2011

Sea level rise and sediment elevation dynamics in a hydrologically altered Puget Sound estuary

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SEA LEVEL RISE AND SEDIMENT ELEVATION DYNAMICS IN A HYDROLOGICALLY ALTERED PUGET SOUND ESTUARY

By

Kara D. Kuhlman

Accepted in Partial Completion
Of the Requirements for the Degree
Master of Science

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ADVISORY COMMITTEE

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MASTER'S THESIS

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Kara Kuhlman

November 3, 2011

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A Thesis
Presented to
The Faculty of
Western Washington University

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science

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ABSTRACT

As sea level rise (SLR) accelerates in response to climate change, coastal wetlands must accrete vertically to prevent submergence and habitat loss. Padilla Bay, an estuary in the Puget Sound containing an expansive eelgrass meadow, has been hydrologically altered such that insufficient sedimentation may now prevent vertical accretion, potentially affecting the long-term survival of the eelgrass meadow. The objective of this study was to quantify trends in surface elevation change throughout Padilla Bay. To this end, our research group monitored surface elevation change at 19 sites from 2002-2010 using sediment elevation tables (SET's). Additionally, I explored potential ecogeomorphic relationships between surface elevation change and selected physical (elevation, sediment characteristics) and biological (eelgrass biomass) variables. Only 1 of 19 study sites exhibited significant surface elevation gain, whereas, 9 sites exhibited significant elevation loss. The mean rate of surface elevation change throughout Padilla Bay was -0.22 ± 0.27 cm yr^{-1}, values ranged from -0.80 cm yr^{-1} to 0.22 cm yr^{-1}. Accounting for surface elevation change, eustatic SLR (0.33 cm yr^{-1}), and regional geologic uplift (0.09 cm yr^{-1}), I calculated a mean surface elevation deficit of -0.46 ± 0.27 cm yr^{-1}. These findings indicate that surface elevation change in Padilla Bay is not keeping pace with the current rate of SLR. A negative relationship between surface elevation change and elevation, and a positive relationship between surface elevation change and eelgrass biomass were apparent, although correlations were non-significant. There was a significant negative correlation between elevation and eelgrass biomass. Surface elevation change did not correlate with the sediment properties measured (bulk density, mineral matter,

organic matter). Although some ecogeomorphic patterns were detected, relationships remained indistinct and require further study.

Sediment scour, induced by the SET benchmark, was observed at several SET sites in Padilla Bay, particularly un-vegetated and high elevation sites. Addressing potential bias introduced by sediment scour required a supplementary analysis providing both a detailed description of scour and the development of an analytical method for removing scour bias. This assessment provided a precise determination of when scour began to impact the SET data, indicated a specific location for truncating impacted datasets, and allowed scour bias in surface elevation change measurements to be removed. Scour was an unforeseen and undocumented byproduct of surface elevation monitoring, this study provides the first indication that alternative SET designs are necessary for use in macro-tidal mudflat habitats.

ACKNOWLEDGEMENTS

I would like to thank the following people and institutions whose generous support made this project possible: my graduate advisor Dr. John Rybczyk for his thoughtful guidance and unwavering support; my graduate research committee, Dr. Douglas Bulthuis and Dr. Andrew Bunn, for their advice and encouragement; Sacha Maxwell, Richard Gwozdz, and Peter Kairis for the invaluable contributions of their graduate research; Michael Hannam for facilitating the elevation survey; staff at Huxley College of the Environment, Shannon Point Marine Center, and the Padilla Bay National Estuarine Research Reserve who made numerous and varied contributions. I would like to extend a special thanks to those who participated in my field research: Kevin Hager, Kyle Hager, Tristan Currin, and Monte Richardson.

TABLE OF CONTENTS Page

LIST OF FIGURES AND TABLES

Figures

Tables

1 INTRODUCTION

1.1 Estuaries and seagrasses

1.1.1 Economic and ecological valuation of estuaries and seagrasses

Estuaries form where rivers meet the sea and comprise ecosystems with significant economic and ecological value. In a global assessment of the goods and services provided by different ecosystems, estuaries were valued at nearly \$23,000 ha^{-1} yr^{-1} (Costanza et al. 1997). By comparison, estuaries were 10 times more valuable than tropical forests and nearly 250 times more valuable than agricultural lands. In a similar assessment in Washington's Puget Sound, seagrass beds, another coastal wetland type and an important component of many estuaries, also qualified as a significant environmental asset, worth up to \$15,000 ha^{-1} yr^{-1} (Batker et al. 2008). Some of the vital ecosystem goods and services estuaries and seagrasses provide include improved water quality, through enhanced nutrient cycling and sediment stabilization, and disturbance regulation, through shoreline protection and storm abatement (Costanza et al. 1997, Duarte 2002, Mitsch and Gosselink 2007). The considerable valuation of coastal wetlands is facilitated by the high levels of primary productivity in these ecosystems, which rank amongst the world's most productive biomes (Day et al. 1989, Duarte 2002). Global net seagrass production is nearly $0.6 \cdot 10^{15}$ g C yr^{-1}, generating the structural foundation of these habitats and yielding the organic matter necessary to support abundant estuarine fauna (Duarte and Chiscano 1999, Duarte 2002). Accordingly, seagrasses sustain high biodiversity, serving as nurseries and refuge for an array of organisms ranging from finfish, shellfish, and crustaceans to birds and marine mammals (Phillips 1984).

Based on these ecological goods and services, seagrasses are recognized as key coastal ecosystems, the persistence of which is considered indicative of broad-scale ecosystem health (Duarte 2002, Orth et al. 2006). As such, increasing reports of seagrass losses are particularly disconcerting (Orth et al. 2006, Waycott et al. 2009). The global extent of seagrasses has declined nearly 30% since the late 1800's, with the highest rates of habitat loss observed in recent decades (Waycott et al. 2009). With few reports of seagrass deterioration linked to natural disturbances, the majority of seagrass declines are tied to anthropogenic activities.

1.1.2 Anthropogenic impacts on estuaries and seagrasses

To date, the leading anthropogenic impact on estuaries has been habitat destruction for shoreline development and farmland reclamation, accomplished with the impounding, draining, and filling of coastal wetlands (Day et al. 1989, Duarte 2002, Borde et al. 2003). Concurrent with increasing coastal development, landscape-scale hydrologic alterations, including upstream damming, shoreline dike construction, and stream channelization, for purposes of hydroelectric power generation, flood management, and navigation, have disrupted wetland hydrology and natural sedimentation patterns (Day et al. 1989, Syvitski et al. 2009). Increased nutrient inputs, pollutant runoff (e.g. heavy metals, pesticides), and aquaculture have degraded water quality, leading to deterioration in light and sediment conditions, and in some cases, eutrophication (Day et al. 1989, Duarte 2002). Biological impacts stemming from the overharvest of native species and the introduction of non-native species have lead to changes in species composition, often with cascading effects on food web dynamics (Day et al. 1989, Duarte 2002). Arguably, the most unpredictable and salient threats to the future resiliency of estuarine ecosystems are caused by anthropogenic climate change.

While the impacts of climate change on estuaries include multiple, simultaneous factors such as changes in the frequency and intensity of storm events, changes in freshwater runoff and subsequent delivery of nutrients and sediments, increased seawater temperature, and ocean acidification, my research focuses on the impacts of accelerated eustatic sea level rise (Scavia et al. 2002, Solomon et al. 2007, Day et al. 2008). Elevated atmospheric concentrations of greenhouse gases, particularly carbon dioxide, have increased global mean temperatures by approximately 0.74 ± 0.18 °C over the past century (Solomon et al. 2007). Warmer global temperatures have accelerated the rate of eustatic sea level rise (ESLR), due to the combined effects of increased land ice melt and thermal expansion of the world's oceans. Throughout the 20th century, sea level rose at a rate of 0.17 ± 0.05 cm yr^{-1}, but in recent decades (1993-2009) has accelerated to 0.33 ± 0.04 cm yr^{-1} (Solomon et al. 2007, Beckley et al. 2010). Given future greenhouse gas emission scenarios, the Intergovernmental Panel on Climate Change (IPCC) predicts an increase in mean sea level between 0.2 and 0.6 m by 2100 (Solomon et al. 2007). However, the IPCC models do not account for dynamic changes in ice flow; consequently, the IPCC projections may underestimate future sea level rise in the event of rapid ice loss (Solomon et al. 2007, Allison et al. 2009). Other reports, which address the IPCC model shortcomings, indicate that the upper limit of sea level rise projections should be expanded to encompass a potential 2.0 m increase in mean sea level over the next century (Rahmstorf 2007, Pfeffer et al. 2008). Utilizing predictions of future sea level, estimated coastal wetland losses by 2080 range between 14-20%; however, projected losses increase nearly threefold when considered in combination with other human impacts (Nicholls 2004).

Coastal wetland losses resulting from accelerated ESLR are due to submergence of estuarine habitats and their permanent conversion to open water, as well as subsequent shifts in habitat types as vegetation communities migrate shoreward to keep within optimum depth tolerances (Scavia et al. 2002). For example, *Zostera marina*, a seagrass (or eelgrass) found at temperate latitudes in the northern hemisphere, is adapted to specific elevations within the intertidal range; limited shoreward by desiccation and seaward by light attenuation (Boese et al. 2005, Thom et al. 2008). Water depth, therefore, directly impacts eelgrass distribution and productivity. Morris et al. (2002) described a quadratic relationship between elevation and intertidal marsh vegetation, wherein peak productivity was observed at some optimum depth (Figure 1A). Above and below this optimum, productivity decreased until species-specific physiological tolerances associated with the upper and lower elevation limits reduced growth and decreased plant survival (Morris et al. 2002). Although the specific environmental controls on marsh vegetation are distinct from those that influence the growth and survival of eelgrass, the quadratic relationship between vegetation and elevation is consistent across intertidal flora. Accordingly, as sea level rises and light availability falls below *Z. marina* tolerances, habitats in the lower tidal range will be converted to open water and the persistence of eelgrass communities will require shoreward migration (Short and Neckles 1999). Shoreline dikes, however, often preclude such landward movement. When vegetation communities reach barriers to migration, they may be extirpated from the bottom-up, termed coastal squeeze (Scavia et al. 2002, Orth et al. 2006).

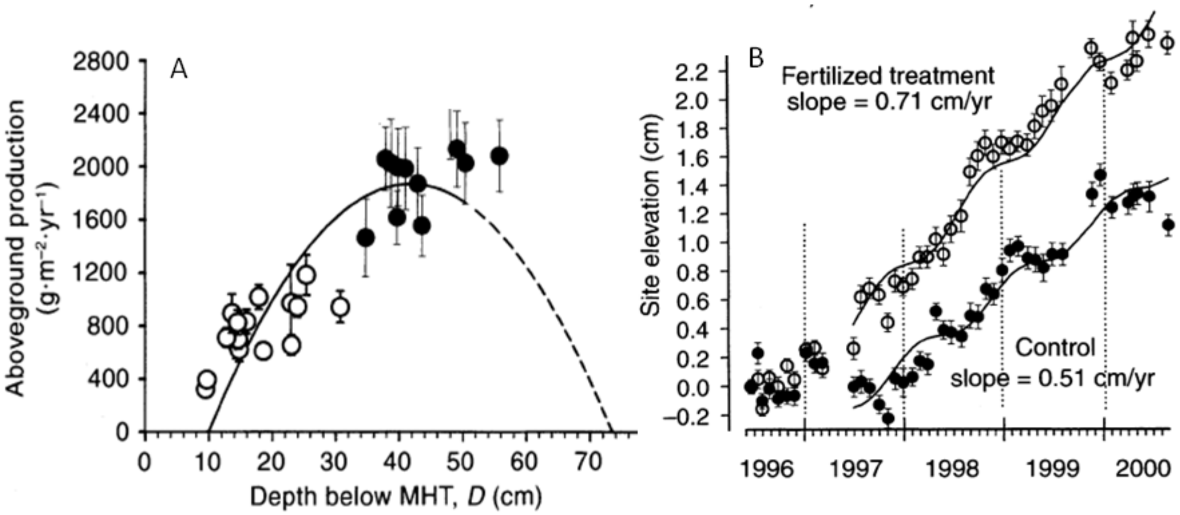


Figure 1. (A) Quadratic relationship between elevation and aboveground production of *Spartina alterniflora* at sites in the high marsh (open circles) and low marsh (closed circles). (B) Surface elevation change in fertilized (open circles) and control (closed circles) treatments at high marsh sites. Figures from Morris et al. (2002), copyright by the Ecological Society of America, reprinted by permission.

Although ESLR occurs globally, regional differences in vertical land movement and surface sediment dynamics are expected to generate variability in realized sea level change (Cahoon et al. 2006). Relative sea level rise (RSLR), a measure accounting for geologic-scale vertical land movement (geologic uplift or deep subsidence) in combination with ESLR, often creates local conditions that significantly depart from global changes in mean sea level (Day et al. 2008). Likewise, surface elevation dynamics (accretion, shallow subsidence, and erosion) occurring within the upper three meters of the sediment profile, may act to either exacerbate or mitigate changes in RSLR, depending on the magnitude and direction of these dynamics (Cahoon et al. 1995, Rybczyk and Cahoon 2002b). Calculating a surface elevation deficit, a variable reflecting changes not only ESLR and vertical land movement, but also surface elevation dynamics, which are often unaccounted for in sea level rise studies, is therefore necessary in order to quantify local changes in water depth.

1.2 Estuarine surface elevation dynamics

1.2.1 Accretion, deterioration, and dynamic equilibrium

Estuarine surface elevation (or sediment elevation) is determined by the interactions of sediment building processes, inherent in estuarine establishment and maintenance, and the deteriorative processes that lead to surface elevation loss (Figure 2) (Day et al. 1999). Accretion, the vertical accumulation of material above and within surface sediments, results from allocthonous organic and mineral matter deposition and *in situ* organic matter production (Reed 1995). Surface elevation loss may result from any combination of shallow subsidence (primary sediment compaction, organic matter decomposition), erosion, or relative sea level rise (ESLR ± vertical land movement) (Callaway et al. 1996). Historically, a dynamic equilibrium existed between sediment building processes and deteriorative processes, whereby the rate of surface elevation gain equaled the rate of RSLR and maintained the elevation of the estuarine surface with respect to sea level (Reed 1995, Day et al. 1999). Under conditions of relatively slow sea level rise (approximately 1 mm yr^{-1} over the past 7 kyrs) and high sediment availability, this equilibrium facilitated the persistence of intertidal habitats for thousands of years (Redfield 1972, Blum and Roberts 2009, Kemp et al. 2011).

In the last century, however, accelerated ESLR and decreased sediment inputs have disrupted the natural balances between surface elevation controls. Rivers are often the most important source of mineral sedimentation in estuaries (Hensel et al. 1999, Day et al. 2011).

Although anthropogenic land-use changes have increased erosion and sediment transport in rivers, retention of these materials behind dams has subsequently reduced the delivery of sediments to estuaries relative to pre-settlement conditions (Syvitski et al. 2005). In many estuaries, dams and other impoundments have also hydrologically uncoupled rivers and estuaries, restricting or eliminating the pulsing events, including overland flooding, necessary for the delivery of remaining sediments (Cahoon 1994, Day et al. 1995). Given insufficient accretion under conditions of reduced sedimentation, many estuaries around the world are losing elevation at rates faster than sea level rise (Syvitski et al. 2009). The resilience of estuaries in response to accelerated ESLR, therefore, depends not only on the natural capacity of these ecosystems to adapt to changes in sea level, but also on the extent to which potential adaptations are hindered by human activities (Scavia et al. 2002, Day et al. 2008).

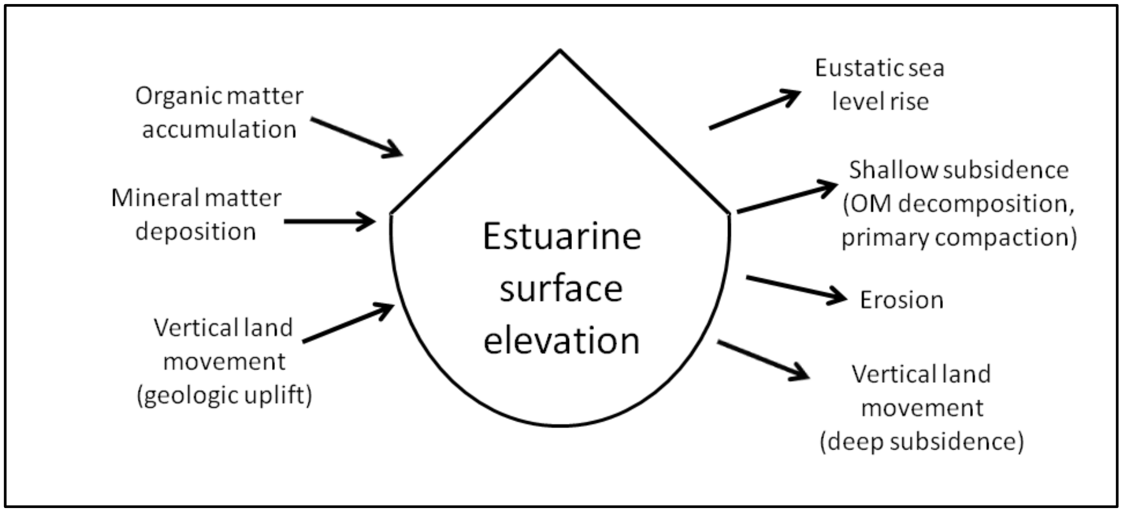


Figure 2. Conceptual diagram of surface elevation processes. On the left are processes contributing to relative surface elevation gain including organic matter accumulation, mineral mater deposition, and positive vertical land movement (e.g. geologic uplift). Processes leading to relative surface elevation loss are shown to the right, including eustatic sea level rise, shallow subsidence (e.g. organic matter decomposition, primary compaction), erosion, and negative vertical land movement (e.g. deep subsidence).

1.2.2 Patterns in estuarine surface elevation change

Within estuaries, patterns in surface elevation change are influenced by non-linear feedback mechanisms between physical (e.g. elevation) and biological (e.g. vegetation) variables (Rybczyk et al. 1998). Often, these feedback mechanisms, or ecogeomorphic interactions, manifest across spatial gradients. For example, within the intertidal range, low elevations are flooded more frequently and for longer durations than higher elevations. Increased inundation provides an increased opportunity for allogenic sedimentation, resulting in higher accretion rates at low elevation sites compared to those at higher elevations (Cahoon and Reed 1995, Reed 1995). Biological variables operate simultaneously. Vegetation attenuates water flows, allowing sediments to fall out of suspension and enhancing the sediment-trapping potential of the estuarine surface (Hemminga and Duarte 2000, Fagherazzi et al. 2004). Moreover, Morris et al. (2002) demonstrated a positive relationship between vegetation productivity and surface elevation change; wherein, high net primary productivity, enhanced in fertilized plots, significantly increased the rate of surface elevation gain compared to controls (Figure 1B). Conversely, loss of marsh vegetation has lead to observed reductions in soil strength, followed by rapid marsh deterioration and significant sediment elevation losses (Day et al. 2011). Ecogeomorphic patterns may also be temporal in nature, as variability in sedimentation rates have been tied to seasonal flux in vegetation biomass (Pasternack and Brush 2001, 2002). Landscape-scale considerations of sediment elevation dynamics should examine these ecogeomorphic relationships as a means to account for spatial and temporal variability in surface elevation change.

1.3 Study area

1.3.1 Puget Sound

Located in western Washington, the Puget Sound consists of a complex network of fjords formed by glacial scouring during the last ice age, approximately 15 kyr BP (Boule 1981, Emmett et al. 2000). Given this geologic history, shorelines are characterized by steep bluffs and correspondingly steep bathymetry, adjoined by narrow beaches. Most Puget Sound estuaries are localized around river deltas where the low topographic relief associated with riverine floodplains facilitates the presence of intertidal habitats (Boule 1981). Since the late 1800's, estimated coastal wetland loss in the Puget Sound range between 70-82%, largely the result of anthropogenic landscape modifications (Emmett et al. 2000, Batker et al. 2008).

1.3.2 Padilla Bay

Padilla Bay, a National Estuarine Research Reserve, is an estuary of significant regional value in the Puget Sound (Figure 3). Padilla Bay is located 15 km north of the current Skagit River delta and covers an area of approximately 4200 ha and (Kairis and Rybczyk 2010). The surrounding terrestrial habitats are predominantly agricultural with some forested uplands (Thom 1990). The bay itself is shallow and largely intertidal. The tidal regime is mixed semi-diurnal, with a maximum tidal range of 4.0 m (Bulthuis 1995). Current freshwater inputs to Padilla Bay include several estuarine sloughs draining surrounding agricultural lands and Skagit River discharge moving north through the Swinomish Channel; although the extent of mixing from the latter is limited, as surface currents from the Swinomish Channel flow predominantly northeast into the Guemes Channel (Bulthuis and Conrad 1995).

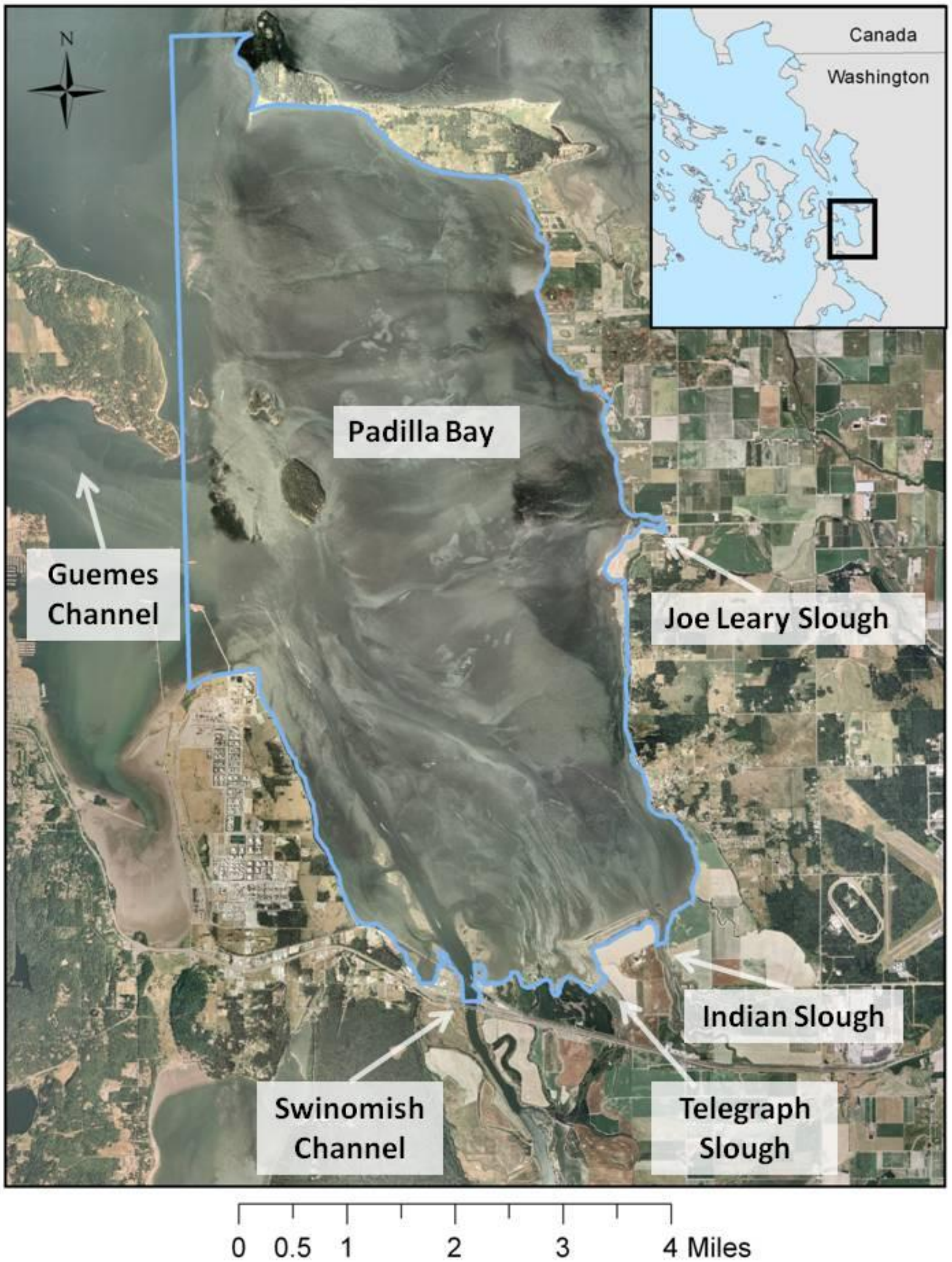


Figure 3. Aerial photo of Padilla Bay with the Padilla Bay National Estuarine Research Reserve boundary outlined in blue. Photo from the USDA National Agricultural Imagery Program (2006).

Dominant estuarine habitat types include intertidal eelgrass meadows and mudflats (Figure 4). The native eelgrass, *Zostera marina,* covers approximately 2900 ha in the upper subtidal to lower intertidal zone (≈ -3.0 - 0.3 m MLLW) (Thom 1990, Bulthuis 1995). A non-native eelgrass species, *Zostera japonica*, is found in the mid intertidal zone (≈ 0.3 - 0.8 m MLLW) and occupies a lesser areal extent, approximately 324 ha (Thom 1990, Bulthuis 1995). Although eelgrass stands are generally monotypic, a narrow mixing zone is observed where the species' elevational ranges overlap. Together, these two species constitute one of the largest intertidal eelgrass meadows on the North American Pacific coast (Bulthuis 1995). This eelgrass meadow provides vital habitat for a diverse assemblage of organisms including Dungeness crab, juvenile chum salmon, and overwintering and migratory shorebirds and waterfowl, including brant geese (Phillips 1984, Bulthuis 1995).

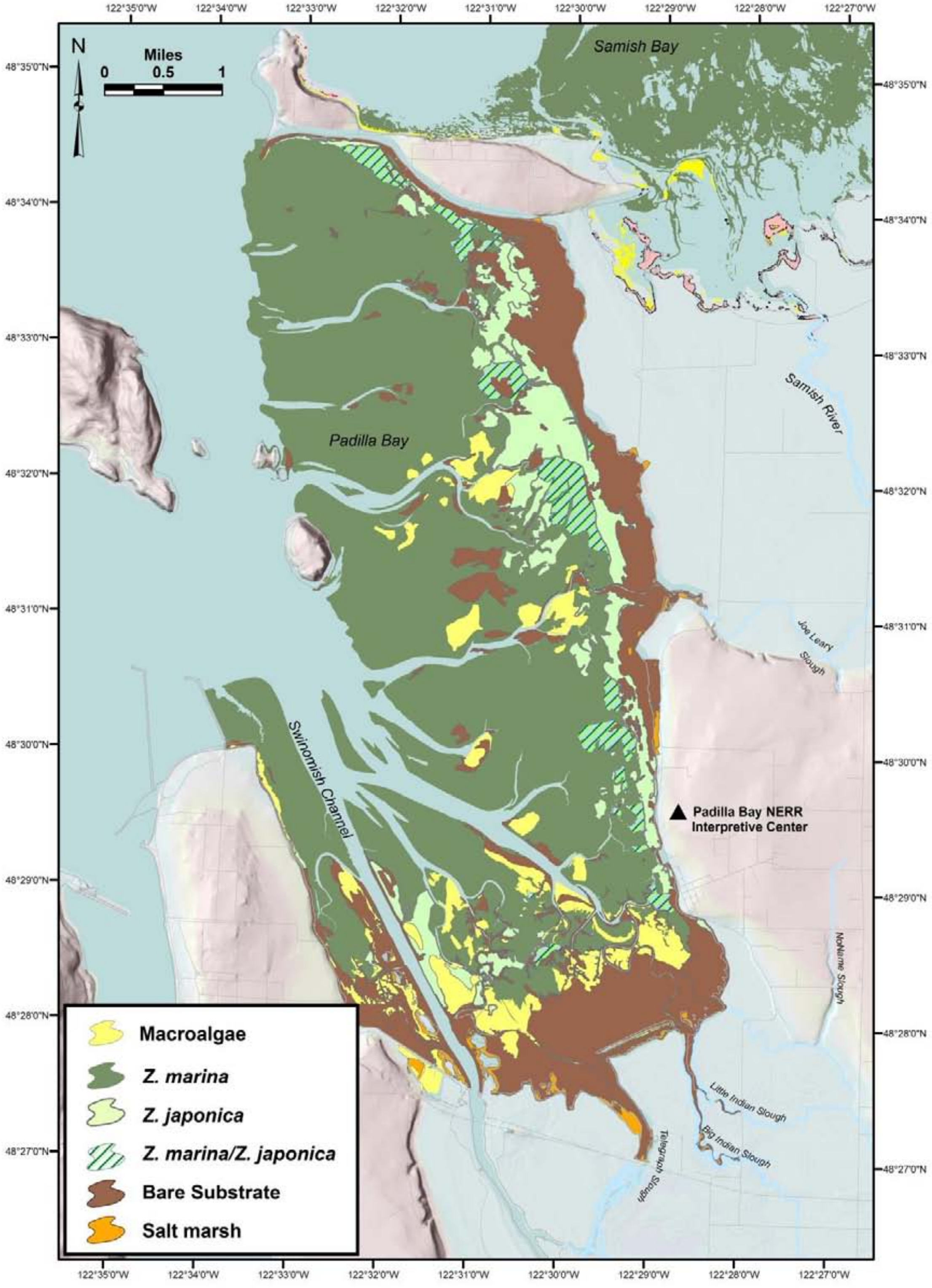


Figure 4. Map of eelgrass habitats in Padilla Bay. Courtesy of the Padilla Bay National Estuarine Research Reserve, reprinted by permission (Bulthuis and Shull 2006).

Padilla Bay has been hydrologically isolated from historical mineral sediment inputs once provided during overland flood events on the Skagit River. Dike construction, for farmland reclamation, beginning in the early 1860's effectively secluded the estuary from floodplain runoff (Collins 1998). The simultaneous removal of extensive log jams on the Skagit River eliminated backwater flood events, thereby reducing freshwater input to the distributaries that maintained hydrologic connectivity with the southern region of the bay (Collins 1998). In the 1930's, construction began on a series of hydroelectric dams on the Skagit River. Sediment retention behind these dams is expected to have reduced sediment loads below historic levels (Collins 1998). The Skagit River currently exports approximately 2,800,000 tons of sediment each year into Skagit Bay, located south of Padilla Bay (Curran et al. *in press*). However, the Skagit Bay jetty near the south end of the Swinomish Channel disrupts the movement of suspended sediments from the Skagit River into the channel, reducing the opportunity for sediment transport north into Padilla Bay (Grossman et al. 2011). Together, these hydrologic modifications are suspected of reducing mineral sediment inputs to Padilla Bay, making the estuary vulnerable to accelerated rates of eustatic sea level rise. Losing eelgrass meadows due to submergence and coastal squeeze will likely degrade or eliminate the ecosystem goods and services provided by this habitat and may have far reaching implications for the organisms relying on this ecosystem for food and refuge.

1.3.3 Project history

This project represents the most recent phase of a long-term research program, under the advisement of Dr. John Rybczyk, designed to predict the impacts of sea level rise on coastal ecosystems in the Pacific Northwest. Although there is extensive research regarding estuarine surface elevation dynamics in wetlands along the Gulf and Atlantic coasts of North America, few studies have addressed this topic in coastal wetlands on the Pacific (Cahoon et al. 1995, Day et al. 1995, 2011, Cahoon and Lynch 1997, Rybczyk and Cahoon 2002, Morris et al. 2002, Whelan et al. 2005). Furthermore, the bulk of existing research has focused on salt marshes and mangroves, leaving gaps in our understanding of tidal wetland habitats (e.g. mudflats and eelgrass meadows) (Cahoon et al. 2006). In this thesis, I present the first assessment of surface elevation dynamics in intertidal mudflat and eelgrass habitats.

My research directly builds on the work of three previous graduate students, Maxwell (2004), Gwozdz (2006), and Kairis (2008), who were responsible for installing and monitoring 23 estuarine surface elevation monitoring sites throughout Padilla Bay beginning in 2002. Preliminary results suggested surface elevation gain in Padilla Bay was insufficient to keep pace with rising sea level, but the temporal extent of these data were limited and initial results lacked the statistical power to make a robust determination of surface elevation trends (Maxwell 2004). With an eight year monitoring record now available, my research provides a comprehensive analysis of estuarine surface elevation changes in Padilla Bay from 2002 to 2010.

1.4 Project scope and objectives

The primary purpose of this research was to quantify trends in surface elevation change throughout Padilla Bay. Based on increasing global mean sea level and a suspected reduction in mineral sediment inputs, I hypothesized that vertical accretion in Padilla Bay may be insufficient to maintain estuarine surface elevation relative to sea level. Additionally, I measured selected physical and biological variables shown to correlate with sediment elevation dynamics as a means to explore relationships in elevation change along an estuarine gradient. The results of this study will provide an understanding of the current surface elevation dynamics throughout the estuary and will be incorporated into a relative elevation model designed to predict changes in eelgrass distribution and productivity in Padilla Bay under a range of sea level rise scenarios (Kairis and Rybczyk 2010). Conclusions may also be utilized for management and conservation planning consistent with the mandate of the Padilla Bay National Estuarine Research Reserve.

Given this project scope, I addressed the following objectives:

1. Assessment of surface elevation dynamics in Padilla Bay:
    a. Determine the rate of surface elevation change and surface elevation deficit at study sites distributed throughout Padilla Bay
    b. Examine seasonal patterns in surface elevation change
    c. Explore ecogeomorphic relationships between rates of surface elevation change and physical (elevation) and biological (aboveground *Zostera* biomass) variables
2. Analysis of sediment qualities from Padilla Bay:
    a. Describe sediment characteristics throughout Padilla Bay, including bulk density, percent weight of mineral matter and organic matter, and the percent volume of mineral matter, organic matter, and pore space
    b. Assess potential covariance between sediment characteristics and surface elevation changes measured throughout Padilla Bay
    c. Explore whether the single accreting site (site 8) had sediment characteristics distinct from the sites with negative elevation change
3. Finally, SET induced scour arising at some SET sites required the development of a quantitative method for removing the bias introduced by sediment scour:
    a. Provide a description of sediment scour
    b. Develop an *a posteriori* analytical method for removing scour bias

Objectives one, two, and three are the subject of chapters two, three, and four respectively.

2 ESTUARINE SURFACE ELEVATION DYNAMICS

2.1 Introduction

2.1.1 Estuarine surface elevation change

As discussed in Chapter 1, estuarine surface elevation is determined by the interactions of accretion, shallow subsidence, erosion, and RSLR. Currently, under conditions of accelerated ESLR and reduced sedimentation, coastal wetlands are becoming increasingly vulnerable to submergence (Syvitski et al. 2009). Accordingly, I hypothesized that surface elevation gain in Padilla Bay, an estuary where reductions in mineral sediment inputs are suspected, may be insufficient to keep pace with rising sea level. Additionally, I sought to examine the non-linear feedback mechanisms that generate spatial and temporal variability in surface elevation change within estuaries. Accretion is generally highest at low elevations and in areas with high vegetation biomass, whereas accretion is generally lowest at high elevations and in areas with low vegetation biomass (Reed 1995, Morris et al. 2002). Consequently, I hypothesized that elevation changes in Padilla Bay would parallel these documented ecogeomorphic patterns.

2.1.2 Objectives

My primary objective was to quantify trends in surface elevation change throughout Padilla Bay from 2002-2010. Second, in an *a posteriori* analysis based on observations noted in preliminary results, I examined seasonal changes in surface elevation. Finally, I measured selected physical (elevation) and biological (aboveground *Zostera* biomass) variables shown to correlate with sediment elevation dynamics as a means to explore ecogeomorphic relationships in elevation change along an estuarine gradient and account for variability in surface elevation change observed within the estuary.

2.2 Methods

2.2.1 Elevation change

Elevation change is measured with a sediment elevation table (Figure 5) (Boumans and Day 1993, Cahoon et al. 2002). There are two components to the sediment elevation table, a stable benchmark and a portable leveling device. The latter is referred to as the SET. The benchmark is established by driving a steel rod vertically into the sediment until reaching the point of refusal, between 5-7 m deep at sites in Padilla Bay. At this depth, benchmark stability in the vertical plane is assumed. Lateral stability is ensured by fitting the benchmark with a cylindrical cement collar (15 cm diameter, 20 cm deep) resting flush with the sediment surface. Finally, to provide a fixed platform for SET coupling, a metal collar is fastened atop the aboveground segment of the benchmark rod.

