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Philadelphia, Pennsylvania



Dune Slack Wetlands Vegetation Monitoring, Cape Cod National Seashore, 2009

Technical Report NPS/NER/NRTR—2010/150



ON THE COVER

Dune slack wetland in the Province Lands; photo by Jesse Wheeler (2009).

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U.S. Department of the Interior
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Northeast Region
Philadelphia, Pennsylvania

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Executive Summary

During 2003–2004, a study was conducted to map and inventory interdunal vernal wetlands (dune slacks) across the Province Lands region of Cape Cod National Seashore. A total of 336 sites were found scattered throughout the entire expanse of the dune system, from southwest Provincetown to Truro (Smith et al. 2008).

In 2009, using LIDAR (Light Detection and Ranging) elevations acquired in 2005, more potential dune slack wetlands were identified (based on elevations likely to seasonally intersect with the water table). These sites were then investigated to confirm whether wetland vegetation was present or not. If the former, the vegetation composition and structure were surveyed using visual estimates of cover (as in 2003). In addition to this general survey, an intensively monitored subset (IS) of fifteen wetlands (first established in 2003) were re-surveyed. An additional 11 wetlands were randomly selected, setup with permanent transects, and surveyed in order to expand the number of IS sites from 15 to 26.

Significant findings

- We mapped and inventoried 178 new wetlands. Their general structure ranged from 100% trees and shrubs to 100% graminoids/forbs. A total of 65 wetland plant species were found. Of these species, 62 were common to the 2003/2004 survey, while three (*Rubus idaeus* [American red raspberry], *Salix sericea* [silky willow], and *Polygonum hidropiper* [marshpepper knotweed]) had not been recorded previously. The most common species were *Myrica pensylvanica* (northern bayberry), *Vaccinium macrocarpon* (cranberry), *Vaccinium corymbosum* (highbush blueberry), *Kalmia angustifolia* (sheep laurel), and *Juncus greenei* (Greene's rush). No federal- or state-listed rare species were found.
- Analysis of vegetation change between 2004 and 2009 in the 15 original IS sites revealed clear evidence of succession, with woody species increasing in cover and herbaceous species diminishing. Unfortunately, the exotic *Phragmites australis* (common reed) also increased, particularly at one site that experiences occasional flooding by salt water.
- Using water level loggers, we were able to acquire hydrologic data every 30 minutes within 10 wetlands from May 4 to August 15. This kind of high resolution water level data has never before been collected in any of these wetlands. This information revealed how complex hydrology is within these sites across the Province Lands dunes region.
- Through this effort as a whole, we were able to expand the scope of long-term monitoring, add to our inventory of known wetlands, and collect data that allowed for change analysis and will provide critical information for the development of an official protocol, including statistical power analysis.

Introduction

The following is excerpted from the previous dune slack wetland technical report (Smith et al. 2010). It is included in this report to provide some background on this landscape and ecosystem type.

“At the northern tip of Cape Cod, spanning approximately 1,800 hectares (ha) within the Cape Cod National Seashore (CACO), lies a vast system of dunes and interdunal wetlands known as the Province Lands. This part of the Cape Cod peninsula began forming ca. 18,000 years ago as longshore currents transported eroded materials from Atlantic-side beaches in a northward direction. Concurrently, wind carried sand grains inland and the landform gradually assumed its characteristic shape.

Although once covered by mature forest, European settlers engaged in clear cutting and grazing practices that by the early 1800s had eliminated much of this community and destabilized the ground surface. The legacy of these activities is a sparsely vegetated landscape of shifting dunes and interdunal depressions. The latter are formed by the scouring action of wind, which can lower ground elevations to the point that they intersect the groundwater table for part of the year. These seasonally flooded wetlands, also known as dune slacks, develop distinctive hydrophytic plant communities and are virtual oases of biodiversity in an otherwise desert-like environment. Dune slacks are one of the last refuges on the outer Cape for species such as the insectivorous sundews (*Drosera* spp.) and orchids (*Calapogon tuberosus*, *Pogonia ophioglossoides*). From a wildlife perspective, they are critical habitat for the reproduction and survival of numerous invertebrates and amphibians such as the spadefoot (*Scaphiopus holbrookii*) and Fowler’s toad (*Bufo fowleri*). For larger mammals and birds, dune slacks are an important source of drinking water, succulent forage, and prey. Finally, these areas are very popular with visitors, as they possess aesthetic qualities that are a valued component of the Province Lands scenery.”

The main objectives of the 2009 monitoring efforts were to: 1) map and inventory new dune slack wetland sites that were identified using 2005 LIDAR data; 2) re-survey the 15 original sites that were selected in 2003 for more intensive long-term vegetation monitoring of vegetation change (IS sites); 3) increase the number of these intensively monitored wetlands; and 4) reassess and refine protocol methods.

Methods

Mapping and Inventory

Based on elevation and proximity to known wetlands, additional sites were identified using LIDAR data acquired in April 2005. Using ArcGIS ver. 9.3, each potential wetland was identified with a point symbol. The coordinates of these points were then exported and uploaded into a Garmin (GPSmap 76S) GPS unit. During the summer of 2009, the two-person field crew ground-truthed these sites. The characterization of sites as wetlands was based on the presence of hydrophytic taxa with wetland indicator designations (USACOE 1987) of facultative (FAC), facultative-wet (FACW), or obligate (OBL). When a potential site was confirmed as a wetland, the following data were collected:

- Percent canopy cover of trees vs. shrubs - estimated to the nearest 5%.
- Height of the tallest trees (estimated occularly to the nearest meter)
- Cover by species - estimated visually based on a Braun-Blanquet cover class value (0=0%, 1=<1%, 2=1–5%, 3=6–25%, 4=26–50%, 5=51–75%, 6=76–100%)

Intensively Monitored Subset (IS) Sites

The original 15 IS wetlands were re-surveyed in 2009 by the same methods described in Smith et al. (2005). An additional 11 sites were randomly selected from the total inventory of wetlands, set up with five permanent monitoring transects, and surveyed in the same manner as was done in 2003 (see Figure 1).

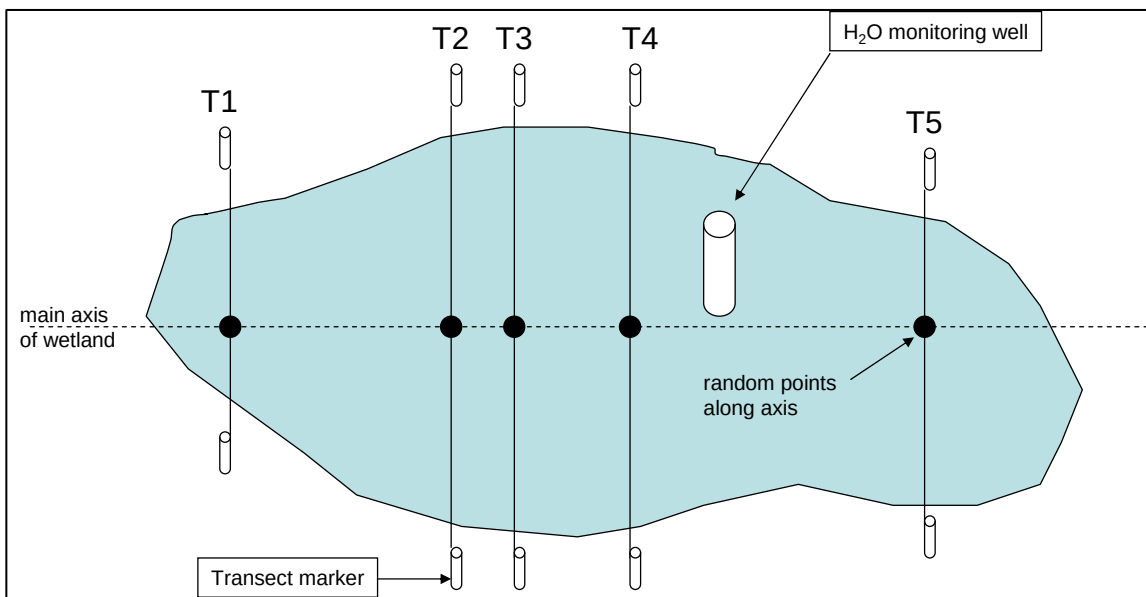


Figure 1. Diagram of an Intensively Monitored Subset site with transect layout. Transect markers are PVC pipes with GPS coordinates.

