Hatches Harbor Salt Marsh Restoration: 2005 Annual Report

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INTRODUCTION

In cooperation with the Town of Provincetown, Federal Aviation Administration and Massachusetts Aeronautics Commission, the National Park Service (NPS) has been incrementally restoring tidal exchange to the diked portions of Hatches Harbor since March of 1999. The overall objective of this project is to restore native salt marsh functions and values to the tide-restricted wetland to the extent possible without compromising safety at the Provincetown Municipal Airport.

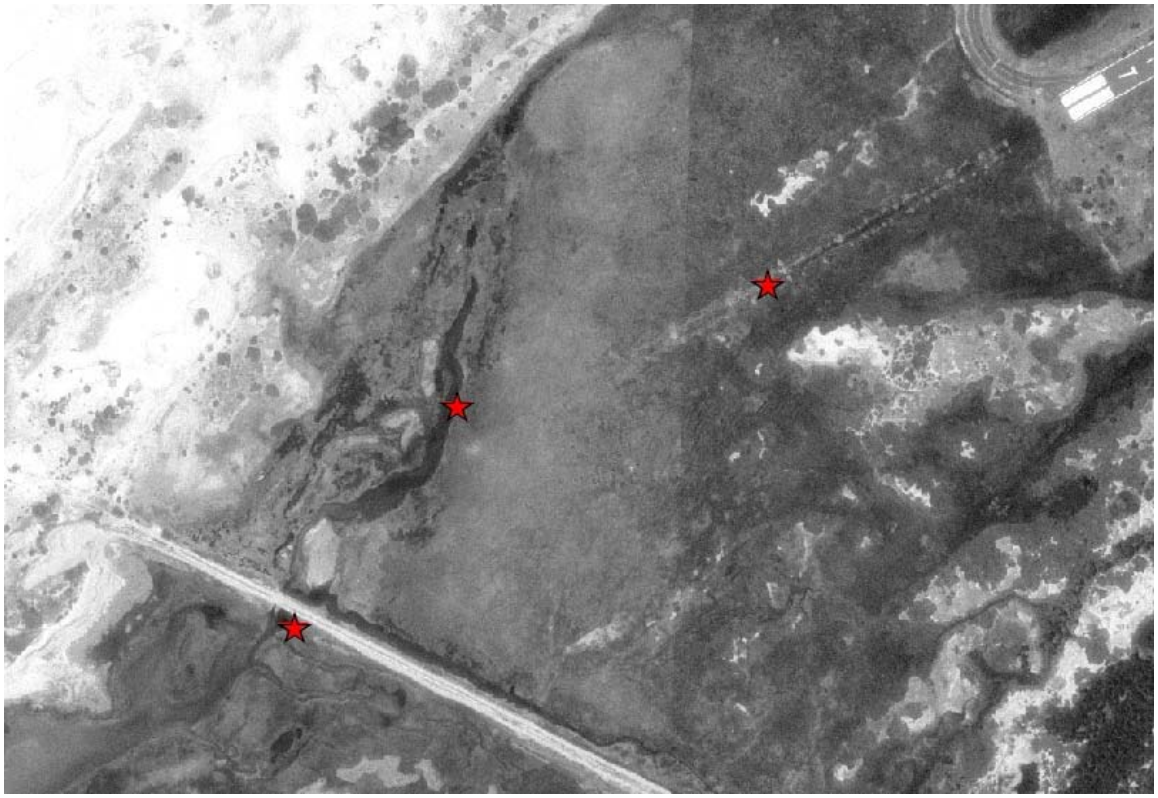
After an hydrodynamic assessment in 1987 (Roman 1995), large culverts were installed through the Hatches Harbor Dike by the NPS in the winter of 1998-99 to accommodate increased tidal flow. The NPS has opened these gated culverts in small increments each year (Table 1) to ensure Airport safety from flooding and to control and adaptively manage ecosystem response; culverts were finally opened fully in June 2005. Cape Cod National Seashore (CCNS) staff and cooperators collected base line data in 1997 before new culvert construction in 1998-9, and have monitored system response intensively since then.

This reports on tide-height, vegetation (emergent macrophytes), and nekton monitoring undertaken in 2005 and summarizes progress towards habitat restoration. We also include some quantification and discussion of the net increase in wetland area in the restricted marsh since tidal restoration began in 1999. Monitoring has included tide heights, sedimentation, sediment-water quality, wetland vegetation, and nekton (fin-fish and decapod crustaceans) within both natural (unrestricted) and diked portions of the Hatches Harbor flood plain (Fig. 1). Adult mosquito monitoring was discontinued in 2005 because data from 1997 through 2004 showed that increased tide heights and salinities did not lead to increased nuisance mosquito production in the Hatches Harbor flood plain (Portnoy et al. 2005).

Table 1. Recent history of incremental culvert gate openings at Hatches Harbor**.**

Years	Number of open culverts	Dimensions of opening	Opening area (m^2)
Pre-1999	1	2-ft ID old circular culvert	0.29
Mar 1999 – Mar 2000	2	2.13 m wide X 0.10 m high	0.42
Mar 2000 – Mar 2001	4	2.13 m wide X 0.10 m high	0.85
Mar 2001- Oct 2003	4	2.13 m wide X 0.40 m high	3.41
Oct 2003 – Jun 2005	4	2.13 m wide X 0.70 m high	5.96
Jun 2005 onward	4	2.13 m wide X 0.90 m high	7.79

Figure 1. Hatches Harbor salt marsh showing tide gauge locations.



TIDE HEIGHTS

A major objective of the Hatches Harbor Salt Marsh Restoration is to restore the tide-restricted wetland to the extent possible without compromising safety at the Provincetown Municipal Airport. In order to meet this objective, NPS has monitored tide heights since 1997, and the system's response to incremental tidal restoration since March 1999. This section focuses on tidal height data that were collected in the summer of 2005 at three locations within this salt marsh system.

