Identifying the drivers of marsh loss in the Westport River Watershed: What Next?

Westport River marshes have declined by nearly 50% during the past 80 years (Figure 1). Previous work by Costa and Weiner suggest that the rate of this decline has increased dramatically over the past 15 years (Costa & Weiner 2017). However, the underlying cause of this accelerated loss is not fully understood. A number of potential drivers of marsh loss have been identified, including changes in nitrogen pollution, sea level rise, dredging, coastal development, erosion, and grazing from crabs. Both branches of the Westport River watershed have experienced many of these changes to some degree. Importantly, these multiple drivers may also be operating at different scales across the watershed.

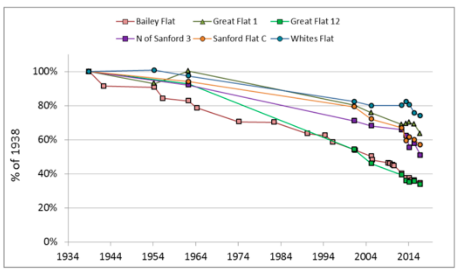


Figure 1: Decline in the Salt Marsh area relative to the area of marsh in 1938. From Costa and Weiner 2017.

Elevated levels of nitrogen are generally considered prime suspects for the marsh decline observed in both branches of the Westport River. While both branches have been shown to have elevated levels of nitrogen pollution (Figure 2) and high nitrogen levels have been shown in other New England marshes to cause marsh loss (Deegan et al. 2012), testing this correlation experimentally in Westport River was the major focus of this study.

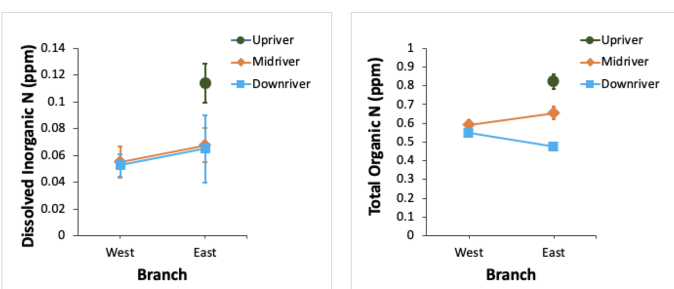


Figure 2: Average (±SE) annual dissolved inorganic and total organic nitrogen levels in both the East and West Branch of the Westport River from 2010 -2017. Data compiled from http://savebuzzardsbay.org

The overarching goal of our research has been to identify the drivers of marsh loss and gain a mechanistic understanding of how marsh loss is occurring in the Westport River Watershed. To achieve this goal, we deployed a series of experiments at a total of **14** field sites t (**7** within each branch of the river) in summer 2018. Our series of experiments were designed to address the following hypotheses and provide the experimental evidence necessary to identify the underlying mechanism(s) of marsh loss:

Hypothesis I – Differing nitrogen loading and eutrophication drive vegetation and marsh loss differences between the branches of the Westport River.

Hypothesis II – Differing water flow and sediment dynamics drive differences in vegetation and marsh loss between the branches of the Westport River.

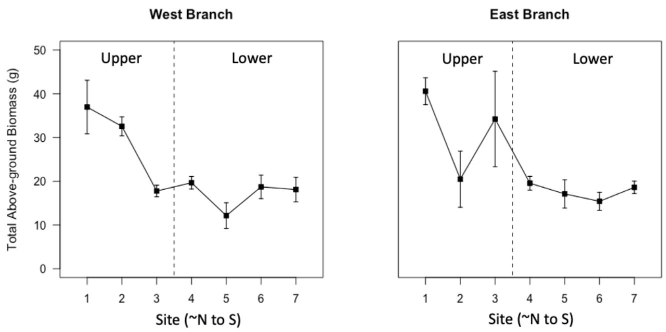
While these multi-year experiments are now complete, we have not yet been able to fully complete our data analysis. Like everyone else around the world Covid-19 has impacted our progress. However, using the data we have collected, processed and analyzed so far and our two years of field observations on the river we have been able to come to some conclusions. In addition, we are also confident that our conclusions presented here will continue to be supported upon completion of processing and analyzing remaining samples currently in the lab. We anticipate renewed access to our laboratories in June 2021.

