Investigation of the Impact of Vegetation Type on Sedimentation Rates in a Freshwater Tidal Wetland, Jug Bay, Maryland, USA

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Introduction:

Tidal freshwater wetlands are characterized by periodic inundation by low salinity (<0.5 ppt salinity) water as a result of tides and, in contrast to *Spartina*-dominated salt marshes, support a high diversity vascular plant community (Odum 1984). However, it has been found that prolonged inundation, either by frequency or duration, can be harmful to plant diversity. Baldwin *et al*. (2001) demonstrated that 3-10 cm of flooding negatively impacted seedling recruitment and growth for many tidal freshwater marsh plant species and lowered overall diversity. Because of this and other evidence, there has been growing concern over increasing rates of sea level rise, especially since this rate is anticipated to accelerate due to global warming (Morris 2007).

While sea level is a driving factor influencing marsh elevation, the tidal marsh platform is also affected by other processes such as erosion, sedimentation and hydrodynamics (Baldwin *et al.* 2001, Darke *et al*. 2003, Morris 2007, Yang 1998). With such strong and variable physical forces at work in this environment, the emergent vegetation inhabiting the intertidal zones has been described in terms of ecological engineering properties (Morris 2007). Plant biomass, density, height and structure have been found to influence wave and current attenuation in salt marsh plant canopies (Leonard and Luther 1995). If the canopy is above the water height, wave velocity will vary inversely with canopy drag (Lightbody *et al*. 2006, Yang 1998). Bottom current velocity also decreases when stems are present, which in turn contributes to sedimentation by diminishing particle resuspension and increasing particle capture by vegetation (López *et al*. 1998).

Marsh evolution, specifically in terms of sedimentation, is a well-studied phenomenon for salt-water mashes. Sedimentation can occur through either organogenic deposition, such as compaction, decomposition and shrink-swell (Cahoo *et al* 1997), or sediment trapping. While salt marshes can experience one or both of these processes, it has been found that those that accrete through sediment trapping can more readily adjust to changes in sea level (Mudd *et al.* 2004). Evidence that salt marsh elevation can keep pace with rising sea levels has also been found by Morris (2007), Redfield (1972), Reed *et al*. (2008), and Rooth *et al*. (2000) among others. In salt marshes, sedimentation rates are positively correlated with the density of marsh plant communities and their productivity (Morris *et al*. 2002). Plant stems increase sedimentation both by reducing current velocities, thereby allowing larger particles to settle, and by physically "capturing" particles that then fall to the bottom. Indeed, less suspended sediment occurs over mashes when compared to open mud flats (Yang 1998). Salt marshes have been found to be stable against variations in sea level when their relative elevations are supraoptimal for vegetation, thus optimizing sedimentation rates (Morris 2007).

Much less is known about sedimentation processes in freshwater marshes. Further study is warranted because they are often closer to sedimentation sources, such as riparian forests, and so are likely to have higher accretion rates (Pasternack *et al*. 2001). They are also more diverse and more complex, and as a result, they are harder to restore than salt marshes (Baldwin 2004) and may be more effective at accreting sediment (Morris 2007). Freshwater plant species occupy different elevational ranges due to varying degrees of tolerance to flooding, hypoxia, desiccation and competition (Odum 1984). By occupying separate niches throughout the scale of marsh elevation, freshwater marsh plants may have a greater impact on the spatial patterns in sedimentation and erosion than do salt marshes (Pasternack *et al*. 2001, Darke *et al*. 2003).

While some studies have found that sediment rates can be independent of particular plant assemblages (Darke *et al*. 2003), it is indisputable that plant communities have a large effect on sedimentation and accretion rates on the marsh platform. For example a study by Rooth *et al*. in 2000 found that stands of *Phragmites australis* occurred at higher elevations than the surrounding marsh, due to the species' high rates of below ground accumulation. Sediment capture is also affected by plant morphology, with plants that have a higher density of leaves or branched and rough stems capturing more sediment (Palmer *et al*. 2004, Yang 1998). Plant controls on sedimentation rates are further affected by growing/flooding season and proximity to sediment source (Darke 2003, Pasternack *et al*. 2001).

Finally, marsh evolution and accretion rates are dependent on the chemical makeup of the sediment, which can be either mineral (inorganic), or organic (Cahoon *et al*. 1997). Reed *et al.* (2008) found that sediment composed of organic matter will not contribute to long-term elevation gain due to microbial degradation and plant die-off, though the same study also found that in fresh tidal marshes organic sedimentation is often the primary driver of sediment accretion.

Although general processes regarding sediment capture and hydrodynamics that have been extensively studied in tidal salt marshes may be applicable to freshwater tidal ecosystems, few investigations have explored the effect of freshwater morphological diversity on sediment capture. The focus of this study is to evaluate how general hypotheses regarding sediment accretion previously developed in salt marshes (e.g. Morris 2007) apply to freshwater tidal communities. Additionally, prior measurements of sediment accretion at the Jug Bay Wetland Sanctuary site where this study was carried out have revealed losses in elevation on the marsh platform (Childers 1993).

