the total number of species recorded in the box plots from 8 in 2010 to 15 in 2016. Box plots along the transects had relatively constant distances between years (Figure 33).

Table 34. ANOSIM (R=goodness of fit, p=significance level) and SIMPER (Cum %=percent contribution to dissimilarity between years) results from comparisons of Slough Pond % cover in 2010 vs. 2016 within box plots at Cape Cod National Seashore.

Species	2010	2016	Cum %
<i>Lobelia dortmanna</i>	20.0	9.4	31.9
<i>Elatine minima</i>	31.4	7.0	53.7
<i>Eleocharis parvula</i>	37.1	0.9	67.2
<i>Isoetes</i> spp.	0.0	3.4	76.6
Total spp.	8	15	–

ANOSIM R=-0.052, p=0.667

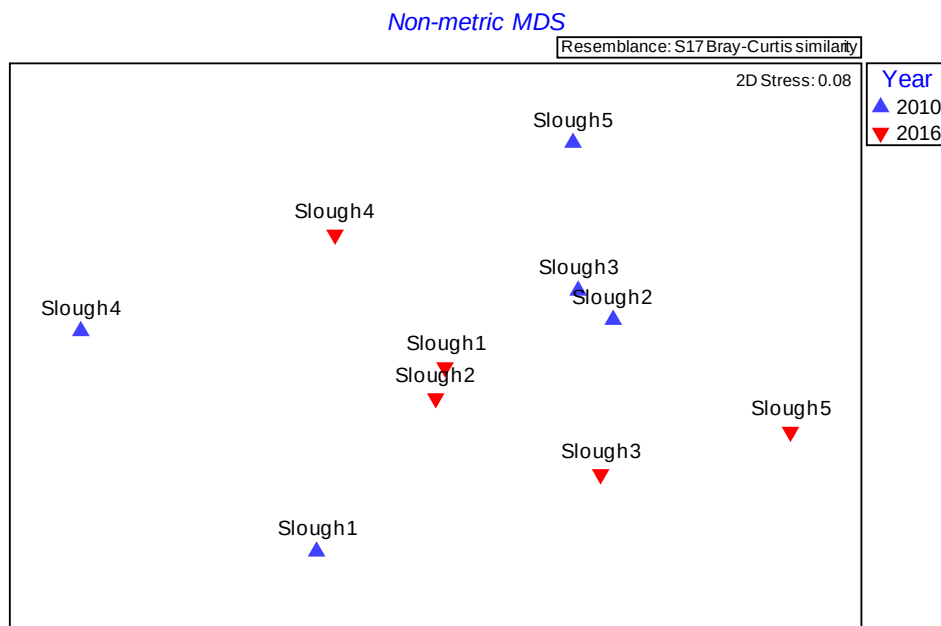


Figure 33. NMDS of sum % cover for Slough Pond by transect-box plots in 2010 and 2016 at Cape Cod National Seashore.

Snow Pond

Snow Pond also exhibited no statistical change in box plot vegetation communities between 2010 and 2016 (Table 35). *Utricularia* spp. declined, while *N. odorata*, *P. cordata*, and *P. epihydrous* all increased, but these changes were not enough to significantly influence overall communities. Total species richness declined from 16 to 14 between surveys. NMDS revealed that plots along transects 3 and 5 shifted to the largest extent (Figure 34).

Table 35. ANOSIM (R=goodness of fit, p=significance level) and SIMPER (Cum %=percent contribution to dissimilarity between years) results from comparisons of Snow Pond % cover in 2010 vs. 2016 within box plots at Cape Cod National Seashore.

Species	2010	2016	Cum %
<i>Utricularia</i> spp.	53.7	24.1	27.6
<i>Nymphaea odorata</i>	19.5	37.7	48.2
<i>Pontedaria cordata</i>	17.2	28	63.3
<i>Potamogeton epihydus</i>	0	20.8	73.3
Total spp.	16	14	–

