Annual Report on Estuarine Restoration at East Harbor (Truro, MA), Cape Cod National Seashore, 2007

John Portnoy, Stephen Smith, Krista Lee, Kelly Chapman,

Michelle Galvin, and Evan Gwilliam

Cape Cod National Seashore

and

Patrick Lyons and Carol Thornber

University of Rhode Island

Image by Barbara Dougan

Annual Report on Estuarine Restoration at East Harbor (Truro, MA),
Cape Cod National Seashore, 2007

SUMMARY

National Park Service environmental monitoring of the East Harbor back-barrier estuary began with observations of an oxygen depletion and fish kill in 2001 and has continued to the present.

The clapper valves in the 4-ft diameter by 700-ft-long culvert connecting the system to Cape Cod Bay have been held open since November 2002 to try to improve water quality in the East Harbor lagoon.

Ten-foot tides in Cape Cod Bay are reduced by passage through the culvert to 1.5 ft in Moon Pond; in East Harbor lagoon ("Pilgrim Lake") tides are barely detectable, at most 0.1 ft.

Salinity, which was about 4 parts per thousand (ppt) prior to clapper-valve opening, is now quite stable at about 20 ppt in winter and 25-27 ppt in summer in most of the lagoon; however, the surrounding wetlands, with the exception of Moon Pond, receive little seawater.

Dissolved oxygen stress was less severe in 2007 than in 2006, with benefits to bivalves and other colonizing estuarine animals.

As in 2005 and 2006, dense beds of macroalgae (*Cladophora* spp. and *Ulva intestinalis*) and filamentous cyanobacteria began to accumulate in June and July, but died back in August.

A preliminary nutrient bioassay, plus observed water-column nutrient ratios, indicated that macroalgal growth in East Harbor lagoon is strongly nitrogen limited.

Potential nitrogen sources include: 1) "recycled" nitrogen released from the decomposition of organic matter from the lagoon's sediments and extensive wetlands; 2) nitrogen fixation by cyanobacteria; 3) wastewater from adjacent development; 4) atmospheric deposition; and 5) tidal water from Cape Cod Bay. The relative importance of these sources is as yet unknown.

Monthly observations of lagoon water quality showed consistently low dissolved inorganic nitrogen, phytoplankton densities and chlorophyll, and high water clarity except during periods of ice cover.

A one-day flux study at the High Head Road culvert showed four times the nitrogen exported during ebb tide, than imported from Cape Cod Bay during flood tide, suggesting that Cape Cod Bay water is not an important source of nitrogen to the lagoon.

Observed low nutrient concentrations in inflowing Cape Cod Bay water also indicate that increased tidal exchange (i.e. flushing) will reduce the concentration of nitrogen that is apparently stimulating macroalgal blooms.

Widgeon grass, which had proliferated throughout the lagoon since 2004, was much less abundant in 2007, perhaps explaining the 2007 decrease in macroalgae, which are often light-limited and benefit from attachment to submerged seagrasses.

Phragmites in Moon Pond wetlands, particularly at low elevations, continues to decline in vigor.

A slight increase in the salinity of wetlands on the southwest margins of the lagoon have resulted in a shift to more salt-tolerant vegetation.

Experimental seeding has successfully established salt-marsh grasses in salt-killed cattail stands near High Head Road; in addition, these plants are producing seed which is colonizing beyond planted areas.

To supplement past seeding of salt marsh plants, plugs of cord grass were experimentally planted all along the shore of the lagoon in summer 2007.

Fecal coliform, the water-quality standard for shellfish-waters, was consistently high in the northwest cove and in freshwater discharging from Salt Meadow, but very low throughout the lagoon except after heavy rain, suggesting runoff pollution from Route 6.

Soft-shell clams were abundant throughout most of the estuary, with hard clams restricted to the creeks of Moon Pond. Unlike in 2006, clam survival was apparently high during the 2007 summer, probably due to decreased organic loading from macroalgae and consequently higher dissolved oxygen.

Many species of estuarine finfish, shellfish and other benthic animals continue to reestablish throughout the East Harbor lagoon and Moon Pond.

In East Harbor lagoon and Moon Meadow former fresh/brackish finfish have been replaced by an assemblage of species typical of lower Cape salt marshes. These animals are using the system for spawning, as a nursery habitat and for feeding.

For the first time in at least several decades, hundreds of bay and sea ducks began to feed, probably on submerged plants, fish and benthic animals, in the lagoon in winter 2006-7.

Further analysis of hydrodynamic modeling, completed in 2005, shows that:

- the replacement of the 4-ft diameter culvert with an opening at least 16 ft wide would increase flushing about ten fold, likely improving lagoon water quality, but tidal range would be only about 0.4 ft, yielding little increase in intertidal area.
- increasing the opening to the full 150-ft width of undeveloped land at Noons Landing would increase flushing 78 fold, increase tidal range to nearly four feet, and yield a restored intertidal area of 325 acres including both unvegetated flats and wetlands.

In an effort to assess potential sources of nutrients fueling macroalgae blooms, NPS and Cape Cod Commission are studying the groundwater system of Beach Point to determine flow direction and the potential for nutrients from wastewater to reach the East Harbor lagoon.

Otherwise, the above environmental monitoring of East Harbor lagoon will continue in 2008, with additional wetland-vegetation transects, macroalgae nutrient bioassays and intensified surface water-quality monitoring.

The US Army Corps of Engineers plans to continue its Comprehensive Feasibility Study of more complete tidal restoration in East Harbor once new funding is obtained.

East Harbor Water Quality Stations

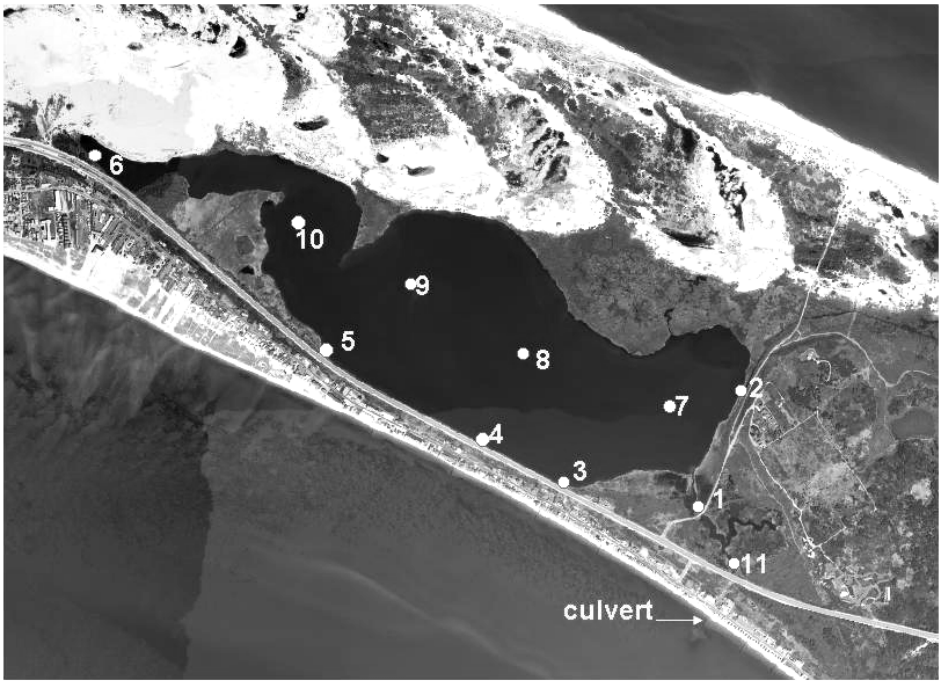


Figure 1-1. Aerial image of East Harbor showing water-quality stations and location of culvert connecting the estuary to Cape Cod Bay.

TABLE OF CONTENTS

1. INTRODUCTION

The 720-acre East Harbor, comprising Moon Pond, Pilgrim Lake and Salt Meadow, has been artificially isolated from the Cape Cod Bay marine environment since 1868 filling of the original 1000-ft wide inlet at the northwest end of the system (Figure 1-1). 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 2001prompted 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.

The following is a summary of monitoring results for tide heights, water quality (salinity, temperature, dissolved oxygen, nutrients and fecal coliform), macroalgae, both submerged and emergent vegetation, nekton (fish and decapod crustaceans), shellfish and waterfowl from 2007. Further analysis of recent hydrodynamic modeling results is also presented in relation to concerns for water quality, tidal flushing and wetland habitat restoration. See earlier reports (Portnoy et al. 2005, 2006) for monitoring results back to 2002.

2. TIDE HEIGHTS, SALINITY, TEMPERATURE AND DISSOLVED OXYGEN

Tide heights and salinity

Tide height and salinity (Fig. 2-1), and temperature and dissolved oxygen (Fig. 2-2) were recorded by an automatic data logger (YSI model number) at 30 minute intervals about 30 cm above the bottom (mean water depth ~ 75 cm) in the southeastern corner of the lagoon. Data are presented for 21 June to 13 September 2006 and from 25 May to 23 November 2007.

Formatted: Font color: Auto

Because the flood tide volume passing under High Head Road is so small compared to the large (350-acre) area of East Harbor Lagoon, tidal fluctuations have remained at most 2-3 cm, ~0.1 ft, as in previous years. Figure 2-3 clearly illustrates that there was more precipitation in 2006 than in 2007. Higher precipitation in 2007, compared to 2006 (Fig. 2-3), was reflected in both consistently lower lagoon water levels and higher (and steadily increasing) lagoon salinity during the dry 2007 summer (Fig. 2-1). Salinity ranged from 21 to 29 ppt with a mean of 26 ppt (+/- 2ppt) as opposed to last year's 22 to 27 ppt with a mean of only 21 ppt (+/- 3.5ppt) within the same sampling period. As in previous years, salinity was highest during spring tides, and lowest during neap tides. The mean lagoon water level dropped from 0.5 ft-NAVD-88 in 2006 to 0.09 ft-NAVD-88 in 2007.

Temperature and dissolved oxygen

In late July and early August 2006, extremely high water temperatures during the day (~30°C) and near oxygen depletion at night resulted in the death of benthic animals (most conspicuously thousands of juvenile softshell clams) and the death and decomposition of macroalgae that had covered almost the entire lagoon (Portnoy, et.al. 2006). Despite comparable water temperatures in 2007, dissolved oxygen concentrations were substantially higher than in 2006, particularly at night (Fig. 2-2) probably because macroalgae were much less abundant this year. However, the water column in East Harbor lagoon continued to show strong diel fluctuations in both temperature and dissolved oxygen, indicative of a highly eutrophic system.

[Note: A radical change in dissolved oxygen ranges was measured in early August of 2006 (Fig. 2-2), but no probe malfunctions were evident. Nevertheless, a calibration error is possible in one of the two instruments that were exchanged at that time.]

Figure 2-1. Salinity and tidal stage records for East Harbor lagoon in 2006 and 2007.

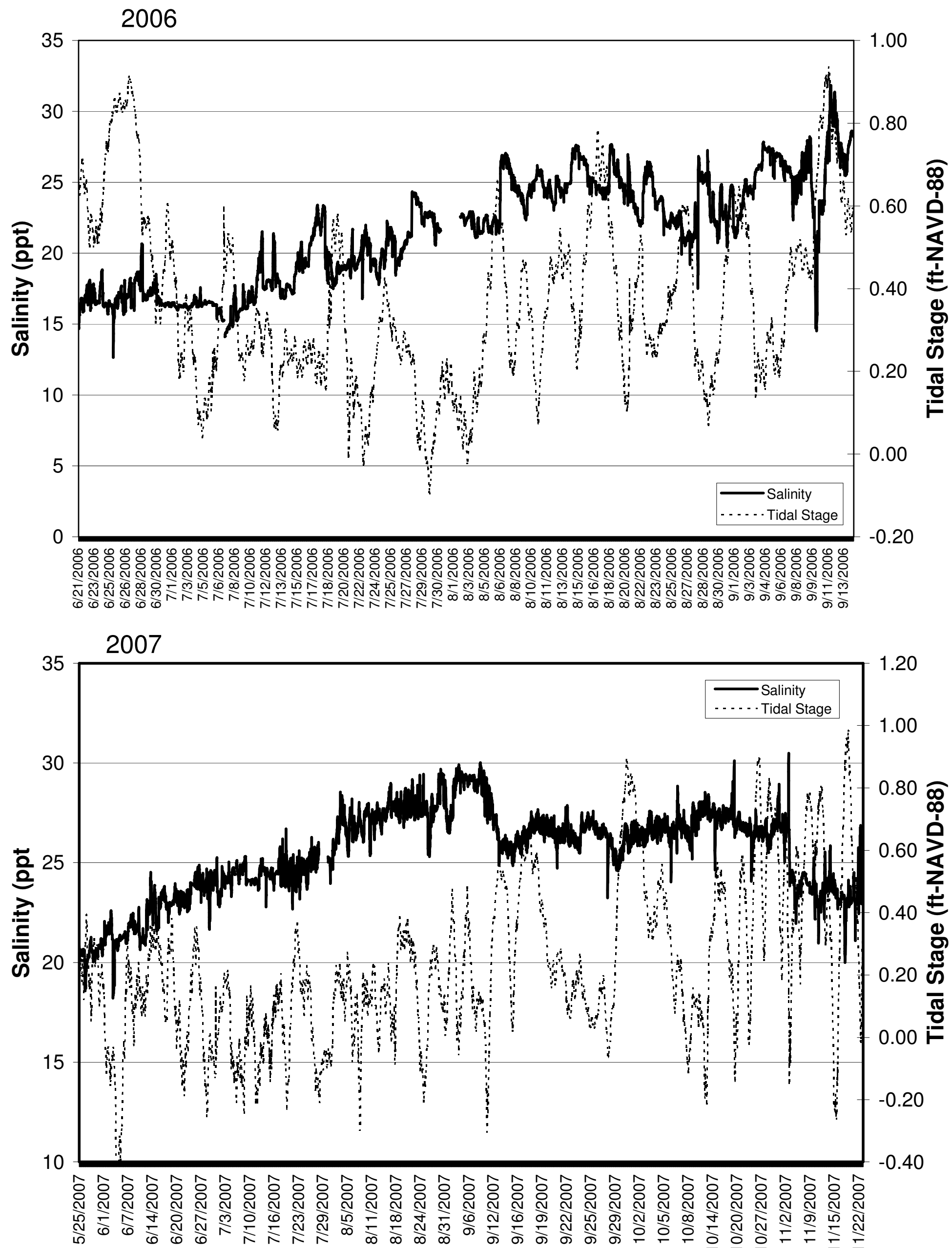
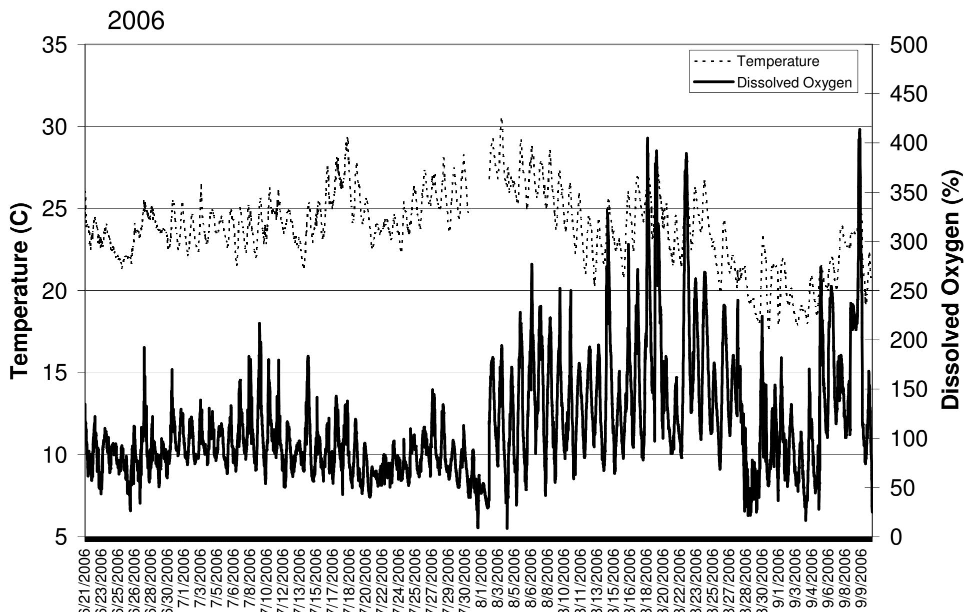
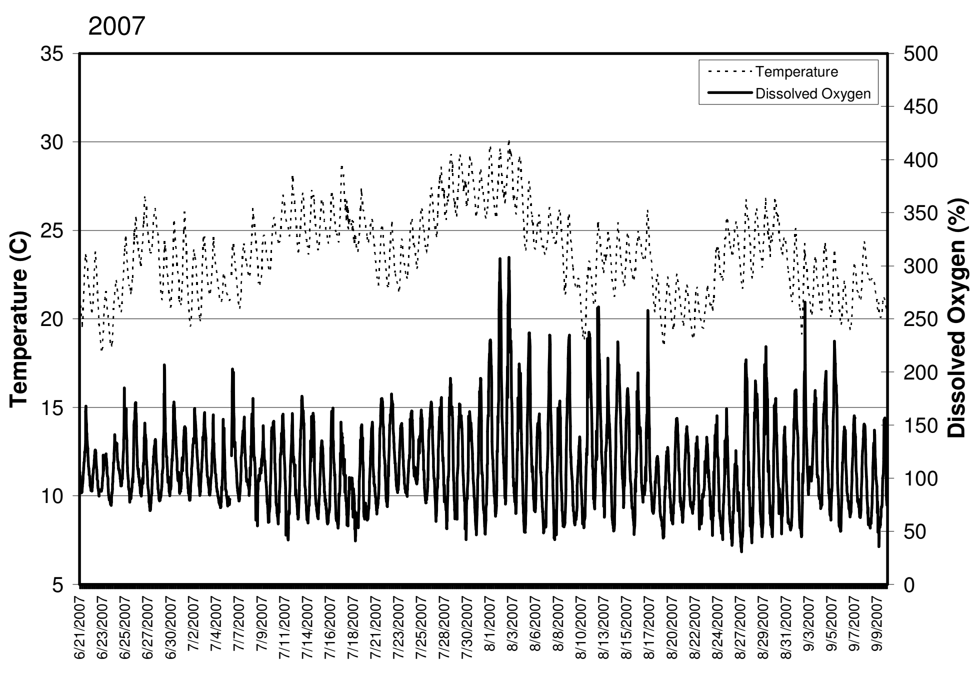