This study was organized around three primary research hypotheses:

1) Species composition of habitat in Jug Bay affects sedimentation rates.
2) Sedimentation rates are dependent on their distance from sediment sources
3) Rates of accretion will affect whether Jug Bay tidal freshwater marshes remain in equilibrium with sea level rise.

Materials and Methods:

2.1 Study Site and Sampling Design:

Reed *et al*. (2008) found that the current rate of sea level rise in the upper part of the Chesapeake Bay is approximately 3 mm/yr, while sedimentation rates for Jug Bay are thought to be over 15 mm/yr (Boumans *et al.* 2002). Nutrient delivery is expected to increase in the Chesapeake Bay region due to climatic effects and land use changes that will likely result in greater runoff (Reed *et al*. 2008) and an increase in sedimentation.

The Jug Bay Wetland Sanctuary (JBWS) protects over 700 hectares of tidal freshwater marsh, along with forests, meadows and fields. It is located along the eastern bank of the Patuxent River, which drains into the Chesapeake Bay. In the early 1900s a railroad was constructed through the sanctuary that operated through 1934 before being dismantled. The JBWS is also a component of the National Estuarine Research Reserve (NERR), a key partner in this study. Figure 1 shows the location of the two sampling sites, situated alongside the permanent plant community transects monitored by the NERR. The Observation Creek transect was located in a diverse plant community composed predominantly of spatterdock (*Nuphar advena*), arrow arum (*Peltandra virginica)* and narrow leaf cattail *(Typha angustifolia).* The Otter Point site occurred in a spatterdock dominated community and acted as a control.

At each of the two sites, a transect line was set running perpendicular from the creek bank, traversing the low marsh up to the high marsh zones. Using the same point-line-intersect method (NERR protocol) used to record plant community characteristics in the parallel NERR transects, plants were collected and bagged every 2.5 m at Otter Point and approximately every 5-7 m at Observation Creek in order to establish a possible source-distance relationship for sediment capture rates. In addition, to record changes in plant communities and densities, plants were collected from 5 plots at Observation Creek and 3 plots at Otter Point using a quarter meter square quadrat. Plants were collected through late June and early July during the peak growing season.

2.3 Data Collection

Sediment capture was measured using a technique developed by Yang (1998) in *Scirpus* marsh communities. Plant samples from the various species collected were bagged and identified by site and transect location at low tide following a high spring tide. Back at the lab at Chesapeake Bay Laboratories, these samples were rinsed of sediment into collection jars using deionized water and filtered onto pre-weighed 40µM glass filters. Filters were then dried at 60° C and weighed after several days using a micro-balance, establishing two similar dry weights separated by a day to establish that the samples had reached a true dry weight.

Rinsed plants were measured for their morphological characteristics (stem length, diameter, leaf length, width) and then dried at 60° C and weighed to obtain dry weight biomass. Surface area of spatterdock and arrow arum leaves was measured in three ways: 1) Using the morphological leaf measurements, 2) estimating the area of an ellipse, and 3) by scanning the leaves into the computer and analyzing surface area using the ImageJ software program available from the National Institutes of Health (Rasband 1997).

2.4 Data Analysis:

The sediment collected from the plant surfaces was compared to the vegetation surface area to determine how the morphology of the plants affects sediment capture. Because prior studies have found that sediment availability decreases exponentially with distance from the creek bank (Leonard and Luther 1995), these results were plotted with the transect location data to determine a source-distance relationship. Surface area and biomass were also plotted with transect location data to find out if plants exhibit plasticity in their morphological measurements.

To analyze sediment capture at the community level, sediment rinsed from plants collected by plot were summed and plotted against transect distance and density. Projected area of plots was also calculated and plotted against sediment capture by summing the surface area of all measured plot plants and dividing by the volume of water reaching each plot at the height of the spring high tide. Finally, an estimate of accretion was calculated for each site and compared to predicted measures of sea level rise. This value was estimated by multiplying the sediment captured over the tidal cycle in this study by the five-month growing season of the freshwater tidal community. Phemister (2004) measured the organic versus inorganic portion of the sediments as well as bulk density at Observation Creek, close to one of the transects used in this study. These values (89.4% inorganics and 0.70 g/cm^3 bulk density) were used to transform the estimated annual sediment capture rates into sediment accretion values. Data collected during this study was compared with values measured by Pasternack and Brush (2001), Darke and Megonigal (2003), Khan and Brush (1994), and salt marsh sedimentation rates compiled by L. Harris (unpubl.).

