Annual Report on Estuarine Restoration at East Harbor (Truro, MA), Cape Cod National Seashore, September 2006

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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 almost continuously since November 2002 to try to improve tidal flushing and aeration.

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

With the clapper valves open, salinity has risen from about 4 to about 20-25 parts per thousand (ppt) in the East Harbor lagoon ("Pilgrim Lake"); however, most of the surrounding wetlands receive little seawater.

Increased salinity has eliminated most nuisance chironomid midge breeding in lagoon sediments.

Enterococcus, an indicator organism for bathing water quality, was initially (2001) high in culvert discharge, but low throughout succeeding summers.

Many species of estuarine finfish, shellfish and other benthic animals have rapidly reestablished 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In East Harbor lagoon and Moon Meadow former fresh/brackish finfish have been replaced by an assemblage of species typical of lower Cape salt marshes.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.

Benthic animal abundance increased rapidly until 2004, but declined in 2006, probably due to observed oxygen depletions during hot summer weather.

Since culvert opening, widgeon grass has proliferated throughout the lagoon, increasing habitat value for finfish, crustaceans and waterfowl.

Healthy eelgrass is spreading in Moon Pond creek, which receives regularly tidal flushing.

Exotic common reed (*Phragmites*) has declined in Moon Pond due to increased salinity and probably sulfide accompanying partial tidal restoration.

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.

Dense beds of macroalgae and filamentous cyanobacteria accumulated in the late summers of 2005 and 2006, produced an odor nuisance as they decomposed, and signaled continued poor tidal flushing and nutrient loading, perhaps from adjacent development. This problem will be studied more intensively in 2007.

Two state-listed rare animals, the water-willow stem borer (a noctuid moth) and the northern harrier, occur within the diked East Harbor flood plain and would likely be adversely affected by full tidal restoration.

Hydrodynamic modeling shows that the replacement of the 4-ft diameter culvert with a opening at least 16 ft wide would increase flushing about ten fold and likely greatly improve water quality.

The US Army Corps of Engineers continues their Comprehensive Feasibility Study of more complete tidal restoration in East Harbor.


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 the 1868 filling of the original 1000-ft wide inlet at the northwest end of the system (Figure 1-1). [See Appendix A for a chronology.] 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 native 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: the 1911 state survey reported "turbidity of eight inches" (presumably the extent of visibility) with cloudiness caused by a "yellow substance" (likely cyanobacteria) that clogged their plankton net. Generally low salinity (4-10 ppt), cyanobacterial blooms, nuisance chironomid midge hatches (Mozgala 1974) and chronic summertime dissolved oxygen stress continued until the 21st century (Emery & Redfield 1969, Cape Cod National Seashore 2002).

An oxygen depletion and fish kill in September 2001, involving about 40,000 alewives (*Alosa pseudoharengus*), originally introduced in the late 1960s, and several hundred white perch (*Morone Americana*), prompted consultation between Truro, Cape Cod National Seashore and state officials on possible measures to improve water quality. As an interim measure, the clapper valves in the 4-ft diameter drainage pipe connecting the south end of the system (Moon Pond) with Cape Cod Bay (Fig. 1-1) were opened in December 2001 to try to increase aeration by partially restoring some tidal exchange. As an immediate consequence, increasing salinity in Pilgrim Lake killed several hundred carp (*Cyprinus carpio*), forcing several hundred individuals into Salt Meadow which remained freshwater; most of the latter fish were netted and removed by NPS staff in early 2002.

The clapper valves were closed in February 2002 at the request of the Division of Marine Fisheries (DMF) to allow lagoon salinity to decrease enough for river herring spawning, but reopened in November. The DMF has since determined that the restoration of estuarine finfish is preferable to maintenance of an introduced herring run; therefore, the clapper valves have remained open to date. See Appendix A for a chronology of these events.

The following is a summary of monitoring results for tide heights, water quality, both submerged and emergent vegetation, nekton (fish and decapod crustaceans), and benthic invertebrates, including chironomid midges, from 2005 and 2006. See our earlier report (Portnoy et al. 2005) for monitoring results back to 2002.

Figure 1-1. East Harbor, comprising "Pilgrim Lake", the original back-barrier lagoon, and Moon Pond and Salt Meadow, both back-barrier salt marshes. Also shown are the position of the original inlet, filled in 1868, and the current four-foot diameter culvert connecting the system to Cape Cod Bay.
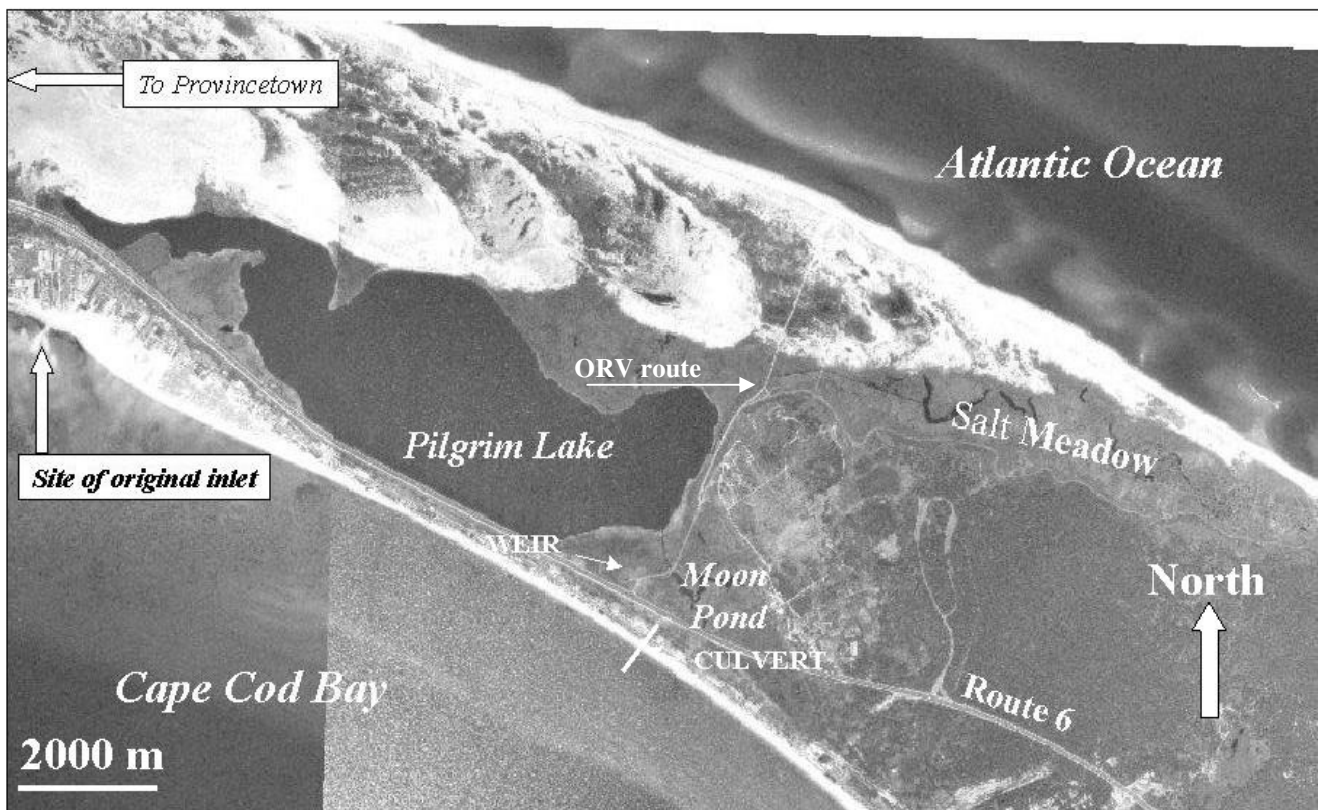
2. HYDRODYNAMIC MODEL

Hydrodynamic and salinity models for existing conditions and for several tidal-restoration alternatives were completed in October 2005 by Drs. Malcolm Spaulding and Annette Grilli of the University of Rhode Island, under contract to the National Park Service. Copies of their report, *Hydrodynamic Assessment of Estuarine Restoration of Pilgrim Lake, Moon Pond, and Salt Meadow, Truro, Massachusetts,* are available from the authors of this progress report.

Here is the Executive Summary:

The National Park Service (NPS) is interested in restoration of the natural tidal exchange between Cape Cod Bay and East Harbor to eliminate eutrophication, chronic oxygen depletions and fish kills in Pilgrim Lake and the peat drainage and acid sulfate soil formation in upstream wetlands. Within the context of this overall effort the goals of the present study, focusing on the physical processes in the system, are to:

1. *Characterize the topography, bathymetry, and geomorphology of the system*
2. *Determine the existing hydrology and tidal hydrodynamics and hydrography (salinity and temperature) of the system.*
3. *Apply, calibrate, and verify hydrodynamic and salinity models for the system*
4. *Apply the hydrodynamic and salinity models to assess the impact of potential tidal restoration scenarios (control of tidal gates, installation of additional culverts, construction of tidal inlet) proposed by NPS.*

As part of this study a variety of field collection efforts were performed to characterize the existing system. Intensive tidal cycle survey data were collected on May 19-20, 2004; July 15, 2004; and August 5, 2004, to characterize the currents/flows, sea surface elevations, salinity, and temperature field in the Pilgrim Lake system and adjacent Cape Cod Bay over a lunar, semi-diurnal (M_2) tidal cycle (period-12.42 hrs). Measurements were made at the Rte 6 and High Head Road culverts, with an accompanying hydrographic survey of Pilgrim Lake. In addition time series data on the water levels at Provincetown, Moon Pond, and Pilgrim Lake were collected simultaneously for period of about 7 months.

Analysis of the data resulted in the following insight into the lake dynamics.

- *For the dominant M_2 tides, the amplitude decreases from 1.34 m at Provincetown to 0.153 m in Moon Pond (11% of the Provincetown amplitude). The M_2 phase in Moon Pond (126.7 degrees GMT) lags that at Provincetown (115.95 degrees GMT) by 10.75 degrees or 0.370 hrs (22.2 min). The other major tidal constituents (N_2, S_2, K_1, and O_1) are seen to show amplitude reductions, on the order of a factor of 10, between Provincetown and Moon Pond. For comparison the intensive tidal cycle surveys showed a reduction in tidal range from the ocean (2.8 m) to Moon Pond (0.2 m) of about a factor of 14. The tidal range at Provincetown is approximately 96% of the Boston with high tide lagged by about 16 minutes.*

- *Water level fluctuations in Pilgrim Lake are dominated by low frequency non-tidal forcing. No water level variations at tidal time scales were observed in the lake. This is a direct result of the very limited tidally induced flux of water into the lake and the very large volume of the lake.*

- *Tidal current speeds are 40 % to 70 % stronger at flood than at ebb tide at the Rte 6 culvert.   The flood tide however is of shorter duration (5.1 hrs) than the ebb (7.3 hrs). The flood tide currents display a sine like shape, whereas ebb tides are almost constant throughout the ebb tide. Tidal currents at High Head Road culvert show a similar shape to those at Rte 6 but are about 2 to 3 times weaker. The shape of the tidal current curve is a direct result of strong ocean forcing on flood tide followed by draining of the system on the ebb.*

- *Hydrographic surveys show that lake waters are vertically and horizontally well mixed throughout the system. The exception is that in the northwestern end of the lake the water is stratified due to a local source of ground water entering the system. Since there were no observed tidal currents in the lake the lack of vertical or horizontal stratification seems likely due to wind mixing.*

An inlet basin hydrodynamic model was applied to the Pilgrim Lake system. Two basins, Moon Pond and Pilgrim Lake, connected to each other by High Head Road culvert, and to the ocean via Moon Pond by the Rte 6 culvert, were used to represent the system. Input data on the culvert system geometry and elevations were based on a survey of the infrastructure and the as built drawings. The storage capacity of the basin was determined by NPS personnel based on an analysis of existing data, supplemented by a topographic survey of selected sections of the system, and in particular Salt Meadow, performed by Slade Associates Inc. as part of this study. The model was forced by the ocean water level. The model was calibrated by comparison of model predictions to data collected during the intensive tidal cycle surveys and the time series measurement program. A Manning coefficient was used to characterize losses in the culvert under High Head Road and a relative roughness coefficient was used for the same purpose for the culvert system from the ocean to Moon Pond.

The simulations show a dramatic reduction of tidal variations between Provincetown and Moon Pond and essentially no tidal signal in Pilgrim Lake; both consistent with the observations. Predicted water levels in Moon Pond were within several centimeters of the observed values. The model predicts a slightly earlier rise in water level in Moon Pond than observed but accurately reproduces the decrease in water level with time. The large differentials in water levels between Moon Pond and the ocean are a direct result of the frictional losses in the Rte 6 culvert system and the large differential in storage capacities of the two basins. At elevations typical of those currently observed in the field measurement program, Moon Pond comprises 2 % and Pilgrim Lake and Salt Meadow the remaining 98% of the surface area of the combined system. The amount of water entering/exiting Moon Pond on the flood/ebb tide is sufficient to raise/lower the water level in Moon Pond because of its relatively limited storage capacity. The amount of water that enters/exits Pilgrim Lake over a tidal cycle however is extremely small

compared to the storage capacity of the basin and hence doesn't measurably affect the water level in the lake.

A tidal prism based model was applied to Pilgrim Lake System to predict the mean salinity in the system. The model used output from the hydrodynamic model to specify the volume exchanges between the lake and the ocean. A mean freshwater input rate of 0.073 m³/sec was assumed based on a groundwater and runoff model developed by Masterson (2004). The ocean salinity was set at 31 ppt. Model predictions were compared with data collected by NPS at four monitoring stations that they occupied in the lake following the opening of the tidal gates. At approximate steady state conditions the model predicted a salinity of 24.5 ppt, compared to a mean of the observations of about 23.5 ppt.

A sensitivity study was performed varying the freshwater input to the lake by +/- 10 and 20 %. As expected the predicted salinity decreases/increases as the freshwater input rate increases/decreases. Variations are on the order of 0.5 ppt. If the freshwater input is increased by 100 % then the salinity decreases by 5 ppt.

Next a series of simulations were performed where the freshwater input rate was held fixed at the mean value and the return parameter, b, varied between 0 and 1. The return parameter specifies the amount of water exiting on the ebb tide that re-enters on the next flood. The model shows that the higher the amount returned the lower the salinity in the lake. For b= 0.8 the salinity is about 17 ppt at the end of the simulation compared to a value of 25 ppt for b = 0. Model predictions with b = 0.4 result in a salinity of 23.5 ppt in good agreement with the average of all the station data.

Based on input from NPS, the State of Massachusetts, and the US Army Corp of Engineers a total of 26 restoration options were investigated. The options were divided into two major classes. Option 1 (12 cases) assumed that the current culvert system at the southwestern end of the lake continues to exist, connecting the ocean to Moon Pond, and that a new inlet is constructed at the location of the historic inlet on the northwestern end of the lake. Option 2 (14 cases) assumes that a new inlet replaces the current culvert system, with Sub-option 1 (2-1) assuming that the Salt Meadow Dikes are removed and Sub-option 2 (2-2) that they continue to exist. Within each option the impact of inlet width and bottom depth were investigated. For the new inlet on the northwestern end of the lake widths of 50, 100, 200, and 300 m were investigated. For the replacement inlet on the southwestern end of the system widths of 5, 10, 25, and 50 m were studied. The maximum width of the southwestern inlet was constrained by the existing Town of Truro Park. Inlet depths of 0.0, -0.5 and –1.0 m (NAVD88) were explored. For reference the mean depth of Pilgrim Lake is about -1 m. Simulations were performed for each case using the hydrodynamic model and results summarized in terms of the high and low water levels and tidal range in Pilgrim Lake compared to equivalent values in the ocean. In broad overview, model predictions show that
  - *Low tide levels decrease (lower levels) with increasing inlet width and depth and reach their lowest values for a width of 200 m or greater and depths of –1.0 m.*

- *High tide levels increase (higher levels) with increasing inlet width and reach their highest value for a width of 200 m or greater. The depth of the inlet has little impact on high tide levels. For inlet widths greater than 200 m high tides in the lake are the same as in the ocean.*
- *Tidal range increases with inlet width and reaches a maximum for a width of 200 m or greater. The lower the depth of the inlet the larger the tidal range. The depth of the inlet restricts the tidal range for the case with the largest width (300 m) and depth (-1.0 m).*
- *Removal of the Salt Meadow dike and culvert system decreases the tidal range slightly (about 15 %) compared to existing conditions. This difference is a direct result of the differential storage capacity for the lake with and without Salt Meadow dike restrictions.*

To achieve the maximum tidal exchange with the ocean and hence the largest tidal range (approximately 80 % of the ocean range) in the lake requires an inlet with a width of 200 m or larger and an inlet depth of –1 m. The tidal range in this case is restricted by low tide levels and in turn the depth of the lake. At ebb tide much of the lake bottom would be exposed.