Methods

In previous years, tidal height data were collected by YSI6000 and YSI6600 multi-parameter data loggers. From May 2005 through mid July 2005, HOBO water level recorders were used at three locations. Initially, three stilling wells were installed and the instruments were then deployed. One was located 10 m seaward of the dike structure (unrestricted side); another was located about 500 meters upstream of the structure on the restricted marsh side; and a final one was located near the berm at the Airport catwalk (Figure 1). Data were uploaded every two weeks after the initial deployment for two months. Temperature, absolute pressure (including atmospheric and water head) data were collected by the instruments at 15-minute intervals. Once the data were uploaded, a pressure correction was completed by the accompanying HOBO software, in order to get corrected tidal heights.

Results

The final 20-cm increase in culvert opening in June 2005 yielded little increase, over the culverts' prior setting, in mean high- and low-tide heights and in tidal range (Table 2). Tidal range in the restricted marsh is 0.7 m, as opposed to about 1.02 in the unrestricted marsh seaward of the dike (Table 2).

Table 2. Mean high, mean low and tidal ranges (m-MSL) from three tide gauge locations in Hatches Harbor salt marsh before and after the final culvert opening in June 2005.

Station	**Mean High**	**Mean Low**	**Tidal Range**
Unrestricted			
October 2003 - June 2005	1.78	0.72	1.06
June 2005 onward	1.72	0.70	1.02
Restricted			
October 2003 - June 2005	1.58	0.91	0.67
June 2005 onward	1.57	0.87	0.70
Airport			
October 2003 - June 2005	1.03	0.86	0.17
June 2005 onward	1.46	1.27	0.19

Data collected before and after the final opening indicates that there is still a dampening effect from the dike and culvert system. As hydrodynamic modeling predicted (Roman et al. 1995), extreme high tides that exceed the Airport's critical threshold (10 ft-MLW = 1.66 m-NGVD) are filtered out by the structure, especially during spring tides (Figure 2).

With the culverts now fully open, high tides are still lower and low tides higher in the restricted, than in the unrestricted marsh (Figure 3). This is likely due to the combined impedance of the structure (albeit fully open) plus a shallow sill in the main creek between the culverts and the "restricted" data logger 500 m upstream, which restricts low-tide drainage.

Figure 4 shows incremental increases in mean tidal range in the diked marsh with culvert opening over the period of step-wise culvert opening, 1999 - 2005. With the culverts now fully open, tidal range in the restricted marsh is about 69% of downstream tidal forcing, as compared to only 26% prior to new culvert installation.

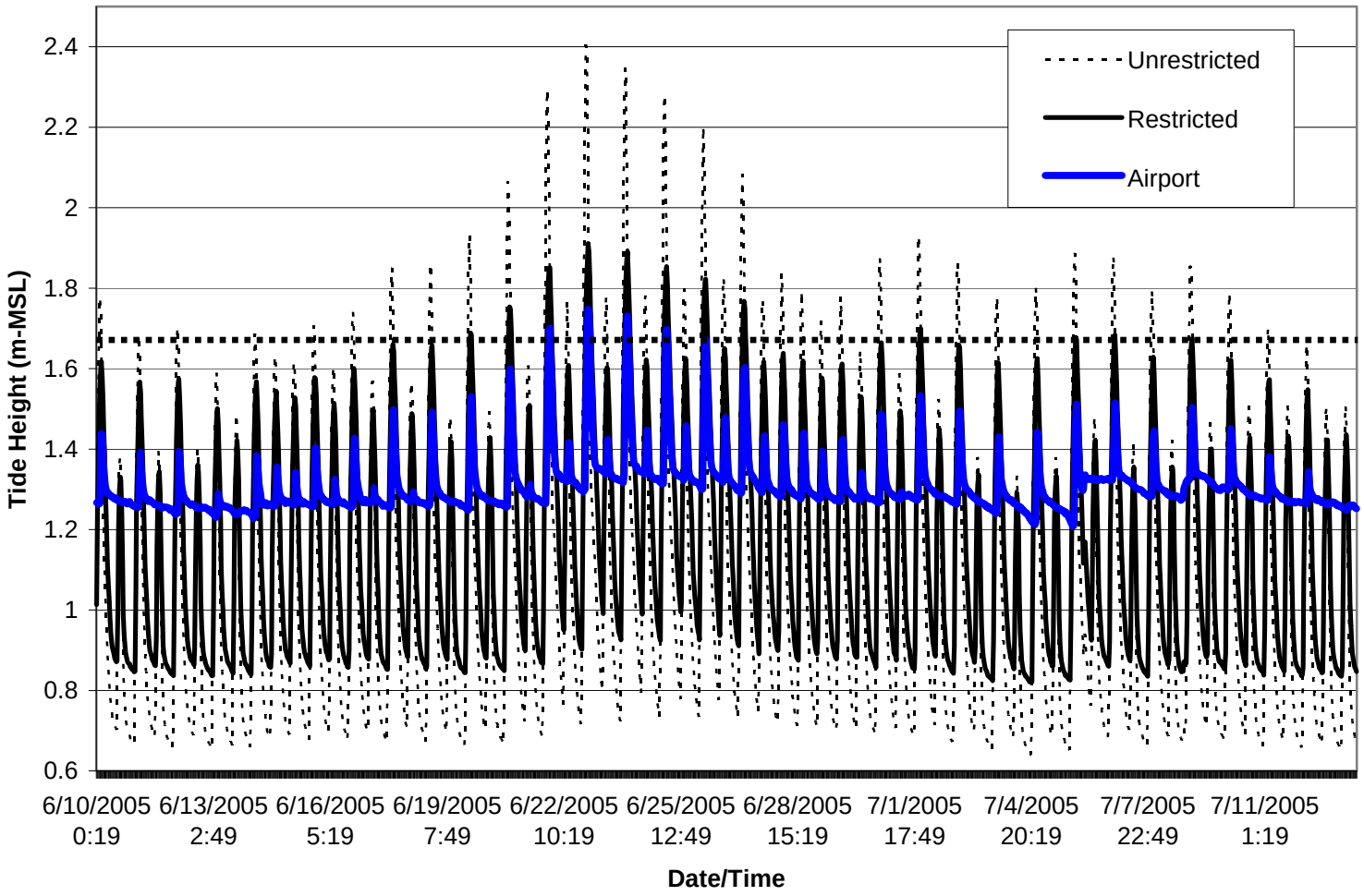
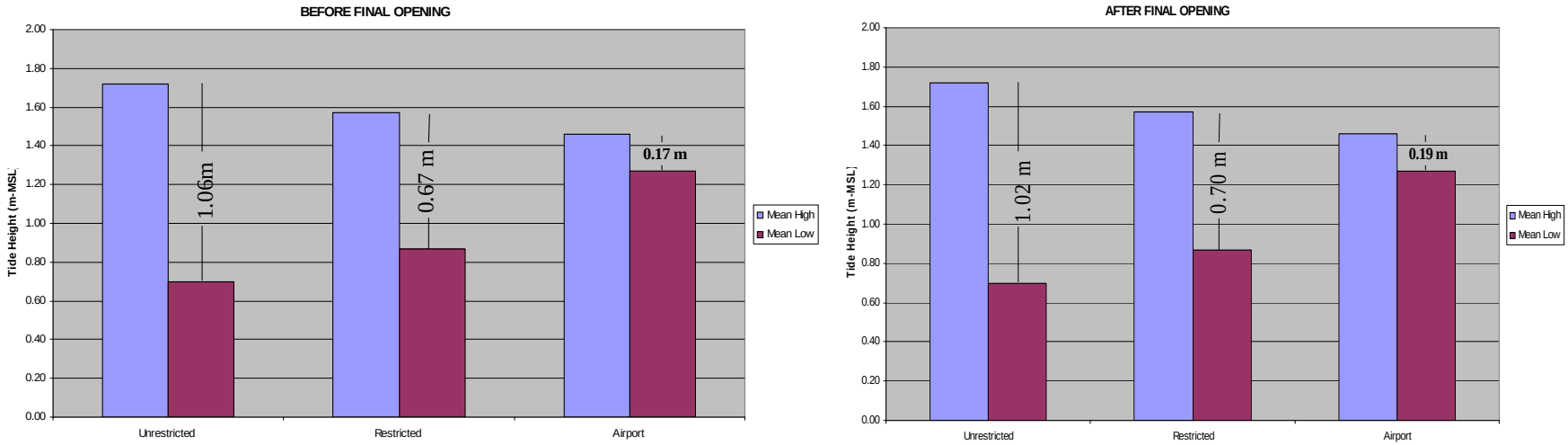