To begin sampling, the SET is attached atop the metal collar and securely locked into one of eight fixed horizontal arm positions. Once the SET is fastened and mechanically leveled, nine fiberglass pins are then lowered through the leveling arm to touch the sediment surface. The length of the pin extending above the leveling arm is measured; accretion of the sediment surface increases pin length, whereas, shallow sediment subsidence or erosion will decrease pin length. Pin height measurements reflect changes relative to the bottom of the benchmark rod, which defines the zone of shallow subsidence. These methods allow operators to make repeated and high precision measurements of sediment elevation change accurate to within 1.5 mm (Cahoon et al. 2002).

The primary advantage of using SET's rather than other accretion methods, such as marker horizons, which indicate vertical accumulation above a physical marker, is that SET measurements simultaneously incorporate vertical accretion, shallow subsidence, and erosion into elevation change data. Researchers utilizing marker horizons must implicitly assume a 1:1 relationship between accretion and surface elevation gain, leaving shallow subsidence and erosion unaccounted for and potentially overestimating actual sediment elevation gain (Cahoon et al. 1995).

Surface elevation change was measured from 2002-2010 at sites located systematically throughout Padilla Bay (Figure 6). Eighteen sites were established in the summer of 2002, with five additional sites added during the summers of 2004 and 2005 (sites labeled "B") (Maxwell 2004, Kairis 2008). One deep rod SET was installed per site. Sites 1-16 were accessible by foot from shore, whereas the remaining sites were accessible only by boat. The occurrence of extreme low tides necessary for site access allowed for two annual sampling periods: spring sampling, completed between April and May, and summer sampling, completed between July and August. Monitoring was conducted biannually for the first four years of the study with less frequent sampling in subsequent years.

To allow researchers ready access to the sites while minimizing potential disturbance to the sediments measured, SET measurements were restricted to four of the eight arm positions. Selection of arm positions was based on site access; the four seaward arm positions were selected at sites accessible by foot, whereas the four arm positions perpendicular to the nearest channel were selected at sites accessible by boat. Accordingly, researchers always approached sites from the same direction and the estuarine surface where measurements were taken was never directly disturbed.

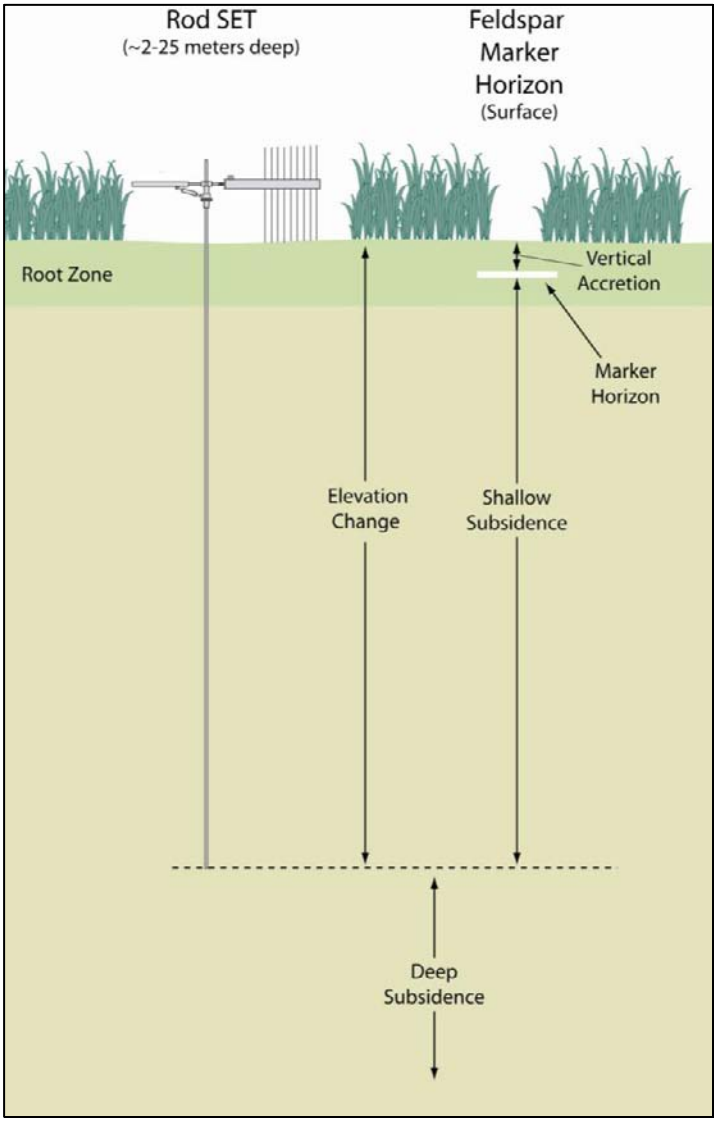


Figure 5. Surface elevation change measurements are made using sediment elevation tables (SETs), depicted on the left. SET's integrate sediment building processes (vertical accretion) and deteriorative processes (shallow subsidence and erosion) to a depth of several meters. Elevation changes below the SET benchmark are classified as geologic-scale vertical land movements (deep subsidence or geologic uplift). Figure courtesy of the USGS Patuxent Wildlife Research Center, reprinted by permission.

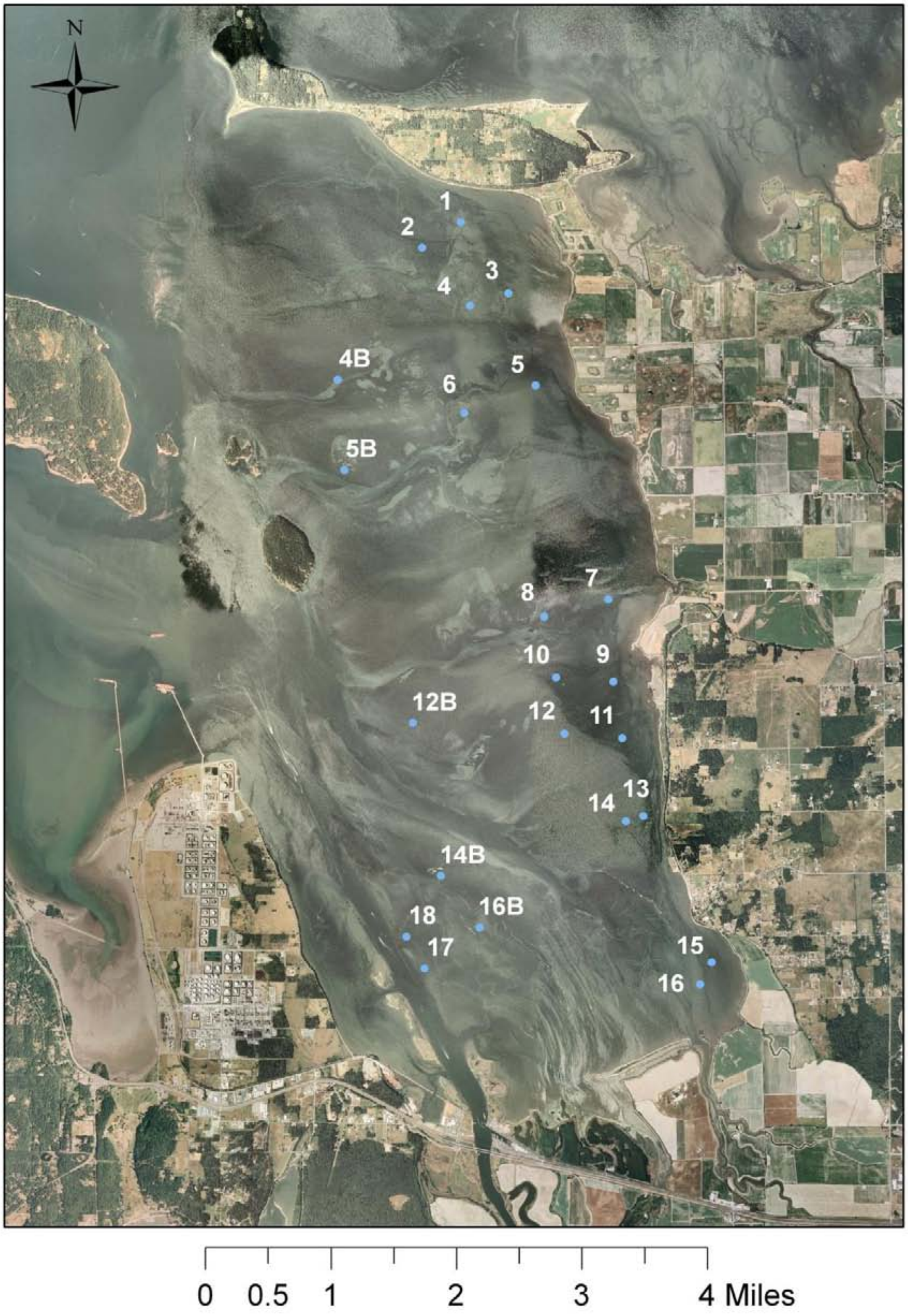


Figure 6. Study site locations (n=23) throughout Padilla Bay.

2.2.2 Sediment elevation table QA/QC

Although 23 SET sites were established and monitored throughout Padilla Bay, I removed 4 sites (sites 17, 18, 4B, and 16B) from my analysis for quality assurance and control purposes. Sites 17 and 18 were located on the Swinomish Channel, a man-made, navigable waterway maintained by the Army Corps of Engineers. Dredging and heavy boating traffic have artificially disrupted natural hydrodynamics and sedimentation patterns surrounding the channel, observed in year-to-year surface elevation changes well beyond the range of natural variability. Site 4B was removed due to the natural migration of a nearby channel, during which elevation gain in excess of 7 cm was observed (2006-2008). Inclusion of this site would significantly overestimate actual surface elevation gain in the region. Lastly, site 16B was removed due to extensive scour around the SET's cement collar and is discussed in detail in Chapter 4: Scour Correction. After the removal of these 4 sites, I retained records from 19 sites. I further amended this dataset by truncating records at 6 sites to remove bias introduced by sediment scour around the SET's cement collar. For a detailed discussion of this matter see Chapter 4: Scour Correction.

2.2.3 Elevation

Site elevation was collected between May 2010 and January 2011 using rapid static GPS surveying. The GPS receiver (Javad Maxor GGDT) was securely fastened to the top of the SET benchmark using a custom-built 3/8" - 5/8" threaded adapter. The SET's cement collar was used to provide a permanent surface datum. For this reason, the height of the receiver above the cement collar was recorded and used to correct the offset distance. Accordingly, all elevations represent site elevation at the time of SET installation, when the cement collar was flush with the sediment surface. Concurrent with field sampling was the continuous operation of a second GPS receiver, or base station. The base station was centered over the National Geodetic Survey (NGS) marker near the Padilla Bay Breazeale Interpretive Center, where it remained operational until field sampling for the day was completed. The base station data were post-processed using both NGS Continuously Operating Reference Stations and the Washington State Reference Network. Elevations were reported with respect to mean lower low water (MLLW), a tidal datum reflecting the average water height at the lower low of the daily tidal cycle. Michael Hannam, PhD candidate at the University of Washington, provided the necessary GPS and survey equipment and processed all GPS data.

2.2.4 Biomass

Eelgrass biomass was collected during three seasons to capture inter-annual variability, including spring (May/June 2010), summer (August 2010), and winter (January 2011). Aboveground biomass was harvested from three replicate quadrats (0.15 m^2) distributed haphazardly near each SET site and stored in labeled plastic bags. Samples were refrigerated for up to three days until they could be rinsed clean of sediments and epiphytes. Clean samples were dried at 105˚C for 48 hours and then weighted. Each site was visited during spring sampling, but logistical constraints prevented sampling at several sites during the summer and winter. For this reason, spring biomass values were used in all statistical analyses.

2.2.5 Data analysis

2.2.5.1 Rate of surface elevation change

Elevation change was calculated from the SET data as the difference between the individual pin height measured at a given sampling interval from the baseline measurement established at the initial pin reading. Mean elevation change (average of all 36 pins) was used to attain one value per SET per sampling period; thereby designating the SET as the experimental unit, used in all subsequent analyses, and avoiding pseudo-replication due to non-independence of the SET arms. Mean elevation changes at each site were fit with an ordinary least squares linear regression with time as the independent variable and elevation change as the dependent variable. The rate of surface elevation change (cm yr^{-1}) was determined from the slope of the regression. Regression residual plots (standardized residuals versus predicted values) were visually inspected to assess general agreement with the test assumption requiring the homogeneous distribution of regression residuals.

2.2.5.2 Surface elevation deficit

The surface elevation deficit at each site was calculated according to the following equation:

Elevation deficit = surface elevation change - ESLR ± vertical land movement

[Eq. 1]

Surface elevation change was calculated from the SET data as described above. The rate of ESLR derived using satellite altimetry from 1993 to 2009 was 0.33 ± 0.04 cm yr^{-1} (Beckley et al. 2010). The rate of vertical land movement reported by Verdonck (2006) for Friday Harbor, WA, was 0.09 ± 0.01 cm yr^{-1}, determined from analysis of a 55 year tide gauge record and repeated leveling surveys. Friday Harbor is in close proximity to the study area and this value was considered a best estimate in the absence of data specific to Padilla Bay. Additionally, the Friday Harbor record is consistent with coarse-scale geospatial interpolations of regional vertical land movements ranging between 0.00 - 0.20 cm yr^{-1}, derived from both tide gauge and GPS records throughout the Pacific Northwest (Verdonck 2006, Mote et al. 2008).

2.2.5.3 Seasonal variance in surface elevation change

Based on observations of a seasonal pattern in surface elevation change, wherein elevation gain was generally observed over the summer and elevation loss was generally observed over the winter, I pursued an *a posteriori* analysis of incremental elevation changes between sampling periods. Biannual sampling intervals (4 winter increments, 4 summer increments), including data collected in 2002-2005 and 2010, were used in this analysis; inter-annual measurements (2006-2009) were excluded. Sites 1-14 met the biannual sampling criteria, although not all of the site records included each winter and summer increment (n=102 rather than n=112). Some sites were excluded from the seasonal analysis altogether because biannual measurements had either not been taken (sites 5B, 12B, 14B) or were removed for scour correction (sites 15, 16). Descriptive analysis was considered appropriate, as these data were not spatially or temporally independent, hence they did not meet assumptions of statistical hypothesis testing.

Incremental elevation change was calculated as the difference between the pin height measured at a given sampling period from the previous pin height measurement, thereby isolating changes between consecutive sampling periods. Again, all 36 pins were averaged to obtain one value per SET per interval. I then calculated the approximate rate of elevation change per season for each interval, taking into account the disparity between summer and winter season lengths. The summer interval was approximately 3.5 months, whereas the winter interval was approximately 8.5 months. Because season length varied from site-to-site and year-to-year depending on the sampling schedule, the mean season length was used in these calculations. Thus, these estimates are intended only for making relative comparisons between seasons.

2.2.5.4 Physical and biological variance in surface elevation change

I used Pearson's R to test bay-wide correlations between three variables, including the rate of surface elevation change, elevation, and spring biomass. These data were tested for normality and spatial autocorrelation. A multiple regression, with elevation change as the dependent variable and elevation and spring biomass as the independent variables, was performed to determine the predictive capacity of these two independent variables in relation to elevation change.

2.2.5.5 Statistical analysis

All statistical analyses were completed in the R programming environment and used a critical value (α) of 0.05 (R Development Core Team 2009).

2.3 Results

2.3.1 Rate of surface elevation change and surface elevation deficit

Of the 19 sites analyzed, only 1 (site 8) exhibited significant surface elevation gain (Table 1). Conversely, 9 sites exhibited significant elevation loss (Figure 7). The mean rate of surface elevation change throughout Padilla Bay was -0.22 ± 0.27 cm yr^{-1} (± 1 standard deviation), with a range of -0.80 cm yr^{-1} to 0.22 cm yr^{-1} (Table 1). Non-significant changes in surface elevation (n=9) were generally restricted to sites with elevation change of low magnitude or sites with only two sampling periods (sites 15, 16) where the regression slope was used without an associated p-value. The rate of elevation change derived at each site was included in mean elevation change calculations and subsequent analyses regardless of statistical significance. All study sites exhibited an elevation deficit with respect to relative sea level rise. Site specific elevation deficits ranged between -1.04 cm yr^{-1} to -0.02 cm yr^{-1}, with a bay-wide mean elevation deficit of -0.46 ± 0.27 cm yr^{-1} (Table 1).

Table 1. Rate of surface elevation change and the elevation deficit derived at each study site. The regression test statistic (r^2) and statistical significance are also reported. The elevation deficit is calculated according to Equation 1 (Elevation deficit = surface elevation change - ESLR ± vertical land movement) and uses ESLR = 0.33 cm yr^{-1} and vertical land movement = 0.09 cm yr^{-1}.

Site	Elevation change (cm yr^{-1})	r^2	Elevation deficit (cm yr^{-1})	Years
1[1]	-0.80	0.75*	-1.04	2002-2005
2	-0.29	0.91*	-0.53	2002-2010
3[1]	-0.15	0.11	-0.39	2002-2005
4	-0.52	0.96*	-0.76	2002-2010
5[1]	-0.02	0.00	-0.26	2002-2004
6	-0.19	0.75*	-0.43	2002-2010
7	-0.45	0.89*	-0.69	2002-2010
8	0.16	0.52*	-0.08	2002-2010
9[1]	-0.12	0.16	-0.36	2002-2005
10	-0.26	0.65*	-0.50	2002-2010
11	-0.15	0.36*	-0.39	2002-2010
12	-0.27	0.59*	-0.51	2002-2010
13	-0.50	0.91*	-0.74	2002-2010
14	-0.08	0.31	-0.32	2002-2010
15[1]	-0.21	na	-0.45	2002-2003
16[1]	-0.57	na	-0.81	2002-2003
5B	-0.02	0.01	-0.26	2005-2010
12B	0.13	0.21	-0.11	2004-2010
14B	0.22	0.25	-0.02	2004-2010
mean	-0.22 ± 0.27 (±sd)		-0.46 ± 0.27 (±sd)	

[1] Data were scour corrected

* Significant linear regression at $p < 0.05$

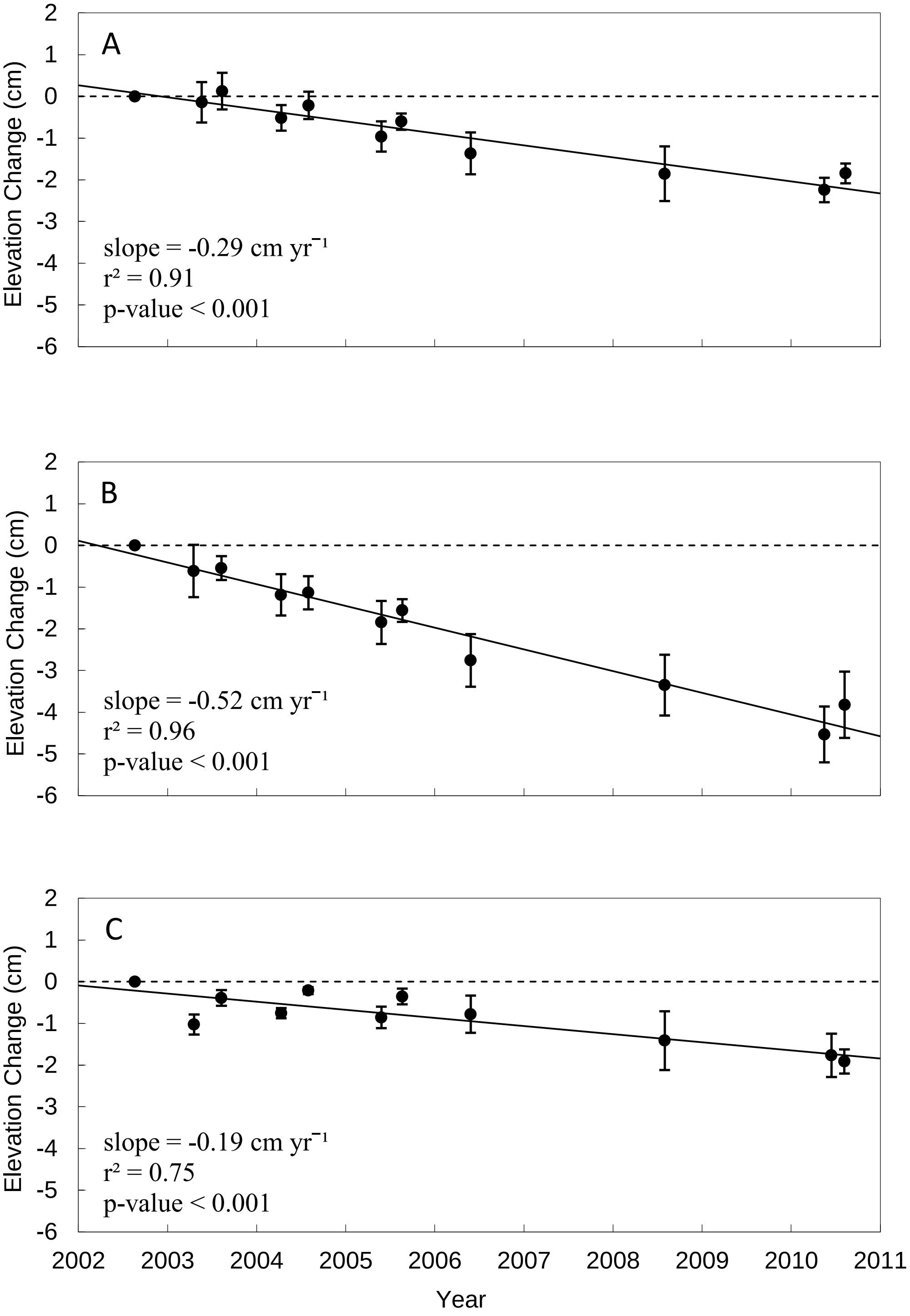


Figure 7. Surface elevation changes from 2002-2010 at three selected sites (A) site 2, (B) site 4, (C) site 6. Error bars representing ± 1 standard deviation of SET arm means (n=4) are used to indicate variance, although arm means were not used in regression calculations.

2.3.2 Seasonal variance in surface elevation change

A seasonal pattern in surface elevation change was evident in the SET data and appeared to be both spatially and temporally consistent (Figure 8, 9). The summer increment had a 90% occurrence of elevation gain (46 of 51 intervals). The five instances of negative elevation change during the summer interval occurred in 2004 (sites 1, 14) and 2010 (sites 6, 7, 11). There was a 94% occurrence of elevation loss (48 of 51 intervals) observed during the winter increment; the three anomalous instances of positive elevation change occurred over the winter of 2004-2005 at three sites (sites 9, 10, 11) in the central region of Padilla Bay south of Joe Leary Slough. At sites with significant rates of elevation loss as discussed previously, the magnitude of surface elevation gains during the summer increments were generally not large enough to offset winter losses over the long-term.

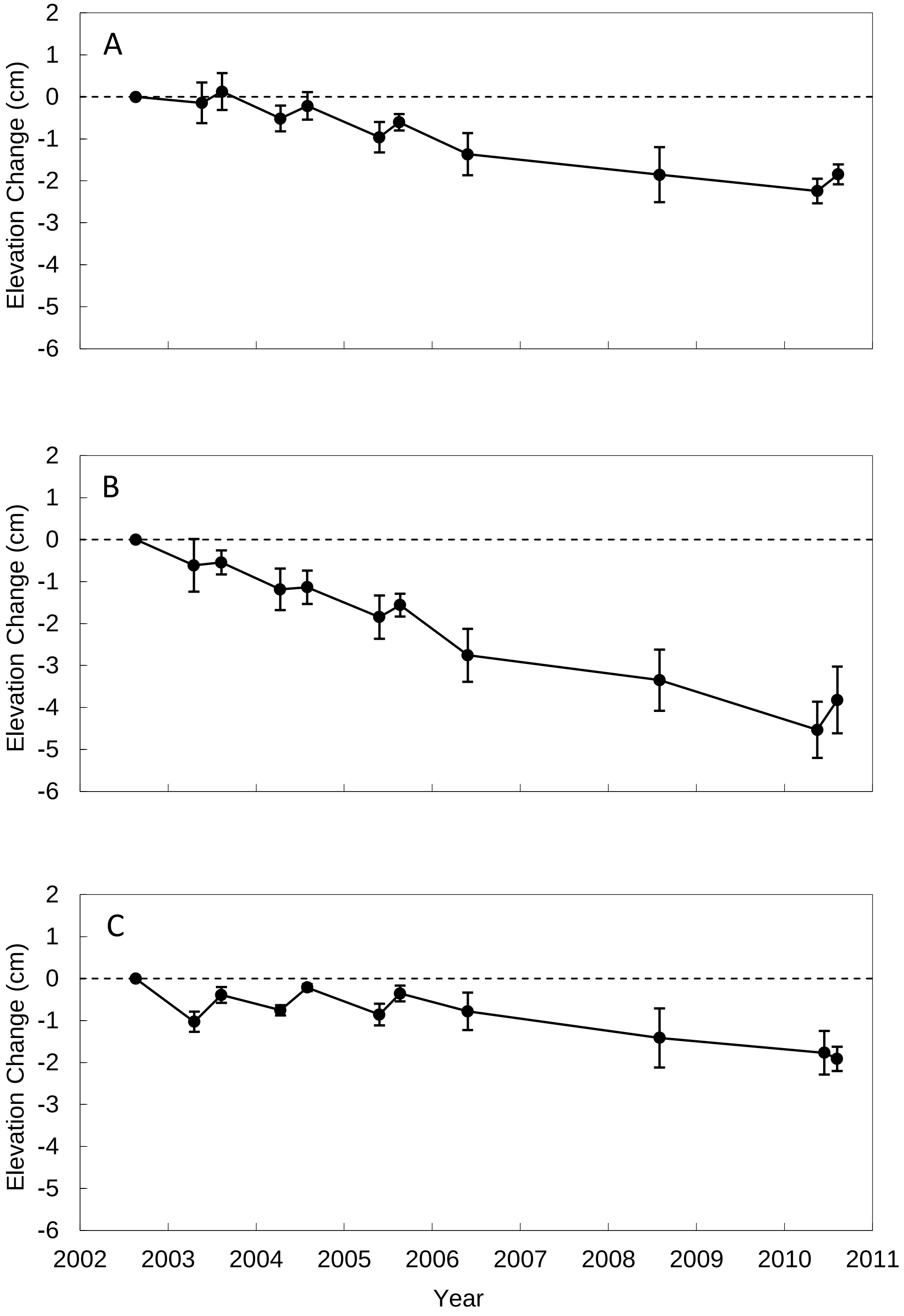


Figure 8. Surface elevation changes from 2002-2010 at three selected sites illustrating the seasonal pattern of accretion during the summer interval and elevation loss over the winter interval (A) site 2, (B) site 4, (C) site 6. Error bars representing ± 1 standard deviation of SET arm means (n=4) are used to indicate variance, although arm means were not used in regression calculations. Line added for emphasis.

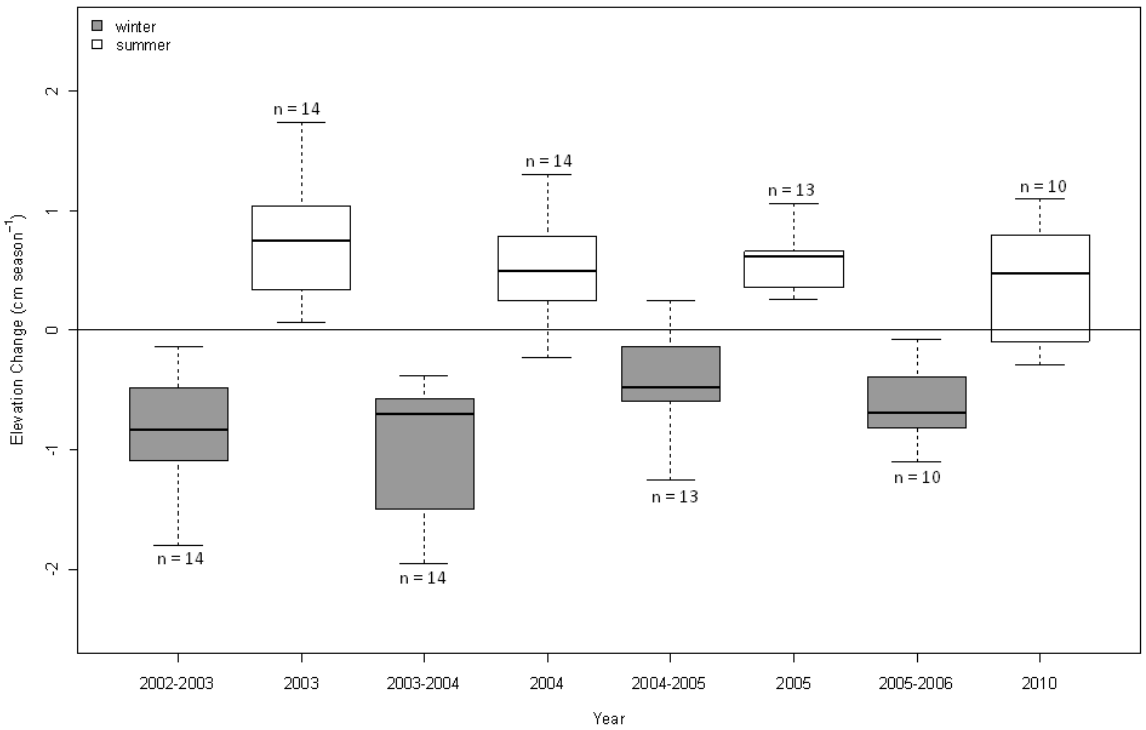


Figure 9. Box and whisker plots depicting seasonal elevation changes at sites throughout Padilla Bay. Box edges extend to the 25th and 75th quartiles, box whiskers extend to the highest and lowest values. The median is indicated by the dark line within the box. The number of sites (n) used in each seasonal interval is also shown.

2.3.3 Elevation

Site elevations ranged between -0.88 m MLLW to 1.06 m MLLW, with a mean elevation of 0.36 ± 0.46 m MLLW (n=19) (Table 2).

Table 2. The elevation and location of study sites in Padilla Bay determined from the GPS survey. Latitude and longitude are reported in decimal degrees.

Site	Elevation (m MLLW)	Date acquired	Latitude	Longitude
1	0.51	1/3/2011	48.5623	-122.5175
2	0.36	1/3/2011	48.5593	-122.5242
3	0.79	1/2/2011	48.5540	-122.5093
4	0.33	1/2/2011	48.5526	-122.5160
5	0.70	8/5/2010	48.5433	-122.5047
6	0.25	8/5/2010	48.5402	-122.5171
7	0.62	6/15/2010	48.5186	-122.4923
8	0.30	6/15/2010	48.5166	-122.5034
9	0.77	5/17/2010	48.5090	-122.4915
10	0.11	1/2/2011	48.5096	-122.5014
11	0.61	5/17/2010	48.5025	-122.4900
12	0.08	5/17/2010	48.5031	-122.5001
13	0.30	6/15/2010	48.4935	-122.4865
14	0.24	6/15/2010	48.4929	-122.4895
15	1.01	6/15/2010	48.4765	-122.4748
16	1.06	6/15/2010	48.4740	-122.4768
17[1]	0.82	8/9/2010	48.4760	-122.5246
18[1]	0.45	8/9/2010	48.4797	-122.5277
4B[1]	-0.34	6/14/2010	48.5441	-122.5391
5B	-0.88	6/14/2010	48.5337	-122.5380
12B	-0.37	6/14/2010	48.5044	-122.5263
14B	0.05	5/14/2010	48.5441	-122.5390
16B[1]	0.75	5/14/2010	48.5337	-122.5380
Mean	0.36 ± 0.46 (±sd)			

[1] Data are reported to establish a permanent record although these sites were not used in my analysis and are not included in the mean (see Sediment elevation table QA/QC: Section 2.2.2)

2.3.4 Biomass

Where vegetation was present, mean spring biomass was 95.1 ± 43.0 g dry weight (DW) m^{-2}, with site averages ranging from 17.4 g DW m^{-2} to 150.1 g DW m^{-2} (Table 3). *Z. marina* was present at twelve sites (mean biomass = 105.7 ± 38.1 g DW m^{-2}), *Z. japonica* was present at three sites (mean biomass = 52.5 ± 35.6 g DW m^{-2}), the four remaining sites were un-vegetated mudflat. Biomass did not change appreciably between the spring and summer at several sites (sites 2, 4, 10, 13, 14); whereas, changes in excess of 20 g DW m^{-2} were observed at sites with increasing biomass (sites 5, 7, 11, and 12), including all sites dominated by *Z. japonica,* and sites with decreasing biomass (sites 6, 8, 9, 14B) (Table 3). During the winter, biomass decreased significantly at all sites surveyed.

Table 3. Mean *Zostera* biomass (± 1 standard deviation, n=3) collected at study sites in spring (May/June 2010), summer (August 2010), and winter (January 2011). Blank cells indicate samples were not taken.

	Mean biomass (g DW m^{-2})			Species (>50 % cover)
Site	Spring	Summer	Winter	
1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	
2	65.2 ± 11.3	71.3 ± 11.1	29.1 ± 6.8	*Z. marina*
3	0.0 ± 0.0	3.2 ± 2.5	0.0 ± 0.0	
4	75.3 ± 18.7	90.8 ± 10.2	16.0 ± 12.6	*Z. marina*
5	48.8 ± 3.2	100.9 ± 10.4		*Z. japonica*
6	123.3 ± 54.4	84.3 ± 34.0		*Z. marina*
7	91.5 ± 30.3	135.0 ± 38.4		*Z. japonica*
8	83.2 ± 77.0	55.5 ± 20.2		*Z. marina*
9	118.7 ± 18.4	86.8 ± 15.7	7.4 ± 2.6	*Z. marina*
10	150.1 ± 16.4	134.9 ± 18.8	14.2 ± 3.7	*Z. marina*
11	17.4 ± 1.8	96.8 ± 10.6		*Z. japonica*
12	95.7 ± 5.6	160.5 ± 41.3		*Z. marina*
13	72.8 ± 17.7	69.4 ± 12.9	22.7 ± 6.8	*Z. marina*
14	111.9 ± 13.9	103.4 ± 11.0	38.2 ± 22.5	*Z. marina*
15	0.0 ± 0.0			
16	0.0 ± 0.0			
5B	143.2 ± 23.5			*Z. marina*
12B	124.0 ± 38.8			*Z. marina*
14B	104.8 ± 12.8	78.4 ± 28.2		*Z. marina*

2.3.5 Physical and biological variance in surface elevation change

The variables used in the correlation analysis, surface elevation change, elevation, and mean spring biomass, met the test assumption of bi-variate normality (surface elevation change: Shapiro-Wilk (W) = 0.97, p-value = 0.82; elevation: W = 0.94, p-value = 0.22; spring biomass: W = 0.91, p-value = 0.07). Furthermore, model residuals from each correlation were independent and identically distributed (i.i.d.), Moran's I test for spatial auto-correlation was non-significant at a range of nearest-neighbor (k) values.

I observed a generally negative, although non-significant, relationship between surface elevation change and elevation ($r^2 = -0.39$, $p = 0.10$, $n = 19$) (Figure 10A). Likewise, I observed a generally positive, but non-significant, relationship between the rate of elevation change and spring biomass ($r^2 = 0.43$, $p = 0.06$, $n = 19$) (Figure 10B). Although the surface elevation change correlations were not statistically significant, some general patterns in elevation change were observed. The site with significant positive elevation change (site 8), in addition to two other sites exhibiting absolute, although non-significant, elevation gain (sites 12B, 14B), were located at elevations at or below 0.30 m MLLW and had substantial *Z. marina* biomass (83.2 g DW m^{-2}, 124.0 g DW m^{-2}, and 104.8 g DW m^{-2} respectively) (Tables 2, 3). The two sites with the highest rates of elevation loss (sites 1, 16) were located at mid-to-upper intertidal elevations (0.51 m MLLW, 1.06 m MLLW) and had either low biomass or no vegetation (Tables 2, 3). *Z. japonica* presence at site 1 has exhibited year-to-year variability; site 16 has remained un-vegetated throughout the course of this study.

