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Variation in Surface Sediment Deposition on Salt Marshes in the Bay of Fundy

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ABSTRACT

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The purpose of this study is to document the magnitude and variability in surface sediment deposition in salt marshes along the New Brunswick coast of the Bay of Fundy. We measured the thickness of sediment accumulated over clay marker horizons for the period of one year. Sediments were sampled at seven sites from the head of the Bay to the outer Bay, distributed to span a gradient in tidal range (6–12 m). Within each marsh sample plots were located to control for relative elevation, distance from vegetated edge, and vegetation zone. Accumulated sediment was greater than 4 cm on some plots. Sediment accumulation generally decreases with relative elevation and distance from vegetated edge within marshes and increases with tidal range, which tends to co-vary with suspended sediment concentration. We conclude that changes in sediment supply will have the greatest impact on low marsh accretion while changes in sea level or marsh hydrology will be most important to high marsh accretion.

ADDITIONAL INDEX WORDS: *Gulf of Maine, tidal range, elevation, sediment supply, vegetation.*

INTRODUCTION

Many investigators have employed marker horizons to examine controls on deposition of sediment from tidal waters to salt marsh surfaces. RANWELL (1964) reported the positive influence of tidal height, specifically spring tides in sedimentation above his marker plots in southern England where the tidal range was as high as 13 m. The influence of tidal height, as varying with tidal range, was demonstrated by HARRISON and BLOOM (1977) in a 10-year study on the meso-tidal Connecticut coast of Long Island Sound where tidal range varies from 0.8 to 1.7 m. At Flax Pond, also on Long Island Sound, RICHARD (1978) demonstrated the importance of elevation within a marsh, as elevation differences result in differences in duration and frequency of tidal submergence. Richard also noted the importance of severity of winter cold, in causing ice scour, thus loss of deposited sediment. After monitoring one year's accretion on a macro-tidal (2–3 m) marsh at Norfolk, England STODDART *et al.* (1989) found that in addition to elevation, rate of sediment deposition was also affected by proximity to a sediment source. In his report on a micro-tidal (0.8 m) marsh in Delaware STUMPF (1983) proposed that storms control the supply and movement of sediment on micro- and meso-tidal marshes, but would be expected to have less influence on marshes in macro-tidal regimes.

In contrast, WOOD *et al.* (1989) placed plots in 26 marshes along the Gulf of Maine coast where the tidal range varies from 2.7 to 5.4 m. After one year they found that sediment deposition corresponded to marsh morphology and that rafted ice deposits were a significant contribution to surface sediment deposition at some sites. No relationship between deposition and tidal range was found on the Maine coast; suggesting to WOOD *et al.* that such relationships do not extend to meso- and macro-tidal regimes.

In this study we re-examine the relationship of tidal range and sediment deposition on tidal marshes in a macro-tidal regime on the Gulf of Maine. Our objective is to document the magnitude and variability of sediment deposition in salt marshes in the Bay of Fundy. Although famous for its tidal range and its mud, there have been few empirical studies of sediment deposition in salt marshes of the Bay. Such information is necessary to construct a sediment budget for the Bay, recently identified as a critical need for the region (PERCY *et al.,* 1997). Information on variability in marsh accretion is also helpful to identify the potential impacts of alterations in sediment sources, sediment transport, and hydrology of the Bay's coastline.

We examine gradients of tidal submergence within and among marshes, as indicated by relative elevation and tidal range, respectively. We also consider variability with suspended sediment supply along the coast.

SITE DESCRIPTION

The Bay of Fundy is a macro-tidal system extending northeast from the Gulf of Maine. Tidal range increases from 6 m at the mouth of the Bay to more than 16 m at its upper reaches (CANADIAN HYDROGRAPHIC SURVEY, 1998). The Bay of Fundy seldom experiences hurricanes, and because it has a macro-tidal regime, storms are less important (in a sedimen-

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Table 1. *Weather recorded at two meteorological stations near the New Brunswick coast during the study period, June 1997–May 1998 (Canadian Meteorological Centre, 1997, 1998).*

Station	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	March
Saint John										
difference from normal (°C)	−0.2	0.1	−0.1	−0.1	−2.1	−1.8	−0.6	2.4	3.6	−1.5
# days with precipitation >1 mm	9	3	9	8	4	11	8	16	7	12
Moncton										
difference from normal (°C)	−0.9	0.5	0	1.1	−1.8	−1.4	−0.2	2.2	3.0	−1.3
# days with precipitation >1 mm	13	6	9	12	4	12	8	14	8	14

tological perspective) than on a micro-tidal coast, but storm surges of 2 m or more have been observed (Greenberg, 1984). During the period of our study, the winter weather was relatively warm with average monthly temperatures as much as 3.6°C above average (Table 1).

