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Sediment Accretion, Elevation Change, and Sea-level Rise in the Quinnipiac Marshes

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 submergence and conversion to unvegetated mudflat, for reasons that are still unclear. In this project, we investigated several aspects of this phenomenon.

Continued monitoring of our 9 long-term marsh plots showed that both Phragmites and Typha stands were accreting sediment and gaining elevation at rates that should be sufficient to keep up with the regional rate of sea-level rise (~3 mm yr^{-1}). The most vulnerable site appeared to be the "degrading Phragmites" site, where elevation change has been barely above this threshold over the last 7 years.

In addition, we used data from the Pfizer Quinnipiac River water-level gauge in North Haven to better understand the tidal hydrology of the Quinnipiac marshes. We tested the hypothesis that the local rate of sea-level rise in the Quinnipiac is higher than in Long Island Sound, and found no support for it, although the data are limited in duration.

The hydrologic data do support the hypothesis that the Quinnipiac marshes are hydrologically vulnerable to waterlogging stress. In particular, we found that flooding durations (hours per year) for both Typha and Phragmites stands were ~45% greater than they would be if those stands were at the same elevations but were subjected to the tidal regime of New Haven Harbor, rather than the Quinnipiac. This hydrologic phenomenon results from two factors: the reduced tidal range upstream; and the influence of river-flood events on the tidal hydrology.

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 "submergence," 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 (SLR). The reasons that submerging 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. Submergence threatens those values.

In this project, we examined the processes determining the stability of the Quinnipiac marshes. In particular, we tested three hypotheses generated by our previous research:

- H1. The areas of vegetated marsh adjacent to the mudflat are losing relative elevation and are likely to soon lose vegetation and become mudflat.
- H2. Rates of SLR in the Quinnipiac are higher than the regional rate recorded in the open waters of Long Island Sound.
- H3. The Quinnipiac marshes are hydrologically vulnerable to submergence because of their upstream position.

This report is divided into 2 main sections: (a) measurements of accretion and elevation change at our 9 long-term plots; (b) analysis of water level data. 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 Phragmites"), and Phragmites away from the drowning area ("healthy Phragmites"). 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 March 2013 (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 March and November 2013.