ANOSIM R=-0.084, p=0.67

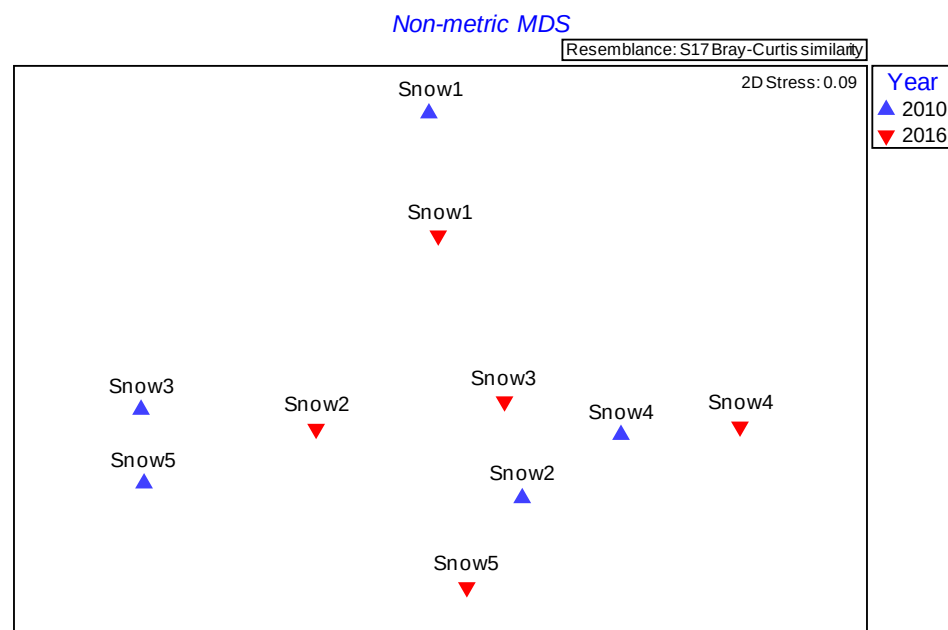


Figure 34. NMDS of sum % cover for Snow Pond by transect-box plots in 2010 and 2016 at Cape Cod National Seashore.

Spectacle Pond

Lastly, Spectacle Pond did exhibit a significant vegetation change between 2010 and 2016 (Table 36). This was primarily due to a doubling of *Utricularia* spp. in abundance and a slight increase/shift in spatial distribution of *N. cordata*. Total species richness remained essentially the same, decreasing by one taxon from 14 in 2005 to 13 in 2016. NMDS illustrates the large species composition that occurred along virtually every transect except transect 4 (Figure 35).

Table 36. ANOSIM (R=goodness of fit, p=significance level) and SIMPER (Cum %=percent contribution to dissimilarity between years) results from comparisons of Spectacle Pond % cover in 2010 vs. 2016 within box plots at Cape Cod National Seashore.

Species	2010	2016	Cum %
<i>Utricularia</i> spp.	120.1	249.4	66.5
<i>Nymphoides cordata</i>	21.5	30.1	76.1
Total spp.	14	13	–

ANOSIM R=0.648, p=0.08

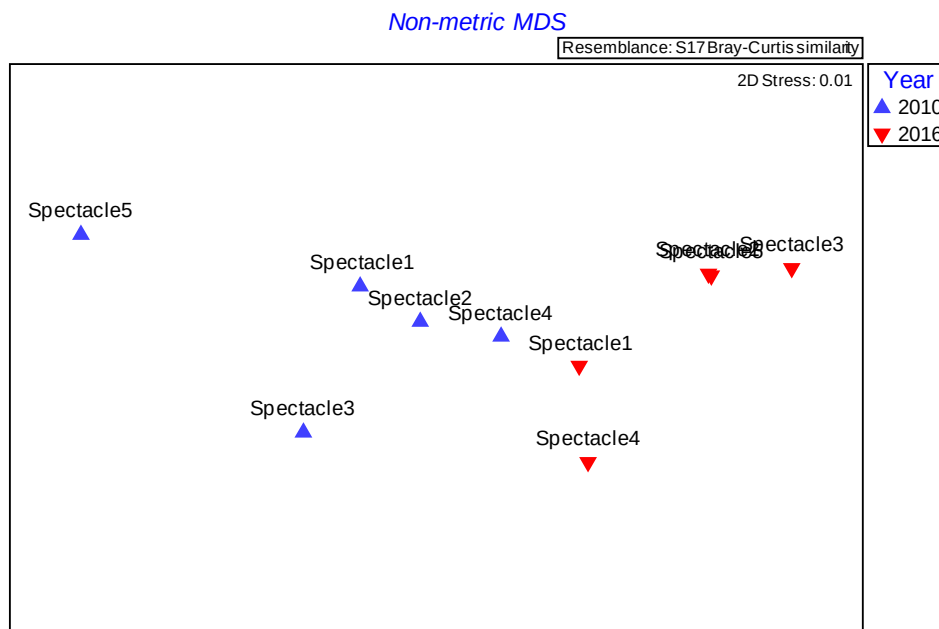


Figure 35. NMDS of sum % cover for Spectacle Pond by transect-box plots in 2010 and 2016 at Cape Cod National Seashore.