I detected a significant negative correlation between elevation and spring biomass ($r^2 = -0.73$, $p < 0.001$, $n = 19$) (Figure 10C). A multiple regression, with elevation change as the dependent variable and elevation and spring biomass as the independent variables was non-significant (adjusted $r^2 = 0.10$, p-value = 0.17, n = 19).

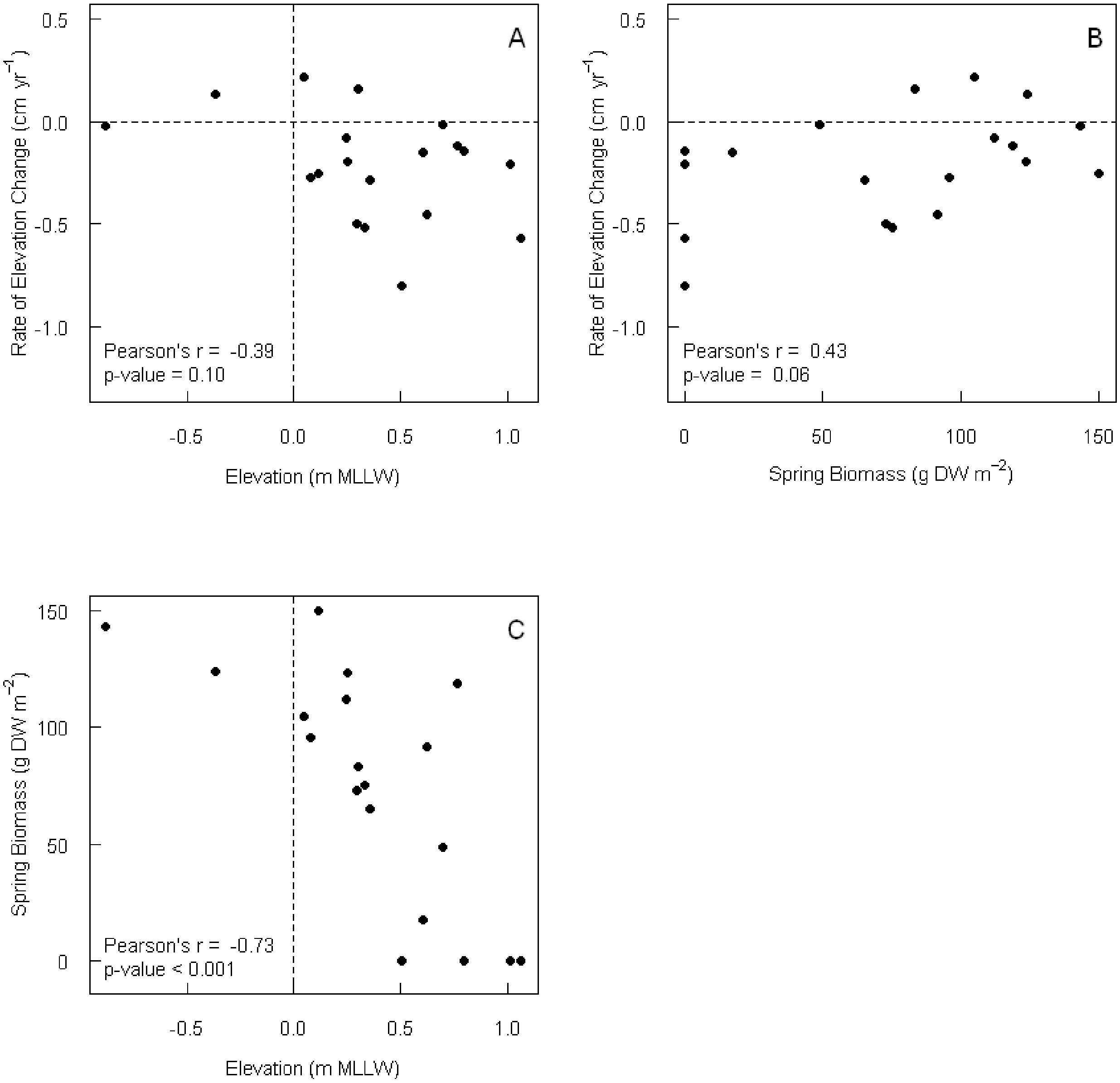


Figure 10. Correlations between (A) elevation and the rate of surface elevation change, (B) spring *Zostera* biomass and the rate of surface elevation change, and (C) elevation and spring *Zostera* biomass.

2.4 Discussion

2.4.1 Surface elevation deficit and deteriorative processes

The surface elevation deficit prevalent throughout Padilla Bay indicates that estuarine surface elevation change is not keeping pace with the current rate of sea level rise. This conclusion is consistent with my hypothesis that the hydrologic uncoupling of Padilla Bay from the Skagit River has lead to insufficient vertical accretion. Under conditions of sediment scarcity, elevation changes in Padilla Bay appear to be controlled by deteriorative surface elevation processes, including shallow subsidence and erosion. Maxwell (2004) reported significant shallow subsidence throughout the estuary, determined from preliminary SET and marker horizon analyses in an earlier phase of this research. Evidence for erosion is documented in several accretion studies whose authors reported difficulty in retrieving marker horizons, the loss or destruction of short-term sedimentation traps, and, in analyses of radioisotope decay in sediment profiles (e.g. ^{210}Pb or ^{137}Cs), deep surface mixed layers (≤ 20 cm) (Carpenter et al. 1985, Ball 2004, Maxwell 2004, Gwozdz 2006, Kairis 2008). The environmental disturbances observed during these studies suggest sediment re-suspension, during storms and tides or resulting from bioturbation, facilitates surface sediment mixing and removal. Indeed, the marker horizon component of this project was abandoned as marker retrieval became increasingly difficult. Given the combined contributions of these deteriorative mechanisms to surface elevation losses, the elevation deficit in Padilla Bay is amplified beyond the extent expected from relative sea level rise (ESLR ± vertical land movement) alone.

2.4.2 Previous accretion studies

Previous accretion studies in Padilla Bay, using multiple radioisotope methods (^{137}Cs, ^{210}Pb, and ^{14}C) and sampling a wide range of elevations (subtidal to high intertidal) and habitats (eelgrass, mudflat, salt marsh), have yielded variable results. Thom (1992) analyzed ^{137}Cs in one sediment core taken from a fringing salt marsh in the central region of the bay and reported an accretion rate of 0.45 cm yr^{-1}. Several studies have utilized ^{210}Pb, yielding accretion rates ranging from 0.22 ± 0.04 cm yr^{-1} (n=5) to 0.69 ± 0.43 cm yr^{-1} (n=3) (Carpenter et al. 1985, Ball 2004, Gwozdz 2006, Kairis 2008). ^{14}C dating of sediment cores taken in a salt marsh, also sampled by Thom (1992), suggest much lower accretion rates at the millennial time scale, with accretion ranging from 0.06 - 0.12 cm yr^{-1} over the past 5000 years (Beale 1990). Given that each radioisotope integrates environmental processes, such as shallow subsidence, over different time scales, some variability in accretion rates are expected (Neubauer et al. 2002). However, this leads to one of the weakness of radioisotope analysis; because accretion rates represent decadal (^{137}Cs), century (^{210}Pb), or millennial (^{14}C) timescales, these values reflect historical rates of accretion and cannot be assumed to accurately depict current conditions. Furthermore, the assumption of stable, undisturbed soil conditions inherent in both ^{210}Pb and ^{137}Cs analysis is violated by surface sediment mixing and erosion, potentially confounding results. The SET data, which simultaneously incorporate accretion, subsidence, and erosion into surface elevation measurements, therefore provide the first robust indication of current surface elevation changes in Padilla Bay. The results of this analysis will serve to better inform coupled sea level rise and surface elevation models like that of Park et al. (2002), where the lack of site specific data required an assumption of accretion (0.50 cm yr^{-1}) that significantly overestimated elevation gain in Padilla Bay.

2.4.3 Long-term surface elevation projections

Barring an increase in sediment availability in Padilla Bay, it is reasonable to expect surface elevation changes will continue at current rates. However, extrapolating linear trends in surface elevation far beyond the temporal extent of this study is inappropriate, as non-linear feedback mechanisms known to govern surface elevation dynamics may modify long-term elevation changes (Rybczyk and Cahoon 2002, Kirwan et al. 2010). For this reason, our research group has developed a spatially explicit relative elevation model for Padilla Bay that incorporates these feedback mechanisms and was initialized and calibrated with the SET data (Kairis 2008, Kairis and Rybczyk 2010). Model results suggest gradual submergence of the estuary with sea level rise, with a projected near-term expansion of eelgrass meadows into currently un-vegetated mudflats (Kairis and Rybczyk 2010). Although *Z. marina* productivity was not diminished under modeled IPCC sea level rise scenarios by 2100, in the longer-term (>100 years) losses in eelgrass extent and productivity are anticipated as shoreline barriers are reached, preventing further inland migration (Kairis and Rybczyk 2010). Again, it is important to note the conservative nature of the IPCC sea level rise estimates, which do not account for rapid changes in ice flow. If sea level rises at rates faster than projected, the implications of coastal squeeze will be realized sooner than expected.

2.4.4 Factors affecting elevation gain at site 8

A qualitative analysis of why only 1 of 19 study sites (site 8) exhibits positive elevation change proves informative, although conclusions have not been explicitly tested.

Surface elevation gain at site 8 is likely due to sediment inputs from nearby Joe Leary Slough, which contributes between 50-100 metric tons of sediment to Padilla Bay annually (Bulthuis 1996). The accretion measured at this site, although insufficient to keep pace with RSLR, implies that regions directly receiving high sediment inputs will be more resilient to rising sea level than regions receiving fewer sediment inputs. Additionally, the distinctive location of site 8, approximately 20 m from a large intertidal channel, may further enhance the opportunity for local sedimentation. The suspended sediments in channels are distributed across the estuarine surface by tidal flooding; deposition is highest in close proximity to the channel and decreases as a function of distance (Neubauer et al. 2002, Kirwan and Guntenspergen 2010). Given this mechanism, the accretion observed at site 8 may, in part, reflect channel proximity. Conceptually, this may also help explain the apparent discrepancy that while high sediment inputs correspond with positive elevation change at site 8, another nearby site (site 7) is not accreting. Site 7 is perhaps more representative of dominant habitats in the bay, located amid a continuous *Zostera* meadow where the nearest channel of similar scale is >200 m distant. These observations suggest that high sediment inputs may facilitate accretion regionally, while also indicating the potential of the intertidal channel network to generate spatial variability in surface elevation changes.

2.4.5 Seasonal variance in surface elevation change

Although elevation loss dominates inter-annual sediment elevation trends, seasonally variable conditions allow for a distinct period of accretion during the summer months. This pattern was observed consistently throughout the bay, but it is necessary to note these results are not representative of the entire dataset, as some sites (sites 15, 16, 5B, 12B, 14B) did not meet analysis criteria (see Seasonal variance in surface elevation change: Section 2.2.5.3).

Mechanisms contributing to elevation gain during the summer may include temporal variability in mineral sediment availability and seasonal flux in *Zostera* biomass. Gwozdz (2006) reported significant seasonal differences in the concentration of total suspended solids (TSS) at one site in Padilla Bay with peak concentrations (>40 mg L^{-1}) observed during the summer, although these data were highly variable and limited in spatial and temporal scope. In contrast, another study of suspended sediments, including data from six sites distributed throughout the bay, did not detect seasonal differences in TSS (Bulthuis *in press*). Interestingly, the range of suspended sediment concentrations reported by Bulthuis (*in press*) was an order of magnitude lower than the range reported by Gwozdz (2006), 4-7 mg L^{-1} versus 30-40 mg L^{-1} respectively. These discrepancies suggest that a comprehensive analysis of suspended sediment concentrations throughout Padilla Bay would be necessary in order to accurately assess potential relationships between TSS and seasonal trends in sedimentation. Likewise, initial observations of seasonal change in *Zostera* biomass support the hypothesis that high biomass in the spring and summer may enhance sediment trapping as reported in other studies, but are based on limited data (Pasternack and Brush 2001, 2002). Discerning seasonal-scale relationships between biomass and elevation change requires an analysis utilizing multiple seasons of concurrent vegetation and elevation change data.

Surface elevation loss over the winter may be partially accounted for by winter storm events, occurring between November and February, which provide an enhanced opportunity for sediment re-suspension and erosion. In a study where turbidity was measured every 30 minutes for 10 years at 1 site in Padilla Bay, Bulthuis (*in press*) reported episodic peaks in turbidity throughout the winter, particularly when high wind events coincided with low tides, compared to summer months when lower mean turbidities and fewer such peaks were observed. These data highlight the potential for wind generated sediment re-suspension and erosion. Given the ephemeral nature of winter storm events, isolating elevation changes due to storms would require higher frequency sampling than our current study design allows. Unfortunately, our data are too coarse to directly measure the impact of winter storms, as the winter interval (8.5 months long) includes periods of low storm activity and likely incorporates the onset of accretion in the early spring.

Sediment shrink-swell driven by seasonal flux in groundwater hydrology noted in other studies is not a plausible cause of the observed seasonal pattern (Cahoon and Lynch 1997, Whelan et al. 2005). All SET measurements were taken during a similar hydroperiod and sediments in Padilla Bay have low organic matter (< 3% by volume), making them less prone to expansion compared to sediments with higher organic content (Sediment characteristics: Section 3.3).

2.4.6 Physical and biological variance in surface elevation change

Although I detected a negative relationship between surface elevation change and elevation and a positive relationship between surface elevation change and eelgrass biomass, correlations were non-significant and ecogeomorphic patterns in surface elevation change remain inconclusive. These relationships are well documented in the literature, suggesting my study design lacked the scope and power to detect them, and thus prohibiting definite conclusions pertaining to ecogeomorphic interactions in Padilla Bay (Cahoon and Reed 1995, Reed 1995, Morris et al. 2002, Fagherazzi et al. 2004). There are several possible reasons that the hypothesized physical and biological patterns were indistinct.

First, the relationship between surface elevation change and elevation may be indiscernible over the range of elevations under consideration. Site selection was constrained by researchers' abilities to travel between sites and methodological limitations of the SET's, which cannot be used at subtidal elevations. Consequently, mid-to-high intertidal elevations were overrepresented, while low elevations were underrepresented. To offset this imbalance, additional sites (sites 5B, 12B, 14B) were added midway through the study, but the subtidal limit to SET monitoring was not overcome. Additionally, deposition may be following the hypothesized pattern but is perhaps obscured by site specific variability in shallow subsidence and erosion, or other factors.

Second, the limited temporal extent of vegetation data and the chosen vegetation metric are perhaps insufficient to adequately assess the relationship between surface elevation change and vegetation. Analysis of the short-term vegetation dataset required an assumption of year-to-year stability in *Zostera* biomass, although inter-annual variability in *Zostera* biomass has been documented in other research (e.g. ice sheets lead to scour of eelgrass beds and loss of habitat in subsequent years) and within this study (e.g. sites with *Zostera* present in the past remained un-vegetated during sampling in 2010), further qualifying conclusions drawn from the analysis (Bulthuis 1991, Maxwell 2004). The inclusion of additional vegetation metrics (e.g. productivity, belowground biomass, percent cover, shoot density) and non-destructive sampling would allow for a more comprehensive, long-term evaluation of this relationship. Further studies may also take into account differences between *Z. marina* and *Z. japonica*, as each species exhibits a distinct life history, physical characteristics, and physiological tolerances (Hemminga and Duarte 2000).

Finally, elevation and biomass are negatively correlated over the range of elevations sampled, as the subsequent decline in biomass at elevations below the optimum depth was not measured, thereby making an independent assessment of the relationship between either of these variable and surface elevation change difficult. Accordingly, less than half (≈ 40%) of the variability in surface elevation changes can be attributed to elevation or biomass, considered independently or together. Given the variability in surface elevation change left unaccounted for by selected variables, future research should incorporate additional factors suspected of influencing surface elevation dynamics in Padilla Bay (e.g. channel proximity, TSS, hydrodynamics). Furthermore, detecting hypothesized patterns between surface elevation change and selected physical and biological variables may require a refined experimental design. High density monitoring along two or three transects running perpendicular to the shoreline, rather than the current systematic bay-wide design, may help discern fine-scale patterns along the intertidal estuarine gradient.

3 SEDIMENT CHARACTERISTICS

3.1 Introduction

3.1.1 Sediment characteristics in Padilla Bay

Sediments in Padilla Bay are predominately sandy (Turner 1980). The northern and middle regions of the bay, accounting for approximately 80% of the total bay area, have sediments classified as loamy sand, sandy loam, or fine sand, in decreasing order of relative importance (Turner 1980). Notably, sediments in the southeastern region of the bay are classified as loam or silt loam, signifying higher silt and clay content (Turner 1980). Organic matter content in the sediment is relatively low, ranging from 1.30% to 2.81% by weight, with higher percentages of organic matter found in regions with higher silt and clay content (Bulthuis 1991). An assessment of sediment characteristics at SET sites in Padilla Bay may be useful in understanding shallow sediment processes. For example, the relative contributions of organic and mineral matter to rates of vertical accretion are not equal; per unit mass, organic matter contributes to a greater increase in sediment volume than the same mass of mineral matter (Neubauer 2008). Perhaps, sediment properties will relate to rates of surface elevation change in Padilla Bay. Additionally, data from sediment cores can be used for further refinement of the relative elevation model being developed for Padilla Bay by our research group (Gwozdz 2006, Kairis 2008).

3.1.2 Objectives

The objective of this analysis was to provide a description of sediment characteristics throughout Padilla Bay, including measures of bulk density, the percent weight of mineral matter and organic matter, and the percent volume of mineral matter, organic matter, and pore space. I then sought to assess potential covariance between these sediment characteristics and the surface elevation changes reported in Chapter 2. Finally, I explored whether the single accreting site (site 8) exhibited sediment characteristics distinct from the sites with negative elevation change.

3.2 Methods

3.2.1 Sediment core collection

I collected 20 sediment cores from SET sites in Padilla Bay throughout July 2010. A single core was taken from sites 1-7, 9-16, 14B, and 16B. Replicate cores (n=3) were taken at site 8 in order to address the aforementioned objective particular to this site. Sites 5B and 12B were not sampled in 2010, requiring the use of data from sediment cores previously collected at these sites (2005/2006) (Kairis 2008).

An undisturbed location within 3 m of the SET was chosen for sampling. Sediment cores were taken by inserting a 10.5 cm diameter, 60 cm long PVC pipe vertically into the sediment surface. Most cores were extracted to a depth of at least 36 cm, although only the top 32 cm were used in analysis. Upon extraction, cores were capped to prevent sediment loss and kept vertical to prevent mixing of the sediment layers. Compaction of sediment during extraction was unavoidable but minimal (≤ 3 cm), and extreme care was taken not to compress the cores during sampling and transportation. Within hours of sampling, the cores were transported back to the lab where they were frozen in the upright position.

3.2.2 Sediment core processing

Frozen cores were partially thawed in order to facilitate core extrusion from the PVC pipe. Once extracted and while still extensively frozen, the cores were sliced horizontally into 2 cm thick sections using a sawzall. Cutting began at the uppermost section of the sediment column and proceeded downward at pre-measured 2 cm intervals, a precaution taken to prevent propagation of cutting errors along the length of the profile. The wet volume of each core section ($\pi r^2 \cdot h$) was calculated from the internal diameter of the PVC pipe and the average height (n=4) taken around the circumference of the section. Next, core sections were placed in pre-labeled aluminum foil trays, dried in an oven at 105 ˚C for 48 hours, and then weighed. The dry bulk density (g cm^{-3}) of each core section was calculated as the oven dry weight divided by the wet volume.

Organic matter content was determined by loss on ignition. First, a subsample of each dried core section was pulverized with a mortar and pestle. From this subsample, approximately 15 g of sediment were placed into a pre-weighted ceramic crucible, weighed, and then ashed in a muffle furnace at 500 ˚C for 24 hours. Post-ashing, the crucible and remaining sample were cooled to room temperature in a dessicator and then re-weighted. Percent organic matter was calculated as the fraction of mass lost during ignition, percent mineral matter accounted for the remaining mass. These values were converted to volumetric measures by taking into account the bulk density of a given core section and the particle density of either mineral or organic matter, 2.62 g cm^{-3} and 1.14 g cm^{-3} respectively (Callaway et al. 1996). Percent pore space was calculated as the remaining volume unaccounted for by mineral and organic matter.

The sediment cores from sites 5B and 12B taken by Kairis (2008) were collected and processed using similar methods, excluding the exceptions noted here. First, the core taken at site 5B was extracted to a depth of only 24 cm. Summary statistics for the 5B core therefore pertain to the top 24 cm of the sediment profile, not the top 32 cm as in all other cores. Second, Kairis (2008) used the external diameter of the PVC corer (10.5 cm) in calculations of bulk density, whereas I used in the internal diameter (10.0 cm or 10.2 cm depending on the PVC corer). Accordingly, sediment characteristic calculations for cores 5B and 12B were corrected using an average diameter of 10.1 cm.

3.2.3 Data analysis

Summary statistics at each site, including mean bulk density, percent mass mineral matter, percent mass organic matter, percent volume mineral matter, percent volume organic matter, and percent volume pore space are reported to evaluate site specific sediment characteristics. Pearson's R correlations were used to assess relationships between each of these sediment characteristics and the rate of surface elevation change. In the correlation analysis, the three samples from site 8 were averaged and site 16B was excluded (see Estuarine surface elevation dynamics: Section 2.2.2). Finally, a vertical sediment profile was created to depict changes in sediment characteristics with depth.

3.3 Results

3.3.1 Sediment characteristics at each site

Bulk density from samples throughout Padilla Bay was relatively high (mean = 1.4 ± 0.2 g cm^{-3}), corresponding with the high mineral matter mass (mean = 98.2 ± 0.4 %) and low organic matter mass (mean = 1.8 ± 0.4 %) (Table 4). Samples from sites 15 and 16, located in the southeast region of the bay, had substantially lower bulk densities than observed in other samples (1.0 ± 0.1 g cm^{-3} and 1.1 ± 0.1 g cm^{-3} respectively), owing to a relatively high organic matter content and slightly lower mineral matter content. Mineral matter, organic matter, and pore space occupied an average of 51.4 ± 6.9 %, 2.0 ± 0.3 %, and 46.6 ± 6.9 % of the sediment volume respectively (Table 4). Again, sites 15 and 16 departed from the bay-wide mean, exhibiting markedly higher pore space volume and lower mineral matter volume. With the exception of sites 15 and 16, sediments appeared to be relatively uniform at sites throughout Padilla Bay. Reported sediment characteristics did not correlate with surface elevation change. Furthermore, data from the three sediment cores taken at site 8 were within a reasonable range of values calculated from other samples.

Table 4. Mean sediment characteristics at study sites throughout Padilla Bay, data were averaged across all depths at each site (±1 standard deviation). Three cores were taken at site 8.

		Percent by weight		Percent by volume		
Site	Bulk density (g cm^{-3})	Mineral matter	Organic matter	Mineral matter	Organic matter	Pore space
1	1.4 ± 0.1	98.3 ± 0.4	1.7 ± 0.4	51.0 ± 4.4	2.0 ± 0.4	47.0 ± 4.2
2	1.5 ± 0.2	98.7 ± 0.4	1.3 ± 0.4	54.9 ± 8.7	1.6 ± 0.4	43.5 ± 8.8
3	1.3 ± 0.1	98.1 ± 0.3	1.9 ± 0.3	48.9 ± 3.5	2.1 ± 0.3	49.0 ± 3.5
4	1.4 ± 0.2	98.5 ±0.3	1.5 ± 0.3	52.1 ± 6.4	1.8 ± 0.2	46.1 ± 6.4
5	1.4 ± 0.2	98.2 ± 0.3	1.8 ± 0.3	52.6 ± 7.3	2.2 ± 0.3	45.2 ± 7.4
6	1.5 ± 0.2	98.8 ± 0.4	1.2 ± 0.4	56.1 ± 7.2	1.5 ± 0.2	42.4 ± 7.1
7	1.4 ± 0.1	98.6 ± 0.2	1.4 ± 0.2	53.1 ± 4.8	1.7 ± 0.2	45.2 ± 4.9
8 #1	1.3 ± 0.1	98.0 ± 0.4	2.0 ± 0.4	49.8 ± 5.0	2.3 ± 0.3	47.9 ± 4.9
8 #2	1.4 ± 0.2	98.3 ± 0.5	1.7 ± 0.5	52.8 ± 6.9	2.0 ± 0.3	45.2 ± 6.7
8 #3	1.3 ± 0.3	98.1 ± 0.9	1.9 ± 0.9	50.5 ± 11.2	2.0 ± 0.2	47.5 ± 11.3
9	1.5 ± 0.1	98.6 ± 0.4	1.4 ± 0.4	56.0 ± 4.2	1.8 ± 0.4	42.2 ± 4.1
10	1.5 ± 0.2	98.7 ± 0.6	1.3 ± 0.6	55.4 ± 9.6	1.6 ± 0.4	43.0 ± 9.5
11	1.4 ± 0.2	98.3 ± 0.5	1.7 ± 0.5	52.5 ± 8.5	2.0 ± 0.2	45.5 ± 8.5
12	1.5 ± 0.2	98.8 ± 0.5	1.2 ± 0.5	56.4 ± 9.0	1.5 ± 0.3	42.1 ± 8.8
13	1.4 ± 0.2	98.4 ± 0.6	1.6 ± 0.6	53.2 ± 6.8	2.0 ± 0.3	44.8 ± 6.6
14	1.4 ± 0.2	98.1 ± 0.6	1.9 ± 0.6	51.1 ± 8.2	2.2 ± 0.3	46.7 ± 8.1
15	1.0 ± 0.1	96.7 ± 0.6	3.3 ± 0.6	38.1 ± 5.7	2.9 ± 0.3	58.9 ± 5.8
16	1.1 ± 0.1	96.9 ± 0.4	3.1 ± 0.4	38.9 ± 4.6	2.8 ± 0.2	58.3 ± 4.6
5B[1]	1.4 ± 0.3	98.5 ± 0.4	1.5 ± 0.4	51.2 ± 10.5	1.7 ± 0.2	47.1 ± 10.6
12B[1]	1.4 ± 0.2	98.2 ± 0.5	1.8 ± 0.5	53.4 ± 8.0	2.1 ± 0.3	44.4 ± 7.9
14B	1.4 ± 0.2	98.2 ± 0.3	1.8 ± 0.3	51.0 ± 7.6	2.1 ± 0.2	47.0 ± 7.7
16B	1.4 ± 0.1	98.0 ± 0.4	2.0 ± 0.4	50.9 ± 3.7	2.4 ± 0.4	46.6 ± 3.7
mean	1.4 ± 0.2	98.2 ± 0.4	1.8 ± 0.4	51.4 ± 6.9	2.0 ± 0.3	46.6 ± 6.9

[1] Samples taken by Kairis (2008)

3.3.2 Bay-wide vertical profile of sediment characteristics

Data from all sites were combined for the vertical sediment profile, deemed appropriate due to the low variability in sediment characteristics observed in samples taken throughout the bay. Bulk density in the upper 4 cm of the sediment profile was lower than in the underlying sediments, as expected with increasing compaction at greater depths (Figure

11A). Mineral matter mass followed a similar pattern, with the lowest mass observed in the upper 4 cm of the sediment column (Figure 11B). Accordingly, there was a higher volume of pore space and lower volume of mineral matter in these upper 4 cm (Figure 11C). Organic matter did not significantly contribute to sediment volume at any depth.

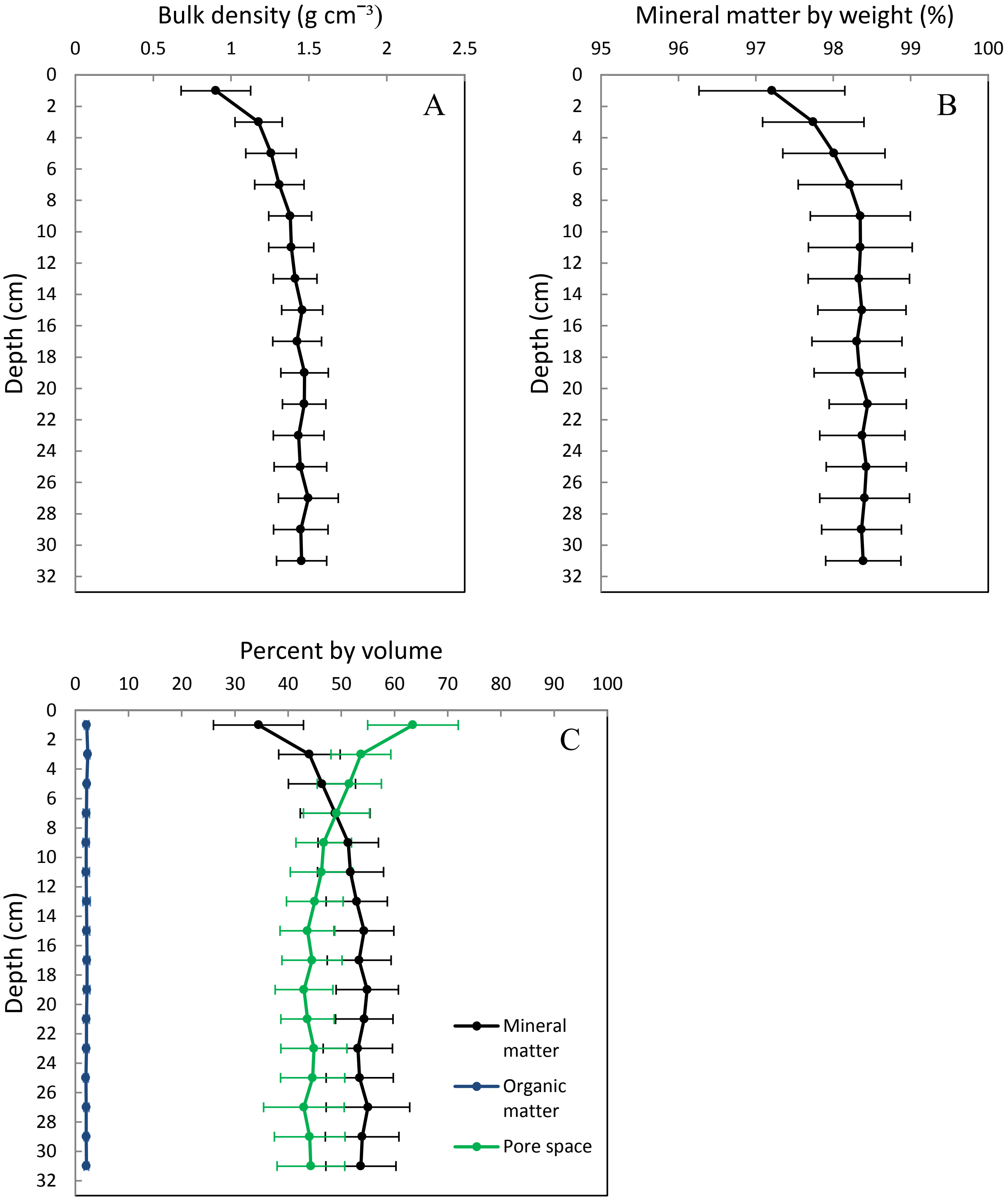


Figure 11. Vertical profile of mean sediment characteristics with depth (A) bulk density (B) percent mineral matter by weight (C) percent volume of mineral matter, organic matter, and pore space. All depths above 25 cm have n=22, depths below 25 cm have n=21. Error bars represent one standard deviation.

3.4 Discussion

The high mineral content and low organic content observed in sediments throughout Padilla is consistent with conclusions from previous studies (Turner 1980, Bulthuis 1991). Sediment characteristics in Padilla Bay appear to be relatively uniform, both regionally and with depth. Exceptions include sites in the southeast region of bay, which exhibit lower bulk density content compared to other sites, and the upper 4 cm of the sediment profile at sites throughout the bay, which exhibit lower bulk density than underlying sediments. The lack of correlation between sediment characteristics and surface elevation change indicates that reported sediment properties cannot account for variability in elevation change across Padilla Bay. However, my analysis did not include sediment grain size, a variable which may relate to patterns in sediment deposition and erosion. Re-suspension and transportation of fine particles requires less wave energy than is necessary to move coarser particles; as such, sediment grain size and texture can be used to infer patterns in sediment transportation and should be included in future research (Grossman et al. 2011). Finally, the similarity between sediment characteristics at site 8 to those observed at sites with elevation loss indicates that the accretion measured at site 8 cannot be attributed to distinctive sediment properties.

4 SCOUR CORRECTION

4.1 Introduction

4.1.1 What is scour?

Sediment scour was observed at several SET sites in Padilla Bay. (Sumer and Fredsoe 2002) describe scour accordingly: "When a structure is placed in a marine environment, the presence of the structure will change the flow pattern in its immediate neighborhood […] these changes usually cause an increase in the local sediment transport capacity and thus lead to scour." Scour around the SET appears as a shallow bowl-shaped depression, referred to as the scour hole, and presents serious methodological problems (Figure 12A). When the presence of instrumentation impacts the environmental variable the instrument is designed to measure, the data are inherently biased. If, in fact, elevation loss measured by the SET is the result of scour, not shallow subsidence or erosion, researchers may falsely attribute elevation changes to natural processes and overestimate negative elevation change. This bias may be rectified only if scour can be sufficiently recognized and data affected by scour removed.

4.1.2 Observations of scour

Scour, indicated by standing water in the scour hole, was initially observed at several SET sites in 2006. In the early stages of scour, the outermost edge of the scour hole did not extend to within reach of SET measurements (i.e. the SET's innermost pin is 33.0 cm from the center of the benchmark rod). However, as the radius of scour increased, a characteristic and predictable pattern was recorded in the SET data. First, the innermost pin(s) began losing elevation at a faster rate than the outermost pins. As the circumference the scour hole expanded, consecutive pins successively rested within the scour hole and pin heights above the SET's leveling arm exhibited a distinctive upward slope, I call this the scour slope (Figure 12B, 13H, 13I). At sites with the most extensive scour, the scour hole grew until the leading edge of the hole extended beyond the reach of the SET's leveling arm (i.e. the SET's outermost pin is 63.5 cm from the center of the benchmark rod) and the pins, now resting along the flat bottom of the pool, no longer exhibited the scour slope (Figure 13J, 13K). The decay of the scour slope typically coincided with a precipitous drop in pin height.

Scour appeared to be triggered by exposure of the SET's cement collar. This collar (15 cm diameter) rested flush with the sediment surface at the time of installation, but was gradually exposed by surface elevation loss due to shallow subsidence and erosion. Once initiated, scour around the collar may have then set into effect a positive feedback mechanism whereby continued elevation loss unearthed more of the cement collar, leading to more extensive scour. The aboveground segment of the SET's benchmark rod (1.5 cm diameter) did not appear to initiate scour. This observation is consistent with conclusions from (Sumer and Fredsoe 2002), wherein the extent of sour around circular piles in marine environments is described primarily as a function of pile diameter. (Sumer and Fredsoe 2002)

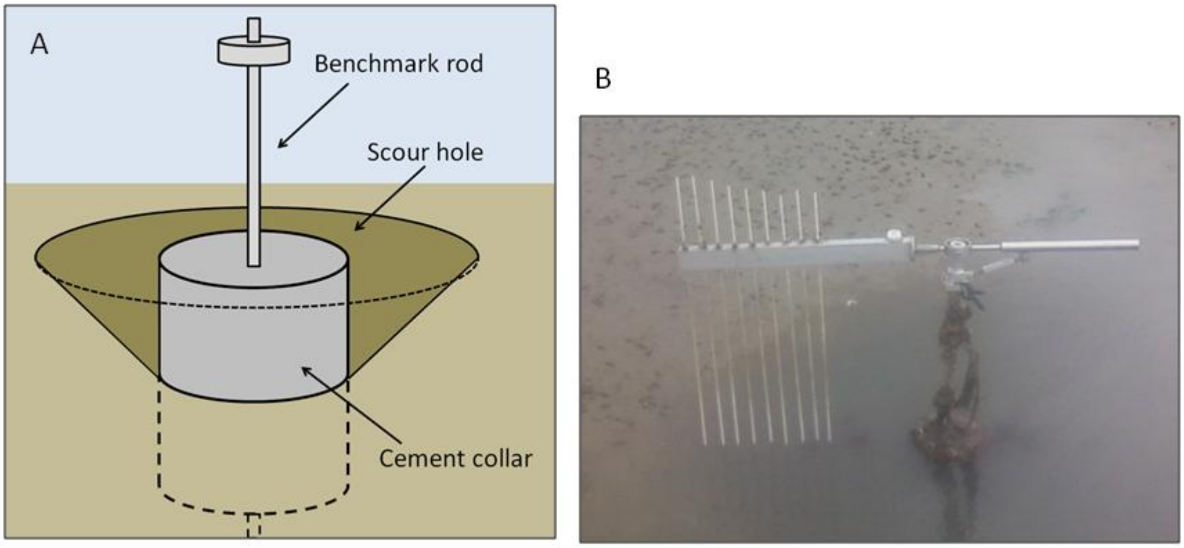


Figure 12. (A) Diagram of scour hole formation around the SET's cement collar, figure is not to scale. (B) An example of the scour slope at a site with extensive scour, photo of site 15 taken June 10, 2010.

