National Park Service
U.S. Department of the Interior

Northeast Region
Philadelphia, Pennsylvania

Annual Report on Estuarine Restoration at East Harbor (Truro, MA), Cape Cod National Seashore, 2009

Natural Resources Report – NPS/NER/NRR-2010

ON THE COVER
Aerial view of East Harbor (June 2008) Cape Cod National Seashore; photo by Stephen Smith

Annual Report on Estuarine Restoration at East Harbor (Truro, MA), Cape Cod National Seashore, 2009

Natural Resources Report NPS/NER/NRR—2010

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National Park Service, Cape Cod National Seashore, Wellfleet, MA

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NPS August 2010

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INTRODUCTION

To provide background and context for this report, which is the latest in a series of annual reports on East Harbor tidal restoration monitoring, the following has been excerpted from (Portnoy et al. 2008):

> East Harbor, a 720-acre back-barrier lagoon comprised of Moon Pond, Pilgrim Lake and Salt Meadow, was artificially isolated from the Cape Cod Bay marine environment in 1868 with the filling of the original 1000-ft wide inlet at the northwest end of the system. A drainage system was installed at the south end of the embayment in 1894 to allow freshwater to escape. The exclusion of tides caused salinity to decline from a likely natural condition of 25-30 parts per thousand (ppt) to nearly freshwater conditions, at least by the time of the first documented fish survey in 1911. By this time the native estuarine fauna were largely extirpated; the State Survey of Inland Waters (1911) recorded "German carp and very few eels and shiners". The blockage of tides apparently caused water quality to decline rapidly along with salinity: surveys from 1911 to the 1970s reported low salinity (4-10 ppt), high turbidity, probably due to carp feeding and cyanobacterial blooms (Mozgala 1974), nuisance chironomid midge breeding and chronic summertime dissolved oxygen stress (Emery & Redfield 1969, Cape Cod National Seashore 2002).
>
> An oxygen depletion and fish kill in September 2001 prompted Truro and Cape Cod National Seashore officials to open the clapper valves in the 4-ft diameter drainage pipe connecting the southeast end of the system (Moon Pond) with Cape Cod Bay (Fig. A) in hopes of restoring some tidal exchange and increasing aeration. These valves have been cabled open almost continuously from November 2002 to the present. Despite limits on tidal exchange imposed by the pipe's small diameter, and the distance that it travels under ground, we have observed an impressive response in the recovery of salinity and estuarine biota.

This report is a summary of monitoring results from 2009 on hydrology, water quality, submerged and emergent vegetation, and nekton (fish and decapod crustaceans). No benthic invertebrate sampling was done in 2009. For more details on monitoring methodologies and results, please refer to previous reports (Portnoy et al. 2005-2008) – now available online at:

http://www.nps.gov/caco/naturescience/east-harbor-tidal-restoration-project-page.htm

SALINITY, TEMPERATURE, DISSOLVED OXYGEN, AND WATER LEVEL

Kelly C. Medeiros and Stephen Smith

Methods

Details on YSI data-logging methods can be found in Portnoy et al. (2008). In 2009, dissolved oxygen (DO) was measured using a ROX Optical Dissolved Oxygen probe (YSI 6150). This is a change from previous years (2005-2008), during which the a rapid pulse DO probe (YSI 6562) was used. This change was made because the optical DO sensor provides a more stable and consistent measurement.

Figure 21 shows the permanent station located in the main tidal creek in Moon Pond and the lagoon station. Tide height, salinity, temperature and DO were recorded every 30 minutes from June 12 to September 22 in 2009 in order to obtain the same period of record as 2008.

Figure 1. Map of YSI datalogger stations in the lagoon (left star) and tidal creek (right star)

Results

The data are summarized in Tables 1-2 and Figures 2-7b below. In Moon Pond's tidal creek, temperatures ranged between 7.7°C and 29.9°C, averaging 21.4°C. In the lagoon these values were 13.5°C, 29.4°C, and 22.3°C. Temperatures peaked near 30°C in August and thereafter started to decline in the fall (Figure 2). Periodically throughout the season, the rapid thermal declines occurred as they did in 2008. These are due to the increased volume of cooler water from the Cape Cod Bay during spring tides.

Figure 3 shows the greater amount of precipitation during the months of July and August compared with September in 2009. This dry period toward the end of the summer accounts for the rising late-season salinity trend in 2009 (Figure 4). This contrasts with the late season reduction in salinity during 2008 Overall, salinities did not change appreciably between 2008 and 2009. (NOTE: the tidal creek salinity data was limited to a much shorter logging period in 2009 (Figure 1) due to a probe malfunction) While the salinities in the tidal creek are more dynamic and have a larger range, over a short time scale(< 2days) salinities in the lagoon can change by as much as 3-4 ppt

Dissolved oxygen continues to be generally higher in the lagoon than in the tidal creek, ranging from ~40% to 180% saturation in the former (Figure 5a). The creek had a slightly narrower range of ~50% to 150% (Figure 5b). The ranges in both parts of the system were slightly higher in 2009 than in 2008. Neither part of the system showed DO levels below the hypoxic threshold of 30%.

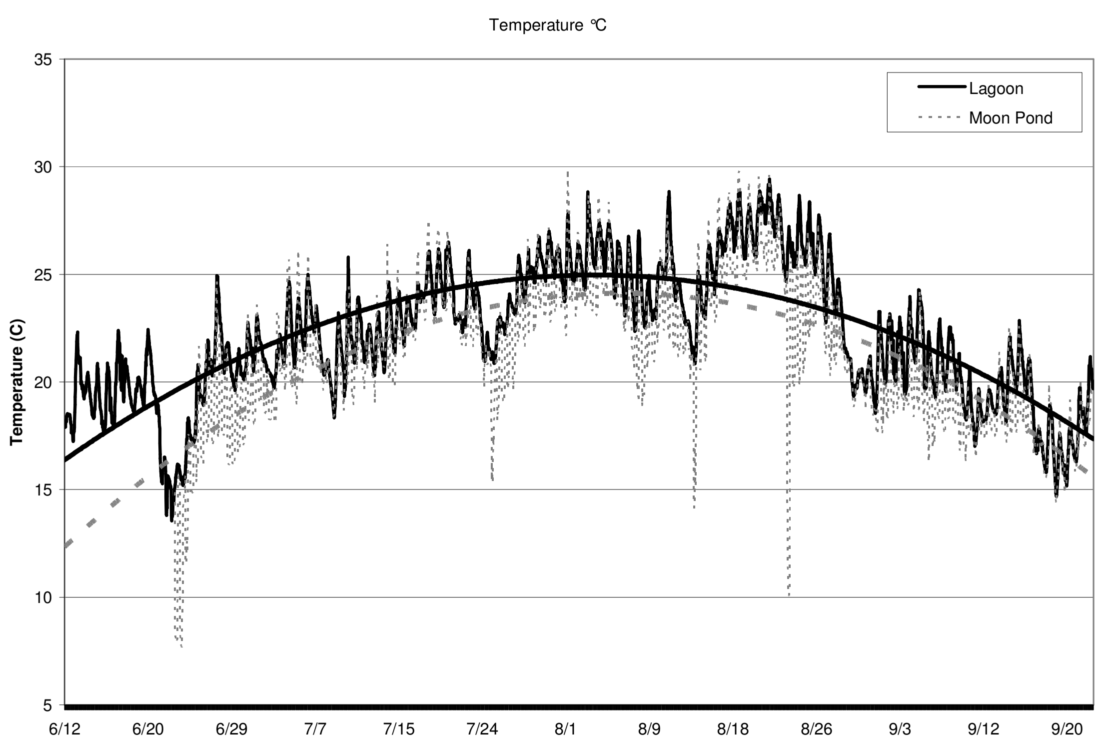

Figure 2. Temperatures in the lagoon (solid line) and tidal creek (dotted line) from June-Sept 2009.

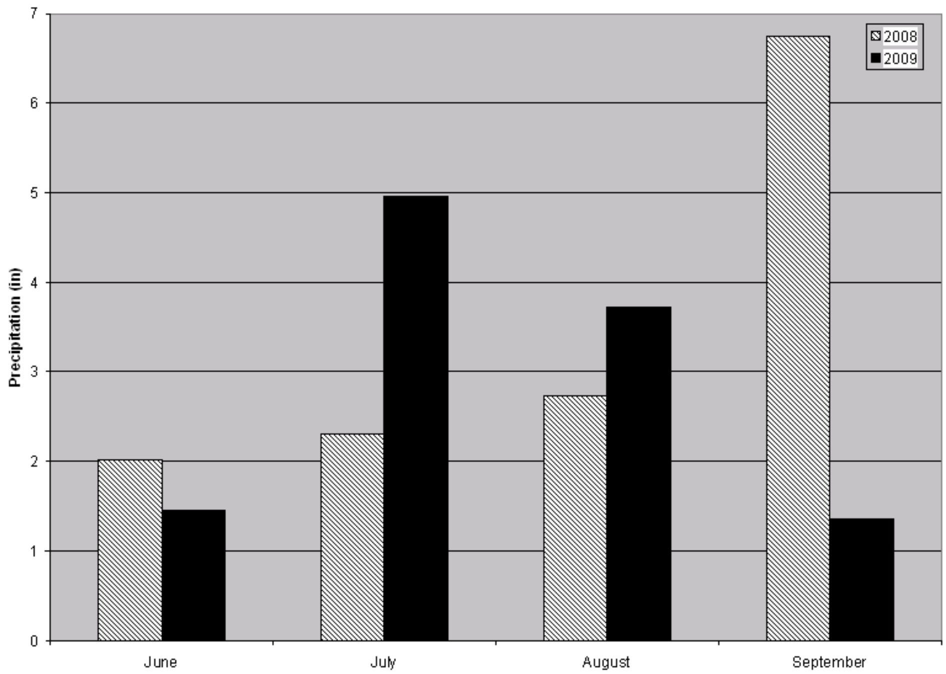

Figure 3. Total monthly precipitation (inches) in 2008 and 2009.

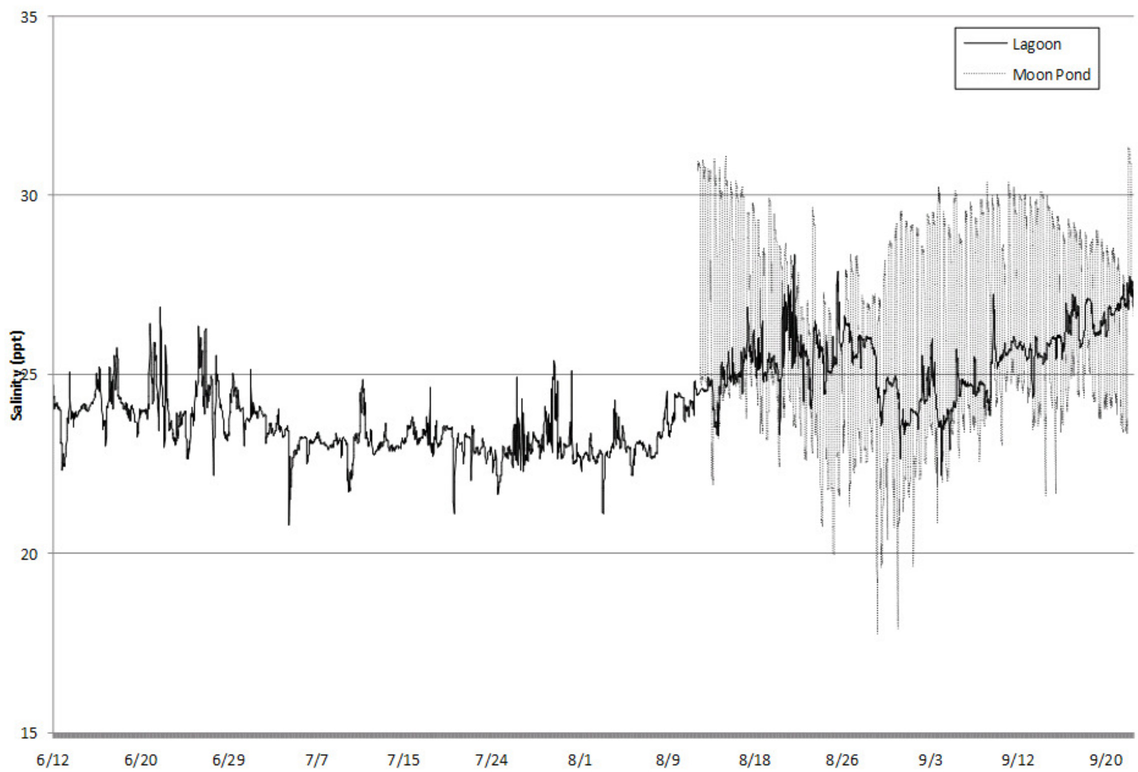

Figure 4. Salinity (ppt) in the lagoon (solid line) and creek (dotted line) from June-Sept 2009.