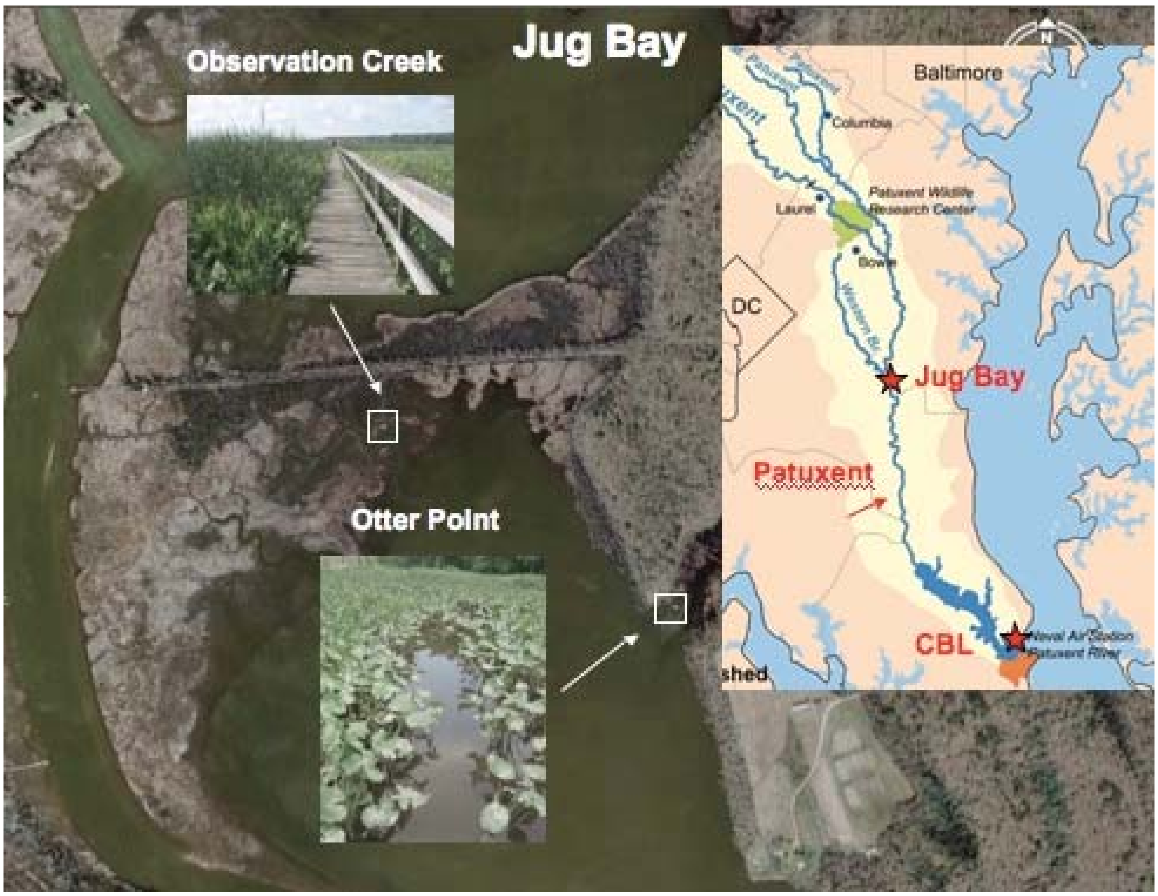

Figure 1. Location of Jug Bay Wetland Sanctuary and two transects.

Results and Discussion:

3.1 Determining if there is a relationship between plant morphology and sediment capture

Captured sediment vs surface area

Plant surface area was plotted against captured sediment per plant for both sites (Figure 2). At Observation Creek no obvious relationship was found between plant surface area and the amount of sediment captured, though interestingly data points seemed to be grouped together by species. The same pattern was more clearly seen at

Otter Point, where plants captured approximately the same amount of sediment regardless of surface area.

Captured sediment vs biomass

When captured sediment was analyzed in relationship to plant biomass at Observation Creek and Otter Point, a similar pattern to that seen with surface area emerged (Figure 3). Data points appeared to be grouped by species, but within species captured sediment was fairly constant across biomass values, as is clearly illustrated by the graphed biomass values at Otter Point. Interestingly, spatterdock at both Observation Creek and Otter Point captured similar amounts of sediment. This is surprising considering that the amount of sediment captured is usually spatially variably due to differences in sediment loads and plant habitats (Pasternack and Brush 1998).

While there does seem to be a pattern in the amount of sediment captured and plant species, this cannot be explained by simple morphological measurements such as surface area or biomass by themselves.

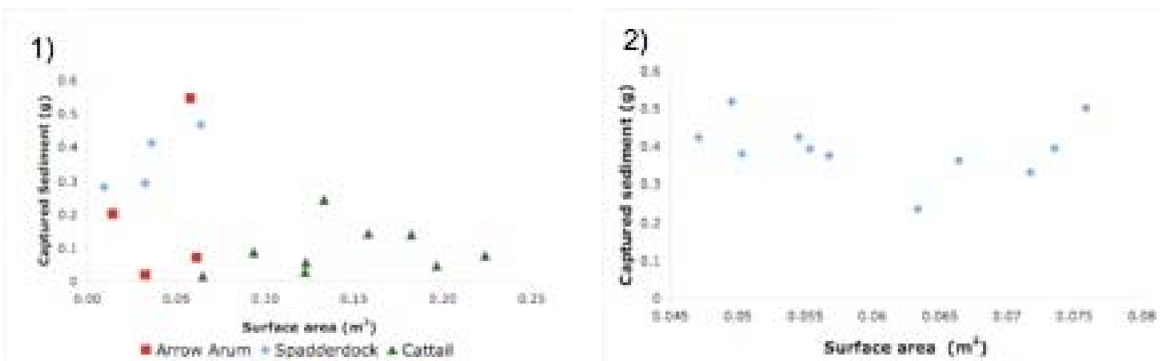

Figure 2. Captured sediment vs surface area of individual plants at 1) Observation Creek and 2) Otter Point.

