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# Sedimentation Cycles in a River-Mouth Tidal Freshwater Marsh

GREGORY B. PASTERNACK[1]
GRACE S. BRUSH
*Department of Geography and Environmental Engineering*
*The Johns Hopkins University*
*Baltimore, Maryland 21218*

**ABSTRACT: Tidal freshwater marshes are critical buffers that exist at the interface between watersheds and estuaries. Little is known about the physical dynamics of tidal freshwater marsh evolution. Over a 21-mo period, July 1995 to March 1997, measurements were made of biweekly sediment deposition at 23 locations in a 3.8-ha tidal freshwater marsh in the Bush River subestuary of the upper Chesapeake Bay. Biweekly accumulation showed high spatial and temporal variability, ranging from $-0.28$ g cm$^{-2}$ to 1.15 g cm$^{-2}$. Spatial variability is accounted for by habitat differences including plant associations, elevation, and hydrology. Temporal variability is accounted for by interannual climate variability, the growth cycles of marsh plants, stream-marsh interactions, forest-marsh interactions, and animal activity.**

## Introduction

Throughout the Chesapeake Bay, fluvial sediments are rapidly building river-mouth deltas (DeFries 1986; Jordan et al. 1986; Brush 1989; Marcus and Kearney 1991). Previous research has demonstrated that the accumulating sediments derive from post-European settlement deforestation, agriculture, and urban development (Gottschalk 1945; Roberts and Pierce 1976; Brush 1984; Khan and Brush 1994; Hilgartner 1995). Analysis of 39 cores from 10 western tributaries showed a doubling of sedimentation rates when land under cultivation reached 40–50% in comparison to presettlement deposition rates (Brush 1984).

In the upper Chesapeake Bay tributaries, water is nearly fresh (<0.5‰) and river-mouth deposits form tidal freshwater wetlands. Because these wetlands include riparian forests, intertidal marshes, and subtidal fronts they provide a wide array of nutrient-rich aquatic and riparian habitats that sustain high plant diversity and productivity (Simpson et al. 1983a; Rozas and Odum 1987; Odum 1988). Suspended sediment and nutrient flux studies (e.g., Simpson et al. 1983b; Wolaver et al. 1983; Dubinski et al. 1986) along with measurements of plant decomposition (e.g., Whigham et al. 1989; Findley et al. 1990) have shown that tidal freshwater marshes are critical buffers protecting estuarine and coastal waters from sediments, nutrients, and toxics derived from deleterious upland human activities and land use. Stratigraphic and paleoecologic reconstructions of the long-term history of tidal freshwater marshes extend the results of the flux studies and point toward the long-term overriding impact of European settlement on tidal freshwater marsh evolution (Orson et al. 1990; Orson et al. 1992; Khan and Brush 1994; Hilgartner 1995).

One aspect of tidal freshwater wetlands that remains poorly understood is the temporal dynamics of marsh surface accretion in response to various external forces and internal processes. Orson et al. (1992) postulated a surface accretion model to explain seasonal conditions in Delaware marshes. According to the model, significant summer deposition is stabilized by vegetation that dies off in the early autumn and blankets the marsh surface. While some of this material becomes incorporated into the marsh matrix, an unknown amount is thought to be resuspended and exported during the winter months when no vegetation is present.

The research reported in this paper involved intensive field monitoring that shows the seasonal sedimentation cycle existing in a tidal freshwater marsh, with particular attention to differences between habitats. This research also tests the surface accretion model of Orson et al. (1992).

## Study Location

The Otter Point Creek component of the Chesapeake Bay-Maryland National Estuarine Research Reserve is a 138.7-ha river-mouth tidal freshwater wetland at the head of the Bush River in the upper Chesapeake Bay (Fig. 1). Otter Point Creek consists of a 54.4-ha riparian forest, a 84-ha marsh, a 0.3-ha upland forest island, and an expansive subtidal front. An additional 3.8-ha of marsh and 1.4-ha of riparian forest are present in the HaHa Branch Wetland at the mouth of a small basin adjacent to Otter Point Creek (Fig. 1).

The marsh vegetation at Otter Point Creek and HaHa Branch Wetland has been mapped and analyzed (Pasternack et al. in preparation). Nine dis-

[1] Corresponding author; tele: 410/889-3354; fax: 410/516-8996; e-mail: gpast@jhu.edu.

