IS IT POSSIBLE TO HAVE A SUSTAINED, BIOLOGICALLY HEALTHY ESTUARINE SYSTEM IN THE MIDST OF A HIGHLY POPULATED INDUSTRIAL AREA?

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Abstract:
The Hudson River watershed is a dynamic, highly complex system that includes three physically distinct subbasins: the Upper Hudson, the Mohawk, and the Lower Hudson. The Lower Hudson is a tidal estuary extending from the Federal Dam at Troy to the Battery at the southern tip of Manhattan. Lamont-Doherty Earth Observatory has been deeply enmeshed in a system-wide approach to develop an understanding of how the estuary responds to natural events and human impact. One challenge in university research is to fund and sustain a study that requires a long term data series. At the secondary school level, the central goal of science education is to actively engage students so that they can experience first hand the challenges and rewards of carrying out basic and applied research. This goal can be difficult to attain at because of limited resources and limited research training of high school educators. We provide an example of how these limitations can be overcome through collaborations between students, educators, and university faculty. Learning objectives include experimental design, site assessment, logistics, water safety, data collection, nekton identification techniques, data entry, introduction to statistical analysis, and development of oral and written communication skills. To achieve these outcomes and begin to tease apart the multiple factors at play in addressing the larger question of human impact on the estuarine system, we designed a comparative study of nekton use of habitat in Piermont Marsh, correlated with water quality analysis in the marsh and in the adjacent Hudson River channel. During the summer 2005, a survey of the recent LDEO and governmental projects in the Lower Hudson River Estuary was undertaken to determine how we could design a study that would generate data useful to both the scientific community and be available to the broader community at large. We crafted a proposal for the Toyota Tapestry Grant to investigate the overarching question: Is it possible to have a sustained, biologically healthy system in the midst of a highly populated, industrial area? The challenge is to establish a research method that is technically simple enough to be implemented and sustained with little money. To this end, we used high school students to characterize the study area and test some simple and inexpensive ways to collect data using minnow traps simple water collection techniques. Future plans include: 1) instituting a more rigorous study of marsh biota including seine nets and pit traps in addition to minnow traps; 2) correlating sampling regimes with diurnal in addition to tidal cycles; and 4) beginning a year-long time series of water collections in Piermont Marsh streams and in the Hudson River. The goal is to create a project that is ongoing and manageable with labor supplied by local high school students. The project serves the dual purposes of providing opportunity for high school students to participate in scientific research and serving the needs of the scientific community to develop a deeper understanding of an estuarine system that is both a vital part of our economy and a significant contributor to our quality of life.

Introduction

The Hudson River travels more than 300 miles from its headwaters in the Adirondack Mountains of Northern New York State to its mouth at the southern tip of Manhattan Island. The entire Hudson River Basin includes a watershed area of about 13,300 mi^2 that varies widely in geology, topography, climate, and hydrology, thereby defining a diversity of land use: forested, agricultural or urban/industrial. For purposes of understanding and describing the dynamics of the Hudson River system, the basin is divided into three subbasins—the upper Hudson, the Mohawk, and the lower Hudson (figure 1). The upper Hudson includes all of the watershed area above the confluence of the Hudson and the Mohawk from Wallface Pond in the Adirondacks to Troy. Based on satellite imagery obtained in the mid-1970's, the U.S. Geological Survey (USGS) classified about 76% of the upper basin as forested, 15% agricultural and 3.4% urban, though many areas have undergone land use changes since that time. Due to contamination from PCB's (polychlorinated biphenyls), the U.S. Environmental Protection Agency (USEPA) has designated approximately 200 miles of the Hudson River, from Hudson Falls to the Battery in New York City, as a Superfund site. Accordingly, the USEPA has proposed removal of contaminated sediment from approximately 40 miles of the river between Ft. Edward and the Federal Dam at Troy (Brosnan et.al, 2002).

The Mohawk River is the largest tributary of the Hudson River, nearly doubling the flow below Cohoes, New York, where the two rivers meet. The USGS has classified 55% of the Mohawk subbasin as forested, 34% agricultural and 6.2% urban/industrial (Phillips and Hanchar, 1996).