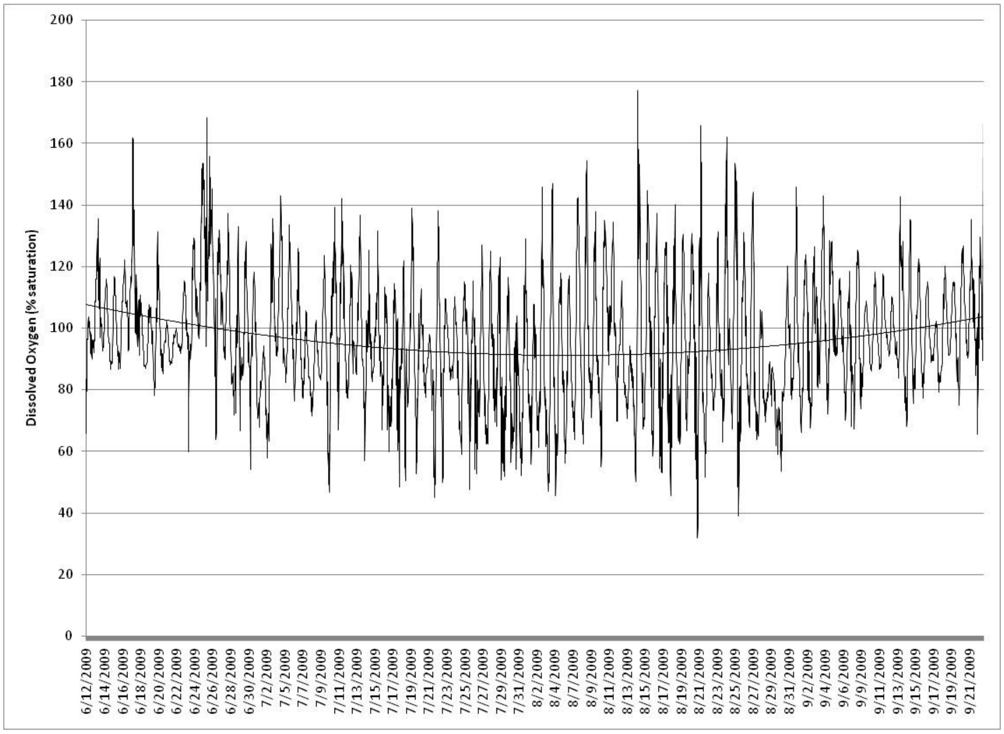

Figure 5a. Dissolved oxygen (% saturation) in the main lagoon in 2009.

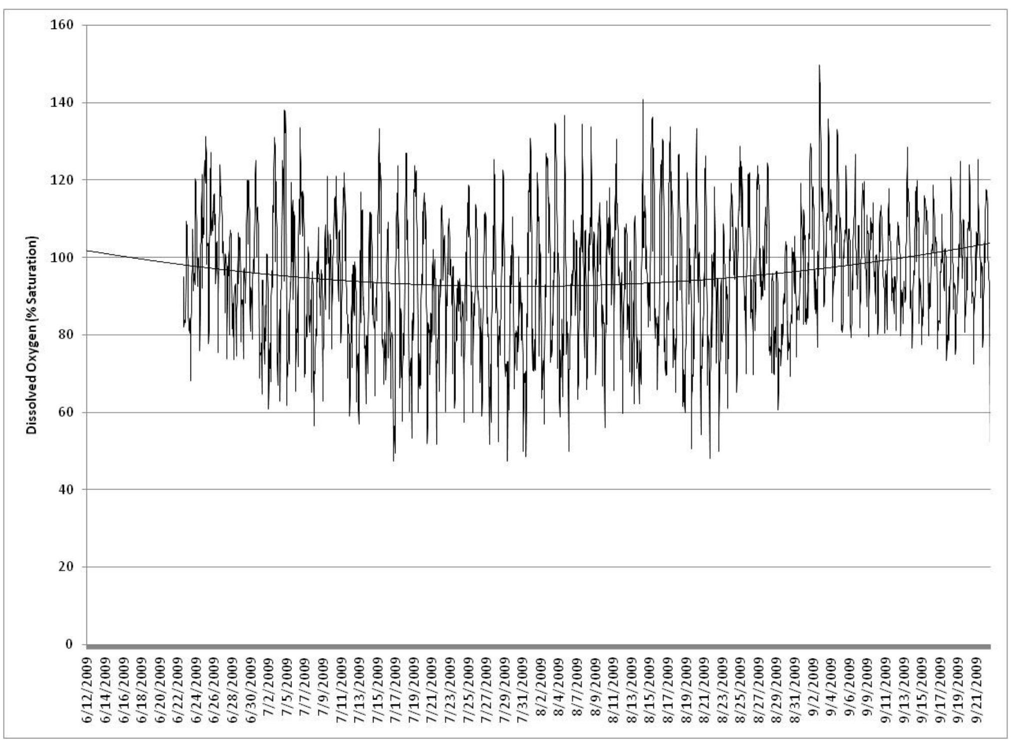

Figure 5b. Dissolved oxygen (% saturation) in the tidal creek in 2009.

Table 1. Minimum, maximum, and mean temperatures, salinities, and % DO in the lagoon (L) and Moon Pond tidal creek (MP) in 2008 and 2009.

2009	Temp (°C)		Salinity (ppt)		DO (%)	
	L	MP	L	MP	L	MP
min	13.5	7.7	20.8	17.8*	32	47
max	29.4	29.9	28.4	31.3*	177	150
mean	22.3	21.4	24.2	26.1*	96	95

2008	Temp (°C)		Salinity (ppt)		DO (%)	
	L	MP	L	MP	L	MP
min	12.8	6.9	16.1	15.3	75	31
max	30.6	29.7	28.9	33.4	192	171
mean	22.7	21.1	23.9	27.1	115	102

Diff	Temp (°C)		Salinity (ppt)		DO (%)	
	L	MP	L	MP	L	MP
min	0.7	0.8	4.7	2.5*	-43	16
max	-1.2	0.2	-0.5	-2.1*	-15	-21
mean	-0.4	0.3	0.3	-1.0*	-19	-7

* Moon Pond 2009 salinity data is calculated from 8/12 to 9/22 only.

In 2009, a new post-processing procedure was used to compensate for changing barometric pressure effects on the water depth in both the lagoon and the tidal creek (for details please refer to the Atlantic Research Center website). Data from 2008 were also corrected using this method. [NOTE:It was determined that in order to gain the best accuracy in water level, the effects that barometric pressure, temperature and salinity have on the water level was an important component to consider. A nearly 20% change in water level data from the original raw data to the compensated data was seen at the lagoon site and almost half that (9%) at the tidal creek site. These numbers confirm the necessity of using this compensation method].

Figures 6a and 6b show the tidal stage and barometric pressure measurements for the lagoon in 2008 and 2009 and Figures 7a and 7b show these same parameters for the tidal creek sites for the same years. The two jumps in water level (indicated with arrows) are apparent at both sites in 2009. On both occasions these increases coincided with large rain events (3+ inches) and a large drop in barometric pressure.

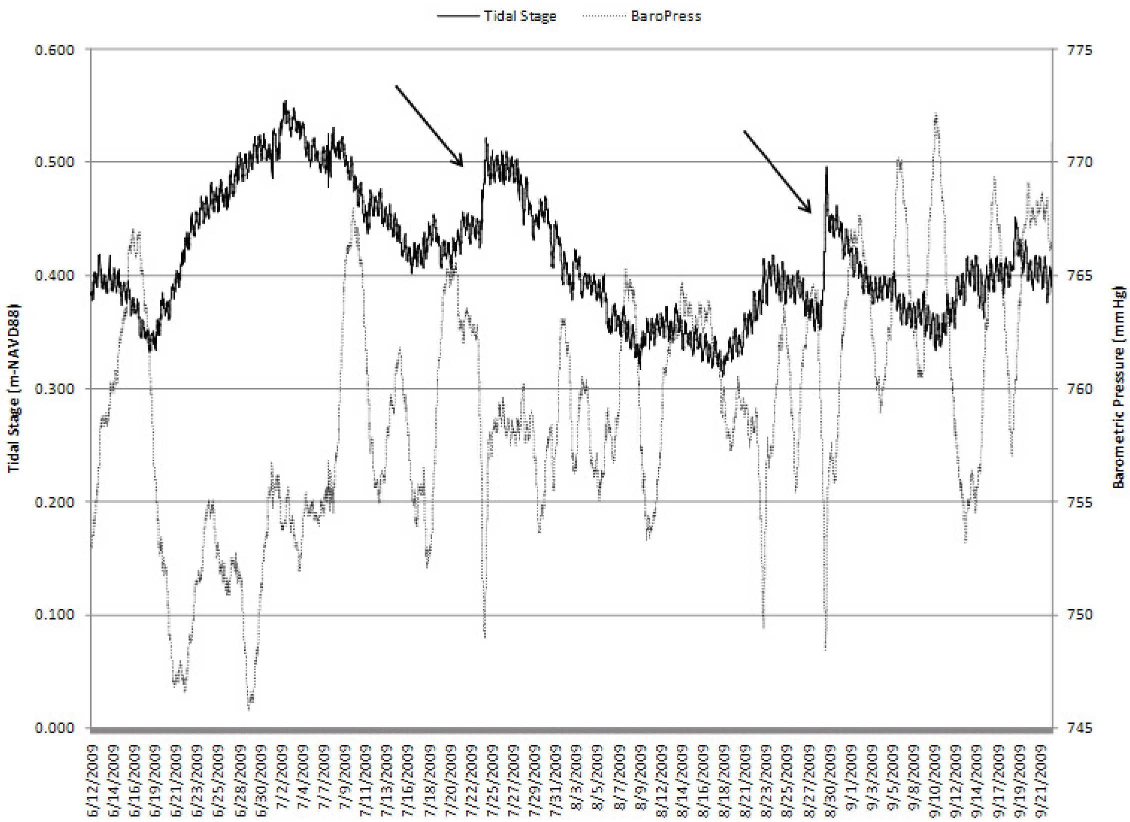

Figure 6a. Tidal stage (m-NAVD88) (solid line) and barometric pressure (dotted line) at the lagoon site in 2009. Arrows indicate spikes in water level due to specific storm events.

Figure 6b. Tidal stage (m-NAVD88) (solid line) and barometric pressure (dotted line) at the lagoon site in 2008 [NOTE: missing data was due to incorrect deployment of instrument that produced unusable data].

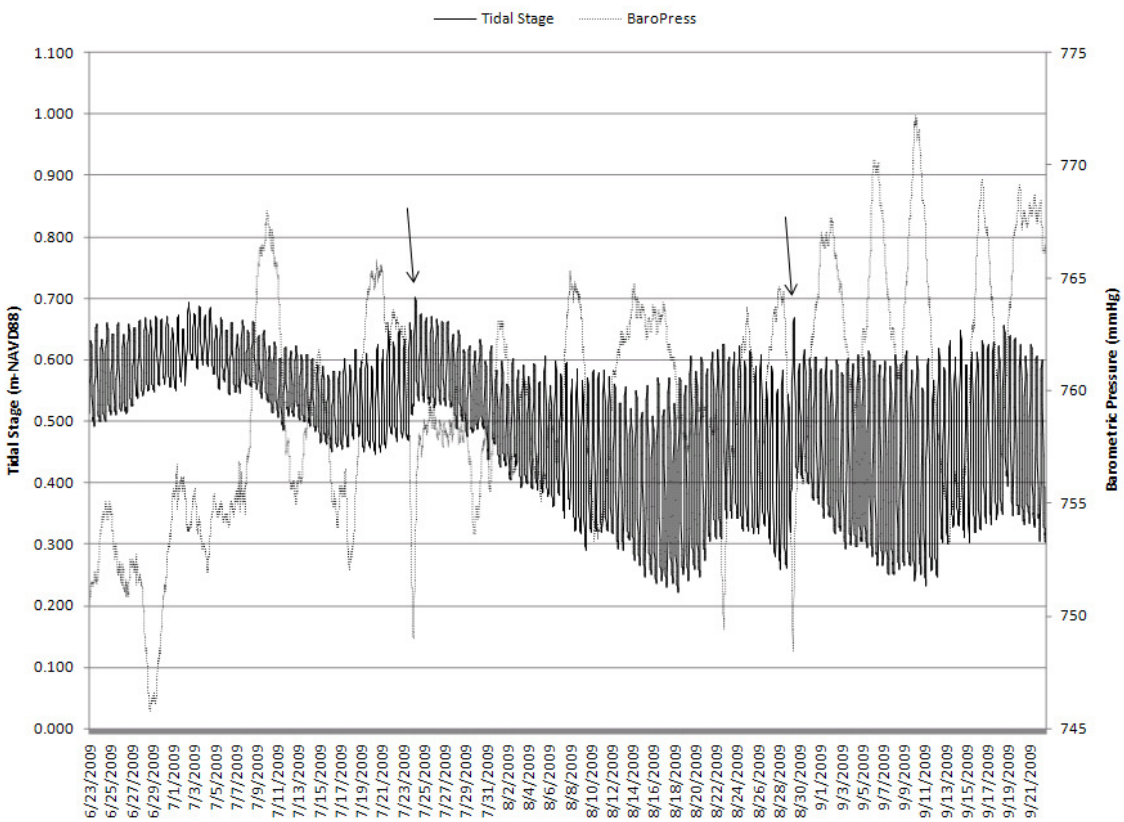

Figure 7a. Tidal stage (m_NAVD88) and barometric pressure (dotted line) at the creek site in 2009. Arrows indicate where large reductions in barometric pressure result in rapid changes in tidal stage.