Figure 2. Tide heights (m-MSL) at three locations in Hatches Harbor salt marsh after the culvert opening in June 2005. The dotted horizontal line marks the 10-ft-MLW (1.66 m-MSL) high-tide limit established under the Memorandum of Understanding with the Town of Provincetown. The earthen berm protecting the airport safety area is at elevation 10.5 ft-MLW (1.8 m-MSL).

Figure 3. Mean high, mean low and mean tidal ranges from three tide gauge locations in Hatches Harbor salt marsh before and after the final opening in June 2005.



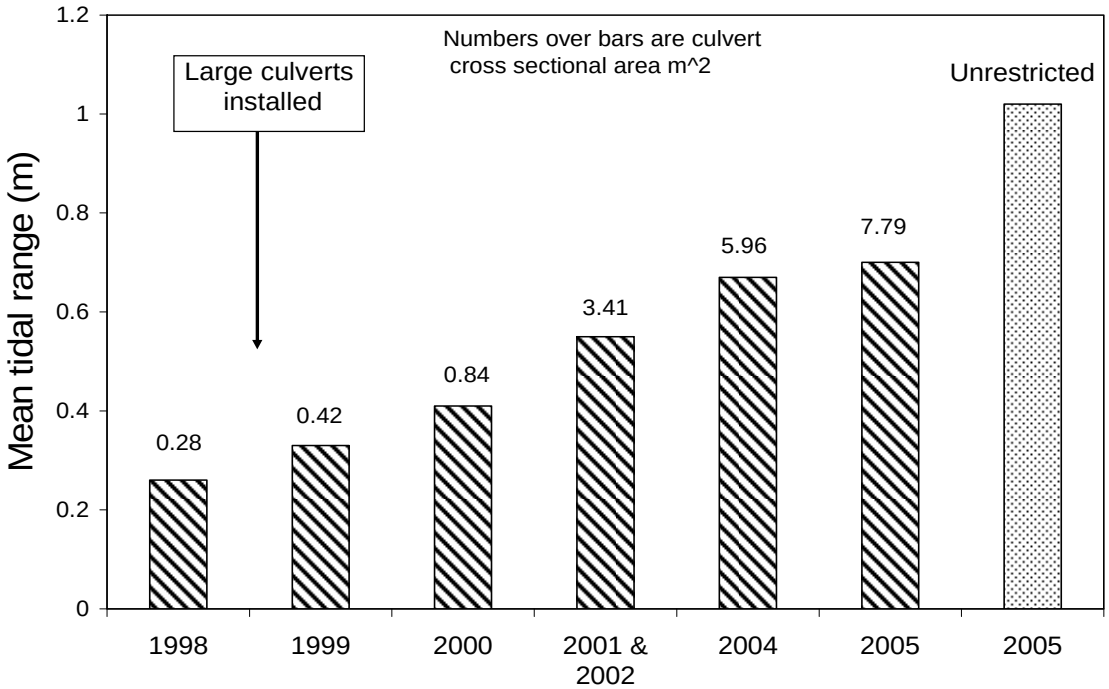


Figure 4. Effect of incremental culvert openings (since March 1999) on tidal range in the diked portion of Hatches Harbor, relative to the unrestricted marsh.