For the maximum width of the southern inlet of 50 m and an inlet depth of –1.0 m the tidal range in the lake is approximately 46% of that in the ocean. Restrictions in this case are imposed both by the high and low tide levels.

For three of the most probable remedial option cases (R21-1C (5 m width), R21-4C (50 m width), and R22-4C (50 m width), all with inlet depths of –1 m, predictions were made for the salinity and water level in the lake from 100 yr storm forcing. These simulations show that as the inlet width increases the lake salinity is predicted to increase and asymptotically approach the oceanic value. The maximum water level in the lake also increases as the width of the inlet increases. For the 50 m case maximum storm levels are about 75 % of those in the ocean. For reference, if an optimal inlet is constructed with a width of 300 m and a depth of –1.0 m, the salinity, high water and the maximum 100 yr water level will be the same as in the ocean. The tidal range in the lake will be about 82.5 % of the oceanic value and restricted by the depth of the lake. Plan view plots of the high and low tide water surface area were prepared for existing conditions and the most probable and optimum remedial options. High tide surface areas are shown to increase as the inlet widths increase (for widths of 50 and 300 m). The differential high tide surface area between the 50 m and 300 m width cases is quite modest and is a direct result of the change in slope of the storage capacity vs elevation curve, reflecting a more vertical sided basin. The low tide surface areas are predicted to decrease as the inlet width increases (for widths of 50 and 300 m). The bowl shaped geometry of the lake limits the change between the two cases.

The simulations show that the tide range, surface area at high tide, and mean salinity can all be substantially increased, compared to existing conditions, by construction of a 50 m wide, -1.0 m deep inlet, within the existing right of way, at southwestern end of the Pilgrim Lake system. With Salt Meadow dikes removed this case results in flooding of the majority of the Salt Meadow system. The optimum inlet, as defined by the largest tidal

range, largest high and smallest low tide surface areas, and highest salinity is achieved for inlet widths greater than 200 m with a depth of –1.0 m.

3. TIDES, WATER QUALITY AND MACROALGAE BLOOMS

<u>Tide heights and salinity</u>
The clapper valves in the culvert connecting East Harbor with Cape Cod Bay have remained open continuously (except for a brief period for culvert repairs in March 2005) since November 2002; therefore, there has been no substantial change to the system's tidal regime since that time. Figure 3-1 shows that the 2.5-3.5 m (~10 ft) tidal range in unrestricted Provincetown Harbor is reduced to less than 0.5 m (~1.5 ft) in Moon Pond.

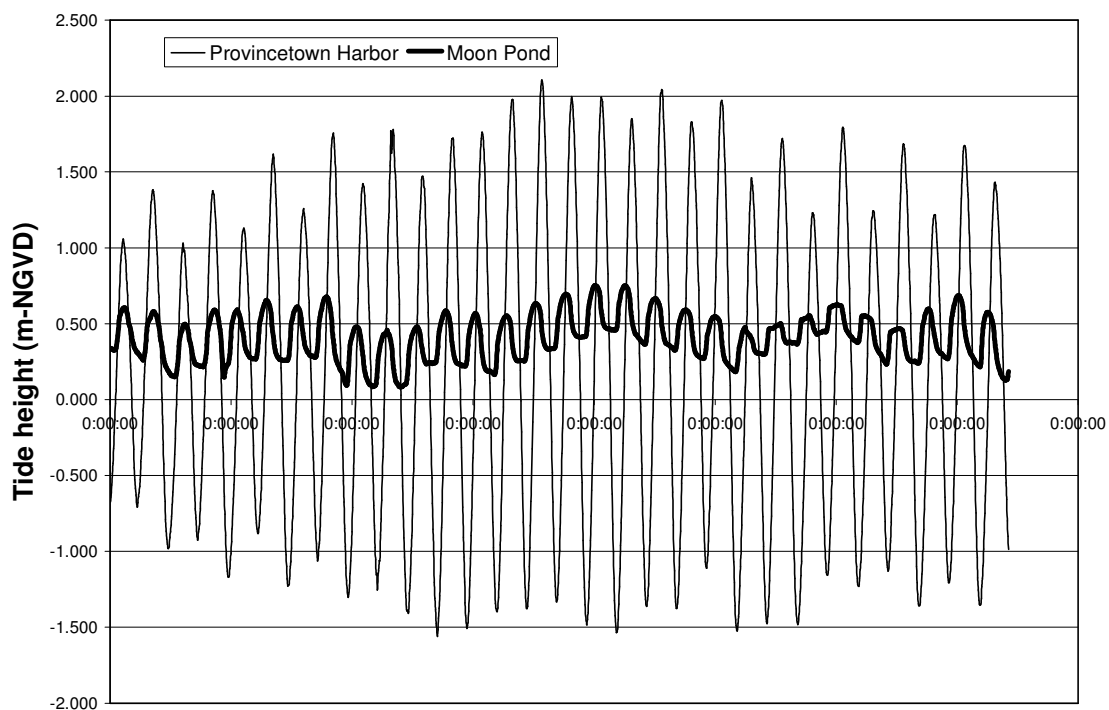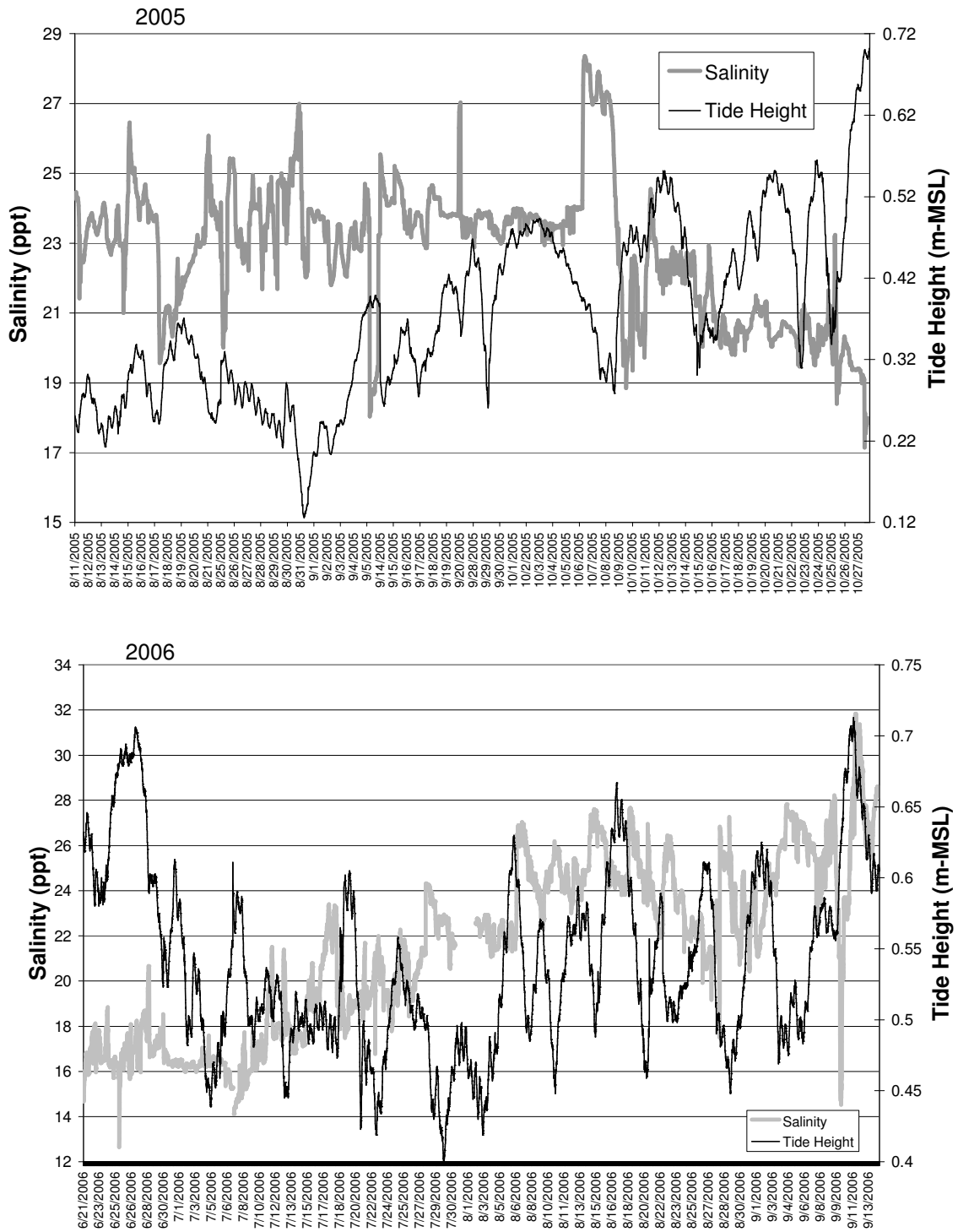Figure 3-1. Tides in Provincetown Harbor and Moon Pond, 1-17 March 2004.

Figure 3-2. Salinity and tide-height records for East Harbor lagoon in 2005 and 2006.

Tide height, salinity, temperature and dissolved oxygen are recorded by an automatic data logger at 30-min intervals about 30 cm above the bottom in the southeast corner of the lagoon. Data are presented for 11 August to 27 October 2005 and from 21 June to 13 september 2006 (Fig. 3-2).   [Note that data collection will continue through October 2006.]

The flood-tide volume that passes under High Head Road is too small to create significant tides in the 350-acre East Harbor Lagoon; at most, 2-3 cm (~0.1 ft) of tidal fluctuations are discernible during calm weather in the 2005 and 2006 records (Fig. 3-2). Water level varies 20-30 cm (up to one foot) between spring and neap tides, with a seasonal variation of about 20 cm due to high evapotranspiration and lower water levels in summer (Fig. 3-2).

Salinity ranged 22-27 ppt in the lagoon, except for the early summer of 2006 when salinity was lower due to high precipitation during late winter and spring. Salinity is highest during spring, and lowest during neap tides.


Temperature and dissolved oxygen

During both 2005 and 2006 summers, the water column in East Harbor lagoon still showed strong diel (day-night) oscillations in temperature and even stronger oscillations in dissolved oxygen (Fig. 3-3). Insolation during the day both heats the shallow lagoon water and provides energy for photosynthetic oxygen production in the highly productive (algae-rich) water column; at night, heat radiates out and all of the aquatic biota respire, consuming and depleting the dissolved oxygen. The extreme day-night range in oxygen indicates a highly organically enriched system, with supersaturation of this dissolved gas during the mid-day, and near oxygen depletion at night. As expected, with decreasing light, temperature and, thus algal biomass in fall 2005 (Fig. 3, bottom), oxygen concentrations stabilize over the day-night cycle at about 100% saturation.

The system's temperature and oxygen environment apparently became critical during very hot weather in late July and early August 2006, with water temperatures about 30° C. during the day and the near depletion of oxygen during the night. It was apparently during this period that the soft-shell clams that had colonized the lagoon died en masse (see Benthic Invertebrates, below); however, fish kills have not been observed since September 2001, before the culvert opening, suggesting that the many finfish of many species (see Nekton, below) that have reestablished in the lagoon have been able to detect and avoid hypoxic water masses.

In summary, the prevalence of high water-column production, both before and after the 2002 culvert opening, has caused water-column hypoxia (dissolved oxygen stress and occasional depletions) during hot summer weather. Prior to 2002 and before salt water was allowed back into the system, these events were signaled by fish kills. After culvert opening in 2002, salinity increased, allowing bivalves to set abundantly throughout the lagoon bottom. Thus, when oxygen depletions occurred in 2006, they were marked by massive soft-shell clam (*Mya arenaria*) mortality. Importantly, fish kills were not evident in 2006, and dense schools of mummichogs and silversides persisted throughout the summer, indicating that hypoxia was limited to the bottom of the water column, affecting only the benthic animals.

Figure 3-3. Temperature and dissolved oxygen records for East Harbor lagoon in 2005 and 2006.
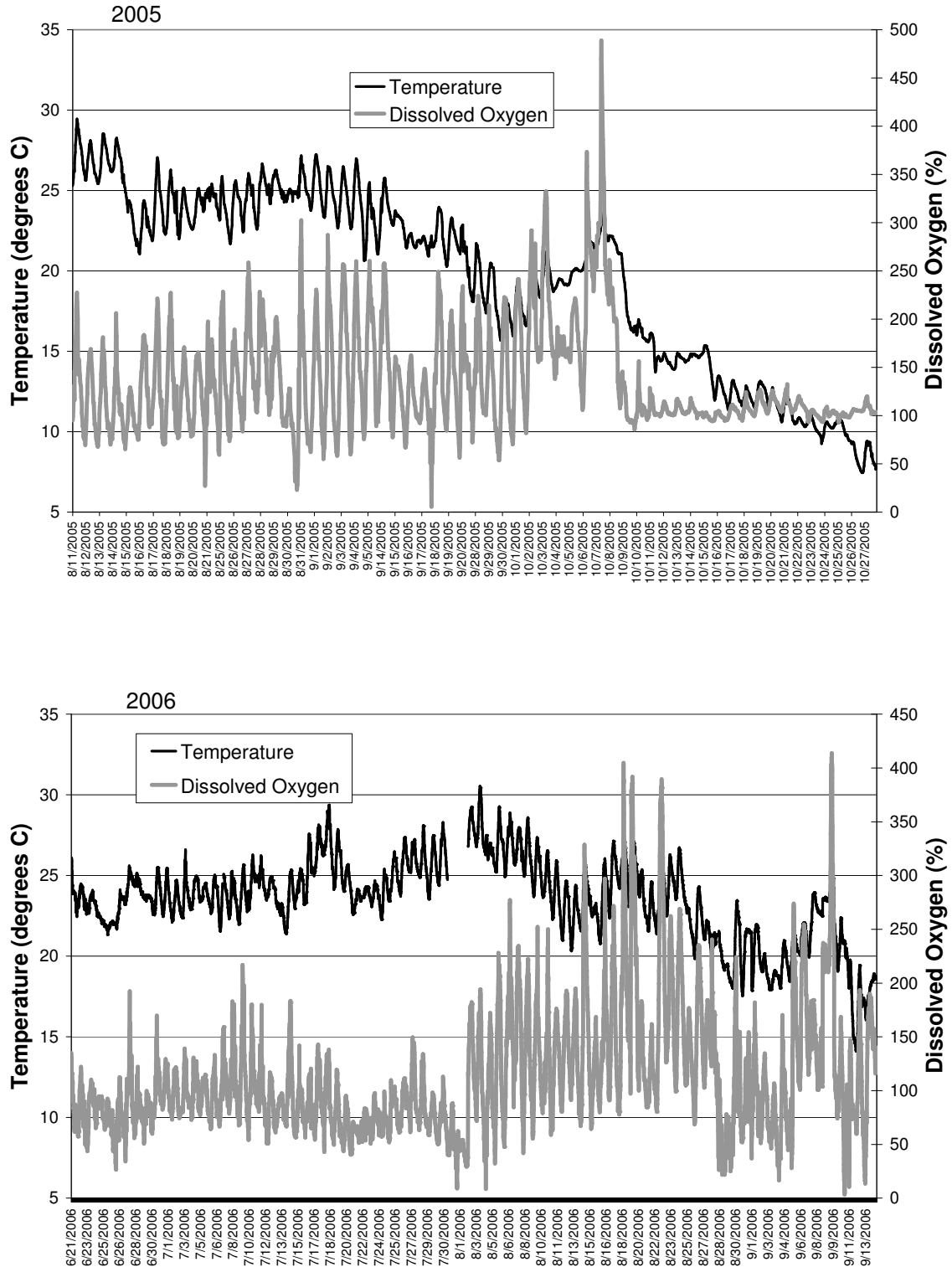
Algae blooms

For at least the past few decades, and evidently as far back as the early 20th century (Massachusetts Survey of Inland Waters 1911), primary production in the water column of impounded and freshened East Harbor has been dominated by high concentrations of planktonic cyanobacteria (Mozgala 1974); consequently lagoon water was always cloudy with Secchi depths less than 20 cm. With increased salinity since 2002, primary production within the water column has shifted from a community dominated by plankton (mostly cyanobacteria) to macrophytes, including widgeon grass, some eelgrass and, since 2005, dense mats of green algae (*Cladophora* and *Enteromorpha* spp.) and filamentous cyanobacteria. The water column itself, however, has become very clear, with visibility commonly extending to the lagoon bottom (1-2 meters depth).

