ASSESSMENT OF VEGETATION IN FORESTED VERNAL WETLANDS OF CAPE COD NATIONAL SEASHORE, 2006

Stephen M. Smith, Jennifer Allen, and Heather Ruggiero

National Park Service,
Cape Cod National Seashore
99 Marconi Site Road,
Wellfleet, MA 02667

Executive Summary

Forested vernal wetlands across the glacial outwash plain of Cape Cod National Seashore were mapped and their vegetation surveyed from June-August of 2006. In addition, vegetation within a subset of nine wetlands, three of which were the subject of study in 1997 and 1999, were characterized along permanent transects and an analysis of temporal change conducted.

A total of 109 wetlands were investigated, 40 of which were previously undocumented sites. The wetlands ranged in size from 16 m^2 to 30,898 m^2 (~3.1 ha). Species richness was unrelated to size and was similar to dune slack wetlands of north Truro and Provincetown. Woody shrubs dominated the plant communities, although their abundance was quite variable among the entire group of 109 sites. One state listed plant species (Special Concern) was discovered. It was also found that CACO's forested vernal wetlands are almost totally free of exotic vegetation. As such they have considerable inherent value as examples of pristine systems. This baseline data provides a useful tool for scientists and managers in that there is now detailed information about the plant communities in a large number of wetland systems that were previously unknown entities. For example, the data are of considerable value in assessing the accuracy of CACO's vegetation map.

The results of the temporal change analysis indicate that large shifts in plant communities can be expected as a result of hydrologic conditions in individual years. This has implications for sampling methodologies and analysis and interpretation of long-term monitoring data.

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Introduction

Description of resource

Scattered across the glacial outwash plain of outer Cape Cod are discrete, variable-sized depressions in the ground surface. These depressions were originally formed by the weight of ice blocks left behind by the retreating glacier almost 18,000 yrs ago. Sea level rise since that time forced a concurrent rise in the fresh groundwater lens, which floats atop of the denser seawater below. This resulted in the permanent flooding of deep depressions (i.e., lakes or "kettle ponds) and seasonal flooding of shallow ones. The latter are vernal wetlands, also known as vernal pools or ponds.

While annual variability in flood duration (hydroperiod) can be substantial depending on precipitation and antecedent groundwater elevation, these wetlands generally have standing water from early spring to mid-summer but little to none by the end of August (Colburn 2005). The seasonal flooding and drying cycle of vernal wetlands fosters the development of distinctive assemblages of plants (Figure 1) and animals. Herbaceous plants, particularly annuals, respond rapidly to water level. As such, vastly different plant communities can develop from year to year depending upon precipitation and the rate of drawdown (Roman and Barrett 2004). Aside from the floodplains of major river systems such as the Herring River (Wellfleet) and the Pamet River (Truro), vernal wetlands constitute the principal habitat for many freshwater wetland taxa. From a wildlife perspective, vernal wetlands are critical habitat in a number of ways. The State Endangered water-willow stem borer depends upon *Decodon verticillatus* (water-willow), which is a common species in many vernal wetlands. For a wide variety of insects and amphibians such as wood frogs (*Rana sylvatica*) and spotted salamanders

(*Ambystoma maculatum*) vernal wetlands provide critical breeding habitat. Along with a lesser number of permanent ponds, they are also an important source of fresh drinking water.

Previous studies

Vernal wetlands on the glacial outwash plain are referred to in this document as “forested vernal wetlands”. This terminology is based on the surrounding landscape of pine woodland or mixed pine-oak forest., something that distinguishes them from dune slack wetlands (also vernal). They are further distinguished from the latter by their geologic origin. Dune slack wetlands occur at the northern tip of Cape Cod, a region that formed by post-glacial erosion and re-deposition of sediments from Atlantic-side beaches. In addition, dune slack wetlands were not formed by glacial processes. Rather, they were (and still are) created by wind scour in the wake of migrating dunes. A detailed description of dune slack formation and vegetation characteristics is provided in Smith et al. (2007).

To date, the focus of study within forested vernal wetlands has been on water chemistry, hydrology, and fauna. Very little quantitative data has been collected on plant communities. Over the past decade, Dr. John Portnoy and Robert Cook (NPS staff) mapped and provided general descriptions of 66 forested vernal wetlands within the boundaries of Cape Cod National Seashore (CACO). In addition, a detailed study of 3 vernal wetlands in Eastham was conducted during a wet (1997) vs. dry (1999) year to examine physico-chemical and floristic responses to hydrology (Roman and Barrett 2004). Sobczak (1999, 2001) and Sobczak et al. (2003) characterized basin profiles, peat depths, and hydrologic functioning of these same wetlands. Colburn et al. (2006) followed hydrology in 9 vernal ponds (including the three mentioned above) in Eastham from 1999 through 2002. Tupper (2006) collected quantitative data along transects in 29 vernal wetlands in an effort to describe breeding habitat for Fowler's toads. Outside of this body of work, there has never been a comprehensive, quantitative survey of vegetation done for all the forested vernal wetlands within CACO. Furthermore, many wetlands that are clearly visible in aerial photographs have never been visited by Park staff and, in a sense, have remained unknown entities.

Threats to forested vernal ponds and rationale for long term monitoring

Anthropogenic influences on forested vernal wetlands are numerous. One of the biggest concerns is the development of adjacent towns, which is accompanied by increasing groundwater withdrawal for urban consumption. Depletion of groundwater can impact the hydrologic regime of nearby wetlands (Sobczak et al. 2002). More broadly, various aspects of climate change such as altered precipitation quantity and quality, temperature, evaporation, and the effects of sea level rise on the groundwater table may have significant effects on these wetlands.

Biological threats to vernal wetlands also exist. For example, exotic and/or invasive plant species such as common reed (*Phragmites australis*) and purple loosestrife (*Lythrum salicaria*) are already significant problem in other wetland systems within CACO. However, the extent of infestation in forested vernal wetlands by such taxa is unknown.

Figure 1. Physiognomy of two different forested vernal ponds across CACO.

Objectives of monitoring

In accordance with the National Park Service's Inventory & Monitoring program to develop inventories and implement monitoring protocols for all ecosystem types within Park units, the main objectives of this work were to:

1) Map and quantitatively assess plant communities in all known and unknown forested vernal ponds within CACO.
2) Re-survey the vegetation at three sites that were studied in 1997 and 1999 for the purpose of analyzing temporal change.
3) Expand the number of wetlands included in the intensive subset of sites with permanent transects for long term vegetation monitoring.

Methods

I. Mapping and Inventory

Potential forested/woodland vernal wetlands were identified using August 2000 (available at CACO) and December 2001/April 2005 digital, georectified images of CACO from Truro to Chatham (available from Massachusetts Department of Environmental Protection). LIDAR elevation data (2002) were overlaid on these images to confirm the location of significant elevation depressions in the land surface. The area of focus was the glacial outwash plain of outer Cape Cod within the boundary of CACO. The northern limit of this area is a bluff known as “High Head” in north Truro. The southern limit is the Nauset Marsh region in Eastham. Excluded from the search were the dunes of Truro and Provincetown (north of High Head) where dune slack wetlands have already been previously mapped and inventoried (Smith et al. 2007).

Using ArcGIS ver. 8.0, each potential wetland was identified with a point symbol. A total of 143 sites were identified, 81 of which had previously been confirmed by Dr. Cook. The remaining 62 were identified as potential vernal wetlands. The coordinates (NAD83 UTM) of all points were then exported and uploaded into a Garmin™ 76s GPS unit. During the summer of 2006, the 2-person field crew navigated to every location to conduct vegetation surveyed. For potential sites, the crew either confirmed or refuted the existence of a wetland based on the presence of hydrophytic taxa with wetland indicator designations of facultative (FAC), facultative-wet (FACW), or obligate (OBL) (USACOE 1987). An additional criterion was the exclusion of upland taxa (facultative upland = FACU and upland = UPL) as a ubiquitous member of the community. Using

GIS software drawing tools, each confirmed wetland was subsequently delineated as a discrete polygon, the shape and size of which was based the aerial photography (Aug 2000, Dec 2001, April 2005) and LIDAR elevation gradients.

Vegetation surveys

Due to the large number of sites requiring surveys (~ 150), analysis of vegetation using transects or plots was not feasible. Such methods would require countless replicates given the large amount of spatial heterogeneity that can exist within a single wetland. Moreover, species occurring outside the boundaries of plots or transects could easily go undetected. Instead, vegetation was scored based on visual estimates of cover across the entire wetland. This was done by thoroughly exploring each site on foot. In many cases, where there was high ground surrounding a wetland, the field crew viewed the wetland from above. Unfortunately, due to constraints on the field crew's time, a large vernal wetland known as the Red Maple Swamp could not be surveyed.

