Final Report

Quinnipiac River Fund
Grant Number: 20110107

Investigations into the Causes and Implications of Marsh Drowning in the Quinnipiac River

Yale University
Shimon Anisfeld, Senior Lecturer & Research Scientist
shimon.anisfeld@yale.edu

Executive Summary

Portions of the Quinnipiac River marshes – a vital ecological and human resource – are being degraded by "drowning" and conversion to unvegetated mudflat, for reasons that are still unclear. In this project, we investigated several aspects of the health of these marshes.

Our measurements of elevational processes in 9 long-term SET-MH plots found that, over the last 5 years, the marsh gained elevation at rates that should be adequate to keep up with the rate of regional sea level rise (SLR; ~3 mm yr^{-1}), though some of the plots were close to this threshold. The Typha plots show large seasonal variation in elevational processes, a fact that must be taken into account in interpreting previous data.

In addition, we investigated hydrology, vegetation, salinity, and foraminifera along both elevational and upstream-downstream gradients. We found that the upper reaches of the study area showed much lower salinity, but only slightly lower tidal range, compared to the lower reaches. This may affect local rates of sea level rise, which are effectively unknown at this point. Tidal lags and asymmetries differed along the river, which could potentially lead to differential susceptibility to drowning through differences in sediment transport. Both vegetation and forams showed clear responses to both elevational and salinity gradients.

Lastly, we collected a sediment core and analyzed it for historic accretion rates and metal concentrations. We found that accretion rates over both 40-year (^{137}Cs) and 100-year (^{210}Pb) time frames were approximately 3 mm yr^{-1}, consistent with current rates measured by SET. Metal concentrations in the sediment were remarkably high, especially for Cu, Ni, and Zn (all >3.5 times NOAA Effects Range-Medium levels), which could potentially contribute to reduced vegetation growth.

Introduction

Tidal marshes are key components of the coastal landscape, and play several valuable roles: habitat for wading birds, juvenile fish, and invertebrates; sites of high primary production and nutrient processing; buffers for removal of land-derived pollutants; and flood protection. These vital ecosystems have been legally protected from direct anthropogenic impacts (dredge and fill), but several sites, including the Quinnipiac, are experiencing unexplained “drowning,” characterized by an increase in wetness, loss of vegetation, and conversion to mudflat.

Healthy marshes can avoid drowning by accreting sediment (organic and inorganic) at rates that allow the marsh to “keep up” with relative sea level rise (RSLR). The reasons that drowning marshes are unable to do this are presently unclear.

The Quinnipiac River’s extensive tidal marshes (brackish and salt) provide a unique ecological and recreational resource. This area is habitat to numerous birds and aquatic organisms and provides a biogeochemical filter for the waters of the river, as well as being a popular site for birding and boating. Drowning threatens those values.

In this project, we examined several aspects of the processes determining the stability of the Quinnipiac marshes. This report is divided into 3 main sections: (a) measurements of accretion and elevation change at our 9 long-term plots; (b) collection of elevation, vegetation, and water level data along an upstream-downstream gradient within the marshes; and (c) analysis of a sediment core for accretion rate and metal concentrations. Each section includes both methods and results.

Accretion and elevation change

Methods

We measured both accretion and elevation change at each of our previously-established Sediment Elevation Table – Marker Horizon (SET-MH) plots (Figure 1) using established methods (Cahoon et al. 2002). Specifically, we sampled triplicate plots in each of 3 vegetation types: *Typha glauca* near the drowning area (“degrading Typha”), *Phragmites australis* near the drowning area (“degrading Phrag”), and Phragmites away from the drowning area (“healthy Phrag”). We have previously determined that at the Phragmites sites, sampling more than once per year results in unacceptable damage to vegetation, so we sampled those sites only in April 2011 (before new shoots reached the elevation of our sampling platform). The Typha site is less susceptible to vegetation damage, so we sampled there in both April and November 2011.

Figure 1. Sampling locations in the Quinnipiac marshes (Google Earth image). Red markers indicate SET sites (each with triplicate plots): A = Typha, B = degrading Phragmites, C = healthy Phragmites. Blue markers indicate water level loggers. Yellow markers indicate transects. The main area of marsh drowning is represented by SET sites A and B, transect 3 (t3), and water logger station 4 (w4).

For accretion, sampling involved collection of a small cryo-core using a liquid nitrogen system, followed by measurement of the depth of sediment on top of the feldspar marker horizons (established in 2006). This deposited sediment was also collected and analyzed for organic matter by Loss on Ignition (LOI). For elevation change, sampling involved deploying the sediment elevation table at each plot and collecting readings from 9 pins in each of 4 directions. These measurements were then compared to the initial readings; differences correspond to increases or decreases in sediment elevation.

Results

All our sites showed average rates of accretion and elevation change that were at or above 3 mm yr^{-1} (Figure 2), the approximate rate of regional relative sea level rise (SLR), indicating that the sites appear to be stable with respect to SLR. The degrading Phragmites site appeared to be in the greatest danger of drowning, as elevation change at this site is very close to the rate of SLR.