The character of suspended sediments and deposits varies within the Bay of Fundy (Amos, 1984). Minas Basin, at the southeastern head of the Bay (in Nova Scotia) is a sandy estuary characterized by sand flats and bars. In contrast, Chignecto Bay is characterized by expansive mudflats and concentrations of suspended sediments an order of magnitude higher than in Minas Basin. Chignecto Bay exports sediment both into the estuaries of the upper Bay, above Hopewell Cape, as well as to the outer Bay of Fundy, distributing it in a zone which extends along the northwestern part of the Bay (Figure 1). Our study sites are located along this northwestern coastline extending above and below Hopewell Cape.

To examine the effect of tidal range we selected study sites representative of the range found along the entire New Brunswick coast (Figure 1). These marshes span a distance of 250 km and represent two different morphological types (Table 2). A majority of the original marsh area of the Bay

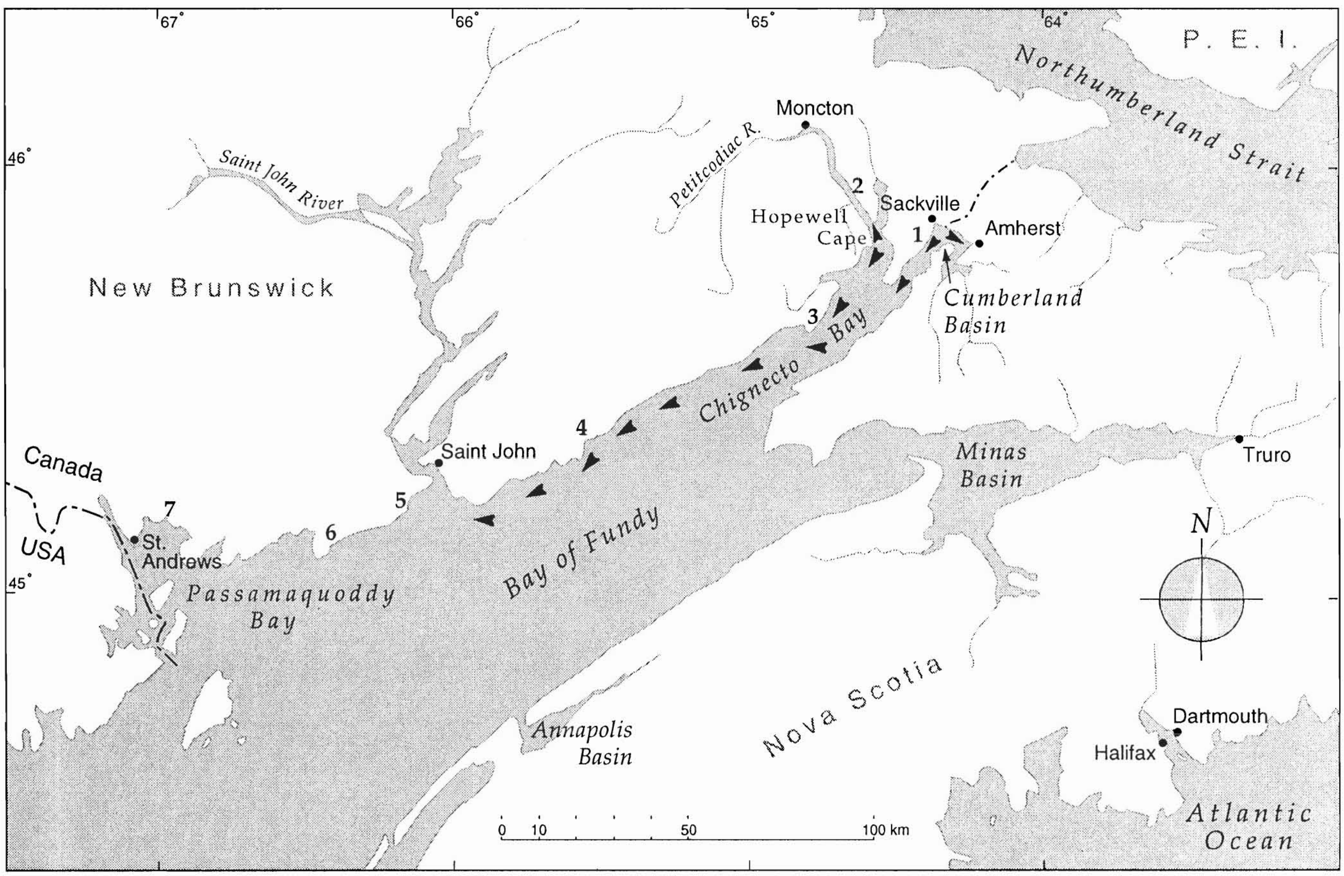


Figure 1. Map of the Bay of Fundy showing direction and divergence of suspended sediment transport near Hopewell Cape. (Adapted from Swift *et al.*, 1973 and Hunter and Associates, 1982.) Location of salt marsh sites where marker horizons were established are denoted by number: 1. Wood Point, 2. Belliveau Village, 3. Cape Enrage, 4. St. Martins, 5. Lorneville, 6. Dipper Harbour, 7. Bocabec.

Table 2. *Characteristics of salt marsh sample sites on the New Brunswick coast, Bay of Fundy. Morphology follows descriptions of* WOOD *et al. (1989).*

Marsh	Morphology	Mean Tidal Range (m)	Distance From Hopewell Cape (km)
Bocabec	fluvial minor	5.97	240
Dipper Harbour	fluvial minor	6.00	183
Lorneville	fluvial minor	6.70	163
St. Martins	back barrier	7.99	108
Cape Enrage	back barrier	9.45	40
Wood Point	fluvial major	10.21	50
Belliveau Village	fluvial major	11.90	58

has been lost, primarily to diking. It was difficult to find accessible study sites which were not disturbed in some manner, but we took care to locate sites seaward of dikes or dike remnants.