Data Collection

Porewater quality - Porewater was collected between June 26 and July 6, 2009 from the mid-points of the three middle vegetation transects (i.e., three samples per wetland in both original and new IS sites). Samples were obtained by inserting a stainless steel probe into the sediment to a depth of 10 cm and then drawing 30 ml of porewater into a syringe fitted over the top of the probe. Samples were then tested for pH, conductivity, and salinity using a portable field unit (Oakton Multi-Parameter PCSTestrTM35).

Soil properties - Three soil cores were extracted using a 4-cm diameter butyrate coring tube from each IS wetland (both original and new sites). After extraction, the thickness of the organic matter layer (quite distinguishable from the subjacent inorganic sand layer by color) was measured to the nearest cm.

Vegetation - Five permanent vegetation transects were established at each new IS site by running a field tape along the main “axis” of the wetland (see Figure 1). At five randomly chosen points along that axis, transects were laid out perpendicularly through the wetland from upland edge to upland edge. PVC pipes (0.5-inch diameter) were then inserted into the ground to demarcate the end points of each transect (a few meters beyond the edge of the wetland) and GPSed with a Garmin 76S.

To assess vegetation cover along each transect in each original and newly established IS wetland, a field tape was stretched out between the two transect end points. Vegetation was recorded at 0.5-m intervals along the line by point intercept (the rod was actually placed 0.5 m to one side of the line to avoid trampled vegetation caused by running out the field tape). All species making contact with a vertical rod placed at each point were recorded and percent abundances were then calculated from counts of species “hits.” Transects were surveyed in August. In addition, species abundances across the entire wetland were recorded as cover class ranks based on the Braun-Blanquet scale.

Photographic documentation - digital photographs were taken from a good vantage point at each wetland so that the general characteristics of the site could be documented. This inventory of photos provides useful, albeit qualitative, information about the state of the wetland at that particular time.

Data Analysis

Age classification of new IS sites - Age analysis of the new IS sites was conducted using aerial photography (1947, 1960, 1987, 1994, 2001, 2005, 2007) and methods described in Smith et al. (2008).

Statistical tests - Statistical analyses were conducted using Primer-5 (Plymouth Laboratories, UK) and XL-Stat ver. 7.5 (AddinsoftTM) software. Multidimensional scaling (MDS), Principle Components Analysis (PCA), and SIMPER analysis were used to illustrate variability in community composition and the key species contributing to similarity/dissimilarity among sites. Analysis of Similarity (ANOSIM) was run on community composition between the 2003/2004 and 2009 surveys of the original IS wetlands (n=15). Regression analysis (Excel 2007) was used to examine the relationship between vegetation structure and soil organic matter thickness.

Results

Mapping and Inventory

One hundred seventy-eight new sites were confirmed as dune slack wetlands in 2009 (Figure 2). Interestingly, a few sites that theoretically should be wetlands (based on LIDAR elevation data) did not have any wetland indicator vegetation (pink dots). The reason for this is unclear. It may be that the LIDAR data are slightly inaccurate in places or that the hydrology of this region is more complicated than we currently understand it to be. This discrepancy requires further investigation to be clearly understood. Notwithstanding, these are sites that could eventually develop into dune slack wetlands with a long-term rise in the groundwater table forced by sea level rise.

In total, there are 524 dune slack wetlands now mapped and inventoried as a result of the 2003/2004 and 2009 surveys (Figure 3). The wetlands occur throughout the entire extent of the Provincetown and Truro dunes.

Vegetation Species Composition

Among the 178 new sites, 65 wetland vascular plant taxa (i.e., species with wetland indicator designations of obligate [OBL], facultative wetland [FACW], or facultative [FAC]) and 1 genus of moss (*Sphagnum* spp.) were found (Table 1). Of these species, 62 were common to the 2003/2004 survey, while only three (*Rubus idaeus*, *Salix sericea*, *Polygonum hidropiper*) had not been recorded previously. The number of species per wetland ranged between 1 and 28 with an average of 10. These numbers are quite similar to the previous mapping (min=2, max = 35, average = 11 spp./wetland).

Sorted by average cover class values, the most common wetland species within the newly mapped wetlands were *Myrica pensylvanica* (northern bayberry), *Vaccinium macrocarpon* (cranberry), *Vaccinium corymbosum* (highbush blueberry), *Kalmia angustifolia* (sheep laurel), and *Juncus greenei* (Greene's rush). Similar to 2004, *Pinus rigida* (pitch-pine) was by far the most abundant non-wetland (FACU designation) species. These species were also the most common in the 338 wetlands inventoried in 2003–2004 (Smith et al. 2008). *Phragmites australis* was found in five of the new sites. *Lythrum salicaria* was not detected in any of the new sites, nor were any state-listed rare species.

A MDS scatterplot (based on species cover scores for each site) of the new dune slack wetlands shows considerable overlap in terms of species composition (Figure 4). Although some sites show some separation from the central cluster, there are no individual or groups of outliers that are vastly distant from it.

Eigenvector values from PCA analysis of all new sites show that *Juncus* spp (primarily *J. greenei*), *Kalmia angustifolia*, *Toxicodendron radicans*, *V. corymbosum*, *Vaccinium macrocarpon*, and *Myrica pensylvanica* accounted for the largest amounts of variation among sites (Figure 5).



Figure 2. Map of new dune slack wetland sites (green circles) confirmed by ground-truthing during 2009. Pink circles represent potential sites identified through LIDAR that were not wetlands.



Figure 3. Map of all dune slack wetlands mapped and surveyed in 2003/2004 and 2009.

Table 1. List of wetland plant taxa (OBL, FACW, and FAC) sorted by their summed cover score values in new wetland sites mapped and inventoried in 2009.

Species	Sum CC	Freq	WETIND	Gform	Species	Sum CC	Freq	WETIND	Gform
<i>Myrica pensylvanica</i>	430	84%	FAC	Shrub	<i>Clethra alnifolia</i>	10	2%	FAC+	Shrub
<i>Vaccinium macrocarpon</i>	420	71%	OBL	Subshrub	<i>Ilex glabra</i>	9	2%	FACW-	Shrub
<i>Vaccinium corymbosum</i>	312	67%	OBL	Shrub	<i>Nyssa sylvatica</i>	9	4%	FAC	Tree
<i>Kalmia angustifolia</i>	306	53%	FAC	Shrub	<i>Pogonia ophioglossoides</i>	9	3%	OBL	Forb
<i>Juncus greenei</i>	208	42%	FAC	Rush	<i>Rhynchospora capitellata</i>	9	3%	OBL	Sedge
<i>Toxicodendron radicans</i>	195	42%	FAC	Shrub	<i>Lycopodiella inundata</i>	8	3%	OBL	Moss
<i>Scirpus cyperinus</i>	179	60%	FAC	Sedge	<i>Phragmites australis</i>	8	3%	OBL	Grass
<i>Ilex verticillata</i>	122	31%	FACW+	Shrub	<i>Solidago rugosa</i>	7	2%	FAC	Forb
<i>Photinia melanocarpa</i>	103	25%	FAC	Shrub	<i>Viburnum nudum</i>	7	3%	OBL	Shrub
<i>Dichanthelium acuminatum</i>	88	30%	OBL	Grass	<i>Juncus sp.</i>	6	3%		Rush
<i>Juncus canadensis</i>	85	31%	OBL	Rush	<i>Lyonia ligustrina</i>	6	2%	FACW	Shrub
<i>Salix cinerea</i>	64	16%	FAC	Tree	<i>Symp sp.</i>	6	2%		Forb
<i>Amelanchier canadensis</i>	55	22%	FAC	Tree	<i>Juncus acuminatus</i>	5	3%	OBL	Rush
<i>Smilax rotundifolia</i>	54	21%	FAC	Vine	<i>Polygonum hydropiper</i>	5	1%	OBL	Forb
<i>Rhododendron viscosum</i>	52	13%	OBL	Shrub	<i>Salix sp.</i>	5	2%		Shrub
<i>Drosera intermedia</i>	49	13%	OBL	Forb	<i>Eupatorium dubium</i>	4	2%	FACW	Forb
<i>Euthamia graminifolia</i>	46	19%	FAC	Forb	<i>Juncus pelocarpus</i>	4	2%	OBL	Rush
<i>Viburnum dentatum</i>	46	16%	FAC	Shrub	<i>Symphiotrichum novi-belgii</i>	4	1%	FACW	Forb
<i>Rubus hispida</i>	45	11%	FACW	Vine	<i>Xyris difformis</i>	4	2%	OBL	Forb
<i>Solidago sempervirens</i>	45	20%	FACW	Forb	<i>Alnus serrulata</i>	3	1%	OBL	Shrub
<i>Spiraea alba</i>	43	15%	FACW	Forb	<i>Carex nigra</i>	3	1%	FACW+	Sedge
<i>Osmunda cinnamomea</i>	39	16%	FACW	Fern	<i>Chamaedaphne calyculata</i>	3	1%	OBL	Shrub
<i>Panicum virgatum</i>	36	12%	FAC	Grass	<i>Eriophorum virginicum</i>	3	1%	OBL	Sedge
<i>Betula populifolia</i>	27	11%	FACW	Tree	<i>Juncus effusus</i>	3	1%	FACW+	Rush
<i>Carex scoparia</i>	26	10%	FACW	Sedge	<i>Rosa palustris</i>	3	1%	OBL	Shrub
<i>Rosa virginiana</i>	25	10%	FAC	Shrub	<i>Salix sericea</i>	3	1%	OBL	Tree
<i>Agrostis hyemalis</i>	18	7%	FAC	Grass	<i>Smilacina stellata</i>	3	1%	FACW	Forb
<i>Drosera rotundifolia</i>	18	3%	OBL	Forb	<i>Thelypteris palustris</i>	3	1%	FACW	Fern
<i>Eupatorium pilosum</i>	18	6%	FACW	Forb	<i>Triadenum virginicum</i>	3	1%	OBL	Forb
<i>Acer rubrum</i>	16	6%	FAC	Tree	<i>Iris versicolor</i>	2	1%	OBL	Forb
<i>Polygonum lapathifolium</i>	15	7%	FACW	Forb	unknown rush	2	1%		Rush
<i>Osmunda regalis</i>	12	4%	OBL	Fern	<i>Carex sp.</i>	2	1%		Sedge
<i>Spiraea tomentosa</i>	12	5%	FACW	Forb	<i>Baccharis halimifolia</i>	1	1%	FACW	Shrub
<i>Calamagrostis canadensis</i>	11	2%	FACW+	Grass	<i>Rhynchospora alba</i>	1	1%	OBL	Sedge
<i>Calopogon tuberosus</i>	10	4%	FACW+	Forb					