Each species found within the wetland was recorded and assigned a modified Braun-Blanquet (1932) cover class value (0=0%, 1=<1%, 2=1-5%, 3=6-10%, 4=10-25%, 5=26-50%, 6=51-75%. 7=76-100%) indicating its relative abundance. Nomenclature is based on the USDA Plants database (USDA, NRCS 2006). A digital photograph was taken of each wetland at the time of the survey. The wetlands were surveyed between mid-June and the end of August.

II. Intensive subset (IS)

A more intensive analysis of vegetation and physico-chemical conditions along transects was conducted in the three wetlands (VP33, VP38, VP41) originally studied in 1997 and 1999 (Roman and Barrett 2004). In 2006, another six wetlands were added to this group to provide a basis for long-term monitoring. Although the baseline data for these additional wetlands are from a more recent time period (i.e., 2006 rather than 1997), they will provide a broader perspective and higher statistical power to detect change. These sites (VP2, VP3, VP20, VP59, VP72, VP120) were randomly chosen from 109 total wetlands using ArcGIS randomization tools (Figure 2).

Figure 2. Intensive study sites locations (circle encompasses the original 3 wetlands in the intensive subset).

For VP 33, 38, and 41, permanent transect markers were already in place from the 1997 and 1999 surveys. To establish transects in the other six wetlands, the field crew walked to the perceived "middle" of the wetland. There, a PVC stake was hammered in to serve as the permanent marker for all 3 transect end points. From this interior center point, one crew member would walk with a tape measure along the following pre-determined (randomly-chosen) bearings to delineate the 3 transects (1st transect = 5º from center point, 2nd transect = 160 º from center point, 3rd transect = 240 º from center point) (Figure 3).

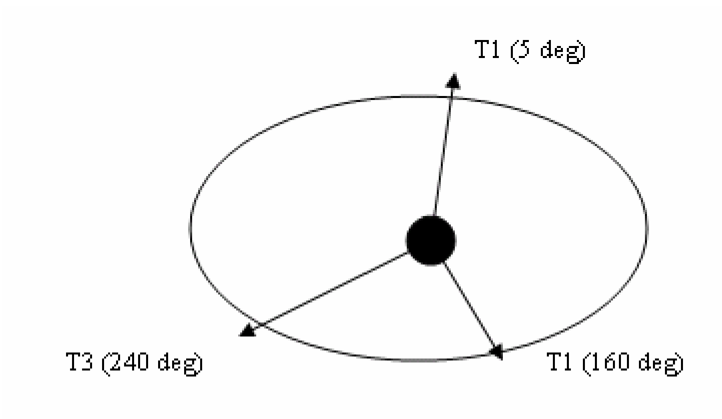

Figure 3. Diagram showing scheme for establishing transects in new IS wetlands.

Each transect was extended several meters onto dry land until upland vegetation was encountered. The total length of each transect was recorded and the upland end points were all marked with PVC posts. In addition, a metal dowel was hammered in beside the PVC markers on which the end of a field tape can be attached. Finally, the nearest tree to the upland marker was tagged with an aluminum tree tag. At times, the crew could only approximate the pre-determined bearings due to the difficulties of navigating through virtually impenetrable vegetation in certain locations. Where such conditions were encountered, the crew placed the transect as close as possible to the bearing, but in an area that was navigable.

Vegetation cover by species was recorded in August within 1-m^2 contiguous plots along the entire transect (defined by meter intervals along the field tape) extending from the upland to the interior of the wetland. Water depth at the middle point of each plot was recorded with a meter stick at the time.

Statistical analysis

Differences in the summed cover class values of individual species between 1997 and 2006 were evaluated by non-parametric Wilcoxen signed-ranks tests (XL-Stat 7.5.2). Analysis of Similarity (ANOSIM) was used to compare whole-site plant community composition between years. Non-metric multidimensional non-metric scaling (NMDS) of cover values was used to portray variability in taxonomic composition (Clarke 1993). Similarity Percentages Analysis (SIMPER) quantified the contribution of individual species to Bray-Curtis dissimilarities among groups (Primer™ ver. 6). While Principle Components Analysis (PCA) is best suited for analyzing continuous, linear data, the technique is commonly used to illustrate the contributions of individual variables to patterns of ordinal data. Accordingly, multivariate datasets were subjected to PCA in order to reveal variables contributing most to directional trends. Finally, cluster analysis was run to provide a tool with which to easily identify groups of wetlands with similar taxonomic character.

Vegetation data collected in August 1997 and August 2006 from along permanent transects in the IS wetlands (VP33, 38, and 41) were analyzed to assess temporal change. The 1997 dataset was selected for comparison with 2006 since it was a wet year, whereas 1999 was a very dry year. As such, the 1997 data provided a better match with 2006 with respect to environmental conditions given that the latter was also a wet year. The 1997 cover data were collected using the point-intercept technique. Accordingly, each percent value was converted to its corresponding cover class rank for comparison with 2006 data. Statistical differences between the two datasets were assessed by ANOSIM for whole communities (based on both summed cover values and presence/absence). Wilcoxen signed-rank tests allowed for comparisons in the cover of specific taxa by year (α=0.05).

Results

I. Mapping and Inventory

Number and location of wetlands

Of the 81 vernal wetlands Dr. Cook originally identified, seven were considered to be part of a riparian floodplain (e.g., Herring or Pamet River), one appeared to be a managed and/or disturbed bog, two were judged to be either permanent ponds or ponds where dry-down was a very infrequent occurrence, and two were dry hollows that may flood only in extremely wet years and at the time did not support any wetland vegetation. Of the 64 potential wetlands identified from aerial photography and elevation data, 21 turned out to be dry hollows while one site was found to be part of a larger floodplain system. In a couple of instances, two separate sites were found to comprise a single wetland. In total, 109 sites were confirmed as wetlands of which 40 were newly recorded (Figure 4; Appendix I).

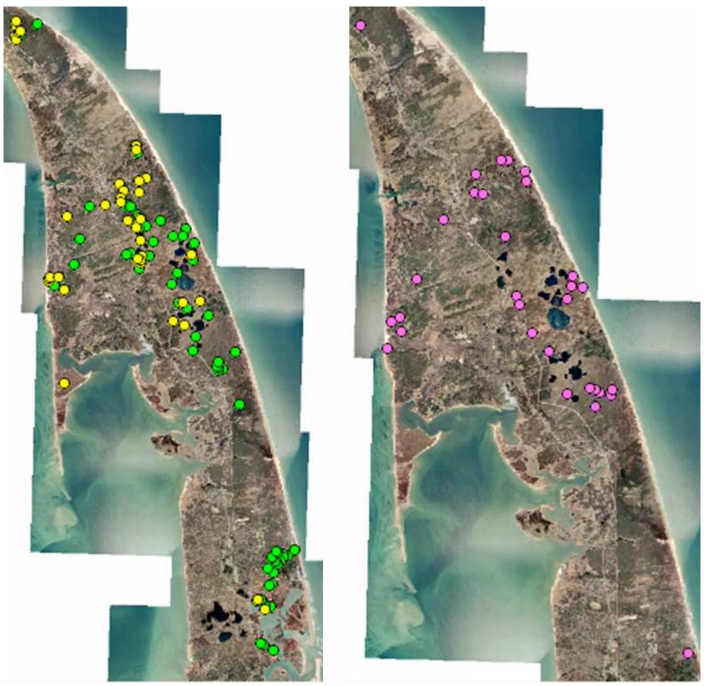

Figure 4. Map of forested vernal wetland sites visited in 2006 showing those previously identified by Dr. Cook (yellow), new sites (green), and wetlands where vegetation was not surveyed for above-stated reasons (pink).

Size of wetlands

Based on GIS delineations on geo-referenced aerial photographs, the wetlands exhibited enormous variation in size (Figure 5). The smallest wetland measured 16 m^2 while the largest was approximately 30,898 m^2 (~3.1 ha), the average being 2,752 m^2. The majority, however, were less than 5,000 m^2 (0.5 ha).