All ponds

ANOSIM confirmed that the kettle pond plant communities as a whole (all ponds pooled) did not exhibit any significant shifts between 2010 and 2016 (Table 37). The taxa contributing most to dissimilarities among years were much the same as reported for individual ponds, including *Utricularia* spp., *N. odorata*, *L. dortmanna*, *E. parvula*, *E. septangulare*, *N. cordata*, and *E. minima* (small waterwort). Although different taxa were present or absent in the two surveys, total species richness remained at 43. The NMDS plot of this data shows that Dyer Pond exhibited the largest divergence in plant species abundance and distribution between the 2010 and 2016 (Figure 36).

Table 37. ANOSIM and SIMPER results from comparisons of all ponds 2010 vs. 2016 box plot data (R=goodness of fit, p=significance level, Cum %=percent contribution to dissimilarity between years) at Cape Cod National Seashore.

Species	2010	2016	Cum %
<i>Utricularia</i> spp.	42.6	39.6	20.3
<i>Nymphaea odorata</i>	35.3	21.4	34.1
<i>Lobelia dortmanna</i>	26.4	14.6	47.5
<i>Juncus militaris</i>	13.7	13.2	55.6
<i>Eleocharis parvula</i>	6.35	3.15	60.7
<i>Eriocaulon septangulare</i>	10.0	0.0	65.2
<i>Nymphoides cordata</i>	9.8	5.1	69.0
<i>Elatine minima</i>	6.5	1.1	72.5
Total spp.	42	42	–

ANOSIM R=0.045, p=0.15

Ranked by abundance change, the species that declined to the largest extent between 2010 and 2016 (all box plots, all ponds) were *L. dortmanna*, *E. septangulare*, *N. odorata*, *Myriophyllum* spp., and *Najas* spp. (Table 38). Those that proliferated most in the box plots were *Osmunda regalis* (royal fern), *S. pungens*, *T. virginicum*, *Lycopus* spp., and *P. cordata*. Total sum % cover decreased from 13,593 to 9,101% between 2010 and 2016.

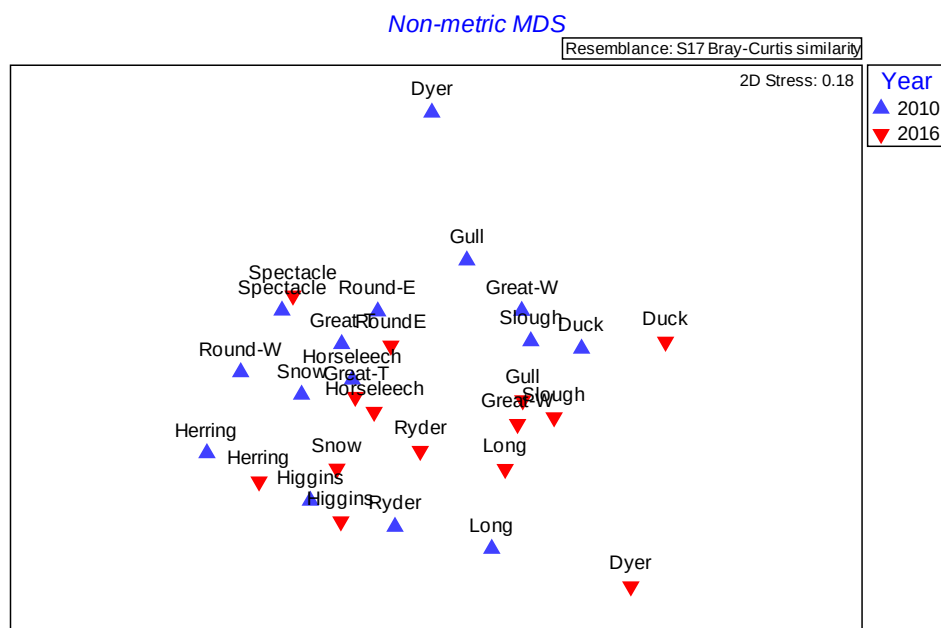


Figure 36. NMDS of sum % cover for all ponds combined in 2010 and 2016 at Cape Cod National Seashore.

Table 38. Aquatic plant species recorded in box plots and their total summed percentage values (all plots, transects, and ponds) ranked from largest negative to positive change between 2010 and 2016 at Cape Cod National Seashore.