Blooms of both planktonic algae and macroalgae (seaweeds) in coastal lagoons are caused by high nutrient supply and/or poor tidal flushing. Despite the open culvert and impressive increase in salinity since 2002, flushing with relatively oxygen-rich and nutrient-poor Cape Cod bay water remains very poor. The infusion of this aerated seawater on flood tides is a very small fraction of the lagoon's total volume and, therefore, has no noticeable effect on the system's oxygen budget. Based on lagoon bathymetric, tide-height and salinity data collected for development of the bathymetric model, we calculate that lagoon flushing time under current conditions is about <u>130 days</u> (Fig. 3-4). Under these conditions, nutrients from surrounding wetlands, precipitation, Route 6 runoff and perhaps Beach Point wastewater, accumulate. In this regard, proposed (and modeled, see above) increases in tidal exchange should improve flushing and water quality significantly (Fig. 3-4).

The continued wide diel fluctuations in dissolved oxygen in this lagoon is sustained not only by a highly eutrophic water column, but also by very limited tidal exchange with relatively clean (i.e. low nutrients and organic matter) Cape Cod Bay water (see below). These conditions will very probably persist until tidal flushing can be increased. Besides a poor rate of flushing, nutrient loading to the system from Route 6 runoff and possible wastewater discharge from adjacent development need more study.
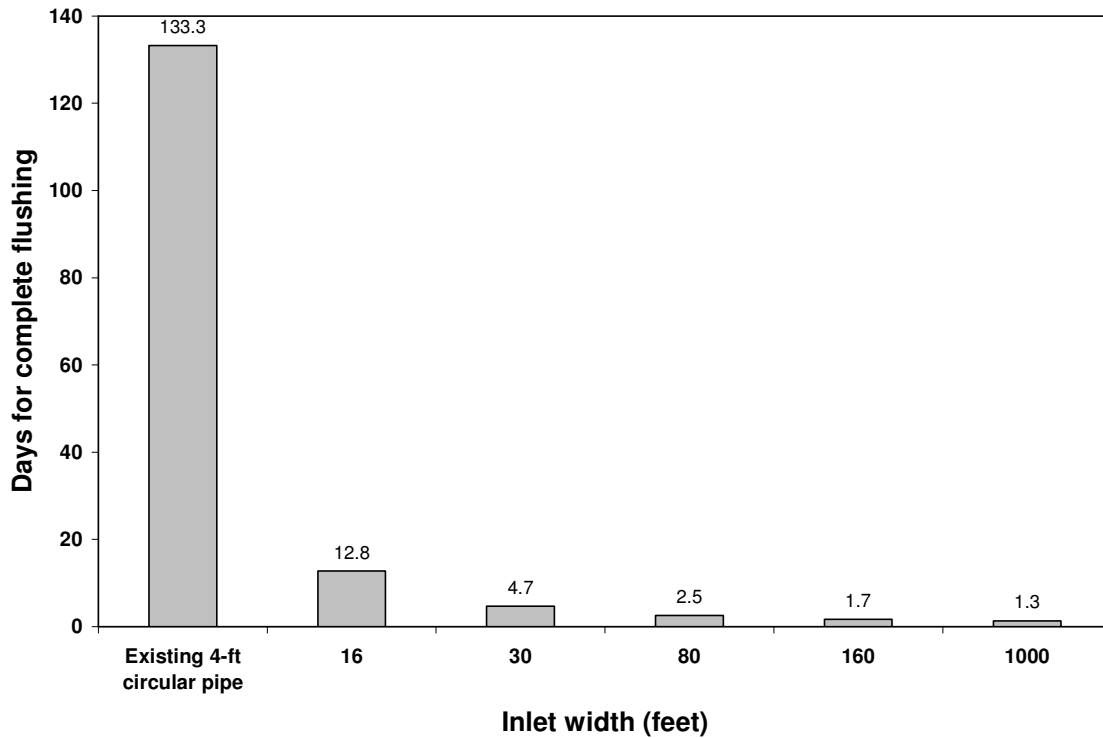
Figure 3-4. Flushing times for East Harbor with various modeled inlet widths, compared to existing 4-ft diameter culvert.

Chronic summer oxygen depletions and attendant fish kills in East Harbor have been documented historically (Mozgala 1974) and observed in recent summers (Fig. 3-4). Although fish kills have not been observed since opening the clapper valves in the culvert, the system is still oxygen-stressed at night and during periods of cloudy weather. This is not surprising given that the infusion of aerated seawater on flood tides is a very small fraction of the lagoon's total volume and, therefore, has no noticeable effect on the system's oxygen budget. In contrast, the open culvert has dramatically increased salinity because salt behaves conservatively, i.e. most of it persists unchanged and is simply mixed throughout the 350-acre lagoon by efficient, wind-driven circulation.

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4. MICROBIOLOGY

Public health microbiology has been an issue at East Harbor because the culvert that drains freshwater from the system discharges into Cape Cod Bay near Beach Point bathing beaches (Fig 1-1). When the culvert was reopened in June 2002 (see chronology, Appendix A), after several months of closure and upstream stagnation, high concentrations of *Enterococcus* bacteria, the current standard indicator organism for marine bathing water quality, were observed in turbid discharge water during ebb tides. Immediately thereafter, the Seashore began to monitor *Enterococcus* at the discharge pipe and at adjacent Noon's Landing bathing beach, a program that has continued on a weekly basis throughout the swimming season (1 Jun – 30 Aug) to the present. Samples are collected during low ebb tide, to represent a worst-case condition for encountering bacteria in pipe discharge, immediately returned to the Seashore laboratory and analyzed using standard methods (mEI agar, EPA Method 1600, Membrane Filter Test Method for *Enterococci* in Water, EPA-821-R-97-004a). Results are expressed as colonies (colony-forming units) per 100 ml of sample.

Despite the high bacteria counts immediately after reopening the culvert in 2002, with the culvert open continuously since November 2002, bacteria concentrations in pipe discharge have been low during the 2003 through 2006 summers (Fig. 4-1).

A slight increase in mean bacteria densities at both Noon's Landing beach and the culvert in 2006 is because two samplings, on 21 and 28 August, followed heavy rain events. Heavy rainfall and freshwater discharge cause high counts in culvert discharge from East Harbor. Importantly, some of this high-*Enterococcus* discharge probably comes from Route 6 runoff, all of which is channeled to East Harbor wetlands by the current highway design. During dry weather, Noon's Landing bathing water often have higher bacteria counts than the water discharging from East Harbor (Fig. 4-2).

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Figure 4-1. *Enterococcus* bacteria in East Harbor culvert discharge and at adjacent Noons Landing bathing beach, 2002-2006. Data are means of weekly samples collected at low-ebb tide June through August.
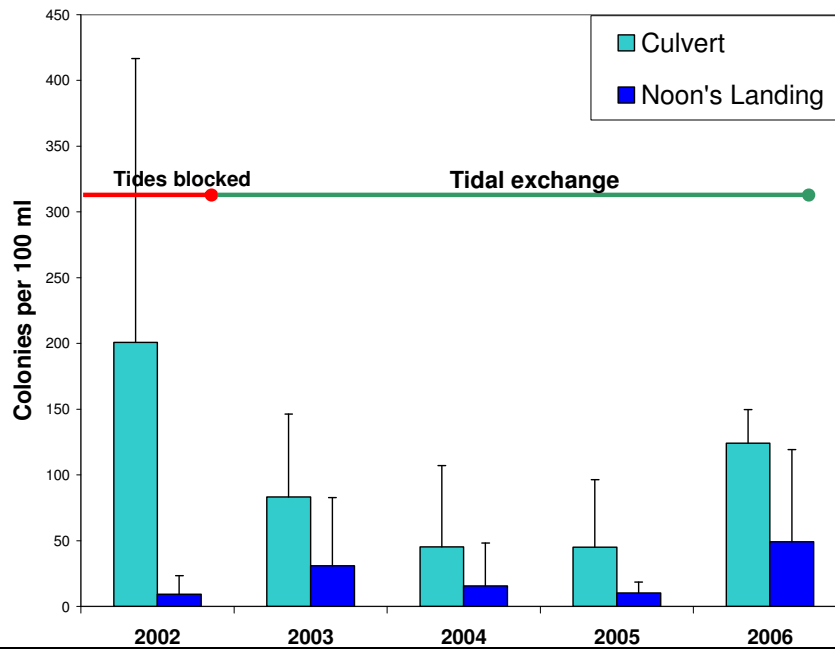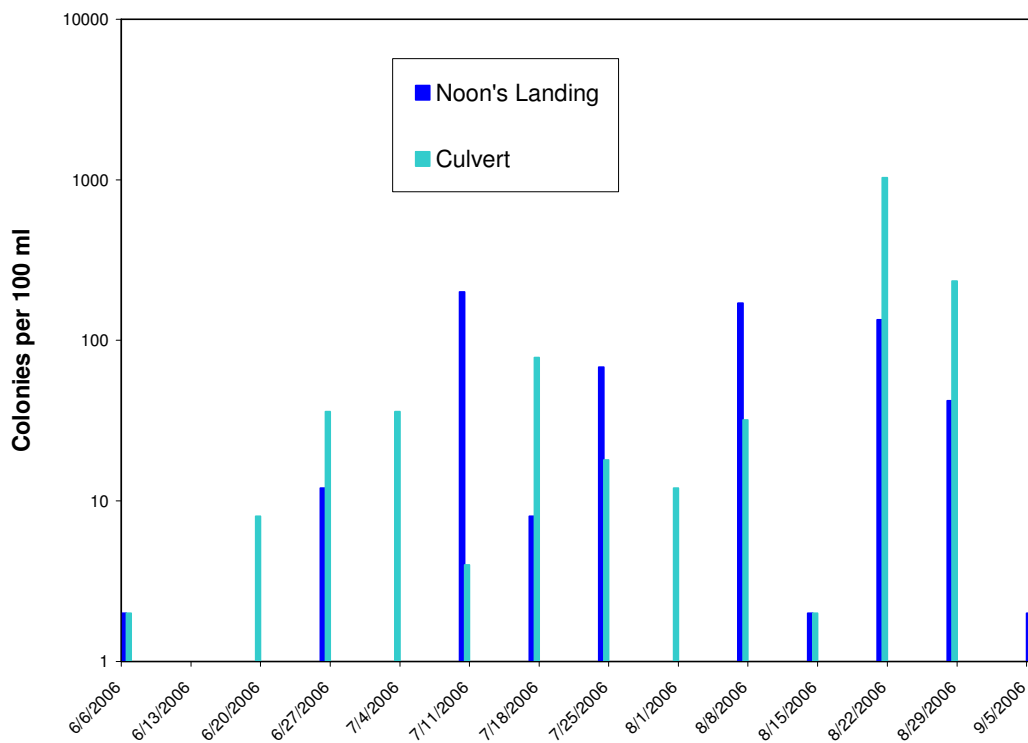

Figure 4-2 . *Enterococcus* bacteria in East Harbor culvert discharge and at adjacent Noons Landing bathing beach during weekly samplings at low tide in summer 2006. High counts in culvert discharge follow heavy rainfall and freshwater discharge from East Harbor

5. BENTHIC INVERTEBRATES

Chironomid midges

The non-biting chironomid midges had been a sporadic problem at Pilgrim Lake and Beach Point for many years where the restriction of tidal flow has created an environment of low salinity and high organic loading conducive to midge production during spring and summer. Adults and larvae have been identified in the past as *Chironomus decorus* (Mozgala 1974), a freshwater to brackish water species. In laboratory cultures Colburn (2003) observed a consistently high adult emergence at low salinities (< 7 ppt), a rapid drop in emergence with no successful metamorphosis as experimental salinities reached 10.5 ppt, and recovery with limited emergence at 14 and even 17.5 ppt.

Several major midge hatches occurred in the late summer of 2002, after state Division of Marine Fisheries concern for anadromous fish spawning, and Truro Board of Health concern for bacteria contamination of nearby beaches led to the blockage of tidal exchange and decrease in salinity beginning in February. By May 2002 salinity was only 5-10 ppt and high densities of midge larvae were widespread throughout the sediment of the main body of the lake. Massive hatches of adults were a nuisance to Beach Point residents in August and September.

As mentioned, with the clapper valves cabled open continuously beginning in November 2002, salinity of East Harbor increased to about 25 ppt in summer and 20 ppt in winter by mid-2003, ending most midge breeding. One exception was the northwest cove where high freshwater discharge and consequent low salinity allows some midges to reach maturity; no complaints were received by Seashore staff in either 2005 or 2006.

Although not a specific target of the study, benthic invertebrate sampling in 2006 found a few chironomid larvae in the northwest cove, but nowhere else in the system, probably because of sustained high salinity.

Other benthic animals

Benthic invertebrates are fundamental to shallow estuarine food webs. These animals feed on organic matter and associated microbes and thereby transfer the products of primary production, fixed by algae and plants, to their predators, including decapod crustaceans, finfish and water birds.

During the summers of 2003, 2004 and 2006, surveys of benthic fauna were undertaken by University of Rhode Island interns under the direction of CCNS staff and Sheldon Pratt, a marine benthic ecologist at the URI Graduate School of Oceanography (Carlson 2003, Lassiter 2004). Cores were collected using a 32 cm^2 PVC tube at random locations within the northwest cove and East Harbor lagoon (the main body of Pilgrim Lake). Sediment was sieved through 0.5-mm mesh and animals retained on the sieve were identified and counted.

Increased tidal exchange and salinity since 2002 has been followed by significant increases in marine invertebrate diversity and abundance, primarily polychaetes, crustacean amphipods and bivalve mollusks. The greatest observed increase occurred

between 2003 and 2004 (Fig. 5-1, Fig. 5-2), although it is very unlikely that many of these estuarine species were present prior to opening of the culvert in 2002 that both restored salinity and allowed marine invertebrate larvae to pass with the tide into East Harbor. Most marine worms and mollusks probably enter the system as larvae, and have to settle and grow before they are detectable by our sampling methods.

In terms of species richness, the invertebrate community in the lagoon has been consistently more diverse than the northwest cove since 2004, which is farthest from the source of seawater and invertebrate larvae, and has lowest salinity. Diversity decreased in both lagoon and cove between 2004 and 2006, probably due to summertime oxygen depletions described above.

Concerning invertebrate abundance, the large increase between 2003 and 2004 was followed by an approximately commensurate decline between 2004 and 2006 (Fig. 5-2). Those populations that rapidly recolonized the system over the first few years of the partial tidal restoration are presently severely limited by summertime hypoxia, and anoxic events. Otherwise, animal abundance has been similar during 2003, 2004 and 2006 in both lagoon and cove, although chironomid midge larvae still account for a large fraction of benthic animal density in the cove.