The lower Hudson subbasin comprises about 40% of the entire Hudson River watershed. USGS classification (based on mid-1970's satellite data) defines 55% as forested, 29% agricultural and 13% urban/industrial. Major urban areas located on the Hudson include Albany, Poughkeepsie, Newburgh and New York City. From the Federal Dam at Troy to the Battery in lower Manhattan, the Hudson River is an estuarine system, controlled by tidal fluctuations that bring saline water as far north as river mile (RM) 85 above Poughkeepsie (de Vries and Weiss, 2001).

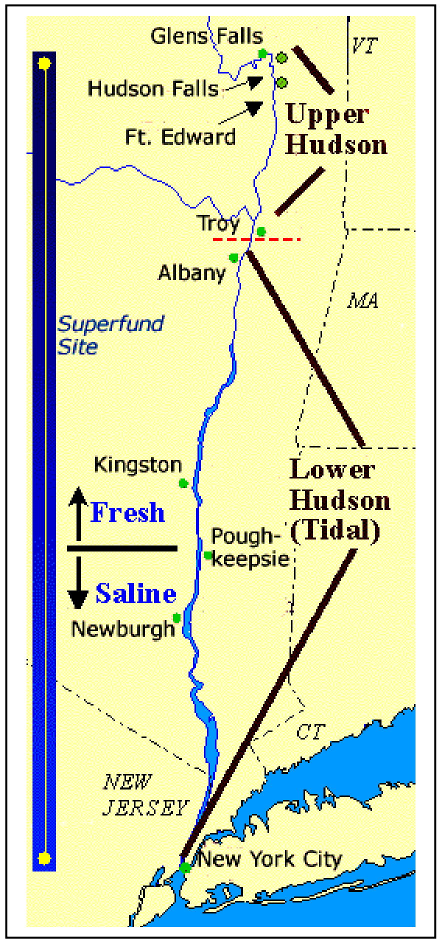

Figure 1. Hudson River Basin
Brosnan, et.al, 2002

Toyota Tapestry Grant Proposal

The Hudson River watershed is a dynamic, highly complex system that includes three physically distinct sub-basins in the state of New York. Scientists from Columbia University's Lamont-

Doherty Earth Observatory (LDEO) are working to develop an understanding of how the estuary responds to natural events and human impacts. Answering the overarching question, "Is it possible to have a sustained, biologically healthy estuarine ecosystem in the midst of a highly populated, industrial area?" creates both a challenge and opportunity. One practical challenge is presented by the large natural variability in biological activity on the time scales of interest. Meaningful correlations between the physical parameters of the estuary and its biological activity require sampling at the tidal, diurnal and seasonal timescales over at least several years. For University researchers this requires establishing an investigative method that is technically simple enough to be implemented and sustained in a cost effective manner in the face of shifting funding priorities. In this project, we have experimented with collaboration between research scientists at Lamont Doherty Earth Observatory and three New York City high schools, The Young Women's Leadership School of East Harlem, Manhattan Hunter Science High School and The Harbor School. Our goal was to address the need for long-term, relatively simple, data collection and analysis in the Hudson Estuary in the context of a positive educational experience for High School students and their teachers. At the high school level, a central goal of science education is to actively engage students so that they can experience first hand the challenges and rewards of carrying out basic and applied research. This goal can be difficult to attain because of limited resources and limited research training of educators. During the summer of 2005, we field tested the approach with 12 students from Manhattan Hunter Science High School. The exercise gave rise to a plan and a proposal to create a monitoring project that is ongoing and manageable with labor supplied by local high school students, directed by their science teachers with scientific leadership from Lamont-Doherty. The project provides an opportunity for high school students and their teachers to participate in scientific research while developing a deeper understanding of an estuarine system that contributes in vital ways to both our economy our quality of life in the Hudson River Basin.

Study Site

Piermont Marsh is located approximately 40 km north of New York City on the west bank of the Hudson River immediately south of Piermont Pier and the Tappan Zee Bridge. The marsh is part of the Hudson River National Estuarine Resource Reserve System (NERRS) and includes an area of 115 hectares (~284 acres) bounded by the Hudson River on the east and Tallman Mountain State Park on the west. Sparkill Creek, which drains approximately 11 square miles of predominantly urban area, discharges into the northern end of the marsh. An unnamed tidal creek flows northeast discharging at the confluence of Sparkill Creek and the Hudson River. Crumkill Creek meanders eastward from the base of Tallman Mountain discharging into the Hudson at the southern end of the marsh. At the northern end of the marsh secondarily treated sewage from Rockland County and Orangetown is discharged into the marsh at the rate of approximately 30 million gallons daily, while up to 6000 gallons of treated wastewater from Tallman Park and runoff from Tallman Mountain is discharged daily into the western edge of the marsh (Mantalto, unpublished draft report).