4.1.3 Objectives

The purpose of this analysis was to create an objective method for truncating the SET datasets in order to remove bias introduced by sediment scour. Although scour hole presence was easily detectable, the full extent of scour was, in all likelihood, imperceptible to the naked eye. For this reason, I combined researchers' field observations with a quantitative analysis of scour in the SET data.

4.2 Methods

Scour correction methods were based on observations of a distinct scour slope, wherein pin height increased from pin position one (inside) through position nine (outside) across the SET's leveling arm. This analysis relied on two primary assumptions. First, although the scour slope may occur by chance at isolated arm positions during isolated sampling periods, it was assumed highly unlikely for the scour slope to be consistently exhibited at all four arm positions for consecutive sampling periods under natural conditions. Second, scour was assumed to be irreversible and deterioration at a site was considered permanent once scour began.

In order to assess the scour slope, field measurements were reconstructed from the raw SET data. For each site, a series of regressions were created where each regression represented one sampling period with pin number as the independent variable and pin height as the dependent variable, all four arm positions were included (Figure 13). The slope of the regression was used to determine if and when a site exhibited the scour slope. Accordingly, sites were divided into two categories, scour (sites 1, 3, 5, 9, 15, 16, 16B) and non-scour (sites 2, 4, 6, 7, 8, 10, 11, 12, 13, 14, 5B, 12B, 14B). The non-scour sites were used to create a quantitative criterion delineating the acceptable range of pin slopes under non-scour conditions. This criterion was defined as any slope within two standard deviations of the mean pin slope calculated from non-scour sites.

At the first indication of scour noted by researchers, no matter the extent of scour pool formation, all subsequent sampling periods were discarded. Then, beginning at the instance of initial scour and working backward through consecutive sampling periods, the quantitative criterion was applied. If the sampling period under consideration failed the criterion because the pin slope fell outside the acceptable range, then this sampling period was discarded. The criterion was then applied to the next sampling period and the process was repeated as necessary, until either the criterion was met or all sampling periods at the site were discarded. Truncated, scour-corrected datasets, as well as, uncorrected datasets were used to calculate the rate of surface elevation change as described previously (Estuarine surface elevation dynamics: Section 2.2.5.1).

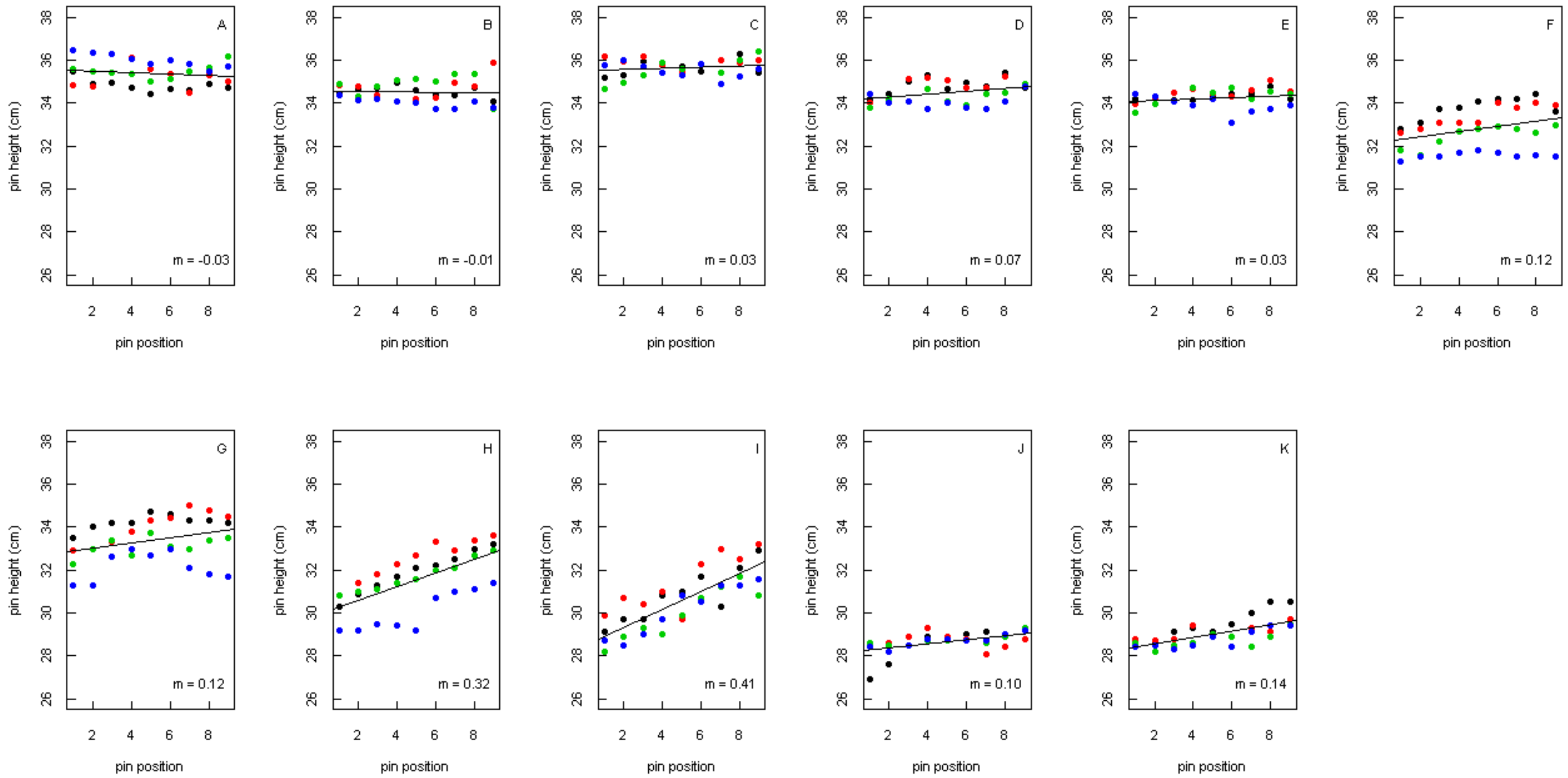


Figure 13. Pin slope regressions for site 1. Graphs A – K each represent distinct sampling periods, beginning with the earliest. Each of the four arms positions are indicated by a different color. The dataset at this site was truncated after G, when the scour slope exceeded the quantitative criterion. Regression lines are included for emphasis.

4.3 Results

The mean pin slope derived from non-scour sites was 0.05 ± 0.14 cm pin^{-1} (± 2 standard deviations); thus, the acceptable range of pin slopes was -0.09 to 0.19 cm pin^{-1}. Accordingly, datasets at six of the seven scour sites were truncated, while one site (site 16B) was removed from the analysis entirely (Figure 14). Researchers' observations and the quantitative criterion coincided at some sites (sites 1, 3, and 9), each indicating truncation at the same sampling period. On the other hand, there were several sites (sites 5, 15, 16, and 16B) where the quantitative criterion indicated scour bias present in the data before detection by researchers. The rate of surface elevation loss calculated with scour-corrected data was less than rate of elevation change calculated from uncorrected data at all scour sites (Table 1). At some sites (sites 1, 3, 9, 16), the difference in elevation change calculated from scour-corrected versus uncorrected data was minimal; whereas at others (sites 5, 15), sour-corrected data indicated substantially lower elevation change than suggested by uncorrected data. The mean rate of surface elevation change in Padilla Bay calculated from scour-corrected SET data was -0.22 ± 0.27 cm yr^{-1} (± 1 standard deviation, n=19). Failing to correct for scour overestimated elevation loss, with a mean rate of surface elevation change calculated from uncorrected data of -0.35 ± 0.40 cm yr^{-1} (n=20).

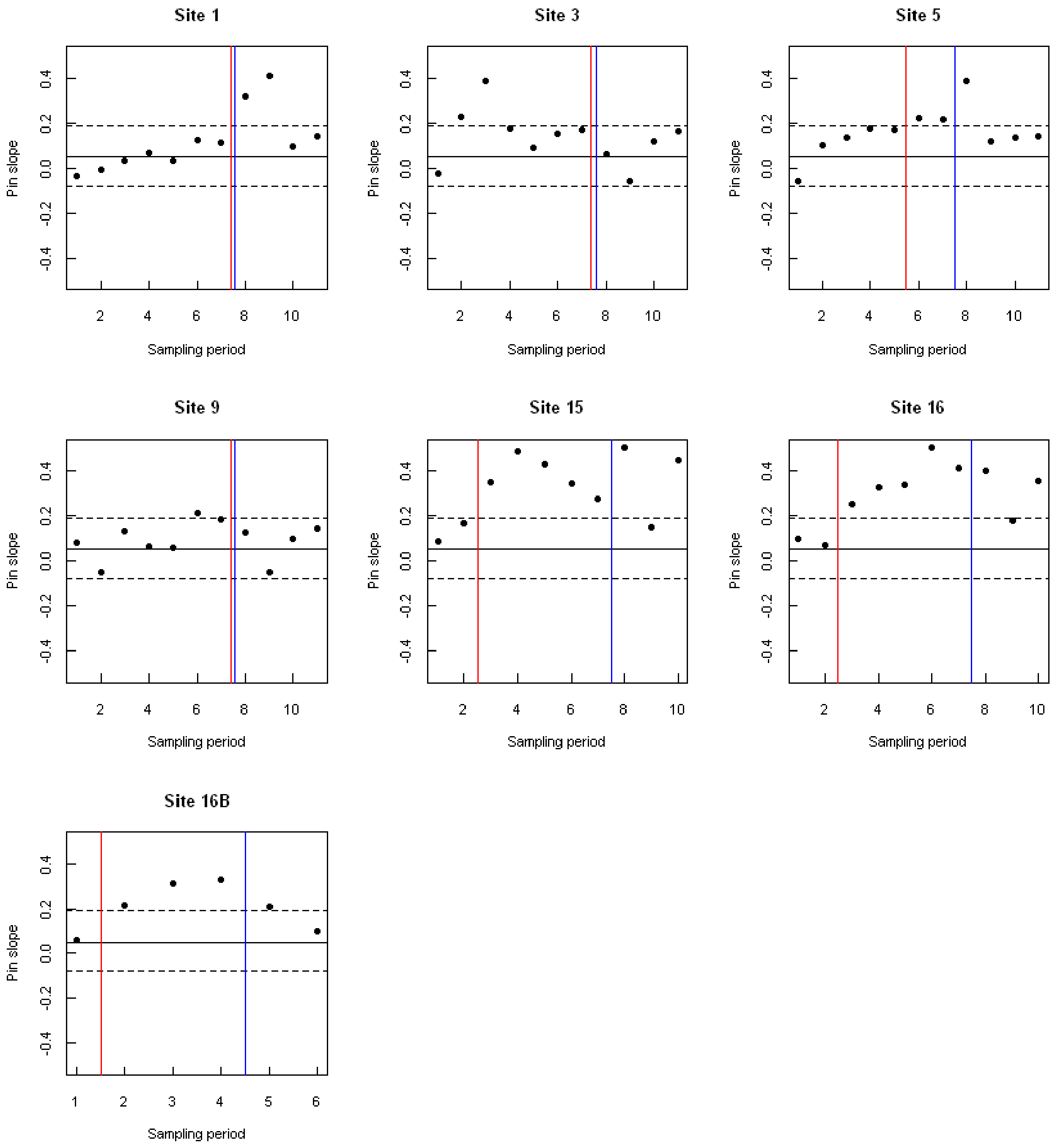


Figure 14. Pin slope summary at each scour site, with sampling period on the x-axis and pin slope on the y-axis. The solid horizontal line represents the mean pin slope of non-scour sites, the dashed horizontal lines delineate the acceptable range of pin slopes as per the quantitative criterion. The vertical red line indicates where the dataset was truncated, the vertical blue line indicates when scour was noted by researchers.

Table 5. Rate of elevation change derived from scour-corrected datasets and uncorrected datasets at scour sites.

Site	Scour-corrected rate of elevation change (cm yr^{-1})	Uncorrected rate of elevation change (cm yr^{-1})	Difference (corrected-uncorrected) (cm yr^{-1})
1	-0.80	-0.87	0.07
3	-0.15	-0.28	0.13
5	-0.01	-0.57	0.56
9	-0.12	-0.19	0.07
15	-0.21	-1.38	1.17
16	-0.57	-0.58	0.01
16B	removed	-0.98	na

4.4 Discussion

Based on the assumptions of my analysis, quantification of the scour slope provided a precise determination of when scour began to impact the SET data, indicated a specific location for truncating impacted datasets, and allowed scour bias in surface elevation change measurements to be removed. Accordingly, elevation loss observed in scour-corrected datasets can be correctly attributed to shallow subsidence and erosion and will not be artificially inflated by scour. In fact, truncating datasets may have actually underestimated elevation loss due to shallow subsidence and erosion, as elevation loss after the onset of scour could not be reported. Scour-corrected elevation changes should therefore be considered conservative estimates. Notably, the quantitative criterion proved to be a more conservative indicator of scour than observations by researchers, suggesting observation alone is insufficient for making determinations of scour correction.

There appear to be certain environmental characteristics predisposing sites to scour and affecting the extent of scour hole formation. In particular, scour sites were located in un-vegetated mudflats at high elevations (0.51 - 1.06 m MLLW); two high elevation sites (sites

5, 9) in *Zostera* meadows present exceptions to the former. Additionally, the degree of scour between sites was highly variable in terms of scour hole depth (2 - 10 cm) and scour hole radius (10 - 200 cm). This variability may be due to differences in current velocity and direction, boundary layer thickness, and bed shear stress, or other unaccounted for environmental factors (Sumer and Fredsoe 2002).

Scour holds important lessons for future SET use in Pacific Northwest estuaries. The SET was designed by researchers working along shorelines of the Gulf of Mexico and southeast Atlantic (Boumans and Day 1993). These regions are characterized by broad deltaic plains with extensive intertidal marsh habitats, particularly *Spartina* marshes, and are micro-tidal (Day et al. 1989). The scour observed in this study indicates SET's may not be adaptable to use in macro-tidal mudflat habitats, with high wave energies and little to no vegetation. If my hypothesis is correct in that the cement collar, not the benchmark rod, triggers scour, then new SET designs reducing the aboveground height of the benchmark rod from approximately 35 cm to approximately 10 cm will do little to prevent scour if the requisite conditions for scour are met. Other methods for monitoring estuarine sediment elevation such as remote sensing (e.g. LiDAR) may be able to detect changes in estuarine surface elevation without introducing a similar instrumental bias. However, these methods are cost prohibitive and currently lack the resolution to make measurements at the precision of the SET's.

5 CONCLUSIONS

5.1 Summary

This study provides the first analysis of surface elevation dynamics within a Pacific Northwest eelgrass meadow. Surface elevation monitoring from 2002-2010 in Padilla Bay indicated significant elevation loss throughout most of the estuary. Only 1 of 19 study sites exhibited significant elevation gain, while 9 sites exhibited significant elevation loss. I did not detect a change in elevation at the remaining 9 sites. When elevation change was considered in combination with eustatic sea level rise and geologic uplift, however, all 19 sites exhibited an elevation deficit. These results are consistent with my hypothesis that hydrologic alterations to the Skagit River have reduced sedimentation in the estuary such that vertical accretion is insufficient to keep pace with the current rate of sea level rise. Elevation loss is likely due to a combination of both shallow subsidence and erosion, as each of these deteriorative processes were observed in Padilla Bay. Interestingly, there was a distinct seasonal pattern in elevation change, with accretion generally observed over the summer months and elevation loss generally observed over the winter months. Although causes of this temporal pattern were not explicitly tested, seasonal variability in elevation change may relate to seasonal trends in suspended sediment availability, vegetation biomass, or storm events.

A nuanced assessment of the spatial variability in surface elevation changes throughout Padilla Bay indicated the presence of ecogeomorphic relationships within the estuary, although my analysis proved too blunt a tool to clearly delineate such fine-scale patterns. A negative relationship between surface elevation change and elevation, and a positive relationship between surface elevation change and eelgrass biomass were apparent, although correlations were non-significant and conclusions were limited. Surface elevation change did not correlate with measured sediment properties, including bulk density, organic matter content, and mineral matter content. Initial results suggest further inquiry into the interrelationships between elevation change, elevation, and vegetation are warranted, whereas measured sediment characteristics appear to have little impact on shallow sediment processes. Additional factors to consider in future research include the distribution and availability of suspended sediments, influences of the intertidal channel network, and bay-wide hydrodynamics. Further investigation of fine-scale ecogeomorphic relationships and intra-annual trends also requires an experimental design allowing for frequent sampling and spanning the full range of the intertidal estuarine gradient.

Finally, sediment scour around some of the SET's indicates the need to consider alternative designs or methods in measurements of surface elevation change. In this study, the long-term monitoring record allowed for a precise description and determination of the impacts of sediment scour, an unforeseen and undocumented byproduct of surface elevation measurements. Given the importance of continued estuarine monitoring and the needed expansion of such programs throughout the Puget Sound and the along Pacific coast, overcoming such limitations are necessary.

5.2 Conclusions

Without an increase in sediment inputs, the elevation deficit in Padilla Bay is expected to increase as eustatic sea level rise accelerates. Under these circumstances, it is reasonable to expect shoreward migration of the eelgrass meadow in order for the species' to stay within optimum depth tolerances. Accordingly, long-term management options for the Padilla Bay National Estuarine Research Reserve should allow for the creation of a buffer zone landward of the current shoreline. In most areas, this will require removing dikes or moving dikes further inland, concurrent with active restoration of agricultural lands opened to tidal influence. Active restoration may include using fill material to construct desired estuarine surface elevations, shown to enhance the development of coastal wetland form and function in another subsiding Pacific Northwest estuary (Cornu and Sadro 2002). Additionally, controlled reintroduction of riverine distributaries has increased sedimentation in other regions and should be explored as a potential management option (DeLaune et al. 2003, Day et al. 2007). Given that sediment reductions in the Skagit delta result from both sediment retention behind dams and loss of hydrologic connectivity due to flood protection measures, it is not feasible to anticipate a change in management policies returning sediment delivery to pre-settlement levels. However, when compared to current sediment-starved conditions, additional sediment contributions, albeit small, may nonetheless have significant value in enhancing the resiliency of eelgrass habitats. This recommendation assumes that extensive monitoring would accompany any sediment reintroduction, ensuring that sediment load and water velocity were appropriately controlled in order to minimize potential disturbance and maintain suitable conditions for eelgrass growth and survival.

Because the extent of historical tidal wetlands in the Puget Sound has declined over 75%, we are increasingly reliant on the few remaining estuaries to provide the ecosystem goods and services on which our economy and our environment depend (Emmett et al. 2000, Batker et al. 2008). Losing the eelgrass meadow in Padilla Bay would not only degrade or eliminate the goods and services provided by this habitat, but may also have far reaching implications for the organisms which rely on this ecosystem for food and refuge. Given the consequences of eelgrass loss, it is important to note that this study only addressed the effects of reduced sediment inputs and accelerated sea level rise on the resiliency of this eelgrass habitat. There are, of course, multiple, simultaneous stressors associated with climate change that will also impact eelgrass growth and survival, including changes in light, nutrient, and carbon dioxide availability, temperature, salinity, and the frequency and intensity of storm events (Short and Neckles 1999). Many of these variables are expected to negatively impact eelgrasses, although potential effects are associated with high levels of uncertainty; thus, assessing eelgrass resilience in response to climate change requires continued research and monitoring.

REFERENCES

Allison, I., N. Bindoff, R. Bindschadler, P. Cox, N. de Noblet, M. England, J. Francis, N. Gruber, A. Haywood, D. Karoly, G. Kaser, C. Le Quere, T. Lenton, M. Mann, B. McNeil, A. Pitman, S. Rahmstorf, E. Rignot, H. Schellnhuber, S. Schneider, S. Sherwood, R. Somerville, K. Steffen, E. Steig, M. Visbeck, and A. Weaver. 2009. The Copenhagen diagnosis, 2009: Updating the world on the latest climate science. The University of New South Wales Climate Change Research Centre (CCRC), Sydney, Australia.

Ball, D. 2004. Monitoring the effects of Spartina alterniflora eradication on sediment dynamics in two Pacific Northwest estuaries. Master's Thesis. Western Washington University. Bellingham, WA.

Batker, D., P. Swedeen, R. Costanza, I. de la Torre, R. M. Boumans, and K. Bagstad. 2008. A new view of the Puget Sound economy: The economic value of nature's services in the Puget Sound Basin. Earth Economics.

Beale, H. 1990. Relative rise in sea-level during the late Holocene at six salt marshes in the Puget Basin, Washington. Master's Thesis. Western Washington University. Bellingham, WA.

Beckley, B. D., N. P. Zelensky, S. A. Holmes, F. G. Lemoine, R. D. Ray, G. T. Mitchum, S. D. Desai, and S. T. Brown. 2010. Assessment of the Jason-2 extension to the TOPEX/Poseidon, Jason-1 sea-surface height time series for global mean sea level monitoring. Marine Geodesy 33:447-471.

Blum, M. D., and H. H. Roberts. 2009. Drowning of the Mississippi Delta due to insufficient sediment supply and global sea-level rise. Nature Geoscience 2:488-491.

Boese, B. L., B. D. Robbins, and G. Thursby. 2005. Desiccation is a limiting factor for eelgrass (Zostera marina L.) distribution in the intertidal zone of a northeastern Pacific (USA) estuary. Botanica Marina 48:274-283.

Borde, A., R. Thom, S. Rumrill, and L. Miller. 2003. Geospatial habitat change analysis in Pacific Northwest coastal estuaries. Estuaries and Coasts 26:1104-1116.

Boule, M. 1981. Tidal wetlands of the Puget Sound region, Washington. Wetlands 1:47-60.

Boumans, R. M., and J. W. Day. 1993. High precision measurements of sediment elevation in shallow coastal areas using a sedimentation-erosion table. Estuaries and Coasts 16:375-380.

Bulthuis, D. A. *In press*. The ecology of Padilla Bay, Washington: An estuarine profile of a National Estuarine Research Reserve. Washington State Department of Ecology, Padilla Bay National Estuarine Research Reserve Technical Report, Mount Vernon, Washington.

Bulthuis, D. A. 1991. Distribution of habitats and summer standing crop of seagrasses and macroalgae in Padilla Bay, Washington, 1989. Washington State Department of Ecology, Padilla Bay National Estuarine Research Reserve Technical Report No. 2, Mount Vernon, Washington.

Bulthuis, D. A. 1995. Distribution of seagrasses in a North Puget Sound estuary: Padilla Bay, Washington, USA. Aquatic Botany 50:99-105.

Bulthuis, D. A. 1996. Suspended sediments in Joe Leary Slough, a north Puget Sound coastal stream draining an agricultural watershed. Washington State Department of Ecology, Padilla Bay National Estuarine Research Reserve Technical Report No. 5, Mount Vernon, Washington.

Bulthuis, D. A., and A. M. Conrad. 1995. Swinomish Channel and Padilla Bay: Surface currents during flood tide and water quality. Washington State Department of Ecology, Padilla Bay National Estuarine Research Reserve Technical Report No. 14, Mount Vernon, Washington.

Bulthuis, D. A., and S. Shull. 2006. Monitoring the distribution of submerged aquatic vegetation in Padilla Bay, NERR—SWMP Biomonitoring Pilot Site, 2004: Final report. A final report submitted to Estuarine Reserves Division, OCRM, NOAA in partial fulfillment of the Padilla Bay NERR Operations Award for 2004-05 to Washington State Department of Ecology.

Cahoon, D. R. 1994. Recent accretion in two managed marsh impoundments in coastal Louisiana. Ecological Applications 4:166-176.

Cahoon, D. R., P. F. Hensel, T. Spencer, D. J. Reed, K. L. McKee, and N. Saintilan. 2006. Coastal wetland vulnerability to relative sea-level rise: Wetland elevation trends and process controls. Pages 271-292 Wetlands and Natural Resource Management. Ecological Studies, Vol. 190. Springer Berlin Heidelberg, New York, NY, USA.

Cahoon, D. R., J. C. Lynch, B. Segura, R. D. Holland, C. Stelly, G. Stephenson, and P. F. Hensel. 2002. High-precision measurements of wetland sediment elevation: II. The rod surface elevation table. Journal of Sedimentary Research 72:734-739.

Cahoon, D. R., D. J. Reed, and J. W. Day. 1995. Estimating shallow subsidence in microtidal salt marshes of the southeastern United States: Kaye and Barghoorn revisited. Marine Geology 128:1-9.

Cahoon, D. R., and J. C. Lynch. 1997. Vertical accretion and shallow subsidence in a mangrove forest of southwestern Florida, U.S.A. Mangroves and Salt Marshes 1:173-186.

Cahoon, D. R., and D. J. Reed. 1995. Relationships among marsh surface topography, hydroperiod, and soil accretion in a deteriorating Louisiana salt marsh. Journal of Coastal Research 11:357-369.

Callaway, J. C., J. A. Nyman, and R. D. DeLaune. 1996. Sediment accretion in coastal wetlands: A review and a simulation model of processes. Current Topics in Wetland Biogeochemistry 2:2-23.

Carpenter, R., M. L. Peterson, and J. T. Bennett. 1985. 210Pb-derived sediment accumulation and mixing rates for the greater Puget Sound region. Marine Geology 64:291-312.

Collins, B. 1998. Preliminary assessment of historic conditions of the Skagit River in the Fir Island area: Implications for Salmonid habitat restoration. Skagit System Cooperative.

Cornu, C. E., and S. Sadro. 2002. Physical and functional responses to experimental marsh surface elevation manipulation in Coos Bay's South Slough. Restoration Ecology 10:474-486.

Costanza, R., R. d' Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387:253-260.

Curran, C., E. Grossman, M. Mastin, and R. Huffman. *In press*. Sediment load and distribution in the lower Skagit River, Skagit County, Washington, USA. Continental Shelf Research.

Day, J. W., D. F. Boesch, E. J. Clairain, G. P. Kemp, S. B. Laska, W. J. Mitsch, K. Orth, H. Mashriqui, D. J. Reed, L. Shabman, C. A. Simenstad, B. J. Streever, R. R. Twilley, C. C. Watson, J. T. Wells, and D. F. Whigham. 2007. Restoration of the Mississippi Delta: Lessons from Hurricanes Katrina and Rita. Science 315:1679 -1684.

Day, J. W., R. R. Christian, D. M. Boesch, A. Yanez-Arancibia, J. Morris, R. R. Twilley, L. Naylor, L. Schaffner, and C. Stevenson. 2008. Consequences of climate change on the ecogeomorphology of coastal wetlands. Estuaries and Coasts 31:477-491.

Day, J. W., C. A. S. Hall, W. M. Kemp, and A. Yanez-Arancibia. 1989. Estuarine ecology. John Wiley and Sons, New York, NY, USA.

Day, J. W., G. P. Kemp, D. J. Reed, D. R. Cahoon, R. M. Boumans, J. M. Suhayda, and R. Gambrell. 2011. Vegetation death and rapid loss of surface elevation in two contrasting Mississippi delta salt marshes: The role of sedimentation, autocompaction and sea-level rise. Ecological Engineering 37:229-240.

Day, J. W., D. Pont, P. Hensel, and C. Ibañez. 1995. Impacts of sea-level rise on deltas in the Gulf of Mexico and the Mediterranean: The importance of pulsing events to sustainability. Estuaries and Coasts 18:636-647.

Day, J. W., J. Rybczyk, F. Scarton, A. Rismondo, D. Are, and G. Cecconi. 1999. Soil accretionary dynamics, sea-level rise and the survival of wetlands in Venice Lagoon: A field and modelling approach. Estuarine, Coastal and Shelf Science 49:607-628.

DeLaune, R. D., A. Jugsujinda, G. W. Peterson, and W. H. Patrick. 2003. Impact of Mississippi River freshwater reintroduction on enhancing marsh accretionary processes in a Louisiana estuary. Estuarine, Coastal and Shelf Science 58:653-662.

Duarte, C. M. 2002. The future of seagrass meadows. Environmental Conservation 29:192-206.

Duarte, C. M., and C. L. Chiscano. 1999. Seagrass biomass and production: a reassessment. Aquatic Botany 65:159-174.

Emmett, R., R. Llanso, J. Newton, R. Thom, M. Hornberger, C. Morgan, C. Levings, A. Copping, and P. Fishman. 2000. Geographic signatures of North American west coast estuaries. Estuaries and Coasts 23:765–792.

Fagherazzi, S., M. Marani, and L. K. Blum. 2004. The ecogeomorphology of tidal marshes. Coastal and Estuarine Studies, Vol. 59. American Geophysical Union, Washington DC, USA.

Grossman, E., D. George, and A. Lam. 2011. Shallow stratigraphy of the Skagit River Delta, Washington, USA derived from sediment cores. U.S. Geological Survey Open-File Report 2011-1194.

Gwozdz, R. 2006. Eelgrass, climate change, and sea-level rise in a Pacific Northwest estuary: A field and modeling study. Master’s Thesis. Western Washington University. Bellingham, WA.

Hemminga, M., and C. M. Duarte. 2000. Seagrass ecology. Cambridge University Press, Cambridge, UK.

Hensel, P. E., J. W. Day, and D. Pont. 1999. Wetland vertical accretion and soil elevation change in the Rhône River delta, France: The importance of riverine flooding. Journal of Coastal Research 15:668-681.

Kairis, P. 2008. A spatially explicit relative elevation model for Padilla Bay, WA. Master's Thesis. Western Washington University. Bellingham, WA.

Kairis, P. A., and J. M. Rybczyk. 2010. Sea level rise and eelgrass (Zostera marina) production: A spatially explicit relative elevation model for Padilla Bay, WA. Ecological Modelling 221:1005–1016.

Kemp, A. C., B. P. Horton, J. P. Donnelly, M. E. Mann, M. Vermeer, and S. Rahmstorf. 2011. Climate related sea-level variations over the past two millennia. Proceedings of the National Academy of Sciences 108:1-6.

Kirwan, M. L., G. R. Guntenspergen, A. D'Alpaos, J. T. Morris, S. M. Mudd, and S. Temmerman. 2010. Limits on the adaptability of coastal marshes to rising sea level. Geophysical Research Letters 37:1-5.

Kirwan, M. L., and G. R. Guntenspergen. 2010. Influence of tidal range on the stability of coastal marshland. Journal of Geophysical Research 115:1-11.

Maxwell, S. 2004. Sea level rise and stability of a hydrologically altered Pacific Northwest estuary. Master's Thesis. Western Washington University. Bellingham, WA.

Mitsch, W. J., and J. G. Gosselink. 2007. Wetlands, 4th edition. John Wiley and Sons, Hoboken, NJ, USA.

Morris, J. T., P. V. Sundareshwar, C. T. Nietch, B. Kjerfve, and D. R. Cahoon. 2002. Responses of coastal wetlands to rising sea level. Ecology 83:2869-2877.

Mote, P., A. Petersen, S. Reeder, H. Shipman, and L. Whitely Binder. 2008. Sea level rise in the coastal waters of Washington State. A report by the University of Washington Climate Impacts Group and the Washington Department of Ecology.

Neubauer, S. C. 2008. Contributions of mineral and organic components to tidal freshwater marsh accretion. Estuarine, Coastal and Shelf Science 78:78-88.

Neubauer, S. C., I. C. Anderson, J. A. Constantine, and S. A. Kuehl. 2002. Sediment deposition and accretion in a Mid-Atlantic (U.S.A.) tidal freshwater marsh. Estuarine, Coastal and Shelf Science 54:713-727.

Nicholls, R. J. 2004. Coastal flooding and wetland loss in the 21st century: Changes under the SRES climate and socio-economic scenarios. Global Environmental Change 14:69-86.

Orth, R. J., T. J. B. Carruthers, W. C. Dennison, C. M. Duarte, J. W. Fourqurean, K. L. Heck Jr., A. R. Hughes, S. Olyarnik, S. L. Williams, G. A. Kendrick, W. J. Kenworthy, F. T. Short, and M. Waycott. 2006. A Global Crisis for Seagrass Ecosystems. Bioscience 56:987.

Park, R. A., J. K. Lee, and D. J. Canning. 1992. Potential effects of sea level rise on Washington state wetlands. School of Public and Environmental Affairs, Indiana University, Bloomington, Indiana and Shorelands and Water Resources Program, Washington Department of Ecology, Olympia, Washington.

Pasternack, G. B., and G. S. Brush. 2001. Seasonal variations in sedimentation and organic content in five plant associations on a Chesapeake Bay tidal freshwater delta. Estuarine, Coastal and Shelf Science 53:93-106.

Pasternack, G. B., and G. S. Brush. 2002. Biogeomorphic controls on sedimentation and substrate on a vegetated tidal freshwater delta in upper Chesapeake Bay. Geomorphology 43:293-311.

Pfeffer, W. T., J. T. Harper, and S. O'neel. 2008. Kinematic constraints on glacier contributions to 21st-century sea-level rise. Science 321:1340-1343.

Phillips, R. C. 1984. The ecology of eelgrass meadows in the Pacific Northwest: A community profile. U.S. Fish and Wildlife Service. FWS/OBS-84/24.

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Rahmstorf, S. 2007. A semi-empirical approach to projecting future sea-level rise. Science 315:368-370.

Redfield, A. C. 1972. Development of a New England salt marsh. Ecological Monographs 42:201-237.

Reed, D. J. 1995. The response of coastal marshes to sea-level rise: Survival or submergence? Earth Surface Processes and Landforms 20:39-48.

Rybczyk, J. M., J. C. Callaway, and J. W. Day. 1998. A relative elevation model for a subsiding coastal forested wetland receiving wastewater effluent. Ecological Modelling 112:23-44.

Rybczyk, J. M., and D. R. Cahoon. 2002. Estimating the potential for submergence for two wetlands in the Mississippi River Delta. Estuaries and Coasts 25:985–998.

Scavia, D., J. C. Field, D. F. Boesch, R. W. Buddemeier, V. Burkett, D. R. Cayan, M. Fogarty, M. A. Harwell, R. W. Howarth, C. Mason, D. Reed, T. Royer, A. Sallenger, and J. Titus. 2002. Climate change impacts on US coastal and marine ecosystems. Estuaries and Coasts 25:149–164.

Short, F. T., and H. A. Neckles. 1999. The effects of global climate change of seagrasses. Aquatic Botany 63:169-196.

Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. Averyt, M. Tignor, and H. Miller. 2007. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA.

Sumer, B. M., and J. Fredsoe. 2002. The mechanics of scour in the marine environment. Advanced Series on Ocean Engineering, Vol. 17. World Scientific Publishing, London, UK.

Syvitski, J. P. M., A. J. Kettner, I. Overeem, E. W. H. Hutton, M. T. Hannon, G. R. Brakenridge, J. Day, C. Vorosmarty, Y. Saito, L. Giosan, and R. J. Nicholls. 2009. Sinking deltas due to human activities. Nature Geoscience 2:681-686.