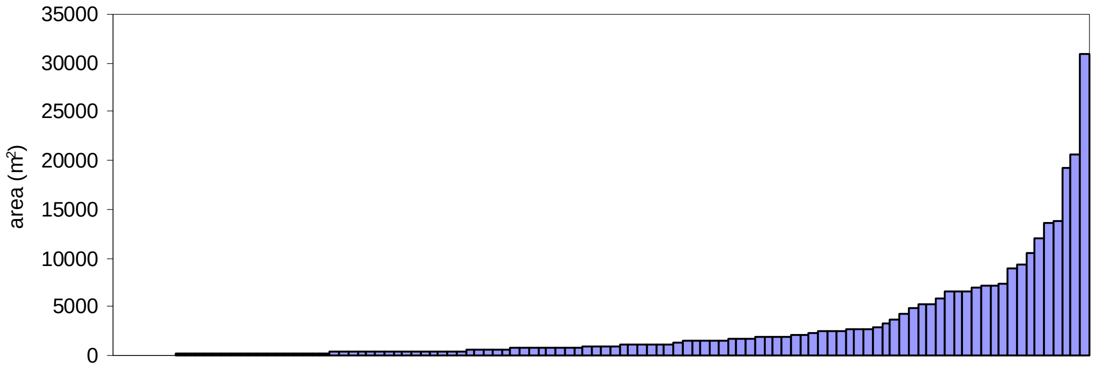

Figure 5. Range in size of mapped wetlands (each histogram represents a single wetland).

Species richness

The number of species belonging to OBL, FACW, or FAC indicator categories (i.e., wetland taxa only) per wetland ranged between 3 and 22, with an average value of 9. These values are very similar to dune slack wetlands (Smith et al. 2007). The total number of wetland species (i.e., those belonging to OBL, FACW±, FAC± categories) recorded was 81 (Appendix II). One genus of non-vascular mosses (*Sphagnum* sp.), which was a common occurrence, was also recorded. Six vascular plant specimens could only be identified to genus (*Carex*, *Salix*, *Eleocharis*, *Juncus*, *Utricularia*, *Potamogeton*).

The most common species by summed cover class and frequency values were *Vaccinium corymbosum* (highbush blueberry), *Sphagnum* sp., *Smilax rotundifolia* (bullbriar), *Acer rubrum* (red maple), and *Clethra alnifolia* (pepperbush). Species richness was unrelated to size, as evidenced by the lack of correlation between these variables depicted in Figure 6.

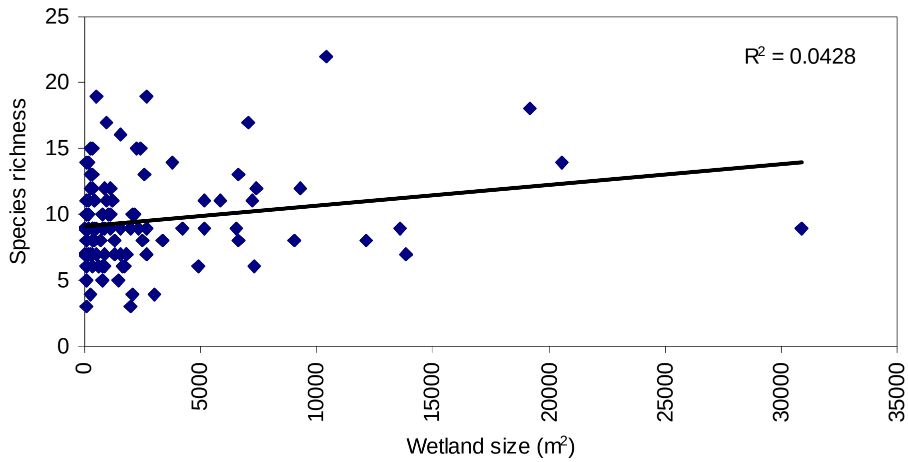

Figure 6. Linear regression of species ricness vs. wetland size.

Rare and invasive species

One previously undocumented rare species (listed by the state of Massachusetts as Special Concern) - *Sagittaria teres* (slender arrowhead) - was found at one site (Note: in 1997 this species was only identified to genus, as *Sagittaria* sp.). In general, plant communities were quite pristine with respect to infestation by exotics. *Lythrum salicaria* (purple loosestrife) and *Phragmites australis* (common reed) were only found at 1 and 3 sites, respectively. *Salix cinerea* (large grey willow), which is an exotic species but has been established in the U.S. for many years, was found in 5 wetlands. However, the extent to which this species aggressively displaces native species is unclear.

Vegetation Structure

Shrub species were by far the most abundant form of vegetation in the wetlands. Although shrub cover was highly variable, it dominated the majority of sites in area cover

(Figure 7). Other growth forms were all low and variable in cover, although graminoids (grasses, sedges, rushes) as a group were more abundant than all other forms except shrubs (Figure 7). Species of submerged aquatic vegetation (SAV) were quite rare and included only *Potamogeton* spp. and *Ceratophyllum demersum*. In terms of species richness, the shrub and forb groups had the highest numbers of taxa.

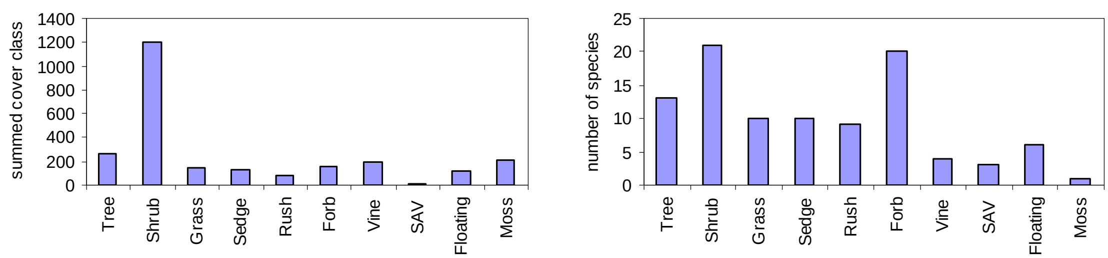

Figure 7. Total cover (left) and species richness (right) by growth form.

Wetland indicator status

OBL species constituted the largest proportion of wetland vegetation in both cover and species richness (Figure 8). Values for the FACW and FAC groups were lower and relatively similar to each other.

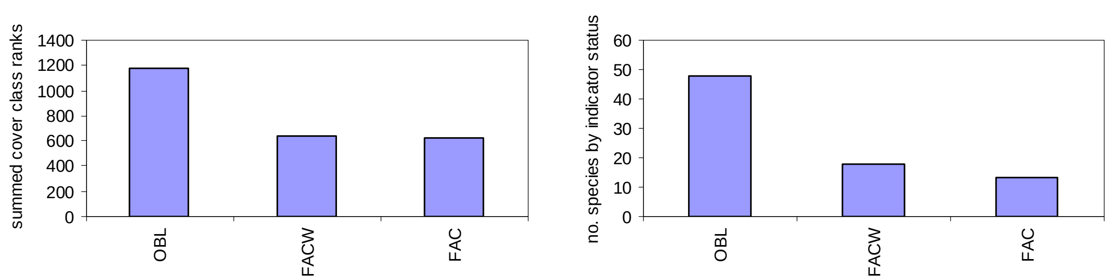

Figure 8. Total cover (left) and species richness (right) by wetland indicator group.

Taxonomic variability among wetlands

Wetlands varied substantially with respect to plant community composition. SIMPER analysis revealed that the abundance of *Acer rubrum* (red maple), *Clethra alnifolia* (pepperbush), *Chamaedaphne calyculata* (leatherleaf), *Sphagnum* moss (Sphagnum), and *Vaccinium corymbosum* (highbush blueberry) contributed most to taxonomic dissimilarity among wetlands (Figure 9).