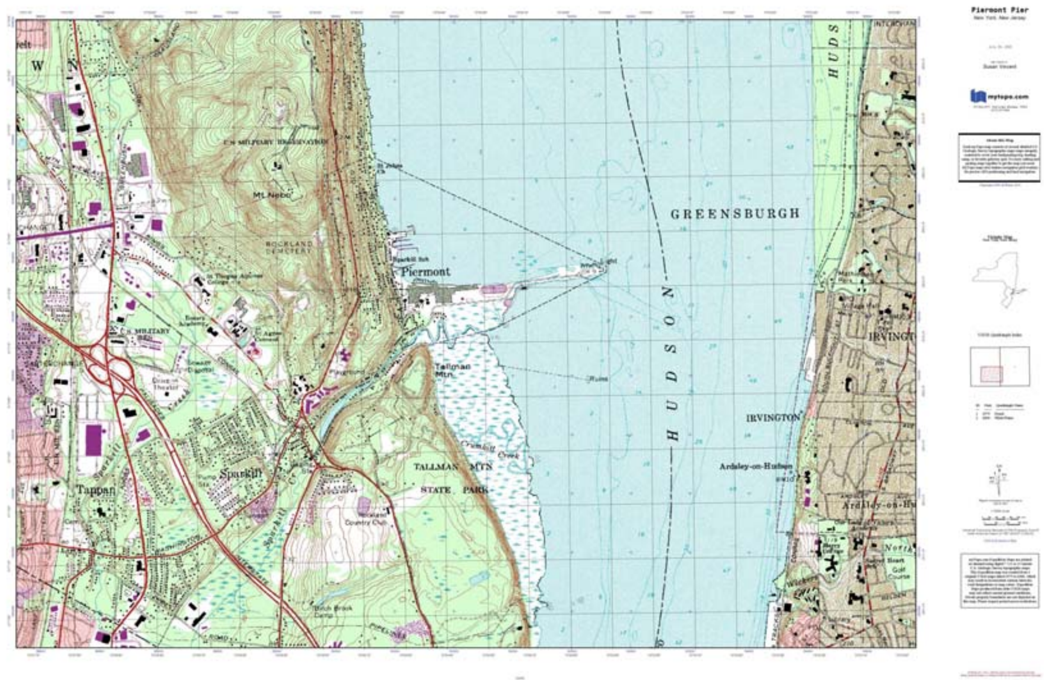

Figure 2: Piermont Marsh and Tallman Mountain State Park

Piermont Marsh is dominated by the plant species *Phragmites australis*, common reed, an invasive that has replaced the native marsh grass *Spartina alternaflora*. *Phragmites* is widely recognized as a wetland pest because of its rapid expansion and its ability to quickly dominate marsh plant communities and alter resources available to other flora and fauna (Meyerson, et.al, 2000). The reed has culms that can reach a height of over 5 meters with rhizomes 1.5 to 2.5 centimeters in diameter and long as 12 meters (Kiviat, 2001, 1987). Colonies can be very dense; we found areas in Piermont Marsh with stem densities greater than 200 per m^2. Common reed is often associated with disturbed areas, but has been documented to invade relatively undisturbed wetland systems as well (Lathrop, et.al, 2003). The Erie Railroad completed construction of Piermont Pier in 1841 and its tracks bisected the marsh from the base of Tallman Mountain eastward through the center of the marsh. Evidence of support system for the track remains near our sample sites at pools 2 and 3 (figure 3). Piermont Marsh is believed to have been invaded by