To address *Hypothesis I* we conducted a large manipulative field experiment to test for nutrient limitation of marsh plant growth across the existing gradients of marsh decline across and within both branches of the Westport River. At each of our 14 sites we established 15 plots (plot size = 50 x 50cm) in three groups of five (N = 210 plots total). Plots in each group were then randomly assigned to receive one of five treatment combinations, including an unmanipulated control as a reference. Treatment combinations included all 4 possible combinations of a nutrient addition (+ or - fertilizer) and an aeration (+ or - aeration) treatment. At the end of each growing season we harvested, dried, and weighed the above-ground plant biomass in each plot. Species were sorted and measured for maximum plant height prior to drying.

Because plant traits and biomass inherently vary from site to site (Figure 3), we quantified the effects of each treatment on plant growth by comparing plant biomass in each of the four treatment plots to that of the corresponding reference plot (unmanipulated control) using a log response ratio ("LRR"), whereby LRR = log(treatment biomass / reference biomass). LRR values greater [less than] than zero indicate that the treatment had a positive [negative] effect on plant growth.

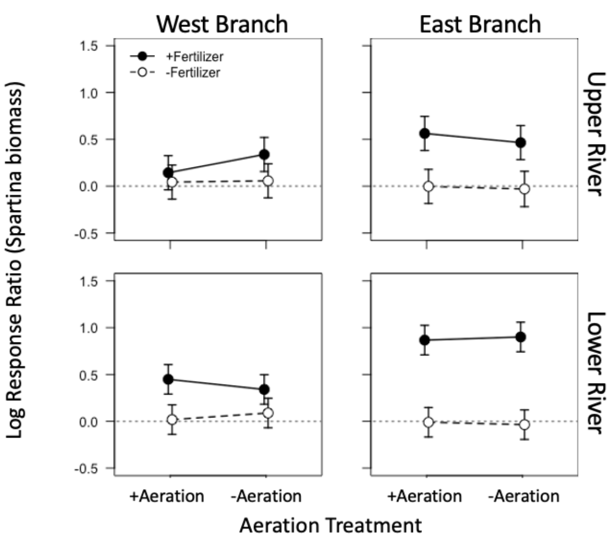
Results from the 2018 growing season show nutrient additions (+ fertilizer) increased final *Spartina* biomass, but the magnitude of this effect was greater at sites that were located either in the lower river or in the East Branch (Figure 3b).

Figure 3a.



(a)
Branch: $F_{1,10}$=0.4, P=0.53
Location: $F_{1,10}$=12.075, P=0.006
BXL: $F_{1,10}$=0.3, P=0.62

Figure 3b.



(b)
Fertilizer: $F_{1,113}$=67.9, P < 0.0001
Aeration: $F_{1,113}$=0.02, P = 0.88
Fertilizer X Branch: $F_{1,113}$=14.08, P=0.0003
Fertilizer X Location: $F_{1,113}$=4.75, P=0.0313

Figure 3. (a) Final total above-ground plant biomass collected from unmanipulated control plots at 7 sites in the West Branch and 7 sites in the East branch (n = 3 plots per site). Sites 1-3 are "upper" river; sites 4-7 are "lower" river, indicated by dashed vertical lines. (b) Treatment effects (calculated as log response ratios, 'LRR' relative to corresponding control plots (a)) on final above-ground *Spartina* biomass (mean ± SE) in the upper (top panels) and lower (bottom panels) sections of the West and East Branches of the Westport River. LRR values greater than 0 indicate that the treatment caused an increase in *Spartina* biomass. Data were analyzed with mixed effects models that included sites and blocks as random effects.

Differences in biomass are largely due to taller plants rather than greater shoot density. Shoot density did not vary significantly between branches or locations (Figure 4a), but total shoot biomass did (Figure 3a) likely because of differences in shoot height (Figure 4b). In the upper river marshes, where ambient nitrogen levels are highest, *Spartina* shoots were much taller than at downriver sites. The most degraded marsh areas in the river are located in the most flushed parts of the river, where water column nitrogen levels are the lowest (Figure 2). Previous direct measurements of nitrogen level in the river show strong positive correlation to our assessment of marsh health (*Spartina alterniflora* height and biomass used as a proxy for marsh health, Figures

2, 3, and 4). Marshes located in areas of the river with the highest levels of nutrients appear to be the healthiest.