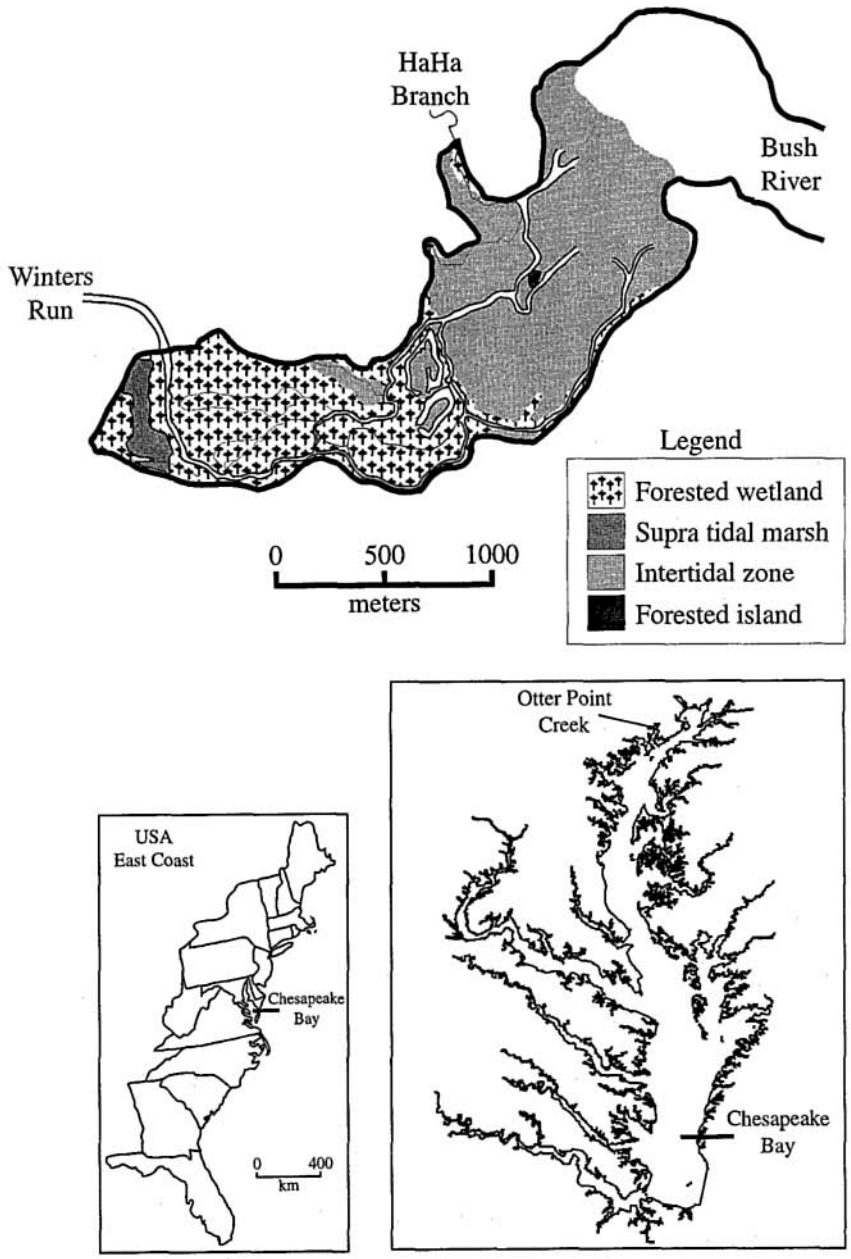


Fig. 1. Map of the Chesapeake Bay showing the location and delta zonation of Otter Point Creek at the head of the Bush River.

tinct plant associations are present at Otter Point Creek in seven tidal freshwater wetland habitat types. Six of the habitat types are present in the HaHa Branch Wetland, including pioneer mudflat, floating leaf, low marsh, middle marsh, high marsh, and shrub marsh (Fig. 2). These habitats occur along a linear environmental gradient (Pasternack et al. in preparation). Water flow in the marsh is controlled primarily by astronomical tides and meteorological forcing, and in the riparian forest by runoff from the 110 km$^2$ Winters Run basin. The water level range in the low marsh averages 0.7 m, but during Hurricane Fran (September 1996), it reached 1.9 m (Pasternack unpublished).

European settlement in the Bush River watershed began in the mid-Seventeenth Century and resulted in deforestation of up to 80% of the landscape by the beginning of the Twentieth Century (Hilgartner 1995). Today the Winters Run basin is 48% forest, 23% grassland, 21% urban-developed, 7% farmland, and 1% other (Maryland Office of

