EFFECTS OF DIFFERENT VEGETATION COVER TYPES ON SEDIMENT DEPOSITION IN THE TIVOLI NORTH BAY TIDAL FRESHWATER MARSH, HUDSON RIVER, NEW YORK

ELIZABETH LOAIZA
University of Costa Rica, San Pedro 10101 CR

MENTOR SCIENTIST: DR. STUART E. G. FINDLAY
Institute of Ecosystem Studies, Millbrook, NY 12545 USA

Abstract. Tidal wetlands are known for their capacity to improve water quality by trapping sediment during tidal exchange. They are considered good sediment retention environments, but little is known about the spatial variability of sedimentation within these wetlands, and the role vegetation plays in sediment retention. This research studied the magnitude and dynamics of sediment deposition and its variability across different vegetation cover types in the Tivoli North Bay tidal freshwater marsh. Deposition trends were examined by using rubber collection discs (RCD) and compared among graminoid, broadleaf, submerged aquatic and shrub vegetation. Significantly different patterns in deposition were related to different vegetation types. Broadleaf and submerged aquatic vegetation showed greater sediment deposition when compared to graminoid and shrub vegetation. Higher deposition is attributed to a greater proximity to the tidal creek, an increase of water depth when inundated, and the presence of greater plant surface area for sediment adhesion. Higher biomass and stem density present in the graminoid and shrub vegetation, promoting sedimentation by slowing current velocities, did not have a large effect on accretion in the studied marsh plant assemblages. Vegetation characteristics are an important spatial component of sedimentation dynamics and may affect marsh stability and vegetation change over time.

Key words*: Tivoli North Bay, wetland, sediment deposition, vegetation*

INTRODUCTION

Tidal freshwater wetlands are considered good sediment retention environments (Boto and Patrick 1979), where tidal exchange supplies particles that may be deposited (Kiviat *et al*. 2006). Tidal wetlands are known for their capacity to transform a variety of constituents such as nutrients, contaminants, and suspended sediments during tidal exchange, thereby improving the quality of out-flowing water (Krieger 2003, Olde Venterink *et al*. 2006). Constituents entering these wetlands at a daily basis can be transformed or retained by biological, physical or chemical processes (Krieger 2003). The deposition rate for tidal marshes of the Hudson River has been measured to range from 0.05-2.9 cm yr^{-1} (Kiviat *et al*. 2006).

Several benefits associated with sediment deposition include the removal of particle-associated contaminants such as heavy metals, the retention of nutrients thus improving plant productivity, and the ability to keep up with rising sea levels by maintaining surface elevations relative to adjacent rivers (Bote and Patrick 1979, Olde Venterink *et al*. 2006).

Marsh surface sedimentation is a discontinuous process (Reed 1989), varying in both time and space (Pasternack and Brush 1998). The type of vegetation in freshwater tidal habitats influences the trapping of sediment loads (Olde Venterink *et al*. 2006), resulting in high deposition variability within a marsh. Some studies have attributed sediment deposition rates to plant habitat characteristics such as plant stem density, morphology and marsh elevation (Gleason *et al*. 1979, Leonard and Luther 1995, Pasternack and Brush 1998). Plant stems on a marsh surface are effective at capturing particles by reducing water velocity and by providing a surface for sediment adhesion (Serodes and Troude 1984, Pasternack and Brush 1998, Olde Venterink *et al.* 2006). The amount of time stems are submerged and the frequency of inundation could also account for sedimentation variability (Jordan and

Correll 1986, Heimann and Roell 2000). These effects on sediment dynamics in freshwater tidal wetlands have not yet been explored extensively and remain only partially understood.

In this study, the magnitude and dynamics of sediment deposition and their variability across different vegetation cover types were assessed by measuring sediment accretion trends in graminoid, broadleaf, submerged aquatic and shrub freshwater wetland vegetation.