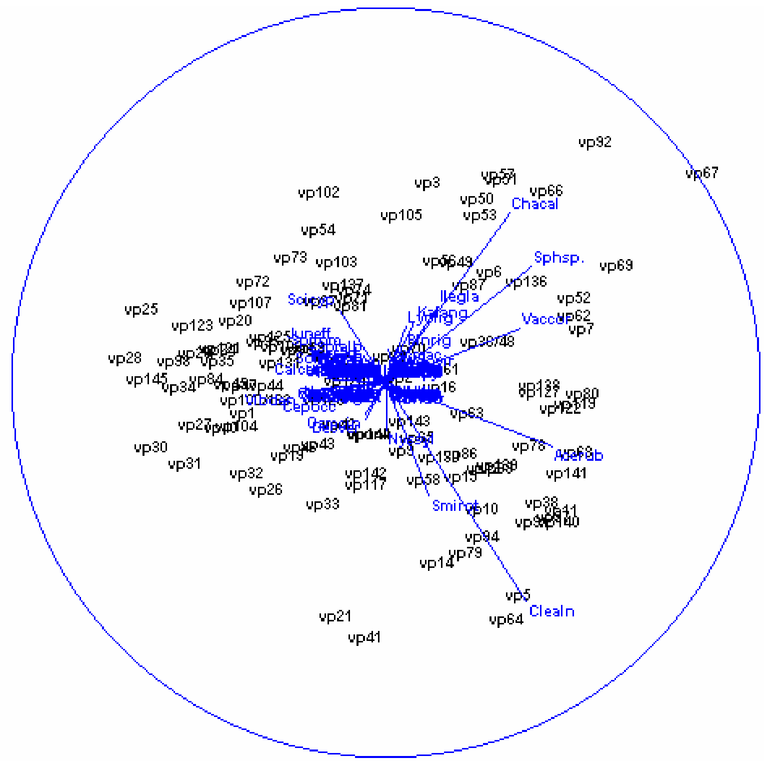

Figure 9. Principle components analysis of wetlands with eignvectors showing the contribution of individual species (denoted by their 6 letter acronyms) to taxonomic variation.

Cluster analysis was run on the species cover data for the purpose of grouping wetlands with similar plant community characteristics (Figure 10). This kind of breakdown can provide useful information for sampling strategies and/or experimental design, particularly when specific vegetation assemblages are sought.

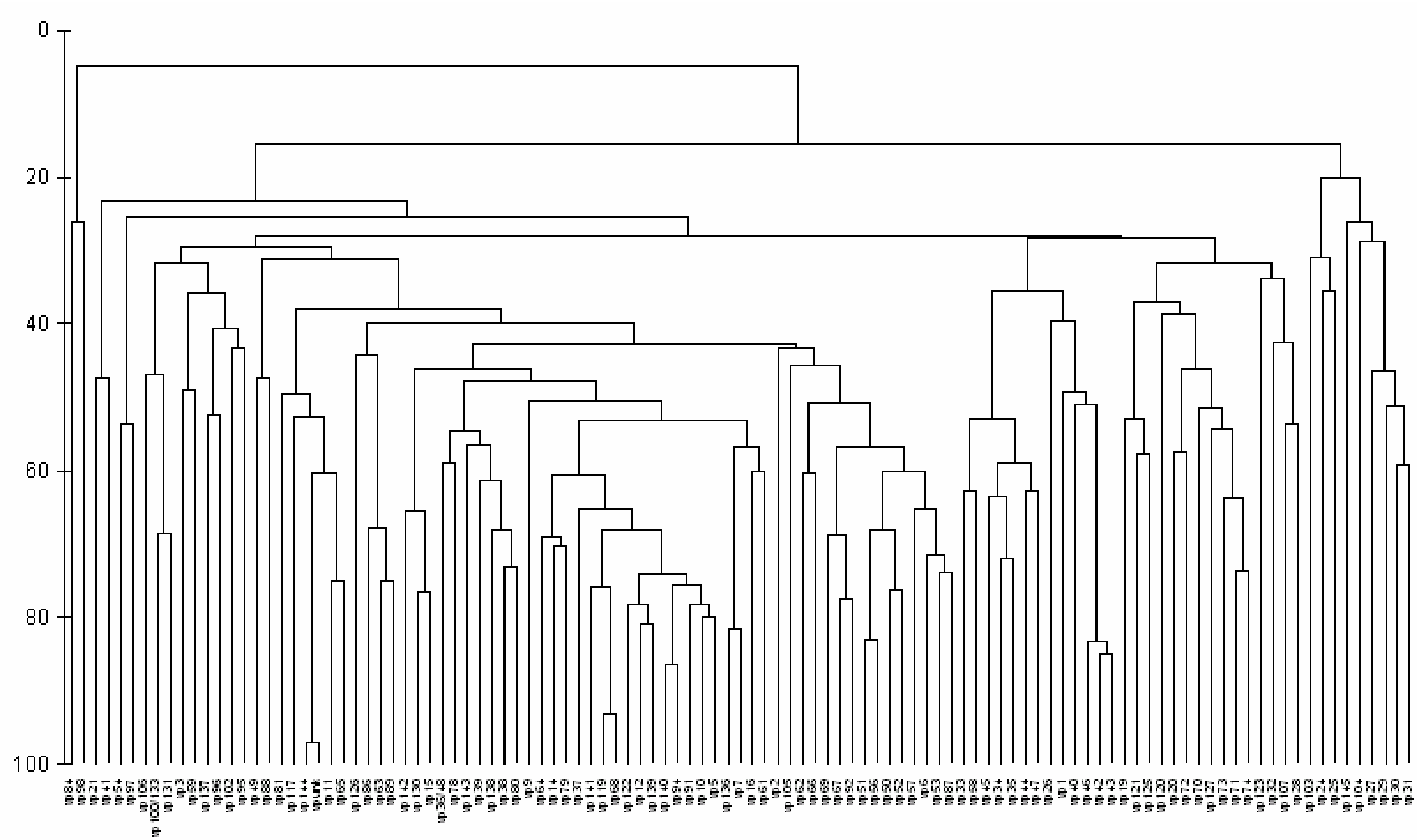

Figure 10. Cluster ordination based on Bray-Curtis distances showing similarities/dissimilarities among individual wetland sites.

When the wetlands were mapped and color-coded by their Bray-Curtis similarity values, subtle clustering patterns based on geographic location were evident. For example, the wetlands in Eastham were fairly similar to a small group of wetlands near the Cape Cod bay side of Wellfleet, yet taxonomically distinct from most other sites throughout Truro and Wellfleet.

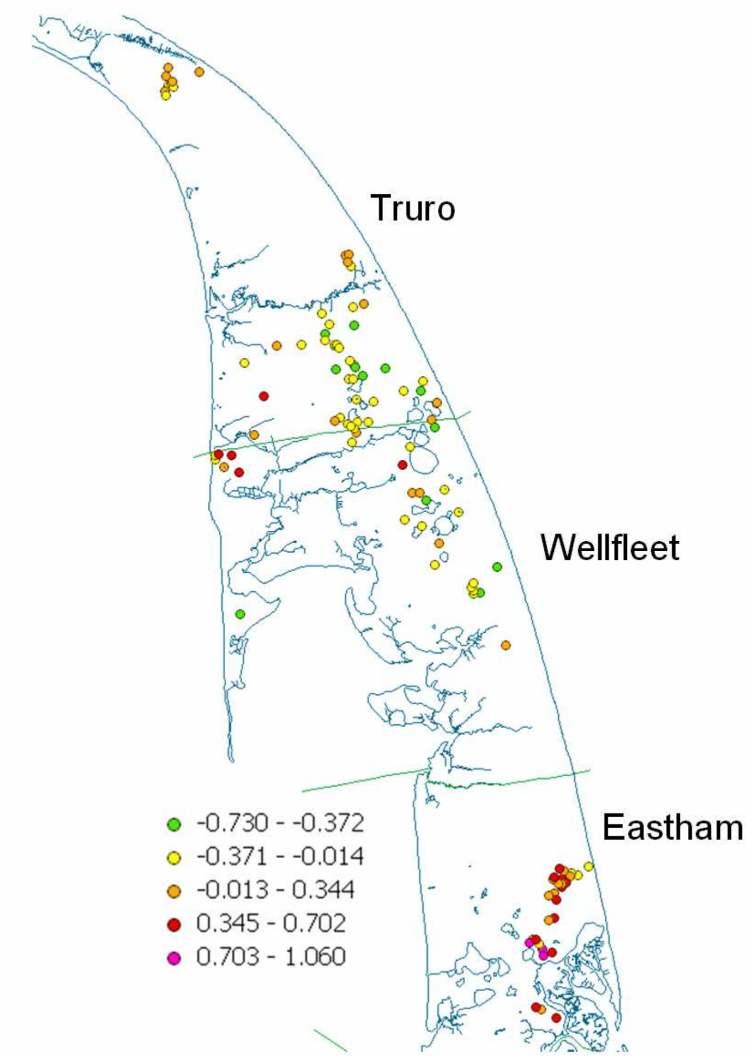

Figure 11. Map of forested vernal wetlands color-coded by Bray-Curtis distances (mean values of NMDS axes coordinates).

