Hatches Harbor: Restoring a Salt Marsh

A summary of the Hatches Harbor Restoration Project
With preliminary results for the pre-restoration field sampling
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The Cape Cod National Seashore is in the middle of an exciting environmental restoration project. The Seashore is partnering with the Town of Provincetown to restore 90 acres of a 200-acre salt marsh adjacent to the Provincetown Municipal Airport (see Figure 1). The Hatches Harbor salt marsh is a remnant of a larger salt marsh complex that existed at the time of the first European settlement. This salt marsh was primarily a *Spartina patens* (salt hay grass) and *S. alternifolia* (smooth cord grass) community. In 1930, the upper 200 acres were enclosed behind a dike in an effort to control salt-water mosquitoes. The elimination of tidal flow dewatered part of the upper marsh, changing the mosaic of salt marsh and wetland communities. Subsequently, a small airport was constructed on the landward end of the marsh and today is a vital part of the town's economy.

Figure 1. Hatches Harbor marsh, on the impacted side looking towards the airport

Today, the seaward end of the upper marsh inside the dike has a restricted tidal range that severely limits the extent of Spartina habitat. As a result *Spartina* (right hand side, Fig. 2) has been displaced by the invasion of *Phragmites australis* (left hand side, Fig. 2), the common reed into substantial parts of the old *Spartina* marsh. This Phragmites invasion has resulted in a degraded salt marsh community, with reduced nursery habitat, loss of shellfish habitat, and increased vulnerability to water quality deterioration. Salt marshes with unrestricted tidal flow have less troublesome mosquito populations because they provide habitat for fish that feed on larval mosquitoes.

Figure 2. Hatches Harbor Marsh from the dike top, restricted (left) and unrestricted (right)

Research conducted by National Park Service (NPS) and United States Geological Survey (USGS) scientists show that increasing the tidal range would greatly reduce Phragmites habitat, re-establishing Spartina habitat in its' place. This project has been designed to preserve the Provincetown Airport as it stands today as well as protect any future alternatives that may be proposed to enhance airport safety. The restored marsh would act as additional flood protection for the airport against big storms. The larger culverts to be installed during restoration would allow faster draining of standing water after heavy rainstorms.

The Seashore's plan is to replace the 2-foot wide culvert with four 7-foot by 3-foot culverts with adjustable tide gates. This will allow the culverts to be slowly opened over a number of years, slowly replacing *Phragmites* with *Spartina* habitat. A phased opening of the culverts will allow NPS scientists to monitor and control the restoration rate, preventing a sudden large die-off of vegetation. Such a quick die-off would create mud flats and open water that may attract large numbers of birds and thus pose a safety hazard to the airport. Five earthen berms will be constructed to protect the airport's instrument landing systems, as well as present and future airport operations. Completion of the restoration project would make it the largest salt marsh restoration project in Massachusetts.

The entire environmental permitting process has been a cooperative effort between the Seashore and the Town. A Memorandum of Understanding was signed to codify the organization and carrying out the restoration project. A NPS/Town Review committee that will review all aspects of the project will approve an operations plan (Figure 3). This operating plan and the review committee will be an essential part of the pre- and post monitoring cooperative effort. The goal of the permitting process is to broadly educate the public as well as all federal, state and local agencies, to the benefits of this project and to gain public support. The Seashore has met and will continue to meet with federal, state, local and Town agencies and committees to further describe construction and operation of the culverts, identify permitting requirements and address environmental and economic concerns.

Figure 3. Recent Restoration Site Assessment meeting attended by NPS, Town, Cape Cod Commission and Mass. DEM officials.

NPS, USGS and University of Rhode Island scientists are completing a season of biological, chemical and physical field sampling at Hatches Harbor. This sampling included vegetation sampling, bird and fish surveying, bivalve censusing and measurement of tidal exchange processes. It gives valuable information to the Seashore and the Town that can be used to help determine the progress of the restoration and reveal any problems during the project. Scientists will be continuing their research at Hatches Harbor throughout the winter and spring.

Hatches Harbor Pre-restoration sampling – Initial results

Section	Analysis
1	Vegetation transects
2	Porewater analysis
3	*Spartina/Phragmites* biomass
4	Bivalve sampling
5	Mosquito sampling
6	Bird habitat sampling
7	Sedimentation and Elevation
8	Fecal coliform
9	Fish sampling

1. Vegetation transects

Introduction

A comprehensive vegetation survey in 1991 characterized vegetative cover on 200 acres of restricted and unrestricted salt marsh. In the summer of 1997, a second comprehensive survey was conducted. The purpose was to determine whether any significant changes in vegetation had occurred in the preceding years. We plan to characterize vegetative cover just prior to restoration as a benchmark for comparison in following years.

Methods

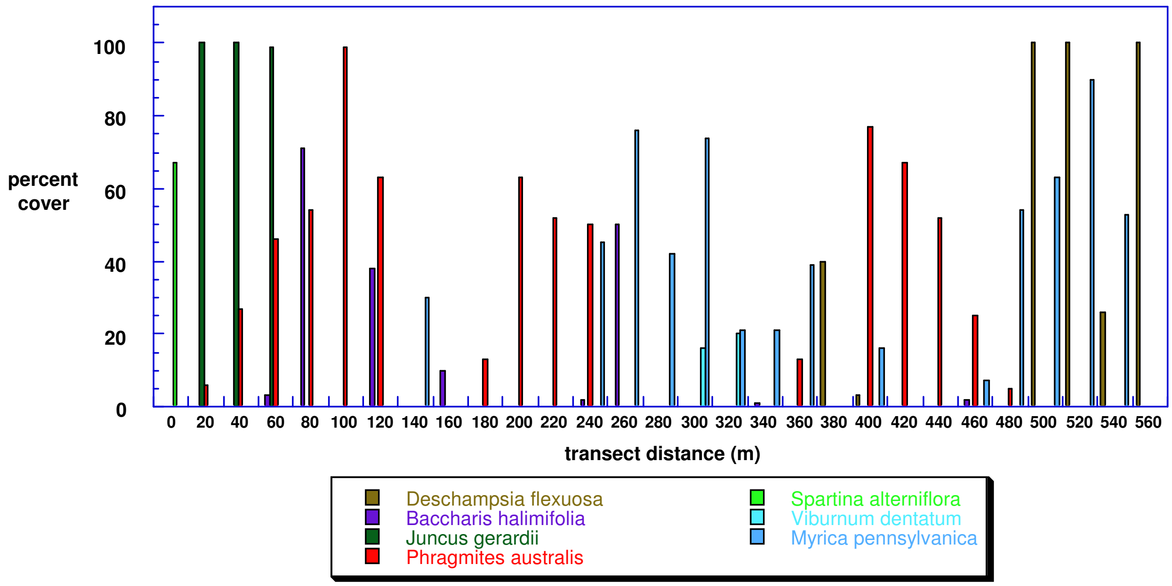
Nine transects have been laid out, three on the unrestricted side and six on the restricted side. Vegetation plots were sampled for percent cover on each quadrat at 1 m^2 quadrats every 30 to 60 m on the unrestricted side and 20 to 40 m on the restricted side. Plant samples were collected when appropriate, to verify field identification. A herbarium was created from field samples and is available for future comparison. Much of the data collected from more than 200 plots still have to be analyzed. However, a representative sample of the vegetation zonation in the restricted marsh can be seen in the results on Transect 2. Transect 2 is found in the restricted marsh and runs parallel to the dike 180 m away between the mainstem of the creek and the dune/pine woods edge to the east.