Phragmites between 1790 and 1858 (Hanson, et.al, 2003) , though as late as 1967, *Spartina* dominated the marsh on the east side, while *Typha angustifolia* (cattail) was the dominant vegetation adjacent to the Palisades escarpment (Wong and Peteet, 1998; Passow, 2002). Currently the plant comprises about 75% of the marsh vegetation and is spreading at a rate of approximately 5 hectares per year (Lathrop, et.al,2003) and (Montalto, et.al, 2005). Colonization of the marsh by *Phragmites* has followed a linear pattern along creek banks. Lathrop (et.al, 2003) proposed that the pattern of colonization influences the impact on marsh ecologic functions. Continuous monotypic stands of common reed along creek banks, as found in Piermont Marsh, may act as a barrier restricting the movement of nekton across the marsh. *P. australis* can accelerate sediment deposition and raise the marsh surface with plant detritus, thereby reducing surface area inundated during high tide and reducing habitat availability to nekton and invertebrates (Hanson, et.al, 2002; Able and Hagan, 2000). Montalto (et.al, 2005) observed that the entire surface of Piermont Marsh is inundated only at spring tides on average 10 to 12 times per month. Although Phragmites is commonly associated with degraded marshes with altered ecosystem functions, some wetland ecologists have found that the reed provides valuable habitat (Fell, et.al, 1998). Jordan (et.al, 2003) found that *Phragmites* habitat in Southern Louisiana wetlands provides the only refuge available during winter months when other marsh vegetation has senesced.

Methods

The long term objective of this project is to answer the questions: 1) What aspects of the Hudson Estuary system control when animals use the marsh? 2) How much of the marsh surface is available habitat for nekton and invertebrates and at what times? 3) How have changes in the vegetation altered habitat? 4) Is there a correlation between marsh use and water chemistry? 5)

How does water chemistry vary between the adjacent Hudson River channel and Piermont Marsh? This summer, as our first systematic sampling of the marsh, we began to address questions (1) and (2).

During 2 summer events, July 25 and August 8, we sampled 3 creeks within the marsh, Sparkill, Tidal (unnamed) and Crumkill, 3 edge habitat sites in the Hudson River channel between the mouths of the Sparkill and Crumkill, 3 ponds in the marsh interior (east and west sides), and one pit dug 1 meter from the edge of the Tidal Creek. Each event took approximately 8 days to complete. In each creek we selected 2 replicate sites that include an erosional bank, a depositional bank, and associated rivulets for each bank with an interior and an edge site. At each site we deployed 3 Gee minnow traps (4 mm wire mesh) along a 3 meter transect. Traps were deployed for a period of 24 hours to sample through an entire tidal cycle. Animals were retrieved from the traps and preserved in 10% formalin solution. After 24 hours, animals were removed from the formalin and placed in 50% solution of Isopropyl alcohol. Habitat was characterized at each site by measuring water depth and canopy height. A ½ m^2 quatrat (¾ inch PVC pipe) was used to quantify stem density. A YSI meter (Yellow Springs Instruments) was used to measure dissolved oxygen, salinity, temperature and conductivity.

Fig. 3 Preparing to deploy minnow traps.

Fig. 4 Retrieving minnow traps.

Figure 5: Site Map, Piermont Marsh, Piermont New York.

Fig. 6 Erosional Bank

Fig. 7 Depositional Bank

Analysis of variance (ANOVA) and linear correlation were used to test for the effects of location, bank type, habitat, and physical parameters including temperature, dissolved oxygen and salinity on fish density, diversity and length. Our goal was to determine if there was a difference in nekton use of the marsh between the creeks and if differences depended upon bank type (erosional vs. depositional) or varied between channel and rivulets.

Results

A total of 5,531 organisms were collected. Eight species of fish were identified including: *Fundulus heteroclitus* (mummichog*), Morone saxatilis* (striped bass*), Anguilla rostrata (*American eel*), Morone americana (*white perch*), Brevoorita tyrannus* (Atalntic menhaden*), Menidia menidia* (silverside*), Seriola zonata (*banded rudderfish*), Micropogonias undulates(Atlantic croaker). Invertebrates* identified included the grass shrimp *Palaemonetes spp.*and two species of crab, *Calinectes sapidus (blue crab) and Panopeus herbstii (Atlantic mud crab).*

Comparison of physical parameters during the sampling period showed some interesting trends (fig. 8). Total organisms showed a significant correlation with temperature ($p<.0001$) and salinity ($p<.0051$). After removing the effects of date isolating each variable using a partial correlation analysis, there was still a significant correlation between total number of animals and temperature (~44%) and salinity (36%). This would suggest that the animals prefer high temperature and salinity. We hypothesize that primary production and phytoplankton density are the mechanism through which temperature and salinity are linked to nekton populations;

however, nutrient and particulate sampling will be required for validation, as opposed, for example, that the mechanism is the avoidance of predators.