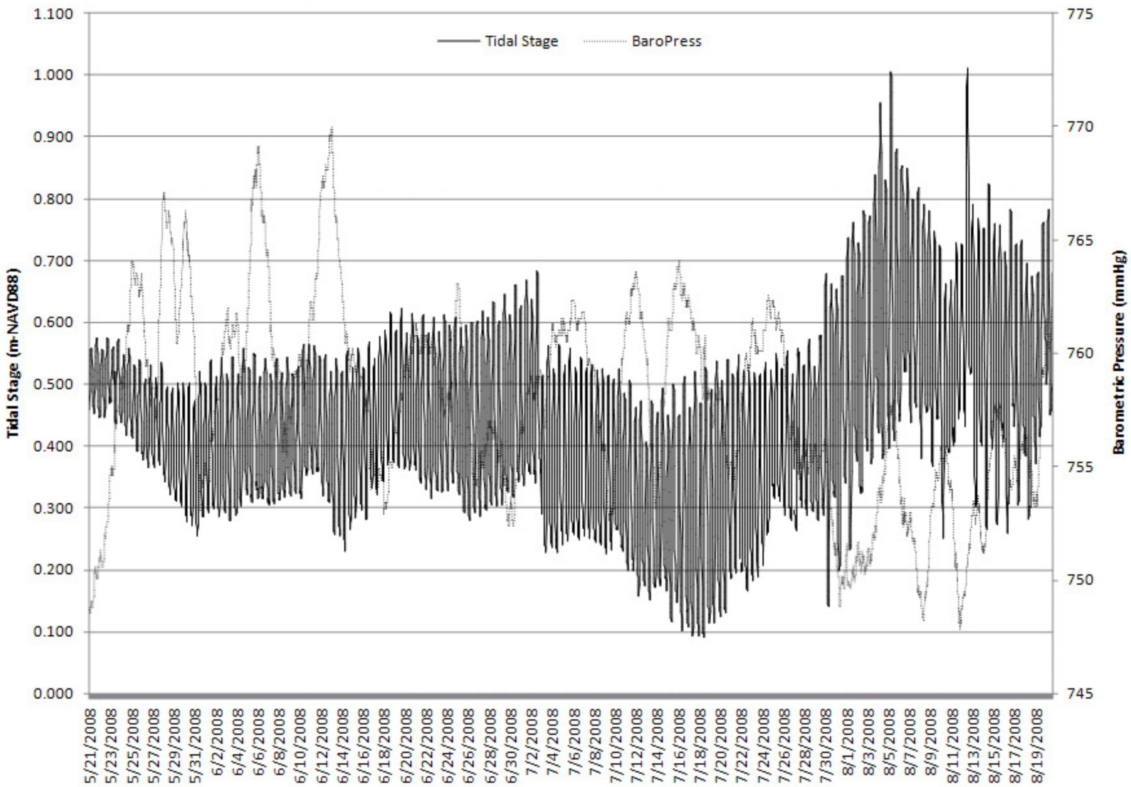

Figure 7b. Tidal stage (m_NAVD88) and barometric pressure (dotted line) at the creek site in 2008.

East Harbor's lagoon shows a small tidal influence on the order of 2-5 cm (depending on the stage in the tidal cycle) but large changes in water level over the course of a year are primarily controlled by precipitation and evaporation. The tidal range (max-min) for both the lagoon and tidal creek sites in 2008 was slightly larger than in 2009, but this variability is likely due to differences in the lagoon stage between years (Table 3). Until further tidal exchange in facilitated, water level fluctuations in the system will continue to be dominated by meteorologic phenomena, rather than the ocean tides.

Table 2. Mean high, mean low and tidal range (meters) in the lagoon (L) and Moon Pond tidal creek (MP) in 2008 and 2009.

WATER QUALITY

Krista Lee

Background

For the past three years (2007-2009), monthly surface water quality monitoring has been conducted at East Harbor to quantify a variety of physico-chmical and biological water quality constituents. Prior to 2007, limited data are available from 2002 and 2003 (total nutrients, chemical oxygen demand, and salinity) at the weir located at High Head Road.

East Harbor Water Quality Stations

Figure 8. Map of 2007-2009 water quality sampling locations.

Basic Sampling Design & Methods

Stations 1-6 were sampled on a monthly basis in 2009 just below the surface (~0.2 m) between 10 am and 3 pm on an outgoing tide for the following parameters; pH, specific conductance (µS/cm), salinity (ppt), dissolved oxygen (% saturation), dissolved oxygen concentration (mg/L), total dissolved solids (g/L), color (absorbance @ 440nm), turbidity (NTU), chlorophyll-α (µg/L) (filtered water/acetone extraction/fluorometric detection), dissolved inorganic nitrogen (µM) (DIN) (filtered/acidified sample: N as nitrate/nitrite + ammonium), total nitrogen (µM) (TN) (whole water sample/persulfate digest: N as NO_3), total dissolved nitrogen (µM) (TDN) (filtered sample/persulfate digest: N as NO_3), dissolved organic nitrogen (µM) (DON) (calculated by difference: TDN-DIN), dissolved inorganic phosphorus (µM) (filtered/acidified: P as PO_4), total phosphorus (µM) (TP) (whole water sample/persulfate digest: P as PO_4), and total dissolved phosphorus (µM) (TDP) (filtered sample/persulfate digest: P as PO_4).

A calibrated hand-held YSI 556 MPS is utilized on station to collect the pH, specific conductance, salinity, total dissolved solids, and dissolved oxygen measurements. A grab sample is collected at each station in clean, triple rinsed, amber 2 liter bottles and stored on ice in a cooler and returned to the lab for immediate processing for all other parameters. Sub-samples are filtered through a 0.45µm filter for all dissolved nutrient species and stored frozen at -20ºC until analysis; sub-samples for total nutrients are frozen at -20ºC until digestion and subsequent analysis. Sub-samples for color are filtered through a 0.45µm filter and analyzed immediately on a Jenway 6305 UV/VIS spectrophotometer at 440nm. Sub-samples for turbidity are analyzed on a calibrated Hach 1200 portable Turbidimeter. Sub-samples for chlorophyll-α are filtered through a 0.45µm glass fiber filter (filtrate volume noted) and filters are immediately placed in vials containing 90% acetone and placed in the dark at 5ºC for extraction of pigment; subsequent fluorometric measurements are taken in 24 hours for chlorophyll-α concentration determination via a Turner Designs Trilogy Fluorometer (USGS SOP #ORGX0337.3, 2005).

Inorganic nutrients (PO_4-P, NH_4-N,NO_2, and NO_3-N) are determined by Lachat FIA+ 8000 following Lachat Methods 10-115-01-1-M (rev. Aug. 27, 2003), 31-107-04-1-C (rev. Sept. 16, 2003), and 10-107-06-1-C (rev. Nov. 2, 2001), respectively. Total nutrients (nitrogen and phosphorus) are determined by simultaneous digestion with persulfate oxidizing reagent followed by FIA+ 8000 Lachat Methods 31-115-01-1-C (rev. Sept. 16, 2003) and 10-115-01-1-M (rev. Aug. 27, 2003). The USGS WRIR 03-4174 (Method for Persulfate Digestion) is utilized for the digestion of samples.

Summary & Discussion

During the 2009 field season, water clarity in the main lagoon averaged 3 NTU, which was similar to 2008 (Figure 9). Surface water temperatures throughout the system ranged from 2ºC in February to 26ºC in August and averaged 23 ±3ºC from June through August. Salinity at the Salt Meadow outflow station (Sta. 2) averaged 1.0 ± 0.4 ppt; all other stations averaged 23 ± 3ppt from February-December. These findings are very similar to 2008.

As average surface water temperatures increased approximately tenfold from February (2ºC) to July (23ºC), average ammonium levels remained relatively consistent at 2µM. However, average chlorophyll-α concentrations increased nearly ten-fold from 1µg/L in April to 9µg/L in July. Chlorophyll- α concentrations also peaked three times this year; in February at 61µg/L; in August at 15µg/L; and in October at 23µg/L.

Average surface water DO levels remained consistently high throughout the main water body (12 mg/L), although Salt Meadow (Sta. 2) DO dropped to less than 5 mg/L in July and remained well below that value throughout the summer and fall (data not shown). Slight increases of Total Phosphorus (TP) concentrations were observed throughout the lagoon (as well as in Salt Meadow) in the summer and again in the fall, which was similar, temporally, to 2008.

Ammonium dominated water-column DIN fraction throughout the winter. DIN values ranged between 1 µM in January to 3 µM throughout the rest of the field season, whereas in 2008 DIN values displayed much more seasonal variability (3-13 µM). The average molar ratio observed for DIN:TP for April-November 2009 was 4 [<<16 (Redfield Ratio)] indicating that primary productivity in East Harbor was strongly nitrogen limited from April to November. Additionally, average DIN:TN and DIN:DON from August indicate approximately ten times more organic nitrogen present in the surface water than dissolved inorganic species. These ratios were similar, albeit somewhat lower in 2007 & 2008.

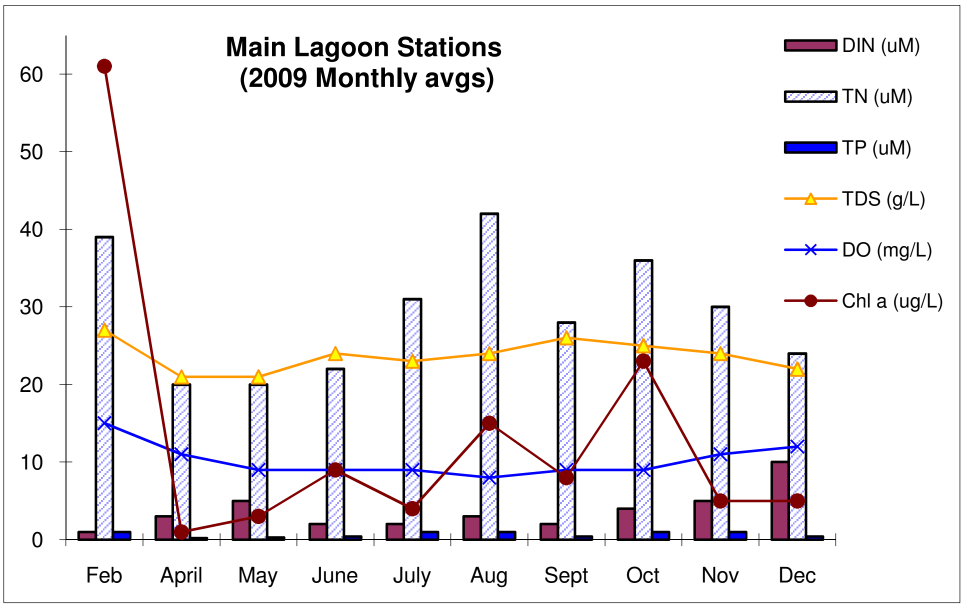

Figure 9. Monthly averages across Main Lagoon stations (Stations 3-5)

Future analysis and monitoring plans

Monthly surface water monitoring will continue on a year round basis and additional nitrogen flux studies may be implemented in 2010.

VEGETATION

Stephen Smith

A detailed overview of vegetation monitoring protocols can be found in Portnoy et al. (2008). The following provides an update to these reports based on data collected during the summer-fall of 2009.

Methods

Plant species abundance in the permanent vegetation plots was assessed by visual estimation of cover class according to a modified Braun-Blanquet scale (0=0, >0-5%=1, 6-25%=2, 26-50%=3, 51-75%=4, 76-100%=5) in August. *Phragmites* maximum stem heights and stem densities for each plot were recorded at the end of the 2009 growing season (September). Biomass was estimated based on regression equations using the two above variables (R^2=0.95). The estimates are very close to those determined from stem densities + maximum stem height.