Results

Percent vegetative cover plots show a zonation along Transect 2 that is dependent on hydroperiod, soil moisture and elevation (Figure 1). In this figure the creek bank is on the left of the plot. Natural salt marsh vegetation typified by *Spartina alternifl*ora and *Juncus gerardi* are found in the first 60 m. Then, the hydroperiod change caused by tidal restriction results in replacement by Phragmites australis. Phragmites dominates except at higher elevations, where *Phragmites* is at lower densities or absent because of the low water table and consequently low soil moisture. Then shrubby species such as bayberry (*Myrica pennsylvanica*), groundsel tree (*Baccharis halimifolia*) and *Vibrurnum dentatum* dominate. At the extreme eastern edge, the terrain moves into old dune face and the vegetation habitat shifts to shrubs and grasses (*Deschampsia flexuosa*).

These results agree with those from the 1991 vegetation study and are indicative of coastal wetlands with tidal restrictions. These data is expected show corresponding changes with the pace of restoration.

Figure 2. Vegetative cover in Hatches Harbor restricted marsh - Transect 2



2. Wetland flooding period and porewater, salinity and sulfide levels over a spring-neap tidal cycle.

Introduction

The species composition and growth form of wetland vegetation in Hatches Harbor is determined by salinity and flooding regimes. High salinity and prolonged seawater flooding stress freshwater, wetland and even saltmarsh plants. Because the wetland surface immediately above the Hatches Harbor dike is about 15 cm below the elevation occupied by intertidal *S. alterniflora* in the unrestricted marsh seaward of the structure, there is concern that wetland plants may be stressed by prolonged waterlogging with tidal restoration. Flooding depth and duration above the dike may exceed those of the unrestricted natural marsh after restoration because the dike restricts discharge, effectively impounding water. For these reasons, excessive flooding and consequently high salinity and/or sulfide may hinder the re-establishment of salt marsh vegetative cover in the Hatches Harbor restoration site.

To establish a basis to assess the effects of increased tidal volume on wetland soil conditions, low-tide water depth and porewater salinity and sulfide were monitored on 9 days, over the spring-neap cycle, between 8 and 27 August 1997. Because wetland plant species have different tolerances to salt content and sulfide, an important objective was to document current relationships between plant distributions and current flooding duration,

Figure 1. Water depth below surface in the unrestricted marsh
Spartina alterniflora

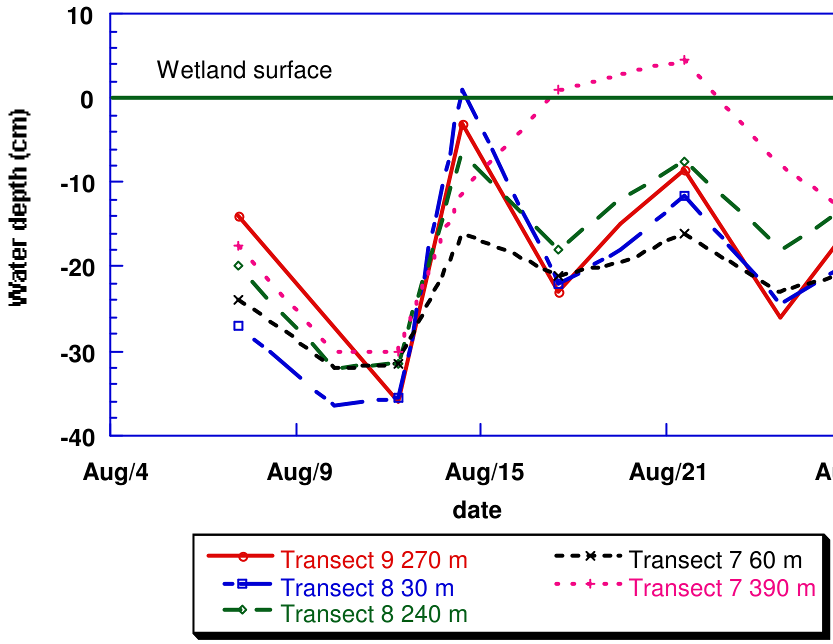
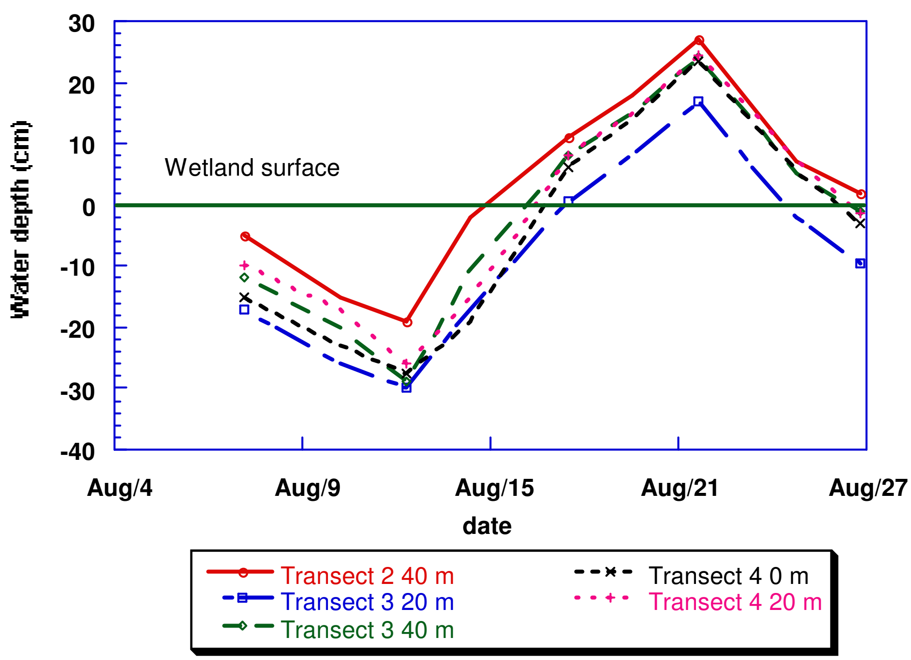


Figure 2. Water depth below surface in the restricted marsh
Spartina alterniflora



salinity and sulfide within the flood plain to be affected by restoration.