METHODS

Study site

The study was conducted in Tivoli North Bay (TNB), a freshwater tidal wetland on the eastern bank of the Hudson River, approximately 160 km north of lower Manhattan, New York, USA. This embayment is part of the Hudson River National Estuarine Research Reserve System (HRNERR), and is one of the largest wetlands in the Hudson River estuary covering approximately 100 ha. As an enclosed marsh separated from the river by a railroad embankment, it exchanges water with the Hudson River during each tidal cycle throughout two bridge openings in the railroad dike.

The tidal range along the river is 1.5m, with a 20-30cm difference in water level from near to spring tide (Kiviat *et al.* 2006). Tides fall twice daily throughout the marsh inside a system of branching tidal creeks and pools separated by the vegetated high marsh surface. Tidal exchange with the Hudson River is considered the primary sediment and surface water inflow source into the Tivoli North Bay. Non-tidal surface water received from two streams upland was not accounted for as a second sediment source because of their insignificant water and sediment supply.

Short-term sediment deposition was studied in four distinct vegetation cover types: 1) graminoid vegetation (GV); 2) broadleaf vegetation (BV); 3) submerged aquatic vegetation (SAV); and 4) shrub vegetation (SS). Total vegetation cover studied at Tivoli North Bay consisted in approximately 54% for GV, 16% BV, 2% SAV, and 11% SS. Graminoid vegetation is predominant in the upper intertidal zone consisting of cattail (*Typha*), bulrushes (*Scirpus tabernaemontani*) and wild rice (*Zizania aquatic*). Woody shrubs and trees (SS) are also found at these high elevation areas. BV occurring as an emergent in the lower intertidal zone includes spatterdock (*Nuphar advena*), pickerelweed (*Pontederia cordata*) and arrow arrum (*Peltandra virginica*). The middle intertidal zone is occupied by a mixture of broadleaf and grass-like vegetation. SAV species include water-chestnut (*Trapa natans*) and wild-celery (*Vallisneria americana*). Mean aboveground biomass calculations measured by Kiviat and Beacher (1991) attained in mid-July to mid-August during peak biomass resulted in 1,100g/m^2 for cattail, 150 g/m^2 for spatterdock and 360 g/m^2 for water-chestnut.

Sediment deposition measurement

Sediment deposition variability was examined during 6 weeks, between June and August 2008. Measurements of sediment deposited on the marsh surface were collected using rubber collection disc (RCD) sediment traps 12cm in diameter and 0.1cm thick. The texture and thinness of the RCDs resembled the marsh surface without modifying depositional processes. Rubber disks were collected weekly during low tide, and replaced with new ones. The sediment collected from the disks was dried and weighed to determine total deposition. After combusting (at 450º C) and reweighing the sediment, total organic content was calculated.

Four study locations, representative of the marsh area, were designated as transects 1, 2, 3 and 4. Each transect spanned two or more vegetation types and a station for a particular vegetation type consisted of one or two sets of two RCDs. Of the 52 discs placed during the 6 week period, 8 disks were for SAV, 18 for BV, 19 for GV and 7 for SS. Transect 1 included all vegetation types except SAV, two different sets of disks for BV positioned 3m horizontally from the creek edge, one set for SS positioned 2m behind BV disks, continuing 10m by the creek edge was one set of disks for GV with a distance of 2m from the creek edge. Transect 2 consisted in a line of three sets of disks placed perpendicular to the creek edge, in which all three were separated 10m from each other, included only BV as the first two following with GV. All vegetation types were covered in site 3 with two sets for SAV placed inside the creek, one set for BV, SS and GV all 2m from the creek edge. GV was placed on one side of the creek from SAV, and 5m away SS and BV each situated on opposite sides of the creek. Transect 4 contained a line of four sets of disks placed perpendicular to the creek edge, separated 10m from each other, BV among the first two followed by GV.

Data on water inflow and outflow turbidity, water level, water and air temperatures were provided by continuously monitoring data sondes and automated samplers permanently placed at the southern bridge opening by the Hudson River Environmental Conditions Observing System (HRECOS).

Data collected from temperature loggers (ibuttons) placed on each sampling site were matched with water and air temperature profiles from the same time interval, to calculate the duration of inundation. Records on water level for that corresponding time allowed estimating the water elevation during inundation. Water samples collected at various locations in the north and south end of the marsh to test for environmental differences such as sediment source, total suspended solids (TSS) and dissolved organic carbon (DOC) concentrations found similar values among sites.