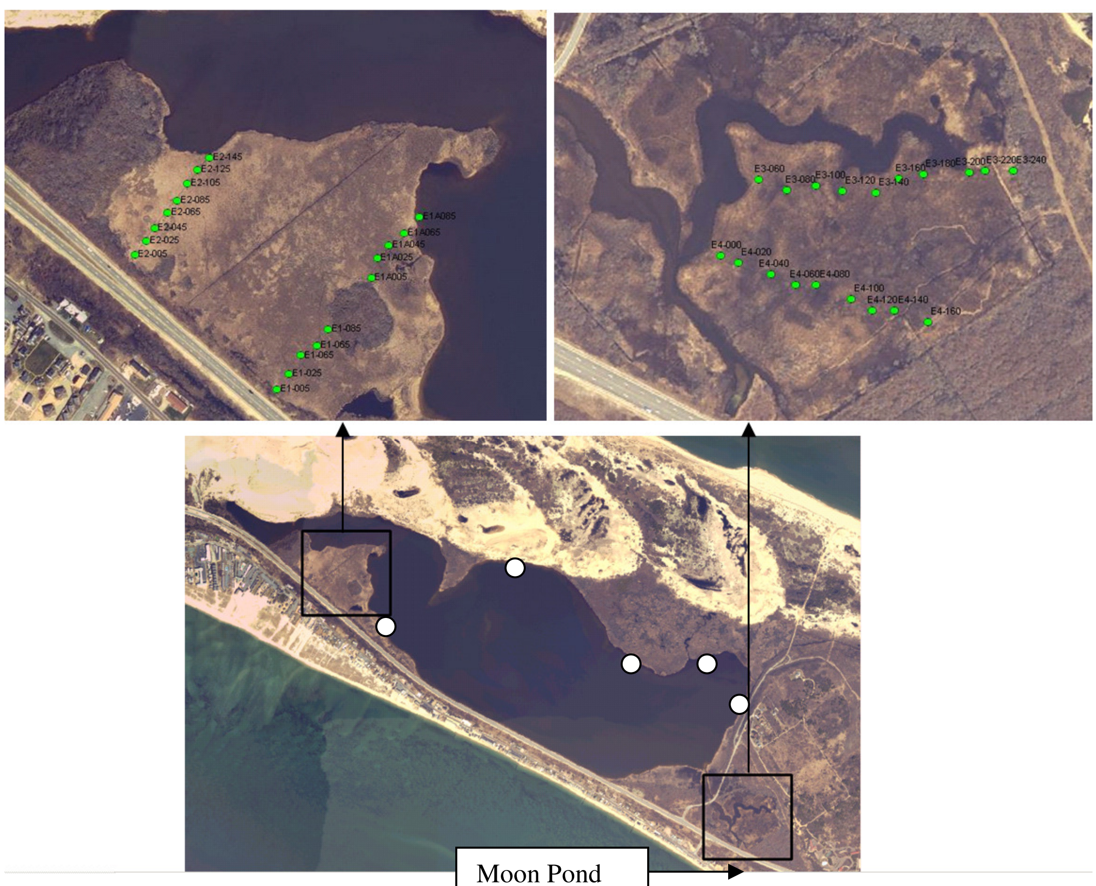

Figure 10. Map of East Harbor with vegetation plot and seagrass monitoring locations.

Data analysis

Non-metric multidimensional (NMDS) scaling was used to illustrate changes in the composition of the plant community between 2008 and 2009. Analysis of Similarities (ANOSIM) was used to test for significance of these changes (Primer™ ver. 6). In addition, Repeated-measures Analysis of Variance (ANOVA) was used to assess annual changes in *Phragmites* heights, densities, and biomass (all plots pooled).

Results

While minor changes in the cover of non-dominant species occurred between 2008 and 2009, there was no statistically significant change in overall species composition as assessed by ANOSIM (Global $R = -0.011$; $p = 0.69$). NMDS of species raw cover scores shows only minor spatial shifts of plots in ordinal space (Figure 11a). Nonetheless, a number of interesting changes did occur, which are reflected in individual species data (Table 3). At the transect level, EH1 showed the largest shift in composition between 2008-2009, which is reflected in the MDS plot of centroid values (Figure 11b). This was primarily due to the disappearance of *Galium trifidum* and *Lysimachia terrestris* and the appearance of *Eupatorium dubium* in 2009. Generally speaking, however, virtually all non-halophytic species had lower summed cover score values in 2009 compared with the year prior. Figure 12 shows the total change between 2002 and 2009, with EH3 and EH4 plots demonstrating the largest shifts.

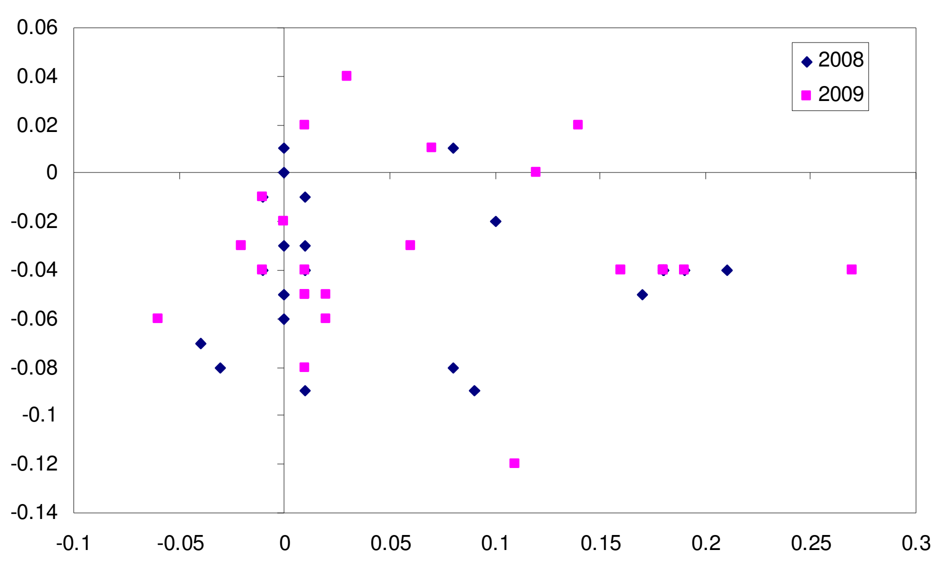

Figure 11a. Non-metric multidimensional scaling of summed cover class values of East harbor plant taxa in vegetation plots (August 2008 vs. August 2009).

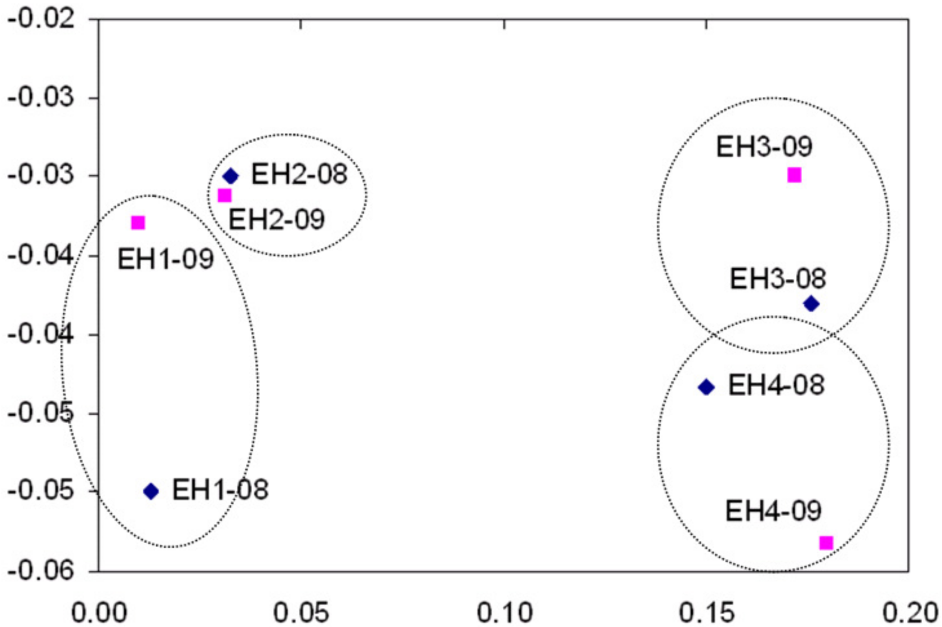

Figure 11b. Centroids of MDS values (depicts means of plot locations by transect; same trasects for the two different years are within circled areas).

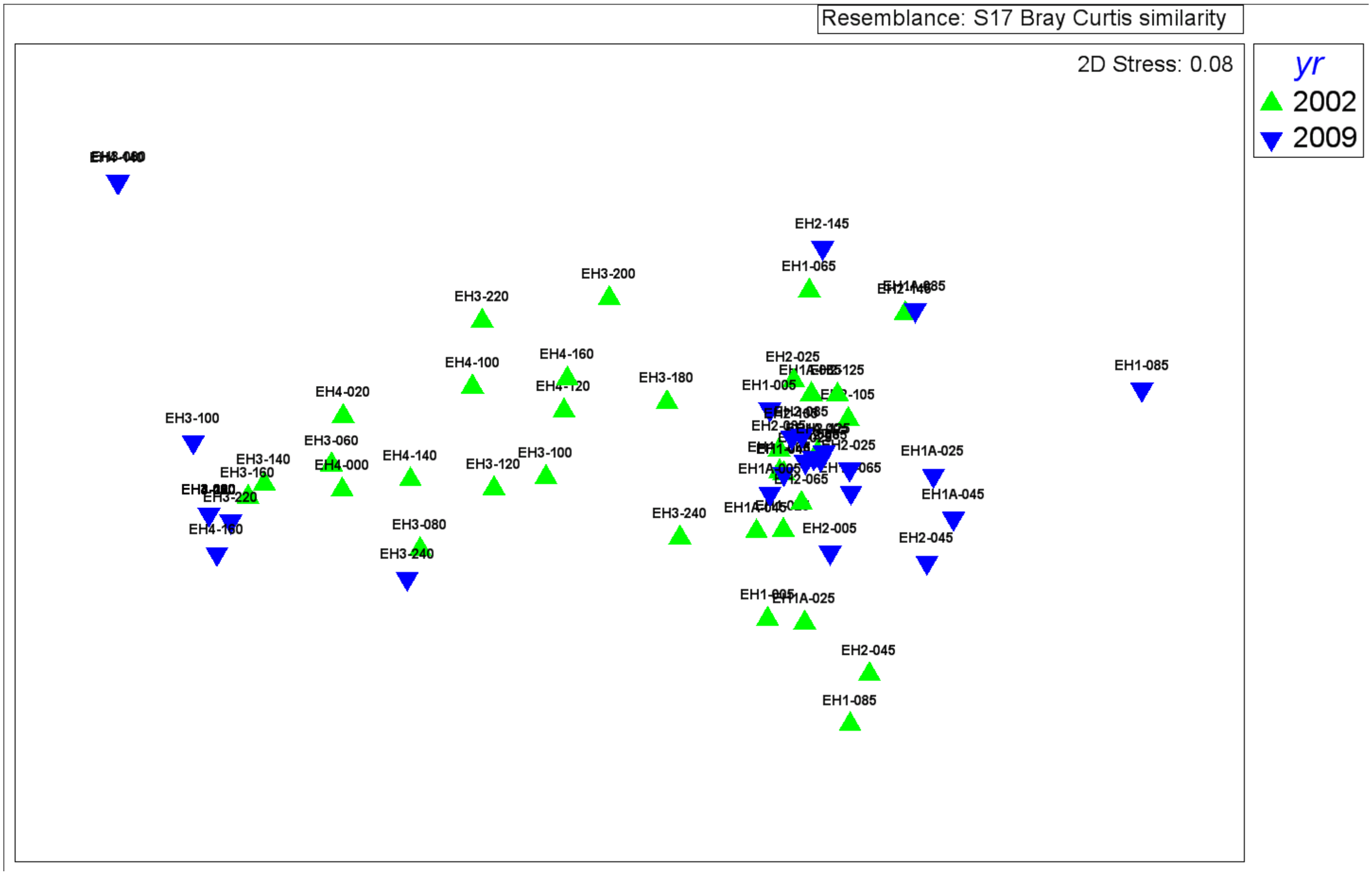

Figure 12. Non-metric multidimensional scaling of summed cover class values of East Harbor plant taxa in vegetation plots (2002 vs. 2009).

Table 3. Frequency of occurrence (% of total plots in which taxa occurs) and summed cover class values of East Harbor plant taxa in 2008 vs. 2009.

	2008	2009	Change	2008	2009	Change
Aster novi-belgii	8%	11%	3%	6	5	-1
Bohmeria cylindrica	8%	11%	3%	10	8	-2
Calystegia sepium	5%	0%	-5%	3	0	-3
Erechtites hieracifolia	3%	3%	0%	6	2	-4
Eupatorium dubium	0%	3%	3%	0	1	1
Galium trifidum	5%	0%	-5%	4	0	-4
Impatiens capensis	3%	3%	0%	2	1	-1
Lemna minor	5%	8%	3%	5	14	9
Lysimachia terrestris	3%	0%	-3%	1	0	-1
Lythrum salicaria	8%	8%	0%	8	5	-3
Onoclea sensibilis	8%	11%	3%	17	16	-1
Parthenocissus cinquefolia	0%	3%	3%	0	1	1
Phragmites australis	46%	43%	-3%	106	96	-10
Polygonum arifolium	3%	0%	-3%	4	0	-4
Rosa palustris	5%	5%	0%	4	2	-2
Rumex orbiculatus	8%	5%	-3%	13	4	-9
Sphagnum sp.	3%	3%	0%	7	2	-5
Thelypteris palustris	43%	43%	0%	75	71	-4
Toxicodendron radicans	43%	46%	3%	81	56	-25
Triadenum virginicum	3%	0%	-3%	2	0	-2
Typha angustifolia	51%	49%	-3%	104	90	-14

For the dominant species of emergent vegetation, *Typha* and *Phragmites*, there were relatively small, mostly negative changes in cover scores within individual plots with the exception a couple of *Typha*-dominated plots, which had fairly large reductions (Table 4). However, it is obvious that there is more decline in both species in many areas outside the monitoring network. This is conspicuous in aerial and ground level photography and is discussed further below.