Results/Conclusion

Flooding regime

Seaward of the dike the wetland surface dewatered at every observed low tide throughout the spring-neap period and at nearly every station (Fig. 1). Essentially, water within the sandy peat rose and fell with the tide throughout most of the marsh.

Salt marsh grasses in the restricted marsh experienced much deeper and more prolonged flooding (Fig. 2). Generally 10-20 cm of water stood on the marsh surface during low tide throughout the tidal cycle for seven days during the spring period. Flooding at low tide occurred over a much briefer period for higher-elevation *Juncus gerardii* and *Phragmites* plots.

Salinity

Salinities never exceeded 34 ppt at any of the monitored plots throughout the study period, expected in the sandy, permeable, and therefore well-flushed marsh peat. Salinity in the root zone of *S. alterniflora* varied over a much narrower range (29-33 ppt) seaward than upstream of the dike (12- 32 ppt) because of the dominance of seawater over freshwater below the restriction.

Salinity in *Phragmites* plots ranged 0-32 ppt, usually with highest salt content nearest the creek bank.

Sulfides

Total sulfide concentrations in porewater were below detection (<10 mM) at most stations; low sulfide is expected in the well-flushed marsh peat. Sulfides exceeded 100 µM on a regular basis only at one station in the restricted marsh that had one of the longest tidal flooding periods of all vegetation plots.

3: Hatches Harbor Biomass Sampling

<u>Introduction</u>

A major effect of reduced tidal exchange is the replacement of natural salt marsh vegetation, like salt marsh cord grass (*Spartina alterniflora*) with vegetation associated with degraded or disturbed wetland habitats, such as the common reed (*Phragmites australis*). This vegetation shift is caused by a reduced tidal range that creates a soil horizon that is poorly dewatered and has a lower range of salinities compared to the soil horizons in the unrestricted marsh. Such conditions degrade the natural *Spartina* salt marsh habitat.

In order to quantify the degraded condition in the restricted marsh, *Spartina* *alterniflora* and *Phragmites australis* biomass were measured by sampling quadrats in both the restricted and unrestricted marsh. For each quadrat, all live and dead stems were counted and weighed. Samples from the left and right sides of the creek were separated as *Phragmites* is found only on the right side of the restricted marsh.

Results/Conclusions

Spartina results

Average *Spartina* stem lengths are larger in the unrestricted marsh. Stem lengths fall roughly between 40 and 150 cm on the unrestricted side and 20 and 120 cm on the restricted side (Figures 1a - 1d). *Spartina* stem heights in the restricted marsh are lower within 200 meters of the dike. This may result from increased inorganic content, decreased organic content and consequently lower ammonia-nitrogen in sediments subjected to sand deposition during historic dike breaches. The unrestricted marsh may not show the same relationship, as the ebb tidal velocities at the dike are much lower than the flood tide ones. Thus, fewer disturbances would be expected on the outer side of the dike.

Phragmites results

Phragmites stem heights showed a sharp gradient within 100 meters of the creek and variable heights between 0 - 250 cm thereafter. Overall, stem heights were between 50 and 350 cm (Figure 2). Heights were most likely dependent on elevation and water level. Within the first 100 m of the creek, the gradient observed may result from a reduction in salt stress experienced by the roots. The highest stem heights are associated with a region of low salt levels and little competition from other wetland plants. The region between 260 - 350 meters, where no *Phragmites* exists, corresponds to an old dune face where the elevation is above the critical 10 feet above MSL* and the water table is too low for survival. At higher elevations, *Phragmites* is at lower densities or absent because of insufficient water table elevations (Figure 2). Most of the *Phragmites* biomass is concentrated in a zone 40 to 110 m from the mainstem creek (Figure 5). This is in comparison to another measure of *Phragmites* (percent cover) performed in summer of 1997. Percent cover showed a broader distribution of *Phragmites* from 40 to 260 m (Figure 6).

Thus, percent cover seems to be an index of spatial extent more than a strict estimation of biomass, at least on this transect with the data collected so far.
Spartina alterniflora productivity is significantly higher in the unrestricted marsh and may imply a rapid response to alterations in tidal range.
Phragmites persistence and vigor seems to be dependent on differences in elevation, hydroperiod and may also be sensitive to competition from other wetland plants in sub optimal conditions for *Phragmites*.

Figure 1a. Average Spartina stem heights on the left side of the unrestricted marsh

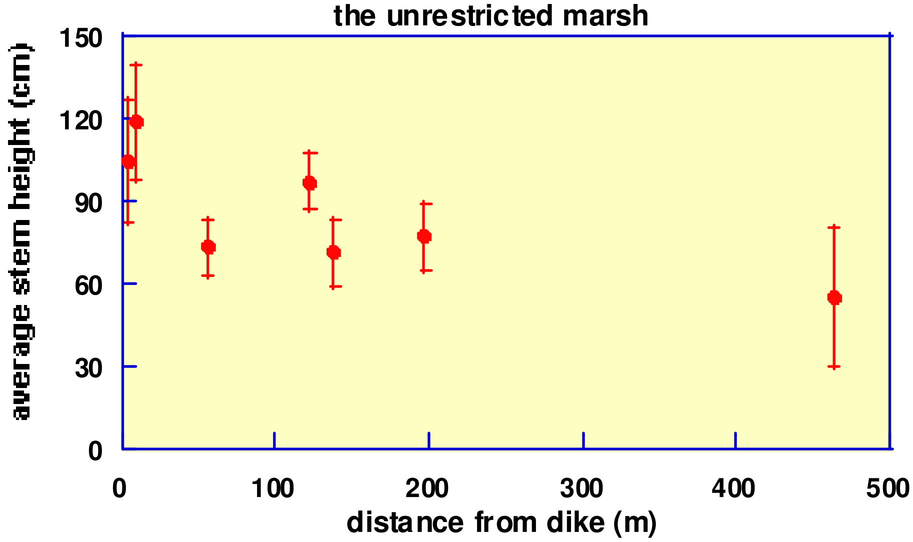


Figure 1b. Average Spartina stem heights on the right side of the unrestricted marsh