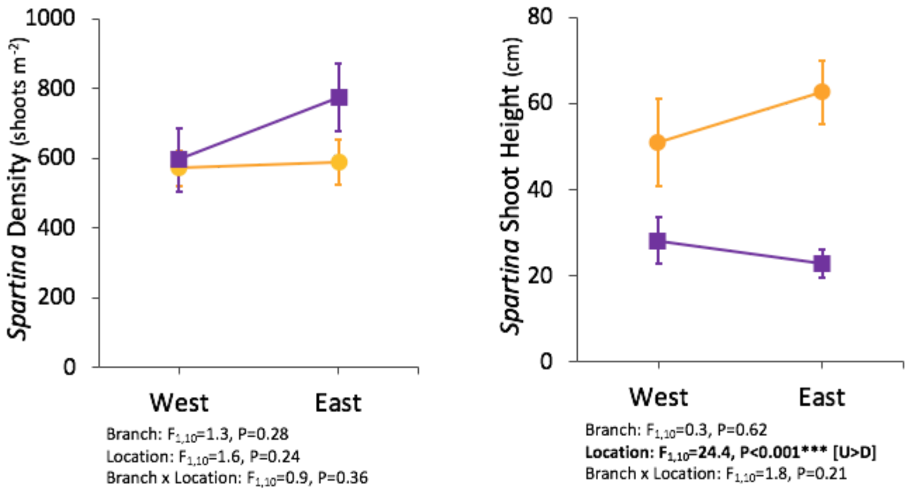


Figure 4. *Spartina alterniflora* density (a) and height (b) at sites in the upper (orange circles) and lower (purple squares) West Branch and East Branch of the Westport River.

These results indicate that across the river, even in areas of high background nitrogen, above-ground *Spartina alterniflora* biomass is still limited by nitrogen. Plants that are nitrogen limited must continue to invest in below-ground biomass (roots) to obtain nutrients, and therefore are not likely to cause the creek-bank collapse observed in eutrophic estuaries elsewhere in New England (Deegan et al 2012). Hence, elevated nitrogen levels are not driving the loss of marsh plants in Westport. This conclusion is additionally supported by the results of our greenhouse study and our field observations over the two years (data from greenhouse study not shown but will be in our final report).

In summary, results of our nutrient addition experiments both in the field and greenhouse, survey and nutrient data suggest that current marsh loss in the Westport River is not a direct result of increased nutrients in the water column. In addition, our site surveys (see below) and observations also suggest that changes in water flow/hydrology or sediment dynamics may play a larger role in the decline of marsh health and loss of marsh area seen in the river, particularly in the lower river. However, more data on changes in hydrology and its role in the growth and establishment of *Spartina alterniflora* are needed (see next steps).

We investigated various lines of evidence to begin addressing *Hypothesis II* – Differing water flow and sediment dynamics drive differences in vegetation and marsh loss between the branches of the Westport River--, but much more information is still needed. We measured a number of environmental and ecological variables at each study site that relate to water flow and sediment dynamics. These data also provide context for our manipulative experiments and helped to fully understand the physical differences within and between the river branches. In addition to the plant communities at each site, we also quantified the abundance of macroalgae, benthic invertebrates, sediment compaction, and erosion potential.

One of the first field observations that we made was the striking difference between upper and lower river marshes in the hardness or peat compaction at the leading edge. This difference in peat compaction was a strong qualitative indicator of marsh health (Figure 5 and 7). In order to attempt to quantify this apparent difference in sediment compaction, we recorded average pressure required to penetrate the sediment using a Pesola penetrometer. The amount of pressure required to penetrate the peat surface was greater in the West branch than in the East branch. However, we found no significant difference between upriver and downriver sites (Figure 6). This is most likely due to a combination of the very different biotic conditions up and downriver and a limitation of the method we used to measure compaction, rather than an actual difference in marsh peat hardness and its biological effects. We noted that our upper river sites had a greater density of infaunal mussels just below the sediment surface (Figure 8). These mussels likely prevented penetration of our measurement device, inflating our estimates of sediment compaction in the upper river. In addition, differences in *Spartina* rhizome biomass may have had a similar effect at the upper river sites.