Structural variability among wetlands

The cover of shrubs, floating vegetation, and to a lesser extent trees accounted for the largest proportion of structural variability among wetlands (Figure 12). In general, it can be inferred that wetlands with few shrubs and abundant floating-type vegetation (bladderworts, lilies) lay at one end of the hydrologic spectrum (deep, long hydroperiod) while dense shrub wetlands are at the other (shallow, short hydroperiod).

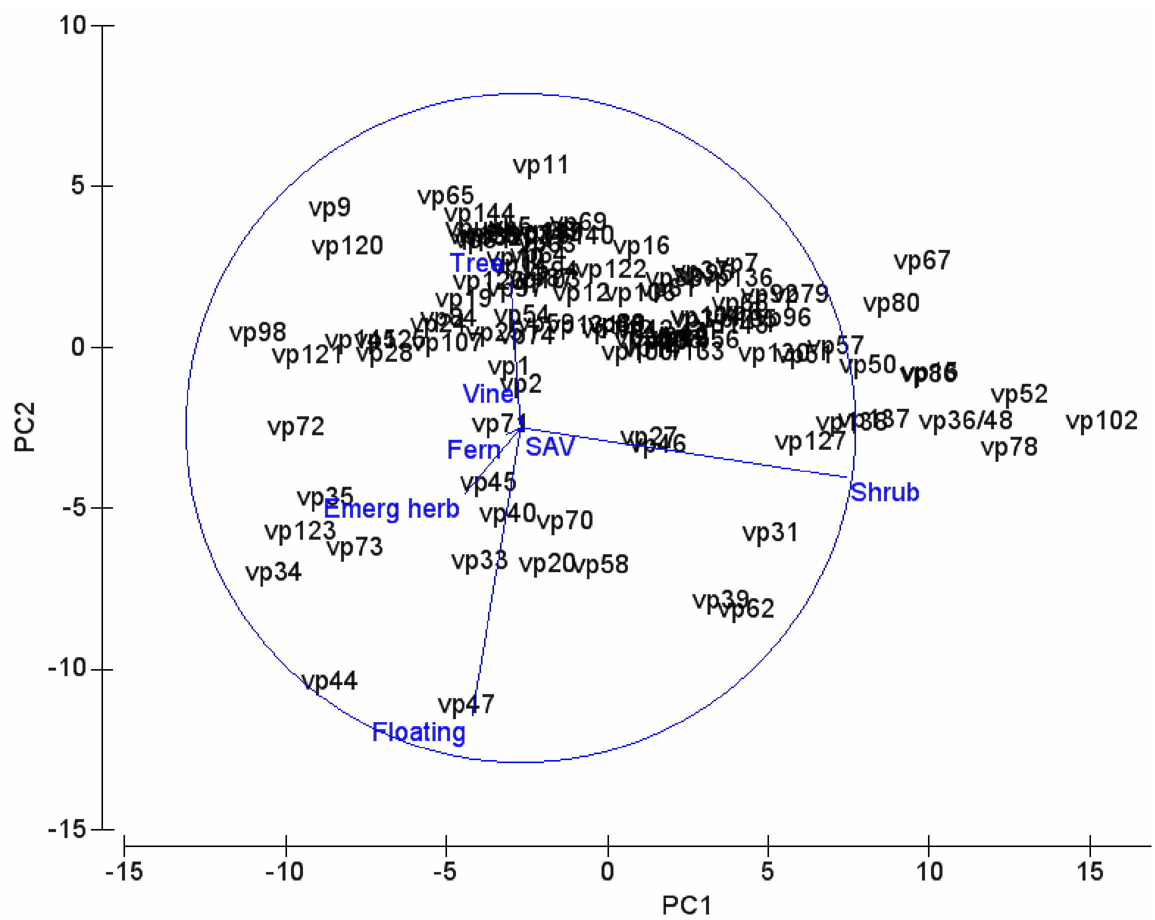

Figure 12. PCA of structural composition among vernal wetland sites.

II. Intensive subset

Comparison of 1997 vs. 2006 plant communities along permanent transects

Comparisons of taxonomic composition between 1997 and 2006 by pond (all transects pooled) showed that the communities were significantly different (Table 1). The cover of almost every species was much reduced in 2006 compared with 1997 (Table 2). The largest changes were observed in herbaceous species. In fact, 3 species present in 1997 (*Scirpus cyperinus*, *Triadenum virginicum*, and *Utricularia* sp.) were not recorded in 2006. Woody shrub species also declined although most of the changes were not statistically significant. Collectively, however, the total cover of shrub vegetation (all species pooled) did exhibit statistically significant decreases. Moreover, the total cover of every structural (trees, SAV, etc.) and functional (OBL, FACW, FAC) group was lower in 2006 than in 1997.

When the data were reduced to presence/absence, VP38 and 41 were still statistically different in 2006 than in 1997 (Table 1). However, the p-value for VP38 was much closer to the cutoff p value of 0.05 for statistical significance. Moreover, the difference between years in VP33 became insignificant. For woody species only (herbaceous excluded), significant differences were detected in only one instance for non-transformed cover data.

Table 1. ANOSIM statistics for species composition variables by pond (comparisons are between 1997 and 2006 plant communities).

All taxa	Site	Test variable	R	p	
	VP33	cover values	0.050	0.01	*
		presence/absence	0.013	0.12	ns
	VP38	cover values	0.071	0.001	*
		presence/absence	0.032	0.004	*
	VP41	cover values	0.318	0.001	*
		presence/absence	0.292	0.001	*

Woody taxa	Site	Test variable	R	p	
	VP33	cover values	0.001	0.375	ns
		presence/absence	0.003	0.28	ns
	VP38	cover values	0.007	0.039	*
		presence/absence	0.001	0.253	ns
	VP41	cover values	0.001	0.350	ns
		presence/absence	-0.001	0.548	ns

Table 2. Summed cover by species in wetland E2 in 1997 vs. 2006 and magnitude of change (%) in these values (highlighted rows are species that showed statistically significant change according to Wilcoxen signed-rank tests).

	E2				E8				E9			
Species	sumCC-97	sumCC-06	change		sumCC-97	sumCC-06	change		sumCC-97	sumCC-06	change	
Amelanchier canadensis									9	0	-9	
Calamagrostis canadensis									55	35	-20	
Cephalanthus occidentalis					15	20	5					
Chamaedaphne calyculata					89	79	-10					
Clethra alnifolia	242	224	-18		220	222	2		56	26	-30	
Decodon verticillatus	184	97	-87	*	113	132	19					
Deschampsia flexuosa	2	1	-1									
Dulichium arundinaceum					48	87	39	*	127	0	-127	*
Glyceria canadensis					9	1	-8		4	43	39	*
Ilex verticillata					33	6	-27	*				
Juncus spp.					569	248	-321	*				
Kalmia angustifolia									23	0	-23	
Lyonia ligustrina	56	39	-17		27	0	-27					
Rhododendron viscosum	27	5	-22		4	0	-4					
Nymphaea odorata					50	1	-49	*	136	102	-34	
Osmunda cinnamomea					9	5	-4					
Photinia floribunda									6	0	-6	
Potamogeton sp.									310	0	-310	*
Rhododendron viscosum					62	42	-20					
Rubus flagellaris					3	1	-2					
Saggitaria teres					2	23	21	*				
Scirpus cyperinus	2	0	-2									
Smilax rotundifolia	95	68	-27	*	137	96	-41		39	34	-5	
Triadenum virginicum	15	0	-15	*	55	52	-3					
Utricularia sp.	22	0	-22	*								
Vaccinium corymbosum	57	35	-22		115	48	-67	*	63	52	-11	
Growth Form												
Tree	0	0	0		0	0	0		9	0	-9	
Shrub	382	303	-79	*	561	417	-144	*	148	78	-70	*
Herb	201	97	-104	*	1378	796	-582	*	186	78	-108	*
Vine	95	68	-27	*	277	193	-84	*	39	34	-5	
Moss	0	0	0		0	0	0		0	0	0	
Floating	22	0	-22	*	50	1	-49	*	136	102	-34	
SAV	0	0	0		0	0	0		310	0	-310	*
Wetland indicator status												
OBL	307	137	-170	*	1160	704	-456	*	640	197	-443	*
FACW	56	39	-17		43	41	-2		61	35	-26	*
FAC	337	292	-45	*	471	414	-57		127	60	-67	*

When the mean Bray-Curtis distance values for each pond in each year were plotted, the divergence over time was obvious (Figure 13). All three wetlands shifted noticeably, with VP33 and VP38 moving in the same direction along axis 1. VP41 shifted primarily along axis 2, which can largely be attributed to a dramatic increase in *Glyceria canadensis*. The reason for this increase is unclear. However, most of the other changes are likely due to the higher water level in 2006 compared with 1997. In this regard, the mean differences in water depth (all plots pooled) between 1997 and 2006 in VP33, VP38, and VP41 were 20, 22, and 48 cm, respectively.