As in previous years, the Typha site continued to show large seasonal variation in accretion and elevation change, with large positive contributions over the summer and small or even negative contributions over the winter. The dramatic subsidence (accretion > elevation change) that we observed at the Typha site over the early years of monitoring is no longer as prominent, with calculated subsidence decreasing from 3.5±1.0 cm over the first monitoring period to 1.2±0.9 cm over the entire period. We believe that the apparent subsidence may be largely an artifact of the large seasonal variation, given that the initial sampling took place in late fall and subsequent sampling efforts took place in spring.

Organic content in deposited sediment (cryo-cores) was high at all sites (Typha April = 32.4±0.3%; Typha November = 34±1%; healthy Phragmites April = 44±5%; degrading Phragmites April = 41±1%). This may indicate a lack of mineral sediment inputs and a high dependence on recycling of peat from elsewhere in the marsh.

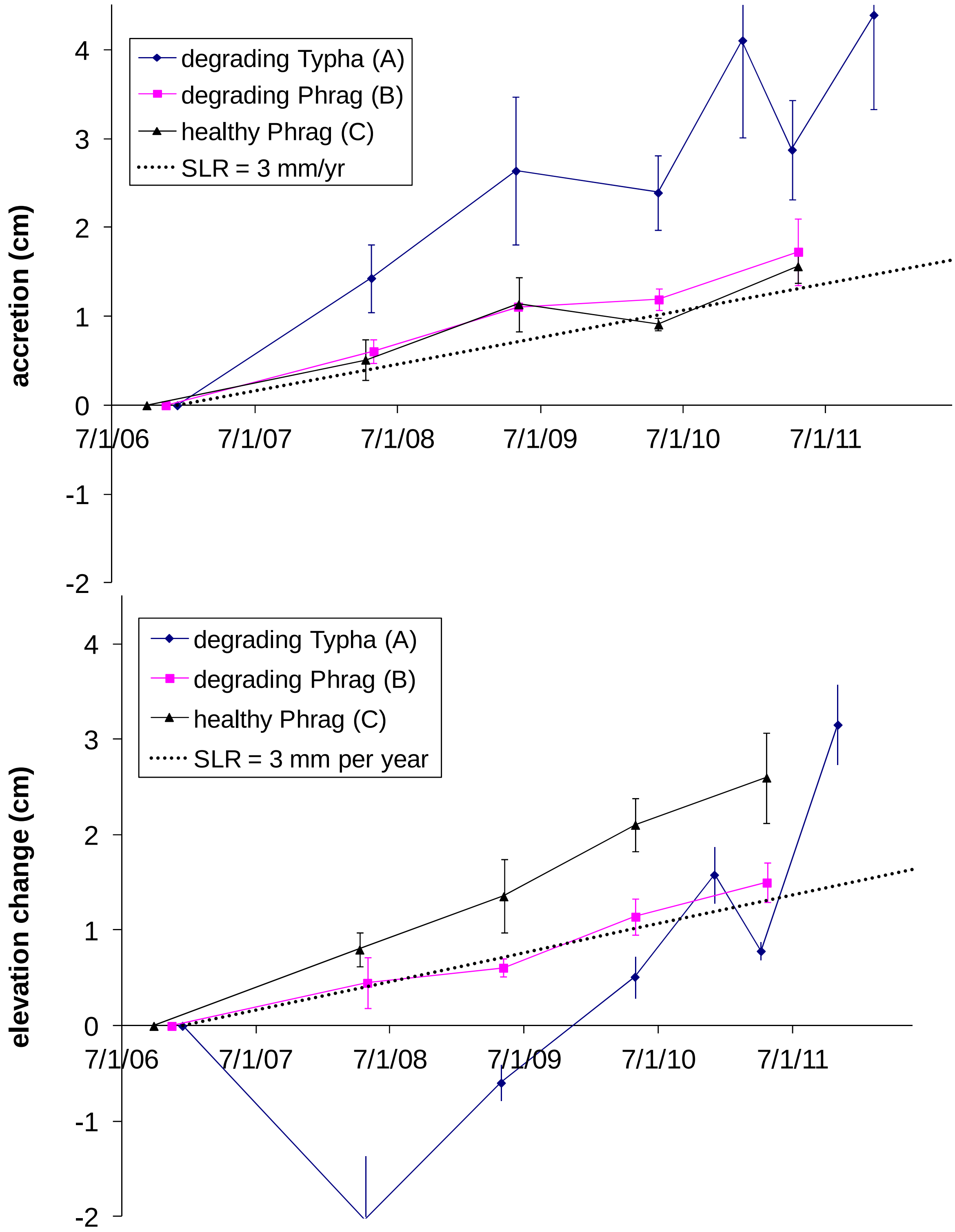

Figure 2. Accretion (top) and elevation change (bottom) at the three SET-MH sites (mean and standard error of triplicate plots at each site). Dashed line shows a constant SLR of 3 mm yr^{-1}.

Water level, salinity, and elevation

Methods

Solinst water level/salinity loggers were deployed at 5 locations along the Quinnipiac River estuary (Figure 1) for various periods of time between June 2011 and May 2012. Loggers were securely attached to temporary benchmarks, which were surveyed to NAVD88 using a Trimble RTK GPS (minimum 50 epochs per reading, minimum two readings per site). Loggers recorded water level and salinity every 5 minutes.