Species	Sum % cover 2010	Sum % cover 2016	Change (%)
<i>Lobelia dortmanna</i>	1984	1021	-964
<i>Eriocaulon septangulare</i>	740	0	-740
<i>Nymphaea odorata</i>	2234	1495	-739
<i>Myriophyllum</i> sp.	642	70	-573
<i>Najas</i> spp.	583	144	-439
<i>Elatine minima</i>	487	74	-413
<i>Nymphoides cordatum</i>	735	356	-379
<i>Eleocharis</i> spp.	495	256	-239
<i>Isoetes</i> spp.	232	49	-183
<i>Phragmites australis</i>	224	81	-143
<i>Juncus militaris</i>	1031	927	-105
<i>Scirpus cyperinus</i>	72	9	-63
<i>Woodwardia virginica</i>	91	42	-49

Table 38 (continued). Aquatic plant species recorded in box plots and their total summed percentage values (all plots, transects, and ponds) ranked from largest negative to positive change between 2010 and 2016 at Cape Cod National Seashore.

Species	Sum % cover 2010	Sum % cover 2016	Change (%)
<i>Decodon verticillatus</i>	310	268	-43
<i>Calamagrostis canadensis</i>	71	39	-33
<i>Onoclea sensibilis</i>	21	0	-21
<i>Nuphar variegatum</i>	73	54	-19
<i>Carex</i> sp.	55	37	-18
<i>Juncus pelocarpus</i>	16	0	-16
<i>Potamogeton epihydrus</i>	233	217	-16
<i>Juncus</i> spp.	8	0	-8
<i>Potamogeton spirillus</i>	5	0	-5
<i>Elodea nuttallii</i>	4	0	-4
<i>Galium tinctorium</i>	4	0	-4
<i>Elatine</i> spp.	3	0	-3
<i>Bidens</i> sp.	1	0	-1
<i>Boehmeria cylindrica</i>	1	0	-1
<i>Spartina pectinata</i>	1	0	-1
<i>Thelypteris palustris</i>	4	3	-1
<i>Daucus carota</i>	0	1	1
<i>Juncus acuminatus</i>	0	1	1
<i>Drosera filiformis</i>	0	3	3
<i>Drosera intermedia</i>	1	4	3
<i>Sium suave</i>	1	4	3
<i>Viola lanceolata</i>	0	4	4
<i>Brasenia schreberi</i>	133	138	5
<i>Cicuta bulbifera</i>	0	7	7
<i>Gratiola aurea</i>	0	10	10
<i>Sagittaria latifolia</i>	0	10	10
<i>Cambomba caroliniana</i>	0	18	18
<i>Galium</i> spp.	0	19	19

Table 38 (continued). Aquatic plant species recorded in box plots and their total summed percentage values (all plots, transects, and ponds) ranked from largest negative to positive change between 2010 and 2016 at Cape Cod National Seashore.

Species	Sum % cover 2010	Sum % cover 2016	Change (%)
<i>Lysimacchia terrestris</i>	31	52	21
<i>Callitriche palustris</i>	0	24	24
<i>Euthamia tenuifolia</i>	22	47	26
<i>Utricularia</i> spp.	2746	2772	27
<i>Hydrocotyle umbellata</i>	27	65	38
<i>Osmunda regalis</i>	0	41	41
<i>Schoenoplectus pungens</i>	0	54	54
<i>Triadenum virginicum</i>	43	143	100
<i>Lycopus</i> spp.	2	133	131
<i>Pontedaria cordata</i>	235	419	184
Total % cover	13593	9101	–

Discussion

Since 1995, there have been some changes in the species composition, species richness, and total plant cover in many CACO kettle ponds. In numerous ponds, species richness and plant cover has decreased over time. The reason(s) for this is unclear. However, CACO's Hydrologic Monitoring program has documented increasing water level trends in both the kettle ponds and numerous groundwater wells. In fact, the average difference (excluding Herring and Gull Ponds which don't seem to be rising) in water level measured at the start of the growing season (April) in 2000 and 2016 is +23 cm. While water levels are generally rising in the summer months as well, the trends are much weaker since evaporation, which lowers ponds, is at its peak during this time. The rise is closely tied to groundwater increases over time, which itself is best correlated with sea level rise, and to a lesser extent precipitation (Smith and Medeiros, in review). Only Duck, Gull, and Herring ponds failed to exhibit this trend, although they match the same lack of increase in the nearest groundwater wells to these sites.