Table 4. *Typha* and *Phragmites* cover scores in August of 2008 and 2009.

Plot	Species	2008	2009	Change	Plot	Species	2008	2009	Change
E3-060	Phragmites australis	7	7	0	E1-005	Typha angustifolia	6	4	-2
E3-080	Phragmites australis	4	2	-2	E1-025	Typha angustifolia	6	5	-1
E3-100	Phragmites australis	6	5	-1	E1-045	Typha angustifolia	6	4	-2
E3-120	Phragmites australis	7	7	0	E1-065	Typha angustifolia	5	5	0
E3-140	Phragmites australis	7	7	0	E1-085	Typha angustifolia	3	6	3
E3-160	Phragmites australis	7	7	0	E1A-005	Typha angustifolia	5	4	-1
E3-180	Phragmites australis	7	7	0	E1A-025	Typha angustifolia	6	6	0
E3-200	Phragmites australis	7	7	0	E1A-045	Typha angustifolia	6	5	-1
E3-220	Phragmites australis	7	6	-1	E1A-065	Typha angustifolia	6	5	-1
E3-240	Phragmites australis	4	6	2	E1A-085	Typha angustifolia	7	4	-3
E4-000	Phragmites australis	7	7	0	E2-005	Typha angustifolia	4	5	1
E4-020	Phragmites australis	7	7	0	E2-025	Typha angustifolia	6	6	0
E4-040	Phragmites australis	0	0	0	E2-045	Typha angustifolia	6	5	-1
E4-060	Phragmites australis	0	0	0	E2-065	Typha angustifolia	6	5	-1
E4-080	Phragmites australis	0	0	0	E2-085	Typha angustifolia	5	5	0
E4-100	Phragmites australis	7	7	0	E2-105	Typha angustifolia	5	4	-1
E4-120	Phragmites australis	7	7	0	E2-125	Typha angustifolia	5	5	0
E4-160	Phragmites australis	7	6	-1	E2-145	Typha angustifolia	7	4	-3
					E3-240	Typha angustifolia	4	0	-4

Phragmites biomass (calculated from maximum stem height measurements and stem density counts), decreased in 11 out of 16 plots between 2008 and 2009 (Figure 13). Overall (all plots pooled), there was no statistically significant change in biomass during the last three years along the transects. Since opening the system to tidal influence over 6 years ago, *Phragmites* has declined significantly with biomass values being almost halved since 2003 (Figure 14).

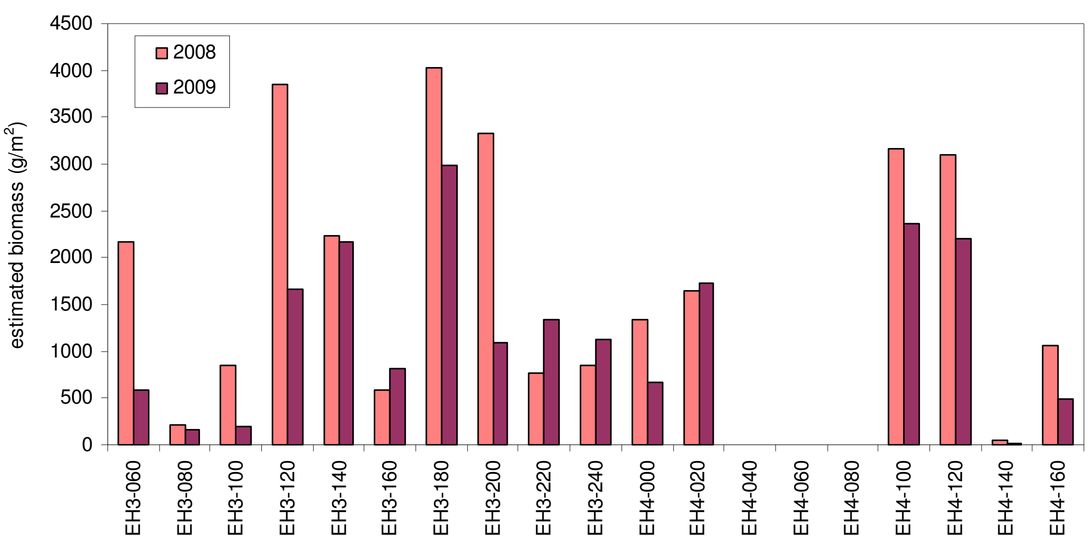

Figure 13. *Phragmites* biomass along transects EH3 and EH4 by individual plots and year (note: there are no error bars as only one biomass value can be calculated for each plot).

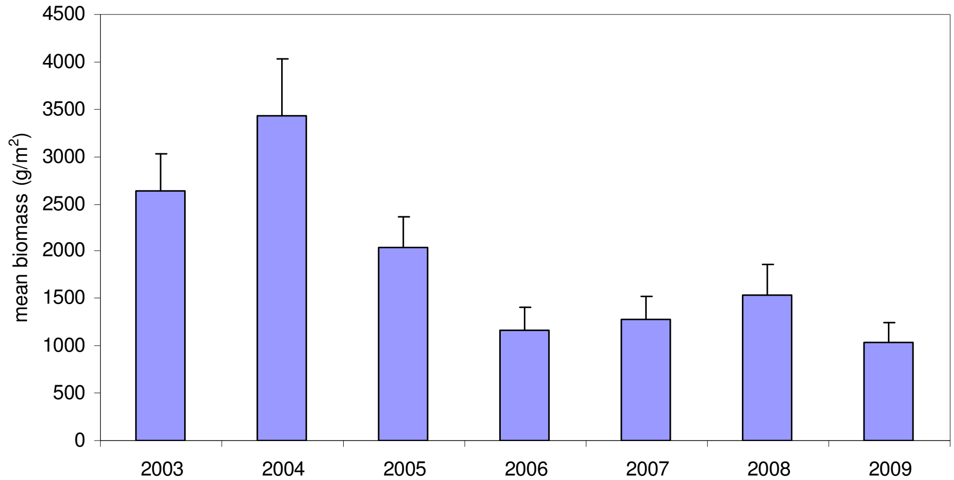

Figure 14. *Phragmites* mean biomass (all plots pooled) by year (error bars are standard error of the mean).

Qualitative observations on emergent vegetation

In and around the Moon Pond area, where 2 permanent transects are located, *Phragmites* outside the plot network appears to be continuing its decline. The grey (dead stems) and light green (surface algae) patches in Figure 15 (below) highlight the areas where *Phragmites* has thinned or disappeared and it is expected that this area will continue to open up and eventually be colonized by halophytes as there are now many source populations that have become established nearby.

Figure 15. Aerial view of Moon Pond showing patches of dead and dying *Phragmites* and *Typha* (gray areas).

There were also several new areas of salt-killed *Typha* observed in 2009 (Figure 16). High water levels during the end of June/beginning of July allowed salt water to penetrate into some of the low-lying peripheral marsh areas. Apparently the duration over which these areas were flooded with salt water was enough to cause major foliage death. It remains to be seen whether the salt stress was lethal or if these areas will recover next year.

Figure 16. Ground-level photo showing a new area of salt-stressed and dead (?) cattail (August 09).

Plantings and seedings of native halophytic vegetation

The planting and seeding efforts of previous years have yielded excellent results. Native halophytes, particularly *S. alterniflora* and *Salicornia maritima* have expanded rapidly throughout the system and are colonizing new areas every year. The *S. alterniflora* plugs that were planted 2 years ago have grown dramatically and are now forming prominent stands along the shoreline of the lagoon (Figure 17).

Figure 17. Map of 2007 planting locations (left) and a stand of *S. alterniflora* that has grown vegetatively from a single 4-inch diameter plug since that time (right; August 2009).

Porewater salinities in the vegetation plots

It is important to reiterate that porewater salinity data represents a single sampling event. In reality, salinity may fluctuate substantially over the course of a single growing season. Notwithstanding, the spatial gradients in salinity remain similar to past years following the permanent opening of the culvert in 2002, with values decreasing sharply near the upland borders and with EH3 and EH4 transects (Moon Pond) having much higher salinities than EH1 and EH2 (Table 5). In general, these snapshots of salinities show that while the system remains salty, there may be considerable year-to-year fluctuation in porewater conditions. Because these data are a one-time sampling event, it is impossible to know whether how well these values reflect seasonal averages. Salinity dataloggers are needed to elucidate the true nature of salinity dynamics over longer periods of time and to assess how closely instantaneous measures reflect overall salinity regimes.

Table 5. Porewater salinities in selected plots along the Moon Pond transects (2003-2009).

	08/19/03	08/23/04	09/22/05	8/25/2006	8/15/2007	9/25/2008	08/31/09
EH1-005	4	2	5	0	2	0	0
EH1-045	5	2	4	2	2	0	0
EH1-085	5	2	5	0	2	1	0
EH1A-005	4	2	4	0	3	2	0
EH1A-045	10	2	8	8	4	2	1
EH1A-085	10	1	9	10	6	3	2
EH2-025	2	0	4	0	1	3	0
EH2-065	2	0	4	0	2	2	0
EH2-105	2	2	4	7	2	1	0
EH2-145	3	2	7	7	8	2	0
	2003	2004	2005	2006	2007	2008	2009
EH3-060	dry	15	dry	dry	dry	dry	6
EH3-100	25	22	23	20	20	26	22
EH3-140	24	13	22	14	-	22	12
EH3-180	23	15	20	12	10	14	9
EH3-220	21	8	14	2	5	3	2
EH4-000	25	20	-	-	25	28	30
EH4-040	33	32	37	34	35	34	40
EH4-080	32	32	34	26	32	33	32
EH4-120	30	20	30	15	20	20	20
EH4-160	29	11	24	12	14	14	22
mean-EH1/2	4.7	1.5	5.4	3.4	3.2	1.6	0.3
mean-EH3/4	26.9	18.8	25.5	16.9	20.1	21.6	19.5

Some ancillary salinity data was collected in 2009 using two newly-purchased conductivity loggers placed within the Moon Pond area on the west and east sides of High Head Road (see map below). The loggers recorded conductivity data every 30 min from Aug 1 to Aug 15, 2009. These data were then transformed to salinities using a standard regression equations determined from previous YSI data (salinity = 0.668*conductivity – 1.148; R^2=0.997). The results show large variations in salinities in both locations that are apparently linked with the tidal cycle. In fact, changes of 8-10 ppt were commonplace during this particular period. As such, this data emphasizes the need for caution when interpreting instantaneous measures of such variables. The data also illustrate the partial loss of the tidal signal due the High Head road. Note that the site west of the road (upstream from where seawater enters the system) shows fewer high and lows than does the east side site which is on the downstream side of the restricting road. In effect, High Head Road appears to be restrictive enough to eliminate the lower high tides and the higher low tides on a daily basis for this particular piece of peripheral marsh.

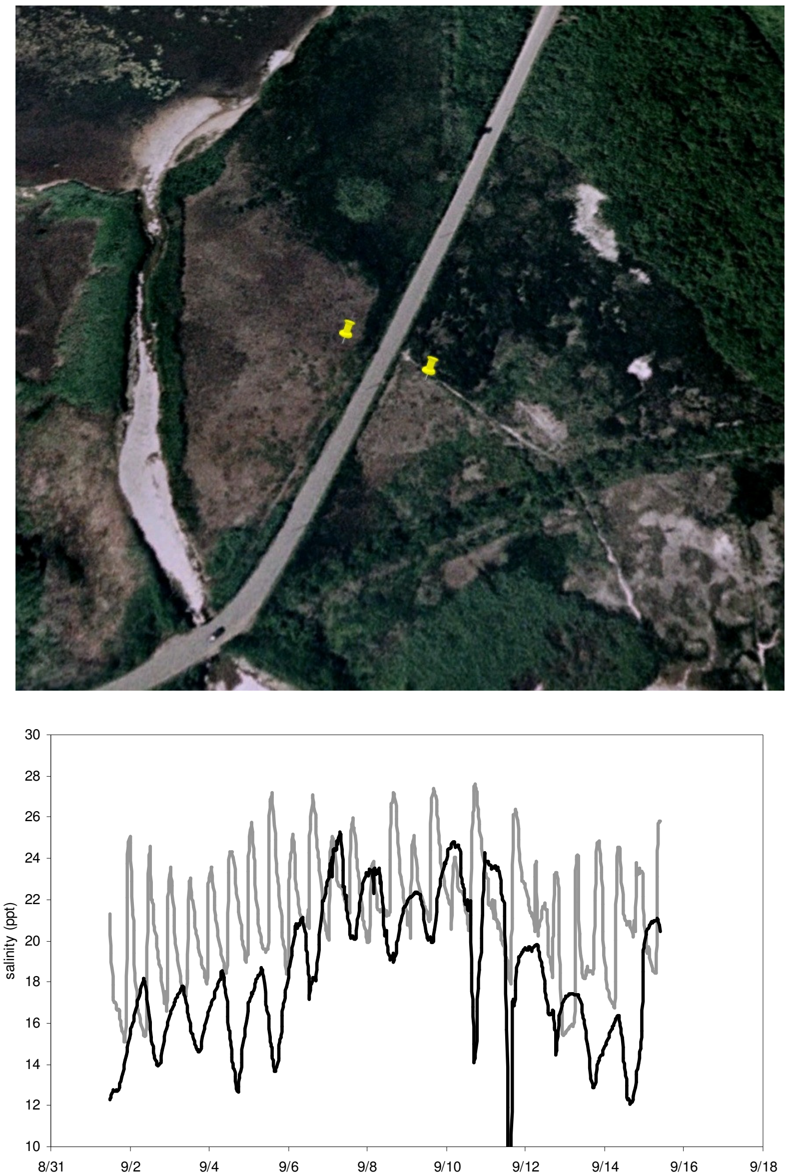

Figure 18. Salinity fluctuations over time in two locations in Moon Pond (Aug 1-15, 2009) (grey line = east side site; black line = west-side site).