Fisher's r to z

	Correlation	P-Value
Total Critters, DO (mg/L)	.203	.0348
Total Critters, Temperature (° celsius)	.359	.0001
Total Critters, Salinity (ppt)	.267	.0051
Total Critters, Water Depth (cm)	-.101	.2967
Total Critters, Stem Count	-.076	.4348
DO (mg/L), Temperature (° celsius)	.233	.0149
DO (mg/L), Salinity (ppt)	.251	.0085
DO (mg/L), Water Depth (cm)	-.120	.2183
DO (mg/L), Stem Count	-.097	.3189
Temperature (° celsius), Salinity (ppt)	-.225	.0188
Temperature (° celsius), Water Depth..	.079	.4167
Temperature (° celsius), Stem Count	-.178	.0652
Salinity (ppt), Water Depth (cm)	-.127	.1901
Salinity (ppt), Stem Count	-.100	.3062
Water Depth (cm), Stem Count	.312	.0010

108 observations were used in this computation.
74 cases were omitted due to missing values.

Partial Correlation Matrix

	Total Critters	DO (mg/L)	Temperature (° celsius)	Salinity (ppt)	Water Depth (cm)	Stem Count
Total Critters	1.000	-.004	.440	.364	-.126	.085
DO (mg/L)	-.004	1.000	.281	.291	-.115	.026
Temperature (° celsius)	.440	.281	1.000	-.420	.191	-.243
Salinity (ppt)	.364	.291	-.420	1.000	.019	-.140
Water Depth (cm)	-.126	-.115	.191	.019	1.000	.329
Stem Count	.085	.026	-.243	-.140	.329	1.000

108 observations were used in this computation.
74 cases were omitted due to missing values.

Fig. 8: These tables show correlations between the observed variables. The number of animals varies significantly with temperature and salinity. These physical factors could be correlated with each other and date of sampling. However, removing variance for time, the partial correlations for both variables are still relatively large (lower table).

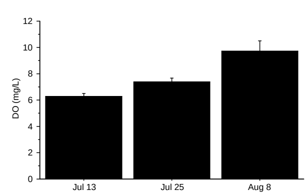

Fig. 9 Temporal variation in mean (+ 1 standard error) dissolved oxygen levels (p<.0001).

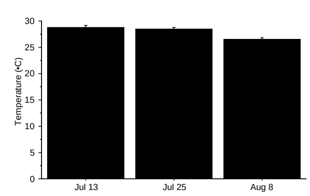

Fig. 10 Temporal variation in mean (+ 1 standard error) water temperature (p<.0001).

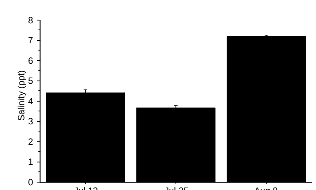

Fig. 11 Temporal variation in mean (+ 1 standard error) salinity (p<.0001).

Data comparing average length of animals, total numbers and diversity with location, channel, pit, pool or rivulet, (figs. 12, 13, 14) is somewhat confounded because of the unequal sampling in these areas. For example, pit sampling was a late addition to our sampling program, and we sampled only one pit once at quarter moon and once at full moon. In upcoming summers we need to dig more pits and sample throughout the lunar cycle to get verifiable results. Pool 1 was sampled during both events (July 25), but pools 2 and 3 were only sampled in event 2 (August 8). Since approximately 60% of total fish trapped were taken from the pools, systematic sampling of them will be critical to establish the statistical significance of variance in population sizes. Nonetheless, data analysis showed a significant effect for diversity as a function of habitat type (p<.0304).

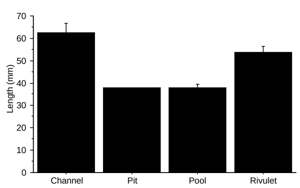

Fig. 12 Mean length variation as a function of habitat type (p<.0902).

Note: Sampling period is somewhat confounded with habitat type by unequal sampling of pits and pools during first half of study.

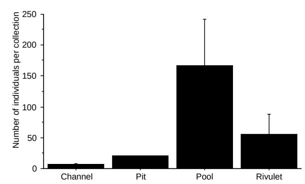

Fig. 13 Total number of animals as a function of habitat type (p<.3528).

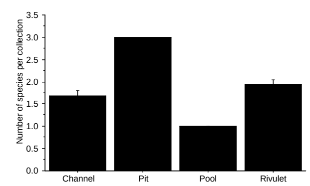

Fig. 14 Diversity of animals as a function of habitat type (p<.0304).