Syvitski, J. P. M., C. J. Vörösmarty, A. J. Kettner, and P. Green. 2005. Impact of humans on the flux of terrestrial sediment to the global coastal ocean. Science 308:376-380.

Thom, R. 1992. Accretion rates of low intertidal salt marshes in the Pacific Northwest. Wetlands 12:147-156.

Thom, R. M. 1990. Spatial and temporal patterns in plant standing stock and primary production in a temperate seagrass system. Botanica Marina 33:497-510.

Thom, R., S. Southard, A. Borde, and P. Stoltz. 2008. Light requirements for growth and survival of eelgrass (Zostera marina L.) in Pacific Northwest (USA) estuaries. Estuaries and Coasts 31:969-980.

Turner, D. 1980. Investigation of the tidal soils of Padilla Bay. Bulletin 0885. Washington State University College of Agricultural Research Center.

Verdonck, D. 2006. Contemporary vertical crustal deformation in Cascadia. Tectonophysics 417:221-230.

Waycott, M., C. M. Duarte, T. J. . Carruthers, R. J. Orth, W. C. Dennison, S. Olyarnik, A. Calladine, J. W. Fourqurean, K. L. Heck, A. R. Hughes, G. Kendrick, W. J. Kenworthy, F. T. Short, and S. L. Williams. 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proceedings of the National Academy of Sciences 106:12377-12381.

Whelan, K., T. Smith, D. R. Cahoon, J. Lynch, and G. Anderson. 2005. Groundwater control of mangrove surface elevation: Shrink and swell varies with soil depth. Estuaries and Coasts 28:833-843.

APPENDICES Page

Figures

Figure A.1. Rate of surface elevation change at site 1

Figure A.2. Rate of surface elevation change at site 2

Figure A.3. Rate of surface elevation change at site 3

Figure A.4. Rate of surface elevation change at site 4

Figure A.5. Rate of surface elevation change at site 5

Figure A.6. Rate of surface elevation change at site 6

Figure A.7. Rate of surface elevation change at site 7

Figure A.8. Rate of surface elevation change at site 8

Figure A.9. Rate of surface elevation change at site 9

Figure A.10. Rate of surface elevation change at site 10

Figure A.11. Rate of surface elevation change at site 11

Figure A.12. Rate of surface elevation change at site 12

Figure A.13. Rate of surface elevation change at site 13

Figure A.14. Rate of surface elevation change at site 14

Figure A.15. Rate of surface elevation change at site 15

Figure A.16. Rate of surface elevation change at site 16

Figure A.17. Rate of surface elevation change at site 5B

Figure A.18. Rate of surface elevation change at site 12B

Figure A.19. Rate of surface elevation change at site 14B

Tables

Appendix A. Surface elevation changes and regression test statistics at each SET site. Error bars representing ± 1 standard deviation of SET arm means (n=4) are used to indicate variance, although arm means were not used in regression calculations.

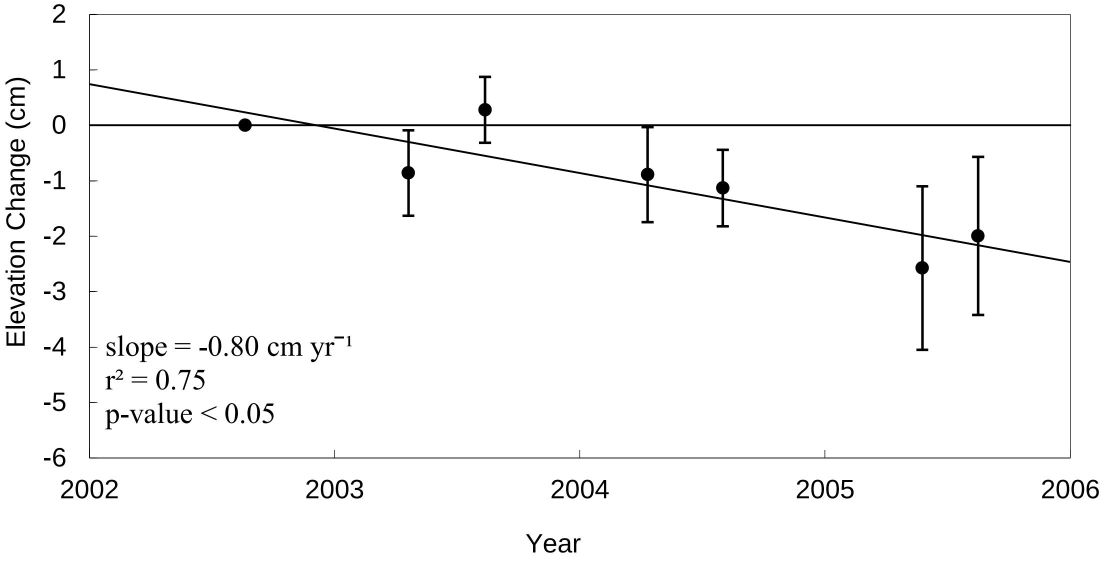
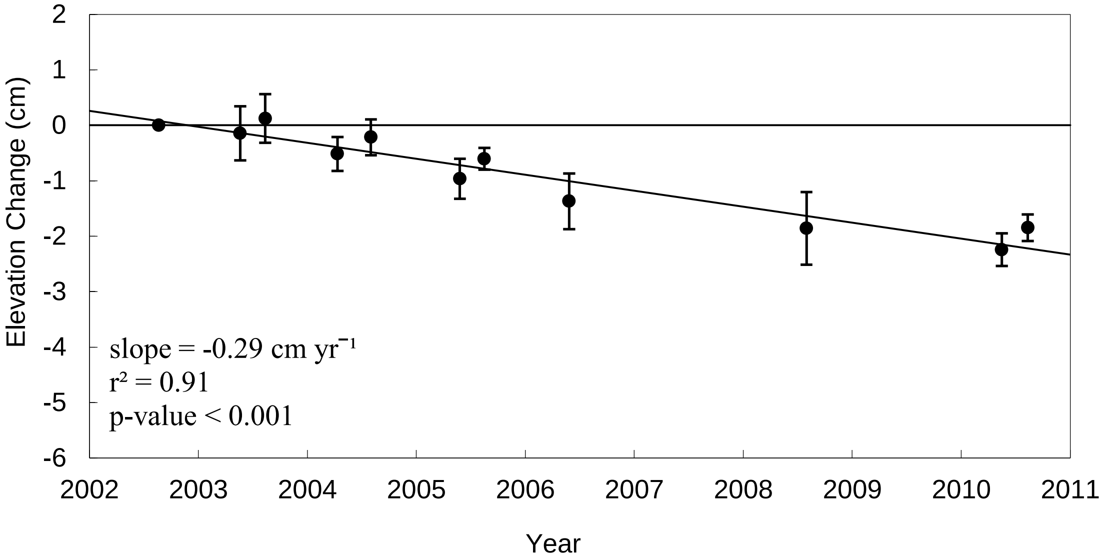


Figure A.1. Rate of surface elevation change at site 1.



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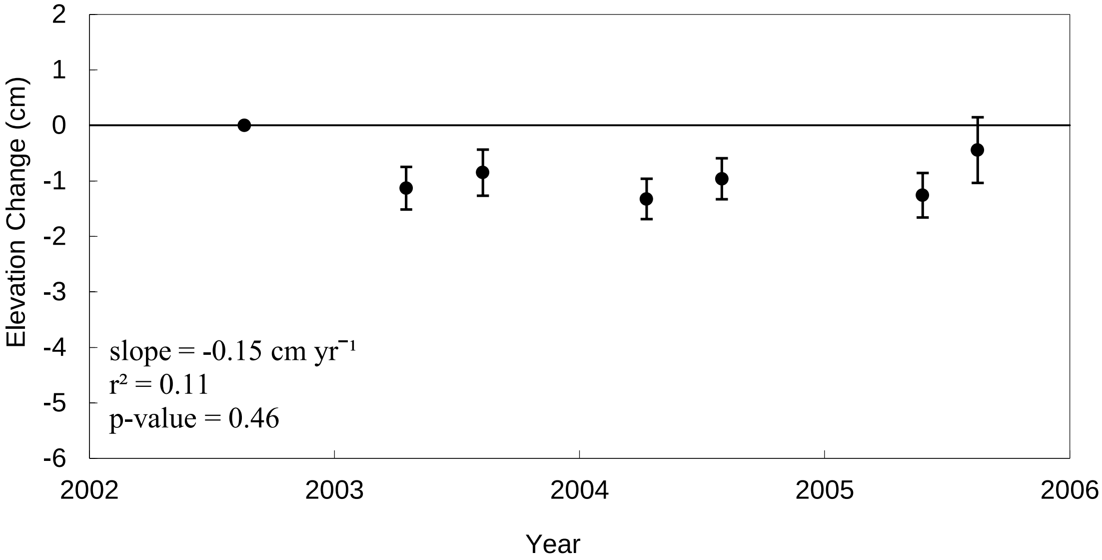

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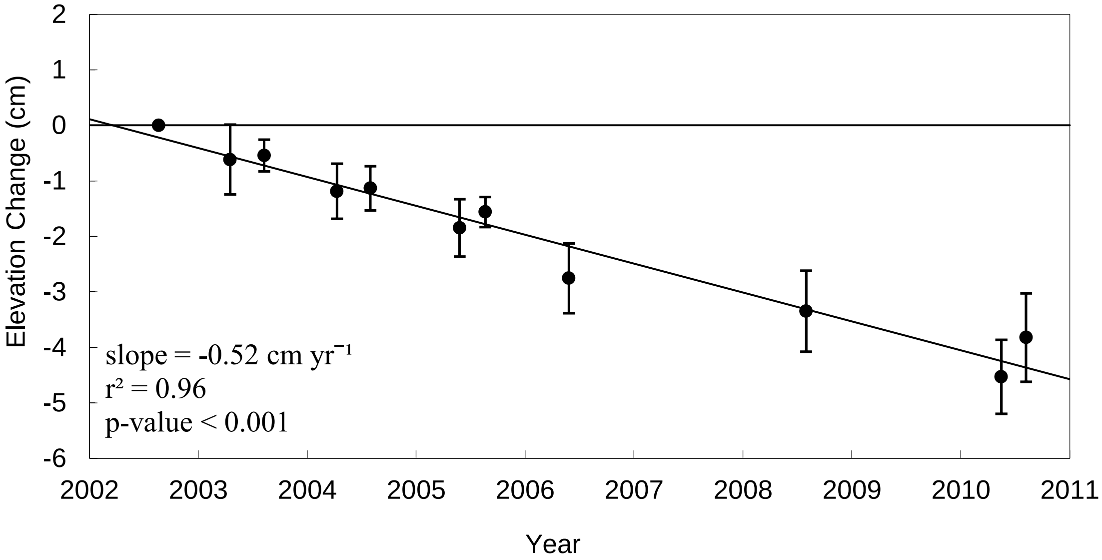

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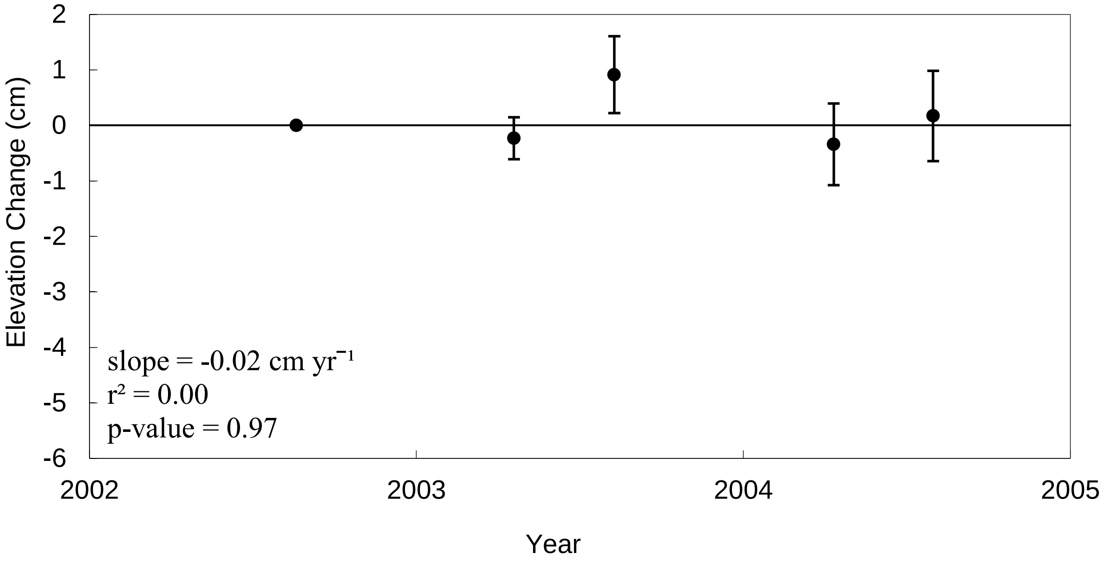

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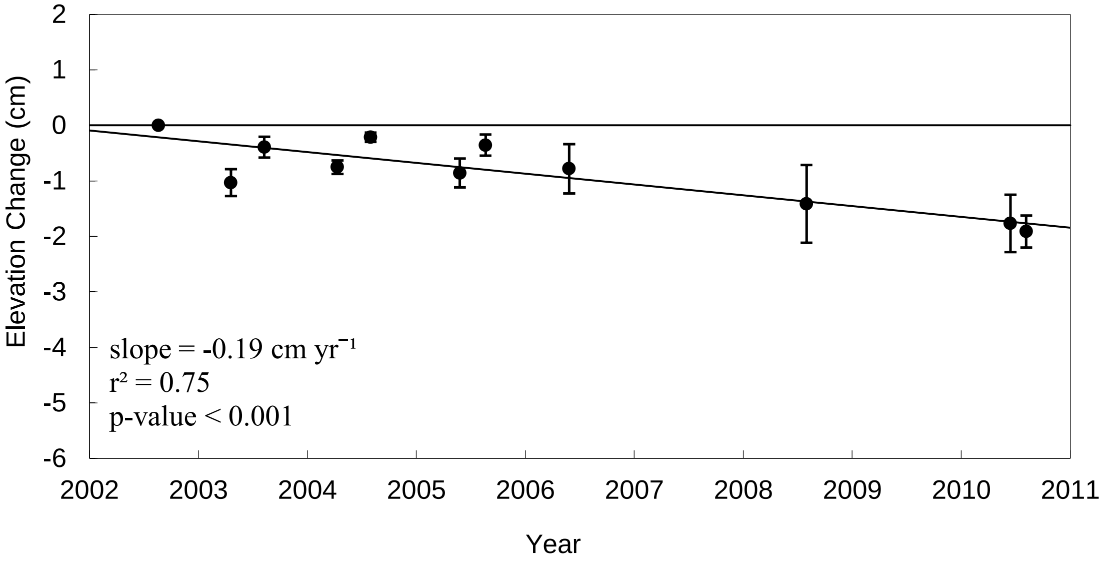

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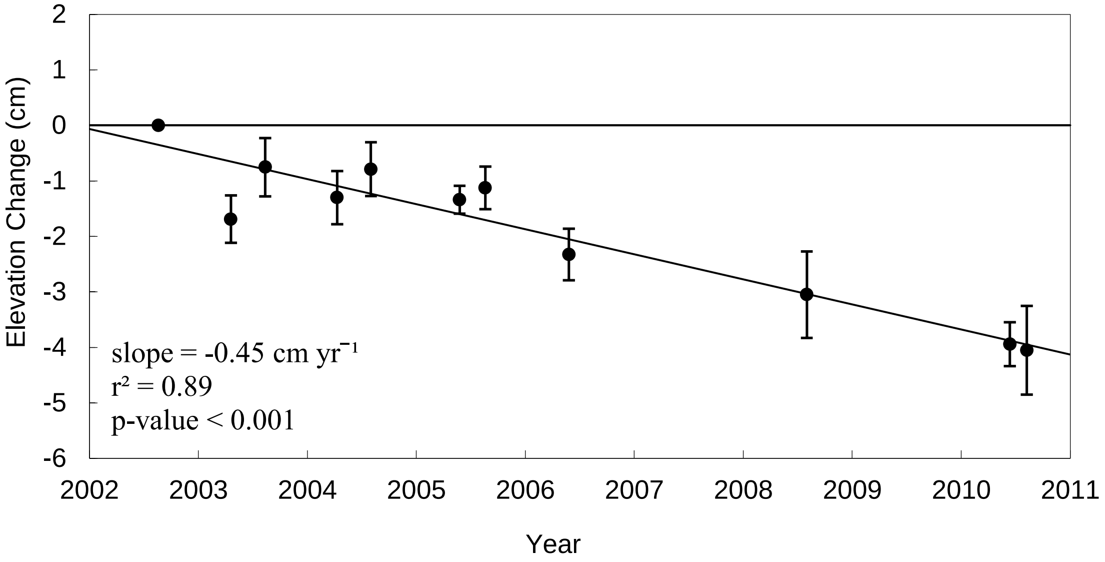

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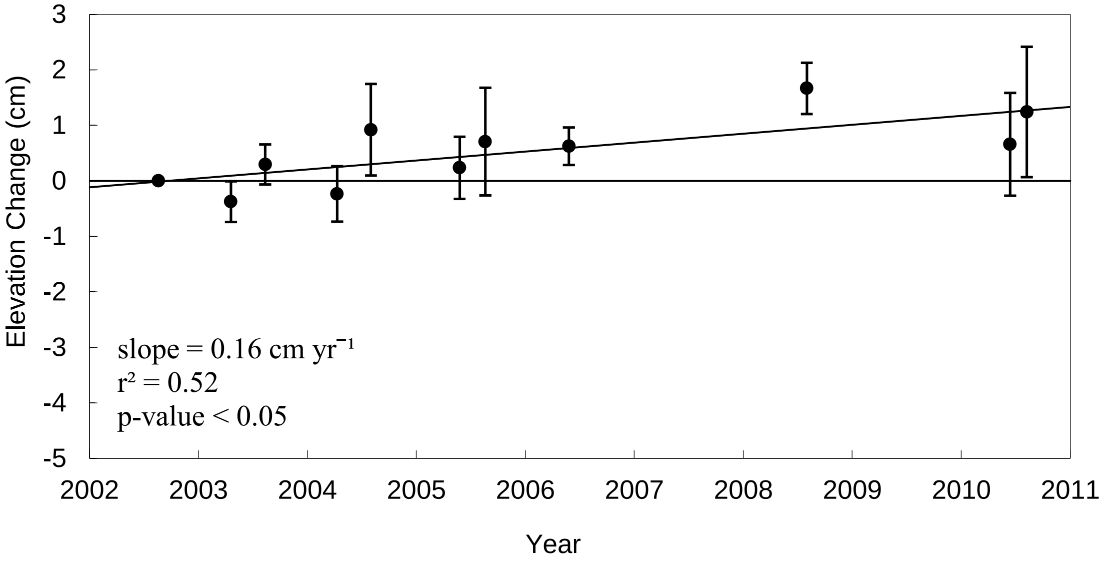

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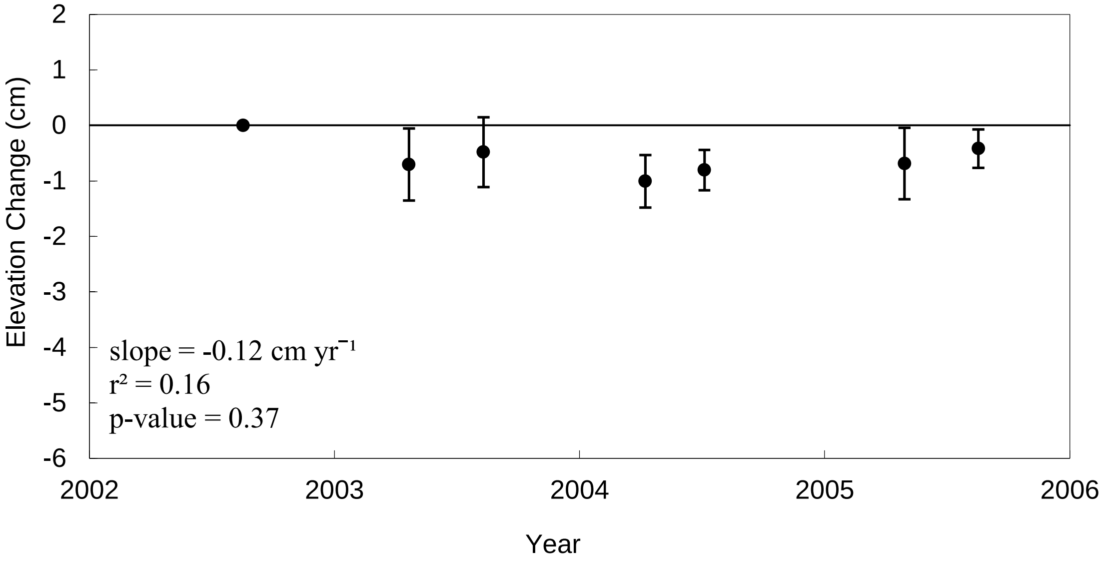

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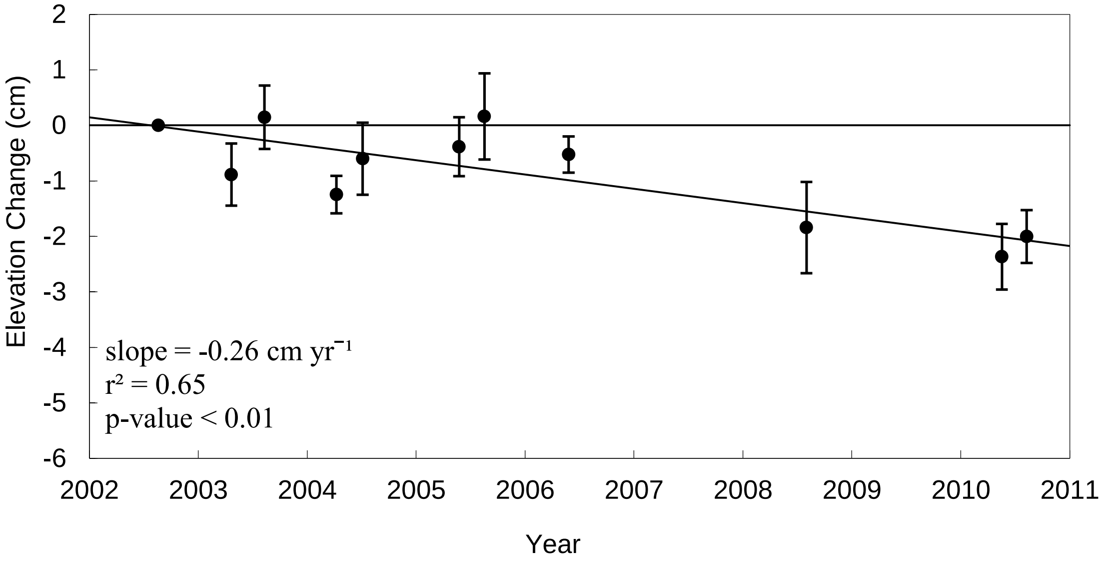

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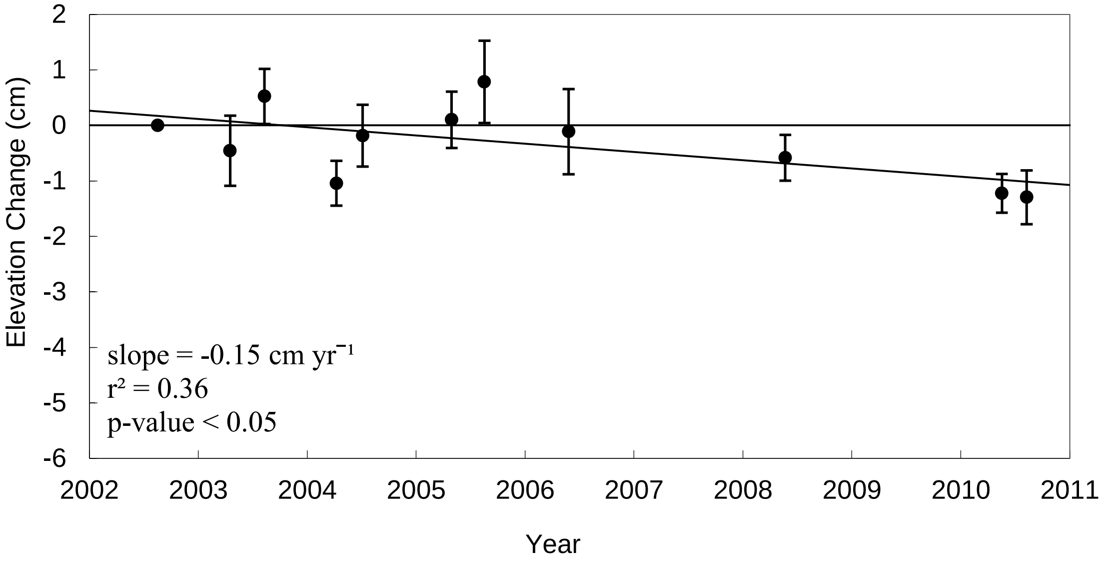

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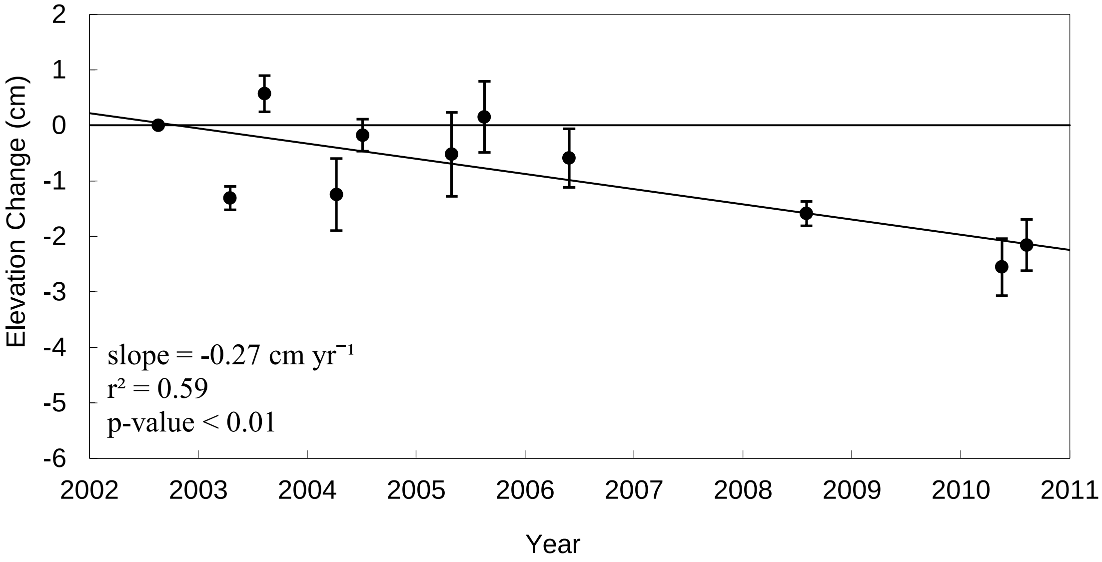

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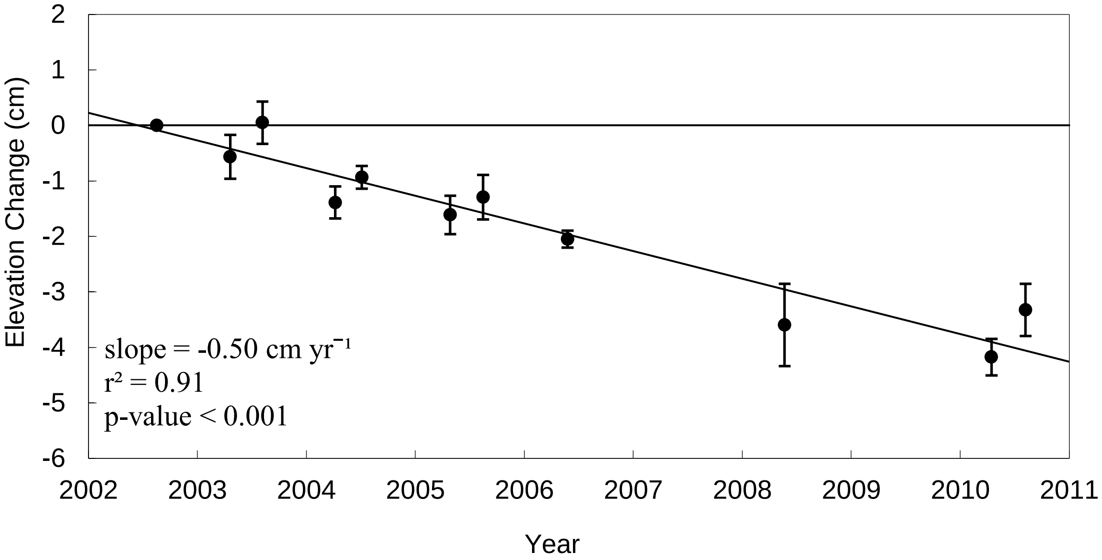

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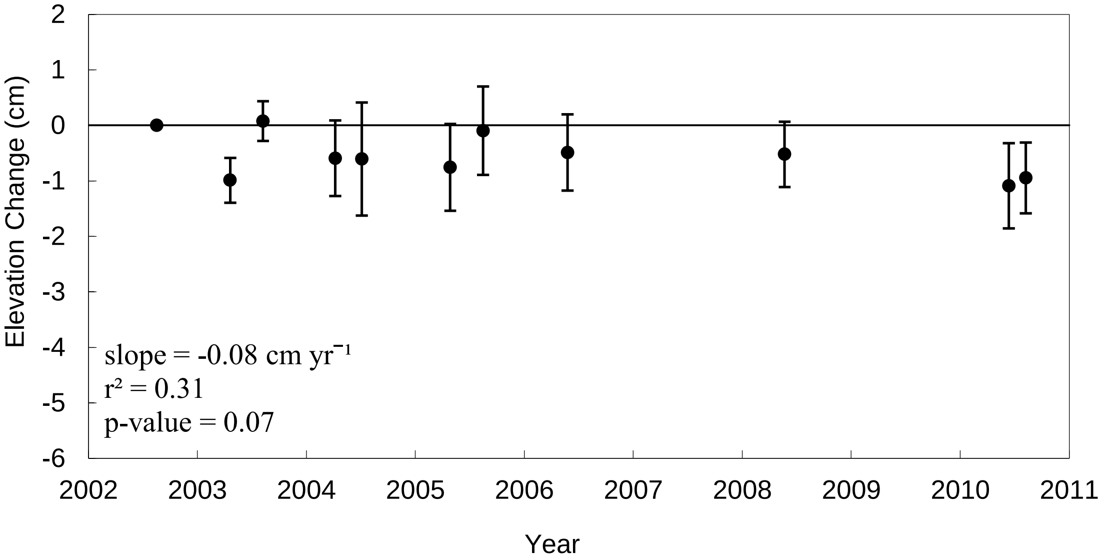

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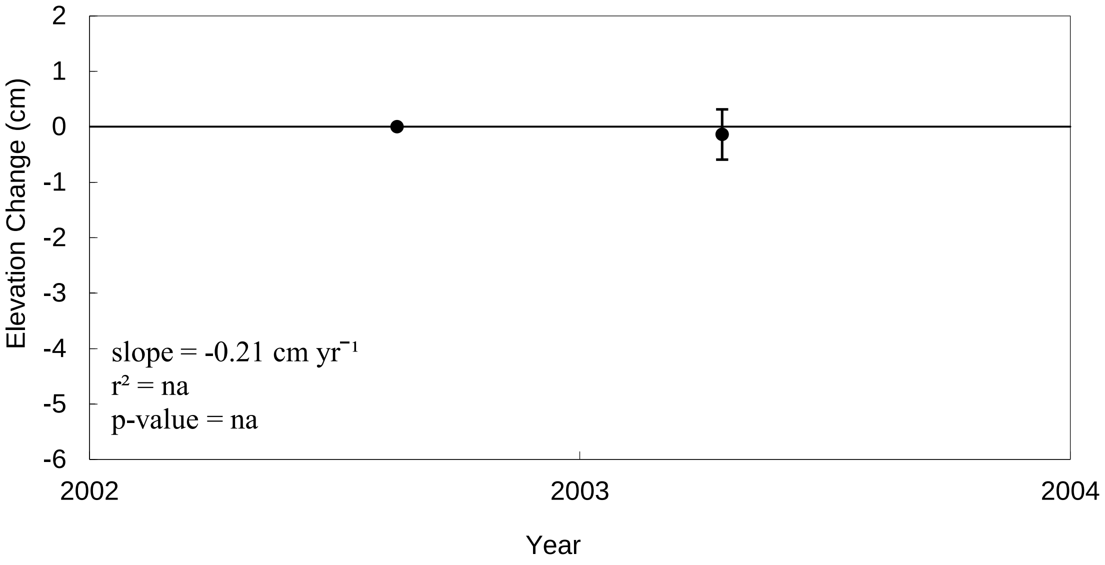

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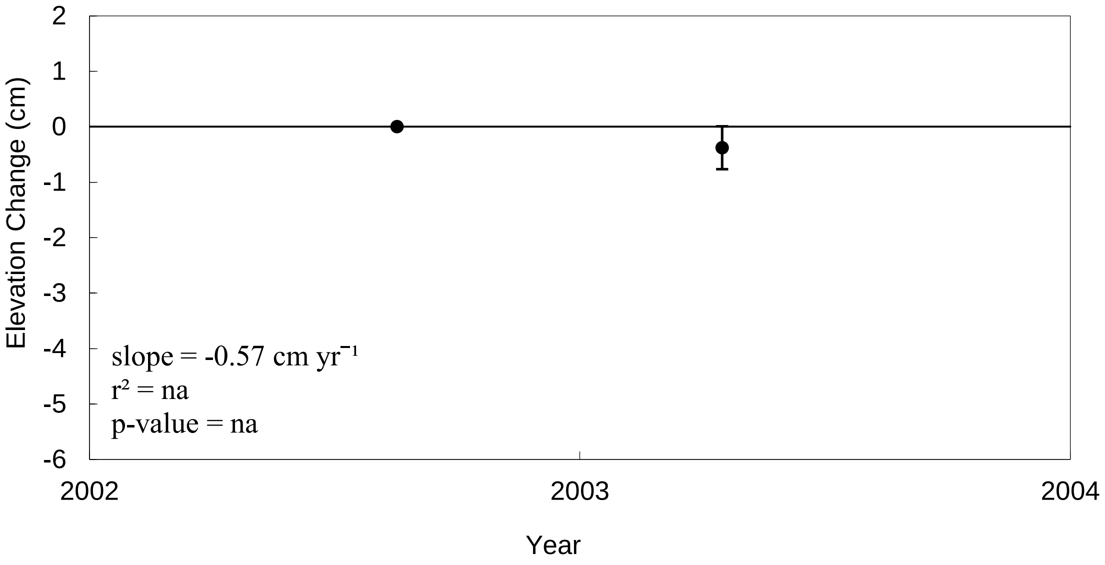

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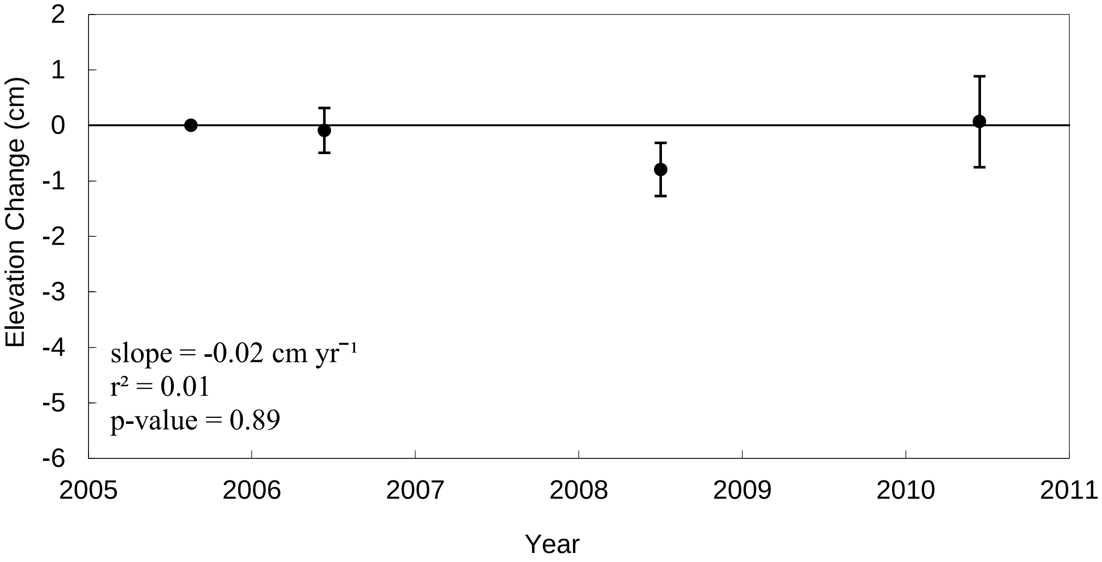

Figure A.17. Rate of surface elevation change at site 5B.