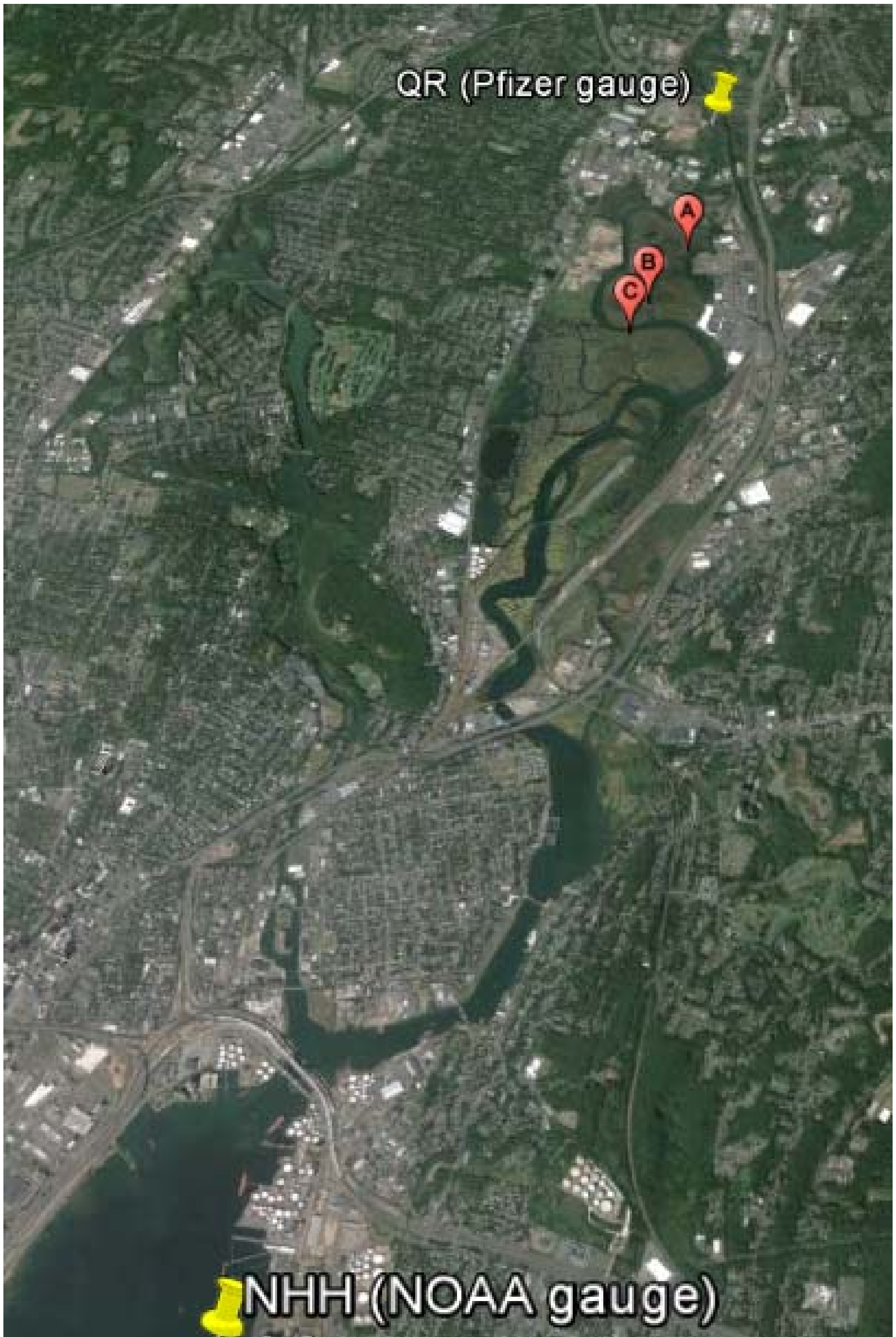

Figure 1. Sampling locations in the Quinnipiac marshes (Google Earth image). Red markers indicate SET sites (each with triplicate plots): A = degrading Typha, B = degrading Phragmites, C = healthy Phragmites. Yellow markers indicate tide gauges. The main area of marsh submergence is represented by SET sites A and B.

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

The two Phragmites sites showed very similar patterns of accretion over time (Figure 2, top), with both sites accreting sediment at just over 3 mm yr^{-1}, roughly the regional rate of SLR. The two sites differed, however, in their elevation change (Figure 2, bottom), with the healthy site showing a considerably higher rate (5.8 mm yr^{-1}).

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. Examining only spring data (Figure 3) revealed that the site is both accreting and gaining elevation at rates well in excess of 3 mm yr^{-1}.