Although the sampling gear and plot size (only 32 cm^2) were not intended to adequately sample sediment for moderate to large mollusks, we nevertheless began to encounter soft-shell clams (*Mya arenaria*) in Moon Pond Creek and the eastern half of Pilgrim Lake in summer 2004. These clams were abundant and widely distributed throughout the lagoon in 2005 (Brett Thelen, personal communication). Small individuals of this species were again extremely abundant until August 2006, when a period of hot weather, extremely high water temperature (30° C.) and oxygen depletion was followed by mass mortality throughout the lagoon proper, but not in Moon Pond creek.
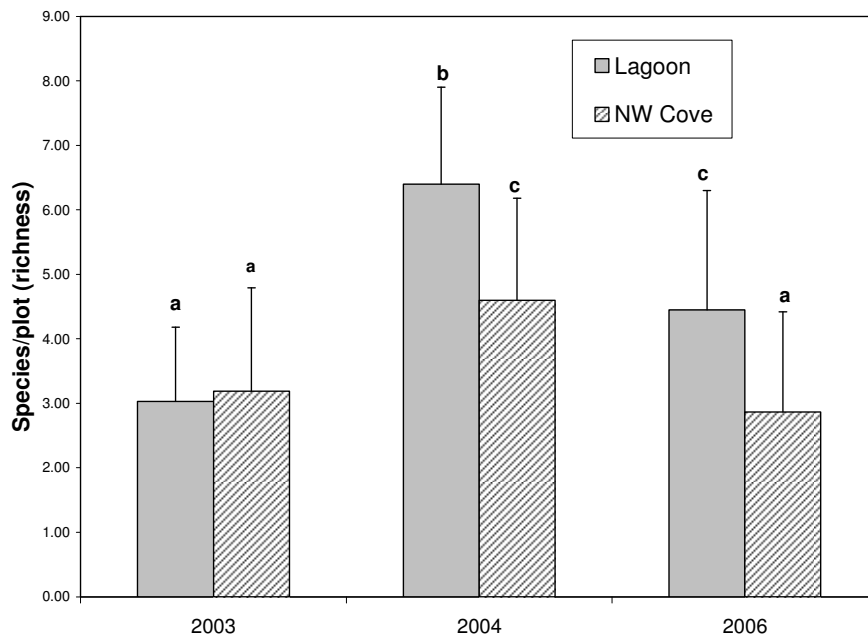
Figure 5-1. Species richness, i.e. average number of benthic invertebrate species per plot, in East Harbor lagoon and its northwest cove in 2003, 2004 and 2006. Columns with dissimilar letters are significantly different, ANOVA, P<0.05).

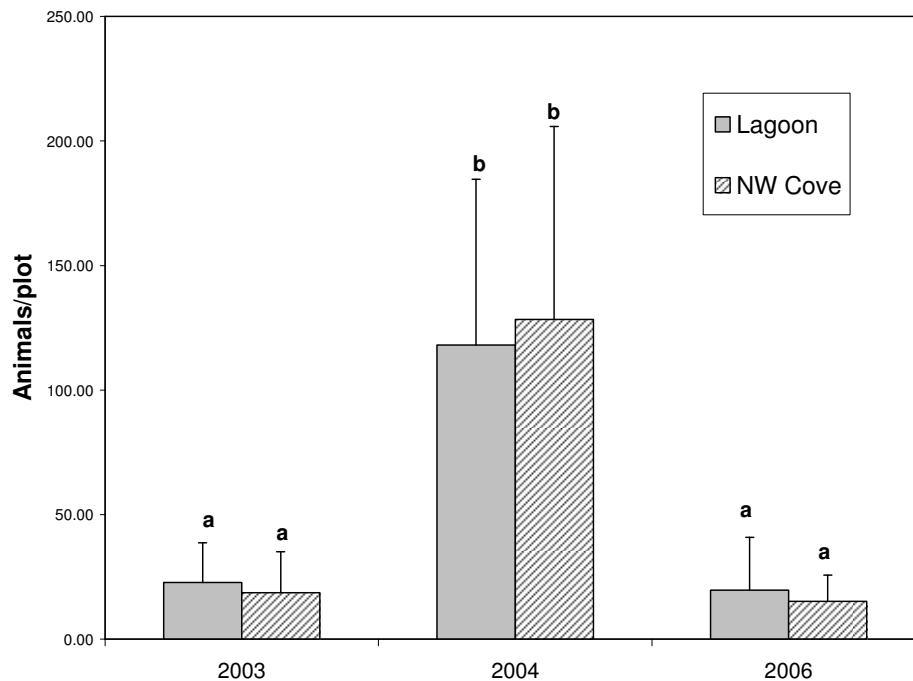Figure 5-2. Benthic invertebrate abundance, i.e. average number of animals per plot, in East Harbor lagoon and its northwest cove in 2003, 2004 and 2006. Columns with dissimilar letters are significantly different, ANOVA, P<0.05).

6. RARE ANIMALS POTENTIALLY AFFECTED BY TIDAL RESTORATION

Two State-listed rare animals are found within the East Harbor system, the water-willow stem borer (*Papaipema sulphurata*), endemic to southeastern Massachusetts and Cape Cod and the northern harrier (*Circus cyaneus*).   Inventories for both species were conducted over the past two years (Mello 2006 and Bowen (in review 2006), respectively).

<u>Water-willow Stem Borer</u>

Stem borer larvae feed almost exclusively on water willow (*Decodon verticillatus*), a widely distributed freshwater wetland plant on Cape Cod that has established in Salt Meadow, where diking since at least 1868 has maintained freshwater conditions. *Decodon* has little salinity tolerance; therefore, tide restoration alternatives that flood Salt Meadow with seawater would likely eliminate any *Decodon,* which presently occupies main creeks and ditches. Complete loss of water willow from Salt Meadow, if it were to occur, would likely extirpate this local population of stem borers; however, many other stem borer populations occur throughout the outer Cape in more natural freshwater wetlands (M. Mello, personal communication).

With a grant from the Massachusetts Environmental Trust, the National Seashore contracted with Mark Mello, Research Director of the Lloyd Center for the Environment and an expert on the Lepidoptera of the state, to conduct an inventory of Papaipema throughout the East Harbor coastal flood plain. A final report, available by request from the Seashore, documents eight *Decodon* patches harboring stem borer larvae within Salt Meadow, all but one of these is behind dikes east of the off-road vehicle route from High Head to the ocean. The one exception is between the two dikes at the west end of the Meadow; no *Papaipema* were found in Moon Pond or the wetlands surrounding East Harbor lagoon proper (Fig. 6-1).

The conclusions from Mello's report follow:

Both the Herring River and Salt Meadow watersheds produced multiple records for Papaipema sulphurata*. Because these systems were historically salt marsh in much (Herring River) or most (Salt Meadow) of their now, freshwater wetlands,* P. sulphurata *has actually expanded its range on the outer Cape into habitat not previously available to it. Although water willow is a native plant, it often "invades" wetlands that have been disturbed, particularly nutrient-rich wetlands. Thus mosquito ditches, former cranberry bogs, and/or diked former salt marshes are readily colonized by water-willow; and subsequently* P. sulphurata *will move into these patches. Indeed, this has been the case in both Salt Meadow and Herring River. Until water-willow is either out-competed by* Phragmites *or shaded out by succession of wetland shrubs and trees,* P. sulphurata *would be expected to continue to use these patches. Currently the Herring River watershed supports the majority of* P. sulphurata *sites in Wellfleet, and Salt Meadow is one of the larger colonies in truro. Thuis both these systems are significant, albeit relatively recent, habitats for* P. sulphurata*..*

In order to assess the impacts of increasing tidal flow in these systems upon P. sulphurata, the following factors need to be addressed:

- *How far will salt water (which will kill water-willow) rerach upstreasm under normal conditions (an occasional storm-driven tidal overwash will probably not kill the plant) as tidal flow is restored?*

- *What will be the overall change in water levels within the impacted part of the system?*

- *What is the long-term prognosis for the persistence of water-willow if no action is taken?*

- *Are there portions of the Herring River system (for example, from Old county road eastward) that can be precluded from tidal restoration without adverse impacts?*

Figure 6-1. General locations of water-willow stem borers (*Papaipema sulphurata*) feeding on water-willow (*Decodon verticillatus*) in Salt Meadow, East Harbor estuary, Truro, MA.

<u>Northern Harrier</u>

As mentioned, a draft report of a recently completed harrier survey is still in review; therefore, only excerpts of findings relevant to East Harbor tidal restoration are noted below:

Northern harrier nesting is almost entirely restricted to Martha's Vineyard, Nantucket and Cape Cod.

Study objectives were to survey suitable harrier habitat, count harrier territories, measure reproductive success; and identify habitat preference for nesting and foraging during the breeding season.

Ten breeding pairs nested within the Seashore in 2004 and five pairs nested in 2005.

Five of ten total nests found in 2004, and one of five nests found in 2005, were within East Harbor.

Nesting success was limited to 38% and 33% in 2004 and 2005, respectively, with failure due to nest predation, although the identity of predators was undetermined.

Outer Cape harriers selected wetlands, rather than uplands, for nesting sites, in contrast with island populations in Massachusetts, perhaps to minimize predation.

If tidal restoration at East Harbor were to cause the replacement of existing cattail marshes with Spartina *salt marsh, resident harriers may not shift to other locations in the park.*

Low harrier breeding density on the outer Cape may be due to the lack of open, unforested habitat.

Recommendations for managemanet include:

1. *Maintaining suitable harrier habitat, i.e. cattail marshes and oak barrens;*
2. *Avoiding human disturbance to harrier nests; and*
3. *Controlling nest predators.*

7. WETLAND VEGETATION

Emergent Wetland Vegetation

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

Review of methods

Species coverage in the permanent vegetation plots (Figure 7-1) 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). The plots were assessed in both June and August so that comparisons could be made to other years where cover data are limited to June only or August only. *Phragmites* stem heights, stem densities, and % flowering stems were recorded at the end of the 2006 growing season (October 2006). From these data, biomass was estimated as per Thursby et al. (2002).
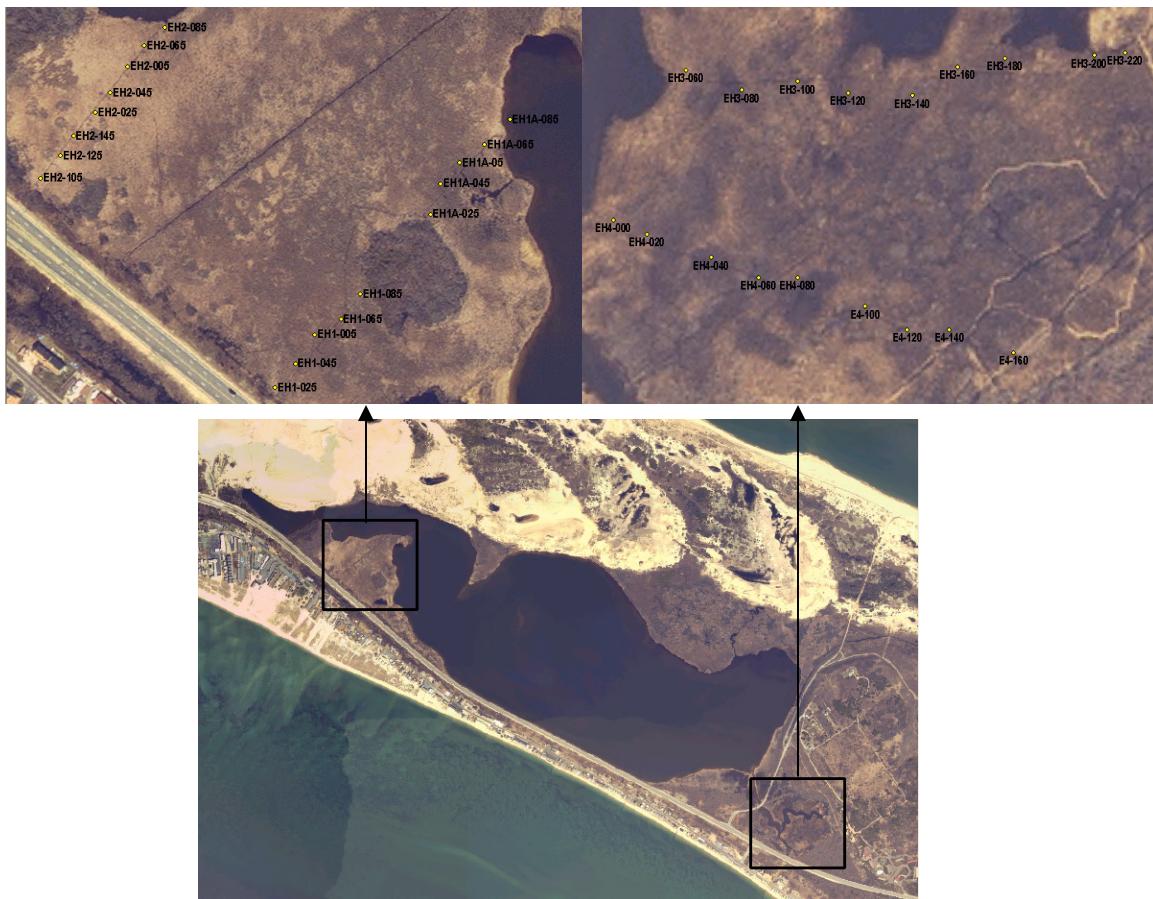

Figure 7-1. Overview of East Harbor with vegetation plot locations along transects EH1 through EH4.

Data analysis - Principle components Analysis (PCA) was used to portray temporal shifts in community composition, while Analysis of Similarities (ANOSIM) tested the statistical significance of community-level responses. Non-parametric Wilcoxon signed-ranks tests (repeated measures non parametric testing to compare two groups) were used to compare cover class data between specific years. *Phragmites* stem height and biomass data were subjected to T-tests and ANOVA significance testing.

Results

Relatively small changes in the emergent vegetation have occurred over the last year (Table 7-1). One exception is the increased abundance of *Thelypteris palustris* (marsh fern). This species presumably rebounded due to lowered porewater salinities in 2006 that resulted from large amounts of precipitation in May and June. The largest decrease in cover occurred in *Phragmites*, although the difference value is a small percentage of the total cover of this species.

Table 7-1. Summed cover class values of East harbor plant taxa in vegetation plots (August 2005 vs. August 2006).

	Aug-05	Aug-06	Diff
Aster novi-belgii	2	0	-2
Boehmeria cylindrica	4	4	0
Decodon verticillatus	2	2	0
Lysimachia terrestris	1	0	-1
Lythrum salicaria	3	5	2
Onoclea sensibilis	8	8	0
Phragmites australis	73	68	-5
Rosa palustris	3	2	-1
Rumex orbiculatus	0	1	1
Sphagnum sp.	1	2	1
Thelypteris palustris	28	48	20
Toxicodendron radicans	26	30	4
Typha angustifolia	55	60	5

With respect to longer-term change, there have been large and statistically significant (ANOSIM p=0.001) shifts in species composition over the last 4 years with many taxa exhibiting significant reductions in cover or disappearing altogether from the plots. Table 7-2 summarizes plant cover in June 2002 vs. June 2006 and August 2004 vs. August 2006. It should be noted that cover generally reaches a maximum sometime in August. In addition, some of the rarer species may be relatively inconspicuous in June compared to August, and may therefore go undetected. Unfortunately, the earliest available cover data for the month of August was collected in 2004, which precludes any comparisons to baseline (2002) conditions. Notwithstanding, both sets of data show virtually the same trends and the August 2006 data provides confirmation that many of the true freshwater taxa have disappeared. Those that remain are largely confined to transects EH1 and EH2 in the western portion of the system.