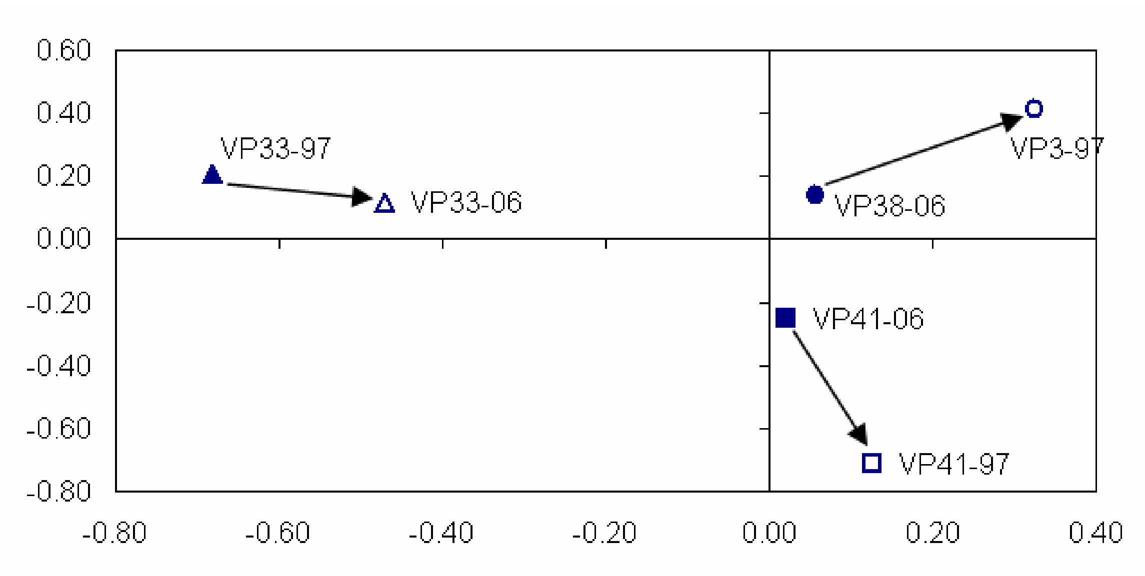

Figure 13. NMDS (centroids of Bray Curtis distances) of species composition among wetlands in 1997 vs. 2006.

Comparison of species composition among all nine IS wetlands for 2006

NMDS of the nine IS wetlands revealed a widely scattered distribution of sites with little discernible clustering, indicating that the plant communities are widely disparate (Figure 14). As such, they appear to be a good representation of the range of plant communities observed among the 109 total sites.

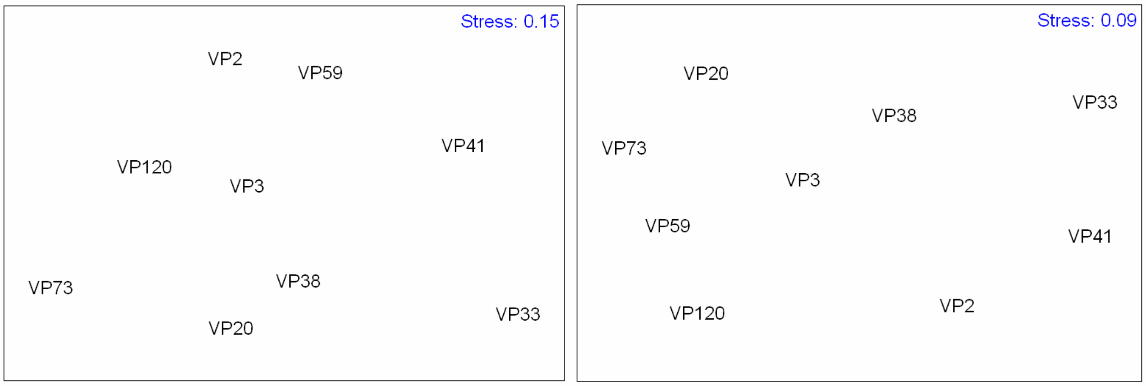

Figure 14. NMDS of cover values (left) vs. species presence/absence (right).

Water depths recorded in these wetlands reflect a broad hydrologic spectrum. For example, maximum depth ranged between 0 and 75 cm, while mean depth ranged between 0 and 98 cm (Table 3).

Table 3. Maximum and mean water depths in August along transects in IS wetlands (there was no standing water in VP 120)

Site	Max depth (cm)	Mean depth (cm)
vp120	0	0 (no surface water present at time of sampling)
vp2	55	18
vp20	70	27
vp3	17	7
vp33	98	75
vp38	66	38
vp41	52	24
vp59	51	47
vp73	56	22

In certain ways, vegetation structure reflected the differences in water depth characteristics. The proportion of floating-leaved aquatics (*Nymphaea odorata*, *Utricularia* spp.) in relation to the total cover of vegetation was positively correlated with maximum depth (R^2 = 0.46), while tree cover was negatively correlated (R^2=0.42). Variables related to wetland indicator status did not show any strong correlation with max or mean water depths.

Discussion

The work described in this report provides baseline data on the plant communities of forested vernal wetlands within Cape Cod National Seashore. As a result of this effort, species lists are now available for 109 forested vernal wetlands. In addition, baseline data for an additional 6 sites added to the intensive subset of wetlands with permanent vegetation transects was collected. The total set of 9 wetlands will be repeatedly monitored over the long-term. A frequency of at least once every 8-10 years is recommended so that changes in vegetation communities (particularly the woody component) integrate conditions over long time periods. Analysis of species composition among all sites and the mapping of similarity indices provide a tool for researchers to focus their efforts on particular groups of wetlands or individual sites with specific characteristics. Other notable results of this study include the discovery of a state-listed rare species and a surprising absence of exotic taxa in the vast majority of wetlands. The latter is significant from the standpoint of resource value in that CACO sites can be considered pristine examples of forested vernal wetland systems.

In the analysis of plant community change over the last ~ 10 yrs., an interesting trend emerged. There was a significant reduction in overall shrub cover in all of the original IS wetlands (VP33, 38, and 41) from 1997 to 2006. With only two data points (i.e., 1997 and 2006), it is difficult to know whether the declining trend in shrub cover is real or simply an artifact of insufficient data. In addition, wetland shrubs have many adaptations to flooding and often exhibit physiological and anatomical changes rather than mortality (Pereira and Kozlowski 1977, Kozlowski 1985, 1997, 2002). As such, rapid responses to water level fluctuations do not occur anywhere near the extent to which they do in herbaceous taxa. However, there have been a number of years in the very recent past during which water levels have been extremely high. Moreover, rainfall and water level data from a network of groundwater wells throughout Eastham and Wellfleet show distinct positive trends since between 1999 and 2006 (Figure 15, 16). The mean elevation for the set of wells depicted below was 10.7 ft. in 1999 and 11.8 ft. in 2006. Thus, it is within the realm of possibility that woody shrubs have declined as a result of prolonged flooding stress.

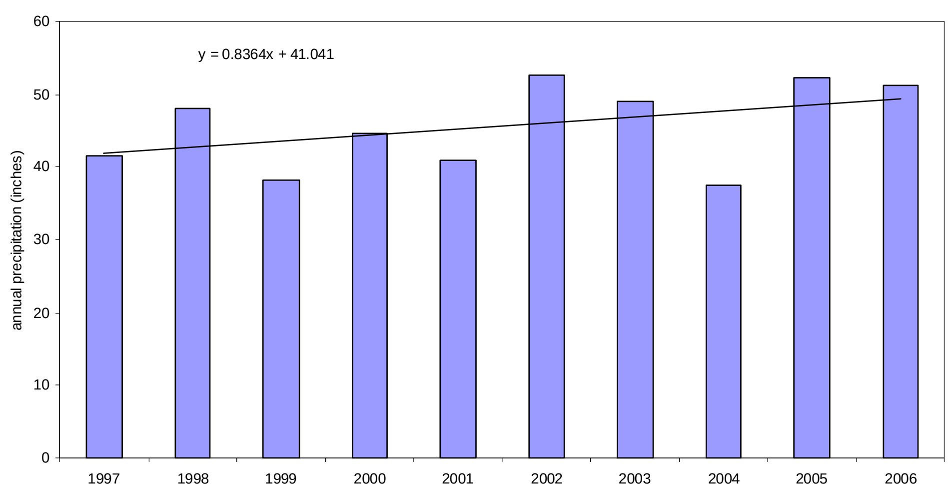

Figure 15. Trend of increasing in annual precipitation (Eastham) from 1997 to 2006.