A comparison of average length, total animals and diversity with habitat, channel vs. rivulet, and time (figs. 15, 16, 17) showed no significant effect for length. In total number of animals, there was a significant effect of habitat (p<.0295); more animals were found in the rivulets than the channel. In a similar study, Rozas (et.al 1988) found that a greater number of animals chose the rivulets because they flood sooner and stay inundated longer. Diversity was significantly greater as a function of time (p<.0335) and habitat (p<.0260). We found greater diversity in the second event and in the rivulets.

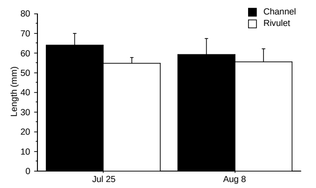

Fig. 15 Avg. length as a function of time and habitat type. Event (p<.7079), Habitat (p<.2550), Event+habitat (p<.6211).

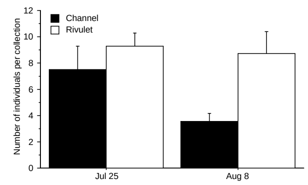

Fig. 16 Total number of animals as a function of time and habitat type. Event (p<.1515), Habitat (p<.0295), Event+habitat (p<.2921).

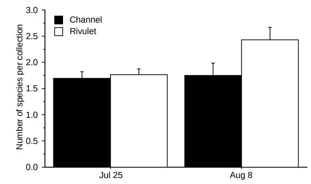

Fig. 17 Diversity of animals as a function of time and habitat type. Event (p<,0335), Habitat (p<.0260), Event+habitat (p<.0713).

We compared average length, total number of animals and diversity at sampling locations along the creeks and the Hudson River (figs. 18, 19, 20). We expected to find larger fish in the Hudson than in the marsh. However, while the data showed some difference, it was not statistically significant (p<.3631). We also recognize that our minnow traps may be more efficient in the creeks than the open channel, and we propose to eliminate possible bias by using seine nets in addition to minnow traps in future sampling events. Results did show that total number of animals and diversity were dependent on location; with a significantly greater number of fish (p<.0370) and significantly higher diversity (p<.0480) in the creeks.

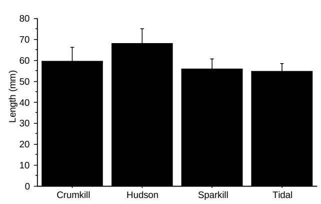

Fig. 18 Avg. length as a function of creek and river (p<.3631).

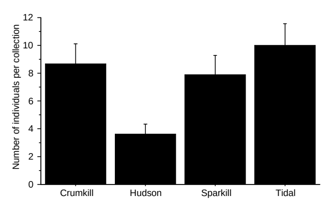

Fig. 19 Total number of animals as a function of creek and river (p<.0370)

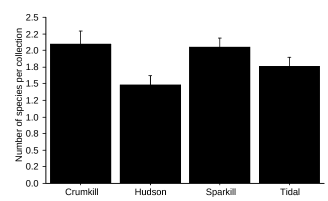

Fig. 20. Diversity as a function of creek and river (p<.0480).

We modeled our comparison of erosional and depositional creek banks (figs. 21, 22, 23) on an earlier study of Piermont Marsh by Hanson (et.al, 2002). In an earlier study, Rozas (et.al, 1988) found that nekton abundance is greater near gently sloping depositional banks than near deeper, erosional banks where there is less cover available to nekton and greater risk of predation. Hanson and her colleagues observed that geomorphology of creeks may play a role in fish use of the marsh surface, but greater use of depositional banks by nekton is not consistent across different types of marshes. Our comparison of length, total animals and diversity across creeks with erosional vs. depositional banks as independent variable showed inconsistent results (figs. 21, 22, 23). Analysis of the 2 main effects, creek and bank type, and interaction between those effects, showed no significant effect among creeks (p<7481) or bank type (p<.9185) for length. Combined effect of both creek and bank showed a significant effect for length (p<.0219). Total number of animals similarly showed no effect among creeks (p<.5871), bank type (p<.4689) or both creek and bank (p<.3523). There was no effect of creek on diversity, but bank type showed a significant effect (p<.0298). Similarly, there was no effect of combined effect of both creek and bank for diversity (p<.2948). Our data indicates that variability in size, density and diversity of nekton found near erosional versus depositional banks depends on the location in the marsh. Longer time series in each creek will add to the certainty of these initial results.

