Saint Mary's University

Monitoring Seasonal Changes in Surface Elevation of Intertidal Environments near the Windsor Causeway

Report Prepared by

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Introduction

Construction of causeways across tidal estuaries causes significant change to the coastal system and salt marsh-mudflat systems are the first environments to feel the effect of coastal modification, gradually adjusting to a new geomorphic equilibrium. Since the construction of the Windsor Causeway across the Avon Estuary in 1970, approximately 185 acres of new intertidal habitat has been created as a result of accumulation of sediment and ice rafting of rhizomes of marsh vegetation (van Proosdij and Townsend, in press; Daborn *et al.*, 2003). The resultant salt marsh and mudflat ecosystems serve important ecological functions such as the export of macro-detritus and providing feeding grounds for a range of waterfowl. Fish have also been observed within tidal creeks, particularly within the channel downstream of the tide gate ("West Channel) and parallel to the causeway ("Causeway channel). A comprehensive fish population study is provided in Daborn and Brylinsky (2004).

Although salt marsh vegetation generally acts as a stabilizing agent within the Bay of Fundy, mudflat environments adjacent to these vegetated areas are highly dynamic, and demonstrate seasonal variability in sediment accumulation and erosion. This variability has been shown to be directly influenced by high wave activity and ice dynamics in the Cumberland Basin (van Proosdij, 2001; Davidson-Arnott *et al*., 2002; van Proosdij, *et al*., 2003). Changes in surface elevation and vegetation cover have been monitored within the Windsor study area since 2002 along 10 transect lines. Data collected during this period indicates that the majority of the intertidal surface has increased in elevation by 0.3 (±0.4) $cm \cdot mth^{-1}$ (Daborn *et al*., 2002). Erosion has been recorded along both the seaward edge of the mudflat along the St. Croix River and within tidal creeks along the eastern edge of the salt marsh-mudflat system. Currently, it appears that the causeway channel is infilling rapidly (van Proosdij and Townsend, in press; Daborn et al., 2003a; van Proosdij et al., 2004). It is anticipated however that after the concentrated ice action this past winter, this region may have been heavily impacted. Due to the fact that the intertidal environments near the Windsor Causeway have been highly modified by human activity, predicting the future 'response' of this system to stresses imposed during construction activities is extremely difficult. Therefore, this project seeks to further understand and monitor the current sediment and vegetation dynamics near the Windsor Causeway.

The main purpose of this research project was to gain a better understanding of the controls on the changes in surface elevation of intertidal environments near the Windsor Causeway. Four primary objectives were developed to address this issue:

1. ***Measure seasonal variations in surface elevation*** using existing sediment elevation plates**.** These plates will provide relative measures of erosion and accumulation for the entire salt marsh-mudflat surface.

2. ***Measure detailed seasonal changes in cross-sectional profiles of the salt marsh-mudflat surface within 200 m of the causeway.*** These cross sections can then be incorporated into a detailed digital elevation model being developed to provide volumetric estimates of the amounts of sediment moving within the system.

3. ***Qualitatively assess the impacts and spatial extent of ice cover during the winter months.***

4. ***Develop a conceptual model of the seasonal variations in surface elevation for the Windsor salt marsh-mudflat system.***

Methods

Changes in surface elevation were measured as the depth to buried aluminum plates along existing transects within the salt marsh-mudflat system (Figure 1). These data were recorded in June and November to quantify changes in surface elevation during the winter/spring, summer and fall. The locations of all stations have previously been recorded using a differential GPS system (van Proosdij *et al*., 2004; Daborn *et al*., 2003). These data were entered into ArcView 8.3 and used to create a preliminary interpolated surface of change in surface elevation. However, given the number and arrangement of the 14 plates which survived the winter, the modeled interpolated surface would not be truly representative of processes operating within the main marsh body or the edges of the tidal creek. Therefore, these data will be provided in tabular and graphical form only. In addition, the spatial pattern of plate survival will be addressed within the winter section of the results and an assessment of the feasibility of continuing with plate monitoring will be provided.

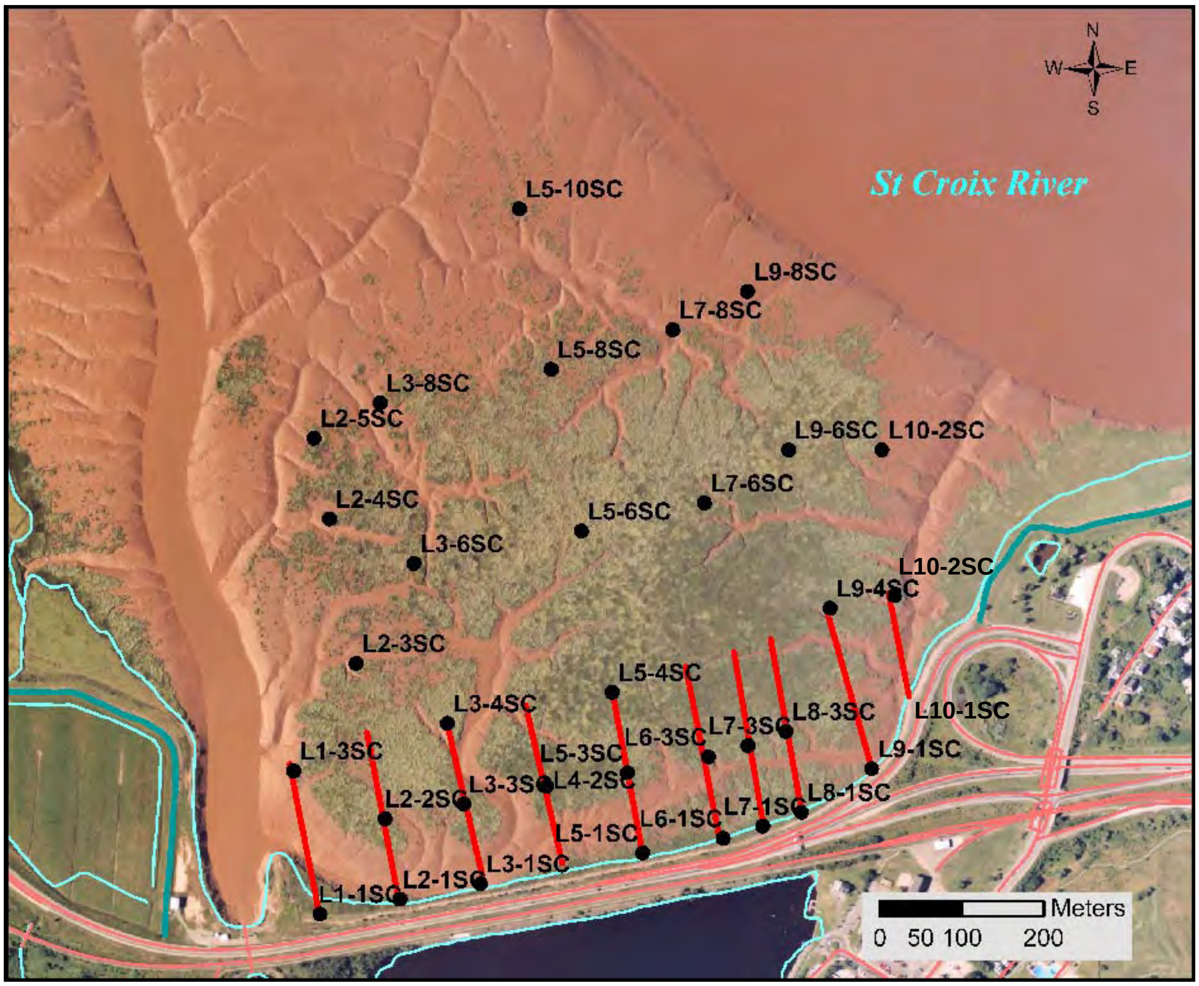


Figure 1: Location of sampling lines over 2003 aerial photograph. Topographic survey lines indicated in red.