In five of seven marshes we established four transects at sites with continuous slope and avoided signs of disturbance, such as bank slumping. Where possible transects were spaced ~10 m apart. Three plots were placed along each transect, sited with respect to vegetation zones. "Low" elevation plots were situated ~1 m inland of the lowermost limit of *Spartina alterniflora,* the vegetation typical of low marshes in the Bay. "Middle" elevation plots were situated ~1 m seaward of the upper limit of the *Spartina alterniflora* zone and "high" elevation plots were situated ~1 m inland of this border or the *Plantago*-dominated zone (CHMURA *et al.,* 1997), when present. The variation in relative elevation among high, middle and low plots was similar from marsh to marsh, with the exception of Cape Enrage (Figure 2). In two marshes we found it necessary to make an exception to our sampling design of four transects of three plots. This variation is at Lorneville and Wood Point and is described in the individual site descriptions, below.

Bocabec. Sample sites are located on the west bank of the Bocabec River, which receives only minor freshwater flow through most of the year. A highway bridge spans the river a few hundred meters downstream, but presents little restriction to ebb or flood flows.

Dipper Harbour. Marshes border a tidal creek which discharges under a bridge into Dipper Habour. An extensive site description is given by CHMURA *et al.* (1997). Two transects are located on each side of the main tidal creek. On the southern creek bank a distinctive *Plantago* zone spans the transect between the mid and high plots.

Lorneville. The marsh is upstream of a 1.3 m-diameter culvert which severely restricts the flow of tidal water. Sample plots are located seaward of an abandoned dike. Marsh morphology and vegetation patterns required a modification of sample design here. Plots were distributed in pairs. Three pairs are located on the bank of the creek which drains through the culvert. The lower plots are dominated by *Scirpus maritimus,* the upper by *S. patens,* the latter a high proportion of forbs. The three remaining pairs are located on the bank of a secondary creek. The vegetation of the lower three plots is dom-