Logger data were downloaded and compensated for changes in barometric pressure (as recorded by a Solinst Barologger located at 370 Prospect St., New Haven). Water level data were converted to NAVD88 using the surveying data together with manual measurements of the position of the logger relative to the benchmark.

Times and magnitudes of high and low tides were extracted from the data using the R statistical software package (R Core Team 2013). In order to compare data that were collected over different time periods, we referenced our data to NOAA tidal data over the same time periods from station 8465705, New Haven Harbor (NHH). Specifically, we: (a) calculated the tidal lag for each high and low tide (Quinnipiac slack tide time minus NHH slack tide time), and (b) regressed Quinnipiac high tide levels against NHH high tide levels. Similar regressions were not calculated for low tides, as we expected that low tide water levels in the Quinnipiac would be determined more by river flow than by low tide level at NHH.

Seven transects along the Quinnipiac estuary were sampled for vegetation, elevation, and foraminifera. Six of the transects had lengths of 58-99m and were occupied at10-12 stations, while transect 3, running through the central mudflat, was 550m long and had 16 stations. At each station, elevation was measured (relative to NAVD88) using a Trimble RTK GPS, the dominant vegetation type was recorded, and a surface sediment sample (top 1 cm) was collected and preserved in ethanol for analysis of forams.

Results

Surveying quality control data were good: The average within-reading error (error of 50+ epochs, as recorded by the survey instrument) was 18mm, and the average between-reading error (standard error of 2-5 replicates) was 6mm.

Water level data (relative to NAVD88) are shown in Figure 3 and summarized in Table 1. All five sites were tidal, and all exhibited good correlations between local high tides and NHH high tides (insets in Figure 3). Mean tidal range (expressed as a % of NHH tidal range over the same period in order to account for temporal variation) decreased slightly upstream, as one would expect (Table 1). However, even at our uppermost site (above the drowning section), tidal range was relatively large (71% of NHH tidal range). The decreasing tidal range upstream came primarily from an increase in MLW rather than a decrease in MHW (Table 1).

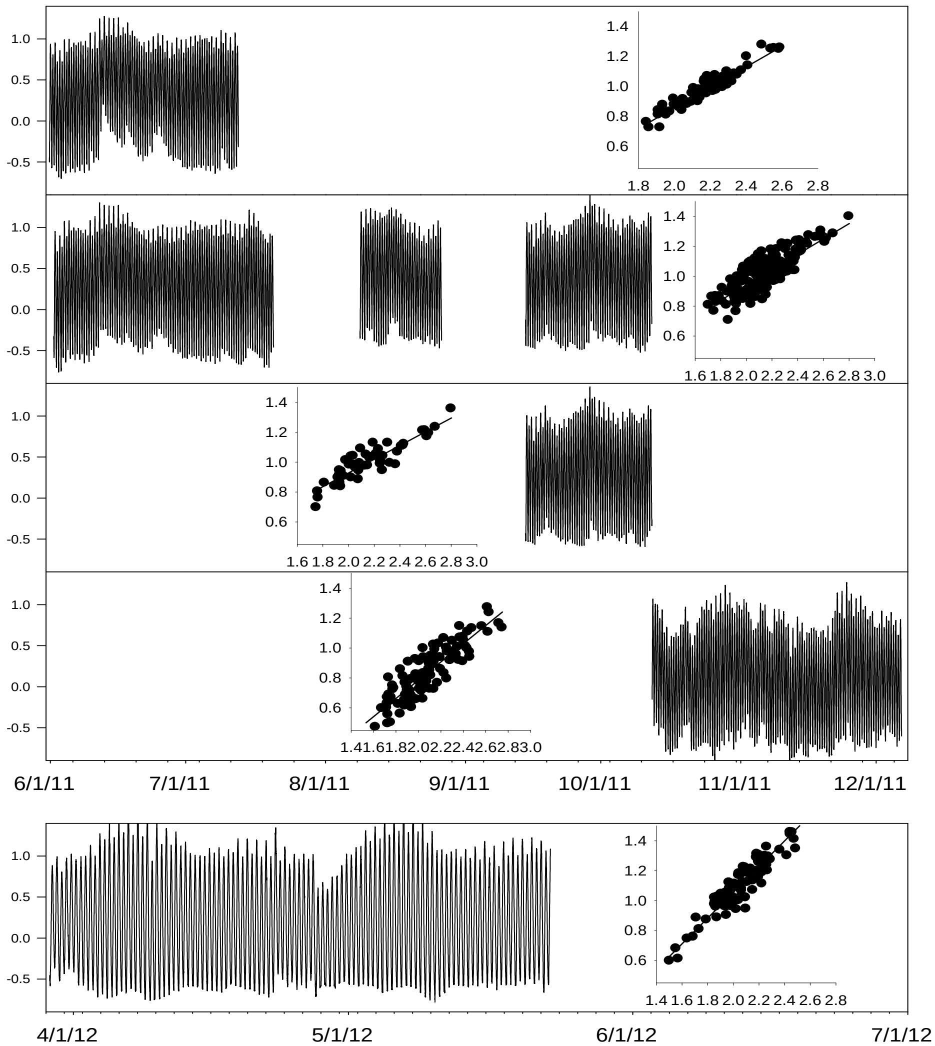

Figure 3. Water level data for (top to bottom) stations 2, 4, 5, 6, and 7 (upstream to downstream). Note different time axis for station 7. Insets show correlations between NHH high tides (x axis) and station high tides (y axis). All data are in m NAVD88, except for NHH data, which are in m local MLLW.