Detailed topographic surveys along existing lines (Figure 1) were conducted using a Leica TCR Reflectorless Total Station set relative to a known geodetic benchmark in June, 2004. This instrument has a precision of 2 mm. However, given the difficulty of surveying within this unconsolidated environment, survey results will likely only be accurate to ± 5 cm. All elevations are expressed as orthometric heights relative to datum (CGVD28) using the HTv2 geoid model. Additional shorter surveys were conducted perpendicular to the causeway over a distance of 200 m in November, 2004. These cross sectional profiles were analyzed using Excel and incorporated into ArcView 8.3 and associated extensions to derive volumetric estimates of sediment deposition and erosion. In addition, winter sediment dynamics (such as movement of ice floes and vegetated root mats) were observed using digital photography and/or direct field observation.

Results and Discussion

Change in Topographic Profiles

Overall the changes in the topographic profile support the data derived from the sedimentation plates. Volumetric estimates were derived for a 1 m^2 planimetric ribbon of marsh /mudflat surface by calculating the change in area between topographic profiles surveyed in June and November 2004 (Table 1). The net change along all lines is positive suggesting an additional source of sediment, and although sediment is eroded in sections (Figure 2), this material is likely deposited within the immediate area.

Profile Line	Erosion (m^3)	Deposition (m^3)	Net Change (m^3)
2	0.47	12.85	12.38
3	1.30	17.72	16.42
4	0.86	14.63	13.77
5	2.19	7.22	5.03
6	0.00	16.06	16.06
7	0.00	15.19	15.19
8	2.22	23.93	21.71
9	1.78	13.31	11.53
10	0.17	19.48	19.31

Table 1: Volume of surface change between June 8 and November 23, 2004 in causeway channel. Location of profile lines shown in Figure 1.

Visual observations of the profiles in May 2005 suggest continued infilling along lines 7 and 8 and a convex creek profile developing. The location of the thalweg however does not appear to be shifting considerably.

Change in Surface Elevation

Changes in surface elevation between sample dates from May 2003 to May 2005 are summarized in Table 2. Data represented as the net change in elevation between those dates and are also normalized by the number of months between sampling dates to enable accurate comparison between time periods. The mean monthly rate of change in surface elevation ranged from 0.4 $cm \cdot mth^{-1}$ between June and November 2004 to 0.6 $cm \cdot mth^{-1}$ from November 2004 to May, 2005. These values are higher than the mean value reported at the Windsor marsh (0.3 $cm \cdot mth^{-1}$) over the entire marsh surface in 2003 (Daborn *et al*., 2003) and higher than most published values in other Fundy marshes (van Proosdij et al., in press; Ollerhead et al., 2003; Chmura et al., 2001;). No consistent trends were apparent in either the spatial location of maximum or minimum values.

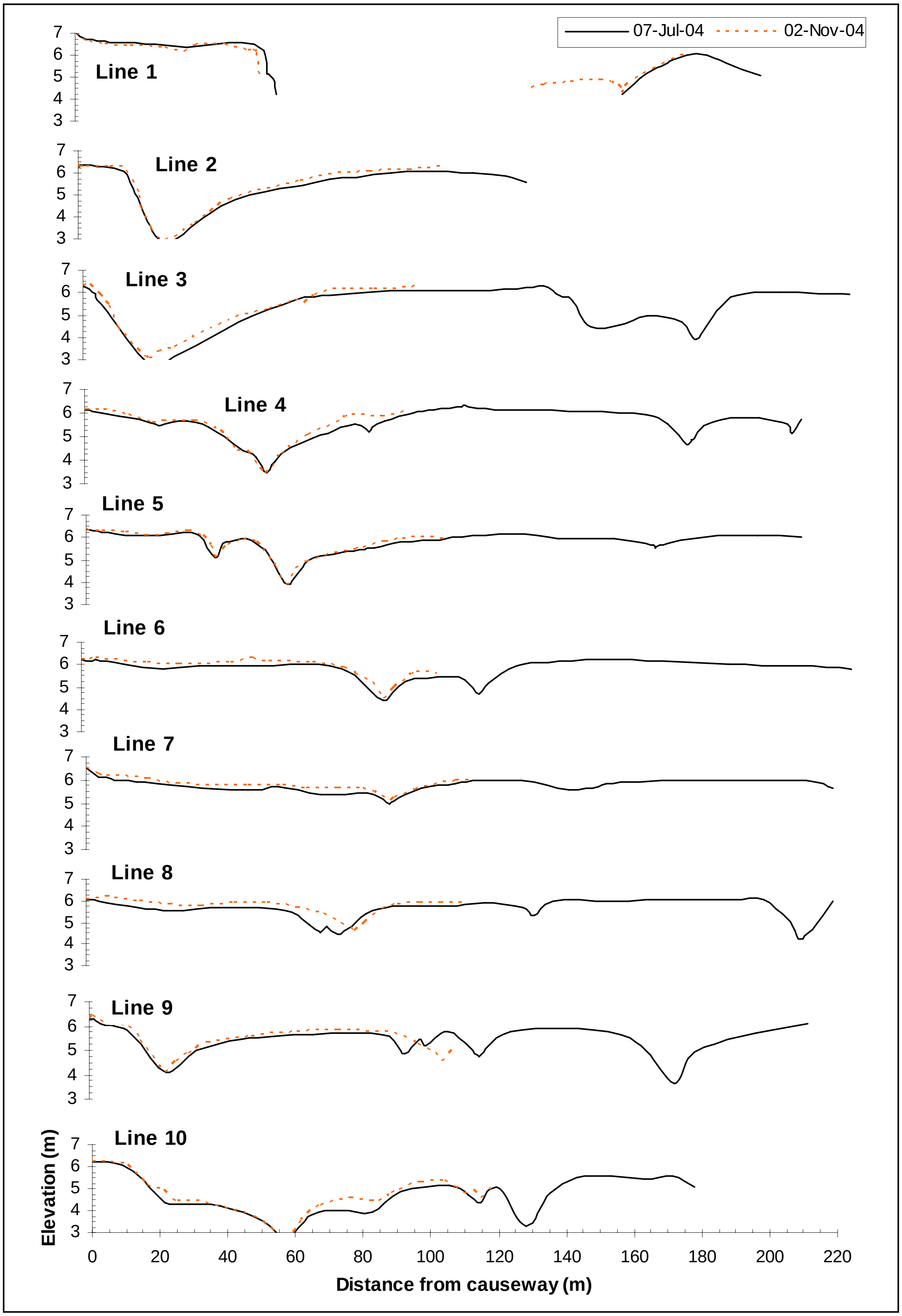


Figure 2: Comparison of topographic profiles surveyed in June and November 2004. Distance measured from base of causeway on marsh surface. Elevation is measured relative to MSL as defined by the CGVD28 datum.