Analyses of variance (one-way ANOVA) were used to determine significant differences in daily total deposition, organic deposition and percent organic deposition per cm^2 among different vegetation cover types, in the four different locations and within spring and neap tides. Post hoc comparisons among vegetation types were performed by Games/Howell tests given unequal variances and different group sizes.

RESULTS

Turbidity measurements confirmed no storms or unusual climatological events during the observation period, therefore, inflow water with normal sediment loads were assumed.

Contrary to the expected, spring and neap tides had no effect on total, organic or % organic deposition ($P= 0.995$) for GV and BV, the only vegetation type present in all four sites, considering that unforeseen difficulties prevented access to all four sites on a weekly basis, resulting in two different locations covered per week.

Each sediment measurement was corrected for the length of time submerged. Both BV and SAV spent more time inundated and had greater water depth than GV and SS. Overall, SAV was inundated 100% of the time, BV between 70-100%, GV 10-20% and SS 2-10%.

Sediment deposition quantities showed that BV and SAV collected significantly greater amounts than GV and SS (P=0.000, Figure 1). BV contributed most of the deposition in the marsh over the studied period, depositing 498% more than GV, (20.44 $g/cm^2/day$ compared to 4.10$g/cm^2/day$, respectively). A similar pattern was observed for organic deposition (P=0.000). Total sediment deposition for all vegetation types ranged from 0.5-54.3$g/cm^2/day$.

The percentage of organic content followed a different trend. BV and SAV collected significantly less (P=0.000) than GV and SS (Figure 2). Total organic matter deposited for all vegetation types ranged from 0.12–5.8$g/cm^2/day$.

There was no difference for total deposition, organic and % organic for BV among the different sites (P=0.594). Regarding GV, total deposition in site 1 was significantly greater compared to site 2 (P=0.006) and site 3 (P=0.003) (Figure 2).

DISCUSSION

BV and SAV sample measurements may be underestimated because of possible resuspension of sediment deposited on discs at moment of removal due to water coverage at almost all times, including low tide.

Magnitudes in sediment deposition were different among the vegetation cover types, demonstrating the effect of a combination of factors influencing sedimentation. For total, organic and % organic deposition, deposition patterns were similar for BV and SAV, whereas GV was similar to SS. BV and SAV showed patterns of greater sediment deposition with respect to both mineral and organic material. Both vegetation types share plant and habitat characteristics, which contribute in making these areas high deposition environments. Considering the entire marsh, although BV covers 71% less area than GV, it deposits 33% more sediment daily. Not only the type of vegetation but also the total area covered by that vegetation has an impact on whole-marsh dynamics.

Relatively dense vegetation was expected to increase sediment deposition by reducing water velocities in vegetation structure, thus contributing to create an adequate environment for sediment settling out of suspension. This was tested by Leonard and Luther (1995) when measuring the change in mean flow velocity and turbulence intensity of particulate and dissolved matter into coastal marshes. Following this line, BV was found to have greater deposition possibly associated with its greater plant surface area. However, although GV presented a high vegetation stem density, there was a decrease in sedimentation. GV was not effective at capturing sediment particles with its greater aboveground biomass and higher stem density, the latter, also present in SS, had little effect on sedimentation. Perhaps a biomass to plant surface area ratio should be accounted for in future studies.

Increased water depth in all vegetation communities is expected to increase sediment deposition. Proximity to the tidal creek increases water depth when inundated. Low accretion patterns found for GV and SS could have been affected by greater distance from the creek edge. Because of GV and SS's high elevation, these areas received only periodic flushing from tidal water, having much smaller water depths when compared to BV and SAV. Accretion patterns have shown to be highest in the lowest marsh areas adjacent to the main bridge opening or to tidal creeks within the marsh, suggesting that marsh surface elevation, water depth, duration, and frequency of inundation, are key factors affecting sedimentation.