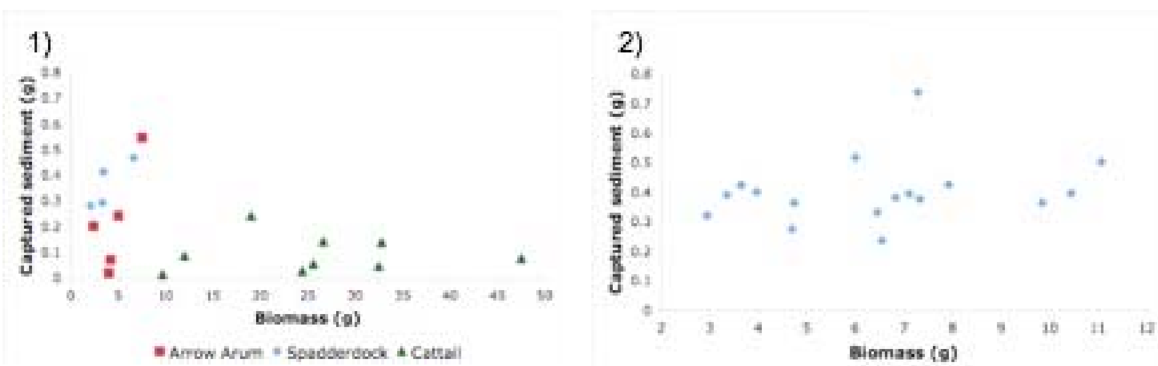

Figure 3. Captured sediment vs biomass of individual plants at 1) Observation Creek and 2) Otter Point.

3.2 Establishing a source-distance relationship for sediment capture

Captured sediment vs distance

There does initially seem to be a negative relationship between sediment captured and distance from the sediment source at Observation Creek, however no such relationship is seen at Otter Point (Figure 4). As with surface area and biomass, spatterdock appear to capture the same amount of sediment regardless of distance along the transect. A closer study of the Observation Creek site shows that the relationship observed is actually one between species and distance. Plant species are grouped together along the transect in such a way that the amount of sediment captured falls off between one plant community and the next, but within communities there is no real difference in the amount of sediment captured.

A similar finding was reported by Pasternack *et al*. (2000), where no significance was found in sedimentation and distance from nearest channel (sediment source). Pasternack *et al*. explained these results from other reports that only major creek and third order tributaries affect sedimentation (Stoddart *et al*. 1989)

Elevation vs distance

To attempt to explain the grouping of species along the transect, elevation was graphed against distance since this has been found to be a determining factor of species composition (Pasternack *et al*. 2000, Darke and Megonigal 2003). Elevation was estimated using calculated habitat indices published in Pasternack *et al*. (2000). It was found that plant communities did indeed occur in separate zones determined by elevation (Figure 5). Spatterdock tended to occur at lower elevations, followed by arrow arum and cattail at the highest elevation. At the end of the transect furthest from the sediment source, where elevation began to decrease again, the plant community transitioned back into broad leaf arrow arum and spatterdock.

Surface area and biomass vs. distance

Surface area and biomass were plotted by distance in order to determine if plants were exhibiting plasticity in their morphological characteristics. It was hypothesized that plants growing closer to the sediment source might have larger surface areas in order to take advantage of the high concentration of sediment available to them. However, this was not supported by the data at Observation Creek or Otter Point (Figure 6). This is a logical finding, given that no clear relationship had previously been found between the amount of sediment captured and surface area or biomass.

In looking at the graphs plotting surface area and biomass against captured sediment, there is a close similarity in the positioning of data points across the graph. This is explained by the near 1:1 allometric relationship between surface area and biomass (Figure 7).

Captured sediment vs distance at the community level

If the amount of captured sediment is analyzed over an area instead of per individual plant, a very clear negative relationship emerges between sediment capture and distance at Otter Point (Figure 8). The farther along the transect the plot is, the less sediment is captured per meter square. Plot density was used to calculate the sediment captured per meter square value, suggesting plot density plays a large role in determining how much sediment is captured.

Looking at the same relationship in mixed plant communities at Observation Creek, density still seems to have an impact on the amount of sediment captured in a plot (Figure 9). The major outlier to this trend is in the spatterdock dominated plot closest to the sediment source. Here it can be seen that spatterdock as a community captured much more sediment then the mixed cattail dominated plot, even though it occurred at a much lower density. Density was also shown to have an important role in determining sediment deposition in a study performed by Darke and Megonigal (2003).