				state	Distance from	Change in surface elevation (cm)			(cm•mth^{-1})		
Station	**Easting**	**Northing**	**Elevation (m)**	**of veg**	**causeway (m)**	**May'03 - Jun'04**	**Jun'04- Nov'04**	**Nov'04- May '05**	**May'03 - Jun'04**	**Jun'04- Nov'04**	**Nov'04- May '05**
L1-1SC	409569.8	4983210	6.56	dense	4	4.8	4.3	1.9	0.4	0.9	0.4
L1-3SC	409537.6	4983385	5.79	dense	172	5.6	0.3	5.4	0.4	0.1	1.1
L3-3SC	409745.3	4983345	5.99	sparse	109	8.0	2.8	4.0	0.6	0.6	0.8
L4-2SC	409846.1	4983366	6.19	sparse	111	5.1	0.2	3.6	0.4	0.0	0.7
L5-3SC	409944.6	4983383	6.30	sparse	110	6.4	-0.5	5.5	0.5	-0.1	1.1
L5-4SC	409926.2	4983481	6.04	dense	210	4.8	3.2	2.3	0.4	0.6	0.5
L6-1SC	410061.3	4983303	7.16	dense	4	2.9	0.8	0.3	0.2	0.2	0.1
L6-3SC	410043.5	4983402	4.86	sparse	105	13.1	3.1	6.2	1.0	0.6	1.2
L7-1SC	410109.4	4983318	6.92	dense	6	5.4	2.2	3.0	0.4	0.4	0.6
L7-3SC	410091.7	4983416	6.49	dense	106	8.8	4.1	2.5	0.7	0.8	0.5
L7-6SC	410038.5	4983713	6.81	sparse	400	8.4	2.1	not found	0.6	0.4	not found
L8-1SC	410156.6	4983335	7.04	dense	4	2.9	2.3	1.0	0.2	0.5	0.2
L8-3SC	410137.9	4983434	6.91	dense	104	9.8	2.9	1.4	0.8	0.6	0.3
L9-4SC	410191.7	4983584	6.98	dense	206	5.7	1.7	0.6	0.4	0.3	0.1
					mean	6.6	2.1	2.9	0.5	0.4	0.6
					stdev	2.8	1.5	1.9	0.2	0.3	0.4
					max	13.1	4.3	6.2	1.0	0.9	1.2
					min	2.9	-0.5	0.3	0.2	-0.1	0.1

Table 2: Summary of changes in surface elevation at plate stations between sampling periods. Only plates that survived the 2003-04 winter season are included. Data were normalized by the number of months between sampling periods.

A total of fourteen plate stations were able to be measured in June 2004. Nine plates were not able to be re-located most likely due to ice scour and plucking as evidenced by marks remaining on the marsh / mudflat surface. These were located primarily along lines 2 and 3 near the Avon River channel and line 10 (Figure 3). The exceptions are L5-1sc and L9-1sc which likely are buried to a depth greater than the measuring rod as evidenced by the thick layer of sediment over top of the vegetation.

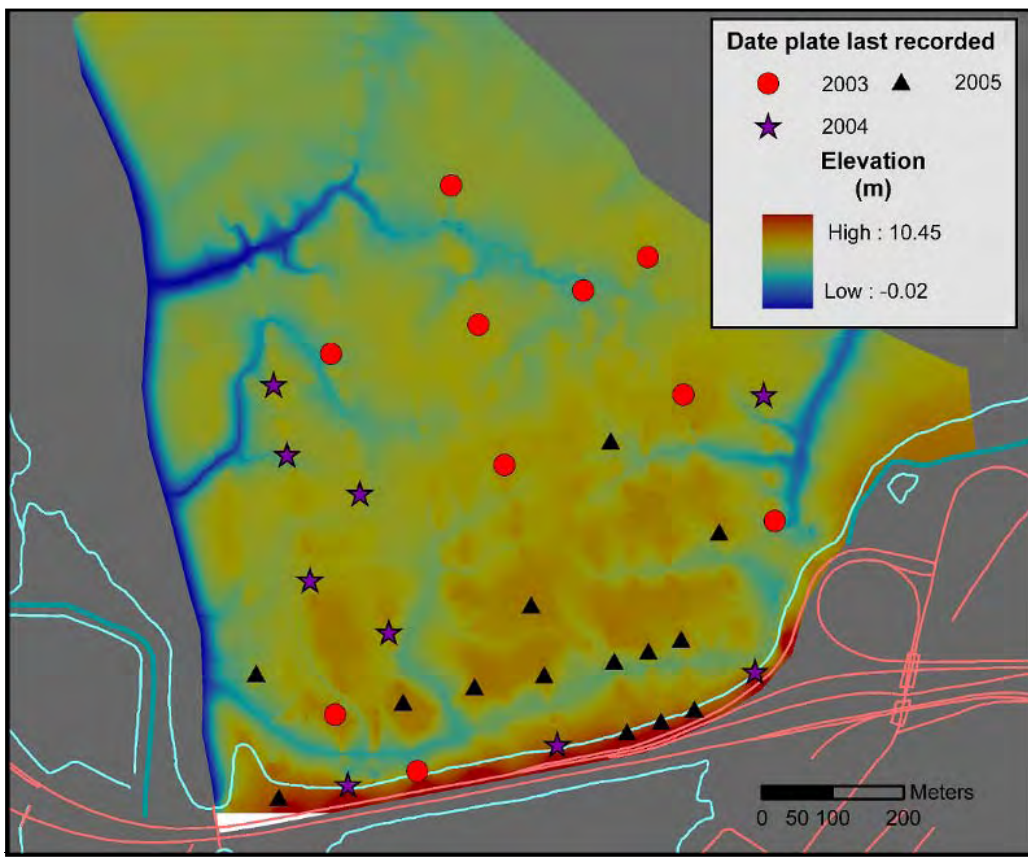


Figure 3: Map indicating 'survival' of plate stations over Winter 2002-03, 2003-04 and 2004-05. A total of 9 plates were lost in 2002-03, 9 in 2003-04 and one in 2004-05. Points are draped over digital elevation model developed by G. Baker in 2004 using TopoGrid command in ArcInfo. Fifteen plates were re-installed during the summer of 2005.

In general, one might be able to discern a decreasing trend in the rate of change in surface elevation with increasing elevation (Figure 4) but this trend is only strong over the November 2004 to May 2005 period and does also appear if the mean data are presented. Additional data are required for a complete statistical analysis. The literature supports a general decrease in sedimentation with increasing marsh elevation due to decreased frequency in tidal flooding. However, other studies conducted in the Bay of Fundy (e.g. van Proosdij *et al.*, in press; Davidson-Arnott *et al.*, 2002) demonstrate that frequency of inundation does not necessarily entrain higher sedimentation rates due to the impact of waves. In the current study, all of the sample stations are sheltered from wave activity, likely facilitating higher sedimentation rates. The sites however would be exposed to higher amounts of suspended sediment concentration during high wave periods which would effectively increase the availability of sediment to be deposited (van Proosdij *et al.*, 2001). This sediment would then be expected to be deposited within the quiescent region of the causeway channel.