Spatially variable sedimentation rates were found within different vegetation types and different locations in the marsh only when comparing GV among all four sampling sites. Transect 1, located near the inflow source (main bridge opening), and transect 4 (close to second bridge opening), collected significantly greater loads of sediment than the other sampling sites located further inside the marsh. This augment in sediment accumulation responds to sediment availability controlled by the proximity to the sediment source (Cahoon, 1994; French *et al*., 1995; Reed *et al*., 1997). Proximity to sediment source, therefore, even in the elevated marsh areas such as that in GV, favors sediment deposition.

The studied plant assembly should be considered when discussing the sedimentation processes or factors affecting accretion. The location of each vegetation type in relation to the others was similar throughout the marsh. GV and SS were always situated behind BV and SAV, while the latter were the closest to the tidal creek. Consequently, sediment entering the site could have been deposited mostly first in SAV and BV before coming into contact with GV and SS. Because of this, we were unable to separate distance from tidal creek and plant characteristics, two important accretion-influencing factors.

In general, organic content in sediment increased with increasing site elevation. Disks from GV stations contained large amounts of plant litter, mainly its own senescent leaves, explaining the high relative organic content found. Accretion in these stations results mostly by organic matter accumulation rather than by inorganic sediment trapping.

This study suggests that higher deposition is related to greater proximity to the tidal creek, to an increase of water depth when inundated and to the presence of greater plant surface area for sediment adhesion. Higher biomass and stem density present in the graminoid and shrub vegetation, promoting sedimentation by slowing current velocities, did not have a large accretion effect in the studied marsh plant assemblage. Differences are linked to a combination of factors, the separation of these merits future study. Vegetation characteristics are an important spatial component of sedimentation dynamics and may affect marsh stability and vegetation change.

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LITERATURE CITED

Boto, K. G. and W. H. Patrick, Jr. 1979. Role of wetlands in the removal of suspended sediments. p. 479–489. *In* P. E. Greeson, J. R. Clark, and J. E. Clark (eds.) Wetland Functions and Values: The State of Our Understanding Proceedings of National Symposium on Wetlands, American Water Resources Association, Minneapolis, MN, USA.

Donald, R. Cahoon. 1994. Recent Accretion in Two Managed Marsh Impoundments in Coastal Louisiana. Ecological Applications 4: 166-176.

French, T. Spencer, A. L. Murray, N. S. Arnold. 1995. Geostatistical Analysis of Sediment Deposition in Two Small Tidal Wetlands, Norfolk, U.K. J. R. Journal of Coastal Research 11: 308-321.

Gleason, M.L., D.A. Elmer, N.C. Pein, and J.S. Fisher.1979. Effects of stem density upon sediment retention by salt marsh cord grass, *Spartina alterniflora* Loisel. Estuaries 2:271-273.

Heiman, D.C and M.J. Roell. 2000. Sediment loads and accumulation in a small riparian wetland system in northern Missouri. Wetlands 20: 219-231.

Jordan, T.E and D.L. Correll. 1986. Flux of particulate matter in the tidal marshes and subtidal shallows of the Rhode River Estuary. Estuaries 9:310-319.

Kiviat, E. and E. Beecher. 1991. Vegetation in fresh-tidal habitats of Tivoli Bays, Hudson River National Estuarine Research Reserve. Report to National Oceanic and Atmospheric Administration. Hudsonia Ltd., Annandale, New York.

Kiviat, E., S. E. G. Findlay, and W. C. Nieder. 2006. Tidal Wetlands. In: J. S. Levinton and J. R. Waldman (eds.). The Hudson River Ecosystem. Cambridge University Press.

Krieger, K. A. 2003. Effectiveness of a coastal wetland in reducing pollution of a Laurentian great lake: hydrology, sediment, and nutrients. Wetlands 4: 778-791.

Leonard, L.A. and M.E Luther. 1995. Flow hydrodynamics in tidal marsh canopies. Limnology and Oceanography 40:1474-1484.