Captured sediment vs projected area

When sediment captured per meter square is plotted against projected area, a very exciting relationship is found. Projected area is a measure that takes into account density, volume and surface area and can be thought of as the area of obstruction presented by vegetation to free floating sediment moving through three dimensional space. When plots are separated into those dominated by spatterdock and mixed plant communities, both show an increase in sediment captured per meter square as projected area increases (Figure 10). However this relationship is greatly emphasized in the spatterdock dominated plots, where a small increase in projected area results in a much larger increase in the amount of sediment captured per plot. The slope of the relationship for the mixed community plots is much more gradual. Furthermore, even at individual projected area values, spatterdock shows a much higher amount of captured sediment than does the mixed communities. This suggests that spatterdock is very efficient at capturing sediment.

A source-distance relationship does exist in regards to sediment capture, however it is an indirect relationship based primarily on plant communities and their tendency to occupy separate zones according to marsh elevation. A much more reliable predictor of sediment capture is the projected area value.

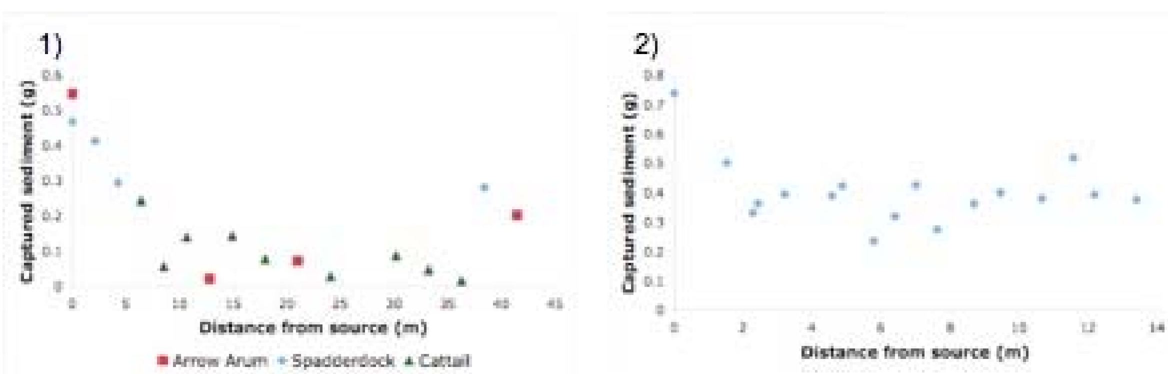

Figure 4. Captured sediment vs distance from sediment source (tidal creek) per individual plants at 1) Observation Creek and 2) Otter Point.

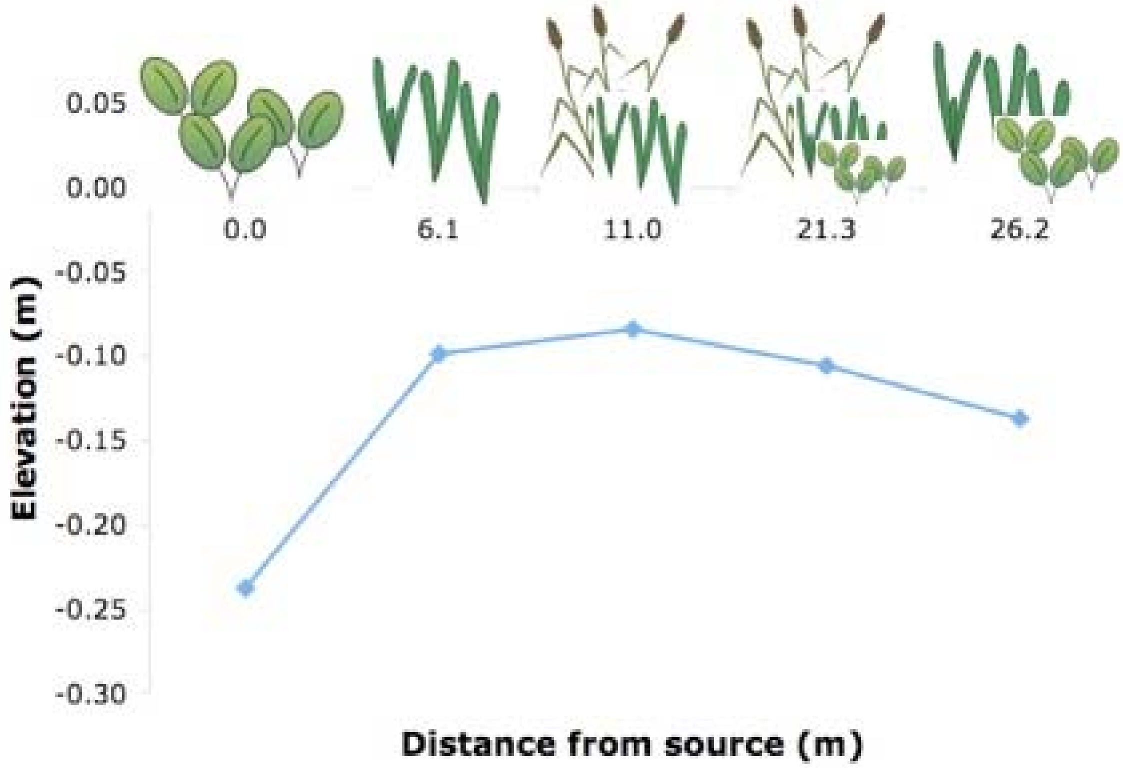

Figure 5. Elevation and plant community vs distance from sediment source (tidal creek) at Observation Creek.