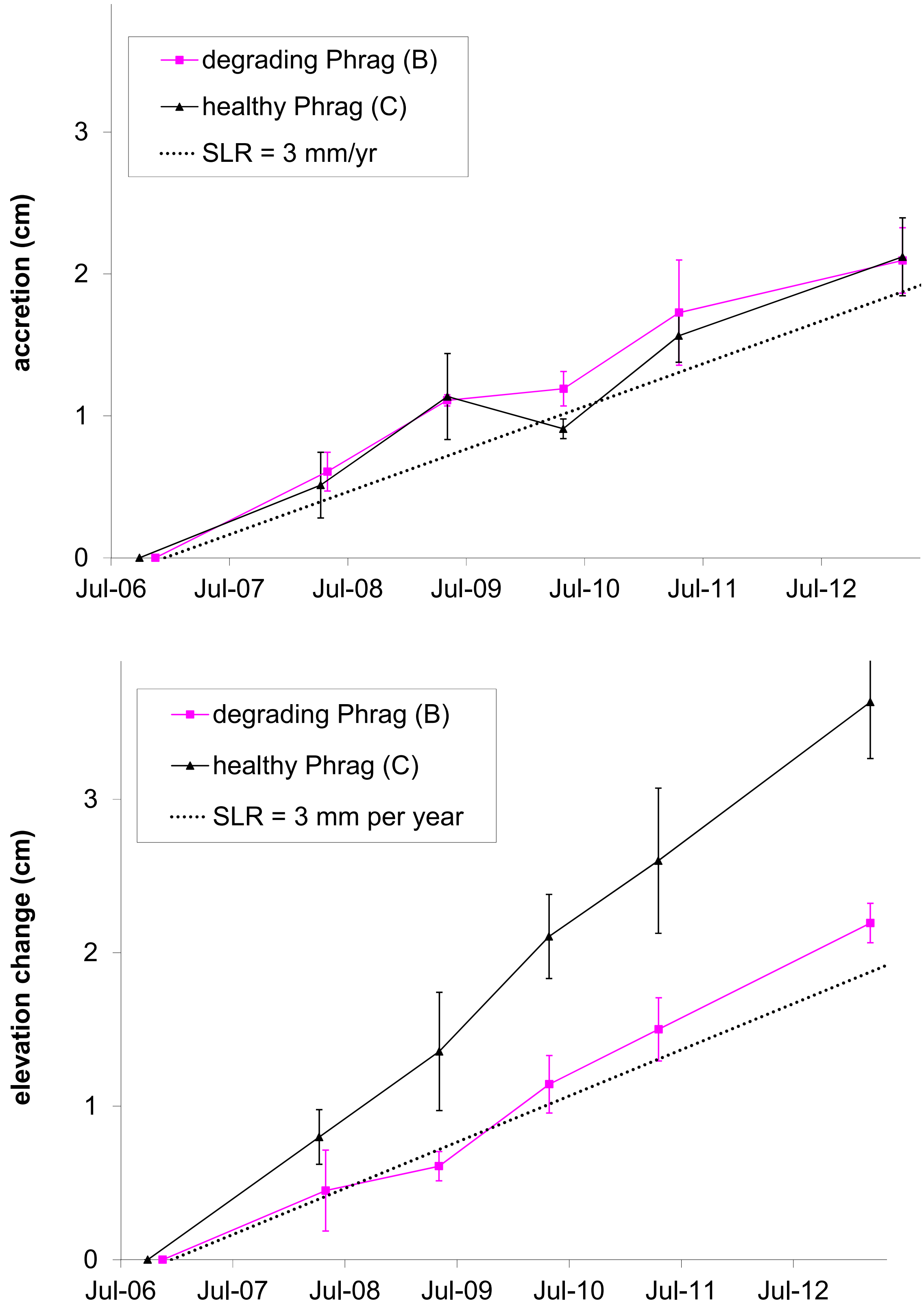

Figure 2. Accretion (top) and elevation change (bottom) at the two SET-MH Phragmites sites (mean and standard error of triplicate plots at each site). Dashed line shows a constant SLR of 3 mm yr^{-1}.