Increasing water levels can have the effect of reducing macrophyte biomass and species richness in the littoral zone (Trei and Pedusaar 2006, Farney and Bookhout 1982, Ashton and Bissell 1987, Geest et al. 2005, Sjöberg and Danell 1983, Nohara 1991, Casanova and Brock 2000). In terms of specific taxa, *Nymphaea odorata*, which generally increased in abundance, has been shown to increase its leaf size and biomass in response to deeper water (Sinden-Hempstead and Killingbeck 1996, Richards et al. 2011). Even small changes in depths can have significant impacts (Paillisson and Marion 2006). In this regard, it is noteworthy that the survey in 1995 was also conducted during a very dry year (Roman et al. 2001). Increases in submerged aquatic plants such as *Najas* spp. and *Utricularia* may also be the result of increasing water clarity in CACO kettle ponds over the last two decades (Smith et al. in review) (Dale 1986, Stewart and Freedman 1989, Loughheed et al. 2001, Zhu et al. 2006). Sea level rise will continue to push the fresh groundwater table upwards, creating deeper water and, depending upon shoreline slopes, a gradual increase in the size of the ponds. From this, we can reasonably predict that there will be a narrowing of the habitable littoral zone, since the steep slopes of the upland banks around most ponds will greatly limit the landward transgression of this zone.

In addition to hydrologic changes, the acidity of CACO's kettle ponds has diminished greatly over the past several decades as a result of decreasing acid rain (Smith et al. 2016). This may have contributed to the declines in some of the species that thrive under acidic conditions (Figure 37), including *N. odorata*, *E. acicularis*, *L. dortmanna*, *J. militaris*, *Isoetes* spp., *Eriocaulon* spp., and certain *Utricularia* species (Rothrock and Wagner 1975, Jackson et al. 1990, Weiher et al. 1994, Srivastava et al. 1995, Fyson 2000, Woodcock et al. 2005, Nierzwicki et al. 2010, Lacoul et al. 2011).

The presence of *Phragmites* in Herring and Horseleech ponds is of concern, since this species has a propensity to proliferate and displace native vegetation. We hope to eradicate this species in the future from what otherwise is a pristine system with respect to plant taxa. It is also a measure of prevention in that there would be a diminished likelihood of *Phragmites* from invading other ponds.

The other two invasive species were the *Cambomba caroliniana* (fanwort) and *Elodea nuttallii* (Nuttall's waterweed), which were found in Herring and Higgins ponds, respectively. These would be much more difficult to eradicate since they are submerged aquatic weeds.



Figure 37. Photos of aquatic plants typical of acidic waters that have largely diminished in CACO kettle ponds in recent decades. From left to right are *Eleocharis acicularis*, *Lobelia dortmanna*, *Juncus militaris*, *Isoetes lacustris*, and *Eriocaulon septangulare*.

In some ponds, plant communities have not changed significantly over the last one to two decades, whereas others have. Many of the larger shifts in cover and species composition may be linked to increasing water levels and diminished pond acidity. However, it will take at least one more survey to confirm whether these are persistent trends. The consequences of such changes may be numerous, as many different organisms utilize or are dependent upon pond macrophytes, including anurans, dragonflies, and birds (Butler 2008, Henning and Remsburg 2009). Pond vegetation also influences nutrient cycling (Schindler, DE and M.D. Scheuerell 2002), phytoplankton growth (van Donk and van de Bund 2002), zooplankton (Lodge 2001), and fish (Slade et al. 2005).

Because littoral zone macrophytes appear to be under some stress, as evidenced by their reduced abundance in many cases, it is important that CACO continues to support current efforts to restore/rehabilitate denuded pond shorelines where visitors have trampled the vegetation. These direct management activities can help offset some of the other losses that are not within the park's control (e.g., hydrology, climate change). As such, the value of these repeated surveys thus far lies in their capacity to inform the park about how pond vegetation is changing over recent time rather than how to manage them, if management is even appropriate. Rather, more targeted research is needed to elucidate the impacts of various human pressures in driving such changes. Where clear anthropogenic impacts can be discerned, the park is then left with the decision as to whether they should be mitigated if possible. If the changes are deemed to be mostly natural variability, or are beyond the park's ability to manage, then no action would be recommended. The next scheduled surveys will occur ~2020 and temporal analysis will be conducted - which may or may confirm that the above-mentioned trends in vegetation are continuing, diminishing, or strengthening.

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The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 609/146267, June 2018

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