Table 7-2. Summed cover class values of East harbor plant taxa in the western (EH1/2) and eastern (EH3/4) portions of the system (June 2002 vs. June 2006 and August 2004 vs. 2006). Taxa that have disappeared from the plots are highlighted.

| | Jun-02 | | Jun-06 | | | Aug-04 | | Aug-06 | |
	EH1/2	EH3/4	EH1/2	EH3/4		EH1/2	EH3/4	EH1/2	EH3/4
Aster novi-belgii	1	5	0	0		6	0	0	0
Bohmeria cylindrica	0	0	1	0		2	0	4	0
Calystegia sepium	1	9	0	0		1	1	0	0
Chenopodium album	0	0	0	0		0	4	0	0
Decodon verticillatus	3	0	1	0		3	0	2	0
Erechtites hieracifolia	0	0	0	0		2	1	0	0
Eupatorium dubium	3	1	0	0		0	0	0	0
Impatiens capensis	0	14	0	0		3	0	0	0
Lemna minor	0	0	2	0		1	0	0	0
Lysimachia terrestris	3	0	1	0		1	0	0	0
Lythrum salicaria	0	0	0	0		1	0	5	0
Onoclea sensibilis	9	1	10	0		9	0	8	0
Parthenocissus quinquefolia	0	2	0	0		0	0	0	0
Phragmites australis	0	57	0	41		0	76	0	68
Polygonum sagittatum	1	0	0	0		2	1	0	0
Ribes hirtellum	1	1	0	0		0	0	0	0
Rosa palustris	0	0	2	0		3	0	2	0
Rosa virginiana	4	1	0	0		0	0	0	0
Rumex orbiculatus	0	1	0	1		0	1	0	1
Smilax rotundifolia	1	0	0	0		0	0	0	0
Solidago sp.	1	0	0	0		0	0	0	0
Thelypteris palustris	38	21	25	1		47	1	46	2
Toxicodendron radicans	31	29	22	0		32	0	30	0
Triadenum virginicum	1	0	0	0		2	0	0	0
Typha angustifolia	43	8	42	2		57	2	58	2
Viola lanceolata	0	0	0	0		0	1	0	0
Total cover of true freshwater taxa (excludes *Phragmites/Typha*)	98	85	64	2		172	12	155	5
Total no. species	15	13	9	4		16	9	8	4

Principle Components Analysis of the cover data shows that species composition has shifted slightly over the past year (2005-2006) but considerably over the past 4 years (2002-2006) (Figure 7-2). Eigenvector values revealed that the separation between 2005 and 2006 was mainly due to changes in *Phragmites*, *Typha*, and *Thelypteris* cover. In contrast to changes since 2002, ANOSIM results indicate that overall plant community change over the past year was not statistically significant.
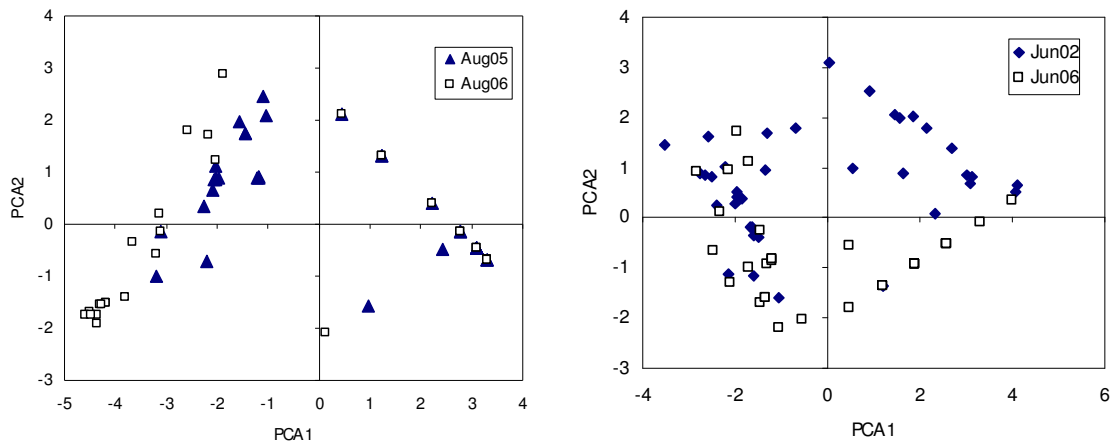
Figure 7-2. PCA of cover data comparing August 2005 vs. August 2006 and June 2002 vs. June 2006 plant communities.

For the dominant species of emergent vegetation, *Typha* and *Phragmites*, there have been small but detectable cover changes over the past year (Table 7-3). Over the last 4 years, with the exception of one plot (EH3-240), *Typha* has been eliminated along transects EH3 and EH4. In contrast, *Typha* has remained relatively stable in the western portion of the system, along EH1 and EH2. Overall, there is no statistical difference between 2002 and 2006 for *Typha* cover across the entire network of plots. When EH3 and EH4 are analyzed separately, however, a significant decrease is evident.

With the exception of just a few plots, *Phragmites* has decreased slightly since 2005 and notably since 2002. The latter change is not statistically significant for EH3 and EH4 pooled together. When only transect EH4 is analyzed, however, there is a statistically significant decline in cover from 2002 to 2006. In addition, it is noteworthy that the only increases in cover occurred in plots along EH3 and toward the upland border – i.e., plots that are furthest removed from the point of seawater entry.

Table 7-3. *Typha* and *Phragmites* cover class changes by plot since the onset of restoration (2002-2006) and during the last year (2005-2006).

Typha	Jun-02	Jun-05	Jun-06	Change (05-06)	Change (02-06)	Phragmites	Aug-02	Aug-05	Aug-06	Change (05-06)	Change (02-06)
EH1-005	2	2	2	0	0	EH3-060	5	5	5	0	0
EH1-025	2	2	1	-1	-1	EH3-080	5	2	2	0	-3
EH1-045	2	3	2	-1	0	EH3-100	5	5	3	-2	-2
EH1-065	2	2	2	0	0	EH3-120	5	5	5	0	0
EH1-085	2	3	2	-1	0	EH3-140	5	5	5	0	0
EH1A-005	3	3	1	-2	-2	EH3-160	5	5	5	0	0
EH1A-025	2	3	3	0	1	EH3-180	3	5	5	0	2
EH1A-045	2	2	3	1	1	EH3-200	4	5	5	0	1
EH1A-065	2	3	3	0	1	EH3-220	5	4	4	0	-1
EH1A-085	4	3	3	0	-1	EH3-240	2	4	3	-1	1
EH2-005	2	3	2	-1	0						
EH2-025	2	3	3	0	1	EH4-000	5	5	5	0	0
EH2-045	2	3	3	0	1	EH4-020	5	3	4	1	-1
EH2-065	2	3	2	-1	0	EH4-040	4	1	0	-1	-4
EH2-085	2	3	2	-1	0	EH4-060	5	2	1	-1	-4
EH2-105	3	4	3	-1	0	EH4-080	2	0	1	1	-1
EH2-125	3	3	2	-1	-1	EH4-100	5	4	3	-1	-2
EH2-145	4	2	3	1	-1	EH4-120	3	5	5	0	2
						EH4-140	5	3	2	-1	-3
EH3-120	1	0	0	0	-1	EH4-160	4	5	5	0	1
EH3-180	2	0	0	0	-2						
EH3-200	1	0	0	0	-1						
EH3-220	1	0	0	0	-1						
EH3-240	2	2	2	0	0						
EH4-160	1	0	0	0	-1						
SUM-EH1/2	43	50	42	-8	-1	SUM-EH3	44	45	42	-3	-2
SUM-EH3/4	8	2	2	0	-6	SUM-EH4	38	28	26	-2	-12

Aerial photography qualitatively illustrates more broadly the changing patterns of vegetation in Moon Pond. In the right-hand photo of Figure 7-3, arrows point to areas of salt-killed *Typha* – an area that was thickly vegetated in 2001 (left). In Figure 7-4, arrows point to low density and dead *Phragmites* in 2005 (right) in areas that had vigorous growth in 2001. Figure 7-5, an oblique angle aerial photo taken in September 2006, provides a lower altitude view of these changes.

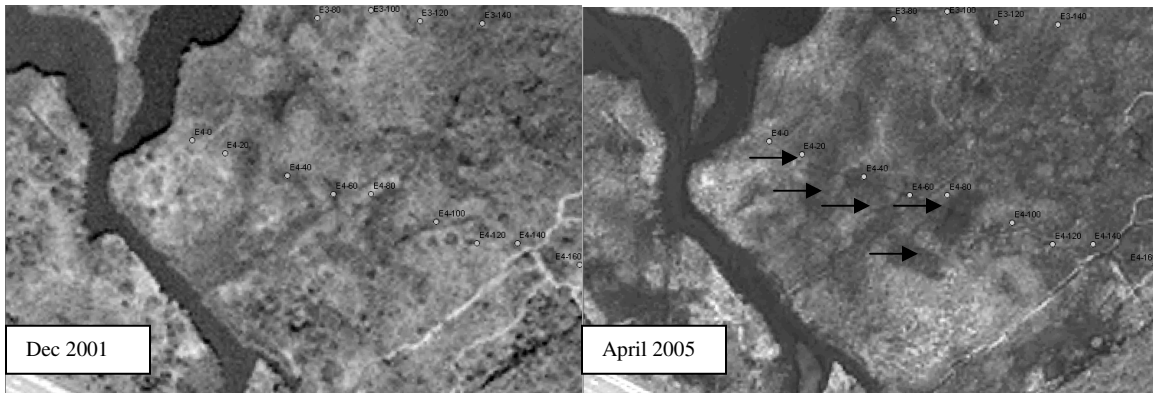Figure 7-3. Changes in *Typha* coverage in Moon Pond (2001 vs. 2006).

Figure 7-4. Changes in *Phragmites* coverage in Moon Pond (2001 vs. 2006).

Figure 7-5. Aerial photo (September 2006) showing salt-killed cattail (solid circles) and *Phragmites* (dotted circle) areas.

Phragmites biomass, a more accurate measure than area cover of changing plant structure, was calculated from stem heights and stem density counts (Thursby et al. 2002). These data are collected in late September or October – well after the shoots have stopped growing and have had a chance to produce an inflorescence. Stems have shown significant decreases in height in the majority of plots since 2002 (Figure 7-6). Mean stem height decrease from 2005 to 2006 was 41 cm although this change was not statistically significant. Stem densities have also decreased (data not shown). Reductions in both have resulted in a precipitous drop in *Phragmites* biomass over the long term and even since last year (Figure 7-7).
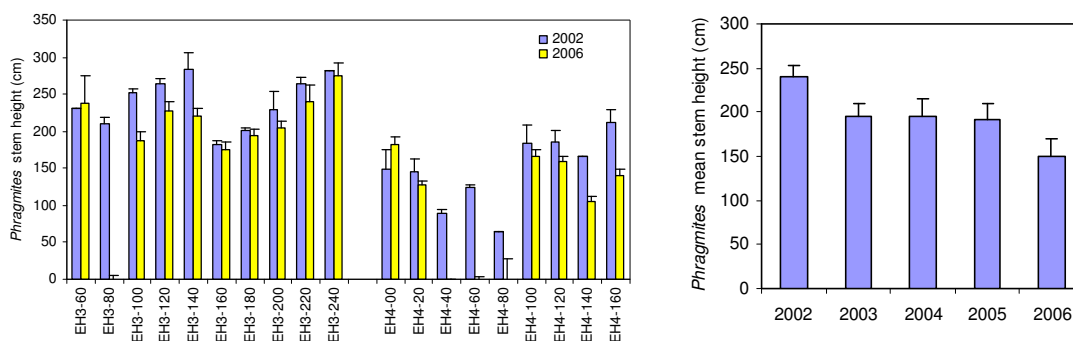

Figure 7-6. *Phragmites* mean stems heights by individual plots in 2002 vs. 2005 (left) and for all plots pooled by year (right).
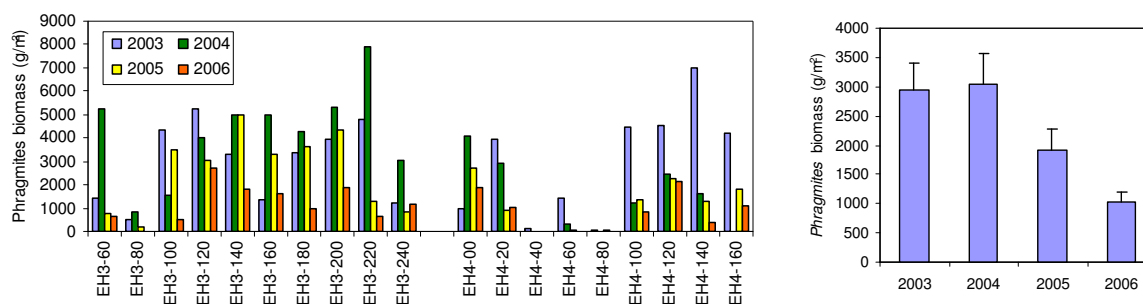
Figure 7-7. *Phragmites* biomass by year in individual plots (left) and marsh-wide (right).

The percentage of flowering shoots, which can be somewhat variable depending upon annual variations in precipitation and other factors, has shown a significant decrease over the past year (Figure 7-8). From 2003 to 2005, an apparent increasing trend was observed; however, there are no statistically significant differences among these groups. Only the 2006 data exhibit a statistical difference from any of the other data sets. The initial increase in flowering could have been due to the absence of interspecific competition from salt-intolerant species that began to vanish shortly after the onset of restoration. Regardless, the current year's data is an encouraging sign that *Phragmites* population vigor continues to decline, a trend that is becoming more and more conspicuous in low level aerial photographs (Figure 7-9).
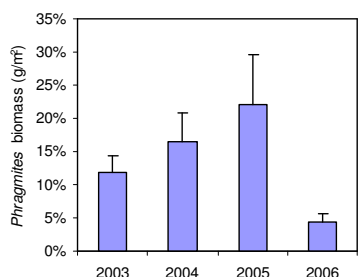
Figure 7-8. Mean percentage of flowering shoots by year (end of the growing season).

Figure 7-9. A closeup image of Moon Pond *Phragmites* shows gradients of physiological stress, ranging between total mortality (dark signatures) and height growth suppression (brown/beige signatures). The distinct signature of stunted plants is caused by the tops of last year's stems (many with remnant inflorescences), which are dead and brown/beige, being taller than the current year's growth, the tops of which are purple-green.

Water chemistry - Late-season porewater salinities (10-cm depth) were dramatically lower in 2006 than in 2003 or 2005 (Table 7-4) as a result of heavy precipitation received during May and June of 2006. Because there is undetectable tidal fluctuation, lowered salinities in the main lagoon would only affect the porewater salinities of plots in close proximity to open water. However, high ground water tables in the surrounding upland would result in prolonged freshwater discharges into the system through the surrounding marshlands during the growing season. High Head, in particular, looks to be a significant source of freshwater seepage as evidenced by the large salinity reductions in plots closest to this geologic feature. For example, plot EH3-220 decreased from a salinity of 21 ppt in 2003 to 2 ppt in 2006.

Table 7-4. Late-season porewater salinities (ppt) (2003-2006).

	08/19/03	09/22/05	8/25/2006	Diff 03-06
EH1-005	4	5	0	-4
EH1-045	5	4	2	-3
EH1-085	5	5	0	-5
EH1A-005	4	4	0	-4
EH1A-045	10	8	8	-2
EH1A-085	10	9	10	0
EH2-025	2	4	0	-2
EH2-065	2	4	0	-2
EH2-105	2	4	7	5
EH2-145	3	7	7	4
EH3-060	24	-	-	
EH3-100	25	23	20	-5
EH3-140	24	22	14	-10
EH3-180	23	20	12	-11
EH3-220	21	14	2	-19
EH4-000	25	-	-	
EH4-040	33	37	34	1
EH4-080	32	34	26	-6
EH4-120	30	30	15	-15
EH4-160	29	24	12	-17
mean-EH1/2	4.7	5.4	3.4	-1.3
mean-EH3/4	26.6	25.5	16.9	-10.3

Summary – Despite low porewater salinities in the vegetation plots in 2006, *Phragmites* has exhibited overall decreases in cover and biomass during the past year. This is presumably due to the synergistic and long-term cumulative effect of elevated salinity and sulfides on plant vigor. Biomass reduction appears to be accompanied by a similar trend in flowering. These trends are noteworthy because they indicate that desirable changes in the emergent vegetation are still happening, despite a very limited amount of seawater exchange. It also suggests quite strongly that *Phragmites* in Moon Pond would decline rapidly in response to increased seawater exchange, coupled with an increased tidal range. As it stands, the emergent marshes around East Harbor are overtopped only by the highest Spring tides. The frequency of these occurrences depends upon the antecedent water level in the open lagoon, which is still regulated by precipitation as opposed to unrestricted systems that are dominated by tides.