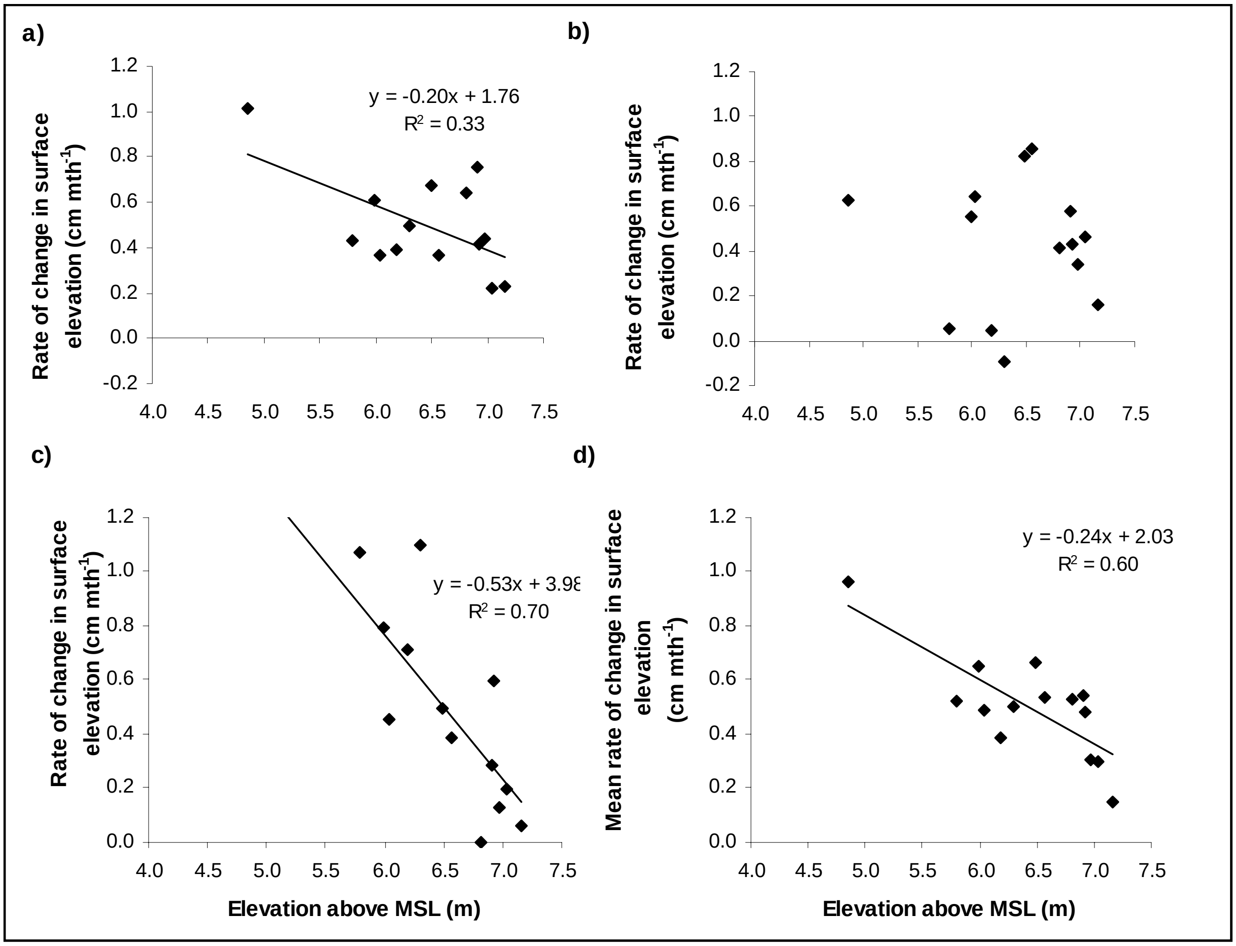
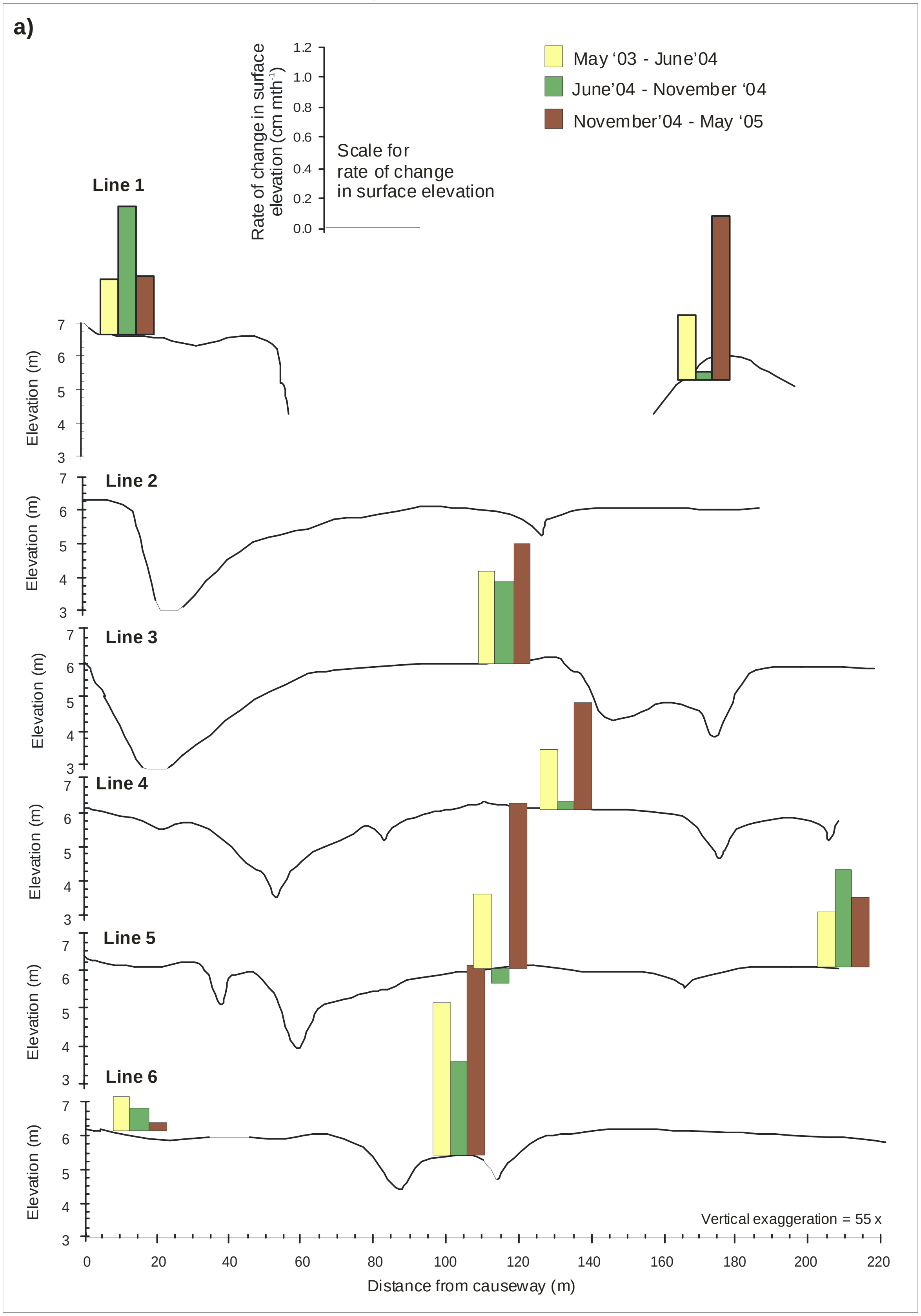


Figure 4: Rate of change in surface elevation in relation to elevation of the station location above sea level from a) May 7, 2003 to June 8, 2004 ; b) June 8 to November 23, 2004 and c) November 23, 2004 to May 2005. The mean rate of change in surface elevation from 2003 to 2005 is presented in d. MSL = mean sea level relative to the CGVD28 vertical datum.