VEGETATION: EMERGENT MACROPHYTES

No community-level surveys were done since the entire network of plots will be surveyed in 2006. Specific measures of *Phragmites* vigor were measured in plots along transect 2, for which we have the longest continuous record for these parameters.

Methods - 2005

Phragmites stem heights and densities were measured along the entire length of transect 2. Biomass was then calculated based on the regressions of Thursby et al. (2002).

Results

Phragmites has been eliminated from 5 plots and reduced to very low levels in another 5 plots along the first 240 m of transect 2 (i.e., approximately 240 m upslope from the creek edge) (Figure 5a). In contrast, *Phragmites* has become established in plots 260-320 where it was absent prior to restoration. Beyond these plots, *Phragmites* has shown little change. The peak biomass of the *Phragmites* population along transect 2 has shifted from plot 100 to plot 320 - a distance of 220 m away from the main tidal creek.

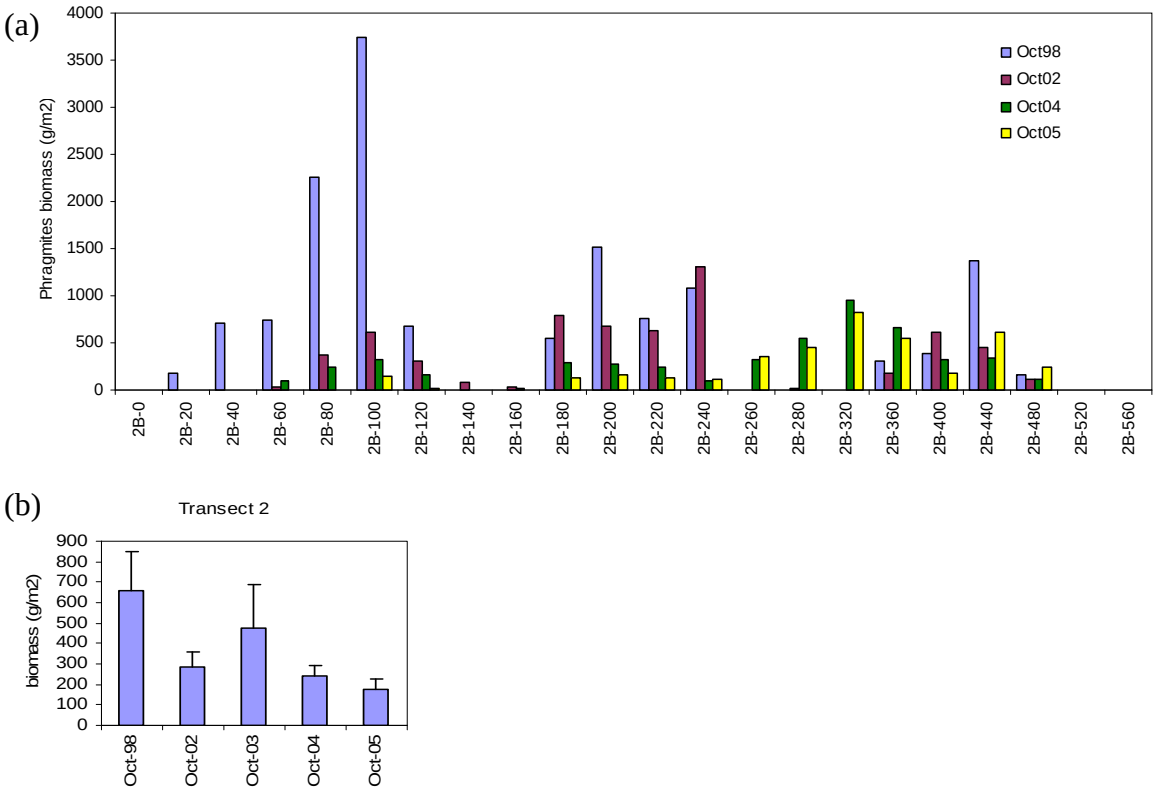


Figure 5. *Phragmites* biomass changes at individual plots (above) and as a whole (below) along transect 2.

Overall, the total amount of *Phragmites* biomass along transect 2 is less than a third of the original amount present (Figure 5b). Although the rate of decline during the last three years has been relatively slow compared to the first four (1998-2002), it is expected that this decreasing trend will continue as salinity exerts a constant metabolic drain on this species.

Anecdotal observations – During 2004 - 2005, it became apparent that the distribution of wrack material, which includes abundant seeds, throughout the restricted side of the marsh had changed – with significant consequences for the spread of desirable vegetation. More specifically, wrack started to penetrate further into the marsh as a result of a decline in some of the standing dead (salt-killed) vegetation. Dead stems of *Phragmites* and woody shrubs, which can remain upright and in place for many years, greatly impedes the movement of wrack material. In fact, a great deal of wrack gets piled up against the front edge of relic *Phragmites* stands. When this impediment is removed – through artificial or natural means – salt marsh vegetation is able to become established more rapidly. This process is clearly evident along the sides of the man-made tidal creeks that were created in 2004 for mosquito control. It is also occurring where foot paths along transects have allowed the passage of seeds through dense *Phragmites* into open areas within the interior.

To further investigate how seed dispersal and subsequent establishment of halophytes may be accelerated by creating wrack "conduits", we have begun to monitor experimental plots in which *Phragmites* and/or standing dead woody vegetation have been cut (treatments) or left in place (controls). The results have direct applicability to the management of salt-killed vegetation in other restoration projects, including the Herring River floodplain where large amounts of freshwater and upland vegetation will suffer rapid mortality soon after tidal restoration is initiated.

Figure 6. Establishment of native halophytes along the banks of an artificial creek created in 2004 (left) and a thick accumulation of wrack at the front edge of salt-killed *Phragmites* (right).

NEKTON

Nekton is an effective and powerful sample population for monitoring the results of tidal restoration in the Hatches Harbor salt marsh, ongoing since spring 1999. 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, i.e., increasing tidal range in the restricted area of Hatches Harbor. 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 predator, an important feature not present in other sample populations (Raposa and Roman 2001a).