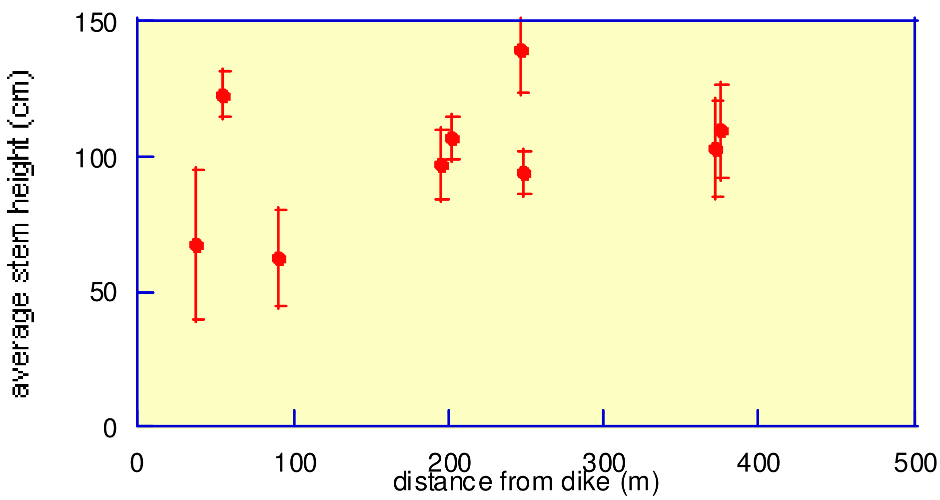


Figure 1c. Average Spartina stem heights on the left side of the restricted marsh

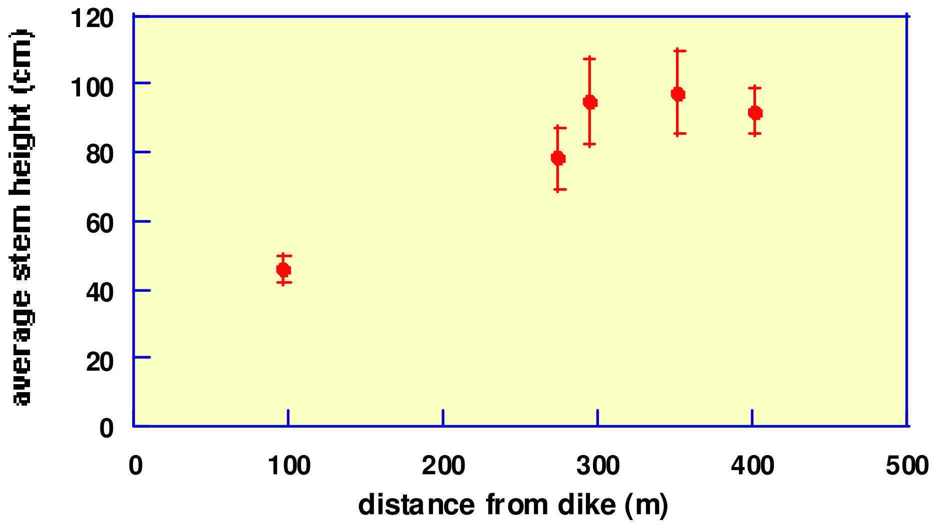


Figure 1d. Average Spartina stem heights on the right side of the restricted marsh

