National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

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

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).

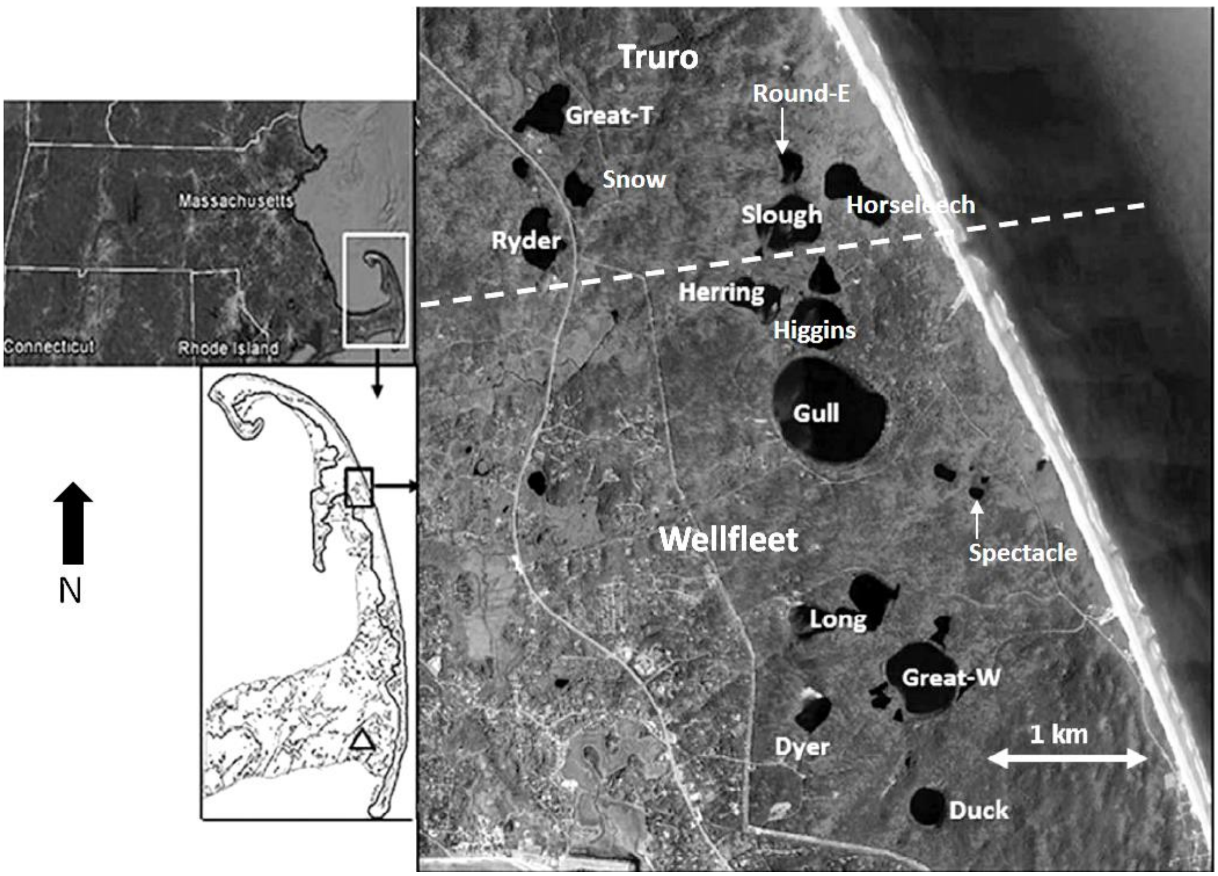

Figure 1. Map of Massachusetts (upper left), outer Cape Cod (lower left; polygon represents boundary of CACO), and CACO kettle ponds where plant communities are being monitored (dashed line represents boundary between the towns of Wellfleet and Truro).

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.