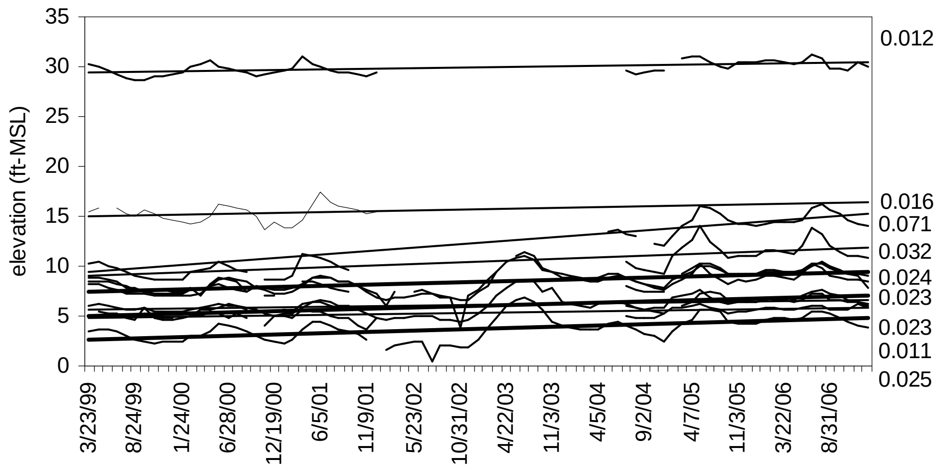

Figure 16. Trend of increasing groundwater elevations for 7 wells in Eastham from 1999 to 2006 (slope coefficients are listed along the right y axis).

Roman and Barrett 2004 reported similar findings in their analysis of vegetation changes between 1997 (a wet year) and 1999 (a dry year). For the wetland VP33 (also known as E2), which is dominated by *Clethra alnifolia*, they found no meaningful change noted in floristic composition between the wet and dry sample year. In VP38 (E8), vegetation changes were also minor, but somewhat more pronounced than in the former. The most dramatic changes occurred in the herbaceous vegetation in VP33 (E9). On all transects, there was a dramatic change from a floating-leaved/SAV community (e.g., *Potomogeton* sp. and *Nymphaea odorata*) to an emergent wet meadow community (e.g., *Calamagrostis canadensis*, *Dulichium arundinaceum*, *Hypericum mutilum*). Roman and Barret (2004) also observed that upland vegetation shifted downslope (i.e., toward the wetland) approximately 1-2 m under dry conditions. Wetland shrubs similarly tended to migrate to lower elevations in the dry year. However, it is likely that while shrubs can become established quickly at lower elevations during a dry year, it takes several years of high water to kill them since, as mentioned above, they generally have a number of physiological and anatomical adaptations to withstand such conditions.

Another important finding of Roman and Barrett is that of all the environmental variables examined, including porewater nutrients, sediment properties, only water depth, or elevation, had a significant influence on plant distributions, accounting for 60% of the variance.

Problems encountered and recommendations for future monitoring

Some of the wetlands were so large and densely-vegetated that it was very difficult to explore the entire area. As a result, a few species may have not been recorded at these sites. Where these conditions occurred, however, it was because shrub and/or trees were very dense. In these circumstances there is generally very little growing in the understory. As such, it is unlikely that large number of species were missed, although there is no absolute certainty in this.

Because the 109 sites were surveyed over a period of approximately 8 weeks, some of the taxonomic variability in herbaceous vegetation is likely due to differences in emergence and growth throughout the summer. Identifications made later in the season tend be more reliable than the those made earlier in the season due to 1) increased experience level of the observers and 2) the more advanced stages of development in the plants themselves. In addition, the date that a wetland is surveyed during the growing season is a key factor in which herbaceous emergent and SAV taxa are observed, especially in years where water levels are abnormally high and emergence is delayed as a result (or vice versa). Even if vegetation is surveyed at the exact same time of year, variation in water level between years can yield dramatically different results in the abundance of these groups of plants. It is difficult to envision how to overcome this problem since it is logistically impossible to visit so many sites within a short window of time. Fortunately, this does not present a problem for woody species, which persist throughout the year and are the dominant form in the majority of wetlands. Moreover, woody vegetation, however, responds in a much slower fashion – particularly with respect to high water conditions.

Given the above difficulties with assessment and analysis, herbaceous data is probably better handled by transforming cover values to presence/absence. By doing this, large differences in abundance will not influence the results, except on occasion where a species totally fails to emerge at all due to extremely high or low water levels. Granted, the sensitivity for detecting real trends of vegetation change above and beyond annual variability is compromised. However, this may be a necessary compromise in order to reduce the effects of natural, short-term fluctuations. In addition, the period of survey for the entire group of forested vernal wetlands (all sites) should be changed from June-August to July-September if possible. That way early-season variability in abundance, which is substantially higher than mid- or late-season, will be much reduced. This is not problem for the IS wetlands since the window of time is small enough to complete all data collection within 2 weeks, at the tail end of the growing season (August) when emergence is complete and biomass is near or at its peak.

In general, comparisons of plant communities should focus on the dynamics of woody species, with one exception. Mature trees that are rooted well outside the wetland but have an overhanging canopy should be excluded because the extent of area cover can be influenced by factors completely unrelated to the wetland. For example, cover can vary substantially if large branches or entire trees fall over during a storm, or if the tree simply dies. Over the longer term, maturation of upland trees will result in a progressive increase in cover that has little or nothing to do with wetland processes. Limiting the analysis to wetland tree species only (e.g., *Acer rubrum, Nyssa sylvatica*) can eliminate this source of variability.

Conclusions

Forested vernal wetlands were mapped and their plant communities inventoried, providing a baseline dataset on species and vegetation structure at both previously known and new sites. These wetlands exhibit substantial variability in size, structure, and species composition, although a number of woody shrub species are almost ubiquitous. In addition, the wetlands are almost complete devoid of problem exotic taxa.

Temporal change analysis was conducted on three wetlands that were originally characterized in 1997. The analyses revealed dramatic differences in community composition between 1997 and 2006. However, hydrologic differences between the two study years confounds our ability to interpret such changes, particularly with respect to herbaceous species. Thus, it is recommended that the next survey be done during a year that is closer to the baseline year (1997) in terms of wetland water depths during the growing season, although predicting this several months ahead of the field season could be extremely difficult. It is more likely that many years of data will be needed to decipher the nature of change in these systems and their future trajectories.

Acknowledgements

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Appendix I. Coordinates for VP sites.

Site number	Easting	Northing
vp001	420300	4634036
vp002	418749	4640383
vp003	416600	4644345
vp005	416157	4645810
vp006	416498	4647574
vp007	415173	4647044
vp009	415968	4645303
vp010	414590	4645931
vp011	414469	4646416
vp012	414257	4646597
vp014	414098	4646514
vp015	411905	4646136
vp016	411107	4645242
vp019	412179	4647165
vp020	412541	4648540
vp021	419726	4630490
vp024	419587	4630529
vp025	420131	4630260
vp026	420028	4632030
vp027	419756	4632112
vp028	420077	4632958
vp029	419667	4632272
vp030	419411	4632299
vp031	419592	4632369
vp032	419930	4632906
vp033	420081	4633633
vp034	420131	4633470
vp035	419918	4633592
vp036	420999	4634356
vp037	420734	4634132
vp038	420530	4634193
vp039	420525	4634098
vp040	420403	4633932
vp041	420281	4633805
vp042	420267	4633898
vp043	420199	4633914
vp044	420059	4634016
vp045	420072	4634079
vp046	420335	4634252
vp047	420224	4634304
vp049	418065	4641830
vp050	417873	4641793
vp051	417877	4641882
vp052	417821	4641961
vp053	417887	4642088
vp054	418537	4642528
vp056	416838	4642575
vp057	417483	4644025
vp058	416953	4643175
vp059	416226	4644537
vp061	415018	4646475
vp062	416437	4647314
vp063	415994	4647314
vp064	416883	4647009