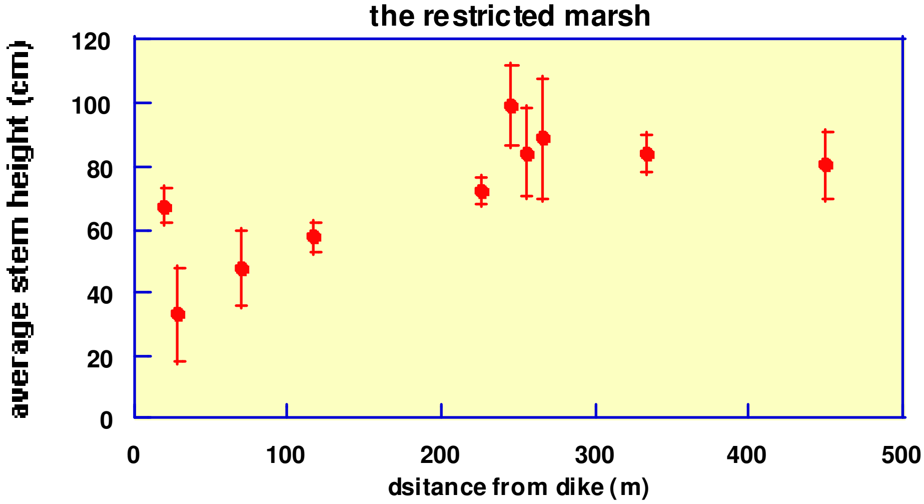


Figure 2. Average Phragmites stem heights in restricted marsh

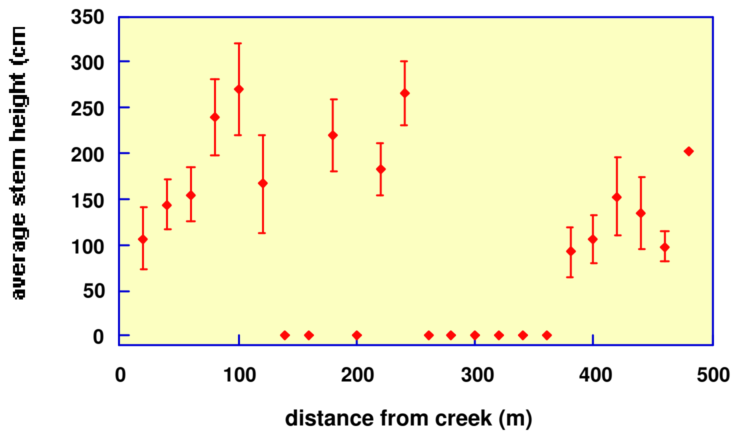


Figure 4. Phragmites biomass in restricted marsh

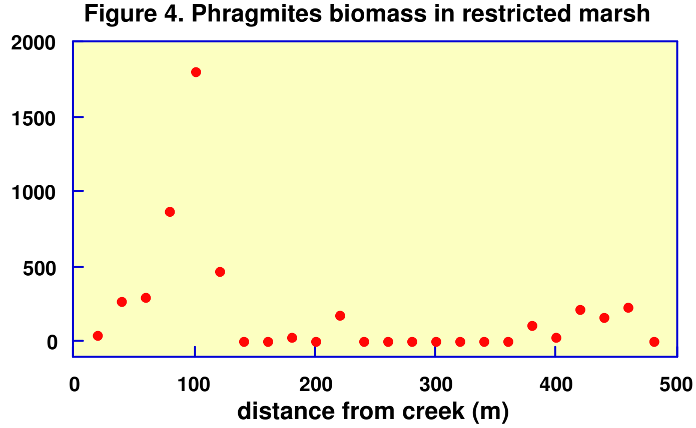
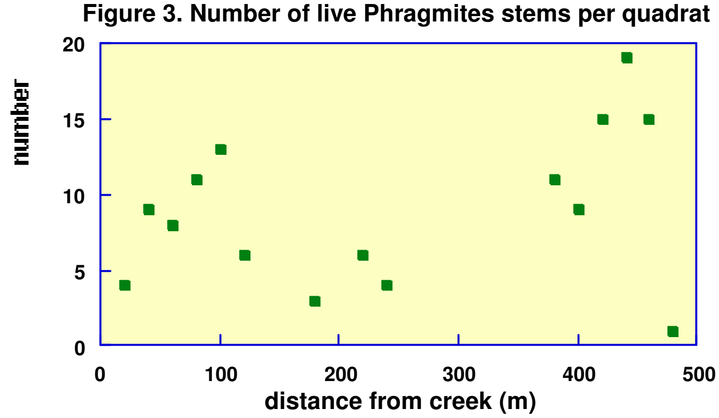


Figure 3. Number of live Phragmites stems per quadrat



4. Sampling of commercially important bivalves

Introduction

Blue mussels, quahogs and soft-shell clams are found in much of Hatches Harbor within the intertidal zone. These bivalves are a valuable resource to the Town of Provincetown. Every three years, small clams that have reached seeding size are rotated out to other beds where they are grown out to marketable size (Reggie Enos, personal communication). Bivalve monitoring was conducted in Hatches Harbor to assess whether increased tidal exchange produced by the restoration would disturb shellfish beds.

This monitoring will consist of periodic interannual sampling to document population levels of commercially important bivalves, the quahog (*Mercenaria mercenaria*), the soft-shell clam (*Mya arenaria*) and the blue mussel (*Mytilus edulis*). Population sampling of bivalves was conducted to establish present levels as a baseline for comparison with later years. For this purpose, thirty bivalve samples were collected, fifteen on each side of the dike, in Hatches Harbor, over a nine-day period from 30 July to 7 August 1997.

Number of bivalves

Quahogs and soft-shells were found in both the restricted and unrestricted marsh (Figure 1a). In contrast, mussels were located only in the unrestricted marsh. The number of bivalves of each species varied widely from one quadrat to the other; the total numbers collected in all quadrats are in Table 1.

Table 1. Total number of bivalves collected

Bivalve	Restricted marsh	Unrestricted marsh
Quahog	78	16
Blue mussel	0	976
Soft-shell clam	10	11

Size of bivalves

Size distribution of bivalves varied widely, even from one quadrat to the next for a species (Figure 1b-d). Average quahog size fell between the seed and littleneck clam categories. The average soft-shell was of seed size. (Table 2).

Table 1. Average size of bivalves collected

Type of bivalve	Restricted marsh	Unrestricted marsh
Quahog	1.2 in. (30.6 mm)	1.3 in. (32.4 mm)
Blue mussel	0	2.7 in. (68.7 mm)
Soft-shell clam	0.4 in. (10.9 mm)	0.3 in. (7.1 mm)

Figure 1a. Density of commercially important shellfish (collected July 30,31 & August 6,7 1997)

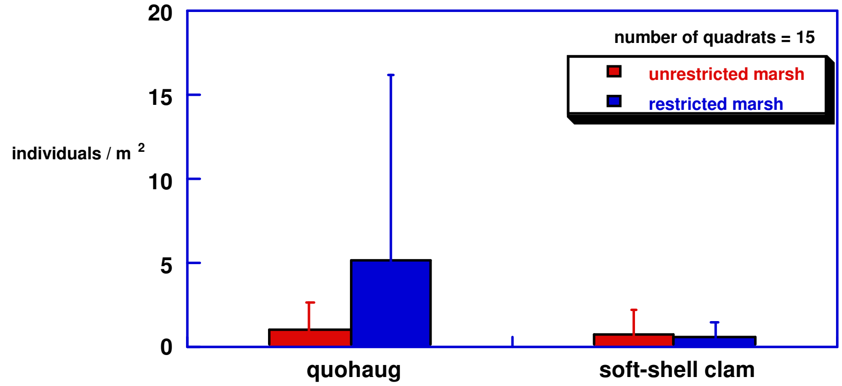


Figure 1b. Quahog size class in restricted marsh (transect 2)

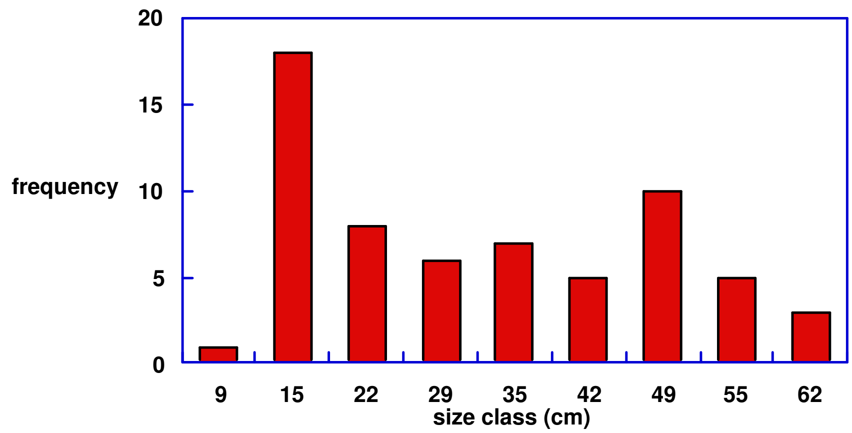
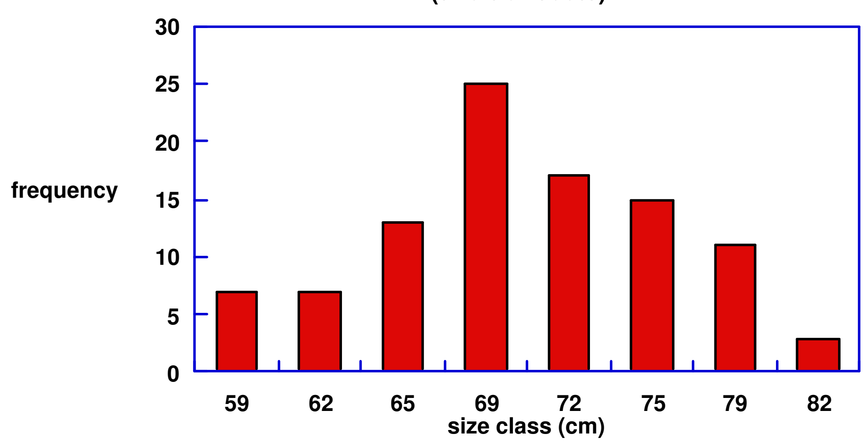


Figure 1c. Blue mussel size class in unrestricted marsh (two transects)



These average sizes and densities may give us a qualitative view of the distribution of these species. However, high variability indicates that much larger sample sizes are required to detect size and density changes after restoration.