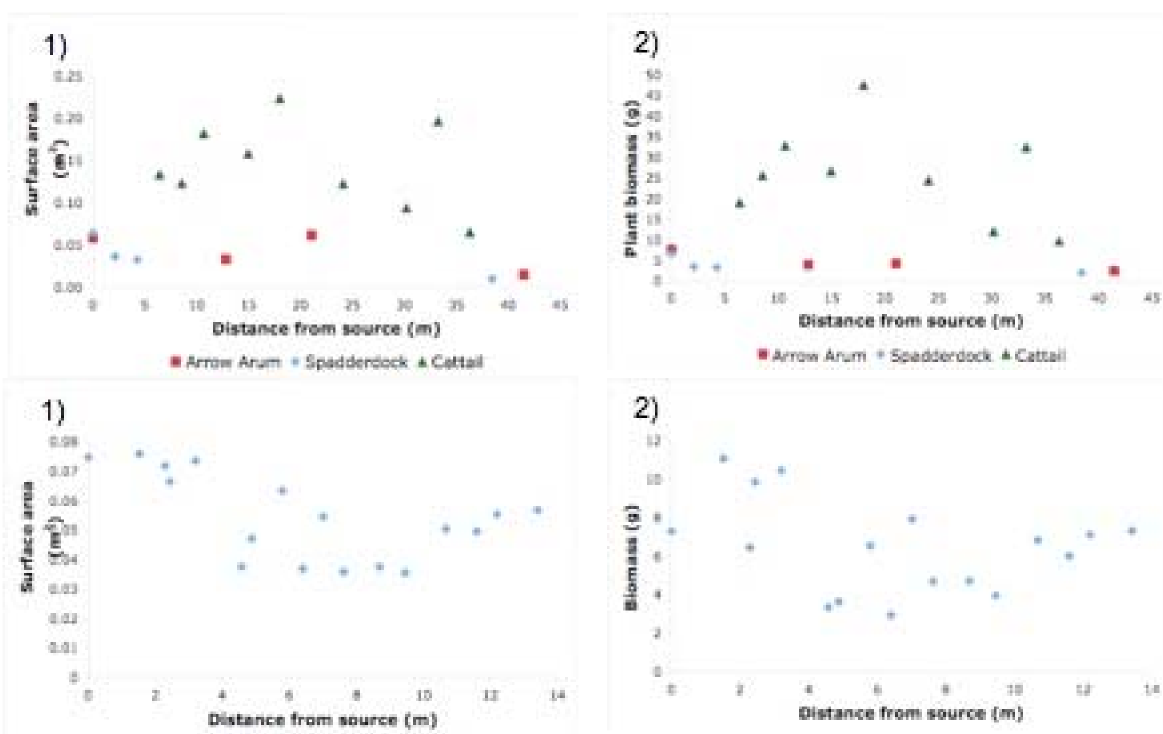

Figure 6. Surface area vs distance from sediment source (tidal creek) at 1a) Observation Creek and 2a) Otter Point and biomass vs distance from sediment souce at 2a) Observation Creek and 2b) Otter Point.

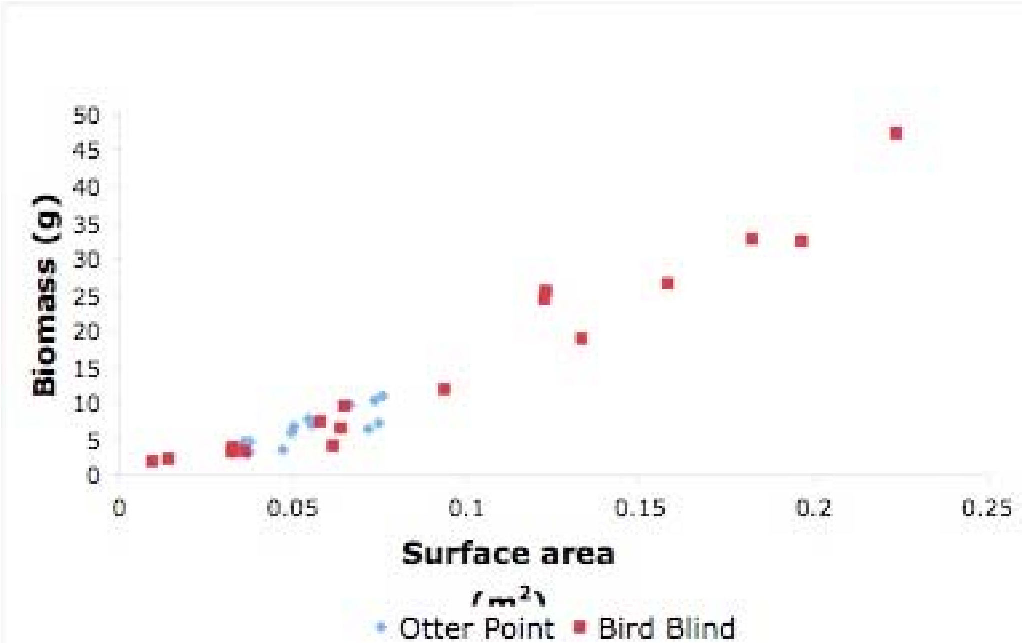

Figure 7. Mixed plot surface area vs biomass.