East Harbor Seeding Program

On October 21, 2005, several salt-killed cattail areas adjacent to High Head Road were seeded with wrack material collected from Hatches Harbor (this activity is described fully in Smith 2006). A total of 85 bags (55 gallon) were filled with wrack, which contains the seeds of a variety of native salt marsh taxa, and then distributed by hand in areas on either side of High Head Road where seawater exchange has killed the cattail that once dominated there.

Germination of seeds was evident in June 2006 (Figure 7-10). In addition to this new germination, plants that had already established from past seedings have exhibited considerable vegetative expansion (Figure 7-11). Moreover, these plants have now become a significant source of seed themselves and new clusters of *S. alterniflora* have recently been found in places far removed from locations that were deliberately seeded (Figure 7-12). This indicates that new populations of salt marsh plants are becoming established from internal sources and seeds and propagules.
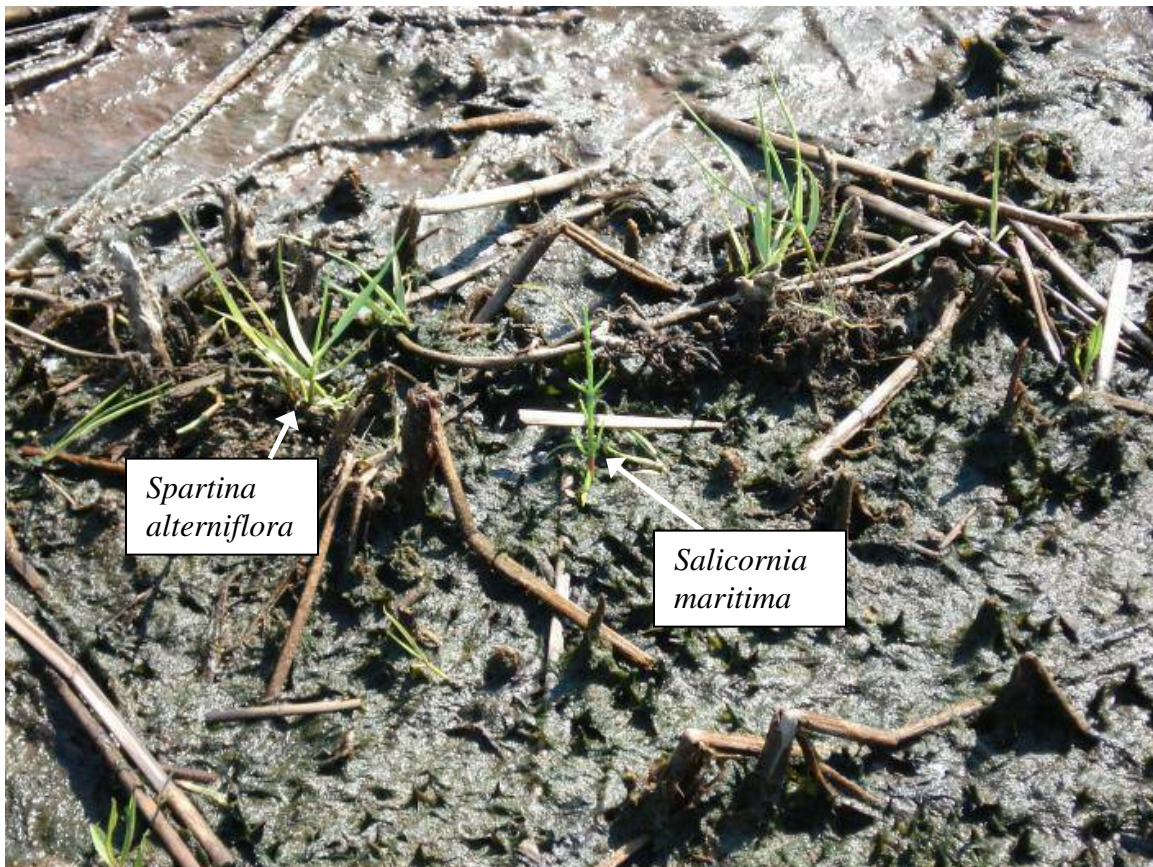

Figure 7-10. New seedlings established from October 2005 seeding effort (June 2006).

Figure 7-11. Zones of *S. alterniflora* expanding out from plants established from October 2004 seeding effort.

Figure 7-12. Newly established cluster of *S. alterniflora* in a location that is > 250 m away from areas that were hand-seeded.

Submerged Aquatic Vegetation

Due to large amounts of algae in East Harbor in 2006, seagrass cover could not be monitored along the permanent transects. Separating macroalgae and periphyton (attached microalgae) from *Ruppia maritima* (widgeongrass) and/or *Zostera marina* (eelgrass) proved to be too difficult to collect reliable data. However, some anecdotal observations can be included here. *Zostera* is thriving in the main tidal channel that runs through Moon Pond and connects East Harbor to Cape Cod Bay via the underground culvert (Figure 7-13). Higher water velocities through this channel are presumably the

reason why algal growth is much reduced on these beds. Regardless, the presence of healthy eelgrass in the main channel is, and will continue to be, a good source of seeds and propagules to the open lagoon. This area also provides a good example of what more of East Harbor might look like if tidal exchange were increased to the fullest extent possible.
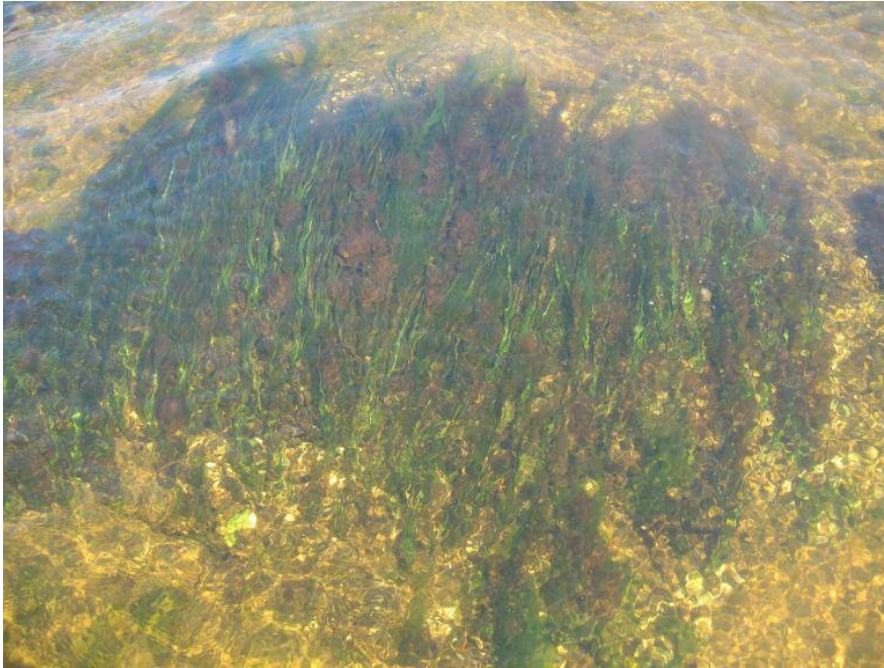

Figure 7-13. Eelgrass bed in main channel of Moon Pond (July 2006).

Algae have inherent value as components of a functionally healthy coastal lagoon. However, at nuisance levels of biomass there can be a range of deleterious effects. Why algae were so productive in the system this year is a complex question and at this point we can only speculate about probable underlying causes. One contributing factor may have been the large amount of early season precipitation in 2006. In addition to lowering the salinity of the system, the rainfall would have driven increased nitrogen loading, both directly from direct atmospheric deposition and indirectly from increased groundwater flushing. Although most of the system is within the undeveloped National Seashore, the southern border lies next to a heavily developed barrier beach. Thus, septic leachate and/or Route 6 runoff are likely sources of additional N to East Harbor, although the magnitude and relative importance of these inputs within the overall N budget is unknown. Notwithstanding, green macroalgae, particularly species of *Cladophora* and *Enteromorpha*, can proliferate rapidly in response to increased N inputs to coastal waters (Valiela et al. 1992).

Filamentous cyanobacteria, or "blue-green algae" (present as floating and attached periphyton mats), were also abundant in the system in 2006. This group of algae has been problematic in East Harbor in the past - even before partial tidal restoration was undertaken. Cyanobacteria blooms are typically fueled by 1) an abundance of both

nitrogen (N) and phosphorus (P) and 2) low ratios of N:P. Therefore, a combination of increased N inputs, followed by enhanced rates of P release from benthic sediments during periods of water column anoxia and high water temperatures, may have stimulated cyanobacterial productivity during the summer of 2006. Such conditions are believed to be responsible for cyanobacteria blooms in the past as well, when the system was even more prone to oxygen depletions. Now, however, instead of freshwater algae serving as the main carbon source for microbial respiration (a process that uses oxygen), submerged aquatic vegetation (seagrasses) has become an important part of this process. Regardless, it still stands to reason that increased seawater exchange, which would bring higher volumes of nutrient-poor, oxygen-rich, cooler water into the system, would dilute nutrients and reduce the flux of sediment P into the water column, thereby limiting extent to which cyanobacteria and other nuisance algae can proliferate.

Fortunately, drifting and detached periphyton and macroalgae are flushed from the system on ebb tides, particularly during the fall when strong winds churn up the open water body. The detachment of macroalgae from the seagrasses and other substrates increases the potential for this material to be exported from the system via tidal exchange (Figure 7-14).
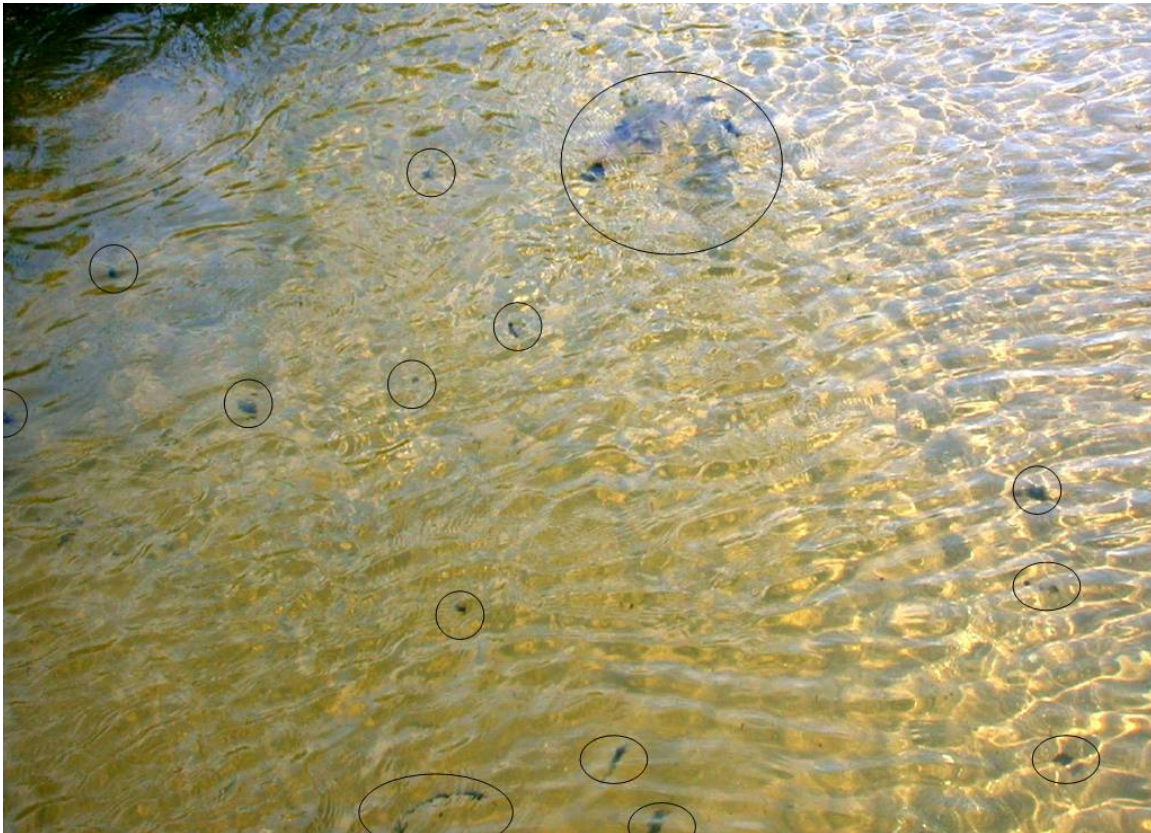

Figure 7-14. Clumps of macroalgae (circled) drifting under High Head road towards the culvert and out of the system (October 2006).

In 2007, steps will be taken to better understand the underlying factors regulating macroalgae abundance and species composition. These steps include sampling of nutrient concentrations in the water column, limiting-nutrient bioassays, and analysis of algae taxonomy, succession, and tissue chemistry.

8. NEKTON (FISH AND DECAPOD CRUSTACEANS)

<u>Introduction</u>
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 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) in relation to trends in water quality and vegetation.

<u>Methods</u>
The East Harbor system is a challenging system to quantitatively sample. The combination of various habitats (e.g., tidal creek, freshwater marsh) and rapid changes in vegetation and algal communities made the use of a single sampling method impossible. A variety of active and passive methods have been tested over the last four years, following and modifying methods suggested in Rapoza and Roman 2001a; James-Pirri and Roman 2004:

> Throw traps—nekton was sampled from creeks and along the edge of East Harbor Lagoon using a 1-m^2 x 0.5-m-high throw trap, with a 3-mm mesh and an aluminum angle-iron frame. Workers carefully approached the sample site and tossed the trap, then removed any animals with a 1-m x 0.5-m dip net (1.5-mm mesh). Each animal was identified (most to species) counted and the length of a representative sample measured (the first 15 individuals, if possible). Sampling stations were randomly established within the Moon Meadow tidal creek, and along the shallow perimeter of the Lagoon. These sites were sampled once in 2003 and 2004 in late summer, and twice in 2005 and 2006 in early summer and

late summer; each sampling event continued over several days. Each sample event was conducted during the ebb tide (in the case of Moon Meadow), commencing after the marsh surface had dewatered.

Beach seine—A 10-m seine with 3-mm nylon mesh was used in the East Harbor system. In the Lagoon, three seine samples were collected in the late summer during 2003 and 2004; three seine samples were collected in the early summer, and three more during the late summer of 2005 and 2006. One seine site was sampled in Moon Meadow during the same time periods. Sample sites were randomly located along the edge of the Lagoon, or in the creek in Moon Meadow. The number of each species and length of a representative sample (the first 15 individuals, if possible) were recorded.

Fyke Net—A 1-m opening fyke net (2.54 cm mesh size) was used briefly (in 2003) in Moon Pond sample site at the weir structure to sample nekton entering the lagoon. It was determined that the mesh size was too large. Future use of this gear was discontinued. Data collected utilizing this method is not presented in this report.

Minnow and crab traps—Minnow traps are 40 cm long with a diameter of 20 cm; mesh size is 5 mm with an opening of 2.5 cm. Crab traps are 75 m x 40 cm x 40 cm with a mesh size of 2 cm and a opening of 15 x 10 cm. Mesh flaps were removed before deployment to allow ease of egress by nekton. Bait was not used. When these traps were deployed in the East Harbor Lagoon, they were tied to buoys, with the minnow trap suspended mid-water column and the crab trap on the bottom

Cast net— This method was tested in 2006. A two-meter diameter cast net, with one-centimeter mesh size was used to sample in the parts of the East Harbor Lagoon with depth > 0.5 cm. The area sampled was estimated for each throw for density estimates. Randomly located sampling stations were navigated to with GPS using a small skiff on the East Harbor Lagoon.