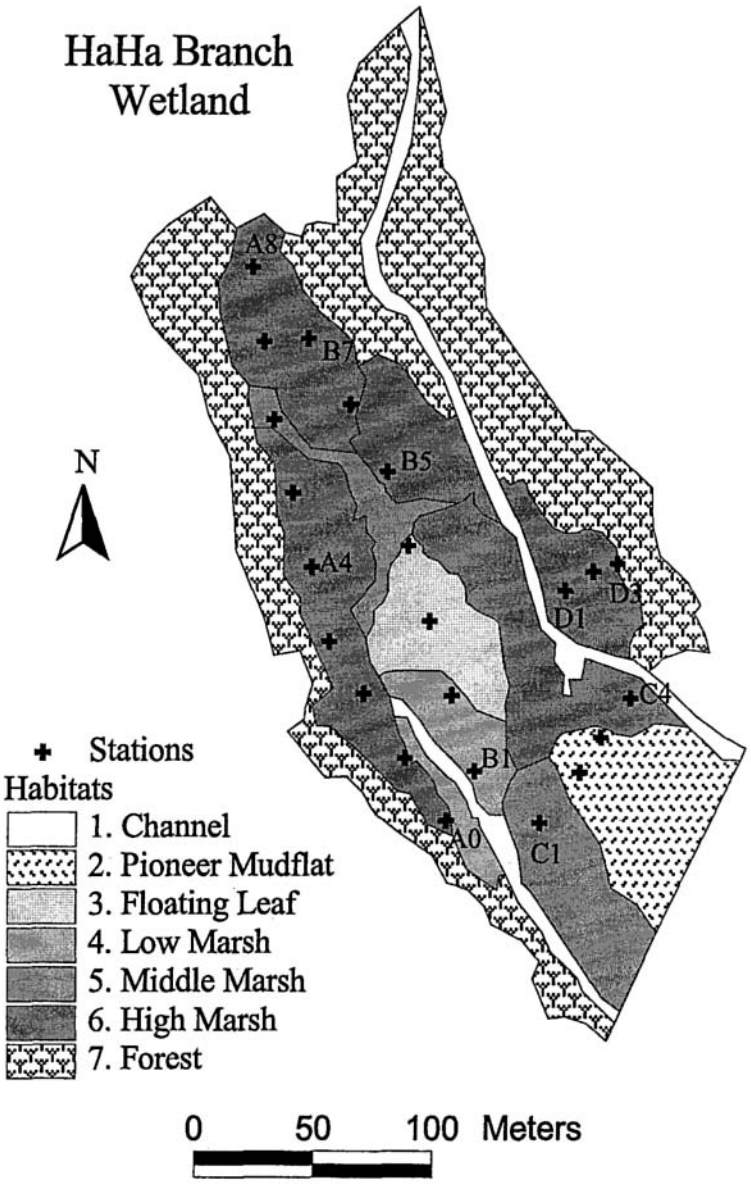


Fig. 2. Map of the HaHa Branch Wetland showing the tidal freshwater wetland habitats and sediment sampling locations.

Planning personal communication). The consequences of land clearance and intensive land use on Otter Point Creek were documented by Hilgartner (1995) using paleoecological reconstructions, and are evident in a sequence of maps and aerial photos from 1836 to 1994. These independent records reveal a rapidly prograding river-mouth delta with a succession of habitats.

## Materials and Methods

Several methods for monitoring sedimentation have been developed for a variety of depositional settings (e.g., Serodes and Troude 1984; Reed 1989; Hupp and Bazemore 1993). Marker horizons, filter paper, stage rods, tree burial dendrochronology, and infrared backscatter detectors are specific examples. For this study a method capable of handling the variable, high deposition rates common in river-mouth systems and of yielding samples for sedimentological and chemical time series analysis was required. To obtain these data, lightweight 1.22 m × 2.5 cm dia. (4′ × 1″) aluminum rods were sunk into the ground and capped with a detachable 20 cm × 20 cm (8″ × 8″) ceramic tile flush with the marsh surface. The detachment mechanism for a tile involved gluing a 5-cm-long acrylic tube with a 2.5-cm inner diameter to the bottom of each tile. The ceramic tile-acrylic tube

assembly drops over the anchor rod and is not susceptible to motion unless subjected to extreme lift forces.

Twenty-three sediment sampling stations using the above apparatus were established along four transects at HaHa Branch Wetland in July 1995 (Fig. 2). Horizontal positions and elevations were surveyed by the Geodetic Measurements Section personnel from the nearby United States Army Aberdeen Proving Ground using a Trimble® real-time kinematic Global Positioning System approach (vertical precision of ±1–3 cm). The vegetation adjacent to each station was mapped using 1-$m^2$ quadrats and included five of the seven tidal freshwater marsh habitat types (Pasternack et al. in preparation). Fifteen stations are located in the high marsh (A0–A5, A7, A8, B5–B7, C4, D1–D3), two in the middle marsh (A6, C1), two in the low marsh (B1, B2), three in the floating leaf habitat (B3, B4, C3), and one in the pioneer mudflat (C2). The distribution of stations among the habitats is approximately representative of their relative areas.

The stations were visited biweekly at low tide from July 7, 1995, to March 13, 1997, and the accumulated sediments were scraped into prewashed and preweighed glass jars. During the winter months, tiles (and sediment) froze in place, so sedimentation rates were averaged between the last collection date of the autumn and first collection date after thawing. Over time, tiles showing significant accumulation were raised to maintain a position at the marsh surface. Surface samples 0.3 m from each station were collected infrequently in a 25-ml acrylic tube, transferred to a preweighed Ziplock bag, and weighed to determine bulk density. Erosion was recorded by measuring the height of each tile edge and the anchor rod above the marsh surface, averaging the measurements, and multiplying by the bulk density. Local scour around the stations was minimal in most instances. Where erosion and deposition were concurrent, the erosion measurements were carried out first to assess conditions below the tile, and then the accumulated sediments on top of it were collected. The difference between erosion and deposition was calculated to obtain the net sediment accumulation in these instances.