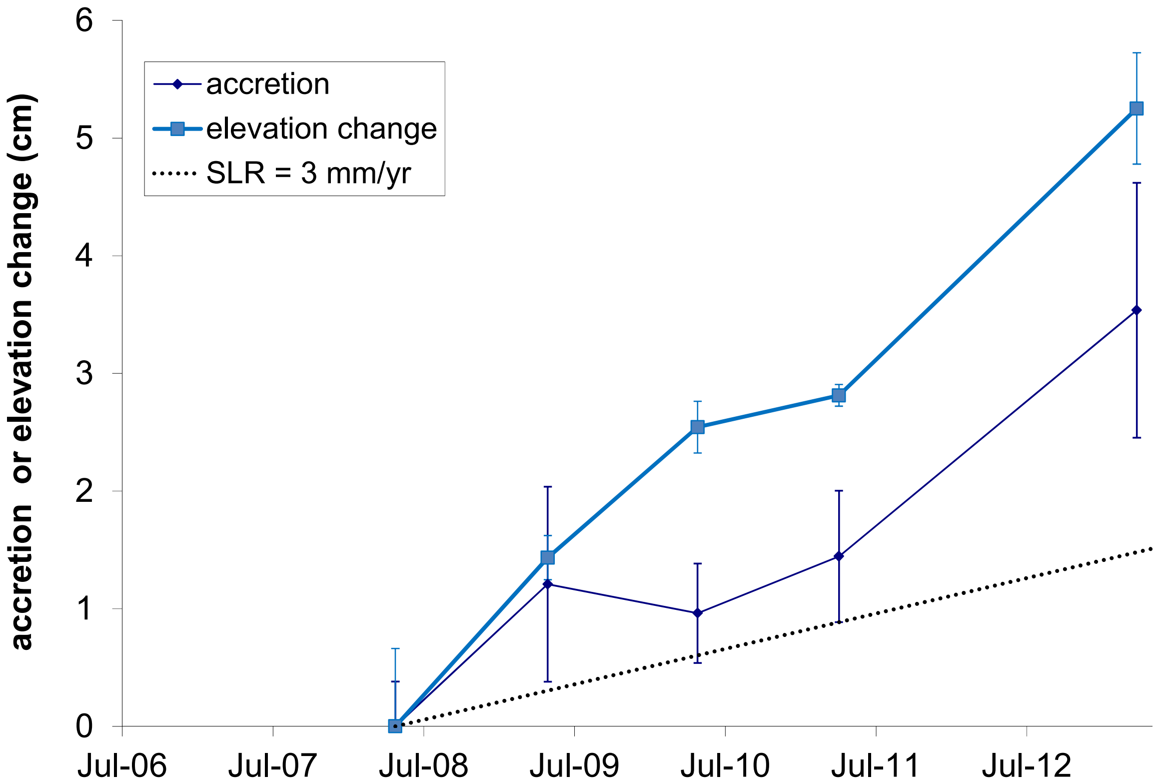

Figure 3. Accretion and elevation change at the SET-MH Typha site (mean and standard error of triplicate plots). Dashed line shows a constant SLR of 3 mm yr^{-1}. Only spring data are shown.

Hydrology

Methods

Hourly water level data were obtained from a tide gauge on the Quinnipiac River (QR), operated by Pfizer as part of a site remediation (Figure 1). Data extended from 1/2/2008 to 11/26/2013, although there were gaps in the record comprising 1.8% of the time points. We extracted high tide times and heights from the dataset using the statistical software package R.

Hourly water level data over the same time period were obtained from the NOAA tide gauge at New Haven Harbor (NHH), station 8465705, 14 river km downstream from the Pfizer gauge, and high tides were extracted. We used high tides extracted from hourly data rather than NOAA-provided high/low data, so that we could directly compare the two sites, given that only hourly data were available for the Quinnipiac.

We used these data to carry out two analyses. First, we assessed the rate of SLR (technically, the rate of rise of MHW) in the Quinnipiac compared to NHH. While the time period for which data were available (less than 5 years) was too short for a true calculation of SLR, a comparison of trends in water levels at the two sites was possible. To do so, we calculated monthly-average MHW levels for both sites, applied a seasonal correction factor, and plotted these over time.

Second, we determined the relationship between elevation and flooding (specifically, flooding frequency and duration) for both sites. As part of this effort, we explored the role of river flow in QR tidal hydrology, using daily discharge data for the nearest upstream (non-tidal) United States Geological Survey (USGS) station, 01196500 (http://waterdata.usgs.gov/usa/nwis/uv?01196500).

Results

Monthly MHW data are shown in Figure 4. Over this 70-month time period, MHW at NHH rose at ~1.5mm $month^{-1}$ (18 mm yr^{-1}), considerably higher than the longer-term regional average of ~3 mm yr^{-1}. Over the same time period, MHW in the Quinnipiac did not have a statistically significant rise.