Nekton data were collected before tidal restoration (1997) and four times during the incremental opening of the new culverts (1999, 2003, 2004 and 2005). Monitoring nekton will continue for the long term. Full implementation of the nekton monitoring protocol (Raposa and Roman 2001a) was conducted in 2005 for the first time, with subsequent sampling proposed for 2006 and 2007, then every three years thereafter.

This report compares nekton abundance and diversity between restricted and unrestricted areas in 2005; it also assesses differences in abundance and diversity between 1997 (pre-restoration data from Raposa and Roman 2001b) and 2005 in the marshes on both restricted and unrestricted sides of the Hatches Harbor dike.

Methods

During 2005, nekton was sampled from subtidal creeks and marsh pools using a $1m^2$ x 0.5 m high throw trap, with a 3-mm mesh frame. Workers carefully approach the sample site and toss the trap, then remove any animals with a 1 m x 0.5m dip net (1.5-mm mesh). Twenty-two creek and five marsh pool stations were randomly established within the unrestricted marsh and 31 creek and eight pool stations in the restricted marsh. These sites were sampled twice; each sampling event continued over several days, one in early August and the other in late September 2005. Each sample event was conducted during the ebb tide, commencing after the marsh surface had dewatered (James-Pirri and Roman 2004).

The selection of new, random stations for each habitat strata each sampling season was suggested in the current revision to the nekton protocol, in response to observations of changes in marsh morphology noted during 2003 and 2004 (Portnoy et al. 2004). A location occupied by a pool one year, for example, may not be occupied by a pool in subsequent years; therefore, each year stations for sampling are newly selected from the current population of pools. This new sample design results in a data set directly comparable to previous sampling years and is as powerful in its ability to detect changes in nekton abundance; in addition, it compensates for any changes in the structure of the marsh (James-Pirri and Roman 2004).

The relative abundance and density of nekton were calculated for both 2005 and 1997 during similar seasons. Tests were conducted using total nekton density, fish and decapod densities, and number of species to evaluate differences between years, between treatments (restricted vs. unrestricted), and between habitats (creek and pool). The non-parametric Kruskal-Wallis test was used (similar to ANOVA), because many of the comparisons violated assumptions of normalcy and equal variance (Sokal and Rohlf 1981). Many comparisons were conducted; only statistically significant results are discussed.

It should be stressed that these data relate only to tidal creeks and marsh pools and not to densities throughout the entire system. The marsh surface is an important habitat for estuarine fishes, especially the common mummichog. Only seven acres (3 ha) of *Spartina alterniflora* marsh habitat were available to nekton in the restricted area before tide restoration, while 60 acres (25 ha) were available in the unrestricted area. The increase in tidal range since 1999 has expanded the area of *S. alterniflora* marsh in the restricted area, potentially by 54 acres (22 ha, see Fig. below); an increase in utilization of *S. alterniflora* marsh habitat by nekton is expected (Portnoy et al. 2003).

Results and discussion

During the 2005 sample period, six species of fish and four of crustaceans were collected, with the common mummichog (*Fundulus heteroclitus*) the dominant fish species, and the sand shrimp (*Crangon septemspinosa*) the dominant crustacean (Table 3a). Similar results were observed in 1997 (Table 3b). A new species was collected in Hatches Harbor in 2005, the white perch (*Morone americana)* This semi-anadromous fish is a popular recreational species, and its presence may indicate an improvement in habitat quality (i.e., spawning and nursery) in response to restoration.

Total nekton densities were similar between both years and treatments (Table 4), and species (Tables 5a, b). Although there were no significant changes in densities among years, *F. heteroclitus* densities were significantly higher in the restricted compared to the unrestricted marsh in 2005 ($p<0.001$, Figure 7).

The significant difference in 2005 of *F. heteroclitus* densities between restricted and unrestricted sample areas is likely a result of changes in marsh morphology in the unrestricted area of the marsh, and a corresponding decrease in preferred *F. heteroclitus* habitat. There have been changes in the shape, depth and character of the smaller creeks and pools of the unrestricted side of the marsh. [Changes in marsh morphology have also been observed in the restricted area). Pools and smaller creeks have been filling with sandy sediment; also *Spartina alterniflora* has been observed growing into the pools and creeks. The mummichog retreats into pools and creeks as the marsh de-waters. Many of the pools and creeks that were available to the fish in 1997 are dry, or extremely shallow in 2005 at a similar tidal stage. Aerial photography from 1986 and 2000 illustrates the changes taken place (Figure 8a, b).

The cause of the change in marsh morphology is unknown, but at least two factors make Hatches Harbor unusual among New England salt marshes and may contribute to its

dynamic morphology. First it is young (less than a few hundred years) with a thin, sandy peat layer and an actively changing barrier beach system that likely affects the hydraulics of the system. Preliminary examination of tidal data suggests that low tides may be 10-20 cm lower in the restricted marsh now than in 1999, when tidal restoration was just beginning. Lower low tides in an environment of highly permeable peat would cause pools to dewater, become unavailable to fish at low tide and encourage the invasion of marsh macrophytes (e.g. *Spartina* spp.). The history of tide-height changes will be studied further. Second, the diking of the system since 1930 may have impacted the hydrography (and subsequently the morphology) of the marsh. A coastal survey map from 1910 (based on surveys from the mid 1800's) indicates that much of Hatches Harbor was a tidal lagoon fed by "Race Run", a tidal creek draining large areas to the northeast (Figure 9).

Conclusion

Restoration of Hatches Harbor is having a positive effect on the nekton community by greatly increasing the area of habitat used as a nursery area and for feeding and breeding. Attempts to quantify nekton response to increasing habitat may be confounded by continuing changes in marsh morphology and also by the geomorphic history of Hatches Harbor.