Summary

The sampling conducted in July and August of 1997 gives a qualitative snapshot of the present state and distribution of the commercially important bivalves in Hatches Harbor. Mussels are limited to the unrestricted marsh and quahogs are more numerous in the restricted marsh. If this is indicative of the actual distribution within the marsh, it is probably due to the greater tidal range and the higher salinity range in the unrestricted marsh. The tidal range or exchange within the restricted marsh may be too small to allow adequate transport of food particles. Additionally, the siltier bottom on the restricted marsh may not allow for attachment of mussel larvae while favoring quahog larvae in sufficient numbers to maintain a stable population.

5. Adult Mosquito Trapping

Introduction

There is concern that increased tide heights over subsided marshes above the Hatches Harbor Dike could increase mosquito production and the mosquito nuisance at the Provincetown Airport. Pre-restoration monitoring of nuisance mosquito populations was conducted in summer 1997 to assess any changes in abundance and/or species composition that could in turn reflect changes in breeding habitat.

The abundance and species composition of nuisance mosquitoes depend in large part on wetland flooding regimes and salinity. On outer Cape Cod, summertime floodwater *Aedes* species comprise chiefly *A. canadensis* and *A. cinereus* emerging from freshwater and *A. sollicitans* and *A. cantator* from brackish or saltwater habitats. *Coquilletidia perturbans* also breeds in freshwater but larvae develop only during winter in emergent wetlands; thus, adult abundance is less affected by episodic flooding than the summer-breeding *Aedes* spp.

The objective of monitoring adult mosquitoes was to represent seasonal abundance and species composition over the entire flood plain using repeatable methods. Species composition should indicate primary breeding habitats, especially with regard those variables that are most sensitive to changes in the Hatches Harbor Dike, i.e. salinity and the extent of wetland flooding.

Adult mosquito traps baited with light and dry ice (CO_2) were set at dusk and retrieved at dawn once each week from 3 July to 10 September at three locations: below the dike, at the end of Runway 7, and at the airport terminal. Adult mosquitoes were identified to species.

Results

In general, freshwater-breeding species were most abundant in early summer, while salt marsh species were most abundant in mid- to late summer (Figure 1a - c). Emergences

Figure 1a. Adult mosquitos captured at airport terminal

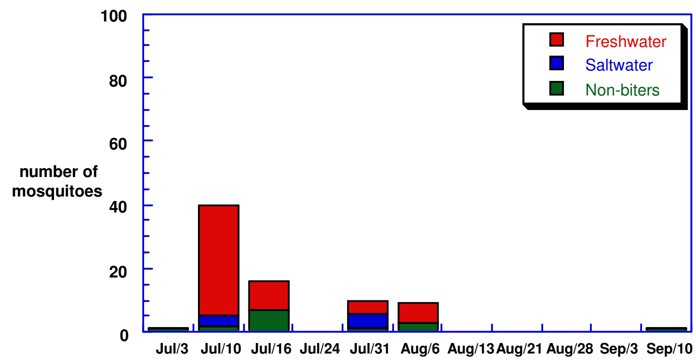


Figure 1b. Adult mosquitos captured in restricted marsh

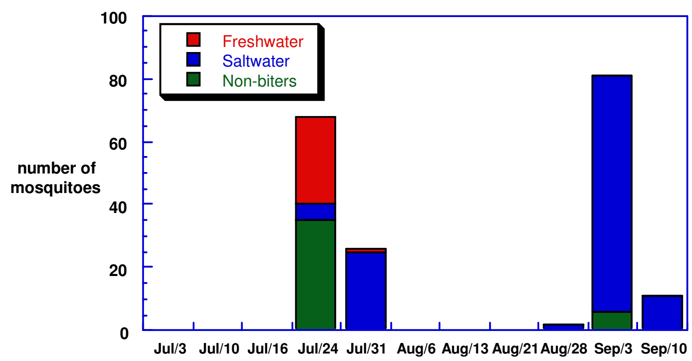
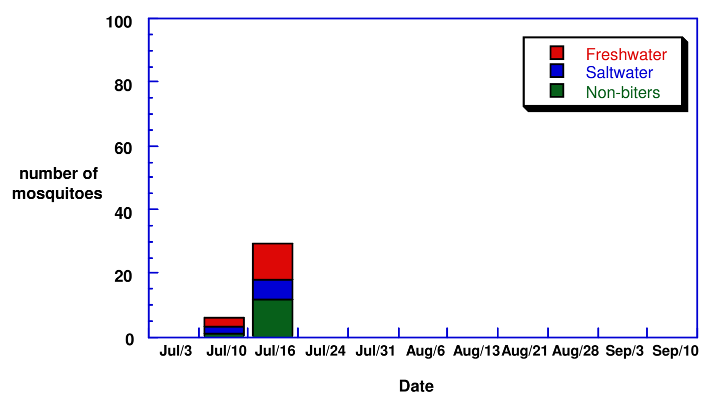


Figure 1c. Adult mosquitos captured in unrestricted marsh



of the

latter followed very high spring tides by about 10-14 days. The restricted marsh only floods during the spring tide period. Eggs of salt marsh mosquitoes develop into adults in 7-10 days.

Freshwater breeders were dominated by a species which emerges from wetlands outside the coastal flood plain, e.g. inter-dune ponds; therefore, its abundance is probably unrelated to habitat changes at Hatches Harbor associated with the restoration. Other freshwater-breeding species that were collected are not biters of humans.

Conclusions

The salt marsh mosquito *Aedes sollicitans* appears to breed within the restricted portion of the Hatches Harbor flood plain where it was a nuisance to the monitoring team. However, adults were most abundant in trap collections at the end of the runway, i.e. in shrubby vegetation above the reach of salt water. These areas remained poorly drained throughout spring tides because of the dike's impedance to drainage at low tide. In contrast, few salt marsh mosquitoes were collected in the unrestricted marsh where the wetland surface was exposed during every low tide, eliminating mosquito breeding sites. Increased tidal range should therefore reduce floodwater *Aedes* breeding at Hatches Harbor.