Table 1. Tidal parameters for stations 2, 4, 5, 6, and 7 (upstream to downstream).

	Stn 2	Stn 4	Stn 5	Stn 6	Stn 7
MHW (m NAVD88)	0.98	1.02	1.00	0.84	1.12
MLW (m NAVD88)	-0.43	-0.44	-0.48	-0.67	-0.61
MTR (% of NHH)[a]	71	75	76	78	81
High tide lag (min)[b]	100	84	62	74	10
Low tide lag (min)[b]	131	112	87	109	32

[a] Mean tidal range (MTR) at the station expressed as a percentage of MTR at New Haven Harbor (NHH) over the same time period.

[b] Time difference between slack tide at NHH and slack tide in the Quinnipiac.

The tidal lag increased upstream, as one would expect, with the exception of station 6, which deviated from the trend for unknown reasons (Table 1). The tidal lag was longer for low tide than for high tide, indicating an asymmetric tide, with the ebb longer than the flood, as expected for a river-dominated estuary. As one moves downstream and the tidal lag decreases, this tidal asymmetry decreases as well (Figure 4).

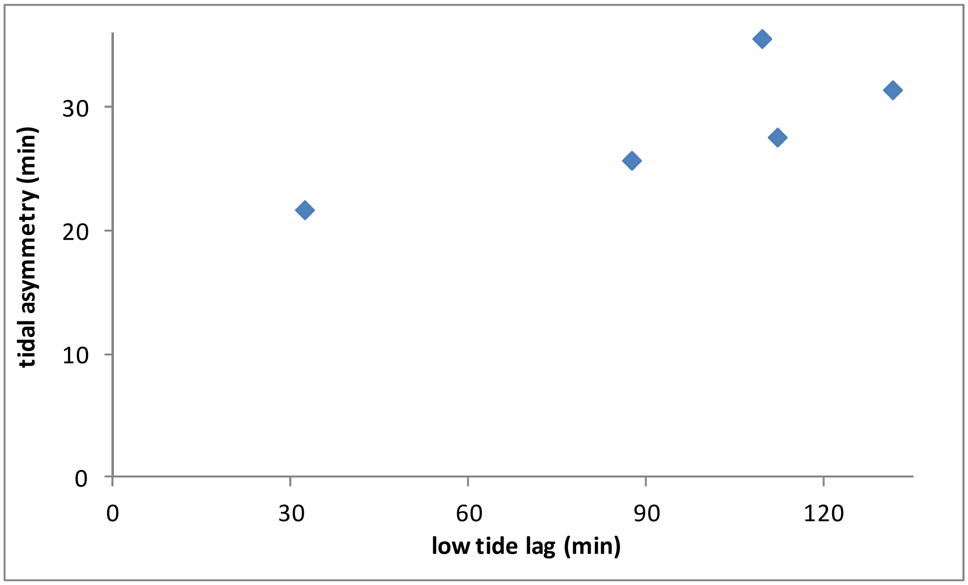

Figure 4. Tidal asymmetry (the extent to which the ebb is longer than the flood) plotted against low tide lag. Points (left to right) are generally downstream to upstream stations, with station 6 being the outlier.

Salinity patterns were dominated by the tidal cycle, along with position in the estuary (Figure 5).

Vegetation was classified into 6 communities: upland/upland edge (dominated by upland plants or *Iva frutescens*); Phragmites; Typha; meadow (*Spartina patens/Distichlis spicata*); *Spartina alterniflora*; and unvegetated. Elevation ranges for each community are shown in Figure 6. The general patterning is as expected, with an elevation gradient from highest to lowest as follows: upland/edge (highest) followed by the three "high marsh" communities (Phragmites, Typha, and marsh meadow), followed by the "low marsh" (*S. alterniflora*), followed by the unvegetated zone (lowest). However, there is considerable overlap in elevation range between the unvegetated zone and the *S. alterniflora* zone and, to a lesser extent, the Phragmites zone.

Besides the elevation gradient, there were also dramatic changes in vegetation along the upstream-downstream gradient. The salt-tolerant plants *S. alterniflora*, *S. patens*, and *D. spicata* were only found in transects 3-7. Typha was found only at intermediate salinities (transect 3). Phragmites was found in every transect. However, its spatial extent appeared to be controlled, at least in part, by salinity. As shown in Figure 7, Phragmites appeared to extend into relatively wetter areas in the upstream transects, where the lack of salinity stress apparently helped Phragmites overcome greater flooding stress.