Figure 2-2. Temperature and dissolved oxygen records for East Harbor lagoon in 2006 and 2007.





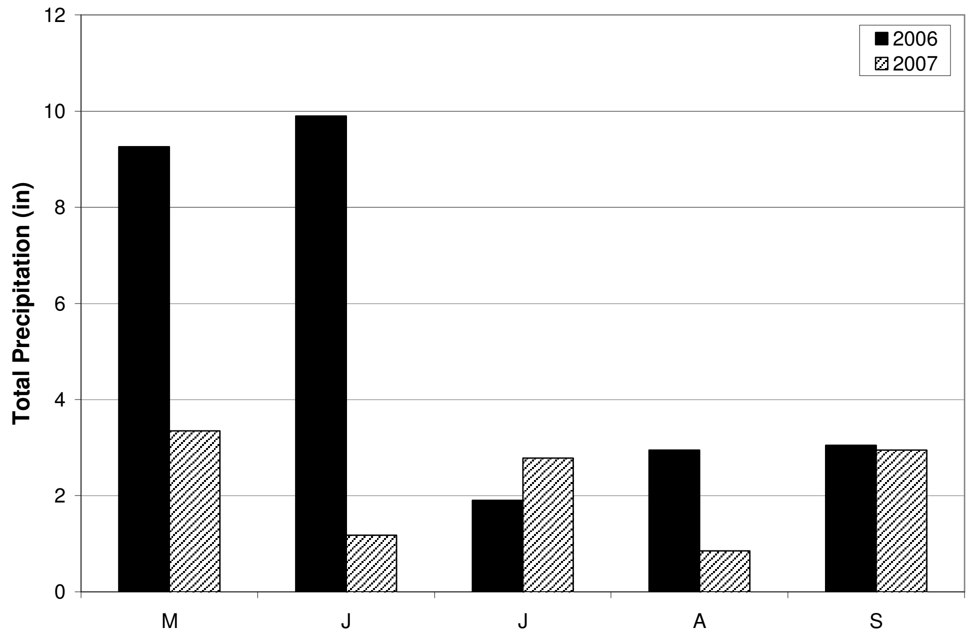


Figure 2-3. Total monthly precipitation in inches for May through September of 2006 and 2007.

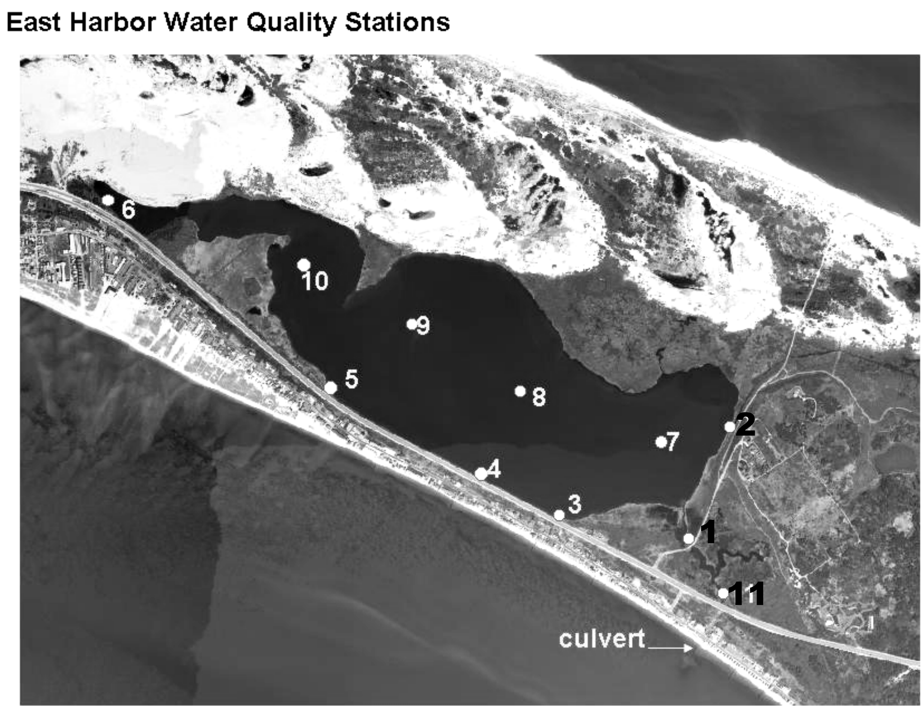
3. MONTHLY OBSERVATIONS OF WATER QUALITY

Krista Lee, Cape Cod National Seashore

Background

Beginning in January 2007, monthly surface water quality monitoring was initiated in order to: 1) quantify nutrients and primary productivity; 2) assess other physical and chemical characteristics on a routine basis; and 3) fill data gaps related to nutrient flux and primary productivity in this tidally restricted system. In the past, routine monitoring of surface water quality parameters, e.g. nutrients and chlorophyll, in East Harbor has not occurred; however, limited data are available from May-August 2002 for total nutrients and for chemical oxygen demand at the weir at High Head Road.

Figure 3-1. Map of 2007 sampling locations.



Basic Sampling Design & Methods

In total, 11 stations (Fig. 3-1) are currently sampled on a monthly basis 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), total dissolved phosphorus (µM) (TDP) (filtered sample/persulfate digest: P as PO_4), and particulate organic carbon and nitrogen (mg/Kg) (filtered sample/elemental analysis). From January through May, stations 1-6 were sampled monthly. In June, stations 7-11 were added to the monthly sampling.

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). Sub-samples for particulate carbon and nitrogen are filtered (filtrate volume noted) through a pre-combusted 0.45µm glass fiber filter and filters are dried at 80ºC to constant weight (~24 hrs) and stored in clean glass sample vials under desiccant until analyzed by combustion technique (US EPA/620/R-95/008, 1995).

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 2007 field season, water clarity in the main lagoon remained relatively high (average turbidity ~7 ± 4 NTU) (Fig. 3-2). Surface water temperatures throughout the system ranged from 3ºC in January (under ice cover) to 25ºC in July and averaged 23 ±3ºC from June through August. Salinity at the Salt Meadow drainage area (Sta. 2) averaged 2 ± 1 ppt; all other stations averaged 22 ± 4.6ppt from January-September.

As average surface water temperatures increased three fold from February (~5ºC) to April (~15ºC) and ice cover completely thawed in March, average ammonium levels decreased dramatically from ~ 30µM (Feb.) to ~2µM (April), and average chlorophyll-α concentrations doubled from ~9µg/L (Feb.) to ~18µg/L (April) (Fig. 3-2). Likewise, phycocyanin pigment fluorescence (a qualitative indicator of the presence of cyanobacteria) in the surface water doubled from February to April. Attempts were made throughout the field season to quantify cyanobacteria under microscope by utilizing Kova slides with grids for very low plankton densities. However, due to the extremely low densities observed throughout this field season, we were unable to quantify densities with any statistical confidence.

Average surface water dissolved oxygen levels remained consistently high throughout the main water body (~102%), although Salt Meadow (Sta. 2) dissolved oxygen dropped to less than 30% in July while total phosphorus (TP) increased throughout the lagoon and in both the Northwest Cove (Sta. 6) and Salt Meadow (Sta. 2) (i.e. TP~1µM in February-May to TP~5µM in July).

Ammonium dominated water-column dissolved inorganic nitrogen in both winter (80%, January and February) and spring-summer (65%, March through September). DIN values ranged widely from 60µM in January to an average of approximately 3µM in summer (May-August). The average molar ratio observed for DIN:TP for March-September was 2.7 [<<16 (Redfield Ratio)] indicating that primary productivity in East Harbor was strongly nitrogen limited from March to at least September (data analysis complete only through September at the time of preparation of this report). Additionally, average DIN:TN and DIN:DON from August indicate approximately 5 times more organic nitrogen present in the surface water than dissolved inorganic species. Results were similar in a one-day nitrogen flux study (this report), demonstrating high export of nitrogen in predominately organic forms during ebb tides. This seems to imply that the ultimate source is internal, but all we know so far is that, whatever its source, most water-column N is incorporated into organic compounds.

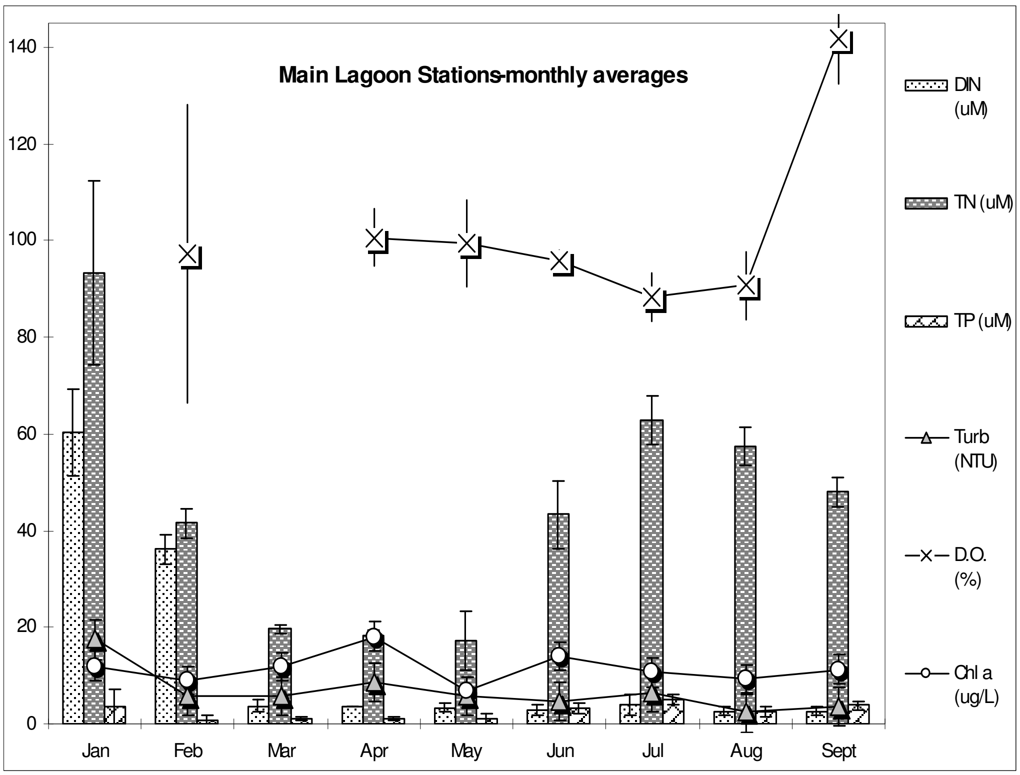
A one -time quantification in August of total dissolved iron indicated average concentrations in the lagoon (Stations 3-10) of 5µM and approximately 10 times that concentration in surface discharge from Salt Meadow (Sta. 2). Leachate high in dissolved Fe is expected from this extensive diked salt marsh (Kostka & Luther 1995, Portnoy & Giblin 1997).

Future analysis and monitoring plans

Additional analysis will be completed this winter to quantify the mass and stable isotopic ratios of particulate organic carbon and nitrogen in samples collected throughout the 2007 sampling period.

Monthly surface water monitoring will continue at all stations on a year round basis through 2008 and additional nitrogen flux studies will be completed in late winter or early spring 2008.

Figure 3-2. Monthly averages across all Main Lagoon stations (Stations 3-5, 7-10)



4. NITROGEN FLUX AND POTENTIAL SOURCES

John Portnoy & Krista Lee,
Cape Cod National Seashore

Prevailing literature on coastal eutrophication and preliminary fertilization experiments using East Harbor green macroalgae (this report) indicate that nitrogen is very likely the element limiting the growth of macroalgae in East Harbor. Potential sources include: 1) "recycled" nitrogen released from the decomposition of organic matter from the lagoon's sediments and extensive wetlands; 2) nitrogen fixation by cyanobacteria; 3) wastewater from adjacent development; 4) atmospheric deposition; and 5) tidal water from Cape Cod Bay.