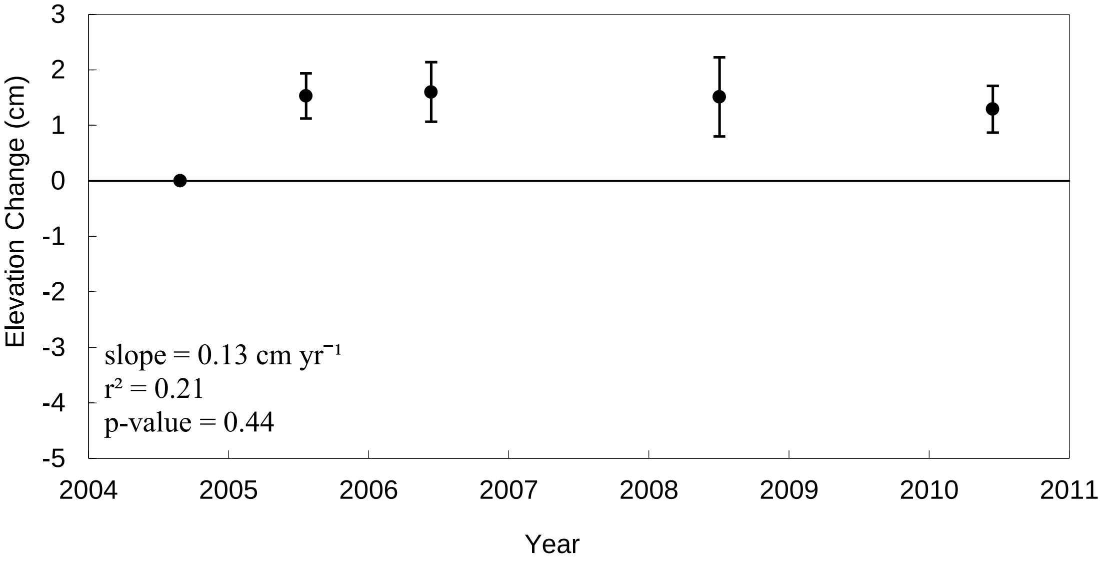

Figure A.18. Rate of surface elevation change at site 12B.

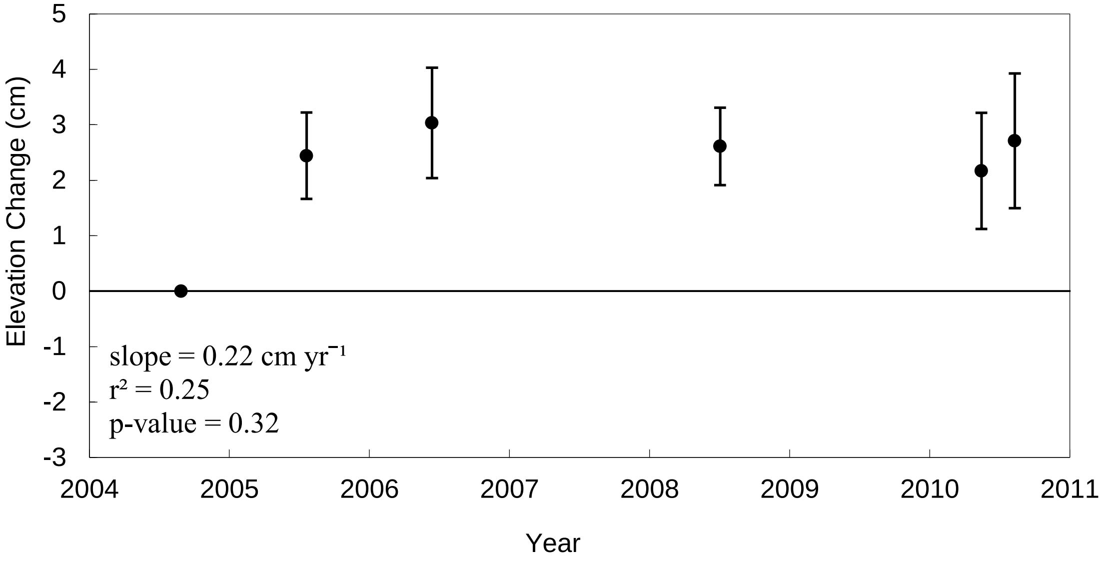

Figure A.19. Rate of surface elevation change at site 14B.

Appendix B. Sediment elevation table data. All measurements in cm.

Table B.1. Sediment elevation measurements at site 1.

arm position	pin	8/21/2002	4/21/2003	8/13/2003	4/11/2004	8/1/2004	5/25/2005	8/16/2005	5/27/2006	7/30/2008	5/15/2010	7/23/2010
1	1	35.5	34.5	35.2	34.2	34.2	32.8	33.5	30.3	29.1	26.9	28.6
1	2	34.9	34.7	35.3	34.4	34.0	33.1	34.0	30.9	29.7	27.6	28.6
1	3	35.0	34.7	36.0	35.0	34.2	33.7	34.2	31.3	29.7	28.5	29.1
1	4	34.7	35.0	35.8	35.3	34.2	33.8	34.2	31.7	30.8	28.9	29.3
1	5	34.4	34.6	35.7	34.7	34.3	34.1	34.7	32.1	31.0	28.8	29.1
1	6	34.7	34.4	35.5	35.0	34.4	34.2	34.6	32.2	31.7	29.0	29.5
1	7	34.6	34.4	35.4	34.8	34.4	34.2	34.3	32.5	30.3	29.1	30.0
1	8	34.9	34.7	36.3	35.4	34.8	34.4	34.3	33.0	32.1	29.0	30.5
1	9	34.7	34.1	35.4	34.7	34.2	33.6	34.2	33.2	32.9	29.2	30.5
8	1	34.9	34.9	36.2	34.0	34.0	32.6	32.9	30.8	29.9	28.5	28.8
8	2	34.8	34.8	36.0	34.1	34.3	32.8	33.0	31.4	30.7	28.6	28.7
8	3	35.4	34.4	36.2	35.1	34.5	33.1	33.3	31.8	30.4	28.9	28.8
8	4	36.1	34.1	35.8	35.2	34.7	33.1	33.8	32.3	31.0	29.3	29.4
8	5	35.6	34.2	35.5	35.1	34.4	33.1	34.3	32.7	29.7	28.9	29.0
8	6	35.4	34.3	35.8	34.7	34.3	34.0	34.4	33.3	32.3	28.8	28.9
8	7	34.5	35.0	36.0	34.7	34.6	33.8	35.0	32.9	33.0	28.1	29.3
8	8	35.3	34.8	35.9	35.3	35.1	34.0	34.8	33.4	32.5	28.4	29.1
8	9	35.0	35.9	36.0	34.9	34.6	33.9	34.5	33.6	33.2	28.8	29.7
7	1	35.6	34.9	34.7	33.8	33.6	31.8	32.3	30.8	28.2	28.6	28.6
7	2	35.5	34.3	35.0	34.2	34.0	31.6	33.0	31.0	28.9	28.5	28.2
7	3	35.4	34.8	35.3	34.1	34.1	32.2	33.4	31.1	29.3	28.5	28.5
7	4	35.4	35.1	35.9	34.7	34.7	32.7	32.7	31.4	29.0	28.7	28.6
7	5	35.0	35.1	35.6	34.1	34.5	32.8	33.7	31.6	29.9	28.7	29.0
7	6	35.1	35.0	35.9	33.9	34.7	32.9	33.1	32.0	30.7	28.7	28.9
7	7	35.5	35.4	35.4	34.4	34.2	32.8	33.0	32.1	31.2	28.6	28.4
7	8	35.7	35.4	36.0	34.5	34.6	32.6	33.4	32.7	31.7	28.9	28.9
7	9	36.2	33.7	36.4	34.9	34.4	33.0	33.5	32.9	30.8	29.3	29.5
6	1	36.5	34.4	35.8	34.4	34.4	31.3	31.3	29.2	28.7	28.4	28.4
6	2	36.4	34.2	36.0	34.0	34.3	31.5	31.3	29.2	28.5	28.2	28.5
6	3	36.3	34.2	35.7	34.1	34.1	31.5	32.6	29.5	29.0	28.5	28.3
6	4	36.1	34.1	35.4	33.7	33.9	31.7	33.0	29.4	29.7	28.8	28.5
6	5	35.9	34.0	35.3	34.0	34.2	31.8	32.7	29.2	30.8	28.8	28.9

6	6	36.0	33.8	35.9	33.8	33.1	31.7	33.0	30.7	30.5	28.7	28.4
6	7	35.8	33.7	34.9	33.7	33.6	31.5	32.1	31.0	31.3	28.7	29.1
6	8	35.5	34.1	35.3	34.1	33.8	31.6	31.8	31.1	31.3	29.0	29.4
6	9	35.7	33.8	35.6	34.8	33.9	31.5	31.7	31.4	31.6	29.2	29.4

Table B.2. Sediment elevation measurements at site 2.

arm position	pin	8/21/2002	5/21/2003	8/13/2003	4/11/2004	8/1/2004	5/26/2005	8/16/2005	5/27/2006	7/30/2008	5/15/2010	8/10/2010
7	1	28.4	27.8	28.5	27.7	28.6	27.5	27.7	26.7	26.4	26.7	26.2
7	2	28.6	28.1	28.2	28.3	28.5	27.6	27.7	27.2	27.5	27.1	27.0
7	3	28.2	28.5	28.1	28.1	28.3	27.7	28.2	28.0	27.3	27.0	27.1
7	4	29.6	28.0	28.5	28.3	28.9	27.8	28.7	28.2	27.1	26.4	27.0
7	5	28.9	28.6	28.8	28.4	27.2	28.3	28.9	27.7	26.8	26.6	26.9
7	6	28.8	29.5	29.2	28.9	28.0	28.4	28.2	27.6	25.7	26.9	27.3
7	7	29.7	29.5	29.7	28.9	29.1	28.5	28.1	27.7	26.0	27.0	27.6
7	8	29.2	29.7	29.9	28.5	29.3	28.7	28.4	28.2	25.5	26.9	27.4
7	9	27.0	29.0	29.4	28.9	29.3	28.4	29.5	28.5	27.4	26.9	27.7
6	1	30.9	28.3	29.2	28.2	28.2	27.3	27.6	26.9	26.7	26.0	26.7
6	2	30.4	28.1	28.0	27.9	28.6	27.4	28.6	27.3	27.2	26.5	26.9
6	3	29.1	28.4	27.2	28.8	28.5	27.6	28.6	27.4	26.9	26.6	27.1
6	4	29.6	28.8	27.3	28.7	28.6	27.7	27.7	27.6	26.9	27.0	27.1
6	5	30.3	28.3	28.5	29.1	28.7	28.2	28.1	27.7	26.4	27.3	27.5
6	6	28.9	28.5	30.1	28.1	28.8	28.5	29.9	27.0	25.2	27.4	28.1
6	7	28.7	29.2	30.4	28.1	29.6	28.8	29.6	27.5	26.5	28.0	28.2
6	8	29.0	29.2	30.7	29.0	29.5	28.6	30.1	27.7	27.9	28.1	28.5
6	9	28.8	29.1	29.7	29.0	29.0	28.7	29.5	28.1	27.6	27.8	28.0
5	1	29.1	29.8	29.0	27.5	29.7	27.5	27.3	27.4	26.6	26.1	26.5
5	2	29.2	29.5	28.8	28.1	28.7	27.8	28.7	27.5	27.4	26.2	26.5
5	3	29.2	28.3	29.3	28.7	28.9	27.9	28.1	27.8	27.1	26.1	25.4
5	4	29.3	28.5	29.3	28.6	28.3	28.5	28.6	27.9	27.8	26.6	27.2
5	5	29.4	28.7	29.3	28.5	29.0	28.4	28.5	28.1	26.9	27.0	27.8
5	6	29.0	28.7	29.9	28.8	28.4	28.1	28.2	28.2	26.9	27.2	28.3
5	7	28.8	29.5	30.4	28.9	28.2	28.4	28.1	28.0	28.0	27.2	27.8
5	8	28.7	29.8	29.6	28.3	29.2	28.3	28.2	28.0	28.7	27.0	27.4
5	9	27.8	28.5	29.3	29.3	29.3	28.6	27.9	28.2	28.6	27.0	27.6
4	1	29.6	29.2	28.7	27.9	28.4	27.6	28.3	26.4	27.1	26.3	26.9
4	2	30.4	29.4	29.5	28.0	29.3	27.9	27.8	27.3	27.3	26.6	26.2

4	3	29.6	29.4	29.4	28.4	30.1	28.4	28.4	27.4	28.0	26.6	26.1
4	4	29.6	29.3	29.6	28.5	28.4	28.3	29.3	27.1	27.8	26.8	26.9
4	5	29.3	28.9	30.0	29.4	29.6	28.3	28.9	27.6	28.0	26.2	27.5
4	6	29.3	29.3	29.6	29.0	29.7	28.1	28.7	28.0	27.9	26.8	27.9
4	7	29.4	29.9	29.6	29.5	29.8	28.2	28.6	28.5	28.6	26.9	27.8
4	8	28.4	29.7	30.4	29.4	29.8	28.4	28.3	29.1	28.6	27.2	27.5
4	9	28.1	30.1	29.8	29.7	28.8	28.6	28.9	28.9	28.5	26.9	27.6

Table B.3. Sediment elevation measurements at site 3.

arm position	pin	8/20/2002	4/18/2003	8/10/2003	4/10/2004	7/31/2004	5/26/2005	8/16/2005	5/27/2006	7/30/2008	5/15/2010	8/6/2010
6	1	20.6	17.7	18.0	19.0	19.9	18.8	19.7	18.6	19.5	17.4	17.4
6	2	20.4	17.7	18.7	19.2	19.9	19.0	19.8	19.7	19.5	17.6	17.7
6	3	20.9	18.9	18.1	19.3	20.5	19.2	19.6	19.6	18.8	17.9	18.9
6	4	20.9	19.7	19.6	19.5	19.8	19.5	20.2	19.2	19.3	18.4	18.8
6	5	20.8	19.7	19.8	19.3	19.8	20.1	22.0	19.0	18.5	18.4	19.1
6	6	21.4	21.2	19.9	19.8	19.9	20.0	21.1	19.7	18.3	18.6	19.2
6	7	20.6	20.5	19.5	20.4	20.4	20.3	20.8	19.7	19.5	18.7	19.0
6	8	20.7	20.5	20.4	20.7	20.5	20.3	21.0	19.9	18.8	18.6	19.1
6	9	21.2	20.4	20.6	20.8	19.8	20.0	20.8	20.0	18.7	19.5	19.0
5	1	21.0	17.5	18.8	18.9	18.9	18.7	19.2	19.6	19.9	17.5	18.2
5	2	21.1	18.5	18.4	19.0	20.0	19.1	19.2	20.0	19.8	17.4	18.2
5	3	22.5	18.7	18.4	19.0	19.6	19.2	19.2	20.2	20.3	17.4	18.7
5	4	22.0	19.7	19.9	19.2	19.8	18.8	19.5	20.5	20.1	17.5	18.6
5	5	21.0	19.7	19.9	19.3	19.6	19.8	19.9	19.8	18.7	18.1	17.8
5	6	20.7	20.5	20.2	19.5	20.0	20.0	20.3	19.9	18.4	18.2	18.8
5	7	20.5	20.5	20.0	19.5	20.0	19.8	20.8	19.8	19.9	18.0	18.1
5	8	20.7	20.4	20.7	19.8	19.9	20.2	20.8	19.7	19.9	18.9	18.6
5	9	20.8	20.6	30.0	19.5	20.3	19.9	21.0	20.3	19.5	18.2	18.6
4	1	20.5	18.8	18.4	18.4	19.0	18.5	19.9	19.7	19.7	16.1	16.6
4	2	20.4	19.8	19.6	19.1	19.2	18.8	20.0	19.9	20.0	16.5	16.1
4	3	20.8	19.8	19.7	19.5	18.9	19.0	20.2	19.9	19.9	16.6	17.1
4	4	20.5	19.2	20.3	18.8	19.6	19.2	19.9	19.6	20.2	16.6	17.4
4	5	20.6	19.6	20.0	19.1	19.9	19.4	20.1	19.6	20.4	16.5	17.5
4	6	21.0	20.1	20.1	19.0	19.7	19.3	20.5	19.7	20.1	16.4	17.9
4	7	20.9	20.0	19.9	19.4	19.6	19.2	20.3	20.1	20.4	16.6	18.0
4	8	20.5	19.7	20.2	20.1	19.6	18.9	19.7	20.0	19.5	17.1	18.4

4	9	20.7	19.3	20.4	20.2	19.7	19.6	19.3	19.7	20.0	16.0	18.5
3	1	20.8	19.1	18.7	18.1	19.0	18.5	19.3	18.6	19.7	16.6	16.4
3	2	20.4	19.3	18.9	18.6	19.3	19.1	19.6	19.4	20.4	16.8	16.2
3	3	20.3	19.5	19.5	19.0	19.4	19.3	19.7	19.0	20.1	17.2	16.2
3	4	20.2	20.1	19.4	19.3	19.7	19.5	20.5	19.1	20.2	16.6	16.7
3	5	19.8	19.3	19.5	19.1	19.6	19.2	20.6	19.5	19.7	17.1	16.9
3	6	20.2	19.4	19.4	19.2	19.7	19.6	21.0	19.1	18.6	17.3	17.4
3	7	20.2	19.7	19.8	19.3	19.8	19.7	21.0	19.3	19.6	17.4	17.8
3	8	20.1	19.8	20.1	19.7	20.1	19.8	21.0	20.0	19.5	17.3	17.2
3	9	20.1	20.0	20.1	19.9	20.3	20.3	21.5	19.8	19.6	17.2	17.2

Table B.4. Sediment elevation measurements at site 4.

arm position	pin	8/21/2002	4/18/2003	8/10/2003	4/10/2004	7/31/2004	5/26/2005	8/20/2005	5/27/2006	7/30/2008	5/15/2010	8/6/2010
3	1	34.0	32.3	33.0	32.9	32.3	31.5	31.8	30.4	30.5	29.0	29.6
3	2	34.7	31.9	33.6	32.5	32.7	31.8	32.3	30.4	31.1	29.1	29.5
3	3	34.1	33.1	33.3	32.8	33.6	32.2	32.3	30.8	30.4	29.0	29.1
3	4	34.3	33.5	33.8	32.7	33.6	32.5	32.7	31.0	30.5	29.3	29.4
3	5	33.9	33.6	33.4	32.8	33.7	32.5	32.4	30.9	30.6	29.2	29.7
3	6	34.4	34.0	34.0	33.4	33.4	32.6	32.7	31.0	29.6	29.6	30.1
3	7	34.2	34.4	34.3	32.2	32.7	32.6	33.0	30.8	29.5	29.2	30.0
3	8	34.6	34.5	34.9	32.4	33.7	32.3	33.2	31.3	29.9	29.2	29.8
3	9	34.9	34.4	35.1	35.4	33.1	32.7	33.1	31.2	28.8	29.1	29.7
2	1	34.0	31.9	32.9	31.9	31.8	31.0	31.5	30.7	29.9	28.4	29.2
2	2	34.3	32.2	33.4	31.9	32.3	31.0	31.7	30.5	30.1	28.6	29.2
2	3	34.2	32.3	33.1	31.6	32.4	30.9	31.6	30.8	30.7	28.9	29.0
2	4	34.2	32.8	33.2	31.9	32.5	31.1	31.8	30.6	30.9	29.0	29.9
2	5	33.8	32.6	33.4	31.7	31.7	31.3	32.3	30.3	30.7	29.3	29.8
2	6	33.8	32.8	32.2	31.9	31.7	31.7	33.0	30.9	30.1	29.2	29.4
2	7	33.9	32.4	33.0	32.2	32.7	31.9	32.6	31.0	30.0	29.1	29.4
2	8	33.1	32.3	32.6	33.0	33.8	31.9	32.6	31.0	29.6	28.8	30.1
2	9	33.8	33.2	34.2	32.5	33.1	31.6	32.8	31.4	30.1	28.7	30.0
1	1	34.5	32.4	32.0	31.6	31.0	30.5	30.8	30.6	30.4	28.2	29.4
1	2	33.7	32.7	32.0	31.4	31.3	30.9	30.9	30.6	30.2	28.5	29.6
1	3	32.7	32.5	31.7	32.9	31.6	31.5	30.7	30.2	30.1	28.6	29.7
1	4	32.5	33.0	32.3	33.4	31.8	31.3	30.9	30.7	30.4	28.2	30.1
1	5	33.0	32.4	32.5	31.5	31.9	31.5	30.9	30.7	30.7	29.0	29.4

1	6	33.0	38.0	32.2	32.3	32.2	32.2	31.8	30.7	29.4	28.9	30.0
1	7	32.9	32.2	32.9	32.0	32.3	32.2	32.4	30.9	29.5	29.1	30.2
1	8	32.8	32.1	32.4	32.0	32.0	32.0	31.8	30.5	30.1	29.0	30.0
1	9	32.8	32.9	33.1	32.6	31.3	32.2	32.0	30.7	30.2	29.1	29.6
8	1	33.1	32.1	32.5	31.9	31.6	31.7	31.5	30.5	29.9	29.0	29.5
8	2	33.7	32.3	33.4	31.9	31.6	31.6	31.2	30.7	31.1	28.9	29.7
8	3	34.1	32.1	32.9	31.8	32.0	31.2	31.2	30.8	30.9	29.0	30.1
8	4	33.3	32.8	33.2	32.5	32.8	31.2	31.6	30.6	30.9	29.5	30.0
8	5	32.8	33.8	33.0	33.4	33.1	31.6	32.4	31.0	30.2	29.5	30.0
8	6	33.1	33.8	32.6	32.2	33.1	32.0	32.4	31.4	30.3	29.5	30.5
8	7	32.7	33.2	32.8	33.1	33.3	31.8	32.4	31.7	30.8	29.9	30.2
8	8	33.1	32.8	33.5	32.9	33.1	32.3	32.8	31.5	30.6	29.9	30.9
8	9	32.8	33.2	33.1	32.5	32.9	32.7	32.7	32.0	30.7	30.3	30.6

Table B.5. Sediment elevation measurements at site 5.

arm position	pin	8/20/2002	4/20/2003	8/10/2003	4/11/2004	7/31/2004	5/26/2005	8/20/2005	5/27/2006	7/30/2008	6/13/2010	8/5/2010
5	1	33.3	31.1	32.0	30.9	30.0	30.3	30.7	27.2	29.8	28.6	27.8
5	2	33.6	30.9	31.9	30.5	30.9	30.5	31.4	28.9	30.1	28.7	28.2
5	3	32.8	31.2	33.1	30.4	31.0	30.8	31.9	29.4	31.0	28.8	28.9
5	4	32.2	31.3	33.2	30.6	30.5	31.9	32.1	29.8	30.9	28.8	28.8
5	5	31.7	31.7	33.6	31.4	32.1	31.9	32.3	30.1	30.1	29.3	29.2
5	6	31.7	32.1	33.5	31.4	31.3	31.3	33.4	30.8	29.9	28.7	29.0
5	7	32.5	31.6	32.9	30.5	31.3	32.4	32.6	30.9	29.8	28.9	29.5
5	8	30.8	32.7	33.0	31.5	31.7	32.9	32.6	31.0	31.1	29.4	29.9
5	9	30.5	31.7	32.2	31.3	31.7	32.1	31.5	30.7	30.1	30.0	29.5
4	1	31.8	31.1	32.1	31.4	31.2	31.2	31.7	27.0	28.9	27.8	27.8
4	2	31.9	31.4	32.5	31.2	31.7	32.0	32.0	28.0	29.3	27.6	28.0
4	3	31.8	31.1	33.3	31.1	32.2	32.5	31.2	29.2	29.5	28.3	27.9
4	4	31.8	31.3	32.7	30.6	32.2	32.3	31.0	30.2	29.6	28.4	27.9
4	5	31.0	31.0	32.3	31.5	31.3	31.9	32.1	30.0	29.5	28.4	28.5
4	6	31.7	30.5	33.0	31.6	32.2	31.8	31.6	30.1	29.6	28.6	28.7
4	7	31.3	32.7	33.4	30.7	32.8	32.0	31.7	30.1	28.9	28.7	28.8
4	8	31.2	33.2	33.4	31.0	32.4	31.8	32.7	30.4	30.1	28.9	29.1
4	9	31.1	31.7	33.1	31.3	32.3	32.3	33.3	31.6	30.2	28.4	29.4
3	1	31.2	31.7	32.5	30.1	30.4	31.7	31.2	27.3	27.5	27.4	26.9
3	2	31.0	30.9	32.5	30.4	30.6	31.6	31.0	28.2	27.5	27.4	26.3

3	3	31.1	30.0	32.1	31.1	30.6	31.6	32.2	28.3	28.8	27.2	27.1
3	4	31.2	30.8	31.8	31.1	31.9	32.8	32.7	29.1	29.4	27.1	27.4
3	5	31.7	31.3	32.2	32.1	32.2	31.3	33.0	29.2	29.4	27.5	27.4
3	6	30.9	31.5	32.9	31.8	32.7	32.3	32.5	29.7	29.9	27.1	27.6
3	7	30.2	31.7	33.0	31.9	32.5	32.4	32.6	29.8	29.8	27.6	27.1
3	8	31.1	32.0	33.7	33.6	33.7	33.4	32.7	30.5	30.2	27.8	27.3
3	9	31.2	30.8	32.8	32.9	33.2	33.6	32.9	31.1	30.0	28.1	27.6
2	1	31.6	30.7	31.0	29.7	31.7	30.8	31.7	27.5	27.1	25.9	26.4
2	2	31.5	32.0	31.5	31.4	32.9	31.1	31.4	27.2	28.0	26.1	26.6
2	3	31.3	32.0	31.4	31.5	32.6	31.2	32.1	27.4	28.0	26.5	27.0
2	4	32.0	32.6	32.2	31.4	33.1	30.3	33.3	27.5	27.9	26.5	27.0
2	5	31.0	31.1	33.4	32.6	32.4	31.4	33.4	28.3	27.7	26.4	26.7
2	6	33.1	30.9	31.9	32.6	31.9	32.3	33.6	28.2	27.0	26.8	26.6
2	7	33.1	31.5	33.0	32.1	32.2	32.7	33.7	28.5	27.5	27.2	26.7
2	8	32.8	32.0	32.7	31.2	32.5	33.3	33.7	29.3	27.6	27.9	26.9
2	9	33.1	31.8	32.7	32.8	31.9	32.9	33.9	29.1	28.1	27.3	27.0

Table B.6. Sediment elevation measurements at site 6.

arm position	pin	8/20/2002	4/20/2003	8/10/2003	4/11/2004	7/31/2004	5/26/2005	8/20/2005	5/27/2006	7/30/2008	6/13/2010	8/5/2010
7	1	33.9	31.0	32.6	31.9	33.3	32.6	33.7	32.8	32.7	32.4	32.5
7	2	33.9	33.4	33.4	32.6	33.5	32.5	33.4	33.1	32.3	32.1	32.4
7	3	33.8	32.9	33.5	33.3	34.1	32.5	33.3	33.3	32.7	32.1	31.5
7	4	34.3	33.3	33.2	33.6	33.2	33.3	33.5	33.4	33.3	31.9	32.2
7	5	34.7	33.4	33.6	33.8	34.0	31.7	33.4	32.7	32.8	31.2	32.8
7	6	34.6	33.8	34.0	34.2	33.5	32.7	32.9	33.2	33.3	31.5	32.5
7	7	34.2	33.6	33.6	33.4	34.7	33.2	33.5	33.3	32.1	31.3	32.1
7	8	34.1	33.2	33.6	34.4	35.2	33.6	33.6	33.9	31.8	31.5	31.7
7	9	33.2	33.6	34.2	33.9	34.2	33.5	33.8	33.6	32.2	31.5	31.6
6	1	34.4	33.0	34.0	33.5	34.1	33.2	33.3	33.5	32.3	32.5	32.3
6	2	34.0	33.0	34.3	33.8	33.6	33.1	33.4	33.7	33.2	33.1	32.2
6	3	34.4	33.7	34.2	32.8	34.2	33.3	33.9	32.8	33.0	32.4	32.3
6	4	34.7	33.8	34.8	33.2	33.8	33.3	33.9	32.8	33.6	33.0	32.1
6	5	35.0	33.7	34.6	33.4	34.3	33.4	34.2	33.1	32.9	32.9	31.9
6	6	34.5	34.0	34.4	34.0	34.7	33.9	34.2	33.0	33.2	32.8	31.6
6	7	34.8	33.6	33.6	33.8	34.0	33.5	34.2	32.8	30.7	32.9	32.1
6	8	34.1	33.5	34.1	34.4	34.2	34.2	34.7	33.2	31.5	33.3	32.1

6	9	34.1	33.4	34.6	34.3	34.3	33.9	34.3	33.0	32.6	33.1	32.4
5	1	34.5	33.1	34.5	33.4	34.5	33.5	34.2	33.5	33.1	31.9	32.3
5	2	34.9	33.5	34.1	33.2	34.5	33.1	34.1	33.5	33.5	31.4	31.9
5	3	34.2	33.3	34.1	33.5	33.9	33.3	34.0	33.6	32.0	31.6	32.3
5	4	33.5	32.9	34.8	33.4	32.3	33.6	34.4	33.7	32.2	32.9	32.0
5	5	35.2	33.1	34.2	33.3	34.7	34.2	34.5	33.8	33.2	32.8	32.3
5	6	34.5	33.0	33.7	33.9	34.9	34.4	34.8	33.9	31.8	33.1	33.3
5	7	34.7	33.0	32.7	33.9	34.4	34.7	34.4	34.0	32.2	32.6	32.9
5	8	34.8	33.6	34.2	34.1	34.3	33.9	34.4	33.7	33.1	32.9	33.3
5	9	34.6	32.9	34.1	34.0	35.0	33.8	34.2	34.0	32.4	33.3	34.1
4	1	34.2	33.0	33.6	34.2	34.2	33.2	32.9	33.7	34.1	31.1	31.3
4	2	34.6	32.9	33.6	34.1	34.2	34.4	34.0	34.0	33.7	32.3	31.1
4	3	34.4	33.1	33.9	33.4	34.0	34.2	34.2	33.8	32.9	32.4	32.2
4	4	34.3	33.3	33.9	33.8	34.1	34.1	34.8	34.0	32.9	32.8	32.5
4	5	33.7	33.3	33.7	33.5	33.8	33.9	34.4	34.0	34.2	33.4	32.6
4	6	34.2	33.9	33.6	34.0	35.0	32.7	34.5	34.3	34.1	33.0	32.8
4	7	33.8	33.4	34.4	32.9	33.9	32.8	33.3	34.0	33.9	33.6	33.5
4	8	34.6	33.6	33.9	31.8	33.6	33.0	33.6	34.1	33.9	34.0	33.2
4	9	33.9	33.4	34.0	33.1	33.2	33.5	33.9	33.7	34.3	34.4	33.9

Table B.7. Sediment elevation measurements at site 7.

arm position	pin	8/20/2002	4/20/2003	8/13/2003	4/10/2004	8/1/2004	5/25/2005	8/19/2005	5/26/2006	7/31/2008	6/11/2010	8/7/2010
4	1	28.0	26.4	25.7	25.8	27.4	26.8	26.8	24.6	24.5	22.6	22.9
4	2	28.3	26.7	26.9	26.3	27.2	26.6	26.8	25.2	25.0	23.4	20.4
4	3	28.2	25.8	27.2	26.5	27.2	26.5	27.1	25.5	26.1	23.4	23.6
4	4	27.9	26.0	26.9	26.5	27.7	26.3	27.1	26.0	26.3	23.5	24.3
4	5	27.9	26.0	26.9	27.0	27.1	26.7	26.8	25.8	26.2	24.0	24.5
4	6	28.2	25.9	27.4	26.7	27.1	26.7	26.5	25.4	26.3	24.4	24.2
4	7	26.6	25.8	26.3	26.5	27.3	25.9	26.4	25.5	25.8	24.4	23.9
4	8	26.8	26.8	26.3	26.3	27.6	26.2	27.0	26.0	25.5	24.6	24.3
4	9	27.0	26.8	27.6	26.4	27.5	26.5	26.5	26.3	25.6	24.3	24.6
3	1	28.0	26.0	26.6	26.7	27.1	26.3	26.4	25.4	24.2	23.3	24.8
3	2	28.0	26.2	26.6	27.7	26.8	26.8	26.4	25.7	24.7	23.2	24.1
3	3	28.4	26.2	27.7	27.4	27.6	26.6	26.6	25.6	24.4	23.2	23.9
3	4	28.0	26.6	27.8	27.0	27.6	26.7	27.0	25.6	23.9	23.7	24.8
3	5	27.4	26.5	27.9	26.9	27.5	26.9	27.2	25.8	23.2	23.6	25.1

3	6	27.2	26.6	28.2	27.0	27.4	27.0	27.2	25.9	24.0	24.1	24.5
3	7	27.6	27.0	28.4	26.4	27.2	26.9	27.0	25.9	24.5	25.1	24.0
3	8	27.5	25.9	27.9	27.0	27.8	26.6	27.2	25.5	25.0	24.5	24.2
3	9	28.5	26.3	27.5	27.8	27.4	26.9	26.9	25.6	24.9	23.7	24.2
2	1	28.0	26.4	26.6	26.8	26.9	26.7	26.5	25.2	24.3	23.6	23.9
2	2	28.9	25.9	27.0	26.4	27.3	26.9	26.6	25.5	24.9	24.1	20.7
2	3	28.9	25.5	26.6	26.2	27.0	27.1	26.9	25.7	24.7	24.5	20.8
2	4	28.9	25.8	26.9	26.4	27.4	26.9	27.0	25.5	25.0	23.2	23.7
2	5	28.8	25.9	27.0	27.1	27.1	27.2	27.3	26.1	25.4	24.2	24.1
2	6	28.4	27.3	27.6	26.3	27.2	27.1	27.3	25.5	25.2	24.3	24.3
2	7	28.6	27.0	27.7	27.0	27.8	27.2	27.2	25.9	25.0	24.4	24.2
2	8	28.6	26.9	27.9	27.2	27.7	27.3	27.0	25.7	25.3	24.7	24.7
2	9	28.9	26.5	27.9	27.4	27.6	27.0	26.9	25.7	25.3	24.9	24.8
1	1	28.4	26.8	26.8	26.5	26.5	26.4	27.0	25.8	25.3	24.1	24.3
1	2	28.3	26.1	27.6	26.3	27.1	26.8	27.1	25.8	24.9	24.6	24.6
1	3	28.2	26.5	27.6	26.3	26.8	26.7	27.0	25.4	24.6	24.6	24.5
1	4	28.3	26.5	27.2	26.8	27.6	26.7	27.4	25.8	24.9	24.9	24.9
1	5	27.9	26.8	27.5	26.8	26.8	26.8	27.2	26.4	24.9	24.3	24.2
1	6	27.9	27.3	27.5	26.9	27.4	27.0	27.3	26.4	25.1	24.8	24.3
1	7	28.1	26.4	28.1	27.2	27.6	26.4	27.2	26.4	25.5	25.0	24.9
1	8	28.2	26.4	28.3	27.4	27.0	26.6	27.2	26.3	25.5	24.8	24.8
1	9	28.5	27.0	28.6	27.4	27.4	26.8	27.1	26.6	25.0	24.8	24.8