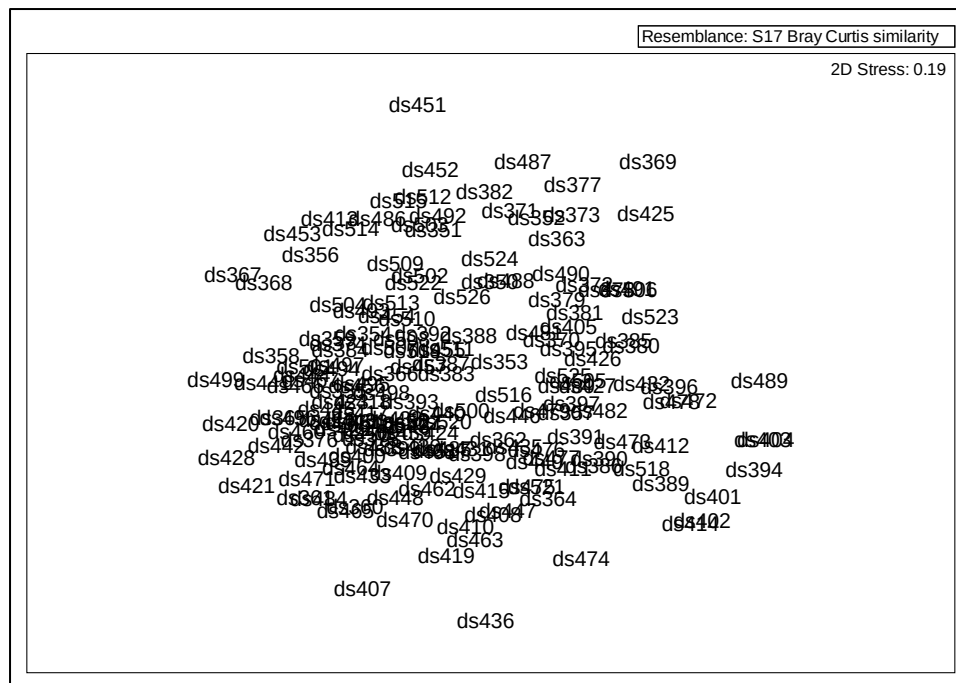


Figure 4. MDS scatterplot of new dune slack wetland sites showing variation by taxonomic composition in ordinal space.

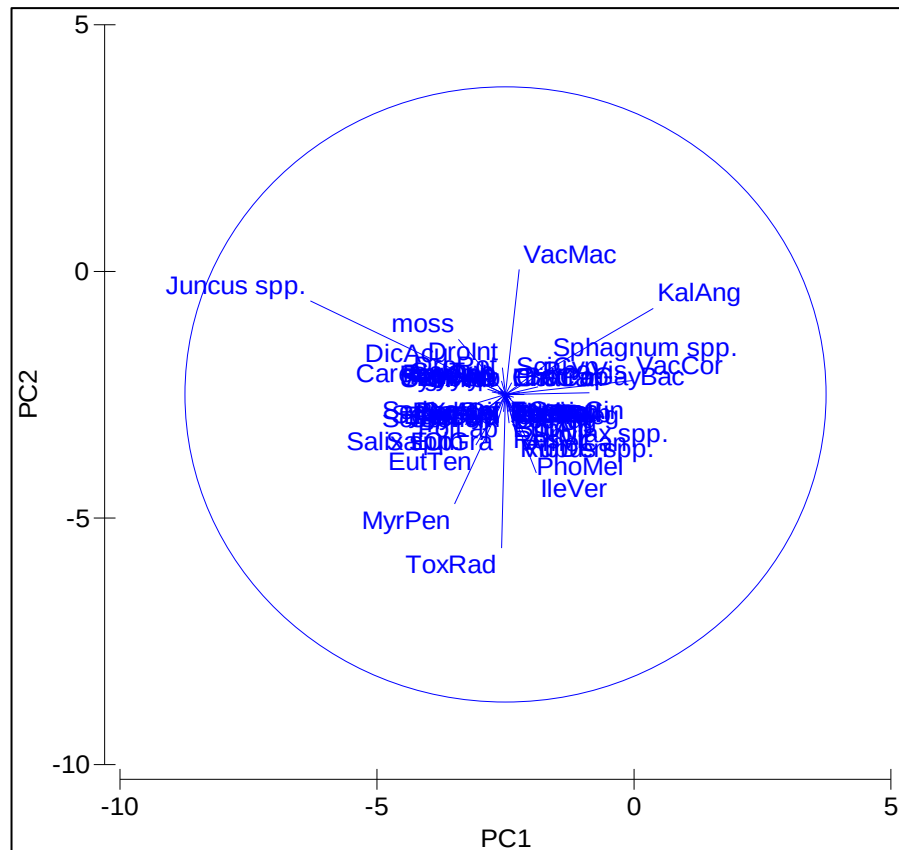


Figure 5. PCA of cover score values showing the relative contribution of various species to among-site variability in plant communities.

General Vegetation Structure

2009 survey - Percent trees, shrubs, and herbaceous growth forms all showed large variation, fluctuating between 0 and 100% cover. On average, the newly mapped wetlands were comprised of 31% trees, 56% shrubs, and 14 % other (forbs, graminoids, vines, etc.). The PCA reveals how the forb and shrub components contribute most to dissimilarity among sites (Figure 6).

Species composition, as viewed from the perspective of wetland indicator status, revealed that FAC and OBL dominated both PCA axes (Figure 7); whereas FACW species were less important in influencing spatial distribution of sites (also see Table 1).