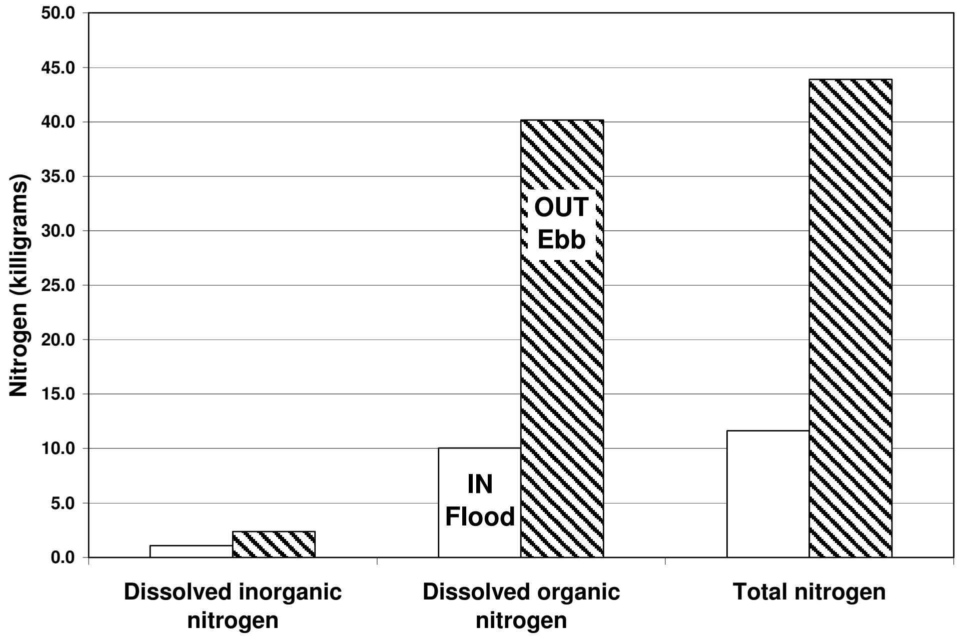
As a first step in identify major sources of nitrogen to the system, we assessed the relative importance of Bay water by estimating the mass of nitrogen entering and leaving the lagoon through a complete 13-hr tidal cycle (Fig. 4-1). This was done by measuring current speed, channel depth and nitrogen concentrations (total, dissolved inorganic and dissolved organic nitrogen) at 20-minute intervals from 4:40 AM to 5:40 PM at the High Head Road culvert on 10 July 2007. The product of current speed and wetted-channel cross-sectional area is water flux per unit time; water flux times nitrogen concentration yields nitrogen flux. Fluxes in and out of the lagoon were computed for each 20-minute time interval and summed to yield a net flux for the full tidal cycle. Total nitrogen includes all forms: dissolved, particulate, organic and inorganic. Dissolved inorganic nitrogen includes ammonium and nitrate, both of which are readily available to primary producers like macroalgae. Particulate nitrogen is that contained in phytoplankton and particles of organic detritus. Dissolved organic nitrogen is often a large component and derives both from incomplete organic decomposition (e.g. from wetland peat) and from leakage and excretion from living organisms.

During this study East Harbor exported about four times more nitrogen than was carried in by flood tides (Fig. 4-1). Most of the total was organic nitrogen. It is expected that the nitrogen-limited biota of a coastal lagoon will incorporate most inorganic nitrogen into organic forms. Also, the extensive wetlands throughout the flood plain would also leach abundant dissolved organic matter, including copious organically bound nitrogen, into receiving water . Even dissolved inorganic nitrogen, which is readily assimilable for algae growth and therefore very low in concentration, showed export twice that of import. These results indicates that, at least in summer, sources within the estuary are much more important in the system's nitrogen budget than inflowing Cape Cod Bay water.

The total mass of nitrogen exported from the lagoon was impressive, 40 kilograms during the ebb tide. The relative importance of wetland leachate, wasterwater and atmospheric deposition is, however, still unknown. [Recent data on atmospheric deposition of nitrogen from Waquoit Bay indicates that this is a minor source, probably accounting for less than 1% of the mass in ebbing water.] We plan to repeat this study in late winter

2008 to see if results are similar at cold temperatures and prior to spring macroalgae blooms.

Figure 4-1. Nitrogen flux at the High Head Road culvert over a 13-hour tidal cycle, East Harbor, 10 July 2007.



5. MACROALGAE

Overview - John Portnoy, Cape Cod National Seashore

Macroalgae blooms, like those observed in East Harbor in 2005 and 2006, are common in coastal bays receiving high loads of plant nutrients and/or poor tidal flushing. East Harbor lagoon was and still is a highly eutrophic system, most likely because of the lack of tidal exchange with Cape Cod Bay. Before 2002 culvert opening, eutrophication was expressed by chronic blooms of planktonic cyanobacteria. Even with the culvert open, tidal flushing is minimal with an estimated residence time for the lagoon of over 130 days (see Chapter 11), so continued high biomass of either phytoplankton or macroalgae is expected. [Note that increased salinity could also increase nitrogen loading to the water column by causing ammonium-nitrogen to be released (by desorption) from previously low-salinity sediments (Fig. 5-1).]

Unlike the nearly lagoon-wide algae bloom of 2006, dense macroalgae were restricted this past summer to the northwest cove (Provincetown end) and the southeast corner of the lagoon. The algae in the northwest cove, a combination of green seaweeds (*Cladophora* spp. and *Ulva intestinalis*) and filamentous cyanobacteria, persisted into early October. The bloom in the southeast corner, comprising mostly green macroalgae species, died back in late July 2007; therefore, the main body of the lagoon had little macroalgae throughout the remainder of the summer and fall. [The seasonal death of the macroalgae and its decomposition, and in 2006 oxygen depletion and odors, have occurred when water temperature approached 30° C. (86° F.).] As a result, summertime dissolved oxygen has remained higher this year than last, and this year's set of soft-shell clams, along with a highly diverse community of estuarine animals, are abundant and thriving.

We do not yet know why macroalgae became so abundant in 2005 and 2006, and were so much less abundant this summer, but we have an hypothesis based on both our own observations at East Harbor over the past six years and on the scientific literature. Factors and processes that may have promoted the growth of macroalgae are summarized in Figure 5-1. It is expected that the radical increase in salinity after culvert opening in 2002 would produce a complicated set of chemical and biological responses. The culvert opening not only allowed seawater to return to this back-barrier estuary, but also restored access for estuarine plants, seaweeds and estuarine animals: prominently including herbivorous crustaceans, filter-feeding bivalves and predatory fish. At the same time, increased salinity eliminated an exotic fish, carp, that had likely suppressed submerged aquatic vegetation (e.g. widgeon grass) through grazing and sediment disturbance. An unprecedented increase in water clarity by 2004 may have been due to both reduced sediment disturbance and the removal of previously dense phytoplankton, primarily cyanobacteria (Mozgala 1974), from the water column by the newly established filter-feeding bivalves and other estuarine invertebrates. Clear water would also promote widgeon grass; however, this plant would also provide good support for macroalgae growth. By 2005, green seaweeds, absent from the diked and freshened lagoon, became established as attached algae on the widgeon grass. Attachment to widgeon grass is an advantage to algal growth because it holds these seaweeds high in the water column, i.e. at the water surface, where light is abundant.

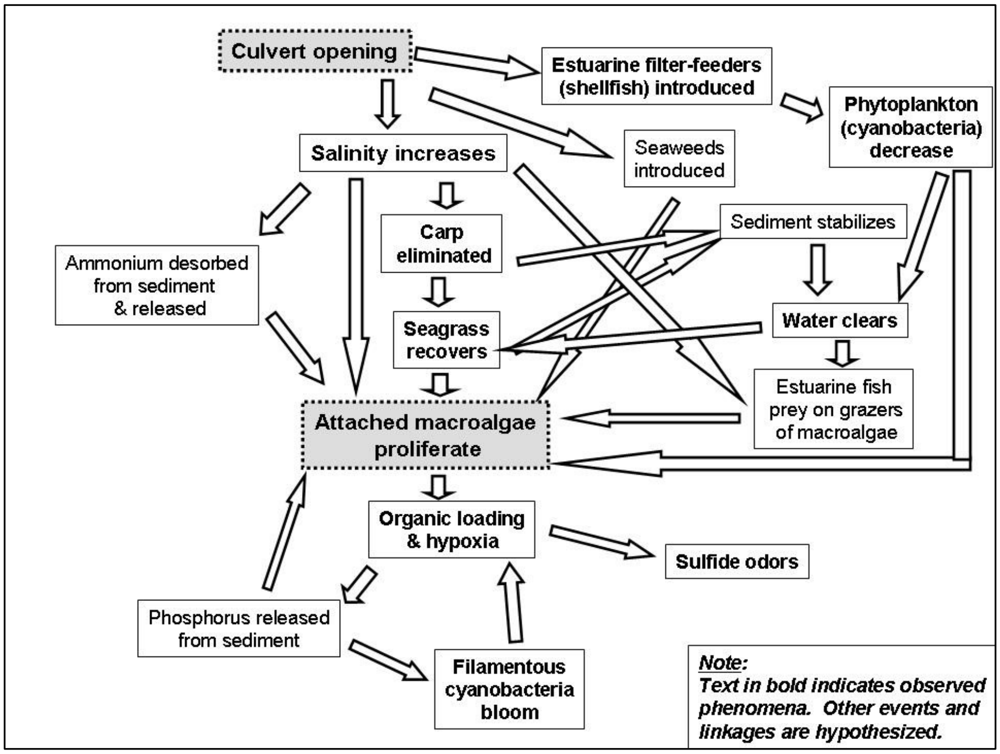
The newly reestablished population of estuarine fish may also play a role in macroalgae growth. These fish prey on crustacean amphipods and other seaweed grazers, perhaps significantly suppressing herbivory.

Once macroalgae became well established and abundant, its seasonal dieoff and decomposition produced an inevitable burden on the system's dissolved oxygen budget, with oxygen depletions (hypoxia) in mid-summer 2006. Hypoxia not only led to a clam dieoff, sulfide production and nuisance odors, but also likely caused the plant nutrient phosphorus to be released from the sediment, perhaps contributing to the observed growth of filamentous cyanobacteria in late summer (Fig. 5-1).

By 2006, however, mats of macroalgae became so dense and widespread that they shaded and suppressed the widgeon grass. The consequent August 2006 oxygen depletion probably further stressed submerged aquatic plants. In summer 2007 we saw much less widgeon grass and speculate that the loss of its structural support caused macroalgae to decrease throughout most of the lagoon. Sustained macroalgae growth in the southeast and northwest extremities of the lagoon in 2007 may probe the rule: both are somewhat protected from wind mixing (i.e. relatively stagnant) allowing macroalgae to remain at the well-lit surface without support from submerged aquatic plants.

We shall continue to test these ideas with ongoing interdisciplinary monitoring of the system. If the above mechanisms are operative, we can expect future conditions to more closely resemble our experience this past year than in 2006, i.e. suppression of widgeon grass by macroalgae and, therefore, only limited macroalgal blooms in protected corners of the East Harbor lagoon. Additional studies of macroalgae species composition, seasonal abundance, distribution and growth rates in 2007 follow.

Figure 5-1. Hypothesized linkages between East Harbor culvert opening and macroalgae blooms.



Seasonal abundance and distribution of nuisance macroalgae - Patrick Lyons & Carol Thornber, University of Rhode Island

The distribution of macroalgae was assessed both temporally and spatially in four different regions within East Harbor: the northwest cove (NWC), the strait connecting the northwest cove and the main body (NWS), the shoal in the center of the main body (MB), and along Route 6 in the main body (Rt.6) (Fig. 1-1). Wet biomass of algae floating and settled on the bottom was measured biweekly using a quadrat or corer, respectively. This was conducted three times in each of three randomly generated sites per region. Algae were spun in a salad spinner to remove excess water and weighed. Significant differences were observed for floating algal biomass with respect to region but not sampling week (Repeated Measures, JMP 5.1 SAS Institute 2003, Table 5-1). Floating algae was only observed in the Northwest Cove region, with highest abundance during the week of 29 July 2007.

Formatted: Font: Not Bold

Independent Variable	F Ratio	DF	P-value
Region	6.277	3,32	**0.001**
Week	2.651	4,29	0.0532

Table 5-1. Spatial and temporal effect on floating algal abundance.

The abundance of submerged algae was similar among sites but with statistically significant differences among weeks (Repeated Measures, JMP 5.1, Table 5-2). Mean biomass was highest during the weeks of 19 July and 2 August 2007 (Fig. 5-2).

Independent Variable	F Ratio	DF	P-value
Region	1.950	3,32	0.141
Week	3.660	4,29	**0.015**

Table 5-2. Spatial and temporal effect on submerged algal abundance.

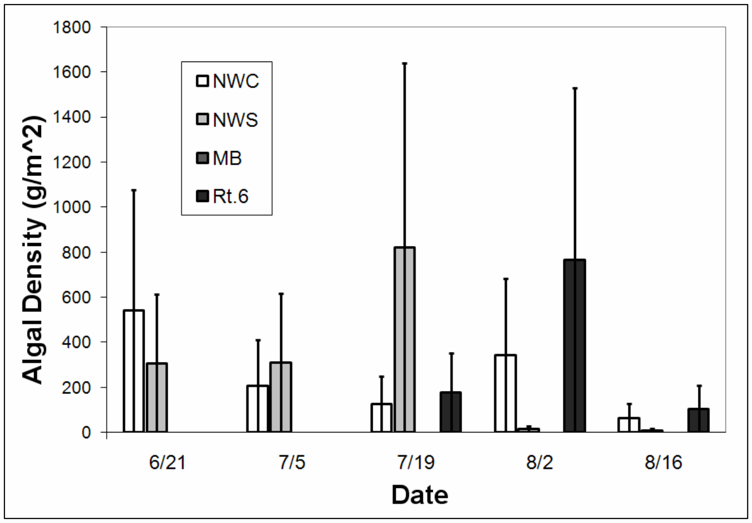


Figure 5-2. Mean submerged algal biomass g*m^{-2}. Error bars represent standard error.

Species present included: *Ulva intestinalis, Ulva flexuosa* ssp. *paradoxa, Cladophora albida, Cladophora serica, Polysiphonia subtilissima, Neosiphonia harveyii,* as well as filamentous cyanobacteria *Lyngbia* spp. and the centric diatom *Melosira* spp.

Growth rates

Growth rates were assessed weekly for both *U. intestinalis* and *C. serica* in situ. Algae were placed in clear polycarbonate tubes 18 cm long by 5 cm wide with mosquito netting on either end to allow water exchange. Marker dye was used to ensure that water could easily pass through the screening. Tubes were affixed at 10 cm (surface) and at 50 cm depth (bottom), at six randomly located locations with two in the northwest cove, two in the main body of the lagoon, and two along the Route 6 shoreline**.** Algae were spun dry (see above), pre-weighed to approximately 10.0 g, and then deployed in clear growth chambers for week-long periods. The growth rates of *U. intestinalis* and *C. serica* did not differ significantly. Algal growth was faster at the surface than at 50 cm depth. Differences existed among regions with macroalgae in the Rt.6 region showing slower growth than those in the other two regions. Lastly, differences existed among weeks; however, pair-wise comparisons yielded no individual differences (Table 5-3, Fig. 5-3).