Changes in Surface Elevation in Causeway Channel

In order to examine the spatial patterns of sedimentation along the causeway channel, surface elevation change data were plotted over topographic profiles surveyed in June, 2004 (Figure 5). In general, there is a greater rate of change over the winter season for most lines except L8 and L9. This may be attributed to a decrease in flooding frequency as the eastern section of the causeway channel continues to infill. Alternatively it might reflect a shift in the position of the creek channel thalweg and associated creek bank on Lines 8 and 9 (Figure 6).



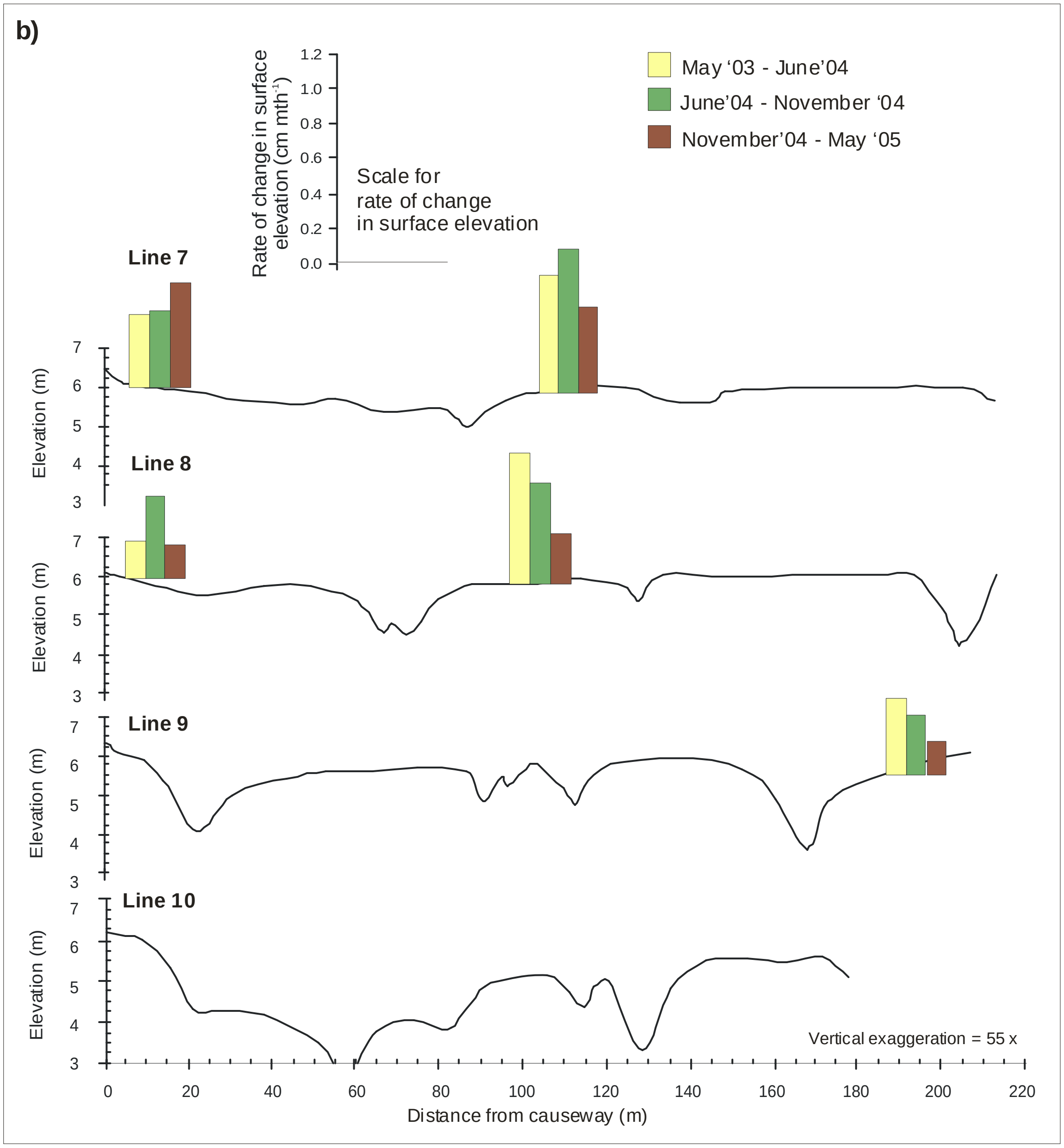


Figure 5: Rate of change in surface elevation at plate stations which survived the winter season. Topographic profiles are presented from the June 2004 survey for a) lines 1 to 6 and b) lines 7 to 10. Distance measured from base of causeway on marsh surface. Elevation is measured relative to MSL as defined by the CGVD28 datum. Depth of channel at line 1 not surveyed due to dangerous, unconsolidated nature of mudflat surface.

Ice Dynamics in 2004

In early January, small amounts of ice were observed by Ken Carroll (NSDAF) at the Windsor tide gate forming in the tidal creek channels during neap tides. By January 10, ice blocks were observed scattered over the marsh surface however strong NW winds moved ice off of the salt marsh surface during the high spring tides that night (Figure 6).

On January 17th, a heavy snow storm deposited 40 cm of snow on the marsh surface. Since this occurred during neap tides, much of this snow was able to bind to surficial sediments forming a layer of ice crust over the marsh surface. An additional 75 cm were deposited between January 20 and 24th, adding to the layer currently present. Spring tides on January 25th (Figure 6) broke up this crust and floating ice and snow 'rafts' were seen floating over the marsh surface. By January 31st, these rafts were observed over the entire marsh surface (Figure 7 and 8).