- Hatches Harbor is a dynamic estuarine system with a diverse nekton community similar to other Lower Cape estuaries. In the unrestricted sample area, however, the number of species captured in 2005 was half that of unrestricted portions of Herring River and Nauset Marsh. This may be an indication of the dynamic nature of Hatches Harbor compared to other marshes sampled in 2005.
- Rapid changes are continuing in hydrology and morphology in both restricted and unrestricted sample areas, indicated by sedimentation data (Portnoy et al. 2004) and interpretation of aerial photography.
- In the restricted marsh, increased tidal range and new creeks allow nekton access to a greater area of habitat.
- Nekton use of habitat (e.g., sandy main creek) is similar seaward and landward of the dike.
- Decrease in habitat results in decrease in nekton density (e.g., mummichog response to decrease in pool habitat) in the unrestricted marsh.
- More work is needed to assess nekton use of restored creeks and marsh surface, both of which have increased since 2004.

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2005			
Species		# animals	Relative Abundance
Mummichog	*Fundulus heteroclitus*	2207	67.53%
Sand Shrimp	*Crangon septemspinosa*	921	28.18%
Atlantic Silverside	*Menidia menidia*	74	2.26%
Striped Killifish	*Fundulus majalis*	37	1.13%
Green Crab	*Carcinus maenas*	21	0.64%
Winter Flounder	*Pseudopleuronectes americanus*	6	0.18%
American Eel	*Anguilla rostrata*	1	0.03%
White Perch	*Morone americana*	1	0.03%
TOTAL FISH		2326	71.18%
TOTAL DECAPOD		942	28.82%
TOTAL NEKTON		3268	100.00%

Table 3a. Total relative abundance of all nekton Hatches Harbor in 2005 (both restricted and unrestricted sample sites are pooled).

1997			
Species		# animals	Relative Abundance
Mummichog	*Fundulus heteroclitus*	2886	83.70%
Sand Shrimp	*Crangon septemspinosa*	343	9.95%
Green Crab	*Carcinus maenas*	89	2.58%
Striped Killifish	*Fundulus majalis*	64	1.86%
Atlantic Silverside	*Menidia menidia*	32	0.93%
American Eel	*Anguilla rostrata*	15	0.44%
Four-spine Stickleback	*Apeltes quadracus*	11	0.32%
White Mullet	*Mugil curema*	5	0.15%
Three-spine Stickleback	*Gasterosteus aculeatus*	1	0.03%
Winter Flounder	*Pseudopleuronectes americanus*	1	0.03%
Pipe fish	*Syngnathus fuscus*	1	0.03%
TOTAL FISH		3016	87.47%
TOTAL DECAPOD		432	12.53%
TOTAL NEKTON		3448	100.00%

Table 3b. Total relative abundance of all nekton Hatches Harbor in 1997 (both restricted and unrestricted sample sites are pooled).

	Total Density			
	1997		2005	
	Mean	Std. Dev.	Mean	Std. Dev.
Restricted	26.05	24.01	25.44	28.35
Unrestricted	9.69	8.88	11.01	15.12

Table 4. Total nekton mean densities, 1997 and 2005.

	Restricted			
	1997		2005	
Species	Mean	Std. Dev.	Mean	Std. Dev.
Anguilla rostrata	2.25	1.06	1.00	n.a.
Apeltes quadracus	2.50	1.73		
Carcinus maenas	1.20	0.37	1.50	1.00
Crangon septemspinosa	3.30	2.54	13.93	24.31
Fundulus heteroclitus	34.62	24.89	51.24	56.10
Fundulus majalis	1.88	0.85	4.00	3.46
Gasterosteus aculeatus	1.00	n.a.		
Menidia menidia	2.50	1.32	7.50	2.12
Morone americana			1.00	n.a.
Mugil curema				
Myoxocephalus aenaeus				
Pagarus sp.				
Pseudopleuronectes americanus			1.00	0.00
Syngnathus fuscus				
TOTAL	26.05	24.01	25.44	28.35

Table 5a. Individual species densities in the restricted area of Hatches Harbor.

	Unrestricted			
	1997		2005	
Species	Mean	Std. Dev.	Mean	Std. Dev.
Anguilla rostrata				
Apeltes quadracus				
Carcinus maenas	2.01	1.13	2.00	1.22
Crangon septemspinosa	11.81	22.47	23.10	26.18
Fundulus heteroclitus	28.28	33.49	6.62	7.72
Fundulus majalis	3.56	2.71	10.50	12.02
Gasterosteus aculeatus				
Menidia menidia	3.00	2.45	9.83	20.66
Morone americana				
Mugil curema	5.00	n.a.		
Myoxocephalus aenaeus				
Pagarus sp.				
Pseudopleuronectes americanus	1.00	n.a.	1.50	0.71
Syngnathus fuscus				
TOTAL	9.69	8.88	11.01	15.12

Table 5b. Individual species densities in the unrestricted area of Hatches Harbor.