Independent Variable	F Ratio	DF	P-value
Species	1.257	1	0.263
Depth	5.718	1	**0.0181**
Region	4.827	2	**0.009**
Week	2.484	7	**0.018**

Table 5-3. Effect on weekly growth rates of *U. intestinalis* and *C. serica.*

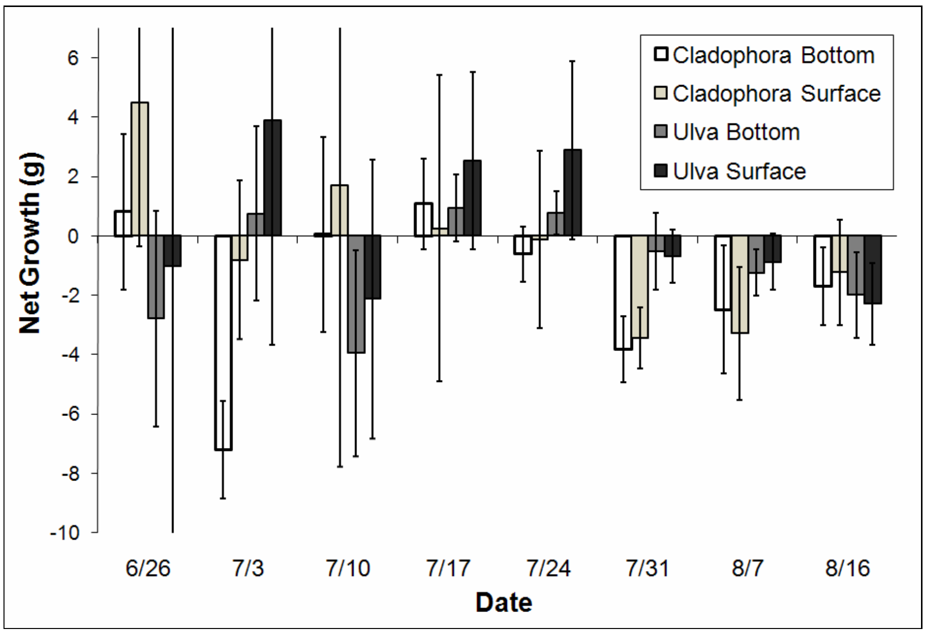


Figure 5-3. Weekly growth rates of *U. intestinalis* and *C. serica*. Error bars represent standard error.

The measurement of growth may have been confounded by grazing by amphipods (*Gammarus* spp.), which were able to enter and exit the growth chambers through small holes used to insert fastens to hold chambers in place. Thus, growth rates represent net growth including loss due to herbivory. Weekly losses in biomass, due apparently to amphipod grazing, exceeded 85% nine times, eight of which were in the Route 6 stratum and all of which occurred from 19 June through 17 July.

Submerged substrate for macroalgae attachment

To assess the dependency of algae on upright structure for substrate, artificial eelgrass (constructed of duct tape; Dassow and Strathmann, 2005) was placed in the same six locations as the growth chambers throughout East Harbor. One individual "leaf" was removed from each site biweekly. Leaves measured 35 cm long by 1 cm wide (70 cm^2 surface area). Epiphytes were spun dry (see previous section) and mass*cm^{-2} leaf surface area was calculated. No differences were seen among regions or length of time immersed (Table 5-4). Lack of observed temporal variation may have been due to the small amount of replicates. Even so, by the last week, all samples were completely covered with as much as 0.575 g*cm^{-2} wet mass.

Independent Variable	F Ratio	DF	P-value
Region	2.156	2	0.135
Week	2.001	4	0.125

Table 5-4. Effect of week and region on epiphyte abundance.

Discussion

Although measurements do not exist for the 2006 summer, macroalgal blooms were noticeably less abundant in 2007 than in 2006. We propose three hypotheses to explain this difference. First, herbivory may play a more important role in controlling algal abundance than was assumed. Although bottom-up control in the form of nitrogen availability is often used to explain abundance of macroalgal blooms (Valiela et al. 1997), herbivory can lower macroalgal biomass, especially with lower inputs of nitrogen (Hauxwell et al. 1998). Several times throughout the 2007 summer, herbivory seemingly reduced net algal growth in East harbor. It is unclear why this occurred more often in the Route 6 region, but this may simply be due to distribution of grazers throughout East Harbor, which in turn could be affected by water quality and/or proximity to the source of seawater entering the system through the 4-ft culvert and creek system. Attempts to correlate grazer abundance in growth chambers with algal biomass were confounded by the ability of grazers to both enter *and leave* the chamber.

The second hypothesis is that algal growth may be controlled by water temperature, exceeding 30°C in July and August (Portnoy et al. 2006) (Fig. 2-2). *Cladophora albida* have been shown to yield highest photosynthetic rate at approximately 28°C (Gordon et al. 1980); however, other studies have shown optimal growth rates at lower temperatures, e.g. 15°C optimal with marked decrease above 20°C (Taylor et al. 2001). Optimal growth rates may be at slightly lower temperatures for *Ulva* spp.; 20°C for *Ulva curvata* (Duke et al. 1989; Taylor et al. 2001), 15°C for *Ulva rigida* and *Ulva linza* (Taylor et al. 2001), and 10°C for *Ulva compressa* (Taylor et al. 2001). Thus, high temperatures may limit algal growth in East Harbor; however, similar temperatures were seen in both 2006 and 2007, suggesting that temperature was not a leading cause of the decreased abundance during 2007.

The third hypothesis for lower macroalgal biomass in 2007 is that decreased submerged aquatic vegetation (SAV), both *Ruppia maritima* and *Zostera marina*, limited algal abundance, as there was less upright substrate. In 2006, extensive beds of *R. maritima* covered the entire northwest cove and much of the main body of East Harbor (Portnoy et al. 2006). In 2007, however, much less *R. maritima* existed and was limited to a few sparse beds in the northwest cove and in the southwest corner of the lagoon. Algae need substrates for settlement of spores and zygotes; also, as the individual thalli grow, they receive higher light levels if they are raised up above the substrate, e.g. through attachment to SAV. Green algae, like all other photosynthetic organisms, need enough sunlight to photosynthesize; levels below 20 μmol $m^{-2}s^{-1}$ yield marked drops in growth rates of several *Ulva* spp. (Taylor et al. 2001). We found lower growth rates at 0.5 m depth than at the surface; thus, growth at deeper depths may be light limited. In 2007, floating algae were limited to the NWC region where it was largely attached or entangled within *Ruppia* beds. Other systems have shown a similar pattern with floating macroalgae accumulating in areas of dense seagrass due to entanglement (Kopecky and Dunton 2006). This observation, paired with the extensive growth measured on artificial eelgrass and observed on actual SAV, leads us to believe that lack of extensive beds of SAV was most important in limiting amounts of algal biomass observed in 2007. It is likely that in 2006 macroalgal blooms negatively affected *R. maritima* through shading and competition for nutrients (Hauxwell et al. 2001), and thus plant survival and seed production may have been low. Recovery from seasonal dieback is dependent not only on adequate seed amounts but also seed germination (Kantrud, 1991). Seed germination is optimal between salinities of 0-10 ppt (Kahn and Durako, 2005). Thus, low salinities in 2006 due to a particularly wet spring may have facilitated *R. maritima* germination. Future studies must be conducted to more firmly link macroalgal blooms and SAV, and to determine if salinity or seed abundance are more important in seasonal *R. maritima* abundance.

In conclusion, a large number of factors may affect macroalgal blooms in East Harbor Lagoon, Cape Cod National Seashore. Further study should be conducted to assess links among herbivory, temperature, SAV and algal growth to predict long-term trends of macroalgal bloom abundance in this region. If SAV is the most important factor, as data would suggest, two different expectations are likely. The first is that SAV will eventually be removed from the system and algal abundance will remain low following local SAV extinction. A second expectation could involve a negative feedback loop in which SAV and macroalgae may display cycles. With current data both expectations are speculative and thus further monitoring and experimentation must be conducted to elucidate the dynamics of East Harbor autotrophs.

6. WETLAND AND SUBMERGED AQUATIC VEGETATION, AND MACROALGAE NUTRIENT BIOASSAY

Stephen Smith, Cape Cod National Seashore

A detailed overview of the East Harbor tidal restoration project, including all aspects of vegetation monitoring, is provided in Portnoy et al. (2005, 2006). The following provides an update to these reports based on data collected during 2007.

Review of methods

Plant species coverage in the permanent vegetation plots (Fig. 6-1) 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* stem heights, stem densities, and % flowering stems were recorded at the end of the 2007 growing season (September). From these data, biomass was estimated as per Thursby et al. (2002).

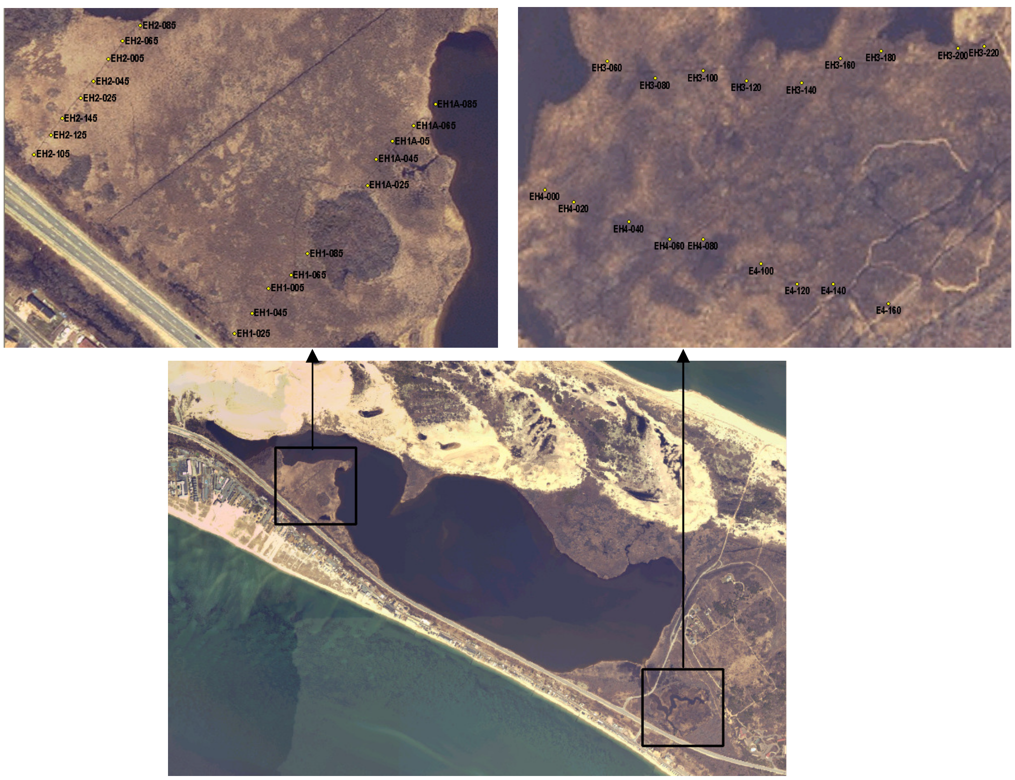


Figure 6-1. Overview of East Harbor with vegetation plot locations along transects EH1 through EH4.

Data analysis - Analysis of Similarities (ANOSIM) was used to test for significant changes in community composition between 2006 and 2007 (Primer ver. 6). Repeated-measures Analysis of Variance (ANOVA) was used to asses temporal changes in *Phragmites* height and biomass (all plots pooled).

Results

Statistically, there was no change in overall species composition between 2006 and 2007 as assessed by ANOSIM (Global R = -0.019; p = 0.99). Figure 6-2 shows a non-metric multidimensional scaling plot where minor changes can be noted. Some of these small changes include the appearance of *Aster novi-belgii* (New York aster). *Polygonum arifolium* (tearthum), and *Erechtites hiericifolia* (fireweed) in 2007. However, these taxa have previously been observed outside the monitoring plots and, as such, are not new to the system. *Theypteris palustris* exhibited a substantial decline, but community composition as a whole did not shifted significantly over the last year.

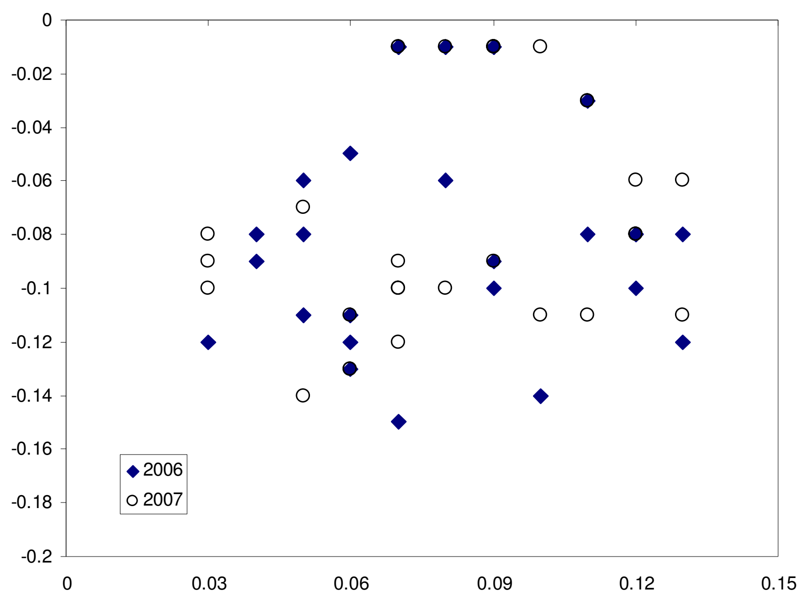


Figure 6-2. Non-metric multidimensional scaling of summed cover class values of East harbor plant taxa in vegetation plots (August 2006 vs. August 2007).

Table 6-1. Summed cover class scores by taxon and year.

	Aug-06	Aug-07	Change
Aster novi-belgii	0	3	3
Boehmeria cylindrica	4	3	-1
Decodon verticillatus	2	2	0
Erechtites hiericifolia	0	1	1
Lemna minor	0	1	1
Lysimachia terrestris	0	0	0
Lythrum salicaria	5	4	-1
Onoclea sensibilis	8	9	1
Parthenocissus cinquefolia	0	2	2
Phragmites australis	68	64	-4
Polygonum arifolium	0	2	2
Rosa palustris	2	2	0
Rumex orbiculatus	1	1	0
Sphagnum sp.	2	4	2
Thelypteris palustris	48	38	-10
Toxicodendron radicans	30	30	0
Typha angustifolia	60	59	-1

For the dominant species of emergent vegetation, *Typha* and *Phragmites*, there also were no major changes in cover from 2006 to 2007 (Table 6-2). However, it is noteworthy that slight reductions in *Phragmites* cover were observed in 6 plots in Moon Meadow during the past year. Anecdotally, it is obvious that despite no change in seawater exchange through the current culvert system, *Phragmites* continues to decline. This decline is well correlated with ground elevation – i.e., stunting and eventually death are occurring in the lowest spots within Moon Meadow where duration of flooding and, consequently, sulfide production are highest.

Table 6-2. *Phragmites* cover scores in August of 2006 and 2007.

	Aug-06	Aug-07	Change
EH3-060	5	5	0
EH3-080	2	2	0
Eh3-100	3	2	-1
EH3-120	5	5	0
EH3-140	5	5	0
EH3-160	5	5	0
EH3-180	5	5	0
EH3-200	5	5	0
EH3-220	4	4	0
EH3-240	3	2	-1

	Aug-06	Aug-07	Change
EH4-000	5	5	0
EH4-020	4	5	1
EH4-040	0	0	0
EH4-060	1	0	-1
EH4-080	1	0	-1
EH4-100	3	3	0
EH4-120	5	4	-1
EH4-140	2	2	0
EH4-160	5	3	-2

Phragmites biomass (calculated from stem height measurements and stem density counts), a more sensitive measure of change than area cover, declined in numerous plots during 2007 (Fig. 6-3). Overall (all plots pooled), there was no statistically significant change in biomass during the last year but the general downward trend was maintained and values have been halved since 2002 (Fig. 6-4).