If as suspected, the other major nuisance species (*Coquilletidia perturbans*) emerged from interdunal ponds outside the study area, salt marsh restoration will not affect this species as a biter at the airport.

6. Bird Monitoring

Introduction

One of the possible changes that may occur as a result of the restoration is a change in bird species or bird habitat utilization within the marsh. This is especially a concern as the proximity of the Provincetown Municipal Airport creates the potential for bird strikes to aircraft using the airfield. Habitat changes that increase waterbird use, e. g. increased open water or mudflats above the dike, are to be avoided to minimize the bird-strike hazard to aircraft. Specific actions to limit the development of habitats attractive to waterbirds are detailed in the Operating Plan for the dike.

Methods

A sample flight corridor was selected: 285m in length, 30m high and 20m wide, (the width of the paved airstrip), from the first taxiway cut off NE and following the runway toward the terminal. Birds were counted within the flight corridor over 15-min.

intervals from 0900 to 18800 h one day each week from 30 June to 8 September.

During the 15 minute recording periods, birds were counted each time they entered, and if applicable, each time they re-entered the sample area. If a bird was flying erratically along the edge of the sample area, it was counted each time it re-entered the sample area. The objective of this monitoring was to quantify the potential of bird-aircraft interaction.

Each bird was identified to species if possible. If identification was not possible, the bird was classified as either "unidentified small bird" or as "unidentified large bird" i.e. smaller than or larger than an American robin (*Turdus migratorius*).

In addition to noting the number and species of birds, the number of take-offs and landings by aircraft during each 15minute recording period were tallied. Weather was recorded, using the Beaufort wind speed code and the weather code

Results

There was little large bird activity associated within the vicinity of the airport (Figure 1). The most numerous bird sighted in the sample area was the tree swallow (*Tachycinete bicolor*, Figure 2). These swallows were observed in flocks of several hundred over the marsh and airport. Tree swallows are commonly seen in these large numbers all along the Massachusetts coast. "Large birds" (common grackle to greater black-backed gull) comprised only 9.3% of the species sighted. For large birds such as gulls and crows, the major period of activity is centered near sunrise and sunset when birds are traveling between overnight roosts and daytime foraging areas.

There was one observed bird strike during the study. On 2 August at 1645, five whimbrels (*Numenius phaeopus*) were observed feeding along the edge of the runway. The whimbrels were startled by a landing plane and flew almost directly into the prop. The strike did not appear to damage the plane, but one whimbrel was killed.

In addition, on 11 August a dead double-crested cormorant (*Phalacrocorax auritus*) was discovered along the edge of the runway. It was not mutilated, so it cannot be ascertained that its death was the result of a strike.

Future surveys will be adjusted to account for the diurnal cycle of bird movements and the effect of weather on the altitude at which birds fly. Birds may fly above or below this artificial ceiling in response to wind speed, wind direction, visibility, and even time of day.

Figure 1. Bird counts by species at Hatches Harbor 1997
End of airport runway - large species

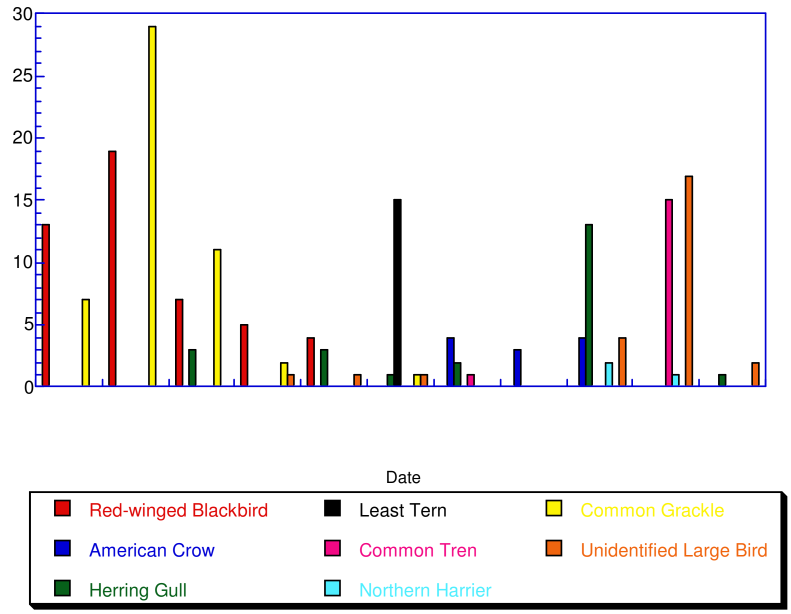
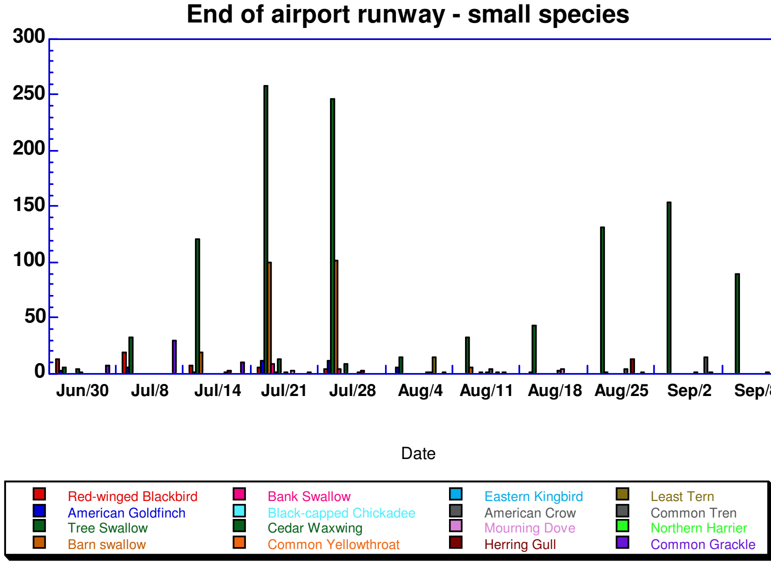


Figure 2. Bird counts by species at Hatches Harbor 1997
End of airport runway - small species