Table B.8. Sediment elevation measurements at site 8.

arm position	pin	8/20/2002	4/20/2003	8/13/2003	4/10/2004	8/1/2004	5/25/2005	8/19/2005	5/26/2006	7/31/2008	6/12/2010	8/7/2010
8	1	28.3	27.8	28.3	27.3	28.4	27.5	27.8	28.5	28.9	27.0	27.1
8	2	28.2	27.5	28.6	27.6	28.3	27.8	27.6	28.8	28.7	27.9	27.6
8	3	28.6	27.0	28.8	27.3	28.7	28.3	27.5	28.8	29.9	27.5	27.4
8	4	28.8	27.2	28.5	27.6	29.0	28.2	28.1	28.6	29.9	27.5	27.7
8	5	27.9	27.3	27.8	27.6	29.2	27.8	28.4	28.7	30.2	28.1	28.1
8	6	27.9	27.4	27.4	27.8	29.2	28.0	28.2	28.3	30.3	28.1	28.0
8	7	28.2	27.0	27.7	27.5	28.7	28.0	28.5	28.0	29.8	27.0	28.3
8	8	27.9	27.0	28.5	28.0	28.3	28.1	27.5	28.0	30.5	27.7	28.3
8	9	27.4	27.2	28.6	27.8	28.9	28.1	27.2	28.3	30.3	28.2	28.9
7	1	27.0	27.3	27.7	27.6	28.4	27.4	29.2	27.9	29.1	28.2	29.0
7	2	26.9	28.0	28.2	27.8	28.8	27.6	29.3	27.9	29.6	28.1	29.3

7	3	27.2	27.5	28.1	27.4	29.1	28.1	29.2	27.8	29.7	28.8	29.5
7	4	28.1	26.7	28.2	28.2	29.3	27.6	28.6	28.1	29.7	28.5	29.7
7	5	27.9	27.0	28.3	28.0	29.0	27.7	28.4	27.6	30.3	28.0	28.7
7	6	27.5	27.1	28.3	27.9	29.2	27.9	28.6	28.8	30.3	27.3	28.2
7	7	27.6	26.5	28.5	27.3	29.2	27.9	29.0	28.5	29.2	27.5	29.1
7	8	27.1	27.8	28.5	27.7	28.4	28.3	29.0	28.7	30.0	27.9	29.3
7	9	27.1	28.4	28.1	28.4	28.3	28.4	29.0	28.2	30.2	27.9	29.5
6	1	28.0	27.1	26.9	27.5	29.4	28.1	28.6	28.5	28.7	28.5	27.9
6	2	28.1	27.8	28.0	27.5	29.4	28.4	29.0	28.6	28.9	28.6	28.6
6	3	27.4	27.3	28.1	26.8	29.0	28.6	28.8	28.6	28.8	28.3	28.6
6	4	27.5	27.7	27.9	27.4	29.3	28.9	29.0	28.5	29.3	28.9	28.9
6	5	27.5	27.2	27.5	27.7	29.6	28.9	29.0	28.2	29.8	29.1	29.5
6	6	27.4	27.4	27.1	26.9	29.1	28.5	28.9	28.4	28.7	29.0	29.9
6	7	27.4	27.3	27.4	27.9	29.1	28.7	28.6	28.8	29.5	29.1	30.3
6	8	26.7	27.5	28.2	27.6	28.9	28.2	28.4	28.5	28.8	29.2	30.7
6	9	28.1	27.1	28.5	27.2	29.3	28.4	28.7	28.6	29.6	29.7	30.6
5	1	27.9	27.3	27.6	27.6	27.8	28.1	27.4	28.4	28.5	29.0	30.0
5	2	28.6	27.3	27.8	27.1	28.1	28.4	28.7	28.6	29.0	29.2	30.0
5	3	28.6	27.6	28.3	27.8	28.2	27.7	28.6	29.0	29.4	29.0	29.6
5	4	28.2	27.4	28.6	27.5	28.2	27.7	28.8	28.8	29.3	29.5	29.4
5	5	27.5	27.7	28.4	27.2	28.0	27.7	28.7	28.7	28.6	28.8	29.4
5	6	28.0	28.6	28.6	27.2	28.2	27.7	28.5	28.8	29.2	29.1	29.0
5	7	28.3	27.7	28.4	28.0	28.0	27.2	28.5	28.3	29.0	29.0	29.5
5	8	28.4	28.2	28.4	27.6	28.1	27.7	28.3	28.2	29.6	29.8	30.0
5	9	28.3	28.0	28.4	27.7	28.1	27.7	28.7	28.2	29.5	29.6	29.9

Table B.9. Sediment elevation measurements at site 9.

arm position	pin	8/18/2002	4/22/2003	8/11/2003	4/8/2004	7/5/2004	4/29/2005	8/17/2005	5/26/2006	7/31/2008	5/17/2010	8/7/2010
4	1	32.6	32.7	31.8	29.6	31.2	31.7	32.7	31.9	33.0	30.5	31.0
4	2	33.3	32.8	32.3	31.2	31.4	31.0	32.5	32.0	33.3	30.6	31.1
4	3	33.0	32.2	33.4	32.1	31.5	31.6	32.4	31.7	32.6	30.6	31.6
4	4	33.2	32.2	33.5	32.6	31.6	32.1	32.5	32.3	32.7	31.0	32.1
4	5	33.3	33.8	33.0	32.4	32.6	33.1	32.7	32.1	33.0	30.8	31.9
4	6	34.0	32.0	32.6	32.1	32.6	33.7	32.7	32.3	33.6	31.3	31.5
4	7	34.0	32.3	32.7	32.1	31.8	33.9	32.8	32.6	33.5	31.2	30.9
4	8	32.9	31.9	32.9	32.0	32.2	33.9	33.7	33.4	33.3	31.3	30.9

4	9	32.8	31.9	32.9	32.6	32.5	33.7	33.7	32.6	32.9	31.0	31.0
3	1	32.7	32.5	32.2	32.3	32.5	30.7	31.7	31.5	32.4	30.0	30.6
3	2	33.0	33.1	32.4	32.8	33.0	31.4	31.8	31.9	32.3	31.0	30.6
3	3	33.1	33.1	32.5	32.3	32.6	32.2	32.3	31.8	32.4	30.9	30.9
3	4	33.6	32.1	32.8	31.9	32.9	32.3	32.7	32.1	32.7	30.8	30.7
3	5	33.7	32.2	32.3	31.9	32.7	32.2	32.9	32.2	32.7	30.5	30.6
3	6	34.0	32.7	33.3	32.1	32.9	32.2	33.3	32.6	33.3	31.1	31.0
3	7	34.5	31.9	33.3	32.0	32.6	32.0	33.7	32.6	32.7	31.1	31.9
3	8	34.6	32.6	32.6	31.9	32.6	32.1	33.7	32.3	31.8	31.9	32.0
3	9	33.2	32.1	32.2	32.7	32.8	32.3	33.5	32.4	32.0	31.5	32.2
2	1	32.7	33.8	32.1	32.2	31.2	31.4	31.4	31.1	33.2	30.5	30.6
2	2	32.5	32.9	32.5	32.0	31.8	31.4	32.0	31.7	33.6	31.2	30.4
2	3	33.3	33.3	33.2	32.2	32.0	32.2	32.9	31.9	33.4	31.4	30.7
2	4	32.8	33.2	33.9	32.5	32.3	32.7	33.1	31.9	33.0	31.3	30.8
2	5	32.5	33.1	34.0	32.4	32.4	33.1	32.5	32.2	32.8	31.2	30.7
2	6	33.4	32.4	33.5	33.1	32.7	33.2	32.6	32.7	33.4	31.5	30.9
2	7	33.1	32.9	33.6	32.8	33.0	32.8	33.9	33.2	33.2	30.6	32.3
2	8	33.0	33.2	33.4	32.8	32.2	32.9	33.8	32.9	32.3	31.5	31.6
2	9	32.5	33.3	33.0	32.2	32.6	33.1	33.8	32.4	33.0	31.2	31.3
1	1	32.6	32.4	30.5	31.7	32.5	31.6	31.9	31.8	32.3	30.5	29.9
1	2	32.9	31.5	30.6	32.7	32.4	32.0	31.7	32.1	32.6	30.5	30.1
1	3	32.6	31.9	31.8	31.9	32.8	32.6	32.4	32.0	32.6	30.5	31.1
1	4	33.0	31.9	32.5	32.8	33.4	33.1	33.2	32.6	32.0	30.5	31.9
1	5	33.4	31.9	33.1	32.6	33.2	33.4	33.0	33.0	32.0	29.4	32.2
1	6	32.9	31.5	32.7	31.7	33.0	33.4	32.7	33.1	32.7	30.4	32.5
1	7	33.2	32.1	32.3	32.2	32.1	33.1	32.4	32.6	31.7	30.6	31.6
1	8	33.8	32.2	32.6	31.8	31.8	33.2	32.4	32.0	31.3	31.3	31.7
1	9	33.2	32.4	33.3	32.2	32.4	32.2	32.2	32.2	31.5	31.3	32.0

Table B.10. Sediment elevation measurements at site 10.

arm position	pin	8/20/2002	4/22/2003	8/11/2003	4/8/2004	7/5/2004	5/24/2005	8/17/2005	5/26/2006	7/31/2008	5/17/2010	8/8/2010
5	1	34.0	32.2	34.2	31.9	32.5	33.4	33.8	32.7	31.3	31.8	31.8
5	2	33.9	32.2	33.2	32.4	32.3	33.6	33.9	32.8	32.6	30.9	31.7
5	3	34.0	32.0	32.4	32.3	33.5	34.2	35.0	32.7	32.3	31.3	32.5
5	4	34.3	32.3	33.1	33.3	33.4	33.9	35.3	33.3	32.2	32.5	31.7
5	5	33.8	33.3	32.8	33.0	33.5	34.3	34.6	33.4	32.2	31.2	31.5

5	6	34.1	32.6	33.4	33.4	33.5	34.2	34.4	33.8	32.2	31.5	31.5
5	7	33.3	32.6	33.2	33.4	33.0	33.4	34.5	33.7	31.9	31.4	32.2
5	8	33.2	32.6	33.4	32.0	32.4	33.0	34.4	33.9	31.8	30.9	32.3
5	9	33.0	32.5	34.2	33.0	33.1	32.3	33.1	33.6	31.7	31.5	31.7
4	1	34.1	32.8	34.1	32.8	33.0	33.2	35.0	32.5	31.6	31.0	30.5
4	2	33.7	33.2	34.7	32.3	32.7	33.2	34.3	32.7	31.4	31.3	31.1
4	3	33.7	33.4	34.6	32.2	33.1	33.3	34.0	32.5	31.7	31.1	31.2
4	4	33.0	33.4	34.7	30.8	33.3	32.8	33.4	33.0	32.4	31.9	31.1
4	5	33.4	33.3	34.1	32.2	33.7	33.6	33.3	32.5	32.0	31.5	32.0
4	6	33.1	33.5	34.0	31.8	33.5	33.4	34.5	33.0	31.8	31.5	32.2
4	7	33.3	33.3	32.7	32.1	34.1	33.5	34.2	32.9	32.2	31.5	32.0
4	8	30.0	30.0	33.1	31.2	33.6	33.6	34.0	33.0	33.3	31.6	32.0
4	9	33.2	32.0	33.9	33.0	33.3	32.7	33.6	32.7	32.5	31.8	31.9
3	1	33.1	33.6	34.7	33.2	33.2	32.8	33.4	32.3	31.2	30.5	30.2
3	2	33.5	33.5	34.3	32.2	32.6	33.3	33.4	33.3	30.4	29.7	32.0
3	3	33.7	33.5	33.8	32.5	33.4	33.6	33.1	33.2	31.3	31.0	31.9
3	4	34.4	32.7	33.5	32.5	33.2	33.2	33.4	33.6	31.9	31.5	32.5
3	5	34.5	33.6	34.1	31.8	33.1	32.9	33.6	33.8	32.0	32.0	31.6
3	6	34.4	33.6	33.8	32.5	33.1	33.3	33.7	32.9	32.8	31.0	32.3
3	7	34.4	33.2	33.6	32.1	32.5	33.2	33.6	33.5	33.5	31.6	31.5
3	8	33.5	33.0	34.3	32.5	32.9	33.0	33.7	33.7	32.9	30.9	32.5
3	9	33.3	33.0	33.7	33.4	33.3	33.0	33.6	34.4	32.3	31.5	31.3
2	1	33.8	32.1	34.2	31.9	33.4	32.5	32.9	33.2	31.5	30.7	31.1
2	2	34.0	31.3	33.9	32.3	33.1	33.1	32.4	33.0	31.3	31.3	30.7
2	3	34.1	31.4	34.3	32.5	32.5	33.5	32.8	33.5	31.2	30.8	31.0
2	4	33.7	33.0	34.3	32.0	32.6	33.4	32.6	33.6	30.8	31.6	31.1
2	5	33.7	33.4	33.8	32.2	33.1	33.0	33.6	32.8	30.1	31.1	30.9
2	6	34.3	32.6	33.9	32.7	32.7	32.9	34.3	32.3	31.8	31.8	31.2
2	7	33.2	32.5	33.4	32.0	31.5	32.9	34.0	32.8	31.4	31.1	31.8
2	8	34.9	33.0	33.8	32.9	32.5	33.1	33.5	32.9	30.8	30.4	31.9
2	9	33.9	33.4	33.7	31.9	33.6	32.6	33.6	32.3	30.2	30.9	32.3

Table B.11. Sediment elevation measurements at site 11.

arm position	pin	8/18/2002	4/18/2003	8/11/2003	4/8/2004	7/5/2004	4/29/2005	8/17/2005	5/26/2006	5/21/2008	5/17/2010	8/8/2010
7	1	29.0	28.9	29.9	28.5	29.4	29.3	30.1	29.0	29.3	28.6	28.8
7	2	30.3	28.8	30.7	28.1	29.9	29.3	29.9	28.5	28.9	29.0	29.2

7	3	30.7	29.5	30.4	28.7	29.6	29.4	29.9	28.6	29.0	29.3	29.2
7	4	31.0	29.6	30.7	30.0	29.3	29.5	30.6	28.6	30.2	29.0	29.1
7	5	30.0	29.3	29.9	29.0	29.0	30.0	30.5	28.7	29.6	29.8	29.0
7	6	31.2	29.5	30.6	27.6	29.8	30.4	30.4	29.5	30.0	29.0	28.9
7	7	29.9	28.7	30.5	28.8	30.2	30.5	29.7	29.6	29.8	28.1	29.4
7	8	30.4	29.0	30.7	29.2	29.6	30.6	30.7	29.8	30.1	29.2	29.3
7	9	30.0	29.0	31.0	29.1	29.0	29.9	30.4	29.7	30.2	29.1	28.6
6	1	30.0	28.8	29.7	28.7	30.4	29.7	30.1	29.8	29.4	28.5	28.6
6	2	29.6	29.6	30.0	28.3	30.2	30.1	30.3	29.7	28.8	28.6	28.8
6	3	29.4	29.7	29.8	28.2	30.5	29.2	30.4	29.3	29.2	28.8	28.1
6	4	29.3	29.7	30.9	28.9	30.0	29.6	30.3	29.6	29.3	28.8	28.7
6	5	29.4	29.5	30.4	29.3	30.3	29.4	30.0	29.4	29.5	28.6	28.9
6	6	29.6	29.7	31.3	28.6	29.9	29.8	30.6	29.6	29.4	28.8	28.5
6	7	29.5	29.1	30.4	28.7	29.6	30.3	30.4	29.6	29.3	28.4	28.8
6	8	29.3	29.4	31.1	28.7	28.9	30.4	30.3	30.0	29.4	29.3	29.0
6	9	29.2	29.9	31.4	28.1	29.6	30.2	30.4	29.7	29.5	28.8	28.6
5	1	30.0	29.8	29.4	29.6	29.5	29.7	31.5	29.9	29.3	28.3	28.0
5	2	30.4	29.8	29.9	29.7	30.5	30.0	31.9	30.1	29.1	27.6	28.1
5	3	29.4	29.6	30.4	28.8	30.0	29.9	31.6	30.3	28.4	27.6	28.4
5	4	29.6	29.6	31.0	29.4	30.0	30.2	31.5	30.6	28.7	28.0	28.8
5	5	29.2	29.6	30.7	29.1	30.0	30.5	31.0	30.1	29.0	28.0	28.6
5	6	29.7	30.0	30.9	28.8	29.6	30.4	31.1	30.0	29.2	28.8	28.4
5	7	29.3	29.8	30.0	28.6	29.6	30.4	31.4	30.5	29.5	28.5	28.7
5	8	29.3	29.8	30.6	28.8	28.9	30.9	31.5	30.5	29.6	28.4	28.1
5	9	29.9	30.1	31.0	28.9	29.3	30.6	31.0	30.6	29.6	28.2	28.5
4	1	30.6	29.8	29.1	29.5	29.6	29.8	31.4	30.4	28.9	28.7	28.2
4	2	30.5	29.4	30.7	29.5	29.7	30.2	30.8	30.4	29.1	28.6	27.8
4	3	30.6	29.4	30.7	29.5	30.3	30.4	30.9	30.3	29.5	29.0	28.6
4	4	30.7	29.8	31.1	29.6	30.4	30.7	31.1	30.7	29.4	29.2	28.4
4	5	30.8	30.0	30.6	29.4	30.1	30.6	31.0	30.8	29.3	29.3	28.8
4	6	30.9	30.2	30.7	29.5	29.6	30.4	31.4	30.9	29.6	29.6	29.4
4	7	30.7	29.5	31.6	29.0	30.2	30.1	31.0	30.2	29.9	29.5	29.6
4	8	30.4	29.6	29.9	28.6	30.2	30.4	31.0	30.0	29.8	29.2	28.9
4	9	30.3	29.9	31.3	29.6	30.4	30.3	31.6	30.4	29.6	29.2	28.0

Table B.12. Sediment elevation measurements at site 12.

arm position	pin	8/20/2002	4/18/2003	8/11/2003	4/8/2004	7/5/2004	4/29/2005	8/17/2005	5/28/2006	7/31/2008	5/17/2010	8/8/2010
7	1	36.0	35.1	36.9	33.9	35.6	35.3	35.0	35.8	34.8	33.1	32.6
7	2	36.4	34.9	37.0	35.4	35.5	34.9	35.0	36.0	33.8	32.0	33.2
7	3	36.3	34.5	37.8	34.9	35.3	35.1	35.2	35.8	34.2	31.8	32.9
7	4	37.0	35.7	37.5	34.4	36.4	36.3	36.2	35.5	35.0	32.9	33.5
7	5	36.7	34.5	36.9	33.7	36.2	36.4	35.7	35.7	34.4	33.5	33.5
7	6	35.4	35.7	37.2	34.6	35.9	36.7	37.1	36.0	34.4	33.4	34.0
7	7	36.1	35.7	35.9	34.5	35.4	35.6	36.4	35.9	34.6	33.4	33.6
7	8	36.4	35.1	37.1	33.4	35.6	34.9	36.3	35.6	34.5	33.3	33.5
7	9	36.2	35.4	37.2	33.2	36.1	36.2	36.7	35.7	34.0	33.4	34.0
6	1	35.5	35.1	36.0	33.7	36.0	36.2	36.5	34.8	34.0	32.8	34.0
6	2	35.6	35.1	36.5	35.0	35.3	36.2	36.6	34.8	34.2	33.5	33.5
6	3	35.9	36.1	37.2	34.8	35.0	35.9	36.7	35.0	34.9	34.2	33.7
6	4	36.3	35.6	35.6	34.7	35.6	36.2	37.3	34.7	35.2	33.9	34.0
6	5	36.5	34.5	35.7	35.0	35.8	36.2	36.4	35.3	34.6	33.1	33.6
6	6	36.0	33.6	35.5	35.4	36.6	36.6	36.5	35.7	34.8	33.0	33.2
6	7	35.5	32.8	34.9	35.3	36.5	34.8	36.9	35.9	33.2	32.9	33.1
6	8	35.1	32.9	35.6	36.1	36.7	36.1	37.1	36.0	34.0	33.4	34.6
6	9	36.2	33.9	36.7	34.2	36.0	35.6	36.3	35.5	34.6	33.9	34.1
5	1	35.7	34.6	36.7	35.5	36.1	35.6	36.6	36.0	34.3	32.8	33.8
5	2	35.8	34.2	37.2	35.6	36.5	35.7	37.0	36.1	34.2	33.9	34.3
5	3	35.7	34.6	37.2	34.6	35.8	35.3	36.4	35.5	34.1	33.8	33.9
5	4	36.1	34.0	36.8	34.8	35.5	34.9	36.4	35.7	34.1	33.3	33.5
5	5	35.4	35.2	36.4	34.4	35.6	35.3	36.3	34.1	34.2	33.5	34.2
5	6	35.6	35.2	36.5	35.4	35.3	35.5	35.6	35.5	34.8	33.7	33.1
5	7	35.7	32.8	35.7	35.0	35.5	35.3	36.5	35.9	34.5	33.8	33.1
5	8	35.8	34.9	36.3	34.8	35.8	36.3	34.5	35.9	34.0	34.0	33.7
5	9	35.1	34.4	35.7	35.6	34.8	35.5	35.8	35.5	34.0	33.4	33.7
4	1	36.0	35.0	36.4	33.9	35.4	34.8	35.8	34.2	34.8	33.0	33.0
4	2	37.0	34.1	35.8	34.3	35.9	34.2	35.5	34.6	34.3	33.1	34.5
4	3	35.9	34.8	35.7	34.9	36.5	33.5	35.4	35.0	34.0	33.0	34.5
4	4	35.7	34.7	36.9	35.2	35.7	34.0	35.4	34.5	34.2	33.2	33.7
4	5	35.7	34.4	37.0	34.8	35.2	34.0	35.6	34.3	34.2	33.4	34.3
4	6	35.8	34.3	36.7	35.2	36.2	34.3	35.7	34.7	34.0	34.1	34.6
4	7	35.8	34.5	36.8	34.1	35.7	34.4	35.3	34.4	34.3	33.2	34.5

4	8	35.8	34.5	36.9	33.7	34.8	35.1	35.3	35.0	34.2	34.5	34.7
4	9	35.9	33.5	36.4	34.0	34.9	35.0	35.2	34.9	34.1	33.6	33.4

Table B.13. Sediment elevation measurements at site 13.

arm position	pin	8/18/2002	4/21/2003	8/7/2003	4/7/2004	7/5/2004	4/27/2005	8/15/2005	5/25/2006	5/21/2008	4/14/2010	8/6/2010
7	1	36.5	36.1	36.5	34.6	36.0	35.1	35.2	33.9	30.5	32.5	32.9
7	2	36.6	36.6	36.7	35.5	35.6	35.3	35.0	34.1	32.0	33.7	33.0
7	3	35.7	36.9	36.6	35.0	35.3	35.0	35.3	34.1	32.3	32.7	33.5
7	4	36.1	36.1	36.7	35.0	34.9	34.3	35.4	34.3	32.6	32.6	34.1
7	5	36.4	37.1	37.3	35.3	34.7	35.3	36.1	34.5	31.9	30.1	34.6
7	6	36.3	36.1	37.2	35.2	35.4	35.1	35.9	34.2	32.0	32.7	34.4
7	7	36.7	36.0	36.8	35.1	36.2	35.1	35.1	34.3	32.4	33.0	34.1
7	8	37.0	36.3	37.3	35.9	35.2	34.5	35.7	34.2	32.7	32.2	33.4
7	9	36.5	36.7	37.0	35.1	36.1	34.8	35.5	34.6	30.6	33.0	32.6
6	1	35.1	35.8	36.3	35.5	35.0	34.2	35.5	34.0	32.7	32.1	32.6
6	2	35.3	35.9	36.0	35.6	35.1	34.9	35.6	33.9	33.3	32.0	32.6
6	3	35.7	35.6	36.3	35.4	35.1	34.7	35.3	33.9	33.6	32.0	33.4
6	4	36.3	34.7	35.7	34.8	34.9	34.9	35.2	34.1	33.7	32.7	33.0
6	5	36.9	35.1	35.7	34.0	35.8	34.9	35.4	34.0	33.4	32.9	33.0
6	6	36.3	36.2	36.8	34.5	36.2	34.5	32.5	34.3	33.6	31.9	32.3
6	7	36.4	35.8	36.7	35.0	35.2	34.6	34.6	34.8	32.8	31.6	33.2
6	8	36.5	35.6	37.0	35.0	35.6	34.7	34.5	34.7	32.8	32.3	33.6
6	9	36.5	34.5	36.9	35.0	35.7	34.6	34.6	34.7	34.0	32.4	33.3
5	1	37.1	35.3	35.7	35.0	34.9	33.9	36.1	34.0	31.6	32.4	31.9
5	2	37.0	35.8	36.5	34.9	35.7	34.2	36.0	34.3	31.4	32.0	33.0
5	3	36.2	35.8	36.5	35.1	34.8	34.8	35.4	34.4	32.0	32.0	33.5
5	4	35.3	35.6	36.3	35.4	35.8	35.6	34.8	34.2	32.4	32.2	33.8
5	5	35.2	35.5	36.5	34.7	36.3	35.7	35.2	34.4	33.3	31.8	32.5
5	6	36.5	35.3	36.3	34.7	35.4	35.6	35.0	34.5	33.4	31.5	31.9
5	7	36.3	36.0	36.2	35.3	35.1	35.3	35.2	34.8	33.2	31.8	32.4
5	8	37.1	35.8	35.9	35.4	35.6	35.2	35.2	34.2	33.3	32.3	33.5
5	9	37.4	34.8	35.5	34.8	36.1	34.8	35.3	34.2	33.3	32.3	32.7
4	1	36.4	34.9	35.7	34.2	35.7	32.6	34.2	33.0	33.1	32.2	32.2
4	2	36.7	35.4	36.2	34.3	35.6	32.1	34.1	33.7	33.2	31.5	32.7
4	3	36.9	35.4	36.2	35.2	35.4	34.3	33.7	34.2	33.1	31.7	32.6
4	4	36.4	35.5	36.1	34.6	34.8	34.3	34.2	34.5	32.6	31.2	33.1

4	5	36.2	35.7	36.4	33.9	34.0	34.3	33.9	34.1	32.4	32.2	32.7
4	6	35.4	36.1	35.6	33.5	34.3	35.1	34.8	34.0	32.4	32.2	32.3
4	7	35.8	35.1	36.0	35.3	34.9	35.0	34.7	34.3	32.5	31.2	31.8
4	8	36.0	35.6	35.8	34.9	34.9	34.0	34.5	34.4	33.4	31.8	32.3
4	9	35.9	35.6	35.8	33.7	35.3	34.6	34.7	34.4	33.0	31.0	31.8

Table B.14. Sediment elevation measurements at site 14.

arm position	pin	8/18/2002	4/21/2003	8/9/2003	4/7/2004	7/5/2004	4/27/2005	8/15/2005	5/25/2006	5/21/2008	6/11/2010	8/7/2010
2	1	33.8	32.5	34.3	32.6	31.9	31.6	33.3	33.3	32.8	31.8	32.0
2	2	32.8	32.1	33.8	33.0	33.2	32.2	33.1	32.6	33.0	31.8	32.9
2	3	33.3	30.0	33.6	32.5	32.1	33.2	33.0	32.5	32.7	32.4	33.5
2	4	33.3	32.1	33.9	32.4	31.9	32.5	32.9	32.4	32.9	32.5	33.1
2	5	33.3	32.4	33.7	32.5	32.2	32.8	32.8	33.2	32.3	32.4	33.5
2	6	32.7	32.6	33.4	32.5	32.2	32.9	32.6	33.3	32.3	31.3	33.2
2	7	34.7	32.4	33.5	32.7	32.0	33.2	33.2	33.2	33.6	32.0	33.2
2	8	34.7	32.7	33.6	32.2	32.5	33.3	33.5	33.1	33.8	31.5	33.2
2	9	33.7	32.5	33.8	33.5	32.0	32.5	32.7	32.6	33.5	31.4	32.6
1	1	33.3	32.2	33.1	32.1	32.6	32.4	34.3	33.2	32.0	32.1	32.3
1	2	33.2	32.9	33.3	32.8	32.3	33.0	34.5	33.4	32.5	31.8	32.6
1	3	33.0	32.5	33.2	33.3	32.2	32.8	33.5	32.6	31.8	31.1	31.3
1	4	33.8	32.8	32.9	33.6	32.5	32.2	32.7	32.8	31.6	31.7	29.9
1	5	33.4	32.4	32.7	32.4	32.1	32.3	32.5	33.2	32.4	32.9	29.9
1	6	33.9	32.4	33.2	32.7	32.1	32.8	33.9	32.4	32.3	33.4	33.2
1	7	34.1	32.7	33.6	33.0	32.5	32.7	33.7	33.4	33.5	33.5	33.2
1	8	33.5	33.0	33.3	33.0	32.9	32.3	34.3	32.5	34.7	33.5	33.4
1	9	33.5	32.5	33.8	32.8	32.3	32.3	34.4	33.2	33.1	33.0	33.7
8	1	33.7	32.2	34.5	33.2	34.1	33.4	34.6	33.7	33.4	33.3	32.4
8	2	33.0	33.2	34.3	33.9	34.7	34.3	34.7	34.1	33.3	33.5	32.9
8	3	34.0	33.2	33.9	33.1	35.0	33.7	34.8	33.8	33.2	33.4	32.9
8	4	33.2	32.8	33.8	33.5	35.1	34.2	33.7	33.4	33.5	33.5	33.3
8	5	33.0	32.8	33.7	34.6	34.0	33.6	33.9	33.8	34.1	33.1	33.1
8	6	33.5	32.5	33.8	34.2	33.2	33.8	33.9	34.3	34.0	32.8	33.4
8	7	33.2	33.7	33.7	33.7	34.5	33.6	34.0	34.0	33.7	33.3	33.2
8	8	33.3	33.2	34.1	34.2	34.3	33.3	34.0	34.0	34.3	33.5	33.6
8	9	34.1	33.1	34.1	34.1	34.0	34.0	34.8	33.7	34.2	33.9	33.5
7	1	33.5	33.1	35.3	33.4	33.2	32.3	33.2	32.9	33.1	33.0	32.2

7	2	33.5	33.4	34.4	33.2	33.1	32.4	32.9	33.5	33.3	33.0	32.5
7	3	34.9	33.0	33.9	33.2	34.0	33.1	32.8	33.2	33.5	32.3	33.0
7	4	34.9	33.2	34.2	34.1	34.3	32.9	33.4	32.8	34.0	32.5	33.2
7	5	34.8	33.4	33.7	33.6	33.7	33.1	33.8	32.7	34.2	32.2	33.9
7	6	34.6	33.5	34.6	33.3	33.5	33.5	34.6	34.4	34.0	33.1	33.2
7	7	34.5	33.6	34.4	33.1	33.7	33.5	34.8	34.1	33.6	33.1	32.8
7	8	35.6	34.1	35.1	33.8	34.0	33.8	34.2	33.9	33.4	33.6	33.0
7	9	35.5	34.5	35.4	33.5	35.0	33.4	33.6	33.3	33.7	33.7	33.2

Table B.15. Sediment elevation measurements at site 15.

arm position	pin	8/18/2002	4/17/2003	8/7/2003	4/7/2004	7/19/2004	4/30/2005	8/15/2005	5/25/2006	8/13/2008	6/10/2010
4	1	27.0	26.8	21.6	24.3	23.2	23.9	24.0	23.2	19.8	15.5
4	2	27.0	26.9	26.3	23.9	23.4	24.2	24.2	23.7	19.3	15.3
4	3	26.5	27.0	26.6	24.2	24.0	24.7	24.6	24.2	19.2	16.0
4	4	26.3	27.3	26.8	24.3	24.3	25.2	25.1	24.5	18.5	14.7
4	5	26.7	27.1	27.0	25.5	24.9	25.6	25.7	25.3	18.7	16.1
4	6	27.0	26.9	27.7	25.0	25.1	25.5	26.2	25.2	18.8	16.4
4	7	26.9	27.1	27.6	25.6	25.5	25.5	26.5	26.3	18.2	15.5
4	8	27.1	27.4	27.4	26.9	26.3	26.1	26.7	26.5	19.4	16.2
4	9	27.0	27.0	27.1	27.0	25.9	26.1	26.7	25.8	19.7	16.2
3	1	25.3	26.2	25.1	23.3	22.9	22.9	24.2	23.9	19.0	14.5
3	2	25.9	26.7	26.1	22.9	22.5	23.8	24.0	24.2	19.2	15.2
3	3	26.6	26.1	26.0	24.5	22.9	24.0	24.3	24.5	19.9	15.8
3	4	26.7	26.6	26.6	24.6	23.6	24.1	24.8	24.3	19.8	16.6
3	5	26.7	26.8	26.5	25.2	24.3	24.3	25.6	24.7	20.1	16.0
3	6	27.0	26.7	27.0	26.6	24.9	25.0	25.6	25.0	20.3	16.8
3	7	26.8	27.4	27.6	27.0	25.7	25.5	25.6	25.3	20.7	17.4
3	8	27.5	27.7	27.8	27.3	26.2	25.7	25.7	25.4	21.4	17.5
3	9	27.3	27.8	27.7	26.9	26.3	25.6	25.5	25.4	21.7	19.1
2	1	27.0	25.0	24.2	23.4	22.5	22.6	23.2	20.9	20.1	12.4
2	2	27.0	24.9	24.4	23.0	22.3	23.0	23.2	21.0	20.2	13.4
2	3	26.2	26.2	25.5	23.7	25.4	24.1	23.2	21.6	20.0	12.1
2	4	27.1	26.4	26.6	25.5	24.2	24.6	23.9	22.5	19.9	13.5
2	5	27.2	27.1	27.0	25.9	24.6	24.7	24.5	23.9	19.6	14.2
2	6	27.0	27.1	27.3	26.9	24.7	24.8	24.6	24.4	20.1	15.0
2	7	27.1	27.5	27.2	27.1	25.0	25.1	25.1	25.2	19.5	16.4

2	8	29.9	27.3	27.6	27.4	25.4	25.7	25.6	25.7	20.2	17.5
2	9	26.2	27.1	28.0	28.1	25.9	26.1	25.8	25.6	20.5	17.5
1	1	26.5	25.5	25.3	23.5	23.9	22.9	23.8	19.9	19.1	14.9
1	2	26.7	25.9	25.9	24.0	24.4	23.3	23.9	20.5	18.2	14.5
1	3	26.5	25.9	26.2	24.5	24.5	23.4	24.4	20.9	18.8	15.0
1	4	26.5	26.2	26.5	24.8	25.2	24.0	24.2	21.5	19.6	15.3
1	5	26.5	26.2	26.3	25.3	26.1	24.6	23.8	22.4	20.5	15.1
1	6	26.3	26.2	26.7	25.2	27.0	25.2	24.1	23.6	20.0	16.0
1	7	26.2	26.3	26.4	25.3	26.9	25.2	24.3	24.5	20.7	17.1
1	8	26.3	26.5	26.4	25.3	27.0	25.3	24.7	24.7	20.6	17.6
1	9	26.5	26.4	26.7	26.8	26.9	25.5	25.0	25.4	20.6	18.9

Table B.16. Sediment elevation measurements at site 16.