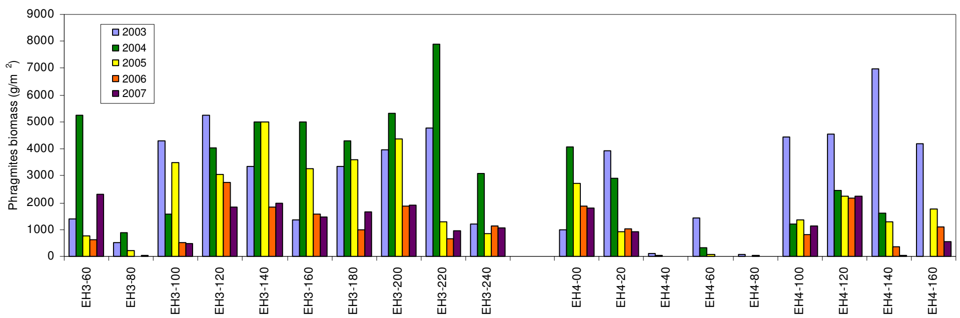


Figure 6-3. *Phragmites* biomass along transects EH3 and EH4 by individual plots and year.

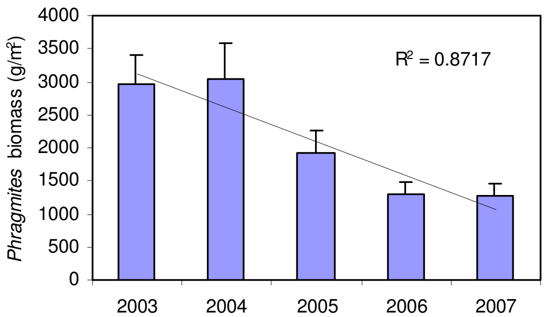


Figure 6-4. *Phragmites* mean biomass (all plots pooled) by year (error bars are standard error of the mean).

Water chemistry – In 2007, late-season porewater salinities in the western portion of the system (EH1&2) were very similar to those measured in 2006. In Moon Meadow (EH3&4), the mean salinity of all plots increased by ~ 3 ppt. although this change was not statistically significant. Lack of rainfall during August and September probably accounted for much of the difference between 2006 and 2007. In general, a lot of annual variability is due to the fact that these data represent one sampling event. In reality, salinity fluctuates substantially over the course of a single growing season. Notwithstanding, the spatial gradients are similar, with salinities decreasing toward the upland border in each area and with EH3&4 transects (Moon Meadow) having much higher salinities than EH1&2 (Table 6-4).

Table 6-4. Porewater salinities (ppt) by plot and year (dash indicates no sample drawn due to highly drained soil).

	08/19/03	09/22/05	8/25/2006	8/14/2006	8/15/2007
EH1-005	4	5	0	0	2
EH1-045	5	4	2	2	2
EH1-085	5	5	0	0	2
EH1A-005	4	4	0	0	3
EH1A-045	10	8	8	8	4
EH1A-085	10	9	10	10	6
EH2-025	2	4	0	0	1
EH2-065	2	4	0	0	2
EH2-105	2	4	7	7	2
EH2-145	3	7	7	-	8
EH3-060	-	-	-	-	-
EH3-100	25	23	20	20	20
EH3-140	24	22	14	14	-
EH3-180	23	20	12	12	10
EH3-220	21	14	2	2	5
EH4-000	25	-	-	-	25
EH4-040	33	37	34	34	35
EH4-080	32	34	26	26	32
EH4-120	30	30	15	15	20
EH4-160	29	24	12	12	14
mean-EH1/2	4.7	5.4	3.4	3.0	3.2
mean-EH3/4	26.9	25.5	16.9	16.9	20.1

East Harbor seeding

Seeding of native species by collecting wrack material from Hatches Harbor (Provincetown) and distributing it in East Harbor was repeated in the fall of 2006 and was again quite successful. Many plants germinated in areas of salt-killed vegetation that were otherwise devoid of any salt marsh vegetation. In addition, it is clear that some plant species are beginning to spread on their own, both vegetatively and by new seed (Figure 6-5). Populations originally established by active seeding are now substantial sources of seed themselves. This kind of positive feedback will continue and unaided expansion of these species is expected.

Figure 6-5. Newly established stand of *Salicornia maritima* in what was originally dense *Phragmites* along the main tidal creek running through Moon Meadow.

East Harbor Plantings

While past seeding efforts have been successful in helping native salt marsh vegetation to become established in the system, they have failed in certain places around the perimeter of the lagoon where high water levels and wave action have pushed seeds upslope off the banks into dense *Typha* or *Phragmites*. In order to encourage the colonization of these areas by native halophytes, plugs of *Spartina alterniflora* (cordgrass) were collected from the Hatches Harbor marsh (Provincetown) and planted around the edges of the lagoon (Figure 6-6). Based on the observation that vigorous vegetative growth has occurred wherever plants have become successfully established from seed in Moon Meadow, it is expected that these plugs will spread rapidly along the shoreline by rhizomatous growth.

Figure 6-6. Locations of *S. alterniflora* plantings (July 2007).

East Harbor Submerged Aquatic Vegetation

After being unable to collect data along the seagrass transects in 2006 due to an enormous macroalgae bloom that occurred during that year, we were again able to monitor these sites in 2007. With the exception of a single point along transect 7, *Zostera martima* was absent from the monitoring transects (Table 6-5). That said, the abundance of this species was low in previous years as well. However, it is strongly suspected that the previous year's macroalgal bloom substantially reduced the abundance of eelgrass in the system. *Ruppia maritima* (widgeon grass) exhibited reductions in percent cover from 2005, decreasing by 18 and 10 percent in the shallow and deep transects, respectively. These cover values are, however, much higher than in 2004 when the system was only 2 years into restoration. Even though *Ruppia* can apparently survive being smothered with thick layers of macroalgae and periphyton, its growth is undoubtedly limited by it.

Table 6-5. Percent cover of submerged aquatic vegetation by transect in East Harbor in 2007.

		R. maritima			Z. marina		
	Transect	Sep 04	Sep 05	Sep 07	Sep 04	Sep 05	Sep 07
shallow	8	10%	16%	16%	2%	2%	0%
	6	22%	64%	98%	0%	0%	0%
	1	34%	68%	0%	0%	0%	0%
	4	6%	42%	58%	0%	0%	0%
	7	26%	74%	46%	0%	0%	2%
deep	8	4%	16%	20%	0%	2%	0%
	6	2%	64%	90%	0%	0%	0%
	1	20%	52%	4%	0%	0%	0%
	4	8%	38%	44%	0%	0%	0%
	7	6%	50%	48%	0%	2%	0%
	mean shallow	22.0%	62.0%	43.6%	0.4%	0.4%	0.4%
	mean deep	9.0%	51.0%	41.2%	0.0%	0.8%	0.0%

East harbor macroalgae bioassays

In order to better understand how macroalgae biomass may be regulated by nutrients in East Harbor, we devised a growth assay involving nitrogen and/or phosphorus additions (i.e., nutrient bioassays). In general, we found that *in situ* nutrient addition bioassays were very difficult to perform due to problems with wind and wave action as well as the proliferation of macroalgae on any apparatus deployed in the lagoon. Accordingly, bioassays were designed so that they could be conducted at the North Atlantic Coastal Laboratory (NACL) in an outside experimental area. To do this, water from East Harbor was collected in July, filtered (0.45µm pore size), and poured into 50 ml clear plastic centrifuge tubes. Nutrients were then added to the tubes. The treatments were N+P (1 mM Na_2HPO_4 and 1mM $NaNO_3$), N only (1mM $NaNO_3$), P only (1 mM Na_2HPO_4), and control (no nutrients added) (9 replicates pre treatment, N=36). Each centrifuge tube was inoculated with 1 ml of macroalgae drawn into a pipette from a “slurry” of macroalgae. The latter was made by homogenizing a large amount of *Cladophora* spp., the dominant macroalgae in the system, (collected from East Harbor in August) in a blender. The tubes were capped and placed in water baths to prevent overheating. At the end of 2 weeks, chlorophyll *a,* a surrogate for algal biomass, was determined fluorometrically.

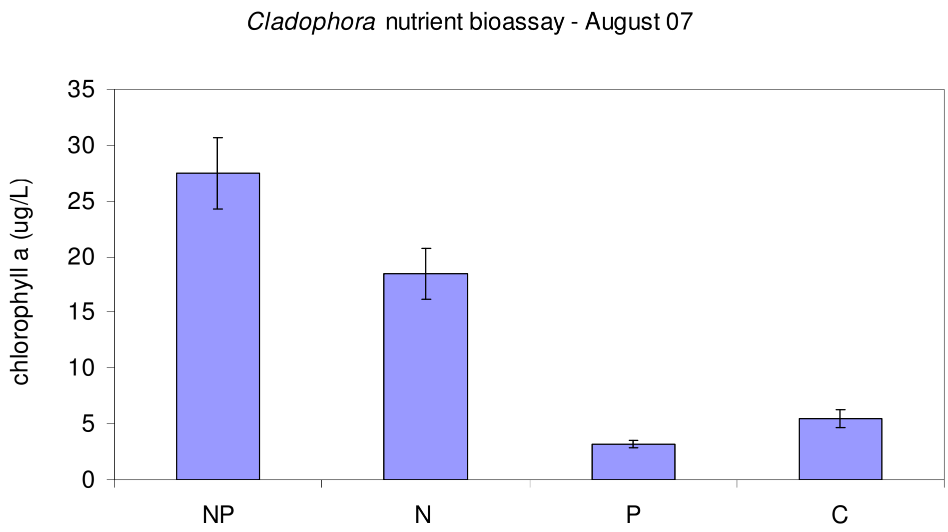


Figure 6-7. Mean chlorophyll *a* concentrations by treatment in the macroalgae bioassay.

While this is only a single assay, the data suggest that nitrogen is the primary limiting nutrient in this system, at least during the time when the water samples were collected in July (Figure 6-7). These responses are what would have been predicted from water quality data that show very low TIN:TP ratios, indicating strong nitrogen limitation. Thus, *Cladophora*, in the presence of adequate light, may proliferate in response to pulses of this nutrient. Such inputs may occur during periods of heavy precipitation that forces groundwater flushing. Because the system is still tidally restricted, extreme fluctuations in macroalgal biomass may occur in the future. Increased tidal exchange with low-nutrient seawater from Cape Cod bay would most likely result in enhanced stability of the system by lowering the concentration of nitrogen throughout the lagoon (through dilution) and, consequently, limiting the growth of macroalgae.

Future work

- In 2008, four new vegetation monitoring transects will be established to obtain a better spatial coverage of the peripheral wetlands. In this way, we will have more statistical power to detect and track plant community changes throughout the system.
- Porewater will continue to be surveyed once during the growing season as will *Phragmites* stem heights and densities (late growing season).

- The existing seagrass transects will also be monitored as long as macroalgae is not so abundant that data can be reliably collected.
- It is also our intention to use prescribed fire to consume standing dead biomass in Moon Meadow. This is expected to have several benefits. First, the removal of salt-killed vegetation from the floodplain will facilitate wider dispersal of seeds from native halophytes (Smith 2007). Secondly, it should greatly decrease resistance to water flow across the marsh with the effect that saltier water from the main tidal channel would be brought farther back into the marsh and, ultimately, accelerate the decline of *Phragmites* and various salt-intolerant plant species that still occupy a large portion of the wetland.

7. FECAL COLIFORM BACTERIA

John Portnoy, Cape Cod National Seashore

The concentration of fecal coliform bacteria is the standard that public health officials use to assess the quality of shellfish-growing waters, with shellfish harvest prohibited at concentrations above 14 colony-forming units (CFU) per 100 milliliters. With the reestablishment of an abundant marine shellfish fauna in East Harbor over the past few years, NPS conducted fecal coliform sampling to augment an ongoing Division of Marine Fisheries assessment of this potentially new shellfish-harvest area. The issue of fecal coliform is also of special interest to NPS managers working on salt-marsh restoration because tidal restrictions have been shown to produce conditions that favor fecal bacteria, and tidal restoration is expected to mitigate this problem (Portnoy & Allen 2006).

We sampled fecal coliform weekly from 3 May to 23 October at six stations in East Harbor (Fig. 1-1) and always at low-ebb tide to represent the worst case (Portnoy & Allen 2006). Fecal coliform was determined using the membrane filtration method, i.e. cultured at 44.5° C. on M-FC agar with rosolic acid (APHA 1998) within six hours of collection (APHA 1998). Because previous sampling showed low variability within a station (CV typically < 5 %), single samples were collected per station and date. Salinity was measured by refractometer. Turbidity was measured with a Hach 2100P turbidimeter, calibrated with primary formazin standards.

Monitoring has generally shown excellent bacteriological water quality everywhere but the northwest cove and Salt Meadow, Stations 6 and 2 (Table 7-1, Fig. 1-1). The Division of Marine Fisheries, who officially monitors shellfish water quality and controls when beds can be open or closed to harvest, reports similar findings; however, DMF will require at least one more year of water-quality data before opening East Harbor to shellfishing (J. Moles, personal communication).

One exceptional date was 4 June when sampling occurred right after heavy rain (1.65 cm) and counts were high at normally clean Stations 4 and 5. This may indicate that Route 6 runoff, which is directly funneled into the lagoon from catch basins, can be an important source of coliform contamination to the lagoon. Mitigation of road runoff pollution should be part of a comprehensive plan for the restoration of shellfish resources here.

Table 7-1. Results of low-tide fecal coliform sampling in East Harbor, 2007. See Figure 1-1 for station locations. Units are colony-forming units (CFU) per 100 milliliters.

	Fecal coliform (CFU/100 ml)					
Date	Sta 1	Sta 2	Sta 3	Sta 4	Sta 5	Sta 6
3-May-07	0	36	22	32	2	12
14-May-07	4	204	0	0	0	48
21-May-07	48	230	4	12	0	32
28-May-07	0	0	10	0	0	298
4-Jun-07	6	214	0	44	104	618
11-Jun-07	0	128	8	0	2	4
18-Jun-07	2	152	2	6	38	4
25-Jun-07	0	164	0	0	6	16
2-Jul-07	10	184	0	0	0	76
9-Jul-07	0	48	0	2	0	176
16-Jul-07	18	648	0	8	10	216
23-Jul-07	2	152	0	0	0	28
30-Jul-07	0	184	0	2	6	256
6-Aug-07	2	276	0	0	0	20
13-Aug-07	6	288	0	4	0	28
20-Aug-07	0	304	14	6	0	4
27-Aug-07	24	292	8	6	96	32
3-Sep-07	0	304	10	0	4	0
14-Sep-07	6	304	0	2	2	44
19-Sep-07	4	236	0	0	2	104
28-Sep-07	32	940	42	6	2	44
16-Oct-07	8	196	6	2	4	8
23-Oct-07	10	210	0	2	4	56

8. SHELLFISH

Jodie Wennemer and Rachel Thiet, Antioch University

Mollusks were sampled in summer 2007 at 85 sites in East Harbor. The estuary was first stratified into three areas, Moon Pond, the lagoon and the northwest cove, because of substantial differences among these areas in salinity and distance from the marine environment (Cape Cod Bay), and their presumed effects on the shellfish community. Sampling sites were then randomly chosen within each stratum to avoid observer bias.