All retrieved samples were processed in the laboratory to obtain wet weight, dry weight, water content, organic content, and sedimentation rate. Exteriors of jars were washed and dried to remove excess material. Jars and samples were weighed wet, opened and heated in an oven at 80°C until completely dry, and weighed again. Even though samples were collected biweekly, dry weights per tile were annualized to units of g $cm^{-2}$ $yr^{-1}$ to facilitate comparison with previously reported values.

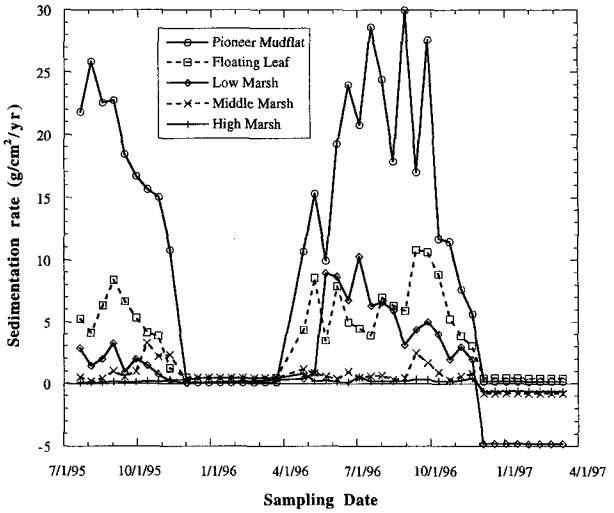


Fig. 3. Cycles of deposition in tidal freshwater marsh habitats indicated by biweekly monitoring of accumulation and erosion. Winter values are averaged over a longer sampling period due to extreme field conditions.

Where significant accumulation occurred, a fraction of each dried sample was homogenized in a crucible and combusted at 450°C until the mass was nearly constant, which was found to be 8 h. For instances where dried weights were low or much organic material was present, the whole sample was homogenized and then combusted at 450°C. After combustion, samples were re-weighed to yield loss-on-ignition. No adjustment of loss-on-ignition was made to account for sulfur oxidation to $SO_2$, because this element is not a significant constituent in the freshwater environment (Odum 1988). Thus, loss-on-ignition is a good measure of organic content.

## Results

The deposition rates measured at the HaHa Branch Wetland ranged from −7.43 g $cm^{-2}$ $yr^{-1}$ to 29.96 g $cm^{-2}$ $yr^{-1}$ over the 88-wk period of the study. Eighty percent of measured values fall between 0 g $cm^{-2}$ $yr^{-1}$ and 2 g $cm^{-2}$ $yr^{-1}$, with a mean rate of 1.21 g $cm^{-2}$ $yr^{-1}$ and a median rate of 0.16 g $cm^{-2}$ $yr^{-1}$. These rates correspond to 19 g and 2.5 g of material deposited per tile per 2 wk, respectively, and indicate a net growth for the marsh over the study period.

When deposition rates for stations within the same habitat are averaged for each period, a similar cycle of deposition is evident for all habitats even though the magnitudes are different (Fig. 3 and Table 1). The number of habitat-averaged values varies between habitats because the floating leaf and low marsh tiles were destroyed during the harsh winter of 1996. To test the hypothesis that

TABLE 1. Statistical data from field monitoring at the HaHa Branch Wetland, Maryland.

| Habitat | Total Deposition | | | Organic Deposition | | | Organic Content | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | Standard Deviation | N[a] | Mean | Standard Deviation | N[a] | Mean | Standard Deviation | N[a] |
| Pioneer Mudflat | 10.79 | 10.30 | 42 | 0.88 | 0.84 | 42 | 7.93 | 1.03 | 42 |
| Floating Leaf | 4.37 | 3.13 | 34 | 0.50 | 0.36 | 34 | 13.06 | 2.39 | 34 |
| Low Marsh | 1.59 | 4.41 | 34 | 0.42 | 0.30 | 26 | 14.07 | 7.47 | 26 |
| Middle Marsh | 0.52 | 0.91 | 42 | 0.20 | 0.17 | 42 | 23.32 | 6.26 | 42 |
| High Marsh | 0.11 | 0.39 | 42 | 0.03 | 0.09 | 42 | 41.11 | 7.42 | 42 |

[a] N = number of biweekly, habitat-averaged values.

the habitat-averaged time series are nonrandom, each was put through the $u$ test of randomness for runs above and below the median (Freund and Simon 1991). All series were found to be nonrandom above the 97% confidence level, with most well above the 99% level (Table 2a). Beginning in spring, deposition increases steadily. Throughout summer it remains high, but with significant variability. In autumn deposition drops off rapidly overall, but an influx of organic riparian debris raises the sedimentation rates for the middle and high marsh sites. Depending on the timing of the onset of winter and the duration of below freezing conditions, ice locks deposited materials in place or lack of ice allows for significant erosion from late November to mid March.

The pattern in the quantity of organic sedimentation mimics the total sediment pattern, but the relative percentage of organic material (i.e., percent loss-on-ignition) shows a different trend. Organic deposition ranged from $-1.38$ g cm$^{-2}$ yr$^{-1}$ to 2.56 g cm$^{-2}$ yr$^{-1}$. The mean rate of organic deposition (0.16 g cm$^{-2}$ yr$^{-1}$) is significantly higher than the median value (0.06 g cm$^{-2}$ yr$^{-1}$), once again illustrating a strong positive skewness in the deposition distribution.