All sites (2003/2004 and 2009) - This analysis was done merely for some general perspective on dune slack communities as an entire group. The analysis is not statistically valid because the surveys of the originally mapped wetlands (2003–2004) and the newly mapped ones (2009) were done five years apart and are, for that reason, not directly comparable. However, in a broad qualitative way, it provides some sense of how these wetlands range in terms of similarity/dissimilarity in taxonomy. Like the previous MDS scatterplot (Figure 4), the majority of dune slack wetlands are quite similar in species composition (Figure 8). The sites on the periphery of the central cluster are obviously different, with the possible exceptions of #125

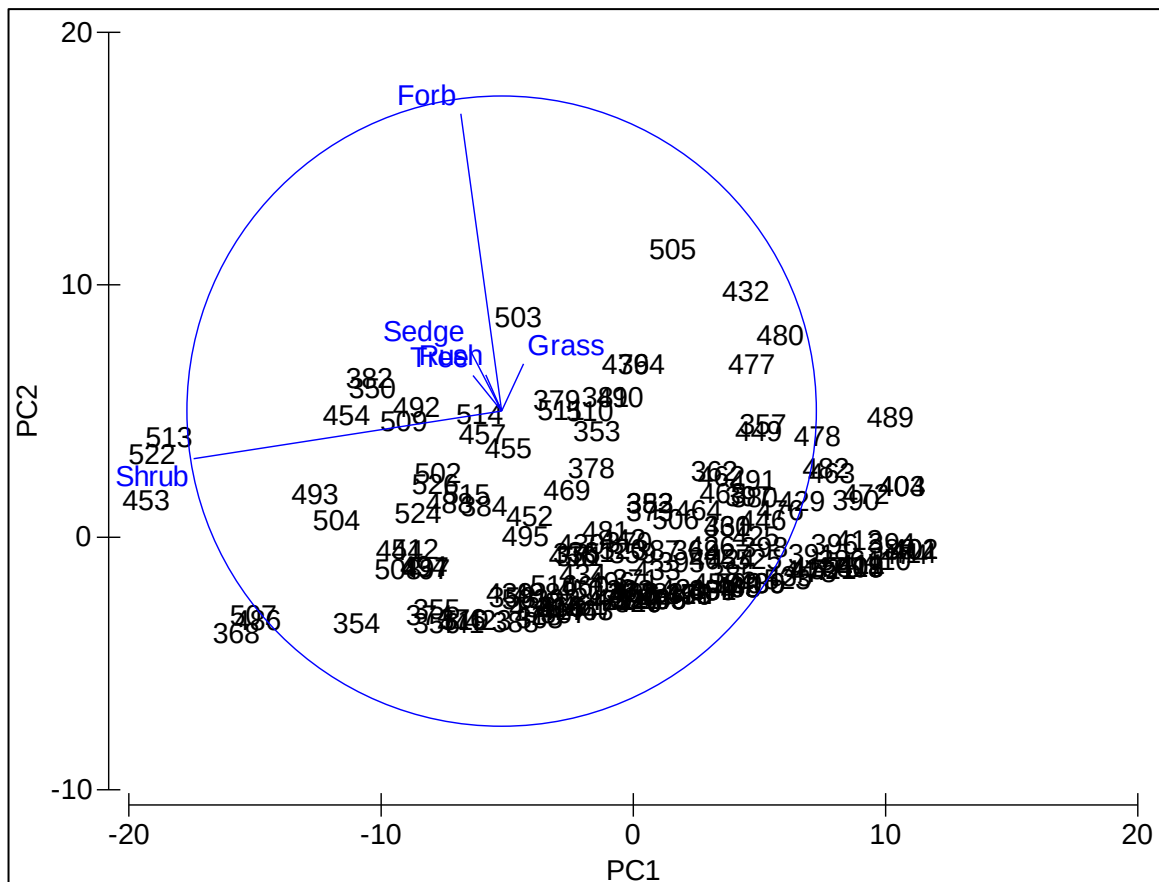


Figure 6. Photos of graminoid- vs. tree/shrub-dominated wetlands (top left and right photos, respectively) and PCA (bottom) showing among-site variability in growth form.

(only wetland with *Iris versicolor*) and #326 (presence of both *L. salicaria* and *P. australis*); however, they do not lie so distant from the main group that they are vastly different.

Soil Properties

Soil organic matter (OM) thickness varied greatly among sites. Similar to the results of the 2003/2004 study, however, this variable was significantly correlated with successional stage as indicated by % cover of woody taxa ($p < 0.001$), although the correlation coefficient between the two was quite low due to high variability about the line ($R^2 = 0.244$) (Figure 9). The accumulation of OM with successional stage in dune slacks has been reported previously by Berendse et al. (1998).

Intensively Monitored Subset (IS) Sites

Wetland Age Analysis

Rough determinations of dune slack ages were made based on aerial photography (Smith et al. 2005). The new IS sites were variable in terms of when they were formed; however, most sites were relatively young, given that none were present in 1947 photos (Table 2). More specifically, three sites formed between 1947 and 1960, four sites between 1960 and 1987, one site between 1987 and 1994, and three sites between 1994 and 2001.

Hydrology

Water levels in the IS wetlands showed remarkable disparities in seasonal trends. For example, while some wetlands generally showed similar patterns of rising and falling water levels through time, others behaved in a completely different manner (Figures 10–13). Moreover, the timing of rapid water level fluctuations were not closely correlated with precipitation (Figure 10), in that water level peaks did not consistently coincide with, or immediately follow, precipitation peaks. A noteworthy discovery was that the dune slack wetlands show a tidal signal which gets stronger (approaching 5 cm in SMA) with decreasing distance from the coast (Figure 14). This would not be possible to see without the extremely high frequency data collected by the HOBO loggers.

In Figure 11, NPA (orange) shows less of an increase than sites HHC (grey) or RPB (blue). However, near the end of the recording period, NPA responds strongly, whereas RPB responds weakly – the opposite pattern.

Porewater

Among the original IS sites, porewater pH ranged between 3.02 (NPC) and 5.15 (HHA) in 2009 (Table 3). Conductivity was low, but varied over two orders of magnitude (e.g., PLB vs. SMA), as did salinity. Compared with the porewater samples collected in 2004, pH values in all wetlands were significantly lower in 2009 ($p < 0.001$). SMA (-3.1) showed the largest decrease, HHB the lowest (-0.1). In contrast, porewater conductivities exhibited variable trends, with some values increasing and some decreasing between surveys (Table 4). As a result, there was no statistical difference between years ($p = 0.23$).

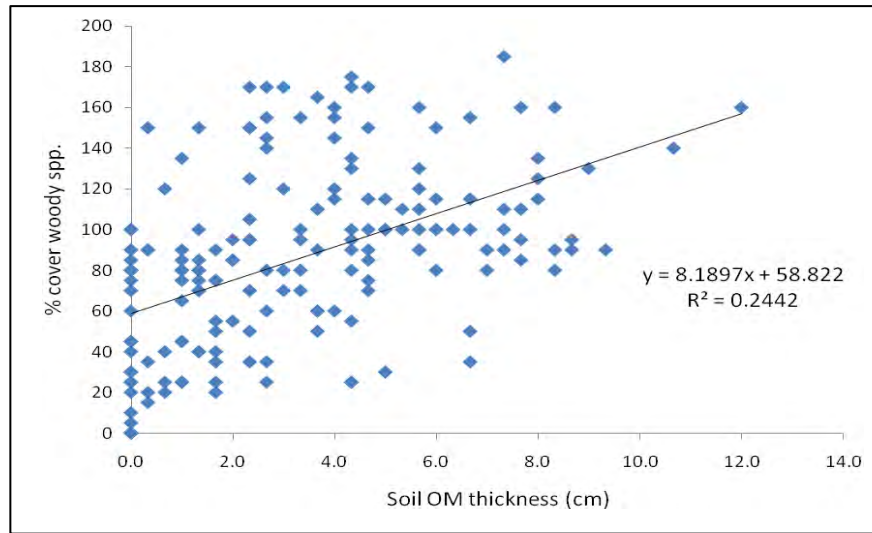


Figure 9. Regression of soil OM thickness vs. % woody vegetation.

Table 2. Age classifications by new IS site. N indicates that no wetland is visually detectable in the photo year; Y indicates wetland was visible in that year.

Site	1947	1960	1987	1994	2001
56	N	Y	Y	Y	Y
140	N	N	N	N	Y
169	N	N	Y	Y	Y
178	N	N	N	N	Y
192	N	N	Y	Y	Y
206	N	N	N	Y	Y
210	N	Y	Y	Y	Y
213	N	N	Y	Y	Y
218	N	N	N	N	Y
236	N	Y	Y	Y	Y
245	N	N	Y	Y	Y