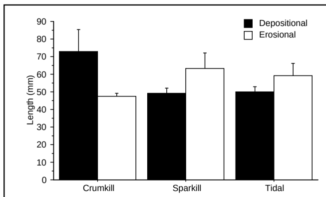

Fig. 21 Avg. length as a function of creek and bank type. Creek (p<.7481), Bank (p<.9185), Creek+Bank (p<.0219).

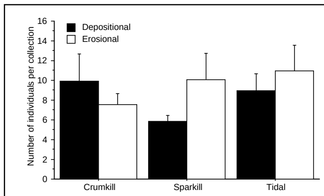

Fig. 22 Total animals as a function of creek and bank type. Creek (p<.5871), Bank (p<.4689), Creek+Bank (p<.3523).

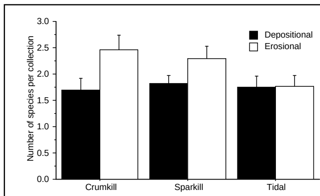

Fig. 23 Diversity as a function of creek and bank type. Creek (p<.2789), Bank (p<.0289), Creek+Bank (p<.2948).

Conclusions

Piermont Marsh is dominated by *Phragmites australis*, yet still offers valuable habitat for nekton and invertebrates. Hanson (et.al, 2002) demonstrated that nekton density can vary within *Phragmites* as a function of either hydrology or geomorphology; our study has shown similar findings. Our most dramatic findings were the extremely high numbers of fish that use the pools in the marsh interior (~60% of total animals collected). A more in-depth study of when the animals are entering the marsh and how diurnal cycles affect abundance is needed. Results show that the dominant species of nekton in Piermont Marsh is *Fundulus heteroclitus.* Our study concurs with findings by Bretsch and Allen (2006) that *F. hereroclitus* is able to tolerate a wide range of physical and ecological conditions. Marsh fauna show nonrandom movement into and out of the intertidal creeks with diurnal tidal cycles, and have access to the marsh surface infrequently during spring tides. As in a study by Bretsch and Allen (2006) our study showed that the migratory behavior of nekton is strongly influenced by water depth. We found a positive correlation between fish abundance and temperature and salinity. However, other factors influenced by these physical parameters, such as primary production, need to be investigated. Further study is needed to determine which physical and biotic factors in combination within the marsh determine distribution and habitat use by nekton and invertebrates.

Goals and Long Term Objectives

Biological census studies conducted by Rozas (1995) and Kneib and Wagner (1994) show that the distribution of marsh residents is highly influenced by hydroperiod. In the summer of 2006 we launched a rigorous biological sampling regime correlated with tidal cycles. During the summer of 2007 we will incorporate diurnal cycles into our sampling protocols to determine if there is a difference in use of marsh during daylight hours versus nighttime, particularly in the interior pools. We plan to replicate the number and location of pits used in a study by Able and Hagan (2000) in which parallel replicates were placed at 0.5 meters, 5 meters and 9.5 meters from creek edge. This model has also been used by Jordan (2003) in *Phragmites* habitat studies. Another study by Hunter (et.al, 2006) placed pit transects at 5, 9 and 13 meters from creek edge. Depth of transects in Piermont Marsh will be determined by local geomorphology. The goal in sampling in pits is to determine size classes and species of fish remain in the marsh throughout the tidal cycle. The pit model mimics small depressions in the marsh surface that might provide refuge for juvenile fishes. Seine net sampling will be done simultaneously with minnow trap deployment during next summer's field season to eliminate possible bias in sampling gear, particularly in the Hudson River. Pool sampling events will be correlated with diurnal tidal cycles, as well as lunar cycles. Water collections will begin in the fall for analysis of nutrient content and particulates.

Regarding the program as an educational experience for students and high school teachers, we found that a key success factor is funding of summer stipends for the students. Stipends make it possible for students from working families to participate; they also give the students a feeling of responsibility to the diligent performance of the research tasks. Therefore, one of our immediate tasks is to write a grant proposal to fund student stipends, as well as ongoing needs for equipment and supplies.

We are in the process of adding nutrient and particulate sampling to our program. We will conduct occasional sampling through the school year, and hope to return to the Marsh with a group of 8 students in the summer of 2007. We expect that the data will be of sufficient quality that our results will be published in a peer-reviewed journal of environmental biology.

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Appendix 1: Raw Data