By averaging the organic deposition rates for stations within the same habitat type, similar annual cycles are revealed for the magnitude of organic material, as were found for total sediment (Fig. 4 and Table 1). There are fewer organic deposition and organic content habitat-averaged values because negative and zero accumulation rates yield no sediment for determining these quantities. Once again, the $u$ test of randomness for runs above and below the median provides strong confidence (99%) that the time series are nonrandom (Table 2a). The pioneer mudflat received the most organic material (0.88 g cm$^{-2}$ yr$^{-1}$) and the high marsh the least (0.03 g cm$^{-2}$ yr$^{-1}$). However, when organic content is plotted as a percentage of total material, an inverted nonrandom annual cycle is found (Fig. 5 and Table 2a). The relative amount of organic material is highest in the high marsh (41.11%) and lowest in the pioneer mudflat (7.93%). In winter, organic content is steady due to ice conditions. When the ice melts in March, organic material is decomposed and exported out of the system. Organic content drops through spring as exports continue and plants grow. The minimum is reached in mid summer when plants

TABLE 2. Test for nonrandom behavior in A) marsh habitat sedimentation time series and B) summer sedimentation only. Low p-values indicate nonrandom behavior.

| Habitat | p-value | | |
|---|---|---|---|
| | Total Sediment | Organic Fraction | Organic Percent |
| A | | | |
| Pioneer Mudflat | 2.89E-07 | 2.89E-07 | 8.87E-05 |
| Floating Leaf | 2.66E-03 | 2.66E-03 | 0.06 |
| Low Marsh | 2.48E-04 | 6.81E-04 | 0.02 |
| Middle Marsh | 0.02 | 2.46E-03 | 8.91E-04 |
| High Marsh | 2.94E-04 | 2.94E-04 | 2.55E-04 |
| B | | | |
| Pioneer Mudflat | 0.03 | 1.23E-03 | 0.27 |
| Floating Leaf | 0.27 | 0.03 | 0.50 |
| Low Marsh | 7.72E-03 | 7.72E-03 | 0.27 |
| Middle Marsh | 0.27 | 0.11 | 0.50 |
| High Marsh | 1.23E-03 | 0.27 | 7.72E-03 |

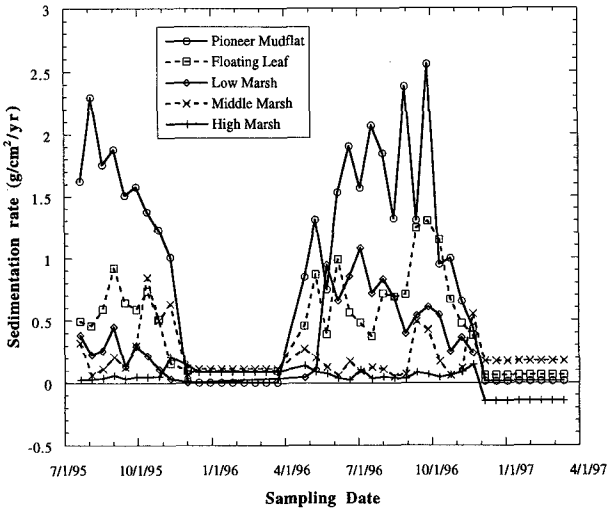


Fig. 4. Organic deposition is highest in the pioneer mudflat and lowest in high marsh but cycles through time. Winter values are averaged over a longer sampling period due to extreme field conditions.

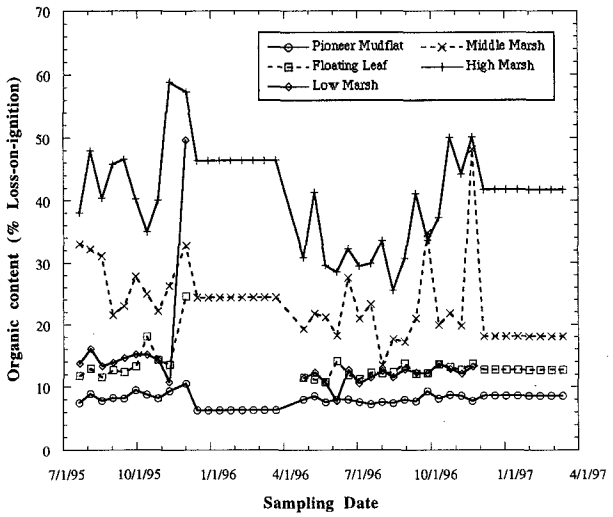


Fig. 5. The organic percentage of sediment deposition is highest in the high marsh and lowest in the pioneer mudflat. Winter values are averaged over a longer sampling period due to extreme field conditions.

are at a peak density and total sedimentation rates are highest. As plants are blown down and decay in late summer and autumn, the organic content of deposited materials increases. Additional pulses of organic detritus are contributed by adjacent riparian buffer zones, particularly to the high marsh. In late autumn some of this debris migrates to the middle and low marsh areas before ice locks it in place for the winter.