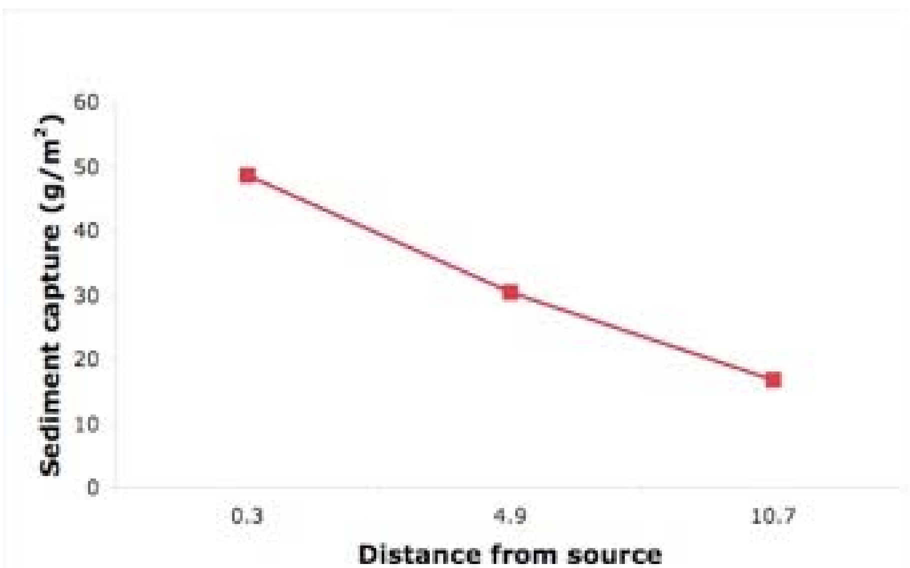

Figure 8. Captured sediment per meter square vs distance from sediment source (tidal creek) at Otter Point.

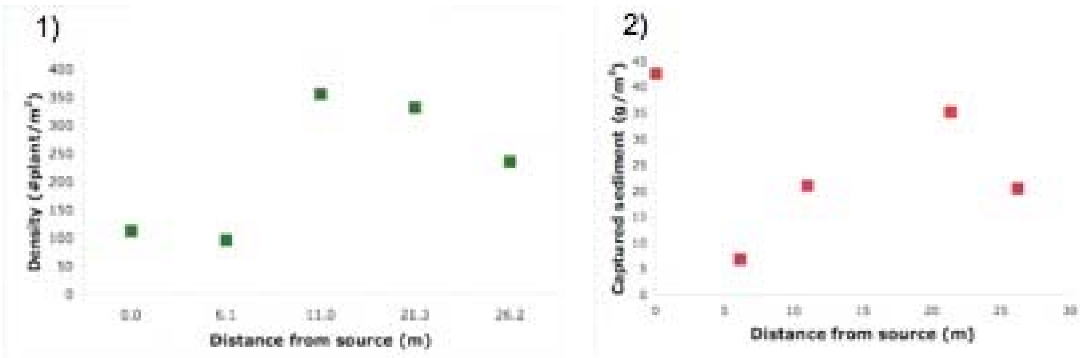

Figure 9. Relationship between 1) plant density and 2) captured sediment per meter square vs distance at Observation Creek.

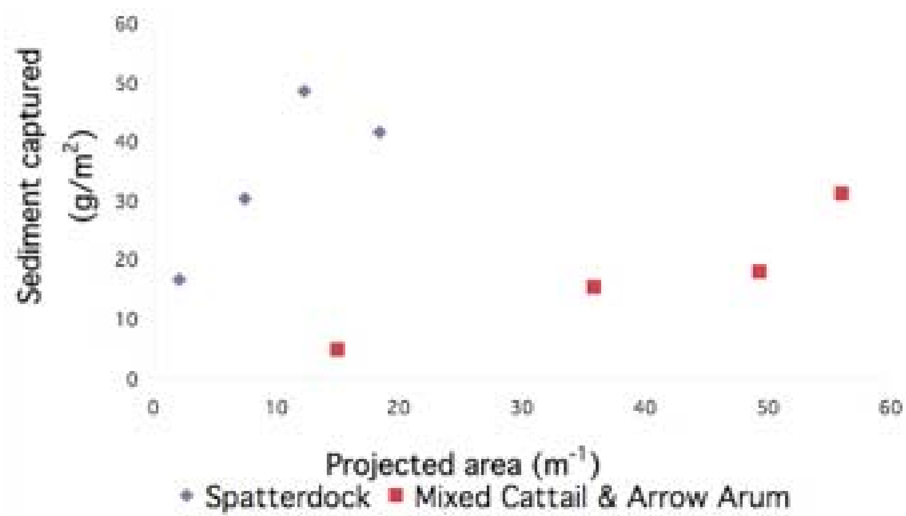

Figure 10. Captured sediment per meter square vs projected area by plant community