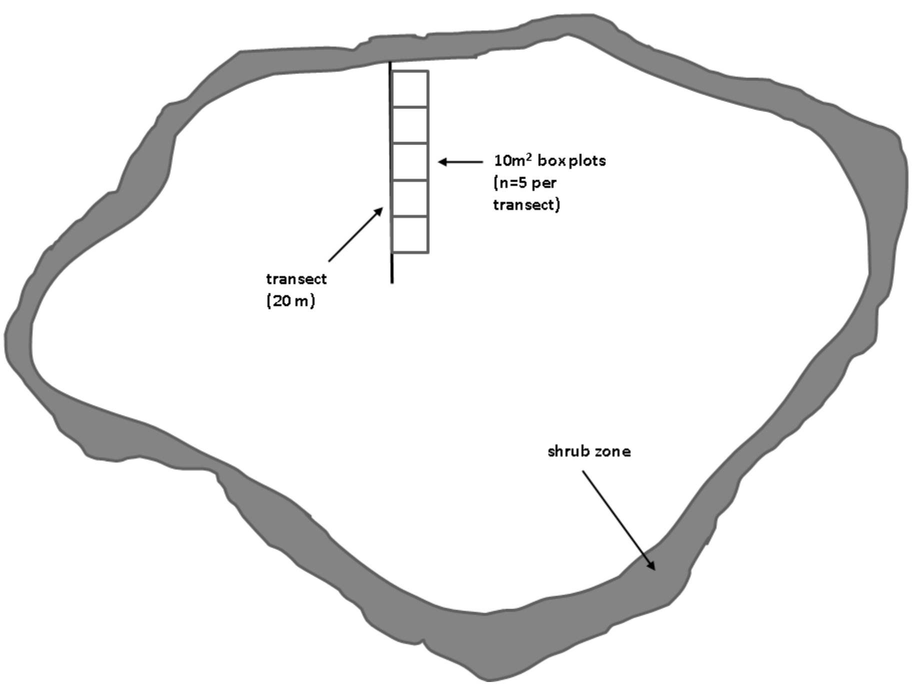

Figure 2. Diagram of current line transect and box plot (five contiguous 3.3 x 3.3 m plots; 10 m^2) each) configuration. There are five transects (20 m each) and therefore 25 box plots per pond.

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 m^2) 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 JMP™ 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 (%)
Lobelia dortmanna	86%
Eriocaulon septangulare	79%
Nymphaea odorata	64%
Nymphoides cordatum	50%
Pontederia cordata	50%
Juncus militaris	50%
Carex spp.	50%
Elatine minima	43%
Utricularia spp.	36%
Nuphar variegatum	29%
Decodon verticillatus	29%
Triadenum virginicum	29%
Isoetes spp.	29%
Myriophyllum humile	29%
Scirpus pungens	29%
Utricularia macrorhiza	21%
Utricularia radiata	21%
Lysimachia terrestris	21%
Euthamia tenuifolia	21%
Potamogeton epihydrus	21%
Najas 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 (%)**
Lycopus virginicus	21%
Eleocharis spp.	21%
Euthamia tenufolia	21%
Isoetes lacustris	21%
Hydrocotyle umbellata	14%
Scirpus pungens	14%
Elodea nuttallii	14%
Phragmites australis	14%
Lycopus spp.	14%
Myriophyllum spp.	14%
Eleocharis palustris	14%
Galium spp.	14%
Brasenia schreberi	7%
Eleocharis parvula	7%
Sagittaria latifolia	7%
Decadon verticillatus	7%
Gratiola aurea	7%
Callitriche palustris	7%
Drosera filiformis	7%
Drosera intermedia	7%
Justicia americana	7%
Woodwardia virginica	7%
Cicuta bulbifera	7%
Elatine spp.	7%
Najas flexilis	7%
Potamogeton amplifolious	7%
Thelypteris palustris	7%
Viola lanceolata	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. ordorata* 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.

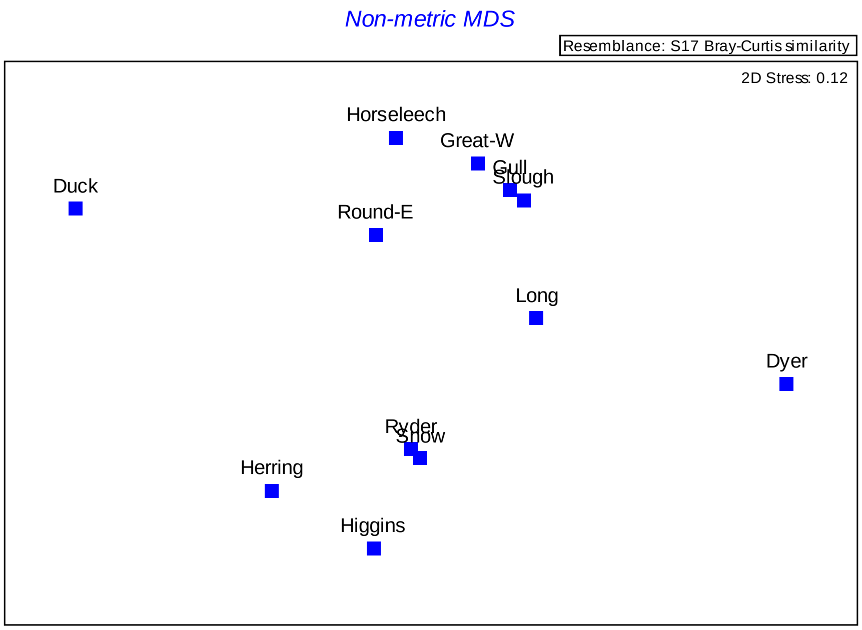

Figure 3. NMDS of species composition among ponds in 2016 by sum % cover at Cape Cod National Seashore.