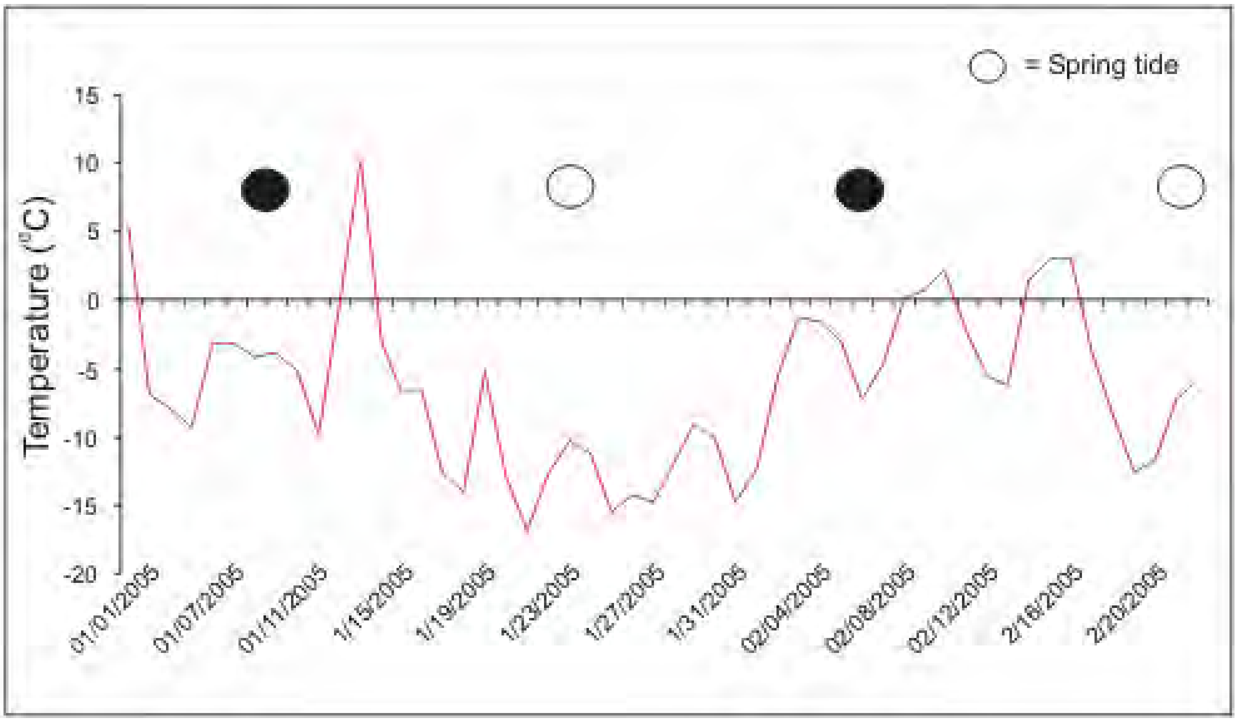


Figure 6: Temperature recorded at the Weatherhawk weather station at the Windsor tide gate for winter study and timing of spring tidal cycle. Filled and open circles represent old and new moons respectively.

These ice floes were generally less than 1-2 m in diameter and relatively flat and remained over the marsh surface, rising and falling with the tides as well as accumulating layers of slush and sediment with each tide until February 8th (Figure 9). This process will be discussed in more detail in the next section. The next spring tide brought larger ice blocks (Figure 8) into the marsh system, likely derived from surrounding marshes and mudflats in the local area but not likely from within the study area.

Some of these blocks of ice were likely re-floated in subsequent tides however those at the highest elevations likely started to become attached to the marsh surface. In addition, piles of ice blocks were observed (Figure 10) and with milder temperatures until February 17th (Figure 6), many of these blocks likely became fused as surface layers melted during the day and re-froze during the night. These would then accumulate in the highest portions of the marsh or upper reaches of the creek channels (Figure 11). These blocks would then in turn trap additional ice floes on subsequent tides, creating a form of feedback condition.

After February 17th, mean temperatures dropped significantly (Figure 6), freezing ice blocks to the marsh and mudflat surface (Figure 11). Subsequent spring tides with any wave action would have the potential to rip out marsh vegetation and their roots (Figure 12).

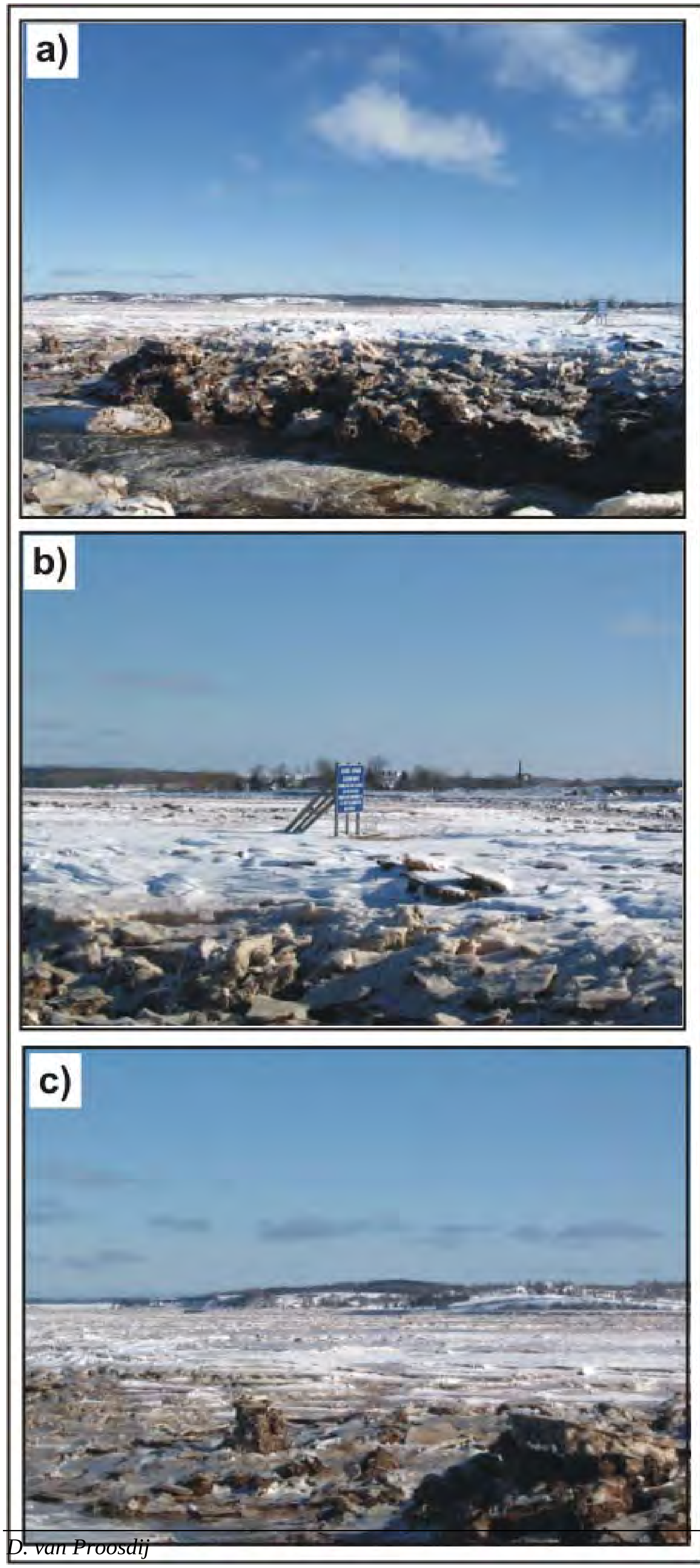


Figure 7 (left): Ice conditions on January 31st, 2005 at a) from tide gate, b) along causeway channel from tide gate and c) N towards main body of marsh from land near Avon River channel. Photos by K. Carroll, NSDAF.

Figure 8: Ice blocks rafted in during spring tide near a) tourist bureau and b) along causeway channel looking west towards tide gate. Photos by K. Carroll.

Figure 9: Winter conditions on Feb 7, 2005 on rising spring tide a) from tide gate towards causeway channel, b) from tide gate out to main body of marsh, c) from east side of causeway looking west toward tide gate and d) from tourist bureau dyke towards NW corner of marsh. Photos by K. Carroll, NSDAF.