Porewater salinities along the additional transects established in 2008 showed an almost identical pattern to transects EH1 and EH2 (Table 7). Salinities were highest in plots along the lagoon edge with sharp decreases upslope. In fact, freshwater predominates in almost in all other plots – a consequence of the current lack of tides in the lagoon.

Table 6. New transect salinity (ppt) data (10 cm depth) from August 2009.

Plot	Sal (ppt)	Plot	Sal (ppt)
EH5-000	8	EH8-000	5
EH5-010	1	EH8-035	0
EH5-035	0	EH8-090	0
EH5-050	0	EH8-095	0
EH5-100	0	EH8-125	0
EH5-120	0		
		EH9-000	6
EH7-000	6	EH9-030	3
EH7-010	0	EH9-070	0
EH7-020	0	EH9-150	0
EH7-050	0	EH9-225	0
EH7-080	0	EH9-295	0
EH7-090	0	EH9-345	0

Submerged Aquatic Vegetation

All previous monitoring results and methods for SAV monitoring can be found in Portnoy et al. (2008). In 2009, there was a dramatic disappearance of seagrass at the monitoring sites and, anecdotally, throughout most of the lagoon. Astonishingly, no *Ruppia maritima* (widgeon grass) or *Zostera marina* (eelgrass) was recorded at any of the monitoring transects, which were all completely bare (Table 7). These species were still present in the lagoon, but only in very small scattered patches. The reason for this is still unclear, but we suspect the combination of high turbidity events during 2009 and more or less continuous macroalgae/periphyton smothering since 2004 may be responsible for the decline. It is also possible that winter storms which move large amounts of sediment around the system (particularly around the edges in shallow water) contributed to some of the loss by burial or uprooting.

Table 7. Percent cover of submerged aquatic vegetation by transect in East Harbor in 2004-2008 (highlighted values at bottom are standard errors of the mean values immediately above).

		R. maritima					*Z. marina*				
		Sep 04	Sep 05	Sep 07	Sep 08	Sep 09	Sep 04	Sep 05	Sep 07	Sep 08	Sep 09
shallow	8	10%	16%	16%	48%	0%	2%	2%	0%	0%	0%
	6	22%	64%	98%	4%	0%	0%	0%	0%	0%	0%
	1	34%	68%	0%	0%	0%	0%	0%	0%	0%	0%
	4	6%	42%	58%	56%	0%	0%	0%	0%	0%	0%
	7	26%	74%	46%	98%	0%	0%	0%	2%	0%	0%
deep	8	4%	16%	20%	78%	0%	0%	2%	0%	0%	0%
	6	2%	64%	90%	96%	0%	0%	0%	0%	0%	0%
	1	20%	52%	4%	0%	0%	0%	0%	0%	0%	0%
	4	8%	38%	44%	64%	0%	0%	0%	0%	0%	0%
	7	6%	50%	48%	94%	0%	0%	2%	0%	0%	0%
	mean shallow	22.0%	62.0%	43.6%	41.2%	0%	0%	0%	0%	0%	0%
	mean deep	9.0%	51.0%	41.2%	66.4%	0%	0%	1%	0%	0%	0%
	mean total	14%	48%	42%	54%	0%	0%	1%	0%	0%	0%
		5%	11%	17%	18%	0%	0%	0%	0%	0%	0%
		3%	8%	15%	18%	0%	0%	0%	0%	0%	0%
		5%	9%	15%	18%	0%	0%	0%	0%	0%	0%

Figure 19. Photo showing turbid water in East Harbor during August of 2009 (left) vs. August 2008 (right).

A comment on the influence of Salt Meadow discharges on East Harbor water quality

With high amounts of precipitation, the freshwater discharge out of salt meadow into the eastern portion of the lagoon can be substantial. This is evident by refraction of sunlight when there is a sharp halocline during periods of high discharge coinciding with calm conditions that limit mixing. It is also evident by a change in color of the lagoon water, as salt meadow outflow is generally quite dark and rich in dissolved organics. The contrast between this and the clearer saltier water from the tidal creek as it moves into the lagoon is illustrated in Figure 20. This photo shows the extent to which salt meadow discharges can influence water quality in the lagoon – primarily salinity and light penetration. Nutrient loading from this system has not been determined but efforts to monitor stream flow from salt meadow are being planned. The fact that this system has been dramatically altered from a sinuous tidal channel to a straightened channel presumably has increased discharge volumes. From this, it would stand to reason that there is more freshwater and nutrient input from salt meadow system than there would be if the original creek structure were still intact.

Figure 20. Photo showing the influence of Salt meadow outflow (organics-rich, colored water) into the lagoon.

Nekton

Sophia E. Fox and Holly K. Bayley

Introduction

To assess the success of the partial restoration of East Harbor, the Cape Cod National Seashore (CACO) has been monitoring the nekton community in the ecosystem since 2003. Nekton are defined as assemblages of free swimming fishes and decapod crustaceans. They are abundant and productive fauna in salt marshes and provide a critical trophic link between primary producers and consumers and top predators (Friedland et al. 1988; Smith 1997; Valiela et al. 2004). Due to their high degree of mobility, nekton respond rapidly to changes in environmental conditions caused by anthropogenic and natural disturbances such as changes in hydrology, water quality, and storms. To examine the relationship between nekton community structure and physical, chemical, and biological properties of the East Harbor ecosystem, CACO monitors nekton species composition, density, and size distributions in combination with environmental parameters, including water temperature, depth, salinity, dissolved oxygen, sediment type, and vegetation. In addition to tracking changes in nekton community structure, the associated environmental monitoring allows natural resource managers and scientists to examine how environmental conditions vary over time.

The nekton of the East Harbor system have been monitored for seven years after restoration of tidal flow to the previously impounded system. Below is a brief synthesis of the nekton monitoring data from the lagoon and Moon Pond within the East Harbor System (Figure 10) for data collected in 2009 and a comparison of 2009 data to previous years.

Methods

Sampling design, methods and equipment were similar to those of the previous years of nekton sampling from 2003-2008. A detailed description of sampling methods for 2003-2009 can be found in the nekton monitoring protocol (Raposa and Roman 2001). In 2009, all nekton samples were collected using throw traps, and supplementary gear types were not utilized as in previous years.

Sample Design

Nekton were sampled at randomly selected stations within the East Harbor Lagoon and Moon Pond in early summer (June/July) and late summer (August/September) 2009. The late summer sampling took place in the same locations as the early summer sampling. Nekton were sampled using a 1m^2 throw trap at 30 locations in East Harbor Lagoon and 15 locations in Moon Pond; these sample sizes were found to be sufficient to characterize the communities in previous years.

Data Analysis

Species richness, species diversity, relative species composition, and average densities were calculated for the entire East Harbor system and for the East Harbor Lagoon and Moon Pond locations individually. For the purpose of these analyses, only samples collected using throw traps were included for all years, and the data were pooled over the early and late summer sampling periods.

Results

The nekton of East Harbor have responded to increased seawater flow through the tidal creek (Moon Pond) to the upstream lagoon (East Harbor Lagoon). In 2009, seven years post-restoration, total nekton density in the East Harbor system was 17.3 individuals/m^2, with similar densities in Moon Pond and East Harbor Lagoon (Table 8). In contrast in 2003, one year post-restoration, total nekton density in the system was higher at 39.1 individuals/m^2, with significantly higher densities of individuals collected in the Moon Pond creek than in the East Harbor Lagoon.

Table 8: Number of nekton species, diversity, as measured by Simpson's diversity index, and total nekton density for the East Harbor System, Moon Pond, and Lagoon, 2003 and 2009.

	Number of species		Simpson's diversity index		Total nekton density	
	2003	2009	2003	2009	2003	2009
East Harbor System	12	13	0.37	0.66	39.1 ± 11.5	17.3 ± 3.4
Moon Pond	9	11	0.29	0.45	80.6 ± 24.1	24.2 ± 8.6
East Harbor Lagoon	6	10	0.69	0.74	8.0 ± 2.7	13.9 ± 2.8

East Harbor species diversity

In 2009, 13 species were collected in the East Harbor system, and the number of species was similar in both East Harbor Lagoon and Moon Pond (Table 8). The number of species collected from the entire system was similar in 2003 to 2009. In the creek and lagoon, however, there were fewer species in 2003 than in 2009, with the fewest species collected in the East Harbor Lagoon.

By applying the Simpson's diversity index, differences in species diversity between habitats and years can be evaluated. As with many diversity indices, the Simpson's index of diversity represents the number of species present, as well as the relative abundances of each species. The Simpson's diversity index (1-*D*) ranges from 0 to 1, with 0 indicating no diversity and 1 indicating infinite diversity. In 2009, the Simpson's diversity index was high for the East Harbor system and the lagoon, while the Moon Pond creek exhibited relatively lower species diversity (Table 8). In contrast, the species diversity in 2003 was low in the East Harbor system overall and in Moon Pond creek, while there was high diversity in the East Harbor Lagoon. The lagoon exhibited higher variability from year to year than the Moon Pond creek and the East harbor system overall (Figure 21).

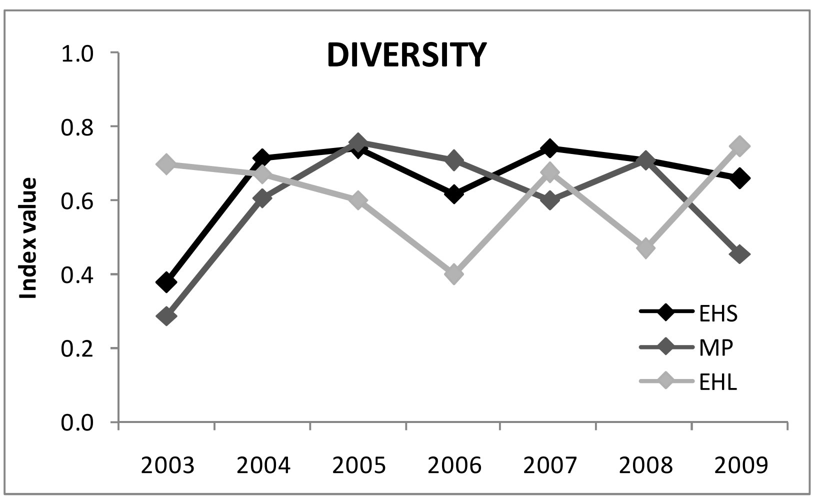

Figure 21. Diversity, as measured by Simpson's index of diversity (1-*D*), for the East Harbor System (EHS), Moon Pond (MP), and Lagoon (EHL), 2003-2009.

Nekton density and species composition

East Harbor system

The nekton community of the East Harbor system has responded to the restoration of tidal estuarine conditions, which occurred in 2002. Nekton density was highly variable during the first couple of years following restoration, 2003 and 2004 (Figure 22). Since 2005, however, the density of nekton in the system has remained relatively constant over time. In 2003, the nekton taxa sampled were mainly crustaceans, but in subsequent years the densities of fish were greater than or similar to densities of crustaceans (Figures 22 & 23). In 2008 and 2009, grass shrimp of the genus *Palaemonetes* were the dominant crustaceans in East Harbor, and the silverside, *Menidia menidia*, and the mummichog, *Fundulus heteroclitus*, were the dominant fish species (Tables 9 & 10). During earlier years, there was a trend of dominance by these three taxa, but there were also notable differences. In 2006 and 2007, for example, the sand shrimp, *Crangon septemspinosa*, was significantly more abundant than *Palaemonetes* spp. (Tables 9 & 10).

Moon Pond

In 2009, total nekton density in Moon Pond was relatively high at 24.2 individuals/m^2, but the species diversity, as measured by the Simpson's diversity index, was relatively low (Table 8). Nekton density in Moon Pond from 2003 to 2009 was highly variable with large inter-annual differences in total nekton and crustacean densities (Figure 22). Fish densities were more constant over time. The 2009 sampling effort yielded the lowest fish density of all sampling years. In 2009, sampling took place in late June/July and early September. The September sampling in Moon Pond accounted for ~93% of the total number of nekton caught (data not shown). The lower densities of fish in 2009, therefore, reflect the low densities observed during the early summer sampling period relative to other years. Crustacean densities were variable across time, but 2009 densities were similar to those from 2008 (Figure 22).