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 (%)
Eriocaulon septangulare	86%
Lobelia dortmanna	86%
Isoetes sp.	71%
Myriophyllum sp.	64%
Nymphaea odorata	64%

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

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

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

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

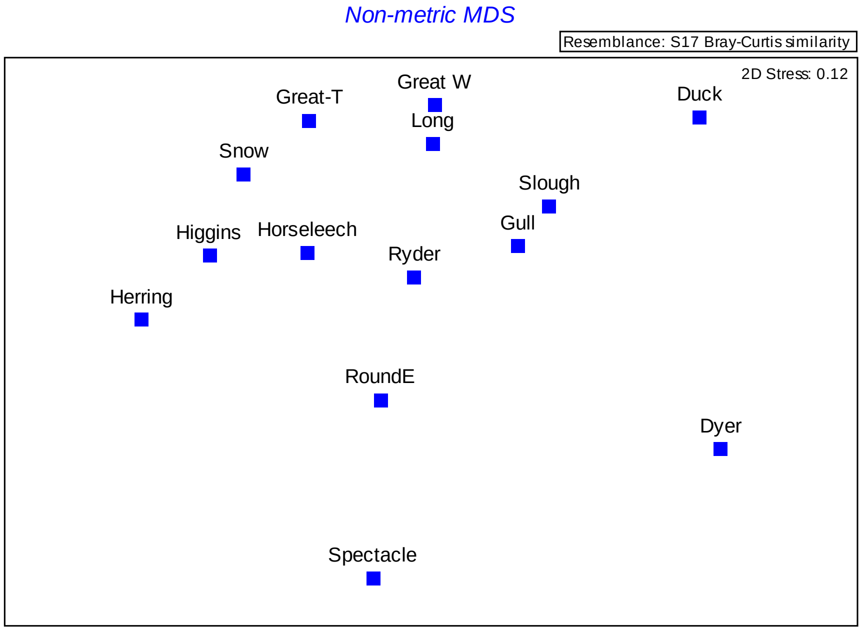

Figure 4. NMDS of ponds based on sum % cover from box plots (2016 data only) at Cape Cod National Seashore.

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* (Nutall'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
Brasenia schreberi	water shield
Calamagrostis canadensis	bluejoint
Callitriche palustris	water star-wort
Cambomba caroliniana	fanwort (I)
Carex spp.	Carex sedges
Cicuta bulbifera	water-hemlock
Clethra alnifolia	pepperbush
Daucus carota	wild carrot
Decadon verticillatus	water-willow
Drosera filiformis	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
Drosera intermedia	spatulaleaf sundew
Elatine minima	small waterwort
Elatine spp.	waterworts
Eleocharis palustris	common spikerush
Eleocharis parvula	dwarf hairgrass
Eleocharis sp.	spikerushhes
Elodea nuttallii	Nuttall's waterweed (I)
Eriocaulon septangulare	pipewort
Euthamia tenuifolia	Slenderleaf goldentop
Galium spp.	bedstraws
Gratiola aurea	golden hedgehyssop
Hydrocotyle umbellata	marshpennywort
Isoetes lacustris	boreal quillwort
Isoetes spp.	quillworts
Juncus acuminatus	tapertip rush
Juncus militaris	bayonet rush
Justicia americana	American water-willow
Lycopus spp.	waterhorehounds
Lycopus virginicus	Virginia waterhorehound
Lysimachia terrestris	Swamp candles
Myriophyllum humile	low watermilfoil
Myriophyllum sp.	watermilfoils
Najas flexilis	nodding waternymph
Najas sp.	waternymphs
Nuphar variegatum	Yellow pondlily
Nymphaea odorata	White waterlily
Nymphoides cordata	Little floating hearts
Osmunda regalis	Royal fern
Phragmites australis (I)	Common reed
Pontederia cordata	Pickerelweed
Potamogeton amplifolious	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
Potamogeton epihydrus	ribbonleaf pondwee
Sagittaria latifolia	broadleaf arrowhead
Scirpus cyperinus	woolgrass
Schoenoplectus pungens	three-square
Sium suave	hemlock waterparsnip
Thelypteris palustris	marsh fern
Triadenum virginicum	Virginia marsh St. Johnswort
Utricularia cornuta	horned bladderwort
Utricularia macrorhiza	common bladderwort
Utricularia pururea	eastern purple bladderwort
Utricularia radiata	floating bladderwort
Utricularia sp.	bladderworts
Viola lanceolata	bog white violet
Woodwardia virginica	Virginia Chain Fern

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, Lougheed 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 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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