Five 10-cm-diameter and 20 cm deep cores were collected at each random site, and sieved through 1-mm mesh. Animals retained by the sieve were identified and counted (Table 8-1).

Table 8-1. Mollusk densities (animals/m^2) in East Harbor by area sampled in July-August 2007. Five 10-cm-diameter, 20 cm deep cores were collected at each sample point in each area (*n* = number of sample points).

Species	***Moon Pond*** *n=20*	***Lagoon*** *n=50*	***Cove*** *n=15*
Euspira heros	0.1	0	0
Gemma gemma	7.3	0	0
Geukensia demissa	0	0.04	0
Littorina spp.	0.1	0	0
Macoma balthica	0	0.52	0.13
Mercenaria mercenaria	2.4	0	0
Mulinia lateralis	0	0.32	0.93
Mya arenaria	45.5	12.52	7.6
Mytilus edulis	0.3	0	0
Nucella lapillus	0.1	0	0
Order *Cephalaspidea*	0	0.08	0
Petricola pholadiformis	1.8	0	0

Table 8-2: Mollusk size distribution (mm) in East Harbor by area sampled in July-August 2007. Five 10-cm cores were collected at each sample point in each area (*n* = number of sample points). Data are mean ± standard error; where no SE is given, only one individual was found.

Species	***Moon Pond*** *n=20*	***Lagoon*** *n=50*	***Cove*** *n=15*
Euspira heros	(21.00)	--	--
Gemma gemma	(2.33 ± 0.08)	--	--
Geukensia demissa	--	(32.00)	--
Littorina spp.	(15.00)	--	--
Macoma balthica	--	(15.92 ± 1.61)	(24.00)
Mercenaria mercenaria	(14.29 ± 1.41)	--	--
Mulinia lateralis	--	(13.25 ± 0.75)	(19.86 ± 1.10)
Mya arenaria	(36.37 ±0.93)	(27.05 ± 0.57)	(55.09 ± 0.92)
Mytilus edulis	(29.67 ± 16.23)	--	--
Nucella lapillus	(16.00)	--	--
Order *Cephalaspidea*	--	(12.5 ± 1.50)	--
Petricola pholadiformis	(12.17 ± 1.31)	--	--

Soft-shell clams (*Mya*) continue to set prolifically throughout the East Harbor system, with highest densities in Moon Pond (Table 8-1). Unlike in 2006, dissolved oxygen remained sufficient throughout the 2007 summer to sustain these populations, with many individuals approaching a legally harvestable size by August (Fig. 8-2). Hard clams (*Mercenaria*) remain abundant in Moon Pond's creek system. The opening of East Harbor to public shellfish harvest will depend on the completion and results of fecal coliform monitoring by the Massachusetts Division of Marine Fisheries and a decision by both DMF and the Truro Shellfish Constable, in consultation with Cape Cod National Seashore.

9. NEKTON (FISH AND DECAPOD CRUSTACEANS)

Michelle Galvin & Evan Gwilliam
Cape Cod National Seashore

Introduction
Nekton monitoring is an effective and powerful tool for monitoring and assessing the results of estuarine restoration in the East Harbor system. Changes in nekton abundance, density and species composition reflect perturbations in multiple ecosystem processes, and comprise an efficient proxy for monitoring changes in these complex processes that would be too difficult or costly to monitor individually. Nekton responds rapidly to ecological changes, especially to changes in hydrology and water quality, i.e., increasing tidal range in Moon Pond and salinity in East Harbor Lagoon. They also respond to disturbances in food chain dynamics, from the bottom up; e.g. removal/change in primary producer populations by anthropogenic impact to estuarine water quality, or from the top down, e.g. removal of predators, an important feature not present in other sample populations (Raposa and Roman 2001a; Raposa and Roman 2001b).

Nekton data were first collected in 2003 and sampling has continued to the present. Annual monitoring in the East Harbor system is expected to continue. This report summarizes results of nekton monitoring in the three major sub-basins of the East Harbor system (Moon Pond, East Harbor Lagoon and Salt Meadow).

Methods

Sample Design
Nekton were sampled at randomly selected stations in East Harbor Lagoon and Moon Meadow. Sampling was attempted twice during the 2007 season at 45 sites randomly distributed in the lagoon (30 sites) and tidal creeks (15 sites).

Sampling Period
Sampling was conducted twice (6/26-6/29 and 9/11-9/13) in 2007. Each sampling session was conducted over several days in bouts lasting three to six hours. All data at Moon Pond were collected during low-tide periods when all water was off the marsh surface.

Data Analysis
For each year, we report the number of animals sampled, number of species, their relative abundance, and mean and standard deviation of nekton density and length. In 2005 to 2007, when there were two samples collected from each sample station, the average density and length of these two annual samples is used for analysis. Trend analysis using the Pearson's correlation coefficient (alpha=0.05) was applied to data for species diversity and density of all nekton, crustaceans, fish and selected individual species using the XLSTAT software package (Sokal and Rohlf 1981).

Results and Discussion

The rapid changes in water quality and habitat over the five sample years have led to changes in nekton species composition, relative abundance and density. In most of the East Harbor system there has been an increase in the number of nekton species, especially the common estuarine species (e.g., the mummichog, *Fundulus heteroclitus*), since the reintroduction of tidal flow in 2002. Prior to 2002 the only nekton species present were carp (*Cyprinus carpio*), white perch (*Morone americana*), alewife (*Alosa pseudoharengus*) and the American eel (*Anguilla rostrata*) (Hartel et al. 2003; Mather 2003; personal observations). The increase in the number of nekton species and relatively stable densities indicates that the system is suitable habitat for typical estuarine species assemblages, a situation that is expected to improve with further restoration efforts. Results and discussion for each part of the East Harbor system and for specific species are presented below:

East Harbor Lagoon

Typical estuarine species populate this system, especially the mummichog, the most common salt marsh fish, while salt-intolerant carp, present before the increase in salinity, have been eliminated. Some species that were present before reintroduction of salt water, American eel and white perch, persist in stable densities, as do re-colonizing estuarine species like Atlantic silverside (*Menidia menidia*). There has been an increase in the number of species sampled in the Lagoon since restoration (Table 9-1). Important commercial species have been sampled in the Lagoon, like the American eel and winter flounder (*Pseudopleuronectes americanus*), indicating that the East Harbor system may provide a place for these species to mature. During summer 2007, schools of feeding bluefish (*Pomatomus saltatrix*), another important recreational and commercial species, were observed in the lagoon on two occasions.

The relative abundance of fish in East Harbor has also increased between 2003 and 2007, probably in response to environmental and habitat change as observed in other tide-restoration projects (Raposa 2002; Roman et al. 2002) (Figure 9-1, Table 9-1). Densities of nekton increased slightly between 2003 and 2004, and have remained fairly stable for the past four years (Figure 9-2, Table 9-2).

Most of the sampling in the Lagoon has been focused on the shoreline in water less than 0.5 m using the throw trap method, excluding most of the lagoon from sampling. Other methods including an otter trawl and a cast net have been used in the Lagoon's open water (> 0.5 m depth); however, results were disappointing. Dense and extensive beds of widgeon grass (*Ruppia maritima*) and macroalgae present in 2006 frequently confounded successful deployment of both trawls and cast nets. Also, weather and time of day may be important in nekton use of this habitat. Methods for open-water sampling will be adjusted and tested again in 2008.

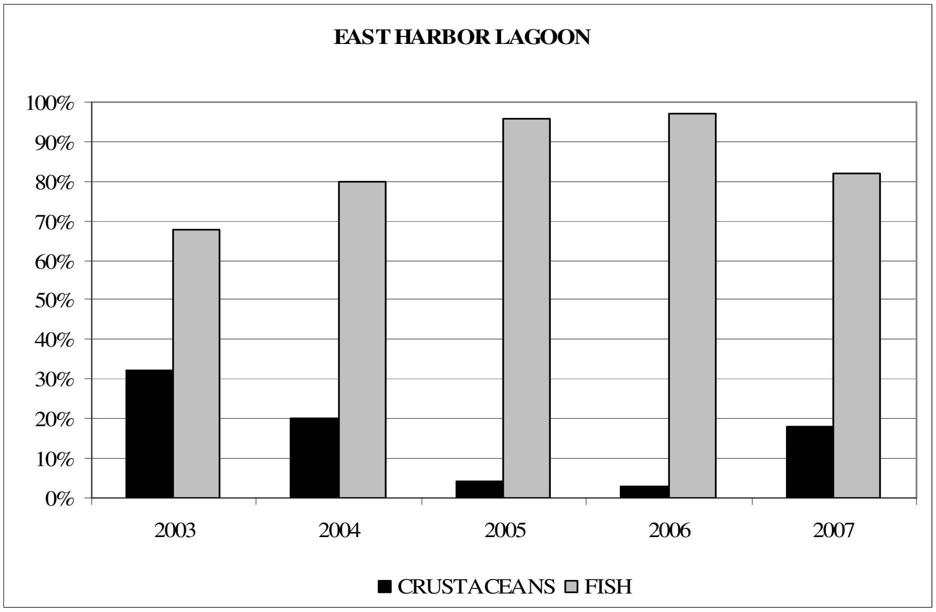


Figure 9-1. Relative abundance of fish and crustaceans in the East Harbor Lagoon from 2003 to 2007.

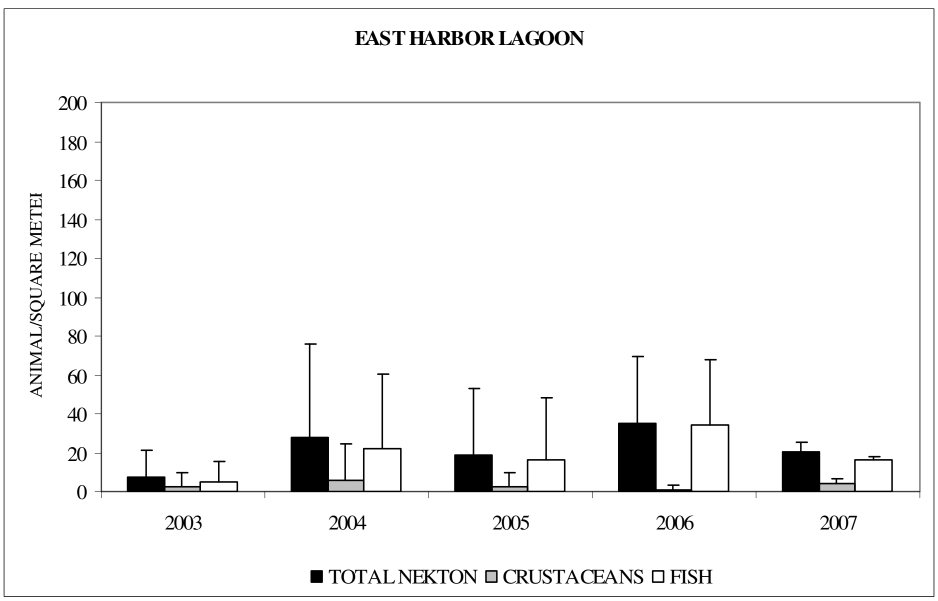


Figure 9-2. Mean density of total nekton, crustaceans and fish in the East Harbor Lagoon from 2003 to 2007.

Moon Pond
This area is most closely connected to Cape Cod Bay through the culvert under Beach Point (Fig. 1-1) and therefore experiences about 0.5 m of tidal range (tides in Salt Meadow and the Lagoon are barely detectable) and high salinity. The nekton community here responded with surprising rapidity to the opening of the culvert and consequent increases in salinity, tidal range and intertidal habitat, with colonization by many common estuarine nekton, some at extremely high densities, (e.g., shore shrimp), (Table 9-4).

There have been interesting shifts in species and densities at Moon Meadow; the shore shrimp (*Palaemonetes spp.*) was initially sampled in high densities; as the habitat in the tidal creeks changed from fine sediments to more coarse materials, the sand shrimp (*Crangon septemspinosum*) has increased significantly in both density (Pearson's correlation coefficient=0.961; p=0.009; alpha=0.05) and relative abundance (Pearson's correlation coefficient=0.949; p=0.014; alpha=0.05).

The nekton community continues to be dominated by crustaceans (Figure 9-3, Table 9-5), unlike East Harbor lagoon where salt-marsh fish predominate. This difference is likely due to differences in habitat: sand shrimp, the most common species in Moon Pond, are often found in wide, shallow sandy creeks like so-called Moon Pond, while mummichogs, a common species in East Harbor, prefer habitats with shelter close at hand, like the dense macrophyte beds in the lagoon. Similar patterns are seen in northeastern salt marshes including Hatches Harbor in Provincetown, MA.

Densities of fish have remained relatively stable while crustacean density has increased slightly (Figure 9-4 and Table 9-4).

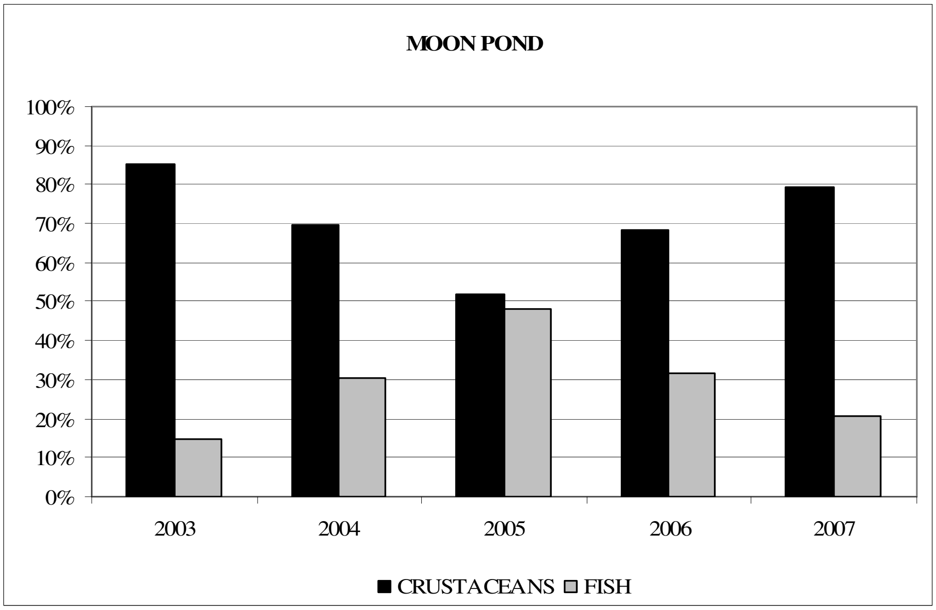


Figure 9-3. Relative abundance of fish and crustaceans in the Moon Pond from 2003 to 2007

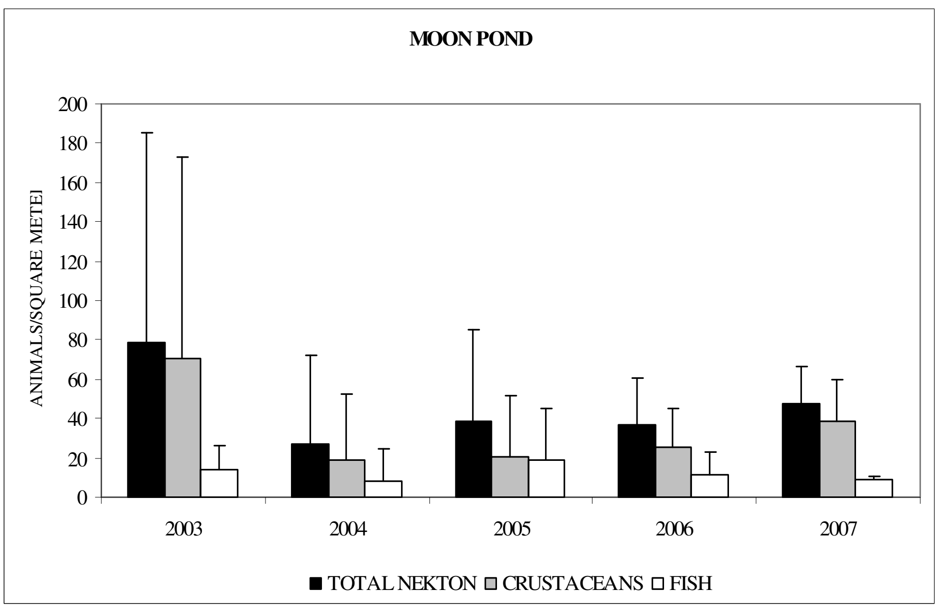


Figure 9-4. Mean density of total nekton, crustaceans and fish in Moon Pond from 2003 to 2007.