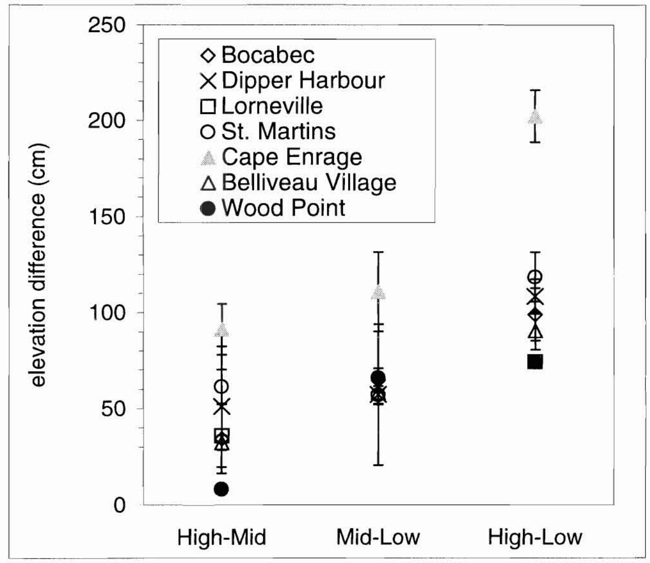


Figure 2. Average differences in relative elevation along marsh transects. Line extension represents one standard deviation. No standard deviation is calculated for Wood Point.

inated by *S. alterniflora,* the upper three by *S. patens.* A *Plantago* zone is situated between the plots.

St. Martins. Sample sites are located directly behind a cobble barrier beach, a few hundred meters from the inlet. Marsh on the opposite side of the primary tidal creek is diked. Dominance of *S. patens* is considerably reduced on the back barrier, requiring that high elevation plots be placed in vegetation co-dominated by *S. patens, S. alterniflora* and forbs.

Wood Point. The marsh is located on the Cumberland Basin, a site of extensive diking. Much of the marsh edge along the Basin is faced with a scarp described by VAN PROOSDIJ *et al.* (1999). It was not possible to situate all three elevation plots on a contiguous slope. Low elevation plots were placed along the bank of a secondary creek where slopes are continuous and *S. alterniflora* is robust. Inland the marsh grades into short *S. alterniflora* and eventually to a narrow band of high marsh vegetation bordered by a road embankment and dike. Middle and high plots are situated in this part of the marsh about 200 m away, approximately 50 m seaward of the embankment.

Cape Enrage. This marsh was once diked, but only remnants of the dike remain. Plots are placed on the bank of a creek which drains into the primary tidal creek which passes through the barrier beach. Creek banks have exceptionally steep slopes.

Belliveau Village. This is a narrow marsh fronting a dike near Belliveau Village. The marsh is located on the Petitcodiac River. As the marsh bordering the river is faced with a scarp, plots were located along the banks of a tidal creek less than 100 m from its mouth.

METHODS

Marker horizons were established during June 7 to 13, 1997. Green shoots had just emerged above the marsh sur-

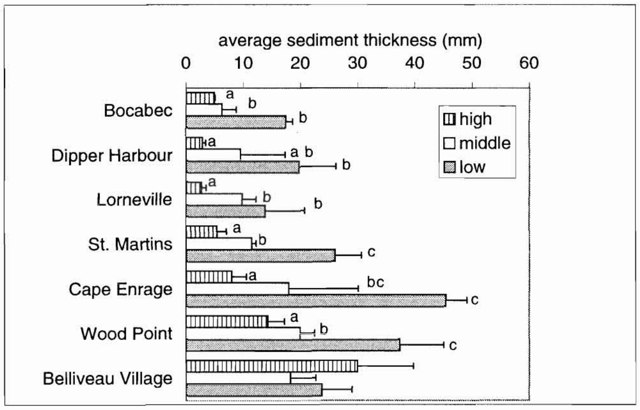


Figure 3. Variability in sediment deposition within marshes as shown by average and standard deviation of sediment accumulation at low, middle, and high elevations of marshes on the New Brunswick coast. Means labeled with the same letter are not significantly different at p ≤ 0.05.

face. Approximately 2 kg of clay-size feldspar (nepheline syenite) was shaken on each 0.5 m^2 plot, producing a visible white layer approximately 0.5 cm thick. In those areas with dense plant cover, such as *S. patens* zones, care was taken to shake clay through dead vegetation to marsh surface below. Within each marsh relative elevation of each plot (the upper edge) was determined with respect to the lowest point measured at that site.

Net sediment deposition above marker horizons was measured in October 1997 and again in May 1998. In October plants were senescing. During our May visit green shoots had begun to emerge from the marsh soil, yet low marsh grass from the previous season was still present on the stem. Rectangular plugs were cut from the marsh surface using a knife during the October sampling, but in May samples were cored with a cryogenic coring system (CAHOON *et al.*, 1996). Sample locations were determined by selecting a pair of random numbers as sampling coordinates associated with two sides of the plot. During both sampling events we observed that white clay layers were generally intact with distinct upper and lower boundaries, signifying that bioturbation and mixing was minimal. Thickness of the clay layer and sediment layer above it were measured to the nearest 0.5 mm with vernier calipers. Multiple measurements were taken on each sample (on each face of the rectangle or at least 3 locations on the cryocore) and averaged for each plot.