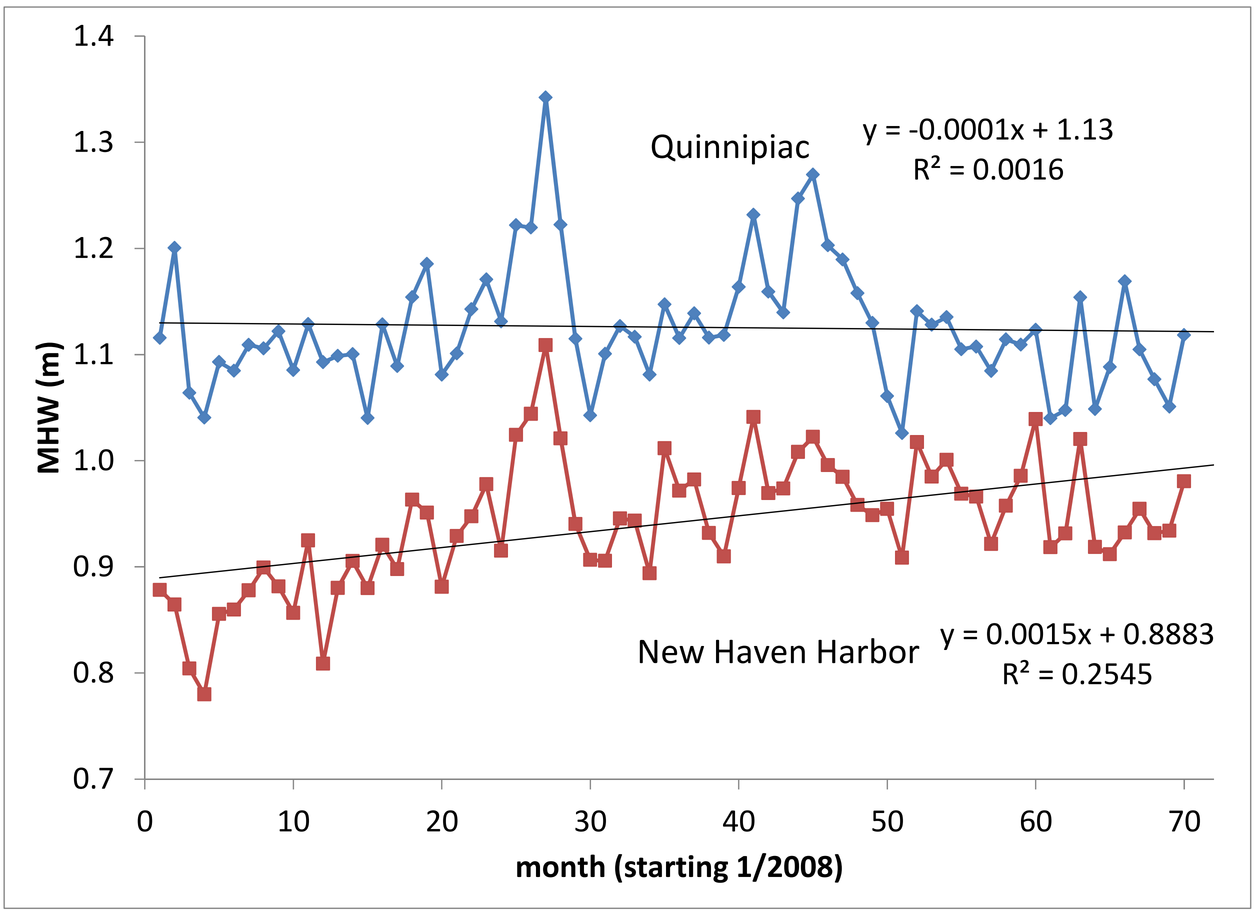

Figure 4. Monthly MHW for QR and NHH gauges, after correction for seasonal variation. Data are in m NAVD88, with an offset of 0.2m applied to the QR data for clarity.

Figure 5 presents the elevation-flooding curves for NHH and QR. At relevant elevations (e.g., the average elevations for Typha and Phragmites in this system, shown as dashed lines), the QR tidal regime results in considerably longer flooding duration relative to the NHH tidal regime (bottom panel).