To quantitatively assess whether deposition is significantly different between marsh habitats, statistical tests were applied to the habitat-averaged data. Before any statistics were used, tests were conducted to assess adherence to the key assumptions made in standard statistical tests, including ANOVA. All three datasets failed Cochran's C test, Bartlett's test, and Hartley's test (performed using Statgraphics 2.1 by Manugistics, Inc.) of the null hypothesis that the standard deviations of each habitat's data are the same (Till 1974). Without similar standard deviations, the datasets are most amenable to analysis using nonparametric statistics in which data are ranked from lowest to highest and then the rankings are analyzed. Nonparametric statistics provide quantitative results and have been widely applied throughout earth sciences, including paleoecology (Reyment 1971), geomorphology (Doornkamp and King 1971), and marine science (Miller and Kahn 1962). These statistics require the data to be random, but it has already been shown that the datasets are nonrandom. However, if just June through September values are used, then the null hypothesis that data are random holds up well (Table 2b).

The nonparametric Kruskal-Wallis test is a rank–sum test that assesses whether multiple independent random samples come from identical populations (null hypothesis) or their means are not all the same (Freund and Simon 1991). When this test was applied to the habitat-averaged summer values of total sedimentation, organic content, and organic percentage, the resulting p-values were all less than $10^{-10}$, demonstrating that at least some of the means in each category are different from one another.

The rank-sum U test for large samples assesses the null hypothesis that two samples come from identical populations (Freund and Simon 1991). This test was applied to the habitat-averaged summer values of each dataset (Table 3). For total sedimentation and organic sedimentation, all means were found to be different at a confidence level greater than 99.98%, except for floating leaf versus low marsh, which were different with a confidence level of 92% for the total and 86% for just organic. The differences between the floating leaf and low marsh habitats are significant, and further confidence is justified by the low marsh sites' susceptibility to winter erosion in contrast to the floating leaf sites, which did not experience erosion. For organic percentage, the means of floating leaf and low marsh are different with only a 65% confidence, indicating that the type of accumulations are similar, even though their fates are different. Otherwise, all means are confidently different (>99.8%).

Within habitat variability evident in the data is largely attributable to local geomorphic and biological processes. In the low marsh, the sedimentation rate at station B1 declined faster in autumn than that at station B2. During winter, B1 experienced the most severe erosion (Fig. 6). Furthermore, B1 receives a peak deposition in May during the *Peltandra virginica* (arrow arum) growing season, while B2 does not reach a peak until July. These differences are consistent with the fact that B1 is adjacent to the HaHa Branch Wetland tidal inlet while B2 is at a slightly higher elevation 30 m further inland (Fig. 2). As the plants grow in late spring, inflowing sediment is trapped close to the tidal inlet first. As summer progresses and the elevation of the low marsh in the vicinity of the inlet rises, more sediment bypasses this area and is deposited further inland.

The middle marsh is indicated by the presence of *Leersia oryzoides* (rice cutgrass), *Eleocharis ambigens* (spike rush), and *Typha angustifolia* (narrow-leaved cattail) (Pasternack et al. in preparation), and is particularly susceptible to animal disturbance. Station A6 is in a middle marsh habitat impacted by beaver activity, including plant uproot-

TABLE 3. Rank-sum U test for large samples that compares the means of habitat-averaged A) total sedimentation, B) organic sedimentation, and C) organic percentage. Low p-values demonstrate that the two samples come from different populations.

| Habitat | Pioneer Mudflat | Floating Leaf | Low Marsh | Middle Marsh | High Marsh |
|---|---|---|---|---|---|
| A | | | | | |
| Pioneer Mudflat | X | $p < 8E\text{-}06$ | $p < 8E\text{-}06$ | $p < 8E\text{-}06$ | $p < 8E\text{-}06$ |
| Floating Leaf | X | X | $p = 0.08$ | $p < 8E\text{-}06$ | $p < 8E\text{-}06$ |
| Low Marsh | X | X | X | $p < 2E\text{-}05$ | $p < 8E\text{-}06$ |
| Middle Marsh | X | X | X | X | $p < 7E\text{-}05$ |
| High Marsh | X | X | X | X | X |
| B | | | | | |
| Pioneer Mudflat | X | $p < 8E\text{-}06$ | $p < 8E\text{-}06$ | $p < 8E\text{-}06$ | $p < 8E\text{-}06$ |
| Floating Leaf | X | X | $p = 0.14$ | $p < 2E\text{-}05$ | $p < 8E\text{-}06$ |
| Low Marsh | X | X | X | $p < 9E\text{-}05$ | $p < 8E\text{-}06$ |
| Middle Marsh | X | X | X | X | $p < 2E\text{-}04$ |
| High Marsh | X | X | X | X | X |
| C | | | | | |
| Pioneer Mudflat | X | $p < 8E\text{-}06$ | $p < 5E\text{-}05$ | $p < 8E\text{-}06$ | $p < 8E\text{-}06$ |
| Floating Leaf | X | X | $p = 0.35$ | $p < 2E\text{-}05$ | $p < 8E\text{-}06$ |
| Low Marsh | X | X | X | $p < 2E\text{-}05$ | $p < 8E\text{-}06$ |
| Middle Marsh | X | X | X | X | $p < 2E\text{-}03$ |
| High Marsh | X | X | X | X | X |