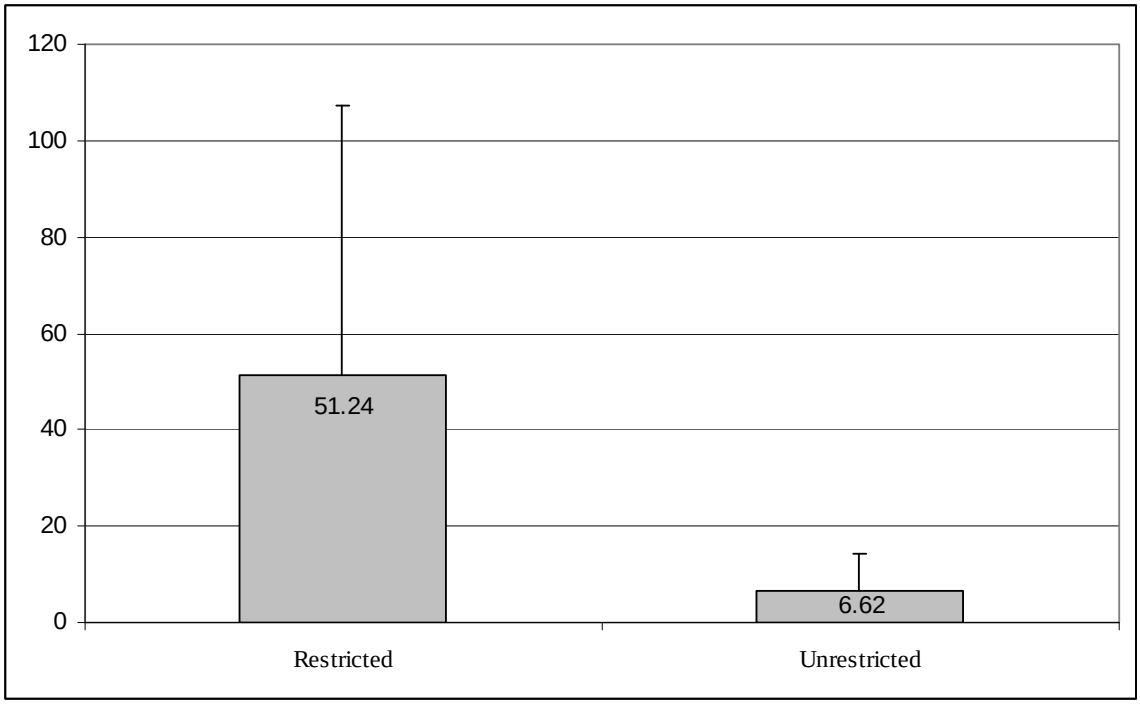


Figure 7. Density (animals/m^2) of *Fundulus heteroclitus* in restricted and unrestricted sample areas of Hatches Harbor 2005. Numbers indicate mean density. Error bars are standard deviation. There is a significant difference between animal density in restricted and unrestricted sample area ($p<0.001$).

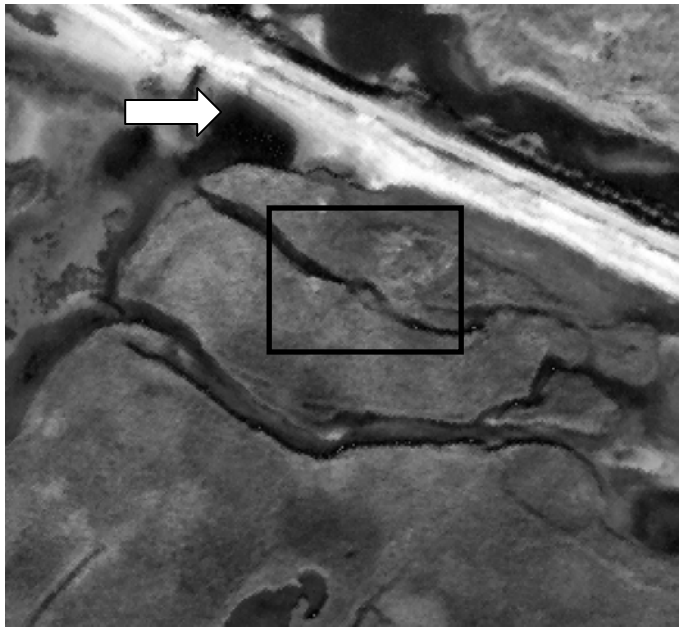


Figure 8a. 1986 aerial photograph of Hatches Harbor unrestricted marsh. Arrow indicates culvert, box indicates area of interest. Note marsh creek channel is clear.

Figure 8b. 2000 aerial photograph of Hatches Harbor unrestricted marsh. Arrow indicates culvert, box indicates area of interest. Note marsh creek channel has closed.