7. Sedimentation and elevation

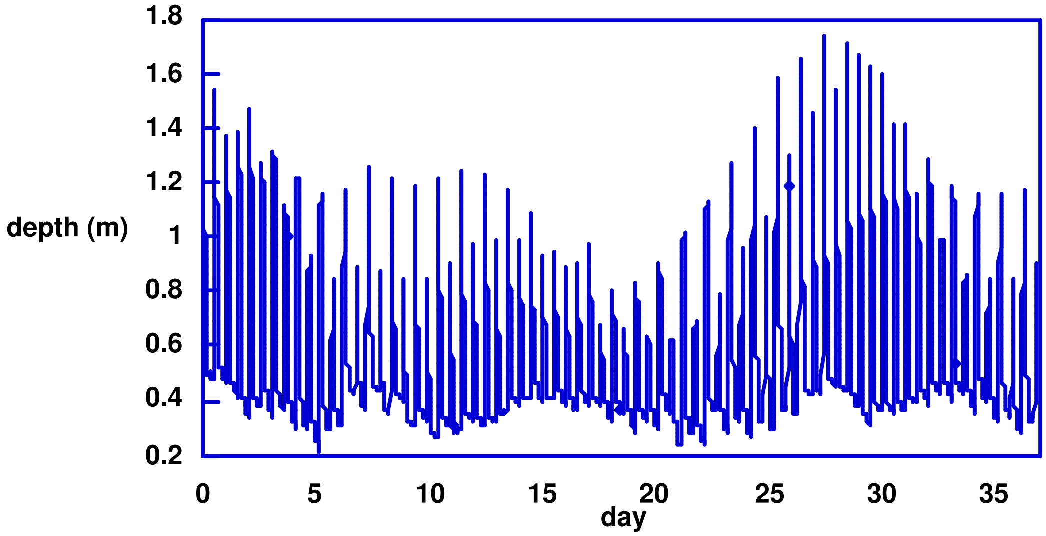
Introduction

Sedimentation and elevation are two crucial environmental factors for a salt marsh. Sediment supply and sea level constitute the main physical factors that initiate marsh development and persistence. Because of their primary importance, sedimentation and elevation measurements have been initiated or are in the planning stage.

Methods

For sedimentation measurements, the Cape Cod National Seashore and the US Geological Survey will use a Sediment Elevation Table (SET), a device that measures sedimentation on the marsh surface. In addition, clay particles will be used to measure accumulation rates. For elevation measurements, Cape Cod National Seashore resource management are using surveying equipment to record exact elevations at every vegetation plot in the marsh. Results will be reported as they are obtained. Water levels and tidal stages on either side of the dike are being monitored with mechanical water level meters. The data has not yet been analyzed; however, preliminary data taken in the unrestricted marsh in the summer of 1997 show a tidal cycle typical of unrestricted tidal marshes (Figure 1).

Figure 1. Water depth with time in unrestricted marsh



8. Fecal coliform bacteria

Introduction

Coliform bacteria can periodically bloom in salt marsh basins. The major source is usually wildlife such as birds and mammals. Weather can be a contributing factor in observed increases of bacteria, as precipitation events can flush coliform organisms into the water column and towards shellfish beds. The National Seashore plans to answer concerns expressed by state officials, the Provincetown shellfish warden and shellfishermen by setting up a monitoring program. This program would monitor coliform levels at various sites around the marsh, reporting to the Advisory Committee and revising culvert manipulation when necessary. Seashore staff is working with Barnstable County health official, George Heufelder, to design an appropriate sampling plan for this purpose.

9. Fish sampling

Introduction

Degraded salt marsh habitats can severely affect resident fish populations. Because of the reduced tidal range, there is a concomitant reduction of intertidal and submerged wetland habitats. Salt marsh restoration can in time reverse this trend, increasing foraging, shelter and spawning areas. Eventually, the increase in natural salt marsh habitat may lead to increases in prey fish available to commercial and recreational fisheries at the mouth of the Hatches Harbor marsh. A monitoring program was initiated to measure changes in fish populations throughout the restoration process. We expect to see significant differences in habitat usage by fish in the restricted versus the unrestricted marsh. These differences as well as absolute differences

Methods

Three types of fishing gear were used to estimate fish populations. One-meter aluminum frame throw traps were deployed at 20 stations in the unrestricted marsh and 15 stations in the restricted marsh every two weeks from June to November 1997. Totals were calculated for marsh pools and subtidal creeks. Fyke nets were used to at one station in both the unrestricted and the restricted marsh to estimate fish populations utilizing the marsh surface. Biweekly sampling was performed from July to October 1997.

Seining was conducted on four dates (June, July, August, and October) to supplement throw trap sampling (the seine covers a larger area and is good for compiling species composition lists). Three stations were selected on each side of the marsh as above. Two replicate seines were collected from each station, each trip. We report preliminary results from the throw trap totaled for all biweekly samples by habitat.

Results

Mummichog (*Fundulus heteroclitus*) was the major fish found in both restricted and unrestricted marshes (Figure 1). Other benthic organisms found in significant numbers were striped killifish (*Fundulus majalis*), green crabs (*Carcinus maenus*) and sand shrimp (*Crangon septemspinosa*). Mummichogs favored tidal creeks in the unrestricted marsh and pools in the restricted marsh (Figure 2). The unrestricted marsh was not as dominated by mummichogs, suggesting a higher species diversity might be observed with more comprehensive sampling. Mummichogs are better adapted to exist in the stagnant pools with low oxygen levels and high temperatures. Their aggressive foraging behavior may allow mummichogs to exploit the smaller available areas of flooding marsh surface at the start of the flood tide. Further analysis of this data will show seasonal trends.

Figure 1. Density of major benthic species

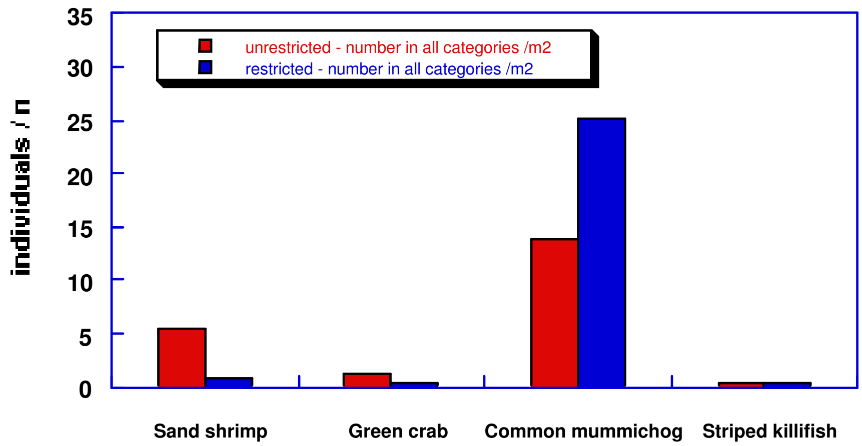


Figure 2. Density of major bottom species by habitat