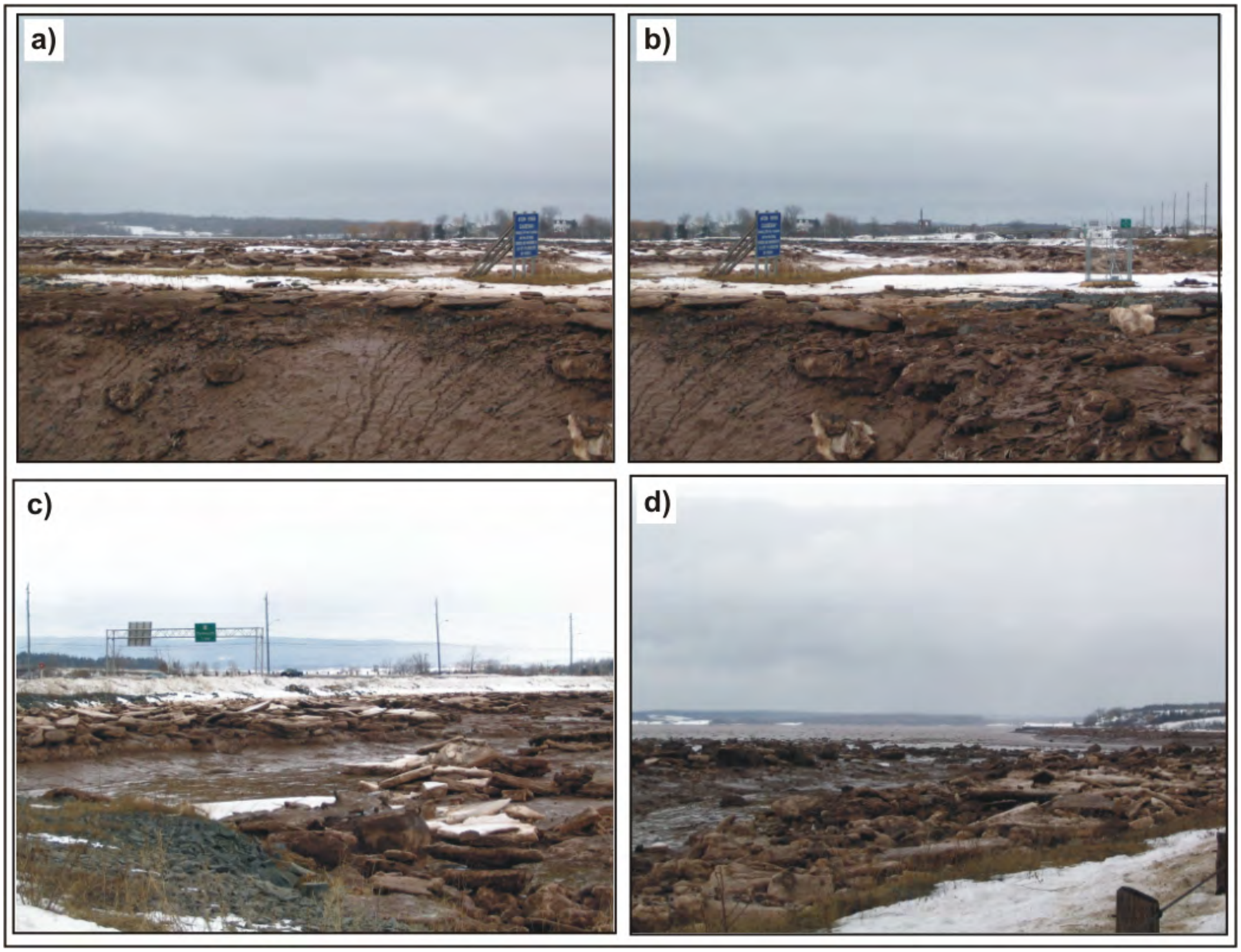


Figure 10: Winter conditions on Feb 11, 2005 after period of spring tides a) from tide gate out to main body of marsh, b) from tide gate towards causeway channel, c) from east side of causeway looking west toward tide gate and d) from tourist bureau dyke towards NW corner of marsh. Photos by K. Carroll, NSDAF. Note large ice pans which will remain on the marsh surface through the upcoming sequence of neap tides. In addition, layers of ice rafts can form steep sided banks along tidal creek channels as seen in photo C.

A detailed field reconnaissance was conducted on February 25th in order to closely examine the types of ice and general impacts of ice on marsh and mudflat morphology. Four principle ice types are generally associated with the marsh surface: i) drift ice found primarily in the lowest reaches of the low marsh, ii) shorefast ice found at the neap/spring limit, iii) frozen crust found on the surface of intertidal sediments and the low marsh and iv) sheet ice found in the upper marsh as described in Ollearhead *et al.,* 1999 at a salt marsh in the Cumberland Basin. All of these forms were found on the Windsor marsh/mudflat however sheet ice was minimal this year, although it has been observed in previous years. Based on the literature, ice generally has three functions: erosion, transportation and sedimentations (Martini, 1981; Gordon and Desplanque, 1983; Drapeau, 1992). Erosion occurs through surface scour (Gordon *et al*., 1985; Dionne, 1998), refloating of ice blocks (Hind, 1875; Desplanque and Bray, 1985) and channeling of tidal flow (Martini, 1981, Gordon and Desplanque, 1983). All of these processes were observed within the Windsor mudflat / salt marsh system.

Figure 11 (above): Winter conditions on Feb 25, 2005 entering into spring tides a) from tide gate out to main body of marsh, b) from west end of causeway looking east long causeway channel, c) from east side of causeway looking west toward tide gate and d) from base of tourist bureau dyke towards NW corner of marsh. Photos by D. van Proosdij.

Figure 12 (at left): Drift ice with attached vegetative matter on Feb 25, 2005. The adhered vegetation in this example contains only dead above ground litter and does not contain root matter. Root matter is incorporated when an ice block freezes to the marsh surface and is later re-suspended on a spring tide, ripping out a mat of vegetation. This process results in depressions on the marsh surface which are evident in the spring particularly along the western and northern sections of the marsh. Photo by D. van Proosdij.

Figure 13 (above): Ice block near causeway channel. Meter stick for scale. Photo by D. van Proosdij, Feb 25, 2005

Figure 14: Layered shorefast ice block formed along causeway channel near L7-3sc. Note covering of ice by layer of sediment. Meter stick for scale. Photo by D. van Proosdij, Feb. 25, 2005.

Figure 15: Drift ice along causeway tidal creek channel. Note the absence of ice in the central section of the channel since this area is flooded every tide. Photo by D. van Proosdij on Feb. 25, 2005.

Figure 16: Approximately 2.5 m high by 4 m block of ice blocking creek channel. Meter stick for scale. Photo by D. van Proosdij on Feb. 25, 2005.

As mentioned previously, a number of ice blocks can coalesce over a series of tides, forming large amalgamations of sediment, ice and vegetative matter (Figure 13). Many of these exceeded 1.5 m in height and 2 m in diameter (Figure 14). Some may also include coarse sediment and rocks derived from the causeway toe itself.