3.3 Site accretion in the face of rising sea levels.

Accretion rates attributable to sediment capture

Accretion rates for Observation Creek and Otter Point were estimated using the equation

1) $$\partial\eta/\partial t = \frac{\text{Sediment Captured}(g \cdot m^{-2} \cdot d^{-1}) \text{ x Vegetation Time}(d \cdot y^{-1}) \text{ x Inorganic\%}}{\text{Bulk Density Marsh Platform}(g \cdot m^{-3})}$$

Because the majority of sediment deposition occurs during the summer (Pasternack and Brush 2001), vegetation time was calculated as being the same as the growing season, from June until October. The estimate of the amount of sediment that would be put down in one year from this study's data was very similar to those found in Khan and Brush (1999) and all habitat types were found to be greater than the rate of sea level rise at 2-4 mm per year (Childers *et al*. 2003) (Figure 11). It is possible that this disparity between accretion rates and sea level rise is due to upland erosion and run off from land clearing (Childers *et al*. 2003). However, because sediment deposition can be up to 10 times higher during the growing season (Darke and Megonigal 2003), looking only at the summer months gives an incomplete picture of yearly accretion rates.

According to these calculations, floating communities (spatterdock) put down almost twice as much sediment as the other two communities, which has also been found in other studies (Pasternack and Brush 2001). While this community is closest to the sediment source, it is also the most endangered from sea level rise. It is possible that the marsh has evolved in this way in order to protect the communities most at risk.

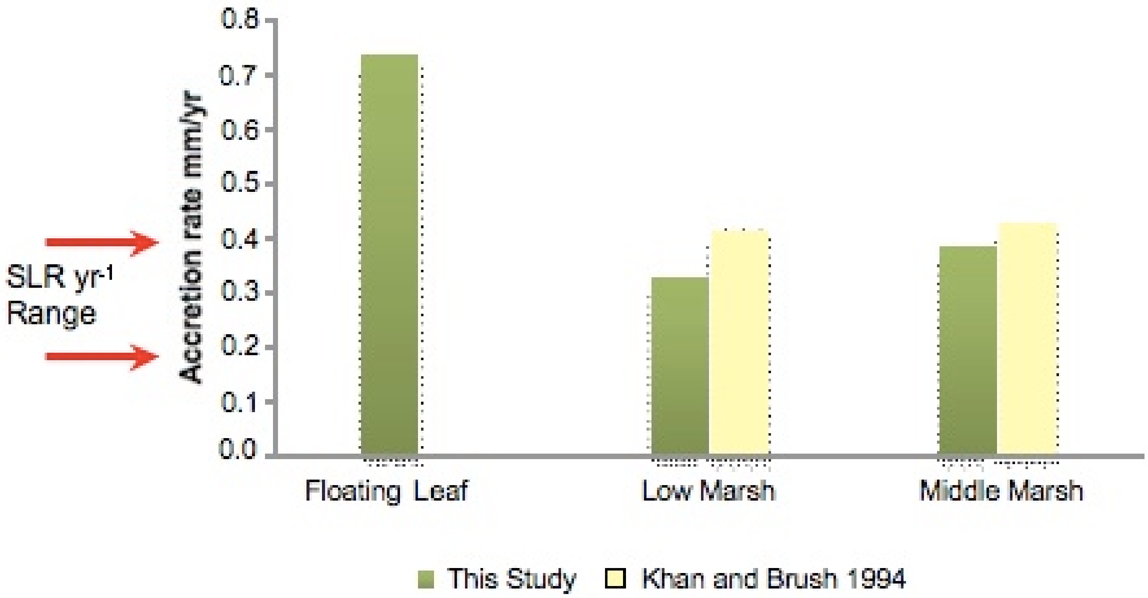

Figure 11. Accretion rate per year of plant communities by type.

Conclusion:

Individual morphological measures and distance from source values do not explain sediment capture rates, though projected area, which takes into account surface area, density and volume, does seem to be a good predictor of plant sediment capture ability. The relationship between sediment capture and distance to sediment sources seems to be indirect, with the true relationship occurring between distance to sediment source and plant community type, as a result of elevation change. Vegetation type is likely the most important determinate of sediment deposition, as long as concentration of suspended sediment is not limiting (Darke and Megonigal 2003, Boumans 2002, Pasternack *et al*. 2000, Pasternack and Brush 1998). Of the different plant communities studied, those dominated by spatterdock seem to be the most efficient at capturing sediment.

Possible ideas for future research would be to incorporate TSS (Total Suspended Solids) and deposition rates in order to determine the relative importance of these processes with sediment capture in sediment accretion rates. Also, in future research it is suggested that plants be washed free of all sediment and then be allowed to experience at least one tidal cycle before being collected to ensure that captured sediment measurements were guaranteed to have been from that tidal cycle. Finally, because only two transects were studied, it is unclear how typical the sites were in regards to the greater marsh. More study sites would be valuable in establishing normality.

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