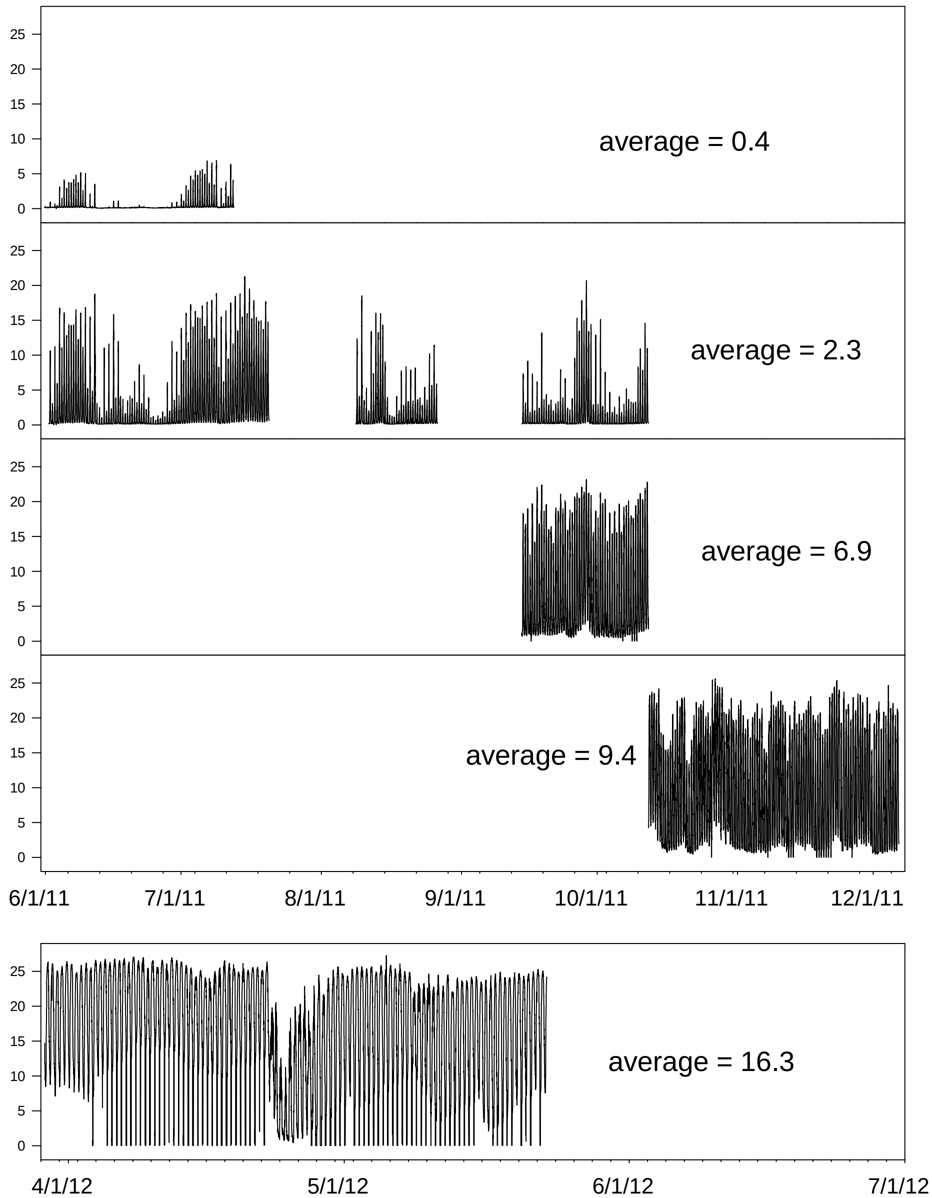

Figure 5. Salinity (psu) for (top to bottom) stations 2, 4, 5, 6, and 7 (upstream to downstream). Note different time axis for station 7.

Foraminifera also responded to both elevation and salinity gradients. Transect 1 (the farthest upstream) had no agglutinated forams present, indicating very low salinity. All other transects had similar foram compositions, with typical zonation by elevation within each transect.

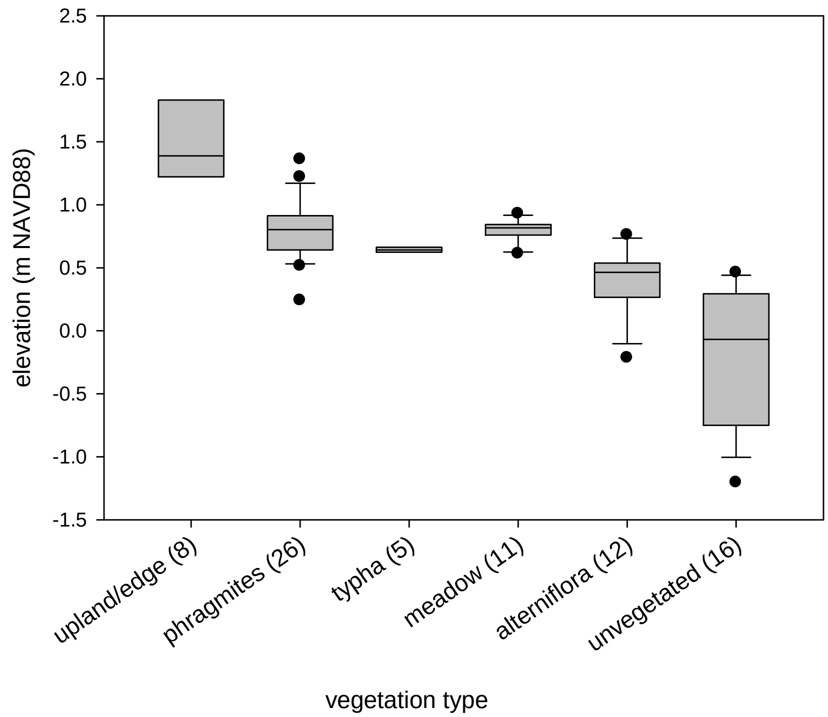

Figure 6. Elevation ranges for different vegetation communities. Numbers in parentheses are the number of stations represented for each vegetation type.