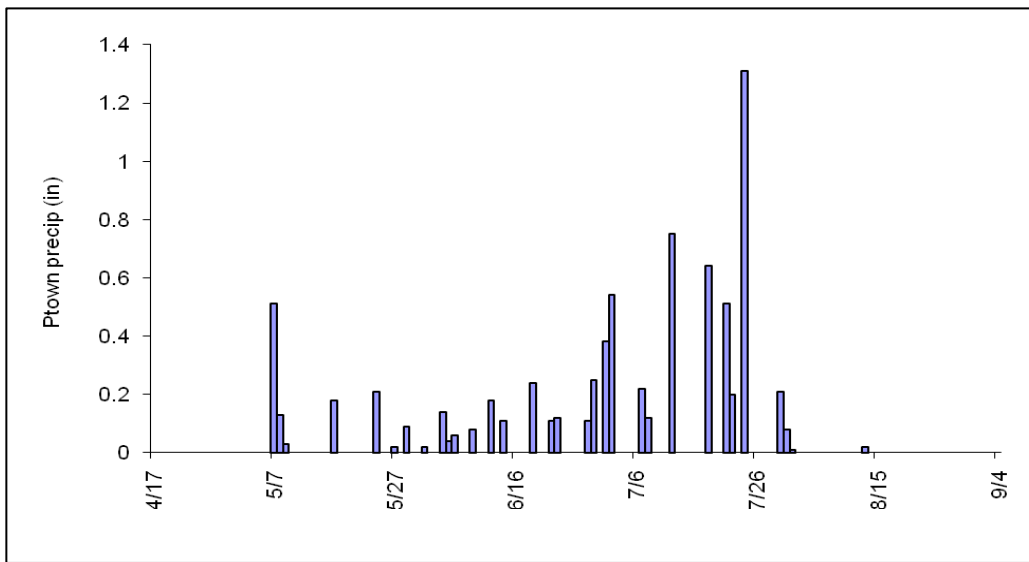
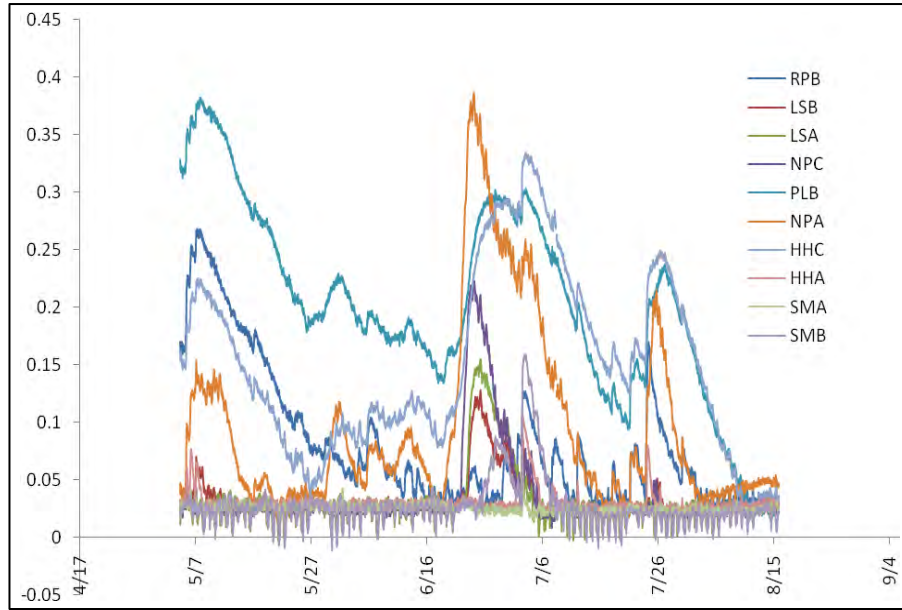


Figure 10. Hydrographs of ten IS sites from May 4–August 15, 2009 (top) and precipitation during that time period (Provincetown airport).

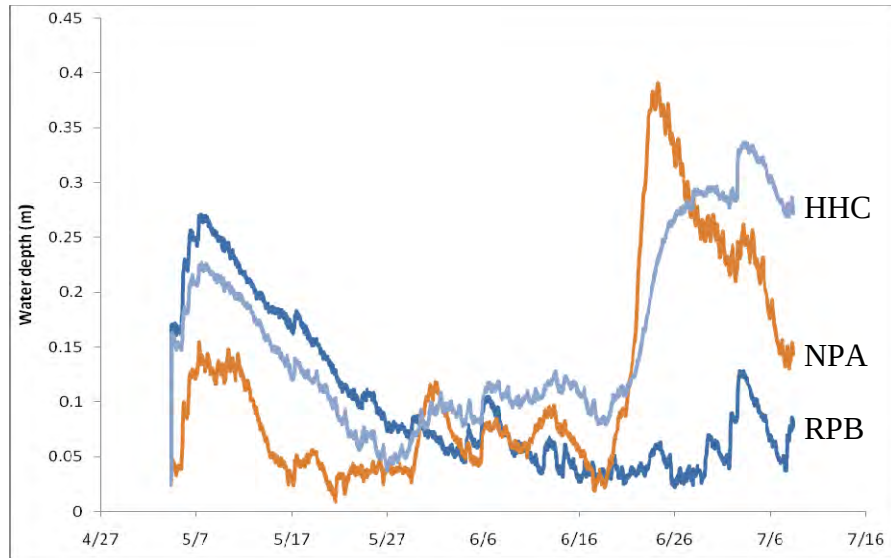


Figure 11. Hydrographs of three selected IS wetlands showing dissimilarities in water level responses throughout the period of deployment in 2009.

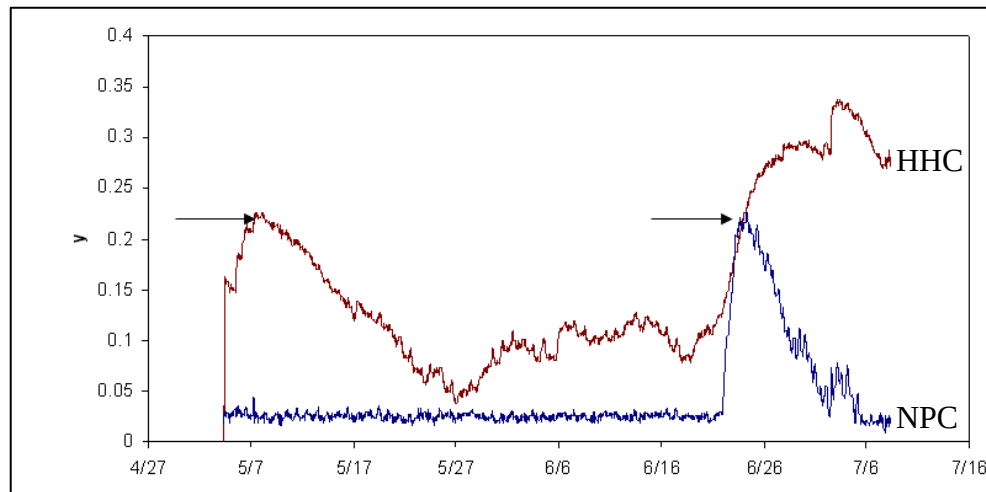


Figure 12. Example of two IS dune slack wetlands (HHC-brown; NPC-blue) showing very different hydrologic regimes during 2009. Arrows indicate where wetlands reached the same water level later in the season (right arrow), but this same correspondence is absent earlier in the season (left arrow), when only one wetland (HHC) reaches this level.

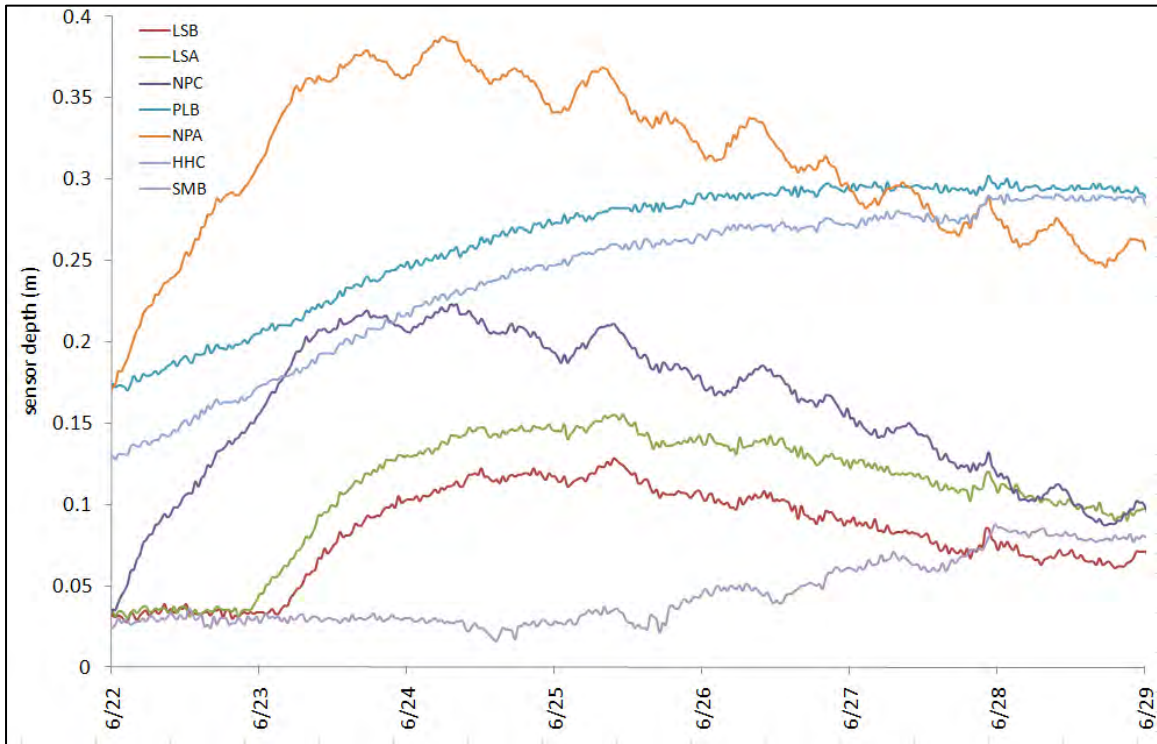


Figure 13. A portion of the logging period (6/22/2009 to 6/29/2009) showing hydrographs of seven IS wetlands. Note how water levels show opposite trends (increasing vs. decreasing) in different wetlands over the same time period.