The relative abundances of fish in Moon Pond tended to be lower than crustaceans across the sampling period, with the exceptions of 2005 and 2008 (Figure 23). The dominant crustaceans in Moon Pond, two shrimp taxa, tended to exhibit an inverse pattern of relative dominance, whereby *Palaemonetes* spp. were less abundant when *C. septemspinosa* were more abundant (Tables 11 & 12). There was a gradual decline in density of *Palaemonetes* spp. from 2003 to 2005 that was accompanied by an increase in density of *C. septemspinosa.* In 2009, *Palaemonetes* spp. represented 72% of all nekton sampled (Table 12). In 2008 and 2009, *M.*

menidia was the most abundant fish species. This was different from earlier years when *F. heteroclitus* was most abundant. *F. heteroclitus*, *M. menidia*, and *Palaemonetes* spp. tended to dominate the nekton assemblages in all years with two exceptions (Tables 11 & 12). First, in 2009, density of *F. heteroclitus* was substantially lower than in any other year. Second, *C. septemspinosa* were more abundant in 2006 and 2007 than in any other year, and were a numerically dominant species in Moon Pond. The flounder, *Pseudopleuronectes americanus*, is a marine species of commercial importance, which has been encountered in relatively low abundances in Moon Pond since 2005. The cunner, *Tautogolabrus adspersus*, is another marine species that has been encountered in more recent years. Other common estuarine species encountered in Moon Pond in 2009 included *Anguilla rostrata*, *Apeltes quadracus*, *Ovalipes ocellatus*, *Carcinus maenas*, and *Syngnathus fuscus*.

East Harbor Lagoon

In 2009, total nekton density in East Harbor Lagoon was relatively high at 13.9 individuals/m^2, and the species diversity, as measured by the Simpson's diversity index, was also quite high (Table 8). Nekton density in East Harbor Lagoon was variable for the first couple of years post-restoration, but from 2005 to 2009 there were few inter-annual differences in total nekton, crustacean and fish densities (Figure 22). Similar to Moon Pond, the 2009 sampling effort yielded the lowest density of fish since 2003. In 2009, sampling took place in late June/July and early September. The September summer sampling accounted for ~95% of the total number of individuals caught (data not shown). The lower densities of fish in 2009, therefore, reflect the low densities observed during the early summer sampling period relative to other years. Crustacean density in 2009 was higher than previous years, but still quite low compared to Moon Pond. In contrast to Moon Pond, the variability in crustacean density among years was lower than the variability in fish density (Figure 22), possibly due to lower densities overall.

The majority of individuals collected in 2009 were fishes, with the relative abundance of fish ~57% versus crustaceans ~43% (Figure 23). The majority of individuals collected were fishes in all years, although the difference between the relative abundances of fishes and crustaceans was lower in 2009 than in previous years (Figure 23). In recent years, fish assemblages have been dominated by *F. heteroclitus* and *M. menidia*, as in Moon Pond (Tables 6 & 7). In some years *A. quadracus* has also been a numerically dominant fish species. Crustacean assemblages have been dominated by *Palaemonetes* spp.in all years, with the exception of 2007 when *C. septemspinosa* was most abundant. Other common estuarine species encountered in East Harbor Lagoon in 2009 included *A. rostrata, A. quadracus, F. diaphanus, Gasterosteus aculeatus, P. americanus,* and *S. fuscus*.

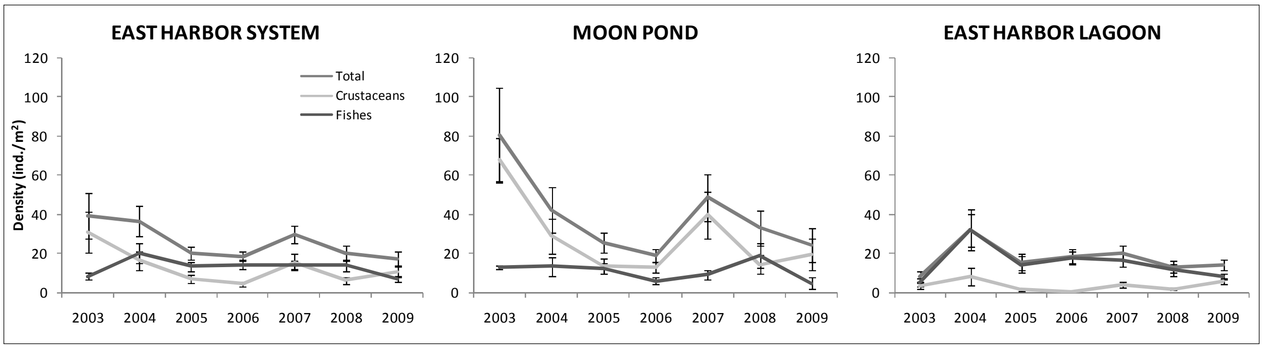

Figure 22. Density (individuals/m^2) ± SE of total nekton, crustaceans, and fishes in the East Harbor System, Moon Pond and East Harbor Lagoon 2003-2009.

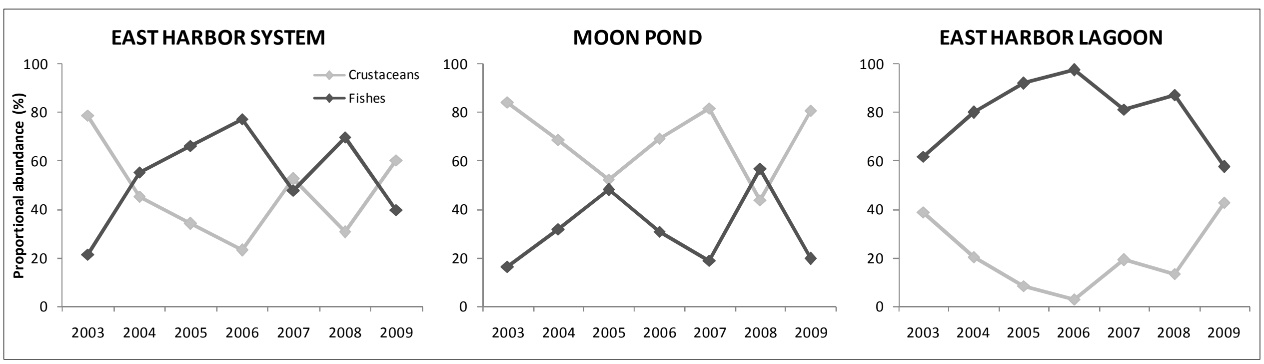

Figure 23: Proportional abundance of crustaceans and fishes in the East Harbor System, Moon Pond, and East Harbor Lagoon, 2003-2009.

Table 9. Density (individuals/m^2) ± SE of nekton species in the East Harbor System, 2003-2009. Numerically dominant species indicated by boxes.

EAST HARBOR SYSTEM							
Species	2003	2004	2005	2006	2007	2008	2009
Crustaceans							
Carcinus maenas	0.06 ± 0.0	0.22 ± 0.1	0.27 ± 0.1	0.43 ± 0.2	0.22 ± 0.1	0.40 ± 0.2	0.33 ± 0.1
Crangon septemspinosa	0.08 ± 0.1	1.67 ± 0.6	2.09 ± 0.5	2.89 ± 0.9	11.46 ± 3.9	0.68 ± 0.2	0.79 ± 0.2
Dyspanopeus sayi					0.03 ± 0.0		
Libinia sp.			0.02 ± 0.0		0.02 ± 0.0	0.03 ± 0.0	
Ovalipes ocellatus						0.05 ± 0.0	
Pagurus longicarpus					0.01 ± 0.0		0.19 ± 0.1
Palaemonetes spp.	30.57 ± 10.6	14.44 ± 4.6	4.37 ± 1.8	0.94 ± 0.3	3.71 ± 1.9	4.91 ± 1.7	9.10 ± 2.8
Panopeus herbstii			0.01 ± 0.0	±	0.01 ± 0.0		
Unknown crab	0.02 ± 0.0	0.02 ± 0.0	0.04 ± 0.0				
Fishes							
Anguilla rostrata	0.10 ± 0.1		0.05 ± 0.0	0.01 ± 0.0	0.06 ± 0.0	0.06 ± 0.0	0.04 ± 0.0
Apeltes quadracus	0.22 ± 0.1	4.27 ± 1.8	3.04 ± 0.7	0.65 ± 0.2	2.55 ± 1.0	0.34 ± 0.1	0.57 ± 0.3
Fundulus diaphanus							0.01 ± 0.0
Fundulus heteroclitus	4.00 ± 1.6	11.73 ± 4.6	8.47 ± 2.3	10.68 ± 2.3	3.63 ± 0.9	7.97 ± 2.0	2.36 ± 0.7
Gasterosteus aculeatus	0.18 ± 0.2			0.01 ± 0.0		0.02 ± 0.0	0.07 ± 0.0
Menidia menidia	2.10 ± 0.9	3.76 ± 1.0	0.99 ± 0.2	2.63 ± 0.9	7.74 ± 1.8	5.28 ± 1.9	3.63 ± 1.2
Morone americana	1.39 ± 0.9	0.07 ± 0.0	0.43 ± 0.2	0.05 ± 0.0	0.03 ± 0.0		
Pseudopleuronectes americanus			0.06 ± 0.0	0.08 ± 0.0		0.10 ± 0.1	0.12 ± 0.1
Pungitius pungitius	0.27 ± 0.1		0.13 ± 0.1	0.01 ± 0.0			
Syngnathus fuscus	0.10 ± 0.1	0.18 ± 0.1	0.05 ± 0.0	0.09 ± 0.0	0.02 ± 0.0	0.05 ± 0.0	0.03 ± 0.0
Tautogolabrus adspersus						0.05 ± 0.0	0.04 ± 0.0

Table 10. Proportional abundance (%) of nekton species in the East Harbor System, 2003-2009. Most abundant species indicated by boxes.

EAST HARBOR SYSTEM							
Species	2003	2004	2005	2006	2007	2008	2009
Crustaceans							
Carcinus maenas	0.2	0.6	1.3	2.3	0.8	2.0	1.9
Crangon septemspinosa	0.2	4.6	10.4	**15.7**	**38.8**	3.4	4.6
Dyspanopeus sayi					0.1		
Libinia sp.			0.1		0.1	0.2	
Ovalipes ocellatus						0.2	
Pagurus longicarpus					0.04		1.1
Palaemonetes spp.	**78.2**	**39.7**	**21.8**	5.1	**12.6**	**24.6**	**52.6**
Panopeus herbstii			0.1		0.04		
Unknown crab	0.1	0.1	0.2				
Fishes							
Anguilla rostrata	0.3		0.3	0.1	0.2	0.3	0.3
Apeltes quadracus	0.6	**11.7**	**15.2**	3.5	8.6	1.7	3.3
Fundulus diaphanus							0.1
Fundulus heteroclitus	**10.2**	**32.3**	**42.3**	**57.9**	**12.3**	**40.0**	**13.6**
Gasterosteus aculeatus	0.5			0.1		0.1	0.4
Menidia menidia	**5.4**	10.3	4.9	**14.2**	**26.2**	**26.5**	**21.0**
Morone americana	3.5	0.2	2.1	0.3	0.1		
Pseudopleuronectes americanus			0.3	0.4		0.5	0.7
Pungitius pungitius	0.7		0.6	0.1			
Syngnathus fuscus	0.3	0.5	0.3	0.5	0.1	0.2	0.2
Tautogolabrus adspersus						0.2	0.3

Table 11. Density (individuals/m^2) ± SE of nekton species in Moon Pond, 2003-2009. Numerically dominant species indicated by boxes.

MOON POND

Species	2003	2004	2005	2006	2007	2008	2009
Crustaceans							
Carcinus maenas	**0.14** ± 0.1	**0.45** ± 0.2	**0.56** ± 0.2	**1.42** ± 0.5	**0.69** ± 0.3	**1.10** ± 0.5	**1.00** ± 0.3
Crangon septemspinosa		**3.35** ± 1.3	**4.12** ± 1.1	**9.04** ± 2.6	**28.69** ± 11.2	**1.70** ± 0.5	**0.47** ± 0.2
Dyspanopeus sayi					**0.10** ± 0.1		
Libinia sp.			**0.05** ± 0.0		**0.07** ± 0.0	**0.10** ± 0.1	
Ovalipes ocellatus						**0.13** ± 0.1	**0.57** ± 0.2
Pagurus longicarpus					**0.03** ± 0.0		
Palaemonetes spp.	**67.43** ± 22.4	**24.85** ± 8.6	**8.35** ± 3.7	**2.46** ± 2.1	**9.86** ± 5.7	**11.30** ± 4.8	**17.40** ± 7.7
Panopeus herbstii			**0.02** ± 0.0		**0.03** ± 0.0		
Unknown crab	**0.05** ± 0.0	**0.05** ± 0.1	**0.09** ± 0.1				
Fishes							
Anguilla rostrata	**0.24** ± 0.1				**0.07** ± 0.0		**0.03** ± 0.0
Apeltes quadracus	**0.52** ± 0.2	**2.20** ± 0.7	**2.16** ± 0.6	**0.21** ± 0.1	**3.07** ± 1.9	**0.07** ± 0.1	**0.07** ± 0.0
Fundulus heteroclitus	**9.29** ± 3.6	**6.50** ± 3.7	**7.91** ± 2.3	**3.04** ± 1.2	**3.31** ± 0.9	**5.40** ± 2.9	**0.40** ± 0.3
Gasterosteus aculeatus	**0.43** ± 0.4						
Menidia menidia	**1.90** ± 1.0	**4.50** ± 1.9	**1.56** ± 0.4	**2.00** ± 1.1	**2.52** ± 1.3	**12.57** ± 5.4	**3.90** ± 3.1
Morone americana			**0.19** ± 0.1				
Pseudopleuronectes americanus			**0.07** ± 0.0	**0.25** ± 0.8		**0.30** ± 0.2	**0.17** ± 0.1
Pungitius pungitius	**0.62** ± 0.3		**0.21** ± 0.1				
Syngnathus fuscus		**0.05** ± 0.1		**0.25** ± 0.1	**0.07** ± 0.1	**0.13** ± 0.1	**0.03** ± 0.0
Tautogolabrus adspersus						**0.13** ± 0.1	**0.13** ± 0.1

Table 12. Proportional abundance (%) of nekton species in Moon Pond, 2003-2009. Most abundant species indicated by boxes.