Olde Venterink, H, J. E. Vermaat, M. Pronk, F. Wiegman, G.E.M. van der Lee, M.W van den Hoorn, L.W.G. Higler, J.T.A.Verhoeven, 2006. Importance of sediment deposition and denitrification for nutrient retention in floodplain wetlands. Applied Vegetation Science 9: 163-174.

Reed, D.J. 1989. Patterns of sediment deposition in subsiding coastal salt marshes, Terrobonne Bay, Louisiana: The role of winter storms. Estuaries 12:222-227.

Reed, D.J., de Luca, N., Lee, A. 1997. Effect of Hydrologic Management on Marsh Surface Sediment Deposition in Coastal Louisiana. Estuaries 20: 301-311.

Serodes, J.B. and J.P. Troude. 1984. Sedimentation cycle of a freshwater tidal flat in the St. Lawrence Estuary. Estuaries 7:119-127.

APPENDIX

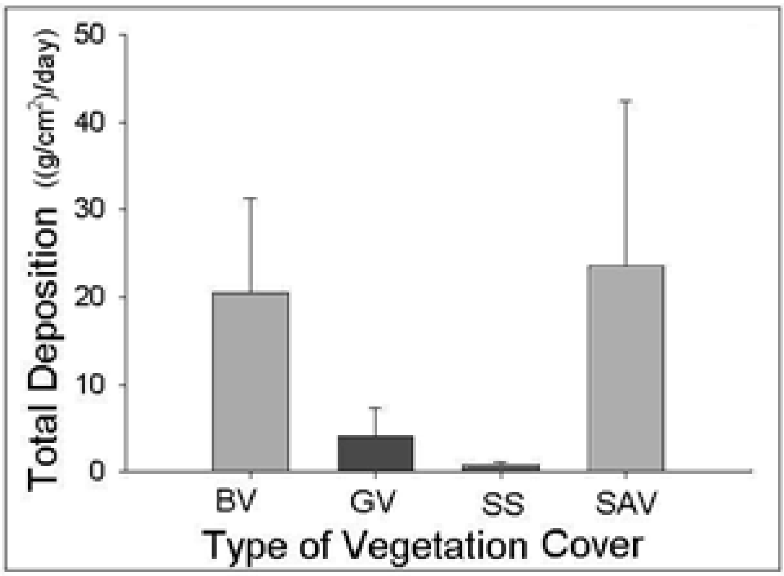

FIGURE 1. Sediment deposited for each cover type averaged across observations spanning 6 weeks.

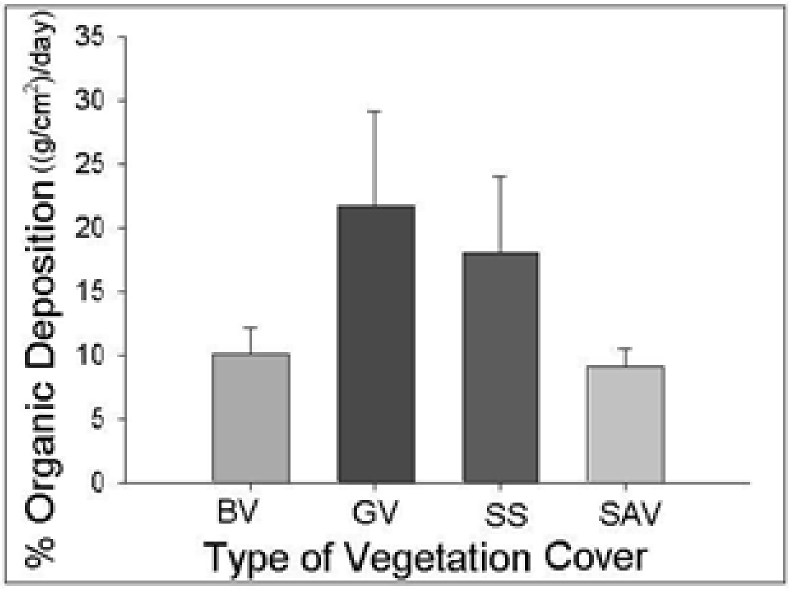

FIGURE 2. Percent of organic deposition for each vegetation type.