Sometime between February 11th and the 25th, a large ice block lodged itself within the large eastern creek channel (Figure 16). This effectively reduced the cross sectional area of the creek, likely increasing flow velocities within the remaining channel and eroding the outer creek bank. This process was observed visually on the rising spring tide later in the day on the 25th. Since tidal flow was blocked, sedimentation was observed on the downstream edge of the ice block. This channelization of flow has the potential to change the location of the creek thalweg. However, since topographic surveys were not conducted in May 2005, this could not be verified.

Ice blocks may also accumulate and form the banks of temporary pools on the marsh surface (Figure 17). These pools trap the highly turbid waters entering into the system (Figure 18), creating favorable conditions for particle settling.

Figure 17: Temporary pool of tidal water formed along dyke near tourist bureau. Photo by D. van Proosdij, Feb. 25, 2005.

Figure 18: Plumes of sediment may be observed in suspension within these pools. In general, the suspended sediment concentrations are much higher during the winter months than during the summer. Photo by D. van Proosdij on Feb. 25, 2005.

Ice can transport significant quantities of sediment and debris acquired by freezing to a substrate or by the gradual accumulation of high concentrations of suspended sediment (Drapeau, 1992). This sediment may settle on top of flattened vegetation (Figure 19) if this matter is not removed during fall storms. Typically standing dead *Spartina alterniflora* is sheared off and accumulates as wrack along the edge of the causeway and dyke. While this process did occur somewhat, a large early snow storm in November flattened much of the vegetation *in-situ*, effectively freezing it in place.

When ice floes are in motion, they are constantly depositing eroded materials on the bottom beneath them as well as transporting a portion of the materials from on location to another (Hind, 1875). This sedimentary material then accumulates at the base of the ice blocks (Figure 20) and will melt *in-situ* if the blocks are not re-suspended (Ollerhead *et al*., 1999). Very few detailed studies have quantified ice-rafted debris however those that have (Wood *et al.*, 1989, Ollearhead *et al.*, 1999) indicate that up to 100% of measured surficial sedimentation can be directly attributable to ice deposits. This material will remain in-situ until the spring and is hypothesized to contribute directly to higher rates of change in surface elevation recorded near the causeway channel

Conceptual Model of Seasonal Variations in Surface Elevation Change

A preliminary conceptual model is presented in Figure 21 to summarize the main factors hypothesized to control the changes in surface elevation within this marsh /mudflat system. The model was developed based on data obtained from this study and ongoing studies within the upper Bay of Fundy (e.g. van Proosdij et al., in press; van Proosdij et al., 2004; Daborn et al., 2003; Davidson-Arnott et al., 2002; Ollearhead et al., 1999). Dominant controls include those with are extrinsic to the marsh system (wave activity, ice, tidal range) and those with are intrinsic to the system (elevation within tidal frame and vegetation). These intrinsic variables will in turn influence how the marsh surface will respond to these external forces.

Figure 19: Sediment deposited over *Spartina alterniflora* along line 6. Overtime, the vegetation will decompose and be incorporated within the soil matrix. Photo by D. van Proosdij on Feb. 25, 2005.

Figure 20 (at right): Sediment incorporated within matrix of ice block forming alternating layers of ice and sediment. Note sediment mound accumulating at base of the ice block. Meter stick for scale. Photo by D. van Proosdij on Feb. 25, 2005.

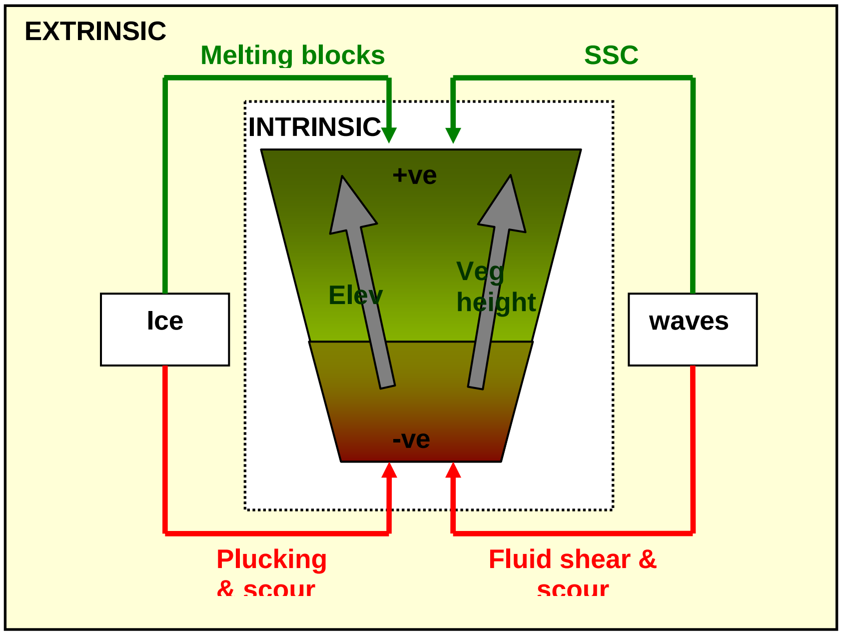


Figure 20: Preliminary conceptual model of factors controlling the change in surface elevation in the Windsor marsh / mudflat system. Ice and waves induce both positive and negative effects. Positive (+ve) effects result from melting ice blocks and high suspended sediment concentrations (SSC). Negative effects which will lower the surface include erosion from ice plucking and scour as well as direct surface shear from wave action. These external or extrinsic forces will be dampened (-ve) or enhanced (+ve) with increasing elevation within the tidal frame and vegetation height.

Conclusions

The Windsor marsh/mudflat system continues to feel the effects of coastal modification, gradually adjusting to a new geomorphic equilibrium. This trend will likely continue until such a time as the marsh rises to a height within the tidal frame that it is no longer regularly inundated with tidal waters. The overall goal of this research project was to gain a better understanding of the controls on the changes in surface elevation of intertidal environments near the Windsor Causeway. The main findings are summarized as follows:

- The rates of sedimentation (mean 0.5 cm·mth^{-1}) exceed those recorded in most Fundy marshes and reflect the sheltered nature of the causeway channel and likely the relatively high position of the marsh surface within the tidal frame. As expected, rates of sedimentation were highest in late fall/winter and spring and lowest during the summer months when previous research has indicated that there are higher amounts of sediment in suspension or contained within melting ice blocks. Erosion by ice scour and plucking occurred primarily along the outer edges of the marsh /mudflat system exposed to wave action.

- The causeway channel is continuing to in-fill as observed in previous years and will likely continue to do so until the surface rises to such an extent that the surface is not flooded as frequently with water. This is beginning to be observed near lines 8 and 9. Net changes in sediment volume are quite similar across the causeway channel with the exception of lines 5, 8 and 10, most likely due to shifts in the creek thalweg.

- Winter conditions can have a significant effect on marsh and mudflat topography, mostly by the deposition of sediment, removal of vegetation root mats and channelizing of tidal flow. Ice arrives quickly, generally within one tidal cycle and covers the majority of the marsh surface. Several 'waves' of ice rafting events may occur throughout the winter months. Drift ice is found primarily in the lowest reaches of the low marsh, shorefast ice found at the neap/spring limit, and frozen crust was found on the surface of intertidal sediments and the low marsh. These ice blocks are mobile and would likely pose a hazard during any construction activities during the winter months.

Acknowledgements

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