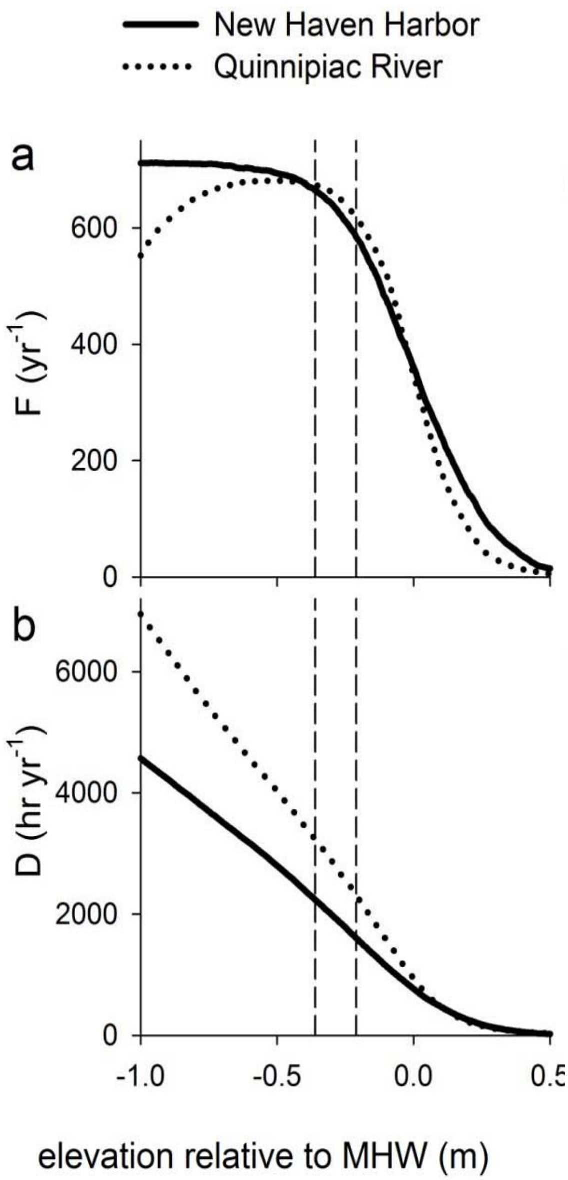

Figure 5. Elevation-flooding curves based on QR and NHH gauges. Top panel shows flooding frequency (number of tidal flooding events per year), while bottom panel shows flooding duration (hours of tidal flooding per year). Vertical dashed lines show average elevation of Typha (-0.36m) and Phragmites (-0.21m) in the Quinnipiac marshes.

Two factors contribute to the greater flooding duration in the Quinnipiac relative to NHH. First, dampening of the tides through frictional effects leads to a lower tidal range upstream; our previous research shows that mean tidal range in the vicinity of the Pfizer gauge is lower than in NHH by about 30%. A lower tidal range results in a greater increase in flooding duration for a given elevation increment.

Second, flooding of the Quinnipiac marshes is affected by high river flows in addition to astronomical tides. The influence of the river can be seen in the fact that river-flood events (defined here as daily average flow >14.2 m^3 sec^{-1} at the USGS Wallingford gauge) deviate from an otherwise very strong relationship between high-tide water level in NHH and high-tide water level in the QR (Figure 6). These high-flow events, which comprise 9% of dates over this time period, are responsible for a portion of the increased flooding experienced in QR relative to NHH. Without high-flow events, QR flooding duration for Typha stands, for example, would be only 35% longer than in NHH, rather than 45% longer (Table 1).