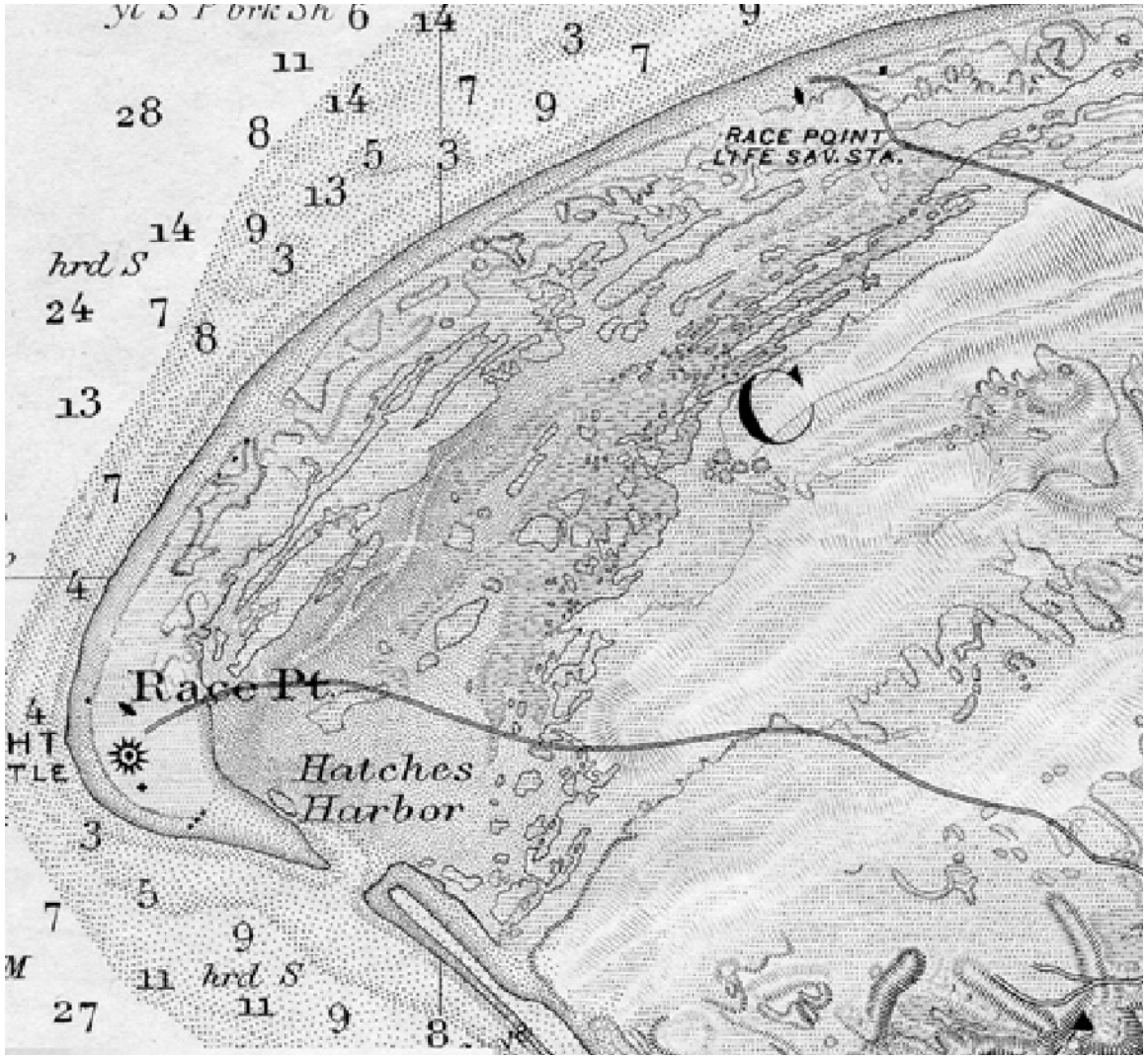


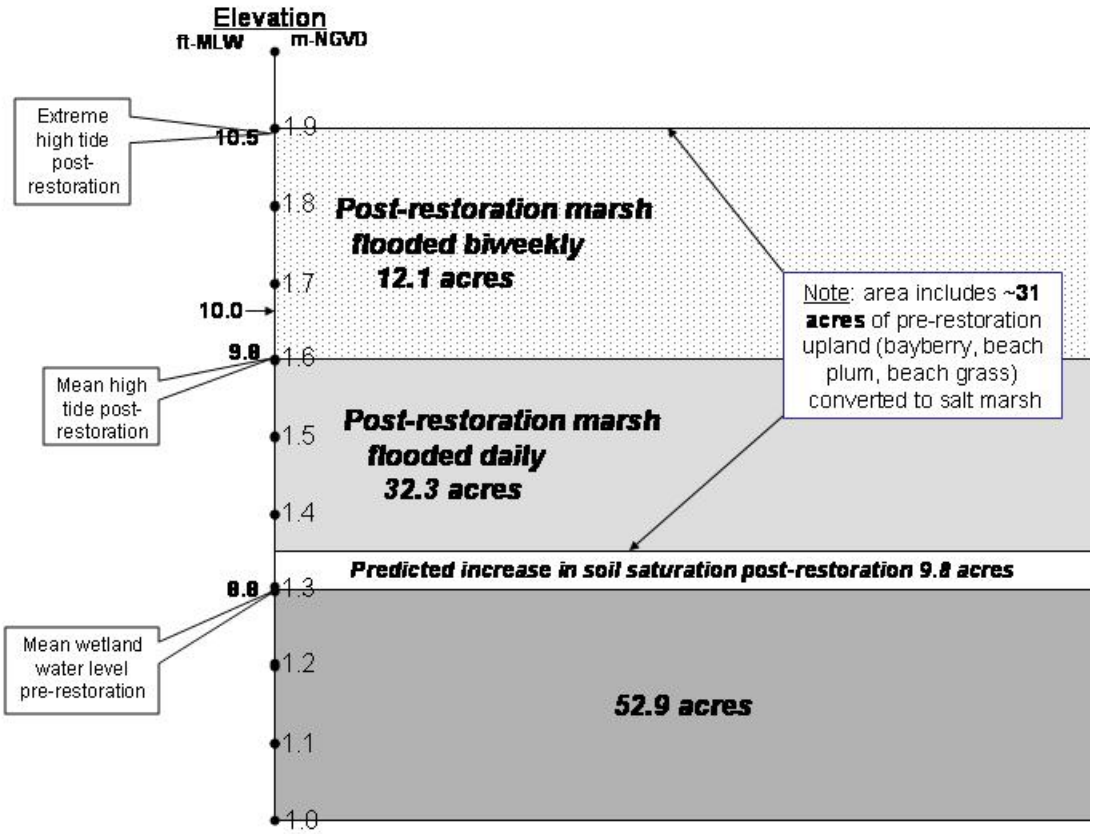
Figure 9. Hatches Harbor from coastal survey map 1910. Much of the current marsh was a tidal lagoon.

INCREASE IN WETLAND AREA

About 1998, in response to a request from Provincetown Airport interests, NPS estimated the increase in wetland area due to the projected increase in mean wetland water level with tidal restoration. This estimate, which amounted to about 7 acres, was based on the assumption that greater tidal forcing would raise the elevation of discharging groundwater, allowing wetlands to extend farther inland. [With newer higher-resolution bathymetry, that estimate has been increased to 9.8 acres, Fig.)]. Although NPS did not specify that these would be freshwater wetlands, it was presumed so in DEP permitting and mitigation for Airport development projects.

With culverts now (as of June 2005) fully open, it is clear that freshwater discharge is insufficient, given observed seawater heights, to maintain low salinity in upland-fringing wetlands at Hatches Harbor. The overall increase in salt marsh, however, has been substantial (Fig. 10). About 54 acres of salt marsh is developing between the elevations of pre-restoration high tide and current spring tide; about 31 acres of this represents conversion of upland dune communities, cover-typed in 1991 as bayberry, beach plum and beach grass, to intertidal salt marsh. The remaining 23 acres represent replacement of freshwater wetland by saline marsh. Dune communities that are within the flood plain and presently being flooded by seawater are artifacts of the 69-year exclusion of tides (1930 to 1999); therefore, we consider their ongoing replacement by salt marsh cover a reversion to the native community.

Figure 10. Pre- and post-restoration tide heights and wetland areas landward of the Hatches Harbor Dike.



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