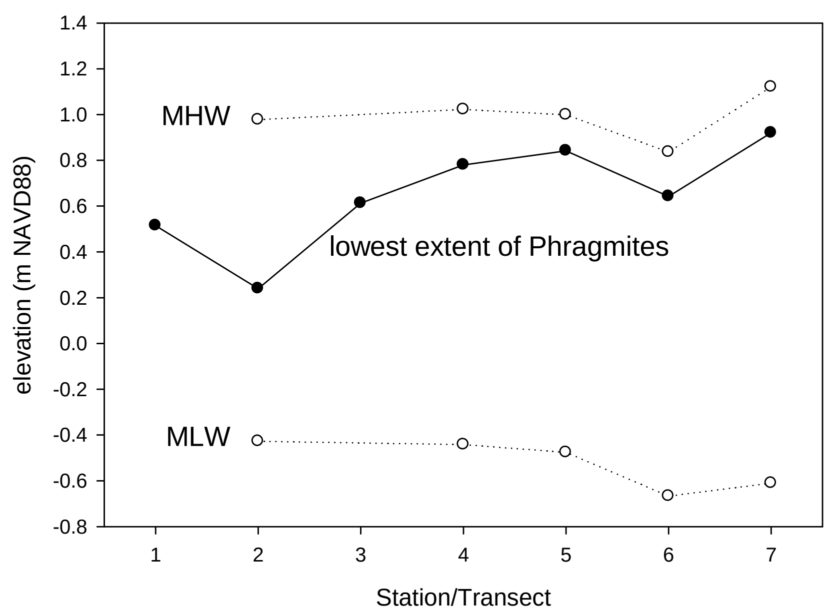

Figure 7. Phragmites extended lower into the intertidal in more upstream stations (left of plot).

Core dating and metal content

Methods

After exploratory coring, a 50-cm sediment core was collected in the Typha stand in the middle of transect 3 using a Russian peat corer. The core was returned to the lab and sectioned into 2-cm sections, which were dried and measured on a gamma counter for the radionuclides ^{210}Pb, ^{214}Pb (a proxy for ^{226}Ra, which in turn is a proxy for supported ^{210}Pb), and ^{137}Cs; these data were used to date the core using standard models (^{137}Cs and the Pb CIC method). Each section was also analyzed for Hg concentrations on a DMA80 Hg elemental analyzer. In addition, a subset of sections was sent to the British Geological Survey, where they were analyzed for a suite of metals as well as the ratio of Pb stable isotopes ($^{206}Pb/^{207}Pb$).

Results

The core appeared to fit the assumptions of radiometric dating, with excess ^{210}Pb (total minus supported) declining exponentially (down to 26-28 cm) and ^{137}Cs showing a clear peak (Figure 8). Accretion rates calculated from the two methods were 3.1 mm yr^{-1} (^{210}Pb) and 2.8 mm yr^{-1} (^{137}Cs). Thus, this portion of the marsh (vegetated but adjacent to expanding mudflat) appeared to be accreting at roughly the current rate of SLR.

Metal concentration profiles with depth are shown in Figure 9. Several observations can be made:

- Although the core was not deep enough to reach true pre-industrial background levels, all metals show relatively low concentrations at depth followed by an increase associated with increased anthropogenic use of these elements.
- For most metals, surface concentrations are lower than peak concentrations, as greater pollution controls have resulted in decreased atmospheric emissions. Peaks for Sb, As, Hg, Ni, Zn, and Cd all occur at a depth of around 20 cm (~1940-1950), while peaks for Cu and Pb are more recent, and Cr and Ag have not yet declined from their peak.
- Concentrations of several metals are quite high. Perhaps most dramatically, maximum levels of Cu, Ni, and Zn are all >3.5 times NOAA ERM levels.
- Metal concentrations do not closely follow national trends of metal production and consumption. For example, it is often assumed that the initial increase in metal concentration occurred around 1880, but it seems likely that it occurred earlier in the Quinnipiac, given that our data for most metals suggest that the increase began below the bottom of the core, which – assuming a constant sedimentation rate of 3 mm yr^{-1} – would be pre-1850. In addition, Pb and Sb follow slightly different patterns in our data, in contrast to the patterns found at other sites (Kemp et al. 2012), and Pb isotopic ratios (Figure 9 bottom right) also do not correspond to typical patterns (Kemp et al. 2012).