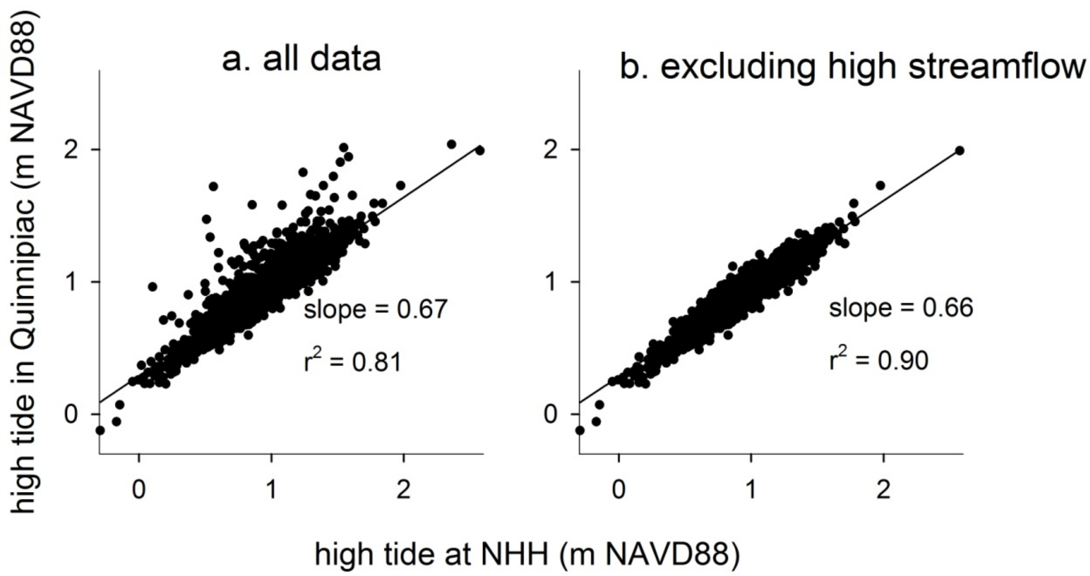

Figure 6. Relationship between high tide levels at the QR and NHH gauges. Left panel includes high-streamflow dates (>14.2 m^3 sec^{-1}), which appear as anomalously high tides at QR.

Table 1. Quinnipiac marsh flooding with and without high-flow events

Elevation (m MHW)	High-flow events	Flooding duration ratio[a]
-0.36[b]	excluded[c]	1.35
	included[d]	1.45
-0.21[e]	excluded	1.33
	included	1.45
0	excluded	0.99
	included	1.21

[a] ratio of flooding duration in QR to flooding duration in NHH, at the indicated elevation
[b] average Typha elevation
[c] dates with flow > 14.2 m^3 sec^{-1} were excluded
[d] all dates were included
[f] average Phragmites elevation

Conclusions

Our data allowed us to test our three hypotheses.

H1. The areas of vegetated marsh adjacent to the mudflat are losing relative elevation and are likely to soon lose vegetation and become mudflat.

This hypothesis **was not** supported by our data. All three SET sites appear to be keeping up with regional SLR, although the degrading Phragmites site is dangerously close to this threshold. How are we to explain this apparent contradiction: we know that parts of the marsh are submerging, but other parts right nearby appear to be doing fine? Future research will address this question, but possible explanations include:

a. Submergence is episodic and patchy. Our SET-MH sites are in areas that are not currently subject to submergence, and thus they do not represent the processes that occurred in the areas that have already undergone submergence.
b. Submergence in the Quinnipiac occurs after, rather than before, vegetation loss. Some factor other than hydrologic stress is responsible for vegetation loss; possibilities include sediment toxicity and increasing salinity.

H2. Rates of SLR in the Quinnipiac are higher than the regional rate recorded in the open waters of Long Island Sound.

This hypothesis **was not** supported by our data. While the data have many limitations (particularly the short time period involved), there is no suggestion in Figure 4 that the Quinnipiac is experiencing accelerated SLR beyond that experienced in Long Island Sound.

H3. The Quinnipiac marshes are hydrologically vulnerable to submergence because of their upstream position.

This hypothesis **was** supported by our data. Because of their hydrologic position in this complex estuary, the Quinnipiac marshes experience longer flooding durations than they would if they were in New Haven Harbor (at the same elevation). Of note, also, is the fact that, in the Quinnipiac, a relatively small decrease in relative elevation translates into a relatively large increase in flooding. This suggests that a process of submergence, once begun, could rapidly accelerate. It does not, however, change the fact that our SET sites are not losing relative elevation.

Acknowledgments

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