Otter Trawl—In 2003, a 1-m opening Otter Trawl (1.27-cm mesh size) was deployed. Eleven ten minute trawls were conducted in the East Harbor Lagoon where depth was >1 m deep. At the end of each sampling interval, species were collected from the net and identified and measured. This method was also attempted in 2004; however, the increase in aquatic plants and algae fouled the gear, rendering the method ineffective. Data from this method are represented in the nekton species list for 2003.

Sample Design—Sample stations were randomly selected in polygons created with the ArcView 3.2, 8.2 and 9.2 GIS software package, representing suitable sampling habitat (e.g, throw traps: shoreline and tidal creeks with depth < 1 m) using a color orthophotograph. Random points were generated using the NPS Alaska Pack extension to the ArcView 3.2, 8.2 and 9.2 GIS software package. Points were assigned UTM

coordinates using the NAD 1983 projection. UTM coordinates were loaded onto a 12 channel WAAS enabled Garmin IV or GPSmap76S GPS unit. Sample stations were navigated to in the field; accuracy was typically ± 2.5 m. In 2005 and 2006, nekton was collected from each sample station twice, once in early summer and once in late summer.

Environmental data—at each sample station, a variety of environmental data was collected. This included water temperature, salinity, percent dissolved oxygen, and in the case of the throw traps, estimates of cover of aquatic plants and algae and sediment quality (percent sand/fine size particles). Habitat adjacent to the sample station was categorized, if applicable. A hand-held YSI 650 multi-parameter meter, thermometers and hand refractometers were used to collect water quality data.

Analysis—For each year, the number of animals sampled, number of species, the relative abundance, mean and standard deviation of nekton density and length were calculated. In 2005 and 2006 when there were two samples collected from each sample station, the mean of density and length of the two annual samples is used for analysis. Trend analysis, using the Pearson's correlation coefficient (alpha=0.10) was conducted on species diversity, annual density values for total nekton, crustaceans, fish and selected individual species using the XLSTAT software package (Sokal and Rohlf 1981).

Results and Discussion
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., *Fundulus heteroclitus*). Before the reintroduction of tidal flow, there were few nekton species present: carp, white perch, alewife and the American eel (Hartel et al. 2003; Mather 2003; personal observations). By 2006, the number of species has nearly doubled (Table 8-1). There has been an increase in the relative dominance of fish throughout the sample period (2003 – 2006, Figure 8-1 and 8-2), probably in response to environmental and habitat change, and is generally consistent with nekton re-colonization (Raposa 2002; Roman et al. 2002). 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 (Figure 8-3 and 8-4). Results and discussion for each part of the East Harbor system and for specific species are offered below:

East Harbor Lagoon—there has been a significant increase in the number of species sampled in the Lagoon (Table 8-1). Typical estuarine species have populated this system, especially the mummichog (*F. heteroclitus*) the most common salt marsh fish, while the species present before the increase in salinity have been reduced or extirpated (salt-intolerant carp). The rapid changes in water quality and habitat over the four sample years have led to changes in nekton relative abundance, density and species composition; however, some species that were present before reintroduction of salt water persist in stable densities, American eel (*Anguilla rostrata*) and white perch (*Morone americana*), as do typical estuarine species like Atlantic silverside (*Menidia menidia*). Additionally, 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.

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. This has excluded most of the lagoon from sampling, although an otter trawl was used in 2003. In 2006, a cast net was used at 30 sample stations in the Lagoon, in water > 0.5 m deep. Results were disappointing; only a few mummichog and four-spine sticklebacks were sampled. The large areas of widgeongrass (*Ruppia maritima*) and algae present in 2006 frequently confounded successful deployment of the cast net. Weather conditions and time of day may be important in nekton use of this habitat. This method will be refined and tested again in 2007.

Moon Pond—This area is the closest to the bay, experiences about 0.5 m tidal range (Salt Meadow and the Lagoon do not), and high salinity. The nekton community responded with surprising rapidity to the increase in salinity and tidal range, with the colonization of the system by many common estuarine nekton, some at extremely high densities, (e.g., shore shrimp), as nekton exploited the new habitat (Table 8-2). There have been interesting shifts in species at Moon Meadow; the shore shrimp (*Palaemonetes spp.*) was initially sampled in high densities; as the habitat in the tidal creeks changes from fine bottom to a more course sandy bottom (Figure 8-5), the sand shrimp (*Crangon septemspinosum*) has become more common (Table 8-5).

Salt Meadow—This area of the East Harbor system was expansive salt marsh habitat before the system of impoundments were built during the 19th and 20th century. The area is currently a fresh water marsh—the amount of freshwater discharge from this system prevents any salt water from entering. Accordingly, freshwater species are found here (Table 8-1). [Note however that the salinity is higher at the Head of the Meadow end of the marsh presumably from intrusion of salt water from the ocean—salinities greater than 10 ppt were recorded in 2003.] If the amount of tidal exchange increases, along with the removal of impoundments to this system, restoration of the nekton community could be achieved.

Alewife—Salt Meadow has been considered possible habitat for alewife (*Alosa pseudoharengus*) spawning. Alewife, stocked by the state in the 1960s, used the East Harbor system as breeding habitat previous to introduction of tidal flow. The decrease or loss of the alewife run at East Harbor was expected; increased salinity in the lagoon has made it impossible for alewife to spawn there. It is speculated that the Salt Meadow portion of the East Harbor system, with several large freshwater pools, may present some breeding habitat for alewife; however, no alewife have been sampled from 2003 to 2006 in any part of the system. Sampling for alewife in the East Harbor system will continue in 2007.

Conclusions
The finfish of East Harbor lagoon comprised white perch, American eels, an introduced run of alewives, some killifish (*Fundulus heteroclitus*) and exotic carp (Mather et al. 2001) prior to the recent partial restoration of tidal exchange and salinity. Reintroduction

of tidal flow and salinity into the East Harbor Lagoon and Moon Pond has resulted in the rapid colonization by estuarine nekton species. 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.

- Continue to monitor nekton annually in the East Harbor system.

- Test 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.

- Work with ecologist to understand the nutrient dynamics of the system and impact on the nekton community.

- Continue to monitor for the presence of alewife in the East Harbor system during migration and for the presence of juveniles in the fresh water pools in Salt Meadow.
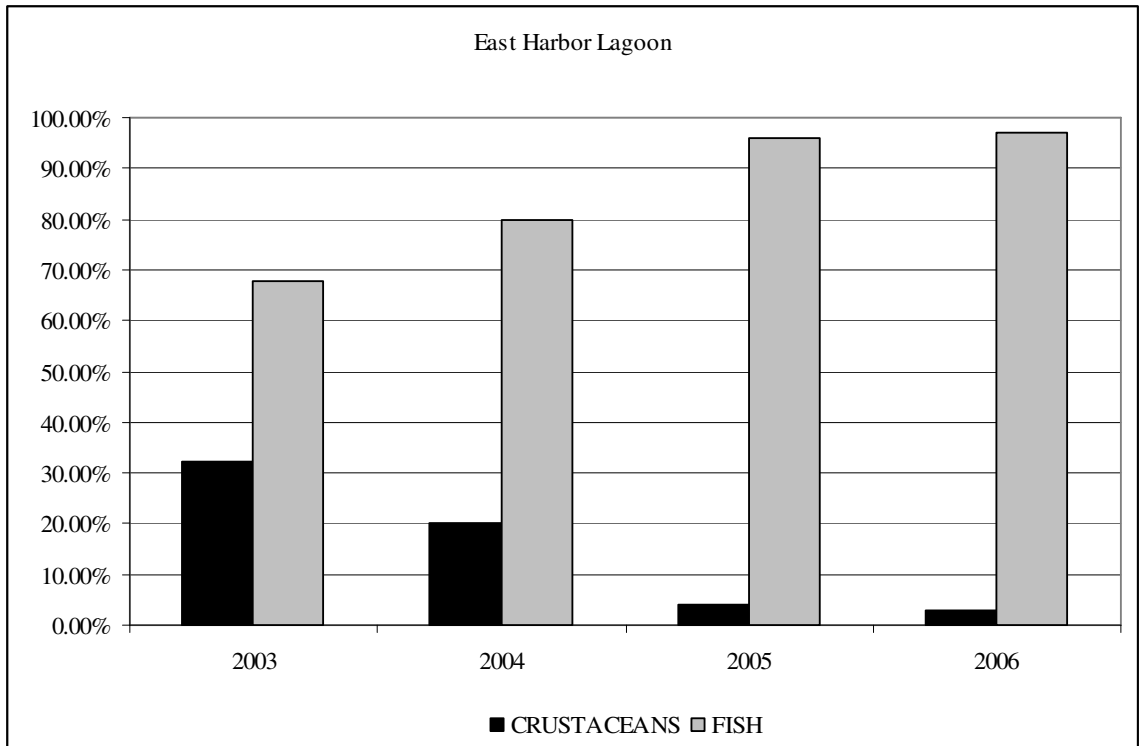
Figure 8-1. Relative abundance of fish and crustaceans in the East Harbor Lagoon from 2003 to 2006.

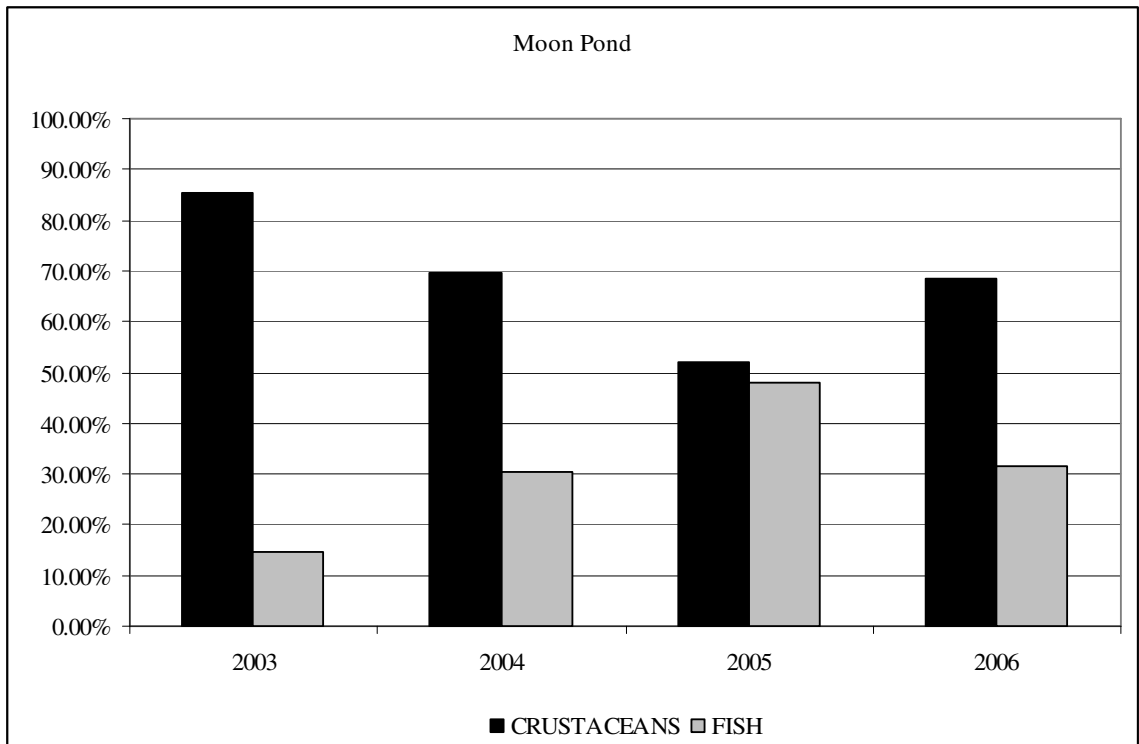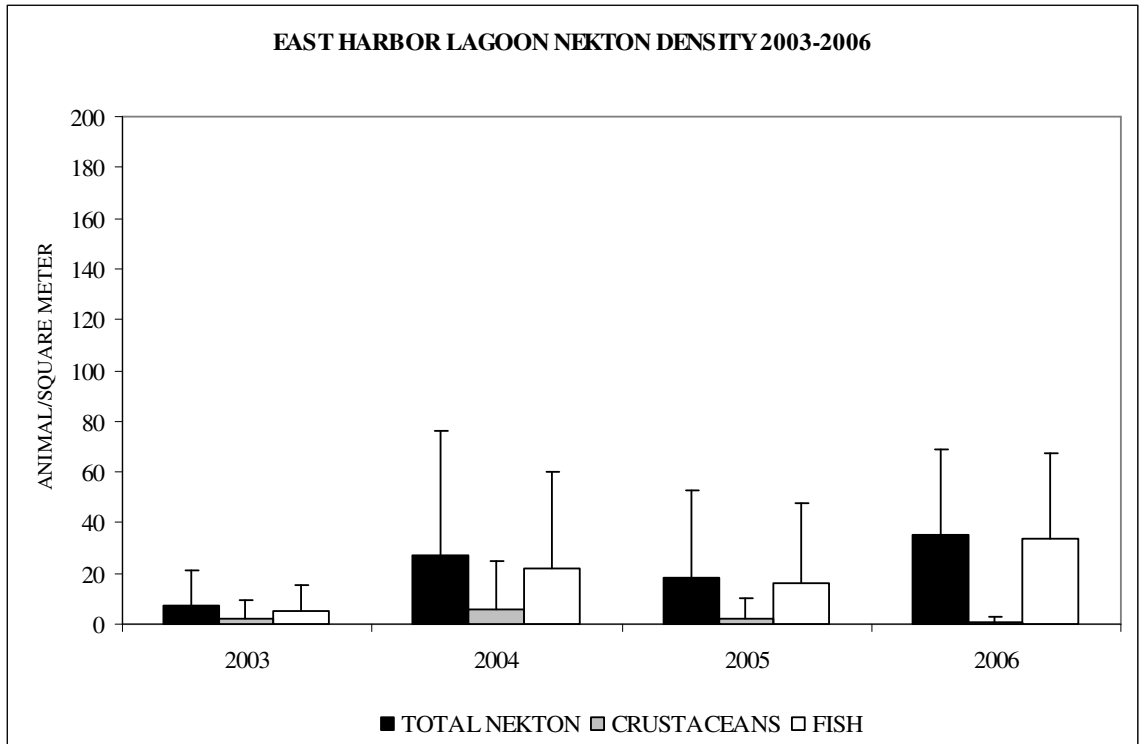Figure 8-2. Relative abundance of fish and crustaceans in the Moon Pond from 2003 to 2006.