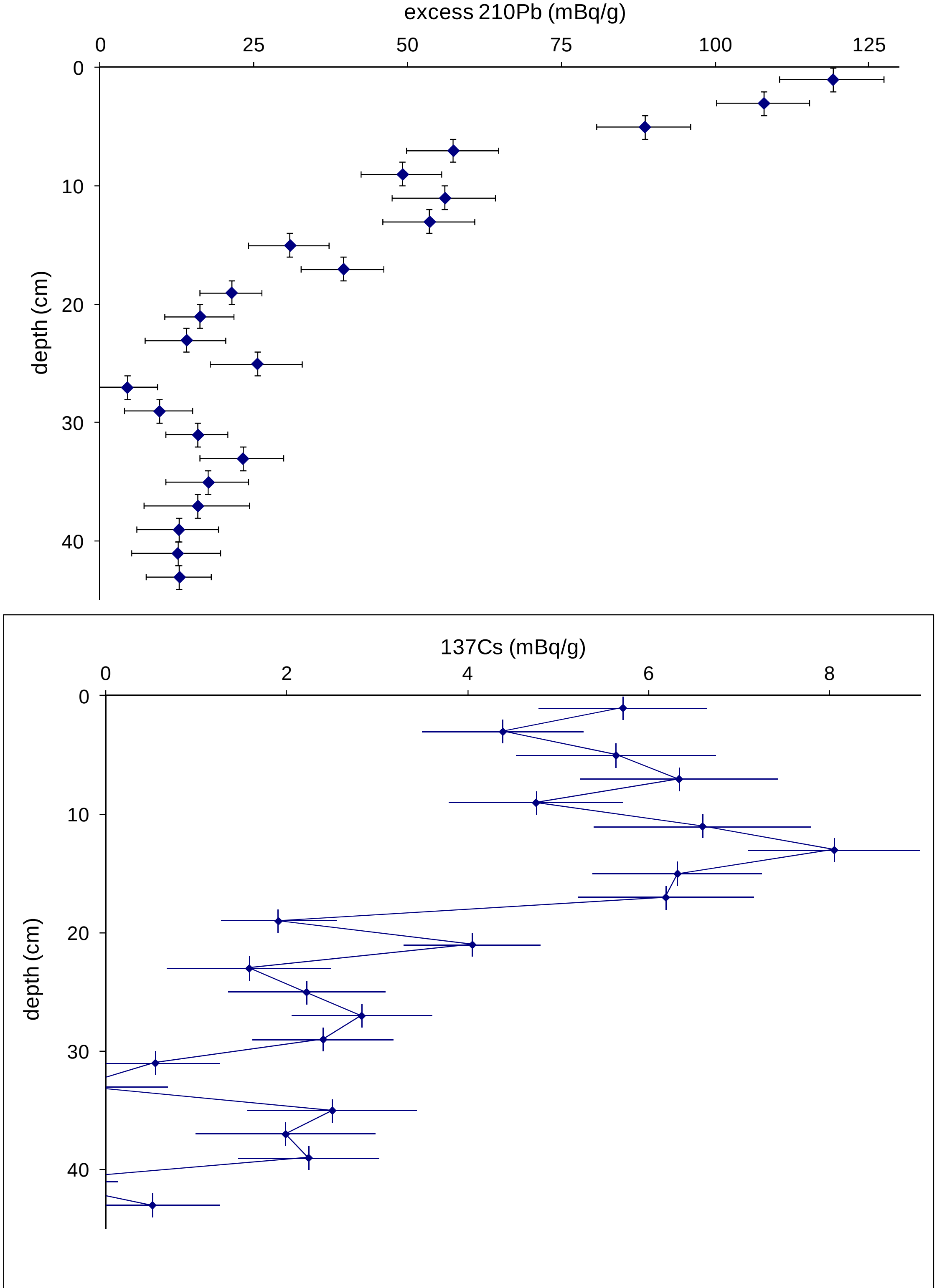

Figure 8. Radionuclide data for the core collected from the Typha stand. Excess ^{210}Pb (top) shows an exponential decline and ^{137}Cs (bottom) shows a clear peak, meeting the assumptions of the methods.