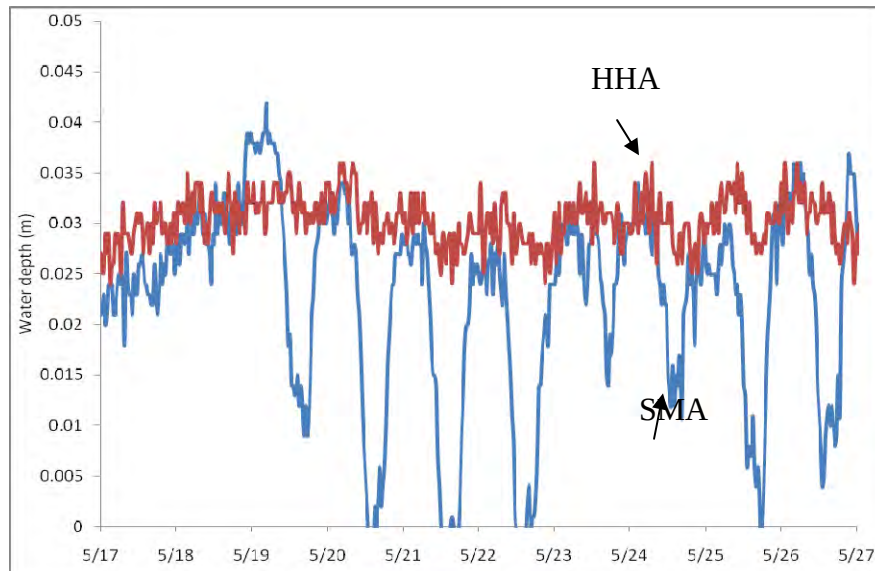


Figure 14. Subset (May 17–27, 2009) of the hydrologic data for IS sites HHA (brown) and SMA (blue) showing the influence of ocean tides on dune slack water levels. HHA is an interior site (408 m away from coastline) with a diminished tidal signal compared to SMA, which is very close to the ocean (130 m from coastline).

Table 3. Porewater pH in original IS wetlands sampled in June 2004 vs. June 2009.

	<u>6/16/2004</u>	<u>6/26/2009</u>	<u>Change</u>
HHA	6.4	5.2	-1.2
HHB	5.0	4.9	-0.1
HHC	5.2	3.8	-1.4
LSA	6.0	3.8	-2.2
LSB	5.5	4.1	-1.4
NPA	5.6	3.8	-1.8
NPB	5.7	3.7	-2.0
NPC	-	3.0	
PLA	5.7	4.3	-1.4
PLB	5.5	4.1	-1.4
PLC	6.1	4.5	-1.6
RPA	5.9	4.7	-1.2
RPB	6.3	4.3	-2.0
SMA	6.6	3.5	-3.1
SMB	6.4	4.8	-1.6
mean	5.9	4.2	-1.6
SE	0.13	0.15	0.17

Table 4. Porewater conductivity in original IS wetlands sampled in June 2004 vs. June 2009.

	<u>6/16/2004</u>	<u>6/26/2009</u>	<u>Change</u>
HHA	170	487	316.7
HHB	130	195	65.0
HHC	170	170	0.3
LSA	290	130	-160.3
LSB	180	295	115.3
NPA	300	270	-30.0
NPB	290	213	-77.3
NPC	-	165	
PLA	180	264	84.0
PLB	140	107	-33.0
PLC	240	144	-96.3
RPA	230	188	-41.7
RPB	110	220	110.0
SMA	> 2000	10447	
SMB	180	374	194.0
mean	201	911	34
SE	17.6	681.6	36.2

In the new IS sites, pH values ranged between 3.04 (#314) and 5.11 (#122) (Table 5). Again, as in 2003/2004, pH was roughly correlated with age, with lower average values in older wetlands (e.g., 3.6 in #236 vs. 5.0 in # 178).

Soil Properties

Measurements of organic matter (OM) thickness in soil cores produced results that are difficult to interpret. As in 2003/2004, OM thickness values differed greatly among wetlands, but they did not show any consistent trends over time. While the general pattern was similar among wetlands, temporal trends were not, with some apparently gaining and some losing OM over time and no significant difference between years ($p=0.41$) (Table 6).

Vegetation Change in Original IS Sites Between 2004 and 2009

The results of ANOSIM showed that as a group, no statistically significant changes occurred between 2004 and 2009 (Global $R = -0.01$, $p=0.52$). A SIMPER analysis showed that *V. macrocarpon*, *Juncus* spp., bare ground, *M. pensylvanica*, and *T. radicans* accounted for the most variability between years. A MDS scatterplot shows the small shifts that occurred within individual wetlands (Figure 15). In this regard, HHA and RPA showed the most change in plant community composition between surveys. In HHA, this was primarily due to a large increase in *M. pensylvanica* and decrease in bare ground. In RPA, it was due to a doubling of *Phragmites* and a large reduction in *V. macrocarpon*. Changes in the latter are most likely due to the occasional flooding of this wetland with seawater from storm surges. The salinity favors *Phragmites* while killing many freshwater taxa.

A noteworthy finding is that species richness along the transects increased from a total of 69 to 82 between 2004 and 2009. This could be a reflection of successional processes, whereby biodiversity increases with age for a period of time before the climax community develops.

In terms of vegetation structure, all the original IS wetlands exhibited a significant (T-test, $p=0.004$) increase in percent cover of woody vegetation between 2003 and 2009. In fact, the average percent increase was 28%, which was statistically significant ($p=0.04$) (Table 7).

Table 5. Porewater pH, conductivity (Cond), salinity (Sal), and age of new IS wetlands sampled in June 2009.

Site #	pH	Cond (us/cm)	Sal (ppm)	Age (yrs)	mean pH by age class
56	4.9	158	105	47–60	4.2
210	4.1	160	76	47–60	
236	3.6	212	100	47–60	
169	4.1	168	79	60–87	4.4
192	4.5	166	81	60–87	
213	4.2	148	72	60–87	
245	4.8	186	88	60–87	
206	4.0	112	61	87–94	- (only 1 rep)
140	4.5	139	68	94–01	4.6
178	5.0	217	104	94–01	
218	4.3	216	103	94–01	

Table 6. Soil OM thickness measured in cores extracted in 2003 vs. 2009 and amount of apparent change in this variable (cm) over that duration.

	<u>2003 (cm)</u>	<u>2009 (cm)</u>	<u>Change</u>
HHA	0.5	0.7	0.2
HHB	4.0	4.0	0.0
HHC	7.0	10.7	3.7
LSA	3.5	3.3	-0.2
LSB	-	8.0	
NPA	12.0	10.7	-1.3
NPB	4.0	5.7	1.7
NPC	0.5	0.0	-0.5
PLA	10.0	6.0	-4.0
PLB	16.0	11.0	-5.0
PLC	4.0	9.3	5.3
RPA	7.0	6.7	-0.3
RPB	4.0	5.7	1.7
SMA	12.0	5.3	-6.7
SMB	5.0	5.3	0.3
mean	6.4	6.2	-0.4
SE	1.2	0.9	0.9