The number of nekton species has doubled just since 2003. In 2007, four new common estuarine species were sampled in Moon Pond: say mud crab (*Dyspanopeus sayi*), Atlantic mud crab (*Panopeus herbstii*), portly spider crab (*Libinia emarginata*) and long-wrist hermit crab (*Pagurus longicarpus*) (Table 9-1).

Salt Meadow
This area of the East Harbor system was expansive salt marsh habitat before 19th century diking. The area is currently a fresh water marsh; tidal forcing from the culvert under Beach Point is insufficient to force seawater into Salt Meadow. Accordingly, freshwater species are found here (Table 9-1). [Note however that the salinity is higher at the east Head of the Meadow end of the marsh presumably from intrusion of salt water from the ocean via groundwater flow. Salinities greater than 10 ppt were recorded in 2003.]

In 2007 species composition was similar to previous years (Table 9-1). It is likely that the removal of artificial impediments to both tides and fish will produce further recovery of the nekton community.

Alewife
Salt Meadow has been considered possible habitat for alewife (*Alosa pseudoharengus*) spawning. These fish were stocked by the state in the 1960s and used East Harbor system as spawning habitat before the culvert was opened and salinities increased in 2002. The decrease or loss of the alewife run at East Harbor was expected; increased salinity in the lagoon has apparently made it impossible for alewife to spawn there. However, several large freshwater pools in Salt Meadow may comprise alewife spawning habitat, albeit very limited in extent. Sampling from 2003 to 2007 using minnow traps and beach seines revealed no alewives.

<u>Conclusions</u>
The finfish of East Harbor lagoon comprised white perch, American eels, an introduced run of alewives, mummichog and exotic carp (Mather 2003) prior to the 2001-2 partial restoration of tidal exchange and salinity. Thereafter, many estuarine nekton species have rapidly colonized East Harbor Lagoon and Moon Pond. Former fresh to brackish species have been replaced by an assemblage of nekton species typical of lower Cape salt marshes. The reintroduction of tidal flow and salinity is having a positive effect on the nekton community by providing habitat for spawning, as a nursery area, and for feeding.

Future work will include:

- Continued monitoring of nekton annually in the East Harbor system.
- Testing of new methods to increase effectiveness of monitoring in the East Harbor system. These may include cast nets, lift nets and extensive use of minnow traps and other passive methods in Salt Meadow and the East Harbor Lagoon.
- Participation in interdisciplinary studies to understand the nutrient dynamics of the system and impact on the nekton community.

	East Harbor Lagoon					Moon Pond					Salt Meadow				
COMMON NAME	*2003*	*2004*	*2005*	*2006*	*2007*	*2003*	*2004*	*2005*	*2006*	*2007*	*2003*	*2004*	*2005*	*2006*	*2007*
American eel	X	X	X	X	X	X				X			X		X
Atlantic mud crab										X					
Atlantic silverside	X	X	X	X	X	X	X	X	X	X					
Brown bullhead											X		X	X	X
Crab species								X							
Four-spine stickleback		X	X	X	X					X			X	X	X
Golden Shiner											X		X		X
Green crab		X	X	X		X	X	X	X	X					
Longnose spider crab								X							
Longwrist hermit crab										X					
Mummichog		X	X	X	X	X	X	X	X	X	X	NO DATA		X	X
Nine-spine stickleback			X	X		X		X					X	X	
Pipe fish		X	X	X	X		X		X	X					
Portly spider crab										X					
Sand shrimp	X	X	X		X		X	X	X	X					
Say mud crab										X					
Shore shrimp	X	X	X	X	X	X	X	X	X	X					
Spider crab species							X								
Striped killifish				X											
Three-spine stickleback				X											
White perch	X	X	X	X	X			X			X			X	X
Winter flounder	X		X					X	X						
Total number of species	**6**	**9**	**11**	**11**	**8**	**6**	**7**	**10**	**7**	**12**	**4**		**5**	**5**	**6**

Table 9-1. Nekton species of the East Harbor system 2003 to 2007. There was no significant increase in the number of species in East Harbor Lagoon, Moon Pond or Salt Meadow. No data were collected in Salt Meadow in 2004.

	EAST HARBOR LAGOON									
	2003		2004		2005		2006		2007	
n	*19*		*30*		*42*		*29*		*30*	
	MEAN	STDEV	MEAN	STDEV	MEAN	STDEV	MEAN	STDEV	MEAN	STDEV
TOTAL NEKTON	7.63	13.56	27.41	48.58	18.43	34.35	35.03	34.14	20.15	4.97
CRUSTACEANS	2.47	7.16	5.52	19.14	2.17	7.90	1.03	2.15	3.88	2.95
FISH	5.16	10.15	21.90	38.19	16.26	31.69	34.00	33.51	16.27	2.03
American eel	0.00	0.00	0.03	0.18	0.12	0.40	0.03	0.19	0.05	0.02
Four-spine stickleback	0.00	0.00	5.21	15.54	4.21	10.17	1.59	3.51	2.30	2.83
Green crab	0.00	0.00	0.03	0.18	0.02	0.15	0.00	0.00	0.00	0.00
Sand shrimp	0.05	0.23	0.21	0.83	0.45	1.50	0.48	1.21	3.15	3.79
Mummichog	0.00	0.00	13.59	35.61	10.19	28.52	26.52	31.81	3.70	3.35
Striped killifish	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.19	0.00	0.00
Three-spine stickleback	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.19	0.00	0.00
Atlantic silverside	3.42	8.73	2.72	4.60	0.60	1.86	5.59	13.43	10.17	8.11
White perch	1.47	3.50	0.10	0.31	0.88	2.09	0.14	0.44	0.05	0.07
Shore shrimp	2.42	7.17	5.28	18.86	1.69	6.44	0.55	1.45	0.73	0.85
Winter flounder	0.00	0.00	0.00	0.00	0.07	0.34	0.00	0.00	0.00	0.00
Nine-spine stickleback	0.00	0.00	0.00	0.00	0.07	0.26	0.03	0.19	0.00	0.00
Pipe fish	0.26	1.15	0.24	0.94	0.12	0.33	0.03	0.19	0.00	0.00

Table 9-2. Mean nekton density (animals/m^2) in East Harbor 2003 to 2007

	East Harbor Lagoon				
	2003	2004	2005	2006	2007
CRUSTACEANS	32.41%	20.28%	4.13%	2.95%	18.02%
FISH	67.59%	79.72%	95.87%	97.05%	81.98%
American eel	0.00%	0.13%	0.32%	0.10%	0.24%
Four-spine stickleback	0.00%	18.90%	10.96%	4.53%	13.56%
Green crab	0.00%	0.13%	0.04%	0.00%	0.00%
Sand shrimp	0.69%	1.00%	0.83%	1.38%	13.73%
Mummichog	0.00%	49.56%	53.89%	75.69%	21.05%
Striped killifish	0.00%	0.00%	0.00%	0.10%	0.00%
Three-spine stickleback	0.00%	0.00%	0.00%	0.10%	0.00%
Atlantic silverside	44.83%	9.89%	25.62%	15.94%	46.92%
White perch	19.31%	0.38%	4.49%	0.39%	0.21%
Shore shrimp	31.72%	19.15%	3.26%	1.57%	4.29%
Winter flounder	0.00%	0.00%	0.12%	0.00%	0.00%
Nine-spine stickleback	0.00%	0.00%	0.24%	0.10%	0.00%
Pipe fish	3.45%	0.88%	0.24%	0.10%	0.00%

Table 9-3. Relative abundance (number/total number) for fish, crustaceans and each species in East Harbor Lagoon 2003 to 2007

	MOON POND									
	2003		2004		2005		2006		2007	
n	*20*		*30*		*28*		*12*		*15*	
	MEAN	STDEV	MEAN	STDEV	MEAN	STDEV	MEAN	STDEV	MEAN	STDEV
TOTAL NEKTON	78.52	107.10	27.10	45.43	38.75	46.66	36.58	23.85	47.60	19.04
CRUSTACEANS	70.25	102.59	18.87	33.99	20.11	31.77	25.08	19.94	38.87	20.65
FISH	13.56	12.41	8.23	16.53	18.64	26.51	11.50	11.49	8.73	1.60
American eel	0.29	0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.09
Four-spine stickleback	1.05	2.22	1.47	2.81	3.36	5.61	0.42	0.79	2.97	3.06
Green crab	0.14	0.36	0.30	0.70	0.86	1.56	2.42	3.48	1.30	0.42
Sand shrimp	0.00	0.00	2.13	4.76	6.32	9.58	17.83	19.60	27.73	33.00
Say mud crab	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.14
Mummichog	7.81	11.22	3.90	11.42	12.14	22.11	6.08	7.98	3.20	1.70
Striped killifish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Three-spine stickleback	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Longnose spider crab	0.00	0.00	0.00	0.00	0.04	0.19	0.00	0.00	0.00	0.00
Spider crab species	0.00	0.00	0.03	0.18	0.00	0.00	0.00	0.00	0.00	0.00
Portly spider crab	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.09
Atlantic silverside	1.81	4.40	2.83	6.97	2.43	3.52	4.00	7.27	2.43	2.97
White perch	0.00	0.00	0.00	0.00	0.29	1.18	0.00	0.00	0.00	0.00
Long wrist hermit crab	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.05
Shore shrimp	66.76	101.14	16.40	33.10	12.75	29.22	4.83	7.42	9.60	12.45
Atlantic mud crab	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.05
Winter flounder	0.00	0.00	0.00	0.00	0.11	0.31	0.50	0.90	0.00	0.00
Nine-spine stickleback	0.67	1.49	0.00	0.00	0.32	0.86	0.00	0.00	0.00	0.00
Pipe fish	0.00	0.00	0.03	0.18	0.00	0.00	0.50	0.90	0.07	0.09
Unknown crab species	0.00	0.00	0.00	0.00	0.14	0.45	0.00	0.00	0.00	0.00

Table 9-4. Mean nekton density (animals/m^2) in Moon Pond 2003 to 2007

	Moon Pond				
	2003	2004	2005	2006	2007
CRUSTACEANS	85.20%	69.62%	51.89%	68.56%	79.32%
FISH	14.80%	30.38%	48.11%	31.44%	20.68%
American eel	0.36%	0.00%	0.00%	0.00%	0.11%
Four-spine stickleback	1.33%	5.41%	8.66%	1.14%	5.37%
Green crab	0.18%	1.11%	2.21%	6.61%	2.77%
Sand shrimp	0.00%	7.87%	16.31%	48.75%	48.26%
Mummichog	9.95%	14.39%	31.34%	16.63%	8.08%
Longnose spider crab	0.00%	0.00%	0.09%	0.00%	0.00%
Spider crab species	0.00%	0.12%	0.00%	0.00%	0.00%
Atlantic silverside	2.30%	10.46%	6.27%	10.93%	6.91%
White perch	0.00%	0.00%	0.74%	0.00%	0.00%
Shore shrimp	85.02%	60.52%	32.90%	13.21%	27.61%
Winter flounder	0.00%	0.00%	0.28%	1.37%	0.00%
Nine-spine stickleback	0.85%	0.00%	0.83%	0.00%	0.00%
Pipe fish	0.00%	0.12%	0.00%	1.37%	0.20%
Unknown crab species	0.00%	0.00%	0.37%	0.00%	0.00%
Say mud crab	0.00%	0.00%	0.00%	0.00%	0.29%
Portly spider crab	0.00%	0.00%	0.00%	0.00%	0.20%
Long wrist hermit crab	0.00%	0.00%	0.00%	0.00%	0.10%
Atlantic mud crab	0.00%	0.00%	0.00%	0.00%	0.10%

Table 9-5. Relative abundance (number/total number) for fish, crustaceans and individual species in Moon Pond 2003 to 2007.

10. WATERFOWL

Observations of greatly increased waterfowl use of East Harbor lagoon are mostly anecdotal to date but nevertheless important. Prior to tidal restoration, waterfowl activity was limited to small flocks of black ducks, red-breasted mergansers and buffleheads.

The first indication of a radical increase in wintering duck use came from a 2006 Christmas bird count reported by Jan Smith of the Massachusetts Coastal Zone Management Office (Table 10-1). These birds continued to use the lagoon throughout the 2006-7 winter, except during periods of ice cover. Most species were observed to dive regularly, likely feeding on benthic animals, with mergansers probably feeding on the many small fish that have populated the system since partial tidal restoration. Dabbling ducks like mallards and black ducks feed on a combination of animal (e.g. bivalves) and plant (widgeon grass) foods.

Increased waterfowl use is expected to continue, along with the re-colonization and proliferation of submerged aquatic vegetation, fish and benthic animals in East Harbor, so long as at least the existing culvert connecting the system with Cape Cod Bay remains open. Casual observations this fall (2007) indicated use by several hundred sea and bay ducks, predominantly lesser scaups, white-winged scoters, surf scoters and buffleheads.

Table 10-1. Waterfowl observed on East Harbor lagoon, 16 December 2006 (Jan Smith, personal communication).

	Common name	Scientific name	Number observed
BLDU	Black Duck	*Anas rubripes*	70
MALL	Mallard	*Anas platyrhynchos*	6
REDH	Redhead	*Aythya americana*	9
GRSC	Greater scaup	*Aythya marila*	125
LESC	Lesser scaup	*Aythya affinis*	4
WWSC	White-winged scoter	*Melanitta fusca*	150
SUSC	Surf scoter	*Melanitta perspicillata*	6
COGO	Common goldeneye	*Bucephala clangula*	20
BUFF	Bufflehead	*Bucephala albeola*	100
COME	Common merganser	*Mergus merganser*	75
RBME	Red-breasted merganser	*Mergus serrator*	20
HOME	Hooded merganser	*Lophodytes cucullatus*	7
RUDU	Ruddy duck	*Oxyura jamaicensis*	45

11. MODELING ESTIMATES FOR HABITAT RESTORATION

John Portnoy, Cape Cod National Seashore

Hydrodynamic modeling was conducted in 2004 (Spaulding & Grilli 2005); an executive summary of major findings is in the 2006 annual East Harbor monitoring report. Model results have been further analyzed, and presented graphically here, to show the potential for the restoration of estuarine habitats, given the real-world physical constraints on inlet width (i.e. residential and commercial development) through the Beach Point barrier beach.