Figure 5: Healthy Marsh site, East Branch Site 1 (left) and Unhealthy Marsh Site, West Branch Site 6 (right).

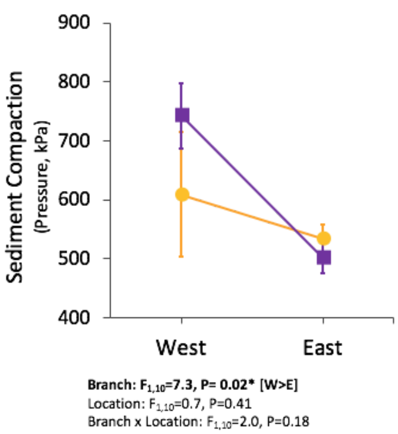


Figure 6. Sediment compaction measured with a Pesola spring scale penetrometer as the maximum resistance pressure of the peat surface. Values are mean ± SE for upper river (orange circles) and lower river (purple squares) sites.

Figure 7: Left panel: hardpack sediments in the lower west branch of the Westport River are easily susceptible to cleavage. Right panel shows sediment so hard that rocky intertidal invertebrate species can be found living there in abundance, including larval barnacles and *Littorina* spp. (periwinkle snails).

The plants and animals of a typical healthy New England salt marshes are easily identified and generally well understood in terms of the biological and physical drivers of their zonation. Differences in these communities among sites can provide another means to evaluate relative marsh health. For example, some benthic invertebrates have specific habitat requirements that can provide insight into the physical conditions, marsh type. and potentially marsh health (Figure 7). In a typical New England salt marsh the leading edge of the marsh is typically dominated by *Spartina* and often is associated with the ribbed mussel, *Geukensia.* The presence of *Geukensia* is often associated with a healthy marsh, as its action as a filter feeder; stabilizes & fertilizes sediment and is known to promote *Spartina* growth. Our surveys indicated that the *Geukensia* was nearly 5X more abundant at upriver sites than at downriver sites (Figure 8). It should be also noted here that we did not find herbivorous purple marsh crabs (*Sesarma reticulatum*) at any of our field sites during our biological surveys or at any other time we were on the marsh.

Another set of strong biological indicators were the presence of two species that are not normally found at the leading edge of healthy salt marshes: littorinid snails (*Littorina spp*) and rockweed (*Fucus vesiculosus*). Both of these species are typical members of the New England rocky intertidal zone where they live on rock or other hard surfaces. Our results show that Littorine snails were more abundant downriver and functionally absent from upriver sites (Figure 8). In addition, in areas of hard packed peat at downriver sites, where marshes are calving, we saw high recruitment of *Fucus,* which is not a normal component of the lower *Spartina* zone (*personal observation*). In fact, we found larval barnacles settling on the hard peat at some of the lower river marsh edges. Barnacles typically settle on rocks, docks, and other hard substrate in areas of high water flow or wave action. These biological indicators suggest that increased water flow may have changed the sediment accretion or sediment removal rates in the lowest river leading to less favorable conditions for salt marsh growth.

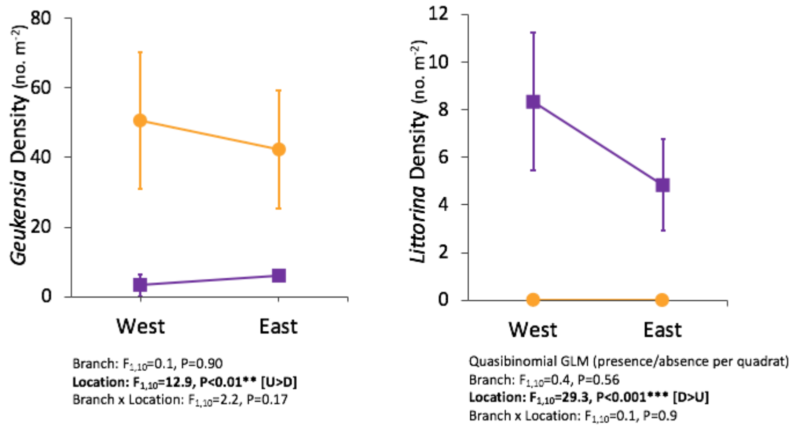


Figure 8. Density of ribbed mussels (*Geukensia demissa*) and littorine snails (*Littorina* spp.). Values are mean ± SE for upper river (orange circles) and lower river (purple squares) sites.