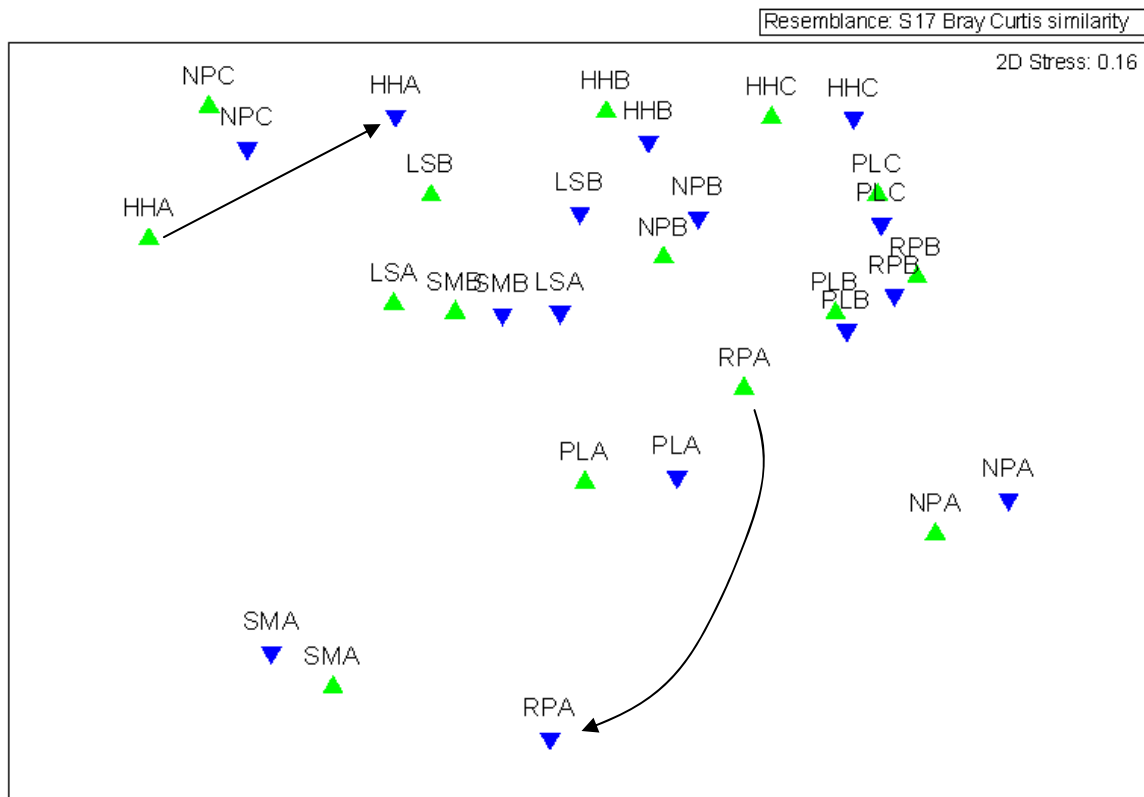


Figure 15. MDS scatterplot of species composition based on percent cover calculated from transects (right-side up green triangles = 2004; upside-down blue triangles = 2009).

Table 7. Change in percent of woody species in original IS wetlands from 2004–2009.

	2004 (%)	2009 (%)	Diff
HHA	5	20	15
HHB	10	20	10
HHC	16	35	19
LSA	11	70	59
LSB	2	75	73
NPA	90	110	20
NPB	70	75	5
NPC	0	45	45
PLA	70	105	35
PLB	20	65	45
PLC	2	30	28
RPA	5	20	15
RPB	5	65	60
SMA	5	0	-5
SMB	5	20	15

Vegetation of New IS Sites

The plant communities of the new IS sites differed primarily in the cover of *V. macrocarpon*, *J. greenii*, and bare ground, and secondarily by *M. pennsylvanica* and *T. radicans* (Figure 16). The most abundant species (average of all sites) was *V. macrocarpon* (20%), followed by *M. pennsylvanica* (8%), *J. greenii* (8%), *K. angustifolia* (6%), and *T. radicans* (2%). In terms of site to site variability, sites #178, #140, #206, #56, and #236 showed considerable separation along the PC2 axis. In contrast, sites #169, #192, #213, and #245 were grouped tightly together, indicating a high degree of similarity.

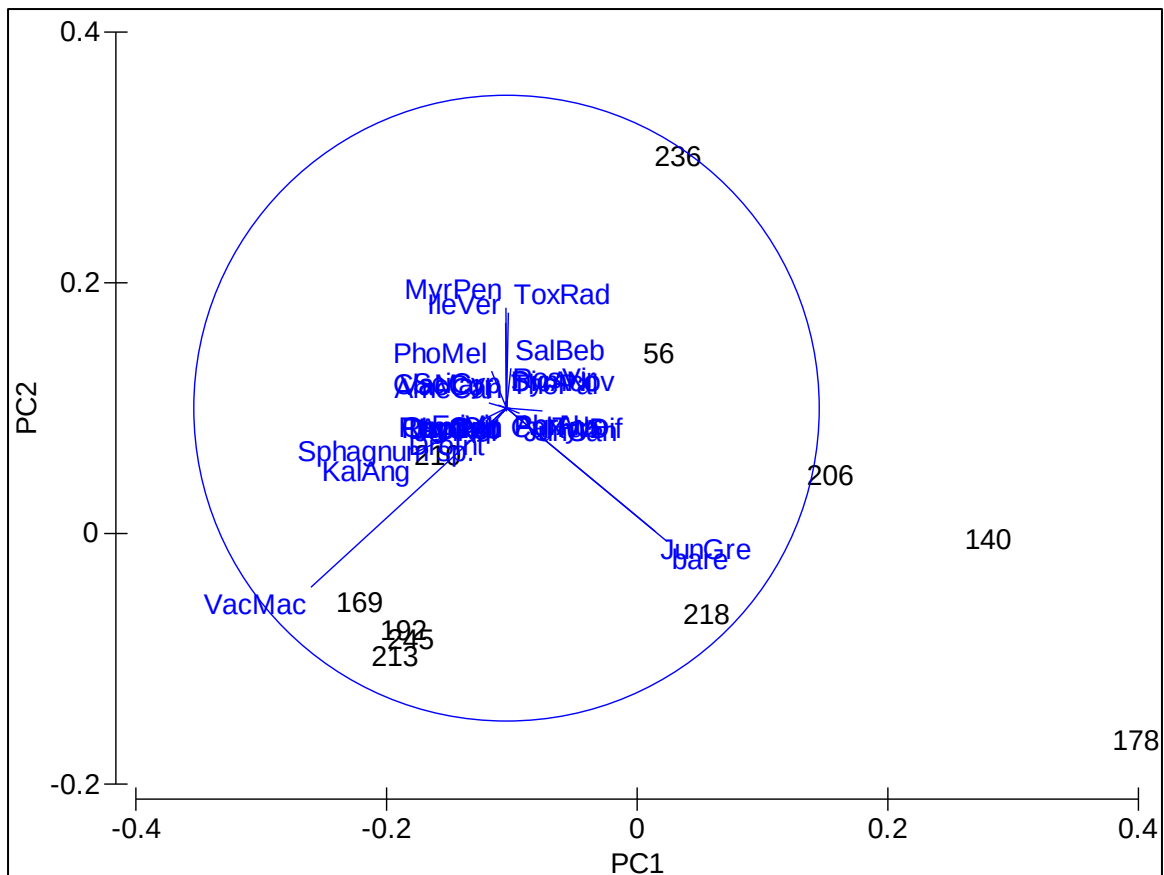


Figure 16. PCA of species composition for new IS sites (site IDs are numeric values within graph).

Discussion

The work described in this report allowed us to expand the scope of long-term monitoring for this ecosystem type, add to our inventory of known wetlands, collect data for change analysis, and provide critical information for the development of a rigorous protocol (including statistical power analysis).

We were also able to acquire water-level data every 30 minutes within 10 wetlands from May 4 to August 15, 2009. This kind of high resolution water-level data has never been obtained before in any of these wetlands. The information provided valuable insights as to the complexity of hydrology throughout the dunes area. For example, some wetlands exhibited increasing water levels while other levels decreased during the same period of record. Moreover, water-level trends were not as closely correlated with precipitation as might be expected. This may be because antecedent water level is a key factor. A rain after a hot dry period may do little to influence water levels in wetlands as most of it would percolate down to the water table below. Conversely, precipitation may have the greatest effect when wetland water levels are already high. At that point, there is nowhere for the water to go but up. The location of the wetland is likely important as well. Sites on the peripheral margins of the groundwater lens will show a lag response, vs. those closest to the center. Other potentially influential factors include evapotranspiration and contributions of water from surrounding dunes (i.e., sub-surface “runoff”).

Notwithstanding, it is clear that hydrology in these wetlands is much more complicated than the simple rise and fall of the groundwater table, which has heretofore been the conventional way of thinking about this system. The discovery of tidal signals in these wetlands – particularly the ones closest to the shoreline – is another interesting feature of their hydrology.