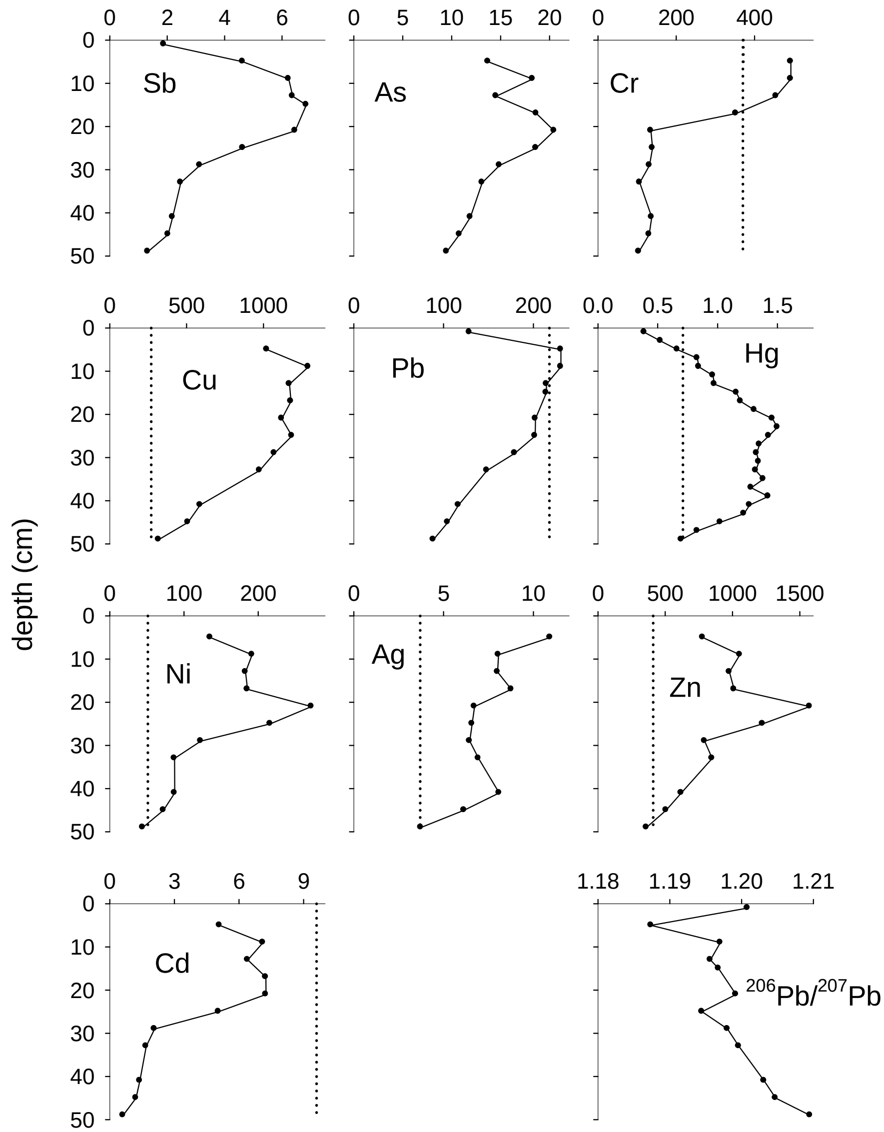

Figure 9. Concentration profiles (μg/g) of various metals with depth in the sediment core. Data courtesy of British Geological Survey (except Hg). Dashed lines indicate NOAA's Effects Range – Medium (ERM).

Is it possible that metal toxicity is inhibiting plant growth in the Quinnipiac marshes and contributing to marsh drowning? Many of the metals present in high concentration in our samples (including Zn, Cr, and Cu) are known to inhibit plant growth at sufficiently high concentrations (Shah et al. 2010). Unfortunately, clear thresholds for plant toxicity are not available in the literature, especially since most of the studies that have been conducted on Phragmites, Typha, and *S. alterniflora* used hydroponic growth media rather than soil (e.g., Hakmaoui et al. 2007, Chai et al. 2013). However, a study by Bah et al. (2011) found that Cr inhibited root growth in *Typha angustifolia* at soil concentrations as low as 26 μg/g, well below the levels found in the rooting zone in the Quinnipiac.

Conclusions

The results of this project suggest the following:

- In the vegetated areas surrounding the central mudflat, accretion rates of ~3 mm yr^{-1} appear to be the norm, both currently (based on SET data) and over the last ~100 years (sediment core). In theory, this rate should be adequate to keep up with current and historic regional SLR. However, the rate of local SLR in the Quinnipiac may differ from that measured in Long Island Sound and is essentially unknown.
- It is clear that there are important differences in tidal hydrology and vegetative communities along the upstream-downstream gradient. It is possible that there have been spatial differences in the rates of effective SLR (and that these contribute to drowning), but this is difficult to prove.
- Sediment metal concentrations in the Quinnipiac appear to be remarkably high. We speculate that this could potentially contribute to drowning by inhibiting growth of plants, especially belowground.

Acknowledgments

I thank Andrew Kemp (Tufts University) for carrying out the bulk of the field and lab work on this project, Chris Vane (British Geological Survey) for carrying out the metal analyses, and Troy Hill (Yale FES) for assistance. This project would not have been possible without the generous financial support of the Quinnipiac River Fund of the Community Foundation for Greater New Haven.

References

Bah, A.M., H.X. Dai, J. Zhao, H.Y. Sun, F.B. Cao, G.P. Zhang, and F.B. Wu, 2011. Effects of Cadmium, Chromium and Lead on Growth, Metal Uptake and Antioxidative Capacity in Typha angustifolia. *Biological Trace Element Research* 142(1):77-92. DOI: 10.1007/s12011-010-8746-6

Cahoon, D.R., J.C. Lynch, B.C. Perez, B. Segura, R.D. Holland, C. Stelly, G. Stephenson, and P. Hensel, 2002. High-precision measurements of wetland sediment elevation: II. The rod surface elevation table. *Journal of Sedimentary Research* 72(5):734-739. DOI: 10.1306/020702720734

Chai, M.W., F.C. Shi, R.L. Li, F.C. Liu, G.Y. Qiu, and L.M. Liu, 2013. Effect of NaCl on growth and Cd accumulation of halophyte Spartina alterniflora under CdCl2 stress. *South African Journal of Botany* 85(63-69. DOI: 10.1016/j.sajb.2012.12.004

Hakmaoui, A., M. Ater, K. Boka, and M. Baron, 2007. Copper and cadmium tolerance, uptake and effect on chloroplast ultrastructure. Studies on Salix purpurea and Phragmites australis. *Zeitschrift Fur Naturforschung Section C-a Journal of Biosciences* 62(5-6):417-426. DOI:

R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Shah, F.U.R., N. Ahmad, K.R. Masood, J.R. Peralta-Videa, and F.D. Ahmand (2010). Heavy Metal Toxicity in Plants. Plant Adaptation and Phytoremediation. M. Ashraf, M. Ozturk and M. Ahmad, Springer: 71-97.