Figure 8-3. Mean density of total nekton, crustaceans and fish in the East Harbor Lagoon from 2003 to 2006.
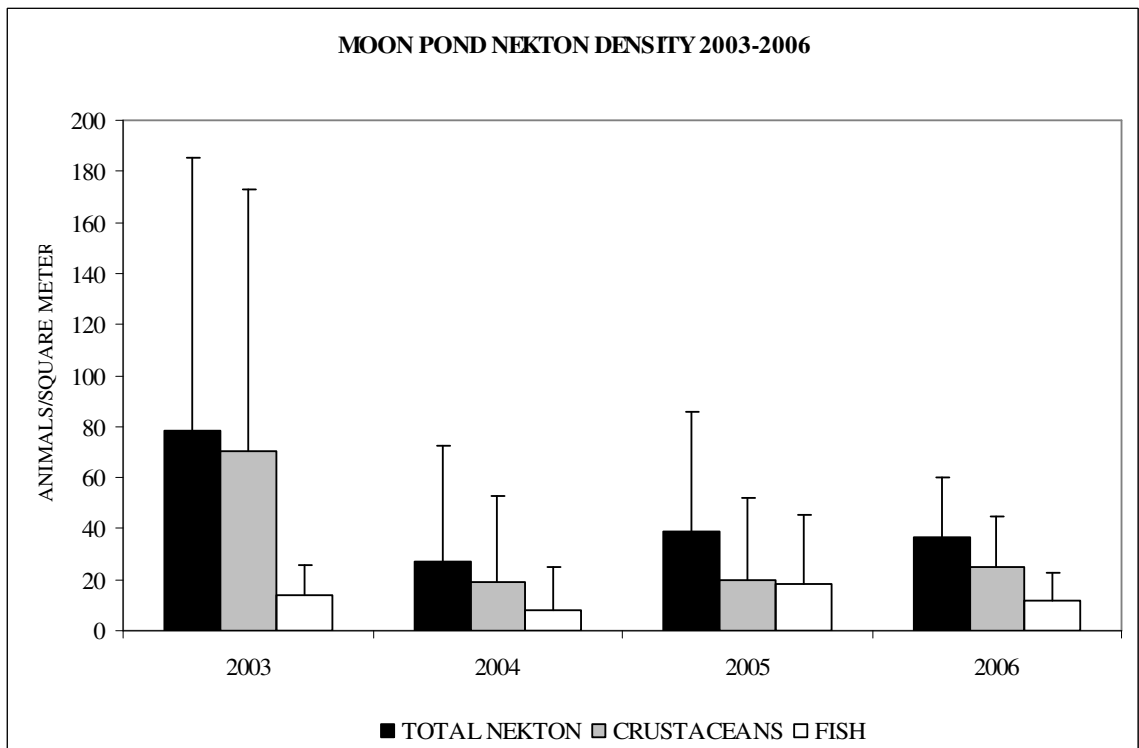
Figure 8-4. Mean density of total nekton, crustaceans and fish in the Moon Pond from 2003 to 2006.
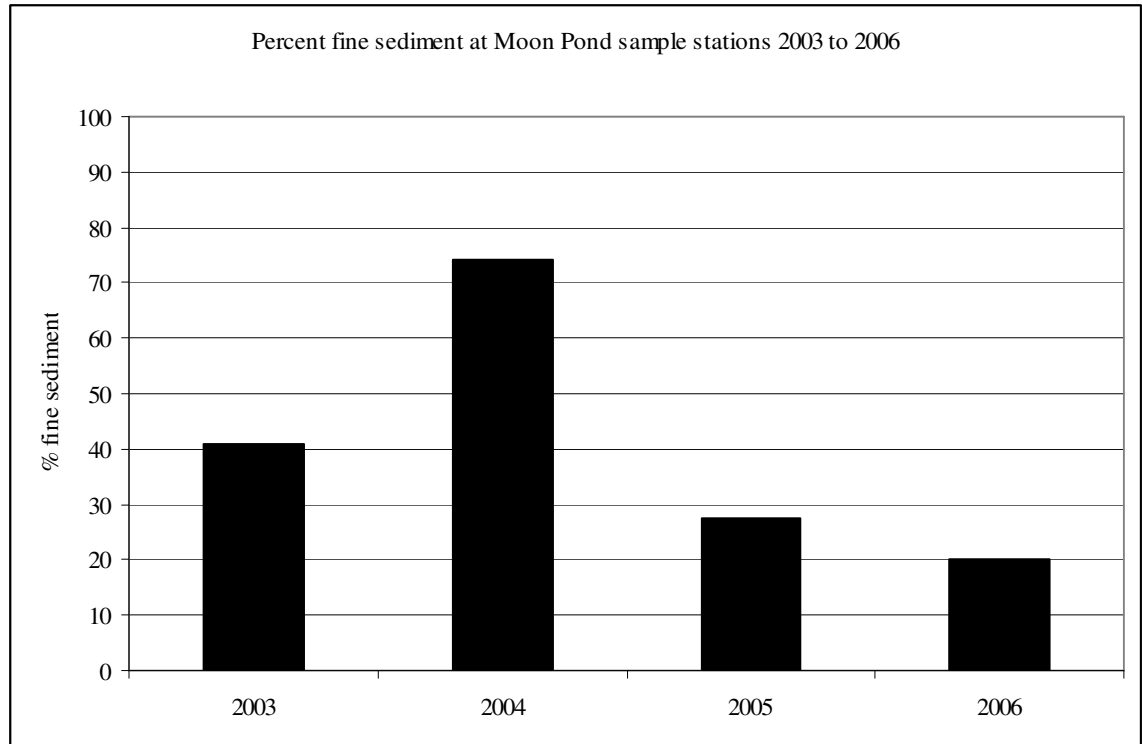
Figure 8-5. Mean percent of fine sediment collected at Moon Pond sample stations from 2003 to 2006.

COMMON NAME	East Harbor Lagoon				Moon Pond				Salt Meadow			
	2003	2004	2005	2006	2003	2004	2005	2006	2003	2004	2005	2006
American eel	X	X	X	X	X						X	
Atlantic silverside	X	X	X	X	X	X	X	X				
Brown bullhead									X		X	X
Crab species							X					
Four-spine stickleback		X	X	X							X	X
Golden Shiner									X	NO DATA	X	
Green crab		X	X	X	X	X	X	X				
Longnose spider crab							X					
Mummichog		X	X	X	X	X	X	X	X			X
Nine-spine stickleback			X	X	X		X				X	X
Pipe fish		X	X	X		X		X				
Sand shrimp	X	X	X			X	X	X				
Shore shrimp	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
Winter flounder	X		X				X	X				
Total number of species	**6**	**9**	**11**	**11**	**6**	**7**	**10**	**7**	**4**		**5**	**5**

Table 8-1. Nekton species of the East Harbor system 2003 to 2006. There was a significant increase in the number of species in East Harbor Lagoon (Pearson's correlation coefficient=0.929; p=0.071; alpha=0.10), there was no significant increase in Moon Pond or Salt Meadow. No data were collected in Salt Meadow in 2004.

SITE	2003				2004				2005				2006			
	EAST HARBOR LAGOON		MOON POND		EAST HARBOR LAGOON		MOON POND		EAST HARBOR LAGOON		MOON POND		EAST HARBOR LAGOON		MOON POND	
n	19		20		30		30		42		28		29		12	
	MEAN	STDEV	MEAN	STDEV	MEAN	STDEV	MEAN	STDEV	MEAN	STDEV	MEAN	STDEV	MEAN	STDEV	MEAN	STDEV
TOTAL NEKTON	7.63	13.56	78.52	107.1	27.41	48.58	27.10	45.43	18.43	34.35	38.75	46.66	35.03	34.14	36.58	23.85
CRUSTACEANS	2.47	7.16	70.25	102.5	5.52	19.14	18.87	33.99	2.17	7.90	20.11	31.77	1.03	2.15	25.08	19.94
FISH	5.16	10.15	13.56	12.41	21.90	38.19	8.23	16.53	16.26	31.69	18.64	26.51	34.00	33.51	11.50	11.49
American eel	0.00	0.00	0.29	0.56	0.03	0.18	0.00	0.00	0.12	0.40	0.00	0.00	0.03	0.19	0.00	0.00
Four-spine stickleback	0.00	0.00	1.05	2.22	5.21	15.54	1.47	2.81	4.21	10.17	3.36	5.61	1.59	3.51	0.42	0.79
Green crab	0.00	0.00	0.14	0.36	0.03	0.18	0.30	0.70	0.02	0.15	0.86	1.56	0.00	0.00	2.42	3.48
Sand shrimp	0.05	0.23	0.00	0.00	0.21	0.83	2.13	4.76	0.45	1.50	6.32	9.58	0.48	1.21	17.83	19.60
Mummichog	0.00	0.00	7.81	11.22	13.59	35.61	3.90	11.42	10.19	28.52	12.14	22.11	26.52	31.81	6.08	7.98
Striped killifish	0.00	0.00	0.00	0.00	0.00	0.00	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	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.19	0.00	0.00
Longnose spider crab	0.00	0.00	0.00	0.00	0.00	0.00	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	0.00	0.00	0.00	0.00	0.03	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Atlantic silverside	3.42	8.73	1.81	4.40	2.72	4.60	2.83	6.97	0.60	1.86	2.43	3.52	5.59	13.43	4.00	7.27
White perch	1.47	3.50	0.00	0.00	0.10	0.31	0.00	0.00	0.88	2.09	0.29	1.18	0.14	0.44	0.00	0.00
Shore shrimp	2.42	7.17	66.76	101.1	5.28	18.86	16.40	33.10	1.69	6.44	12.75	29.22	0.55	1.45	4.83	7.42
Winter flounder	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.34	0.11	0.31	0.00	0.00	0.50	0.90
Nine-spine stickleback	0.00	0.00	0.67	1.49	0.00	0.00	0.00	0.00	0.07	0.26	0.32	0.86	0.03	0.19	0.00	0.00
Pipe fish	0.26	1.15	0.00	0.00	0.24	0.94	0.03	0.18	0.12	0.33	0.00	0.00	0.03	0.19	0.50	0.90
Unknown crab species	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.45	0.00	0.00	0.00	0.00

Table 8-2. Mean nekton density (animals/m^2) in East Harbor system 2003 to 2006.

SITE	2003		2004		2005		2006	
	EAST HARBOR LAGOON	MOON POND	EAST HARBOR LAGOON	MOON POND	EAST HARBOR LAGOON	MOON POND	EAST HARBOR LAGOON	MOON POND
n	*19*	*20*	*30*	*30*	*42*	*28*	*29*	*12*
TOTAL	145	1649	799	813	2518	1085	1016	439
CRUSTACEANS	47	4105	162	566	104	563	30	301
FISH	98	244	637	247	2414	522	986	138

Table 8-3. Total numbers of animals sampled in the East Harbor system 2003 to 2006.

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

Table 8-4. Relative abundance (number/total number) for
Fish, crustaceans and each species in East Harbor Lagoon.

	Moon Pond			
	2003	2004	2005	2006
CRUSTACEANS	85.20%	69.62%	51.89%	68.56%
FISH	14.80%	30.38%	48.11%	31.44%
American eel	0.36%	0.00%	0.00%	0.00%
Four-spine stickleback	1.33%	5.41%	8.66%	1.14%
Green crab	0.18%	1.11%	2.21%	6.61%
Sand shrimp	0.00%	7.87%	16.31%	48.75%
Mummichog	9.95%	14.39%	31.34%	16.63%
Striped killifish	0.00%	0.00%	0.00%	0.00%
Three-spine stickleback	0.00%	0.00%	0.00%	0.00%
Longnose spider crab	0.00%	0.00%	0.09%	0.00%
Spider crab species	0.00%	0.12%	0.00%	0.00%
Atlantic silverside	2.30%	10.46%	6.27%	10.93%
White perch	0.00%	0.00%	0.74%	0.00%
Shore shrimp	85.02%	60.52%	32.90%	13.21%
Winter flounder	0.00%	0.00%	0.28%	1.37%
Nine-spine stickleback	0.85%	0.00%	0.83%	0.00%
Pipe fish	0.00%	0.12%	0.00%	1.37%
Unknown crab species	0.00%	0.00%	0.37%	0.00%

Table 8-5. Relative abundance (number/total number) for
fish, crustaceans and each species in Moon Pond.

PLANS FOR 2007 FIELD SEASON

- Monitoring of tide heights, salinity, dissolved oxygen, nekton (finfish, shrimp and crabs), benthic invertebrates, and both wetland and submerged vegetation will continue as in 2005 and 2006.

- Microbiological monitoring, specifically weekly counts of *Enterococcus* at the Noons Landing outfall pipe, will continue.

- The US Army Corp of Engineers will continue its comprehensive feasibility study for estuarine restoration at East Harbor. [Note that at this writing funding for work in Fiscal Year 2007 is uncertain.]

- Continue to monitor for the presence of alewife in the East Harbor system, during migration and for presence of juveniles in the fresh water pools in Salt Meadow.

- New methods will be tested to increase the effectiveness of nekton monitoring in the East Harbor system. These may include cast nets, lift nets and extensive use of minnow traps and other passive methods.

- Additional new studies will be directed toward the macroalgae blooms of 2005 and 2006. These studies are still under discussion but may include:

  1. Hydrology of Beach Point, to estimate what portion of wastewater-nutrients from the developed barrier beach discharge into East Harbor lagoon;

  2. Bioassays of nutrient limitation, to understand whether the growth of macroalgae is in fact limited by the availability of nitrogen, as from septic discharge.

  3. Monitoring of algae species composition, to understand species-specific physiological limitations (e.g. effects of low or high salinity).

  4. Monitoring of algae abundance, to track trends quantitatively.

  5. Assessment of the effects of macroalgae blooms on finfish.

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APPENDIX A. CHRONOLOGY OF EVENTS AT EAST HARBOR

1845 Bridge built across East Harbor inlet to connect Truro and Provincetown.

1868 East Harbor inlet filled, purportedly to block sand from filling Provincetown Harbor.

1873 Railway built across dike to service Provincetown.

1894 Drainage system constructed at southeast end of system (Moon Pond) connecting back-barrier lagoon to Cape Cod Bay with flume at High Head Road.

1910 East Harbor lagoon renamed "Pilgrim Lake" by local developer.

1911 Carp found in lagoon, origin unknown , perhaps introduced as bait (Mass. Survey of Inland Waters).

1920s Route 6A built on western side of railroad.

1935 WPA reconstructs existing (1894) pipe between East Harbor and Bay.

1952-3 Highway 6 built on fill along southern side of lagoon.

1956-8 Mass. Division of Waterways builds culvert and tide gate system to lower lagoon level for mosquito control with weir in place of 1894 flume at High Head Road.

9/1968 Fish kill (carp & white perch) following removal of weir boards, lowered lagoon level and likely oxygen depletion in remaining water. Salinity 10-18 0/00.

    Chironomid midge problem.

5/1969 9000 alewives (spawners) stocked in lagoon to consume midge larvae by Mass. Division of Fish and Game and Division of Marine Fisheries

6/1969 NPS applies Abate as midge larvicide by helicopter.

8/1969 NPS applies Abate as midge larvicide by helicopter.

5/1970 6000 more alewives stocked by DMF.

    NPS applies Abate as midge larvicide by helicopter.

1976 Mass. DPW repairs tide gates and pipe to bay.

5/1982 Adult alewives observed swimming over weir into lagoon.

9/2001 Fish kill includes > 30,000 juvenile alewives and hundreds of white perch, likely due to oxygen depletion.

12/6/01 NPS and Town of Truro experimentally open culvert valves.

1/25/02 NPS & Truro Health Board plan for bacteria monitoring at culvert & Beach Point.

2/27/02   Valves closed to allow salinity to decline for anadromous fish spawning per
          agreement with DMF.

5/02   NPS sets up vegetation and water quality monitoring plots in Moon Pond and
          East Harbor wetlands

6/24/02   Valves opened by Truro DPW and NPS.

7/4/02   Valves closed by Truro DPW and NPS due to Board of Health concerns for
          high *Enterococcus* at Beach Point. East Harbor Lagoon salinity declines to
          10 ppt.

7/11/02   Boards put in weir by Truro to dampen discharge and see if it helps with

          bacteria problem.

8/2002   Large midge (chironomid) hatch from East Harbor Lagoon.

11/4/02   Valves opened and weir boards removed by Truro DPW and NPS per
          Conservation Commission and Selectmen decision.

6/2003   Salinity reaches 20-25 throughout Harbor;

          Widgeon grass proliferates in East Harbor Lagoon.

9/2003   Ten species of estuarine fish and crustaceans reestablish in East Harbor;

5/2004   Sand eels using East Harbor.

6/2004   Hard clams and steamers observed in sediments of former "Pilgrim Lagoon";

          Blue mussel bed develops in Moon Pond creek.

7/2004   Eelgrass discovered in East Harbor Lagoon.

9/2005   Macroalgae blooms.

8-10/2006   Macroalgae blooms and odors. Oxygen depletion in August causes bivalve
            dieoff.