With respect to water quality, we did not do as extensive an analysis of porewater constituents as was done in 2003/2004. However, porewater pH measurements in the field showed decreased values at all original IS sites between 2003/2004 and 2009. This uniform drop in pH may be due to hydrologic variability between years prior to sampling. In 2009, water levels were higher than in 2004 and while all sites went dry in 2004 by early July, many sites in 2009 had standing water throughout the summer. Alternatively, or additionally, it may reflect successional processes. If pH values are still lower during the next scheduled sampling (2014), then it most likely reflects changes in soil properties due to succession and would therefore be a useful variable to include in the long-term monitoring protocol.

The data on sediment OM thickness are difficult to interpret;; there were both positive and negative changes, and some quite large. Positive changes are expected with succession although successive periods of dry conditions can result in oxidation and a decrease in this layer. A large part of this variability may be due to spatial differences. However, the patterns among the different wetlands of the IS subset are similar (e.g., HHA = thinnest, PLB = thickest). Nonetheless, this parameter may not be worth including in the long-term monitoring protocol if the power to detect change is very low.

Overall, the dune slack wetland communities are remarkably free of exotic species. *Phragmites* was found in five more wetlands, bringing the total to 31 sites (out of 524 total) infested with this species. *Salix cinerea* (gray willow) is another introduced species that is abundant. Fortunately, only four wetlands have *L. salicaria* (purple loosestrife). In terms of rare, native plants, no federal- or state-listed species were found in any of the original or newly mapped wetlands.

From the standpoint of vegetation changes, species richness along the permanent transects (in IS wetlands) increased from a total of 69 to 82 between 2004 and 2009. Like the pH changes mentioned above, this is a trend that is expected to occur during the early stages of secondary succession. Nearer the climax community (i.e., approaching 100% trees/shrub canopy cover), species richness should decline as competition eliminates early successional species and leads to dominance by fewer species. So what does succession mean for the plant communities of dune slack wetlands? There are two competing process – succession vs. increasing water levels expected from climate change. The transition from open, graminoid-dominated systems to shrub/tree communities due to succession will result in the loss of some unique species that are rare occurrences throughout the rest of the national seashore. For example, the orchids *Calopogon tuberosus* and *Pogonia ophioglossoides* as well as the insectivorous sundews will diminish. These losses coincide with decreasing dune slack wetland formation. Upland succession and, consequently, stabilization of the dunes translates into fewer opportunities for wind scour of bare sand to create new depressions that can become wetlands.

Figure 17 shows the succession of bare sand and grassy dune habitat to a dune slack wetland and scattered shrub community over the course of seven years. Not only do these successional changes have consequences for dune movement and wetland creation, but they will change the albedo of this landscape. Thus, the Province Lands region will increasingly absorb more light than it currently reflects as vegetation cover increases. Conceivably, this shift to a darker surface could influence the water table in various ways as more heat is absorbed rather than being mostly reflected by bare sand. However, the feedbacks among vegetation, albedo, and hydrology are complex, and it is difficult to predict how lowered albedo might influence other physical and biological parameters (Levis et al. 2000).

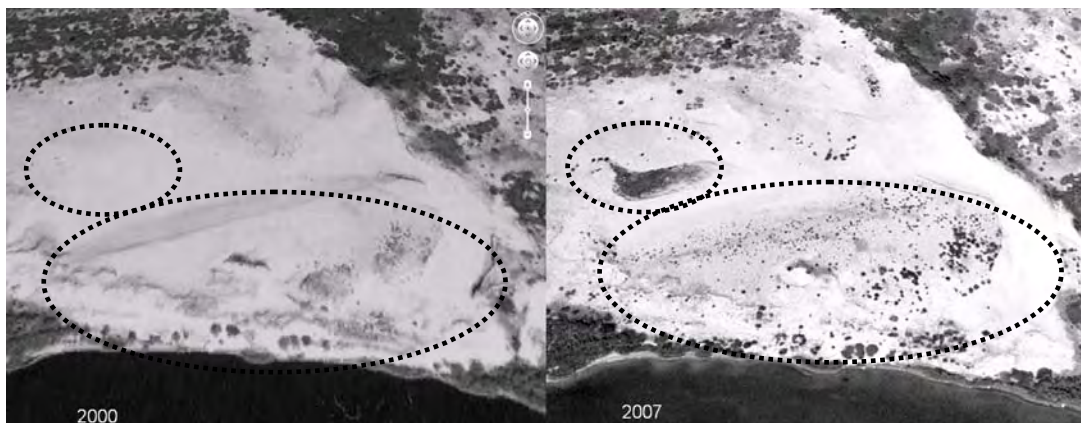


Figure 17. Aerial photos from 2000 (CACO) and 2007 (Google Earth™) showing vegetation succession in a dune slack wetland (small circle). Upland succession (large circle), in the form of increased shrubs, is also quite obvious.

On the other hand, over the longer term climate change is expected to bring more precipitation to the northeastern U.S. (The Copenhagen Diagnosis, 2009). In addition, rising sea level will force the fresh groundwater aquifer upwards (Masterson and Portnoy 2005), thereby making current wetlands experience longer hydroperiods and filling depressions that were formerly upland. Some dune slack wetlands may even transition into true ponds with permanent standing water. This would result in a dramatic shift in vegetation with obligate species predominating over all others. It is expected that long-term monitoring of these wetlands should reveal this trend.

Archive of Data Files

All documents pertaining to the 2009 dune slack wetland sampling are currently contained in Y:\I&M_Projects\Dune_Slack_Wetlands\2009. The following directory structure can be used to guide the user to the appropriate information:

- [-] I&M_Projects
 - [+] Aquatic_Ecology
 - [+] CACO Vegetation Map 2000
 - [+] Climate Change
 - [+] Coastal_Forests
 - [+] Coastal_Heathlands
 - [+] Cover_type_Mapping
 - [+] DM_SOPs
 - [+] Dune_Grassland_Vegetation
 - [+] **Dune_Slack_Wetlands**
 - [-] 2004
 - [+] Bathymetry
 - [-] Data_Synthesis
 - [+] age_res_analyses
 - [-] Intensive_sites
 - [+] Hydrology
 - [+] Porewater
 - [+] Sediments
 - [-] mapping
 - [+] Cook_Smith_reconciled_sites
 - [+] mapping_2003
 - [+] mapping_2004
 - [+] mapping_2005
 - [+] MB additional sediment sampling 2005
 - [+] Myrica_N_enrichment
 - [+] stats
 - [-] 2009
 - [+] duneslack_veg_09
 - [-] IS sites_09
 - [+] 2003-2009_synthesis
 - [+] hydrology
 - [+] porewater_09
 - [+] sediments_09
 - [+] vegetation_09
 - [+] Non-wetlands_09
 - [-] Methods&Metadata
 - [+] Worksheets
 - [+] Nina_Coleman_data
 - [+] Project_History
 - [-] Reports_Publications
 - [+] CCNS_duneslacks_ms
 - [+] stats

- All GIS-related files (shape files) are located in:
W:\GIS_X\gisdata\SMSMITH_duneslack_shapes
- All digital photos are located in: Y:\Images\Dune_Slacks\Photos_new_duneslacks_09

Recommendations for Future Sampling

The basic methodology for surveying dune slack wetland vegetation has now been field-tested twice, and provides a good basis for developing the long-term monitoring protocol.

Notwithstanding, there are a few improvements in sample size and techniques that can be implemented. Also included is a suggestion that eradication of some exotic species should be included in management objectives for this resource.

- Although the number of IS wetlands is now 26 instead of 15, it would be helpful to add more (perhaps a total of 30) so that the statistical power to detect change is enhanced. From the standpoint of making statistical design-based inferences of vegetation change in all the other hundreds of sites, a subset of wetlands on the order of 80–100 should be randomly selected and surveyed for structural and taxonomic character every 5–10 years using the same methods of visual cover assessments described in this document and in Smith et al. (2005).
- Soil OM thickness appears to be a constituent that is too variable to be meaningful. As such, it may be advisable to discard this from the long-term protocol. Soil OM measurements may be better suited for smaller-scale, targeted research studies.
- The long-term expansion or reduction in wetland area should be examined using aerial photography. While hydrologic regime can be vastly different from year to year, the vegetation footprint of the wetland generally reflects long-term conditions. Thus, significant changes in hydrology should ultimately be reflected in the size of this footprint. This kind of analysis should be limited to fully vegetated sites and ones that are not expanding in the wake of dune movement, since are changes would then reflect primary succession rather than long-term hydrologic changes.
- Eradication of *Phragmites* where feasible should be considered as a future management goal. The most appropriate method for accomplishing this would be herbicide (glyphosate or triclopyr) application. *Salix cinerea* (gray willow) and *Lythrum salicaria* are other species that could also be targeted.

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