As described previously, replacing the existing 4-ft diameter culvert with a 5-meter-wide inlet causes flushing time to decrease greatly, from 133 to 13 days (Figure 11-1.) Increasing inlet width to 50 meters, the approximate width of Noons Landing, the only substantial area of undeveloped land remaining on the Beach Point barrier beach, reduces residence time to only about a day. Figure 11-1 also relates model-predicted tidal range, with increasing inlet width, to tidal range in Cape Cod Bay. Existing tidal range is barely perceptible, normally less than 10 centimeters. A 5-meter-wide inlet results in a tidal range about 5% of the bay. Utilizing all of the open land at Noons Landing for an inlet would increase the estuary's tidal range to about 42% that of Cape Cod Bay.

Figure 11-2 shows the model-predicted increase in intertidal area, i.e. extent of exposed flats at low tide, with various inlet widths up to the original 300-meter-wide inlet. Because all modeled scenarios result in improved low-tide drainage (Figure 11-3), substantial increases in intertidal area would result from all increased-inlet options starting at only 5 meters (~16 ft). Utilizing all of the open land at Noons Landing for an inlet would increase the estuary's intertidal area to over 300 acres, including both unvegetated lagoon sediments and bordering emergent wetlands.

Finally, Figure 11-3 shows the effect of increasing inlet width on both high and low tide heights relative to the emergent marsh surface. Both high-tide flooding and low-tide drainage improve substantially with each step increase in inlet width. The productivity of tidal marshes has been shown to increase with tidal range (Steever et al. 1976).

Further assessment of the options for increased tidal exchange in East Harbor awaits restored funding for the US Army Corp of Engineers Comprehensive Feasibility Study of "Pilgrim Lake" tidal restoration.

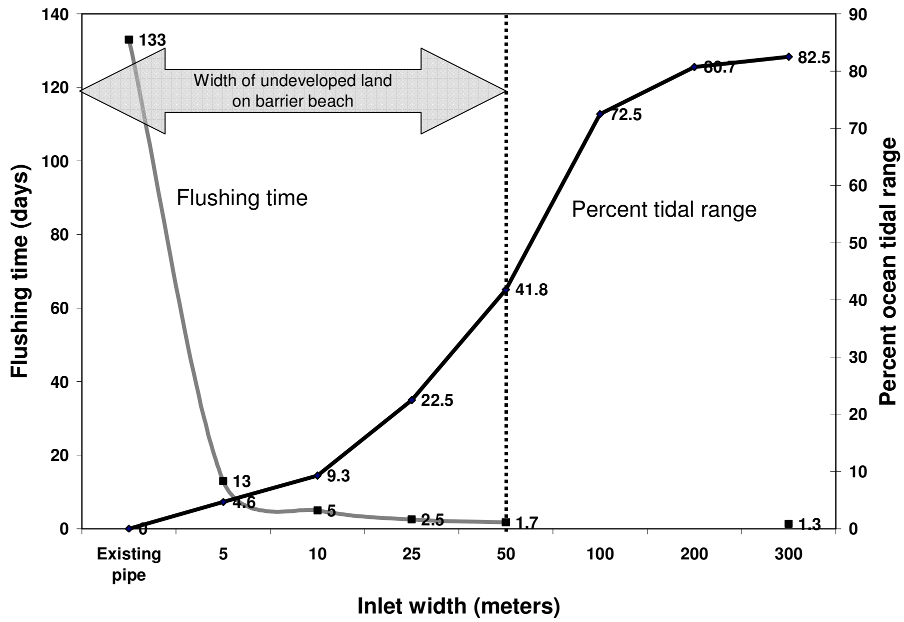


Figure 11-1. Model-predicted increase in flushing and tidal range with increasing inlet width through the Beach Point barrier beach. Note that inlet depth was held constant at -1 m-NAVD. The 50 meters of undeveloped land is at Noons Landing.

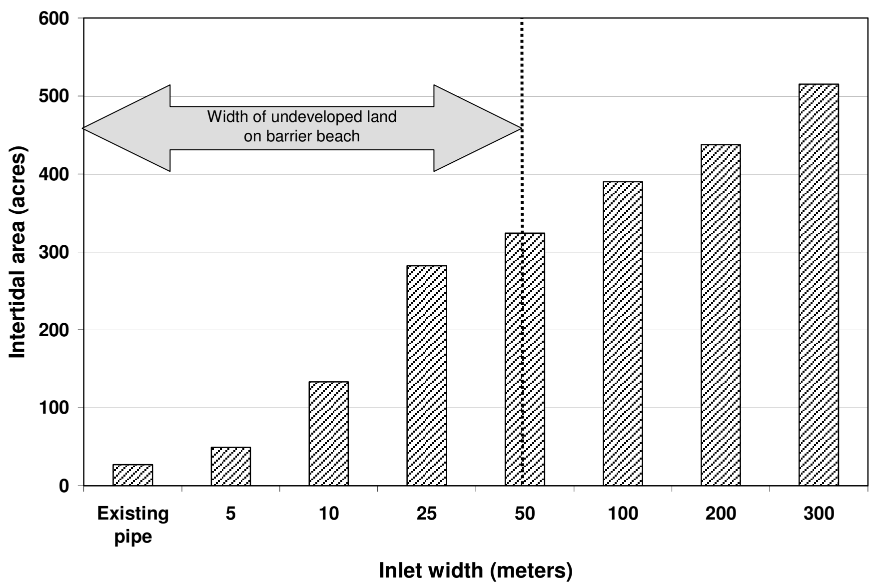


Figure 11-2. Model-predicted increase in intertidal area with increasing inlet width through the Beach Point barrier beach. Inlet depth was held constant at -1 m-NAVD.

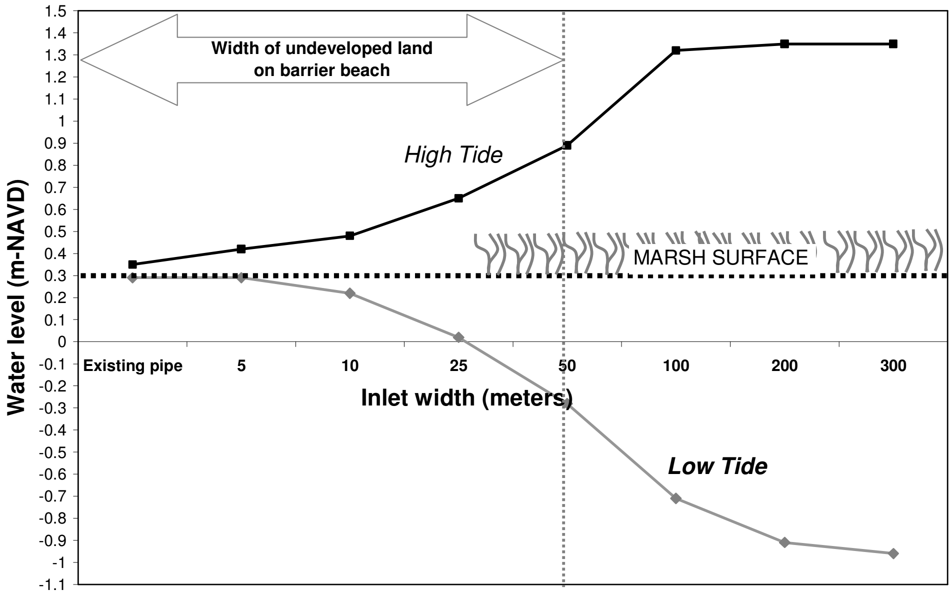


Figure 11-3. The hydrodynamic model for East Harbor shows that increasing the width of an inlet causes high tides to be higher and low tides to be lower. Also, note the increasing depth of marsh flooding, and marsh drainage, with increasing inlet width; salt-marsh productivity is directly related to tidal range.

LITERATURE CITED

Duke C.S., Litaker W., Ramus J. 1989. Effect of temperature on nitrogen-limited growth rate and chemical composition of *Ulva curvata*. *Mar. Bio.* 100:143-150.

Emery, K. O. and A.C. Redfield. 1969. Report on a survey of Pilgrim Lake made for the Scientific Advisory Committee, Cape Cod National Seashore on 16 August 1969. 19 p.

Gordon D.M., Birch P.B., McComb AJ. 1980. The effect of light, temperature and salinity on photosynthetic rates of an estuarine *Cladophora*. *Bot. Mar.* 23:749-755.

Hartel, K.E., Halliwell, D. B. and A.E. Launer. 2003. Inland Fishes of Massachsetts. Massachusetts Audubon Society, Lincoln, MA. 328 pp.

Hauxwell J., Cebrian J., Furlong C., Valiela I. 2001. Macroalgal canopies contribute to eelgrass (*Zostera marina*) decline in temperate estuarine ecosystems. *Ecology* 82:1007-1022.

Hauxwell J., McCelland J., Behr P.J., Valiela I. 1998. Relative importance of grazing and nutrient controls of macroalgal biomass in three temperate shallow estuaries. *Estuaries* 21:347-360.

James-Pirri, M.J., C.T. Roman. (DRAFT). 2004. Monitoring nekton in salt marshes (Revision #1). A Protocol for the National Park Service's Long-Term Monitoring Program, Northeast Coastal and Barrier Network. NPS. Narragansett, RI.

Kahn A.E., Durako MJ. 2005. The effect of salinity and ammonium on seed germination in *Ruppia maritima* from Florida Bay. *Bull. Mar. Sci.* 77:453-458.

Kantrud, H. A. 1991. Widgeongrass (*Ruppia maritima* L.): a literature review. U.S. Fish Wildlf. Serv., Fish. *Wildl. Res.* 10,58.

Kopecky A.L., Dunton K.H. 2006. Variability in drift macroalgal abundance in relation to biotic and abiotic factors in two seagrass dominated estuaries in the western Gulf of Mexico. *Estuaries and Coasts* 29:617-629.

Kostka, J.E. & G.W. Luther. 1995. Seasonal cycling of iron in saltmarsh sediments. Biogeochemistry 29:159-181.

Mather, M. 2003. 2003 Narrative Report on the Freshwater Fish of the Cape Cod National Seashore. Cape Cod National Seashore. 36pp.

Mello, M.J. 2006. Survey of the water-willow stem borer, *Papaipema sulphurata* (Lepidoptera: Noctuidae) and other state-listed wetlands moths in two watersheds, Herring River and Salt Meadow, within Cape Cod National Seashore. Final Report to the National Park service. Lloyd Center report #2006-1. 8 p.

Mozgala, Walter J.Jr. 1974. The Phytoplankton Association of Pilgrim Lake, Cape Cod, Massachusetts. MS Thesis. Amherst, MA. 38 pp.

Portnoy, J. , S. Smith & E. Gwilliam. 2005. Progress Report on Estuarine Restoration at East Harbor (Truro, MA), Cape Cod National Seashore, May 2005. Cape Cod National Seashore. 36 p.

Portnoy, J., S. Smith, E. Gwilliam & K. Chapman. 2006. Annual Report on Estuarine Restoration at East Harbor (Truro, MA), Cape Cod National Seashore, September 2006. NPS Report. Cape Cod National Seashore, Wellfleet, MA.

Portnoy, J.W. & A.E. Giblin. 1997. Effects of historic tidal restrictions on salt marsh sediment chemistry. Biogeochemistry 36:275-303.

Portnoy, J.W. & J. R. Allen. 2006. Effects of tidal restrictions and potential benefits of tidal restoration on fecal coliform and shellfish-water quality. J. Shellfish Research 25:609-617.

Raposa, K.B. 2002. Early Responses of Fishes and Crustaceans to Restoration of a Tidally Restricted New England Salt Marsh. Restoration Ecology Vol. 10 No. 4, pp. 665–676.

Raposa, K.B. and C.T. Roman. 2001a. Monitoring Nekton in Shallow Estuarine Habitats: A Protocol for the Long-term Coastal Ecosystem Monitoring Program at the Cape Cod National Seashore. USGS Patuxent Wildlife Research Center Coastal Research Field Station at the University of Rhode Island, Narragansett, RI 02882

Raposa, K.B. and C.T. Roman. 2001b. Seasonal Habitat-Use Patterns of Nekton in a Tide-Restricted and Unrestricted New England Salt Marsh. *Wetlands* Vol. 21 No. 4. 451-461.

Roman, C.T., Raposa, R.B., Adamowicz, S.C., James-Pirri, M. and J.C. Catena. Quantifying Vegetation and Nekton Response to Tidal Restoration of a New England Salt Marsh. 2002. *Restoration Ecology* Vol. 10 No. 3, pp. 450–460.

Smith, S. M. 2007. Removal of salt-killed vegetation during tidal restoration of a New England salt marsh: effects on wrack movement and the establishment of native halophytes. Ecological Restoration 24:268-273.

Smith, S.M. 2005. 2004 Vegetation monitoring report for salt marsh restoration projects. NPS technical report. Cape Cod National Seashore, Wellfleet, MA.

Smith, S.M. 2006. Salt marsh vegetation monitoring 2005. NPS technical report. Cape Cod National Seashore, Wellfleet, MA.

Sokal, R. R. and F. J. Rohlf. 1981. *Biometry: the principles and practice of statistics in biological research.* 2nd edition. W. H. Freeman and Co.: New York. 859 pp.

Spaulding, M. & A. Grilli. 2005. Hydrodynamic Assessment of Estuarine Restoration of Pilgrim Lake, Moon Pond, and Salt Meadow, Truro, Massachusetts. Report to National Park Service. 46 p.

Steever E.Z., Warren R.S., Niering W.A. (1976) Tidal energy subsidy and standing crop production of *Spartina alterniflora* Est. Coast. Mar. Sci. 4:473--478

Taylor R., Fletcher R.L., Raven J.A. 2001. Preliminary studies on the growth of selected ‘green tide’ algae in laboratory culture: effects of irradiance, temperature, salinity and nutrients on growth rate. *Bot.Mar.* 44:327-336

Thursby, G.B., M.M. Chintala, D. Stetson, C. Wigand, and D.M. Champlin. 2002. A rapid, non-destructive method for estimating aboveground biomass of salt marsh grasses. Wetlands 22(3):626-63.

Valiela I, McClelland J, Hauxwell J, Behr PJ, Hersh D, Foreman K. 1997. Macroalgal blooms in shallow estuaries: controls and ecophysiological and ecosystem consequences. *Limnol. Oceanogr.* 42: 1105-1118.

Valiela, I., K. Foreman, M. LaMontagne, J. Costa, P. Peckol, B. DeMeo-Anderson, C. D'Avanzo, M. Babione, C. Sham, J. Brawley, and K. Lajtha. 1992. Couplings of Watersheds and Coastal Waters: Sources and Consequences of Nutrient Enrichment in Waquoit Bay, Massachusetts. Estuaries. 15(4): 443-457.

Von Dassow Y.J. and R.R. Strathmann. 2005. Full of eggs and no place to lay them: hidden cost of benthic development. *Mar. Ecol. Prog. Ser.* 294:23-34.

XLSTAT version 7.3.5. Addinsoft NY, NY.