ing, surface layer mixing, and channel maintenance. This activity decreased the overall elevation of the area, increased flooding depth and duration, and increased sedimentation for a 2-mo period in late 1995 (Fig. 7). Sedimentation rates at A6 appear to return to normal in 1996 even though the vegetation reverted to low marsh species. However, in the winter of 1997 the station experienced significant erosion, illustrating the longer term consequences of local disturbance. In comparison, the middle marsh at station C1 showed none of these local dynamics (Fig. 7).

The high marsh in HaHa Branch Wetland is characterized by *Acorus calamus* (sweetflag) and is divided into three geomorphic regimes. The "frontal" high marsh is close to the tidal inlet and is responsive to wind and tide impacts (Fig. 8a). Stations A0 and A1 are close to the tidal inlet (Fig. 2), and both showed significant winter erosion in 1997. The "interior" high marsh is geomorphically quiescent, receiving meager deposits except for riparian debris in the autumn and again as it flushed through in the spring (Fig. 8b). No erosion occurred in this zone during the winter of 1997. The "levee" high marsh is the zone adjacent to the HaHa Branch channel where it empties into Otter

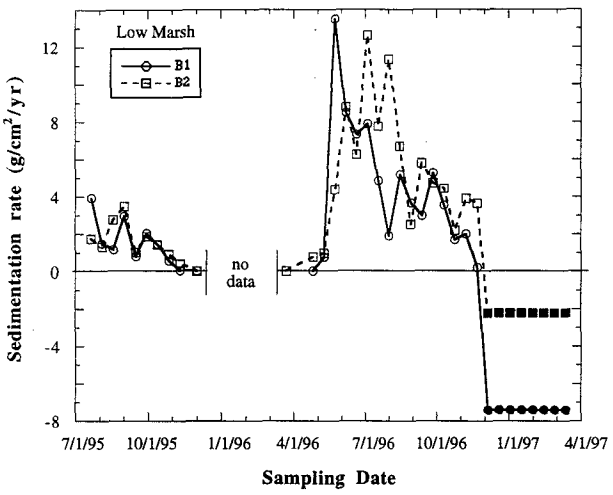


Fig. 6. Low marsh within-habitat variability shows a shorter period and decreased magnitude of erosion away from the tidal inlet. Severe ice conditions in 1996 broke these tiles. Filled symbols indicate data that is averaged over the winter when sites could not be visited.

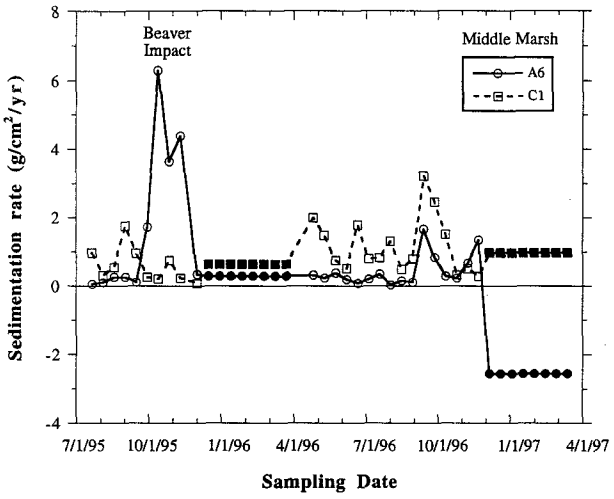


Fig. 7. Middle marsh areas are preferentially susceptible to muskrat and beaver activity, which results in short term increased sedimentation and long-term erosion potential. Filled symbols indicate data that is averaged over the winter when sites could not be visited.