MOON POND

Species	2003	2004	2005	2006	2007	2008	2009
Crustaceans							
Carcinus maenas	0.2	1.1	2.2	7.6	1.4	3.3	**4.1**
Crangon septemspinosa		8.0	**16.3**	**48.4**	**59.1**	5.2	1.9
Dyspanopeus sayi					0.2		
Libinia sp.			0.2		0.1	0.3	
Ovalipes ocellatus						0.4	2.3
Pagurus longicarpus					0.1	0.0	0.0
Palaemonetes spp.	**83.6**	**59.2**	**33.0**	**13.2**	**20.3**	**34.3**	**72.0**
Panopeus herbstii			0.1		0.1		
Unknown crab	0.1	0.1	0.4				
Fishes							
Anguilla rostrata	0.3				0.1		0.1
Apeltes quadracus	0.6	5.2	8.6	1.1	6.3	0.2	0.3
Fundulus heteroclitus	**11.5**	**15.5**	**31.3**	**16.3**	**6.8**	**16.4**	1.7
Gasterosteus aculeatus	0.5						
Menidia menidia	**2.4**	**10.7**	6.2	10.7	5.2	**38.2**	**16.1**
Morone americana			0.7				
Pseudopleuronectes americanus			0.3	1.3		0.9	0.7
Pungitius pungitius	0.8		0.8				
Syngnathus fuscus		0.1		1.3	0.1	0.4	0.1
Tautogolabrus adspersus						0.4	0.6

Table 6. Density (individuals/m^2) ± SE of nekton species in East Harbor Lagoon, 2003-2009. Numerically dominant species indicated by boxes.

EAST HARBOR LAGOON

Species	2003	2004	2005	2006	2007	2008	2009
Crustaceans							
Carcinus maenas		**0.04** ± 0.0	**0.02** ± 0.0			**0.04** ± 0.0	
Crangon septemspinosa	**0.14** ± 0.1	**0.32** ± 0.2	**0.34** ± 0.2	**0.25** ± 0.1	**3.13** ± 1.3	**0.14** ± 0.1	**0.95** ± 0.3
Palaemonetes spp.	**2.93** ± 1.5	**6.12** ± 4.2	**0.94** ± 0.6	**0.29** ± 0.1	**0.73** ± 0.3	**1.54** ± 0.6	**4.95** ± 1.6
Fishes							
Anguilla rostrata			**0.10** ± 0.1	**0.02** ± 0.0	**0.05** ± 0.0	**0.09** ± 0.0	**0.05** ± 0.0
Apeltes quadracus		**5.92** ± 3.3	**3.80** ± 1.3	**0.84** ± 0.3	**2.30** ± 1.2	**0.49** ± 0.2	**0.82** ± 0.4
Fundulus diaphanus							**0.02** ± 0.0
Fundulus heteroclitus	**0.04** ± 0.0	**15.92** ± 7.7	**8.96** ± 3.7	**13.95** ± 3.2	**3.78** ± 1.3	**9.32** ± 2.6	**3.33** ± 1.1
Gasterosteus aculeatus				**0.02** ± 0.0		**0.04** ± 0.0	**0.10** ± 0.1
Menidia menidia	**2.25** ± 1.4	**3.16** ± 1.0	**0.50** ± 0.2	**2.89** ± 1.2	**10.27** ± 2.6	**1.44** ± 0.4	**3.50** ± 1.0
Morone americana	**2.43** ± 1.5	**0.12** ± 0.1	**0.64** ± 0.3	**0.07** ± 0.0	**0.05** ± 0.0		
Pseudopleuronectes americanus			**0.06** ± 0.0				**0.10** ± 0.1
Pungitius pungitius			**0.06** ± 0.0	**0.02** ± 0.0			
Syngnathus fuscus	**0.18** ± 0.2	**0.28** ± 0.2	**0.10** ± 0.0	**0.02** ± 0.0			**0.03** ± 0.0

Table 7. Proportional abundance (%) of nekton species in East Harbor Lagoon, 2003-2009. Most abundant species indicated by boxes.

EAST HARBOR LAGOON

Species	2003	2004	2005	2006	2007	2008	2009
Crustaceans							
Carcinus maenas		0.1	0.1			0.3	
Crangon septemspinosa	1.8	1.0	2.2	1.4	**15.4**	1.1	6.9
Palaemonetes spp.	**36.8**	**19.2**	**6.1**	1.6	3.6	**11.8**	**35.7**
Fishes							
Anguilla rostrata			0.6	0.1	0.2	0.7	0.4
Apeltes quadracus		**18.6**	**24.5**	**4.6**	11.3	3.8	5.9
Fundulus diaphanus							0.1
Fundulus heteroclitus	0.4	**49.9**	**57.7**	**76.0**	**18.6**	**71.2**	**24.1**
Gasterosteus aculeatus				0.1	0.0	0.3	0.7
Menidia menidia	**28.3**	9.9	3.2	**15.8**	**50.5**	**11.0**	**25.3**
Morone americana	**30.5**	0.4	4.1	0.4	0.2		
Pseudopleuronectes americanus			0.4				0.7
Pungitius pungitius			0.4	0.1			
Syngnathus fuscus	2.2	0.9	0.6	0.1			0.2

Environmental Conditions

The spring and early summer season of 2009 was cooler and cloudier than previous years and seems to have affected the East Harbor nekton community (data from National Climate Data Center, not shown). Water temperatures recorded during the early nekton sampling period in 2009 were substantially lower than previous years (Figure 24). Dissolved oxygen also tended to be slightly lower in East Harbor Lagoon, but still within the oxic range in both the lagoon and Moon Pond creek (Figure 24). The lower temperatures observed in early summer could lead to the lower densities of nekton measured in 2009.

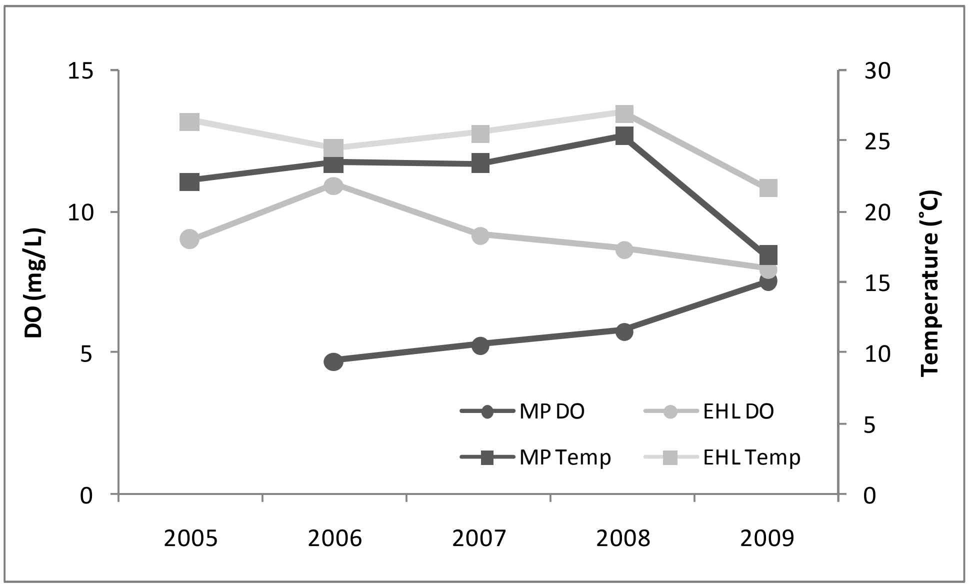

Figure 24: Average water temperature and dissolved oxygen (DO) measurements during the early sampling period at Moon Pond and East Harbor Lagoon sampling stations, 2005-2009.

A note on the observation of horseshoe crabs in East Harbor

In 2008, a number of horseshoe crab (*Limulus polyphemus*) adult shells and smaller molts were found in the lagoon. In 2009, several live animals were observed (Figure 25) and the number of molts observed in the system increased greatly. In fact, many hundreds were washed up along the perimeter of the lagoon by September. This suggests that a thriving *Limulus* population has become established in the lagoon. The finding is significant in that there are no other areas of CACO where *Limulus* is completely surrounded, and therefore protected, by Seashore property. For example, the Nauset marsh and Pleasant Bay parts of the CACO are adjacent to town/state waters, where this species is vulnerable to harvesting.

Figure 25. Horseshoe crab crawling around the edge of the lagoon in May 2009.

Discussion

Before the re-introduction of tidal flow to East Harbor in 2002, there were few nekton species present: *Cyprinus carpio*, *Alosa pseudoharengus* (an introduced species of alewife), *Morone americana*, and *Anguilla rostrata* (Hartel et al. 2003; Mather 2003; personal observations). Overall, the number of nekton species has increased since the restoration. The common estuarine inhabitants *Fundulus heteroclitus* and *Menidia menidia* dominated the fish assemblages in 2009, which was consistent with 2008 and previous years. These species have expansive distributions correlating with their broad tolerance for varying environmental conditions, especially salinity. In 2008 and 2009, two fish species that are closely associated with marine waters were present in Moon Pond, *Tautogolabrus adspersus* and *Pseudopleuronectes americanus*. *P. americanus* was also found inside the East Harbor Lagoon in 2009. The presence of these fishes with stenohaline tolerances means that conditions in Moon Pond as well as East Harbor Lagoon are converging on those of natural coastal systems where tidal restrictions do not impair seawater exchange (Smith et al. 2008). The nekton assemblage found in East

Harbor is representative of other estuaries in the region, including Waquoit Bay and Plum Island Estuary (Ayvazian et al. 1992; Deegan et al. 2007).

It was expected that nekton densities and species richness in Moon Pond would be greater than in the East Harbor Lagoon, since Moon Pond has a greater marine influence as a result of its closer proximity to the culvert and connection to Cape Cod Bay. In fact, nekton density for 2009 was higher in Moon Pond than East Harbor Lagoon (Table 8), and further, nekton density has been higher in Moon Pond in most years (Figure 22).

Environmental Conditions

The lower water temperatures observed in early summer explain the lower densities of nekton measured in 2009. Coming out of the winter months when food is scarce and water temperatures are very cold, estuarine communities can be impacted by the number of sunny or cloudy days in spring and early summer. Average air temperature for the month of June in 2009 was colder than previous monitoring years (Weather Underground, www.wunderground.org). Precipitation totals for spring months in 2009 were not notably greater than previous years, but the number of cloudy days was greater than in most nekton monitoring years (data from Weather Underground, www.wunderground.org, and the National Climate Data Center). Cloudiness decreases solar irradiance, and subsequently can affect water quality. Solar irradiance directly influences photosynthesis of primary producers and temperature of water bodies. So, by blocking sunlight, clouds can affect water temperature, primary production, and consequently dissolved oxygen in aquatic communities. Low light levels limit photosynthesis, and therefore the amount of oxygen replenishment by aquatic plants. The combination of cooler air temperatures and higher number of cloudy days led to colder water temperatures and likely slowed primary production, ultimately causing a delay in estuarine biological production. The delays in production at lower trophic levels could result in the lower nekton densities observed in 2009, especially in the early summer sampling period.

Conclusion

Markedly lower nekton densities observed in 2009 during the early summer sampling period were likely due to lower water temperatures and scarcer food resources that can be associated with the cold air temperatures and number of cloudy days in June. Further analysis is needed to better understand the role of environmental factors in influencing the nekton community in East Harbor. Since the restoration of tidal flow to East Harbor, species diversity has increased substantially. In recent years, a diverse community of polyhaline species (*Fundulus heteroclitus*, *Menidia menidia, Palaemonetes* spp., *Crangon septemspinosa, Apeltes quadracus,* etc.) and stenohaline species (*Tautogolabrus adspersus, Pseudopleuronectes americanus,* etc.) has been observed in East Harbor Lagoon and Moon Pond. The nekton assemblages indicate that species composition is shifting toward that of a natural estuarine community not affected by severe tidal restriction. Despite the negative influence spring and early summer weather may have had on nekton density, key estuarine species are being encountered with greater frequencies than in earlier years, suggesting that the East Harbor system, though tidal flow remains partially restricted by flow through culverts, is supporting a diverse population of estuarine nekton.

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