	Site number	Easting	Northing
55	vp065	416833	4646328
56	vp066	415478	4647939
57	vp067	414871	4647725
58	vp068	414597	4647655
59	vp069	414528	4648152
60	vp070	414125	4648563
61	vp071	414107	4648568
62	vp072	414162	4648548
63	vp073	414157	4648575
64	vp074	414241	4648497
65	vp078	414544	4650715
66	vp079	414414	4651020
67	vp080	409716	4655599
68	vp081	410413	4656008
69	vp084	419791	4631947
70	vp086	416493	4643629
71	vp087	416017	4643825
72	vp088	416418	4644553
73	vp089	417094	4644639
74	vp091	414683	4647095
75	vp092	414668	4647974
76	vp094	414498	4651023
77	vp095	414462	4650839
78	vp096	409696	4655736
79	vp097	411545	4641245
80	vp098	411520	4645098
81	vp100	411305	4645578
82	vp102	410856	4645440
83	vp103	410865	4645561
84	vp104	410944	4645589
85	vp105	414134	4647910
86	vp106	411655	4648085
87	vp107	413208	4648593
88	vp117	416749	4646542
89	vp119	414483	4647633
90	vp120	414629	4649114
91	vp121	414904	4649694
92	vp122	414599	4649590
93	vp123	413774	4649439
94	vp125	413951	4649127
95	vp126	413858	4648879
96	vp127	413847	4648688
97	vp130	409530	4655884
98	vp131	409581	4655626
99	vp136	414625	4648027
100	vp137	409490	4655481
101	vp138	414739	4646486
102	vp139	414687	4646175
103	vp140	414645	4646310
104	vp141	414563	4646354
105	vp142	409569	4656124
106	vp143	409515	4655374
107	vp144	409655	4655676
108	vp145	419480	4632369
109	vp146	not found	not found

Appendix II. List of species and their cover/frequency observed in 109 forested vernal wetlands (2006).

Species	Sum Cover	Frequency	Species	Sum Cover	Frequency
Vaccinium corymbosum	375	0.87	*Juncus pelocarpus*	6	0.03
Sphagnum sp.	207	0.63	*Leersia oryzoides*	6	0.03
Smilax rotundifolia	192	0.67	*Prunus serotina*	6	0.03
Acer rubrum	177	0.50	*Amelanchier canadensis*	5	0.03
Clethra alnifolia	172	0.42	*Betula papyrifera*	5	0.03
Chamaedaphne calyculata	120	0.29	*Potamogeton sp.*	5	0.01
Decodon verticillatus	107	0.32	*Achilea millefolium*	4	0.02
Lyonia ligustrina	105	0.39	*Agrostis hyemalis*	4	0.03
Osmunda cinnamomea	97	0.50	*Juncus acuminatus*	4	0.03
Scirpus cyperinus	86	0.39	*Juncus canadensis*	4	0.01
Viburnum dentatum	72	0.24	*Lysimachia terrestris*	4	0.03
Ilex glabra	68	0.25	*Salix cinerea*	4	0.03
Juncus effusus	63	0.34	*Solanum dulcamara*	4	0.02
Utricularia sp.	58	0.18	*Vaccinium angustifolium*	4	0.02
Calamagrostis canadensis	57	0.17	*Eleocharis sp.*	3	0.02
Nyssa sylvatica	49	0.17	*Hypericum perforatum*	3	0.02
Spiraea tomentosa	44	0.17	*Panicum capillare*	3	0.01
Kalmia angustifolia	43	0.19	*Phragmites australis*	3	0.03
Glyceria canadensis	38	0.13	*Sium suave*	3	0.01
Spiraea alba	35	0.10	*Bidens connata*	2	0.02
Nymphaea odorata	32	0.12	*Carex scoparia*	2	0.02
Toxicodendron radicans	29	0.08	*Cicuta maculata*	2	0.01
Cephalanthus occidentalis	28	0.06	*Elaeagnus umbellata*	2	0.01
Thelypteris palustris	28	0.15	*Eleocharis tenuis*	2	0.01
Viburnum nudum	27	0.13	*Euthamia graminifolia*	2	0.01
Solidago rugosa	26	0.08	*Ludwigia palustris*	2	0.01
Triadenum virginicum	24	0.17	*Nuphar lutea ssp. variegata*	2	0.02
Vitis labrusca	23	0.07	*Dichanthelium clandestinum*	2	0.01
Onoclea sensibilis	19	0.09	*Parthenocissus quinquefolia*	2	0.01
Photinia sp.	19	0.09	*Rhus capallina*	2	0.01
Fragaria virginiana	17	0.04	*Rhynchospora alba*	2	0.01
Dryopteris cristata	16	0.09	*Schoenoplectus pungens*	2	0.01
Dulichium arundinaceum	16	0.07	*Carex canescens*	1	0.01
Holcus lanatus	16	0.06	*Carex hormathodes*	1	0.01
Pinus rigida	15	0.07	*Carex longii*	1	0.01
Typha angustifolia	15	0.04	*Chamaecyparis thyoides*	1	0.01
Vaccinium macrocarpon	15	0.07	*Drosera intermedia*	1	0.01
Lemna minor	12	0.04	*Eleocharis palustris*	1	0.01
Osmunda regalis	12	0.11	*Juncus sp*	1	0.01
Carex sp.	11	0.06	*Justicia americana*	1	0.01
Myrica pensylvanica	11	0.06	*Lycopus sp*	1	0.01
Carex lurida	10	0.06	*Lycopus virginicus*	1	0.01
Ilex laevigata	10	0.05	*Lythrum salicaria*	1	0.01
Rosa palustris	10	0.05	*Photinia melanocarpa*	1	0.01
Utricularia gibba	10	0.02	*Photinia floribunda*	1	0.01
Woodwardia virginica	10	0.04	*Populus grandidentata*	1	0.01
Betula populifolia	8	0.07	*Potamogeton epihydrus*	1	0.01
Parthenocissus vitacea	8	0.03	*Rosa multiflora*	1	0.01
Polygonum hydropiper	8	0.02	*Salix nigra*	1	0.01
Ceratophyllum demersum	7	0.03	*Typha latifolia*	1	0.01
Rubus flagellaris	7	0.03	*Utricularia cornuta*	1	0.01
Salix sp.	7	0.05	*Verbascum thapsus*	1	0.01

Appendix III. Intensive subset wetland locations.

Site	Easting	Northing
VP2	418749	4640383
VP20	412541	4648540
VP3	416600	4644345
VP33	420081	4633633
VP38	420530	4634193
VP41	420281	4633805
VP59	416226	4644537
VP73	414157	4648575
VP120	414629	4649114

Appendix IV. Correspondence between new and original site names.

Site ID	corresponding name (Cook, Portnoy)
vp1	E04
vp2	W18
vp3	W10
vp4	HRUM
vp5	W05
vp6	T08
vp7	T10
vp8	Portnoy's Bog
vp9	W06
vp10	W03
vp11	T16
vp12	T14
vp13	W02 (Duck Harbor)
vp14	T15
vp15	T17
vp16	W01
vp17	W25
vp18	T39
vp19	T38
vp20	T01 (Holsberry Rd)
vp21	E26
vp22	E15 (Red Maple Swamp)
vp23	E25
vp24	E27
vp25	E12
vp26	E20
vp27	E19
vp28	E21
vp29	E18
vp30	E24 (Buttonbush Pond)
vp31	E17
vp32	E22 (Turtle Pond)
vp33	E09
vp34	E10
vp35	E01
vp36	E16
vp37	E08E
vp38	E08N
vp39	E08
vp40	E03

Site ID	corresponding name (Cook, Portnoy)
vp41	E02
vp42	E11E
vp43	E11
vp44	E05A
vp45	E05
vp46	E07
vp47	E06
vp49	W15
vp50	W22
vp51	W23
vp52	W16
vp53	W24
vp54	W14
vp55	W09
vp56	W13
vp57	W11
vp58	W21
vp59	W08
vp60	HRUB
vp61	T12
vp62	T28 (bog N of Round Pnd)
vp63	T09
vp64	T11
vp65	W04
vp68	T05
vp69	T03
vp70	T02E
vp71	T02F
vp72	T02B
vp73	T02
vp74	T02D
vp75	Ballston Marsh
vp77	T33 Pamet Bog-West
vp78	T22
vp79	T23
vp80	T20
vp81	T45
vp94	T23E
vp95	T46
vp96	T20NW
vp102	W27