During the October sampling period we located 77 plots of a total 84 originally established, taking a total of 744 readings. While sampling the following May five of the missed plots were relocated, but clay markers could not be found for six plots. We attribute this to erosional processes, but exclude these from our calculations. The total number of measurements from our 78 successful cryocores was 277.

Statistical analyses were performed using the Microsoft Excel97 analysis tool pack and Systat 7.0.1. Differences in average sediment deposition among elevation groups within each marsh were compared by a t-test (assuming unequal variances). The difference in sediment deposition among marshes was compared by applying a Duncan's Multiple Range Test (LITTLE and HILLS, 1978) to the averages for each elevation at each marsh. Simple and multiple linear regressions were used to test for relationships between sediment deposition and the independent variables: relative elevation, distance from vegetation edge, tidal range and suspended sediment supply (as indicated by distance from Hopewell Cape).

RESULTS

Highest sediment accumulation occurred at the low elevation plots (Figure 3), with the exception of Belliveau Village. Statistical results reveal the close relationship of relative elevation to sediment accumulation (Table 3; Figure 4), significant for all but Belliveau Village. The relationship between distance from the nearest vegetated edge of the marsh to each plot generally is not as close, and significant only at Bocabec, Lorneville, St. Martins, and Cape Enrage.

Although average net sediment deposition over winter for each marsh and elevation was positive, a decrease in sediment thickness did occur in two high elevation plots of Bocabec and a middle elevation plot of the Belliveau Village marsh. Over the year-long study period marshes in the upper Bay, Belliveau Village, Wood Point and Cape Enrage had significantly greater net sediment deposition than marshes in the lower Bay, Bocabec, Dipper Harbour, Lorneville, and St. Martins (Figure 5). This relationship holds at all elevations,

Table 3. *Results of linear regressions (single and multiple) testing relationships of sediment deposition to relative elevation and distance from lowest limit of* Spartina alterniflora *within salt marshes along the New Brunswick coast of the Bay of Fundy. Distances are not available for Wood Point. Probabilities <5% were judged as significant and denoted by an asterisk. (N values represent an average for each marsh.)*

		Relative elevation		Distance From Vegetation Edge		Both variables	
Marsh	n	r^2	P	r^2	P	r^2	P
all	70	0.03	0.151	0.16*	0.001	0.18*	0.001
Bocabec	11	0.94*	<0.000	0.59*	0.006	0.96*	<0.000
Dipper Harbour	12	0.70*	0.001	0.20	0.145	0.70*	0.004
Lorneville	12	0.82*	<0.000	0.53*	0.007	0.82*	<0.000
St. Martins	12	0.89*	<0.000	0.70*	0.001	0.96*	<0.000
Cape Enrage	12	0.81*	<0.000	0.82	<0.000	0.82*	<0.000
Belliveau Village	7	0.04	0.664	0.16	0.381	0.48	0.276
Wood Point	12	0.90*	<0.000	—	—	—	—