Our findings and observations from members of the Westport community suggest that changes in water flow in the past few decades may be the primary driver of the accelerated rate of marsh loss.

To begin to address the variation in water flow in the Westport River, and its potential impact on the marshes, we deployed “flow blocks” along the marsh edge at each of our sites (Figure 9). Flow blocks are cylindrical plaster castings of standardized density and volume. By measuring their mass before and after deployment, we can estimate the rate of mass loss or dissolution (g per minute submerged) as a proxy for erosion due to water motion.

Figure 9: A deployed flow block used to estimate site-to-site variation in water flow/erosion.

Water flow estimates from flow block dissolution varied among field sites, however in both branches there was a clear break in estimated flow rates between the Upriver sites (numbers 1-3) downriver sites (4-7) (Figure 10). This abrupt change in bulk water flow seems to be strongly correlated with all of our indicators of general marsh health, where unhealthy marshes are subjected to high rates of water flow (Figures 4, 5 & 10). However, more data describing the flow of currents, marsh submergrance time, waterlogging, and, probably most importantly, sediment dynamics, throughout the river complex are necessary to understand the historic and ongoing changes in the Westport marshes.

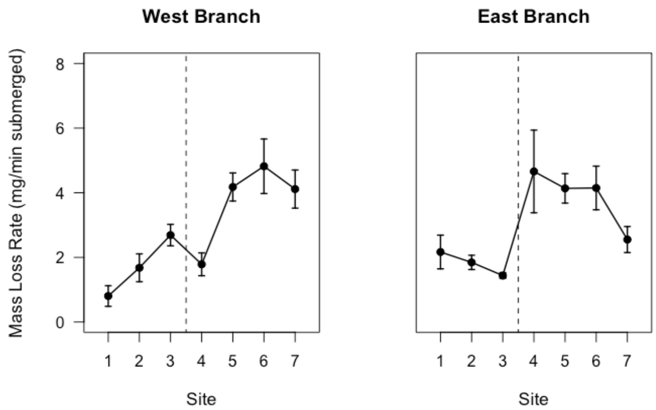


Figure 10. Dissolution rates of flow blocks (mean ± SE) located along the marsh edge at 7 sites in the West Branch and East Branch of the Westport River. The dashed line delineates upper river sites (1-3) and lower river sites (4-7).

Conclusions and Next Steps

The results of our work to date indicate that although nitrogen levels in both branches of the river are generally high, they are not the drivers of marsh loss in the Westport River. Again, it is important to note that excess nitrogen in the water column can lead to a number of other ecological issues, but our data clearly show that marsh plants in river are nutrient-limited, indicating that nutrient loads in the water column are not the primary driver of the observed marsh calving and loss. Our data and observations suggest that in areas of increased water flow, the leading edges of the marshes are losing sediments and eroding. These leading edges become undercut, weakened and eventually calve off (see Figure 5 for an example). This is most notable in the lower river marsh islands that have been and continue to be most vulnerable to possible changes in water flow, wave action, sea level rise, submergence time, and sediment dynamics.

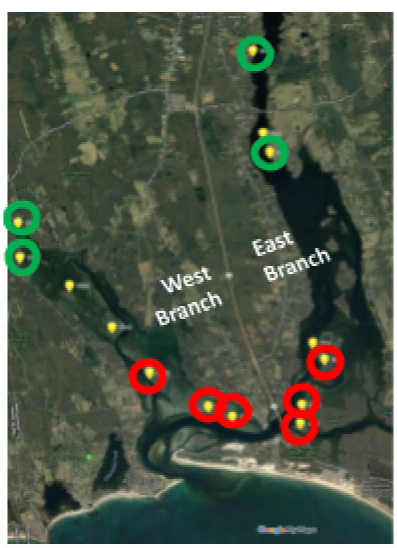


Figure 11: Location of possible tidal and water flow stations. Green sites are "healthy marsh" and red sites are unhealthy based on the degree of historic and ongoing rates of marsh loss, as well as results and data from our study. Yellow markers are locations used in previous our study.

Our experimental results, field surveys and observations to date all point to the need for further studies around *Hypothesis II*: Differing water flow and sediment dynamics drive differences in vegetation and marsh loss between the branches of the Westport River.