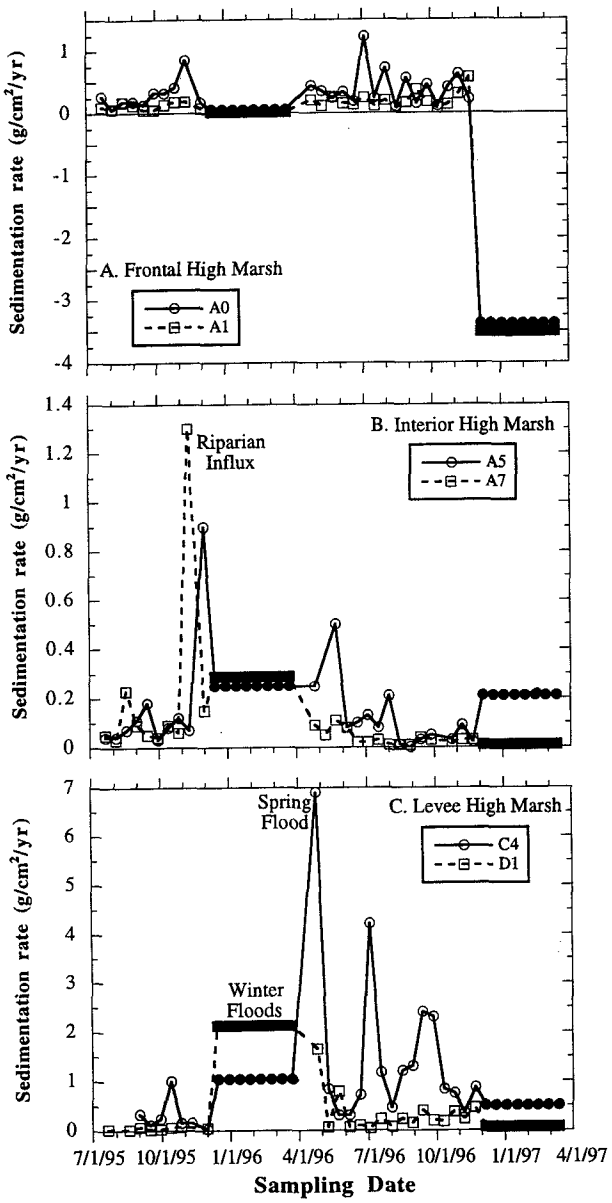


Fig. 8. The high marsh zone is subdivided into a) frontal, b) interior, and c) levee according to local hydrogeomorphic conditions. Filled symbols indicate data that is averaged over the winter when sites could not be visited.

Point Creek. Sedimentation in this zone is dominated by overbank deposition during storms that bring sands down from the HaHa Branch watershed (Fig. 8c). Periods with no storms receive a baseline deposition from tidal flooding, consistent with that received in the "interior" high marsh.

## Discussion

Data from the HaHa Branch Wetland show that sediment accumulation in tidal freshwater marshes varies in both time and space. The sedimentation cycles in the different habitats (Fig. 3) are a combination of two distinct components. The dominant component is a periodic step function whose low value is determined by interannual variability in winter ice coverage and whose high value is determined by the elevation, flooding, and trapping efficiency of distinct habitats. In 1996 all of Otter Point Creek, including HaHa Branch Wetland, was frozen from December until March. In contrast, the winter of 1997 was very mild and HaHa Branch Wetland was frozen only periodically in November, January, and February. The difference in sedimentation between 1996 and 1997 suggests that climate variability and climate change may be important direct controls on long-term accretion, in addition to their indirect influence via sea level changes. Superimposed on the dominant cycle is a fluctuating summertime component, which may be random (Table 2b) or may be caused by biweekly changes in meteorological forcing on the Bush River subestuary (Pasternack and Hinnov in preparation).

Local sources of variability, including animal activity, forest-marsh interactions, and stream-marsh interactions, were observed during the study at HaHa Branch Wetland. Beavers and muskrats redistributed sediment locally and built channels that allowed more material to be carried further in to the marsh during high tide. During the autumn, a significant amount of detritus entered the high marsh from the fringing forest, even in places where the fringe was only a few trees wide. Some of this debris flushed out in the spring, but most was observed to persist and be incorporated into the high marsh, contributing to long-term accretion.

In the past, the HaHa Branch channel cut across the area where the present marsh exists. The sand distributed by the paleochannel provides a firm substrate and higher elevation suitable for a narrow-leaved cattail middle marsh. This plant association provides suitable habitat for some wildlife. Sandy splay deposits from where the channel makes a sharp turn to the east are rapidly building up a pioneer mudflat which is bypassing the floating leaf stage of succession. It is likely that the stream-marsh interactions are responsible for the relatively high plant diversity at HaHa Branch Wetland (4.2 species per acre) compared to low diversity in the adjacent Otter Point Creek marsh (0.33 species per acre), where this interaction does not occur (Pasternack and Hilgartner unpublished data).

Because sedimentation rates in tidal freshwater marshes are a function of both external forces and internal processes, care must be taken in interpreting stratigraphic and paleoecologic records for

reconstructing historic conditions. Changes in sedimentation rates over time are a natural response to changing climate, topography, hydrology, plant dominance, animal activity, upland human activity, and geomorphic interactions.

## Acknowledgments

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## Sources of Unpublished Materials

Pasternack, G. B., unpublished. Water level records from 1993–1997 monitoring program at Otter Point Creek and HaHa Branch Wetland. Available from corresponding author.

Pasternack, G. B. and W. Hilgartner, unpublished. Species lists and habitat area data for Otter Point Creek and the HaHa Branch Wetland. Available from corresponding author.

Pasternack, G. B. and L. A. Hinnov. in preparation Meteorological controls on the hydrology of a tidal freshwater delta, upper Chesapeake Bay.

Pasternack, G. B., W. Hilgartner, and G. S. Brush. in preparation Spatial predictability of habitat dynamics in a tidal freshwater marsh.

Maryland Office of Planning. Planning Data Services, 301 West Preston St., 11th floor, Baltimore, Maryland. 21201-2365.

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