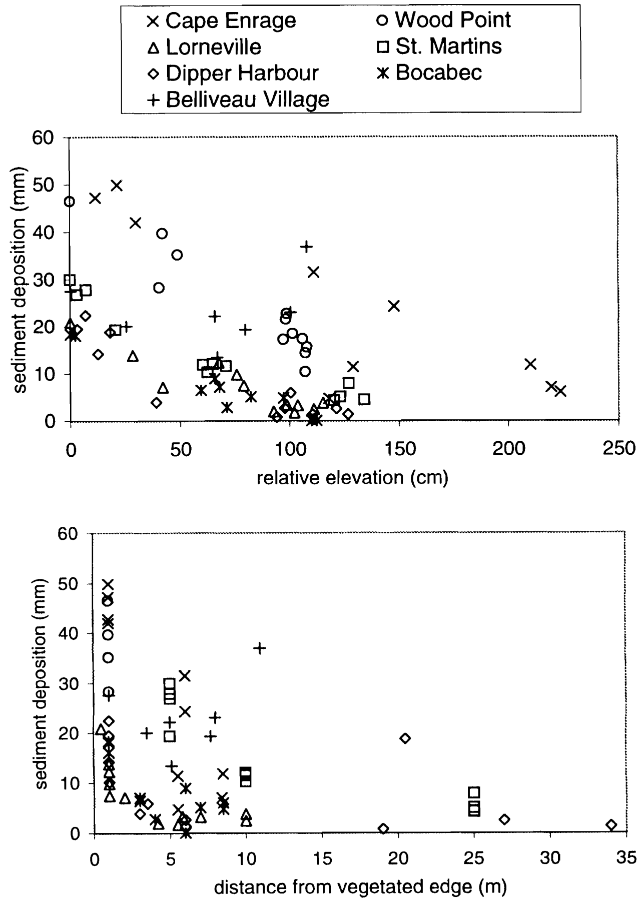


Figure 4. The relationship of average sediment deposition to relative elevation and distance from lowest edge of vegetation within each salt marsh studied on the New Brunswick coast, Bay of Fundy.

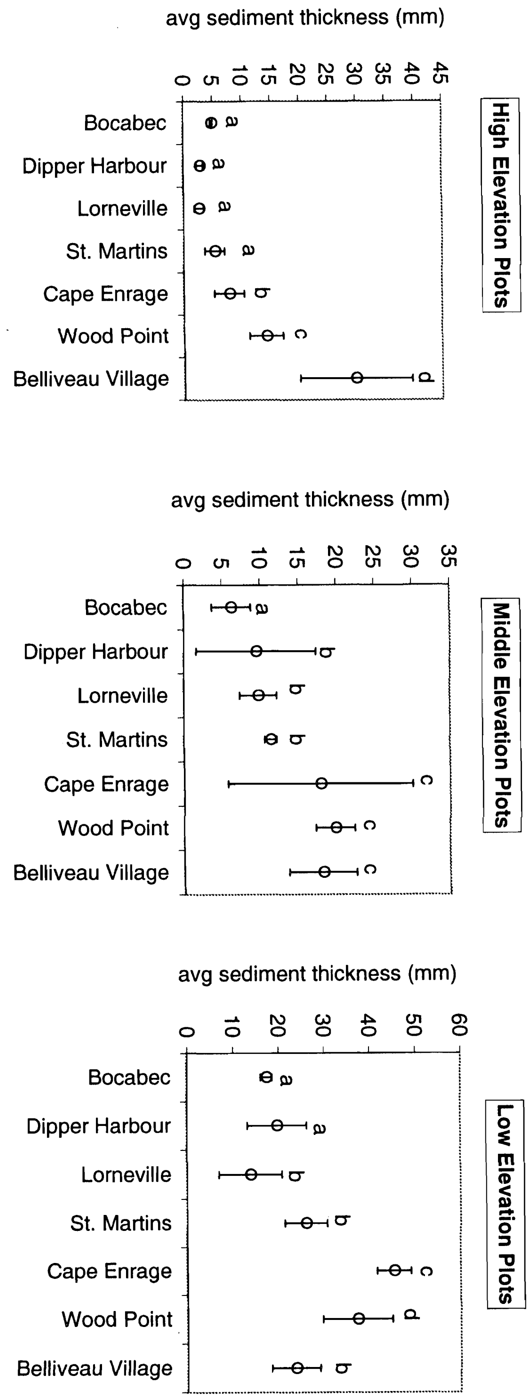


Figure 5. A comparison of sediment accumulation among marshes by elevation. Means labeled with the same letter are not significantly different at $p \leq 0.05$.

with the exception of the low elevation at Belliveau Village, likely an artifact of the loss of replication at this site.

Tidal range serves as a good predictor for sediment accumulation at high and middle elevations, but the coefficient of correlation is only significant for low elevations if Belliveau Village is excluded (Table 4; Figure 6). In contrast, distance from Hopewell Cape is significantly related to sediment accumulation at low and middle elevations, but not to high elevation plots.