As we have discussed, to move forward and fully understand the mechanism for the loss of marsh area in the Westport River we need to fully investigate *Hypothesis II.* Understanding the changes in water flow and sediment dynamics are vital to any possible future successful restoration or mitigation.

A full investigation of *Hypothesis II* should include the following:

- Develop and install tide and flow gauges in the river at a number of sites across a range of current marsh health. Development of tide and flow gauges has been done, thanks to Mike Sullivan. We have now identified 10 sites (Figure 11)--5 marshes in each branch--that will be well suited for deployment of the gauges. Data generated will provide answers to questions of differences in water flow, submergence time, and changes in sea level.

- Install a series of water level monitoring stations at a subsample of the tide gauge sites. These water level monitoring stations will provide marsh peat water logging data necessary to address if changes in marsh peat are leading to some marshes holding on to water (staying waterlogged) longer than others. Water logging has been shown to impair marsh plant growth in other locations and can result in reduced plant biomass and eventually marsh loss. We may also consider soil redox measurements as a proxy for water logging at a larger scale.

- Our erosion estimates and observations of peat compaction indicate that sediment dynamics in the river play an important role. Marshes need to be able to trap and hold on to fine particles of biomass, silt and sand in order to build up the peat base on which the marsh depends. Without trapping sediments from the water column to build peat, the marsh cannot keep up with sea level rise or acquire the nutrients necessary for plant growth. Understanding the sediment dynamics, both the addition to and removal from "healthy vs unhealthy" marshes across the river is imperative to our understanding of how these marshes change over time. The sites used for the tide gauges would be ideal locations for this type of work. At the scale of individual marsh areas, we need to develop a new and more reliable method for assessing sediment removal and deposition at the variable flow speeds around the river. Our previous attempts during the summers of 2018 and 2019 were unsuccessful at the lower river sites due primarily to boat waves and other disturbance events. At a larger scale, a sediment budget for the watershed may provide valuable information about the sources and sinks of various sediment types within and across the estuary.

- It is important to note that marsh islands, as in the lower river, and fringing marshes, as along the shorelines of the upper river, experience vastly different flow regimes due to bathymetry, tides, and shoreline characteristics. Islands may be more vulnerable because of their location or because they do not receive the same degree of sediment from landward sources. Yet, marsh islands exist and persist on other areas along the East Coast of the US. Understanding the abiotic conditions that support similar marsh islands, for example, in coastal Georgia, can provide context for any results emerging from flow and sediment studies in Westport. This will also allow us to develop an understanding of the range of inundation levels, water flows that allow these island marshes to persist. Such comparisons can be particularly valuable when evaluating any potential remediation efforts down the road.

- Develop a map of the total area of Westport Marshes that are "at risk". Our data indicate areas where the marshes are more or less vulnerable to future decline (Figure 11), largely based on the ability of foundation species like *Spartina* to grow and thrive. Data from water flow and sediment studies will improve assessments of marsh vulnerability and help to guide any conservation or restoration efforts.

- Finally, on a positive note, the west branch of the Westport River has some of the healthiest seagrass (*Zostera marina*) beds that either of us have seen on the east coast. Seagrass meadows provide a wealth of ecosystem services, including water filtration, carbon sequestration, and nursery habitat for fish and invertebrates. Further investigation of the extent of seagrass habitats and their dynamics in the Westport River is warranted, including potential links between marshes and seagrass beds. We often observed some of the healthiest seagrass meadows along the unhealthiest, eroding marsh edges. This observation supports our conclusion that nutrient loading is not driving marsh loss because nutrient loading typically has strong negative effects on seagrass beds. However, water flow can have positive effects on seagrass meadows while having negative effects on marsh accretion. Another possibility is that nutrient-rich marsh sediments are "feeding" or "fertilizing" the seagrass beds as they erode away from the marsh. Are changes in water flow driving the loss of salt marsh and at same time driving the increase of seagrass? The possible transition from one highly productive ecosystem (marshes) to another (seagrass) and the maintenance of valuable seagrass meadows could also be sensitive to changes in water flow or sediment dynamics, especially because, unlike marshes, seagrass meadows are capable of thriving under predicted sea level rise.

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