DISCUSSION

Our results demonstrate that control for spatial variability in depositional rates within marshes helps to contrast importance of processes within and among marshes. The importance of tidal range and sediment supply to deposition rates in marshes varies with marsh elevation. In the low marsh sediment supply drives deposition rates. In the absence of erosional forces this process is ruled by a negative feedback as marsh elevation increases and the ability of tidal floodwaters to reach a location becomes more important. These findings are not in contradiction to those of WOOD *et al.* (1989) who found marsh morphology to be a significant factor in sediment accumulation along the outer Gulf of Maine. Marsh morphology may play a role by affecting the degree to which marshes are subject to ice scour, as well as ice rafting. We assume there was minimal sediment loss as

Table 4. *Results of linear regressions (single and multiple) testing relationships of sediment deposition to tidal range and sediment supply to salt marshes along the New Brunswick coast of the Bay of Fundy. Results are shown including and excluding data from Belliveau Village (BV) for which sample retrieval was limited. Probabilities <5% were judged as significant and denoted by an asterisk. (N values represent an average for each marsh.)*

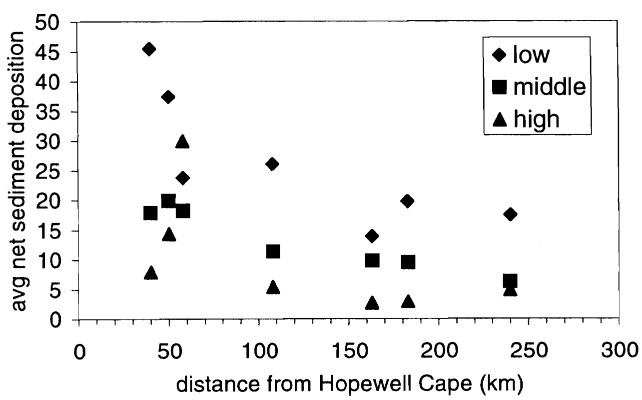
		Tidal Range		Sediment Supply		Both Variables	
Elevation of Plot	n	r^2	P	r^2	P	r^2	P
all	21	0.32*	0.008	0.31*	0.009	0.33*	0.027
low	7	0.33	0.175	0.63*	0.033	0.71	0.084
low without BV	6	0.82*	0.016	0.79*	0.02	0.82	0.078
mid	7	0.85*	0.003	0.92*	0.001	0.94*	0.003
mid without BV	6	0.94*	0.003	0.91*	0.003	0.95*	0.012
high	7	0.79*	0.007	0.36	0.156	0.98*	0.001
high without BV	6	0.78*	0.021	0.51	0.110	0.94*	0.013

dead low marsh vegetation was still present by the next spring. If present, ice scour would have removed the vegetation (GORDON *et al.,* 1985). The coincidence of a mild winter with our study period probably allowed us to detect maximum variation in sediment deposition. This variability is likely to be obscured by disturbance in more severe winters. As such, multi-year accumulation rates are likely to be much lower; a situation we plan to monitor.

We can further assume that changes in sediment supply or budget will have the greatest impact on low marsh accretion rates. Increases of sediment supply to the system will enhance rates of marsh development and decrease the time for transition from low marsh to high marsh.

On the other hand, high marsh sites will be sensitive to changes in the hydrological regime, including variations in sea level. Increases in tidal heights or frequency of extreme tides will increase sediment deposition in these sites. The increased tidal range towards the upper Bay thus can serve as a model for prediction of impacts of rising sea level and increasing tidal range in the lower reaches of the Bay of Fundy.

The pattern of net deposition during this mild winter characterizes the New Brunswick coast of the Bay into an upper and lower unit. However, it will be essential to observe whether this variation is maintained over long time periods, which include variation in weather such as severe winter and storm events.



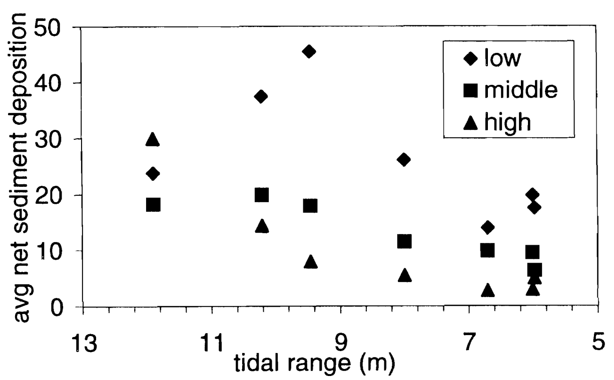


Figure 6. Relationship of salt marsh surface sediment deposition to tidal range and sediment supply (as indicated by distance from the primary sediment source, Hopewell Cape) on the New Brunswick coast, Bay of Fundy. Average values for each elevation are shown. Data on regression is reported in table 4.

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