arm position	pin	8/18/2002	4/17/2003	8/7/2003	4/7/2004	7/19/2004	5/22/2005	8/15/2005	5/25/2006	8/13/2008	6/10/2010
8	1	31.9	31.5	31.2	29.4	29.6	30.4	30.8	30.5	31.0	26.6
8	2	31.9	31.5	31.4	29.2	29.5	30.8	31.6	31.2	31.6	26.8
8	3	32.3	32.0	31.6	29.5	29.5	31.4	31.7	32.3	31.4	27.0
8	4	32.0	32.0	31.9	30.5	29.3	31.9	32.4	33.5	31.6	28.6
8	5	32.2	31.8	31.6	32.7	31.2	32.6	33.0	34.0	32.3	29.8
8	6	32.0	31.8	31.8	32.7	31.9	34.0	33.8	34.4	32.6	30.5
8	7	31.7	32.1	32.6	33.0	32.5	34.5	34.5	34.2	32.3	30.9
8	8	32.0	31.8	32.4	33.5	33.0	34.1	34.6	34.1	31.9	31.4
8	9	31.6	31.5	31.7	33.4	33.5	34.0	34.7	34.5	32.5	31.2
7	1	31.9	31.5	30.6	30.4	28.6	30.1	30.6	30.6	29.1	26.5
7	2	31.8	32.2	29.9	30.3	29.9	30.8	31.2	31.5	29.4	27.3
7	3	32.1	32.6	30.8	30.9	31.3	31.5	32.0	32.4	29.5	28.0
7	4	32.4	32.7	32.0	31.2	32.1	32.4	32.8	33.3	30.2	28.5
7	5	32.7	32.2	32.4	32.0	31.9	33.0	33.6	33.5	31.8	28.8
7	6	32.3	32.2	32.3	32.4	31.9	33.1	33.6	33.9	32.5	29.1
7	7	32.9	32.3	32.5	31.3	31.2	33.7	34.1	34.4	31.9	29.4
7	8	32.9	31.7	32.8	31.5	30.7	33.4	34.4	34.4	31.8	29.6
7	9	32.8	32.3	32.8	32.2	30.9	33.5	34.5	34.4	31.7	30.1
6	1	32.3	31.9	29.0	31.2	29.9	27.6	29.3	29.5	28.7	23.6
6	2	31.7	31.8	30.5	31.2	29.8	28.2	30.2	29.9	28.3	23.3
6	3	32.0	31.7	31.6	32.2	31.5	29.3	30.9	30.0	29.0	24.4
6	4	32.3	32.7	32.4	32.2	31.7	30.1	30.8	30.5	28.8	25.9

6	5	32.4	32.2	32.3	32.9	32.2	30.7	31.0	30.3	28.8	26.1
6	6	32.7	32.2	33.0	32.2	32.1	32.0	31.3	30.7	29.0	26.1
6	7	32.9	32.7	33.1	32.7	31.7	32.0	31.5	31.2	29.0	26.1
6	8	32.9	32.6	32.9	32.8	32.1	32.3	31.5	31.7	29.0	26.5
6	9	32.9	32.6	32.6	32.8	31.9	32.1	32.3	31.9	29.4	26.6
5	1	31.5	30.8	31.5	30.1	29.9	28.2	28.8	28.5	27.8	23.6
5	2	31.6	30.4	31.5	30.1	29.7	28.1	29.2	29.1	28.1	23.6
5	3	31.8	31.0	31.6	30.1	30.4	27.5	30.0	29.4	28.2	24.3
5	4	32.4	31.1	31.7	30.7	30.4	28.2	30.1	29.7	28.1	24.2
5	5	32.3	31.9	32.3	31.2	31.4	28.9	30.4	30.3	28.0	24.5
5	6	32.5	31.4	32.0	31.3	31.4	29.3	31.0	30.7	28.2	24.0
5	7	32.6	31.6	31.9	31.5	32.0	30.0	30.9	31.2	28.3	19.5
5	8	32.7	31.6	32.3	31.7	32.2	30.5	31.1	30.7	28.4	24.4
5	9	32.8	31.7	32.7	31.9	31.8	30.9	31.6	31.2	28.4	23.9

Table B.17. Sediment elevation measurements at site 17.

arm position	pin	8/21/2002	4/22/2003	8/7/2003	6/4/2004	7/19/2004	7/20/2005	6/14/2006	7/2/2008	5/12/2010	8/9/2010
5	1	30.5	34.1	33.3	30.2	30.9	29.6	28.7	28.0	23.3	25.5
5	2	30.3	34.1	33.5	30.5	32.2	30.2	28.7	27.9	22.9	24.6
5	3	29.8	34.1	33.8	30.9	31.9	30.0	29.1	28.5	22.8	24.1
5	4	30.7	33.9	33.8	31.3	32.5	29.0	29.1	28.3	21.8	24.4
5	5	30.7	34.0	33.2	31.9	33.2	30.4	29.1	28.4	22.2	24.3
5	6	30.5	34.4	33.4	32.2	32.9	29.7	28.9	28.8	23.9	24.7
5	7	30.4	34.9	34.1	32.3	33.5	29.7	29.3	28.6	24.1	24.7
5	8	30.7	34.8	34.0	32.7	33.2	29.8	30.1	27.7	24.4	25.1
5	9	30.3	34.8	34.7	33.7	33.6	30.5	30.4	28.5	24.0	24.5
4	1	30.7	33.9	33.0	31.0	33.5	30.5	27.9	27.8	24.5	26.0
4	2	30.6	33.9	33.7	31.7	33.1	30.4	28.6	28.0	24.7	26.0
4	3	30.2	33.6	33.9	31.8	32.2	31.1	28.6	28.1	25.0	25.7
4	4	30.8	33.5	33.5	32.0	32.0	30.8	29.3	28.5	24.6	24.9
4	5	30.7	32.7	33.3	32.2	31.9	31.8	29.2	27.6	23.9	25.7
4	6	30.9	33.0	33.2	32.6	32.7	32.3	29.7	27.2	24.7	25.8
4	7	31.2	33.5	33.2	33.0	33.4	32.3	29.9	27.8	24.1	25.9
4	8	31.0	33.8	33.4	33.7	34.8	32.1	29.8	28.6	24.6	25.6
4	9	31.1	33.8	32.9	33.5	34.6	31.8	30.1	28.4	24.4	25.8
3	1	37.0	33.1	32.4	31.2	32.7	30.4	28.7	29.6	24.4	25.7

3	2	32.5	33.5	33.1	31.8	32.3	31.6	29.2	29.7	24.5	26.0
3	3	30.5	34.0	33.4	32.7	32.3	32.3	28.9	29.9	24.7	26.1
3	4	31.0	33.9	33.2	32.1	32.4	32.0	29.7	29.7	24.7	26.5
3	5	30.5	33.6	33.4	32.9	33.4	31.2	29.9	29.6	24.9	26.4
3	6	30.6	34.3	33.3	32.4	33.1	31.2	30.2	28.8	24.9	26.3
3	7	30.8	33.9	33.1	32.1	32.7	31.7	30.6	28.5	25.0	26.3
3	8	31.0	34.1	33.5	32.7	32.8	32.3	31.0	24.6	25.1	26.2
3	9	30.6	33.6	33.3	32.5	32.8	31.0	31.3	27.9	24.5	26.5
2	1	30.7	31.9	32.5	31.4	30.4	30.9	30.4	31.1	23.9	24.8
2	2	30.6	32.0	32.4	31.9	30.4	31.0	30.9	31.8	24.6	25.7
2	3	30.2	32.3	32.6	31.5	31.6	31.1	30.8	31.6	24.5	26.2
2	4	29.9	32.5	32.4	31.2	32.2	31.8	30.9	31.9	25.0	26.3
2	5	29.5	32.7	32.1	31.5	31.7	32.1	31.7	32.0	24.7	26.2
2	6	30.4	32.2	32.6	31.4	31.7	32.5	31.1	31.9	24.6	26.1
2	7	30.4	32.3	32.4	31.7	31.9	33.0	31.3	31.6	25.9	25.4
2	8	30.2	32.5	32.0	32.9	32.3	32.9	31.5	32.2	25.8	26.6
2	9	30.1	32.4	32.2	33.4	32.7	32.6	31.9	31.7	25.8	26.4

Table B.18. Sediment elevation measurements at site 18.

arm position	pin	8/21/2002	4/22/2003	8/8/2003	6/4/2004	7/19/2004	7/20/2005	6/14/2006	7/15/2008	5/12/2010	8/9/2010
4	1	35.7	34.0	34.3	32.7	36.5	32.8	33.8	36.3		37.8
4	2	34.1	32.9	34.0	33.3	36.4	34.0	33.8	37.1		37.6
4	3	33.7	33.7	35.3	33.0	36.0	34.7	33.8	37.2		38.0
4	4	33.6	33.6	35.4	32.6	37.0	34.8	33.6	37.1		38.2
4	5	33.0	33.0	34.8	32.6	36.3	34.8	34.3	36.1		38.1
4	6	34.7	34.3	33.7	32.3	35.9	35.2	34.1	36.4		38.1
4	7	34.9	33.8	33.5	32.4	35.6	34.1	34.2	36.8		37.4
4	8	34.3	33.4	33.0	32.9	35.6	35.2	34.3	37.2		37.8
4	9	35.1	33.6	33.0	33.3	32.5	35.7	34.8	37.0		36.8
3	1	36.8	32.3	34.6	33.3	37.4	33.9	31.1	37.4	35.4	38.6
3	2	35.2	31.5	33.8	32.7	37.0	34.4	31.6	37.5	36.5	38.5
3	3	36.5	33.5	33.8	32.5	37.4	35.0	32.2	37.4	36.6	38.7
3	4	36.3	33.3	33.5	32.3	37.9	34.9	32.5	37.6	37.7	38.9
3	5	34.5	33.7	33.3	32.3	37.4	35.4	32.6	37.3	37.5	39.1
3	6	33.6	32.8	33.2	32.5	37.4	34.7	33.2	37.6	37.4	39.2
3	7	33.1	32.0	32.8	32.4	37.4	34.9	33.2	37.7	37.6	38.4

3	8	32.3	32.6	33.0	33.5	39.2	34.2	33.8	37.8	38.8	38.9
3	9	33.0	32.3	33.1	32.8	38.5	34.0	33.4	37.6	37.4	39.3
2	1	36.7	32.6	34.7	32.6	37.1	35.1	32.6	35.9	37.5	36.6
2	2	35.9	32.4	34.5	32.6	37.4	34.8	32.5	36.2	37.0	36.9
2	3	36.3	32.4	34.0	32.9	38.2	34.8	32.5	36.2	36.0	37.1
2	4	36.9	32.6	35.1	33.0	38.4	35.0	32.6	36.9	36.9	36.9
2	5	36.3	35.2	35.2	33.3	37.6	35.7	32.6	37.0	37.4	37.6
2	6	36.5	35.7	34.0	33.3	37.7	35.7	33.3	37.0	38.0	37.5
2	7	36.2	35.4	34.3	32.9	37.0	36.0	33.0	36.6	37.8	37.4
2	8	35.2	31.4	34.4	32.7	37.7	35.8	33.4	37.5	37.9	37.3
2	9	34.4	31.3	33.3	30.0	37.6	35.6	33.1	37.2	36.6	38.0
1	1	35.2	32.4	34.0	32.1	36.7	34.4	32.3	36.6	37.2	39.8
1	2	35.6	32.5	33.2	32.0	37.9	34.5	32.4	37.6	36.6	39.0
1	3	36.1	33.1	33.2	33.3	38.2	35.1	32.5	37.4	36.5	38.3
1	4	36.5	32.8	33.6	33.8	38.9	35.5	32.8	37.6	37.0	38.6
1	5	36.6	32.3	34.2	33.4	37.9	35.5	31.7	36.7	37.6	37.7
1	6	35.7	32.3	34.1	32.6	37.6	35.6	32.1	36.6	35.5	36.6
1	7	35.5	32.0	33.6	32.2	36.5	35.7	31.8	36.9	36.0	35.7
1	8	35.2	31.7	33.8	32.5	38.1	35.7	32.3	36.5	36.3	35.9
1	9	34.8	32.3	34.7	31.3	38.4	35.9	33.1	36.0	35.6	37.0

Table B.19. Sediment elevation measurements at site 4B.

arm position	pin	8/18/2005	6/12/2006	7/2/2008	6/14/2010
8	1	38.3	36.5	44.8	47.7
8	2	38.3	37.9	45.3	48.2
8	3	38.0	39.0	45.3	48.3
8	4	37.7	39.6	45.4	48.6
8	5	37.9	39.5	45.4	48.5
8	6	37.9	39.5	45.2	48.2
8	7	38.4	38.7	45.0	48.4
8	8	38.7	38.4	45.4	48.6
8	9	38.7	38.0	45.2	48.1
1	1	37.8	38.6	43.2	44.6
1	2	38.1	38.1	43.4	45.1
1	3	38.5	38.0	44.3	46.2
1	4	38.1	38.2	45.2	47.1

1	5	37.7	38.9	45.5	47.5
1	6	38.2	39.1	45.9	48.2
1	7	38.2	38.6	45.5	48.5
1	8	37.5	38.3	45.5	49.0
1	9	37.3	38.4	45.9	48.8
2	1	38.0	38.5	44.6	47.5
2	2	37.8	38.4	44.9	48.4
2	3	37.4	37.7	44.6	49.2
2	4	37.2	37.4	44.1	49.4
2	5	37.1	37.3	44.7	48.0
2	6	37.9	38.3	44.6	47.0
2	7	38.4	38.5	44.7	46.8
2	8	38.0	38.3	45.4	47.0
2	9	37.4	37.7	44.1	47.0
3	1	37.7	36.3	45.2	46.1
3	2	38.3	36.4	45.3	46.4
3	3	38.8	36.6	45.2	46.2
3	4	38.6	37.0	45.5	46.4
3	5	38.2	37.8	45.5	46.4
3	6	38.8	38.6	45.7	46.5
3	7	38.6	38.5	45.4	46.3
3	8	38.5	38.1	45.3	47.6
3	9	38.4	38.1	46.5	46.9

Table B.20. Sediment elevation measurements at site 5B.

arm position	pin	8/18/2005	6/12/2006	7/2/2008	6/14/2010
1	1	37.0	37.2	37.4	37.1
1	2	36.5	38.1	36.7	37.9
1	3	36.5	38.0	37.0	37.8
1	4	37.1	36.5	37.2	38.9
1	5	37.7	36.5	37.6	38.4
1	6	38.2	37.1	35.9	38.1
1	7	37.9	37.9	38.2	38.3
1	8	37.7	37.7	37.3	39.4
1	9	37.6	38.4	37.1	39.2
2	1	37.6	37.8	36.5	38.1

2	2	38.7	38.2	36.7	38.1
2	3	37.6	38.2	36.3	38.5
2	4	37.8	37.8	37.2	38.9
2	5	38.2	38.3	37.2	38.4
2	6	38.6	39.0	37.2	39.4
2	7	38.5	39.5	37.1	39.4
2	8	38.8	39.5	36.9	39.2
2	9	39.0	38.8	37.8	39.1
3	1	37.3	37.5	36.9	36.8
3	2	38.0	37.8	36.7	37.4
3	3	38.2	37.4	36.8	37.9
3	4	38.1	37.9	36.8	38.1
3	5	38.4	38.8	37.3	37.0
3	6	38.3	38.6	37.8	37.5
3	7	38.2	37.2	38.3	37.1
3	8	37.9	38.0	37.9	36.9
3	9	38.0	38.3	37.9	36.3
4	1	37.5	37.6	38.4	38.8
4	2	38.0	38.8	38.0	38.9
4	3	38.7	38.6	37.6	38.8
4	4	39.3	38.8	37.9	38.8
4	5	39.6	39.2	37.7	38.4
4	6	39.0	38.8	38.0	38.6
4	7	39.1	38.2	37.0	38.5
4	8	40.0	37.9	38.6	38.7
4	9	39.5	36.9	38.6	37.8

Table B.21. Sediment elevation measurements at site 12B.

arm position	pin	8/27/2004	7/21/2005	6/12/2006	7/2/2008	6/14/2010
2	1	37.3	38.7	37.8	38.5	37.3
2	2	36.9	38.4	38.5	38.8	38.4
2	3	36.7	39.1	38.1	38.9	38.4
2	4	36.7	38.4	38.7	38.6	37.8
2	5	37.0	38.0	38.9	39.3	38.2
2	6	37.1	37.7	39.1	38.3	37.9
2	7	36.5	38.4	39.0	38.7	38.6

2	8	35.5	38.3	38.9	38.4	38.1
2	9	36.1	38.0	39.4	38.8	37.6
3	1	38.0	38.1	38.1	38.7	38.8
3	2	37.8	37.5	38.3	39.0	38.2
3	3	36.5	37.9	38.7	38.4	38.3
3	4	37.9	37.7	39.2	39.5	38.6
3	5	36.9	38.8	39.3	39.2	38.6
3	6	35.9	39.2	39.3	39.3	38.9
3	7	36.5	39.4	39.0	38.8	39.4
3	8	35.8	39.8	39.0	38.9	38.8
3	9	36.3	39.7	39.3	39.6	38.5
4	1	37.7	39.0	37.7	37.9	37.2
4	2	36.5	38.9	38.6	37.7	37.5
4	3	37.1	38.8	38.3	37.7	37.5
4	4	37.6	38.5	38.3	37.9	37.5
4	5	37.0	39.7	38.3	38.2	38.3
4	6	36.8	39.1	38.1	38.4	38.4
4	7	36.5	37.9	38.1	37.2	38.5
4	8	36.6	38.0	38.2	37.6	39.2
4	9	37.0	37.9	37.9	37.5	38.4
5	1	37.3	37.2	38.7	37.7	37.7
5	2	37.4	37.6	38.7	38.4	38.0
5	3	38.2	38.3	38.6	37.8	39.2
5	4	37.2	39.0	38.8	38.5	39.2
5	5	38.3	39.1	38.5	38.3	38.2
5	6	37.9	38.7	38.5	40.4	39.3
5	7	37.6	39.2	39.2	39.0	38.4
5	8	37.1	39.4	39.1	39.7	38.5
5	9	38.3	39.2	39.0	38.4	38.6

Table B.22. Sediment elevation measurements at site 14B.

arm position	pin	8/27/2004	7/20/2005	6/12/2006	7/2/2008	5/14/2010	8/9/2010
5	1	39.2	43.1	42.2	42.8	41.4	41.9
5	2	40.0	43.5	42.4	42.5	41.4	42.7
5	3	40.4	43.4	43.6	41.2	41.1	42.5
5	4	38.9	43.6	43.9	40.9	42.5	43.2

5	5	40.1	44.1	43.6	41.4	41.2	42.5
5	6	40.6	43.9	44.2	43.1	41.6	42.2
5	7	41.3	43.8	44.7	43.5	41.5	42.1
5	8	38.8	43.2	43.8	44.4	41.9	42.3
5	9	41.7	42.6	41.9	43.2	42.0	42.7
6	1	40.5	42.0	43.6	42.9	41.3	41.6
6	2	39.8	42.6	43.8	42.5	40.7	42.2
6	3	40.4	42.4	43.4	42.7	41.4	41.6
6	4	40.0	43.3	43.5	43.0	41.7	41.8
6	5	40.6	43.2	43.3	43.0	42.2	41.9
6	6	40.4	43.2	42.9	42.6	42.2	42.3
6	7	41.5	42.9	43.0	43.2	41.7	42.9
6	8	41.4	42.9	43.4	42.5	41.7	42.2
6	9	40.5	43.8	42.5	43.8	42.0	41.4
7	1	40.3	42.5	41.3	41.2	42.5	42.7
7	2	39.6	41.9	41.7	41.0	42.4	42.2
7	3	39.5	42.3	41.3	41.7	42.6	41.3
7	4	39.3	42.1	41.1	43.0	43.1	43.0
7	5	39.1	42.4	40.7	42.3	42.6	42.9
7	6	39.5	42.6	43.3	41.9	42.2	43.3
7	7	40.7	42.0	43.1	41.9	42.5	42.5
7	8	39.7	42.8	41.8	41.7	42.4	42.6
7	9	40.3	42.7	40.9	41.6	42.4	42.3
8	1	38.7	40.5	41.7	42.0	42.1	43.4
8	2	37.3	40.2	41.7	42.5	42.1	43.3
8	3	38.2	40.6	41.8	42.4	42.6	43.2
8	4	37.7	39.8	42.2	42.3	43.2	43.4
8	5	39.2	39.5	43.0	41.7	42.4	43.5
8	6	39.1	39.8	43.5	42.1	41.2	42.9
8	7	39.0	39.8	44.4	42.2	39.5	41.7
8	8	39.3	40.4	44.7	43.1	42.6	42.9
8	9	40.2	41.3	44.2	43.0	43.0	43.4

Table B.23. Sediment elevation measurements at site 16B.

arm position	pin	8/27/2004	7/20/2005	6/12/2006	7/2/2008	5/14/2010	8/9/2010
4	1	36.9	35.8	31.2	32.0	28.3	29.1

4	2	38.5	35.3	31.4	31.8	28.4	28.8
4	3	39.1	35.4	32.2	31.1	29.1	29.2
4	4	39.4	35.7	32.1	31.4	29.0	29.6
4	5	38.7	36.2	31.8	32.1	28.4	29.4
4	6	39.7	36.4	32.5	32.1	29.0	30.1
4	7	39.2	36.7	33.0	32.1	28.5	29.1
4	8	38.2	37.5	33.8	32.4	29.5	29.1
4	9	39.1	37.4	34.1	32.0	29.7	29.5
5	1	38.0	35.7	33.1	31.3	29.7	31.1
5	2	37.0	36.0	33.2	31.6	29.2	33.8
5	3	36.7	36.6	33.4	31.8	30.1	33.6
5	4	35.9	37.4	33.8	31.7	31.4	33.2
5	5	35.0	37.8	34.1	32.4	31.4	31.2
5	6	36.6	38.4	33.8	32.6	31.8	32.5
5	7	37.8	38.7	34.2	33.3	32.3	33.6
5	8	38.2	39.0	34.2	33.7	33.0	34.2
5	9	37.0	38.5	33.7	33.6	32.7	33.3
6	1	37.6	34.7	33.6	33.3	31.1	31.2
6	2	37.6	36.2	33.9	33.7	32.0	33.7
6	3	36.9	37.4	33.8	34.6	32.0	33.9
6	4	37.1	37.1	35.7	34.4	31.9	34.3
6	5	37.0	37.6	35.5	35.4	31.6	33.9
6	6	37.5	38.0	36.2	36.1	32.4	33.6
6	7	36.7	36.7	36.7	36.4	31.9	32.9
6	8	37.2	36.8	36.7	36.3	32.9	32.7
6	9	37.2	37.4	36.8	36.0	32.2	33.0
7	1	37.6	35.7	31.8	30.7	30.6	30.2
7	2	37.1	35.7	32.1	32.0	31.2	32.8
7	3	38.5	36.2	31.9	32.3	32.0	34.2
7	4	38.8	36.3	32.7	32.9	31.8	34.6
7	5	39.1	36.0	33.6	33.8	31.8	33.2
7	6	39.4	36.0	33.8	34.2	31.5	33.5
7	7	38.2	35.5	33.3	33.9	31.6	33.7
7	8	38.3	35.7	33.5	34.9	31.8	33.3
7	9	38.2	35.5	34.5	35.3	32.1	32.9

Appendix C. Sediment core data.

Table C.1. Sediment characteristics at site 1.

section	Bulk Density (g/cm³)	% Mineral matter by weight	% Organic matter by weight	% Volume mineral matter	% Volume organic matter	% Volume pore space
0-2	1.16	98.08	1.92	43.48	1.95	54.57
2-4	1.25	97.97	2.03	46.58	2.22	51.21
4-6	1.29	98.45	1.55	48.54	1.75	49.71
6-8	1.39	98.54	1.46	52.29	1.78	45.92
8-10	1.47	98.64	1.36	55.38	1.75	42.87
10-12	1.37	98.73	1.27	51.49	1.52	46.99
12-14	1.39	98.45	1.55	52.11	1.89	46.00
14-16	1.45	98.27	1.73	54.54	2.20	43.26
16-18	1.34	97.82	2.18	50.01	2.56	47.43
18-20	1.24	97.37	2.63	46.14	2.87	50.99
20-22	1.33	97.83	2.17	49.84	2.54	47.62
22-24	1.40	98.71	1.29	52.70	1.58	45.72
24-26	1.42	98.90	1.10	53.69	1.38	44.93
26-28	1.65	98.56	1.44	61.91	2.07	36.02
28-30	1.27	97.95	2.05	47.65	2.29	50.06
30-32	1.32	98.24	1.76	49.39	2.03	48.58

Table C.2. Sediment characteristics at site 2.

section	Bulk Density (g/cm³)	% Mineral matter by weight	% Organic matter by weight	% Volume mineral matter	% Volume organic matter	% Volume pore space
0-2	0.66	98.05	1.95	24.54	1.12	74.34
2-4	1.29	97.63	2.37	48.05	2.68	49.27
4-6	1.51	98.75	1.25	56.83	1.65	41.51
6-8	1.42	98.76	1.24	53.54	1.54	44.91
8-10	1.47	98.98	1.02	55.51	1.31	43.17
10-12	1.63	98.95	1.05	61.50	1.49	37.01
12-14	1.58	98.96	1.04	59.67	1.44	38.89
14-16	1.56	98.92	1.08	58.92	1.48	39.60
16-18	1.43	98.63	1.37	53.84	1.72	44.44
18-20	1.50	98.92	1.08	56.45	1.42	42.13
20-22	1.47	98.93	1.07	55.68	1.39	42.94
22-24	1.53	98.71	1.29	57.63	1.73	40.64
24-26	1.52	98.83	1.17	57.45	1.57	40.98
26-28	1.56	98.82	1.18	58.67	1.61	39.72
28-30	1.63	98.68	1.32	61.36	1.88	36.77
30-32	1.54	98.49	1.51	58.00	2.04	39.96

Table C.3. Sediment characteristics at site 3.

section	Bulk Density (g/cm³)	% Mineral matter by weight	% Organic matter by weight	% Volume mineral matter	% Volume organic matter	% Volume pore space
0-2	1.16	98.37	1.63	43.55	1.65	54.80
2-4	1.34	98.40	1.60	50.21	1.88	47.91
4-6	1.35	98.36	1.64	50.66	1.94	47.40
6-8	1.35	98.51	1.49	50.68	1.76	47.56
8-10	1.44	98.26	1.74	54.06	2.20	43.75
10-12	1.39	98.06	1.94	52.03	2.37	45.60
12-14	1.33	98.31	1.69	49.74	1.97	48.29
14-16	1.41	98.49	1.51	53.15	1.88	44.97
16-18	1.25	97.81	2.19	46.75	2.41	50.84
18-20	1.34	97.79	2.21	49.95	2.60	47.45
20-22	1.35	98.28	1.72	50.73	2.04	47.23
22-24	1.18	98.21	1.79	44.07	1.85	54.08
24-26	1.19	97.90	2.10	44.59	2.20	53.21
26-28	1.21	97.23	2.77	44.93	2.95	52.12
28-30	1.21	98.24	1.76	45.25	1.87	52.88
30-32	1.40	98.02	1.98	52.41	2.44	45.15

Table C.4. Sediment characteristics at site 4.

section	Bulk Density (g/cm³)	% Mineral matter by weight	% Organic matter by weight	% Volume mineral matter	% Volume organic matter	% Volume pore space
0-2	1.18	98.06	1.94	44.21	2.01	53.79
2-4	1.09	97.88	2.12	40.81	2.03	57.15
4-6	1.12	98.21	1.79	42.06	1.76	56.18
6-8	1.13	98.24	1.76	42.30	1.75	55.95
8-10	1.38	98.72	1.28	52.06	1.55	46.40
10-12	1.41	98.71	1.29	53.06	1.60	45.34
12-14	1.37	98.66	1.34	51.69	1.61	46.70
14-16	1.50	98.68	1.32	56.45	1.74	41.81
16-18	1.40	98.61	1.39	52.66	1.71	45.63
18-20	1.57	98.63	1.37	59.16	1.89	38.95
20-22	1.51	98.71	1.29	56.99	1.71	41.30
22-24	1.61	98.67	1.33	60.68	1.88	37.44
24-26	1.47	98.68	1.32	55.41	1.70	42.89
26-28	1.57	98.56	1.44	59.04	1.99	38.97
28-30	1.47	98.60	1.40	55.35	1.81	42.85
30-32	1.38	98.84	1.16	52.18	1.41	46.41

Table C.5. Sediment characteristics at site 5.

section	Bulk Density (g/cm³)	% Mineral matter by weight	% Organic matter by weight	% Volume mineral matter	% Volume organic matter	% Volume pore space
0-2	0.86	97.87	2.13	32.13	1.61	66.26
2-4	1.20	98.23	1.77	44.99	1.86	53.15
4-6	1.26	97.93	2.07	47.11	2.29	50.61
6-8	1.29	98.05	1.95	48.44	2.22	49.34
8-10	1.35	98.27	1.73	50.56	2.04	47.40
10-12	1.57	98.49	1.51	59.13	2.09	38.78
12-14	1.32	98.42	1.58	49.68	1.84	48.48
14-16	1.52	98.56	1.44	57.29	1.93	40.79
16-18	1.60	98.53	1.47	60.18	2.06	37.75
18-20	1.49	98.13	1.87	55.98	2.45	41.57
20-22	1.56	98.36	1.64	58.48	2.25	39.28
22-24	1.34	97.44	2.56	49.94	3.02	47.04
24-26	1.46	98.02	1.98	54.79	2.55	42.66
26-28	1.51	98.40	1.60	56.73	2.12	41.15
28-30	1.58	98.22	1.78	59.16	2.46	38.38
30-32	1.52	98.67	1.33	57.06	1.76	41.17

Table C.6. Sediment characteristics at site 6.

section	Bulk Density (g/cm³)	% Mineral matter by weight	% Organic matter by weight	% Volume mineral matter	% Volume organic matter	% Volume pore space
0-2	0.98	97.32	2.68	36.25	2.29	61.46
2-4	1.22	98.33	1.67	45.96	1.79	52.24
4-6	1.34	98.78	1.22	50.44	1.44	48.12
6-8	1.47	98.76	1.24	55.28	1.59	43.13
8-10	1.38	98.72	1.28	51.86	1.54	46.60
10-12	1.37	99.02	0.98	51.90	1.18	46.92
12-14	1.66	99.10	0.90	62.73	1.31	35.95
14-16	1.59	99.03	0.97	60.10	1.36	38.54
16-18	1.57	98.87	1.13	59.27	1.55	39.17
18-20	1.57	98.93	1.07	59.13	1.47	39.40
20-22	1.66	98.98	1.02	62.52	1.48	36.00
22-24	1.56	98.89	1.11	58.87	1.52	39.60
24-26	1.57	98.85	1.15	59.11	1.59	39.31
26-28	1.60	98.97	1.03	60.62	1.45	37.93
28-30	1.61	99.03	0.97	60.85	1.37	37.78
30-32	1.65	98.94	1.06	62.45	1.54	36.01

Table C.7. Sediment characteristics at site 7.

section	Bulk Density (g/cm³)	% Mineral matter by weight	% Organic matter by weight	% Volume mineral matter	% Volume organic matter	% Volume pore space
0-2	1.26	98.25	1.75	47.31	1.93	50.76
2-4	1.25	98.45	1.55	46.97	1.70	51.33
4-6	1.23	98.36	1.64	46.11	1.77	52.12
6-8	1.24	98.61	1.39	46.69	1.51	51.80
8-10	1.44	98.91	1.09	54.43	1.38	44.19
10-12	1.32	98.70	1.30	49.81	1.51	48.68
12-14	1.50	98.78	1.22	56.44	1.60	41.96
14-16	1.52	98.57	1.43	57.36	1.91	40.73
16-18	1.47	98.67	1.33	55.48	1.72	42.80
18-20	1.59	98.55	1.45	59.87	2.02	38.11
20-22	1.63	98.67	1.33	61.32	1.91	36.77
22-24	1.38	98.48	1.52	51.77	1.84	46.39
24-26	1.44	98.73	1.27	54.11	1.60	44.29
26-28	1.52	98.48	1.52	57.23	2.03	40.73
28-30	1.38	98.71	1.29	51.90	1.56	46.54
30-32	1.39	98.47	1.53	52.22	1.87	45.91

Table C.8. Sediment characteristics at site 8, sample 1.

section	Bulk Density (g/cm³)	% Mineral matter by weight	% Organic matter by weight	% Volume mineral matter	% Volume organic matter	% Volume pore space
0-2	1.03	97.61	2.39	38.35	2.16	59.49
2-4	1.19	97.44	2.56	44.09	2.66	53.26
4-6	1.22	97.60	2.40	45.26	2.56	52.18
6-8	1.19	97.67	2.33	44.22	2.43	53.35
8-10	1.30	97.85	2.15	48.36	2.45	49.19
10-12	1.36	97.98	2.02	50.82	2.41	46.77
12-14	1.28	97.35	2.65	47.72	2.99	49.29
14-16	1.47	98.04	1.96	55.16	2.53	42.30
16-18	1.42	98.08	1.92	53.18	2.40	44.42
18-20	1.51	98.41	1.59	56.84	2.11	41.05
20-22	1.35	98.43	1.57	50.83	1.86	47.31
22-24	1.45	98.48	1.52	54.54	1.94	43.52
24-26	1.42	98.64	1.36	53.41	1.70	44.89
26-28	1.30	98.15	1.85	48.60	2.11	49.29
28-30	1.38	98.17	1.83	51.56	2.21	46.24
30-32	1.45	98.22	1.78	54.43	2.26	43.30

Table C.9. Sediment characteristics at site 8, sample 2.

section	Bulk Density (g/cm³)	% Mineral matter by weight	% Organic matter by weight	% Volume mineral matter	% Volume organic matter	% Volume pore space
0-2	0.86	96.74	3.26	31.67	2.46	65.87
2-4	1.20	97.97	2.03	44.95	2.14	52.90
4-6	1.33	98.21	1.79	49.93	2.09	47.98
6-8	1.30	98.29	1.71	48.76	1.94	49.30
8-10	1.39	98.06	1.94	51.91	2.37	45.72
10-12	1.38	98.14	1.86	51.84	2.26	45.90
12-14	1.40	98.24	1.76	52.41	2.16	45.43
14-16	1.43	98.35	1.65	53.82	2.07	44.10
16-18	1.52	98.37	1.63	57.10	2.18	40.72
18-20	1.50	98.25	1.75	56.30	2.30	41.40
20-22	1.50	98.76	1.24	56.48	1.62	41.90
22-24	1.55	98.60	1.40	58.37	1.90	39.73
24-26	1.55	99.02	0.98	58.45	1.33	40.22
26-28	1.55	99.02	0.98	58.51	1.33	40.15
28-30	1.55	98.82	1.18	58.37	1.61	40.03
30-32	1.50	98.47	1.53	56.54	2.02	41.44

Table C.10. Sediment characteristics at site 8, sample 3.

section	Bulk Density (g/cm³)	% Mineral matter by weight	% Organic matter by weight	% Volume mineral matter	% Volume organic matter	% Volume pore space
0-2	0.38	94.92	5.08	13.66	1.68	84.66
2-4	1.01	97.74	2.26	37.50	1.99	60.51
4-6	1.26	97.99	2.01	47.28	2.23	50.48
6-8	1.35	98.49	1.51	50.59	1.78	47.63
8-10	1.39	98.42	1.58	52.03	1.92	46.05
10-12	1.36	98.21	1.79	50.85	2.13	47.02
12-14	1.37	98.20	1.80	51.51	2.17	46.33
14-16	1.44	98.22	1.78	53.88	2.24	43.88
16-18	1.43	98.33	1.67	53.75	2.10	44.15
18-20	1.42	98.51	1.49	53.45	1.86	44.69
20-22	1.49	98.52	1.48	55.99	1.93	42.07
22-24	1.47	98.55	1.45	55.32	1.87	42.82
24-26	1.50	98.45	1.55	56.24	2.04	41.72
26-28	1.55	98.54	1.46	58.22	1.98	39.80
28-30	1.65	98.62	1.38	62.00	1.99	36.01
30-32	1.50	98.56	1.44	56.38	1.89	41.73

Table C.11. Sediment characteristics at site 9.

section	Bulk Density (g/cm³)	% Mineral matter by weight	% Organic matter by weight	% Volume mineral matter	% Volume organic matter	% Volume pore space
0-2	1.18	97.79	2.21	44.05	2.29	53.67
2-4	1.37	97.94	2.06	51.14	2.47	46.39
4-6	1.45	98.59	1.41	54.38	1.78	43.83
6-8	1.53	98.71	1.29	57.59	1.73	40.69
8-10	1.43	98.93	1.07	53.99	1.34	44.67
10-12	1.39	98.87	1.13	52.55	1.38	46.07
12-14	1.54	97.96	2.04	57.59	2.75	39.66
14-16	1.55	98.38	1.62	58.28	2.20	39.52
16-18	1.51	98.73	1.27	57.01	1.69	41.30
18-20	1.58	98.88	1.12	59.74	1.56	38.70
20-22	1.53	98.96	1.04	57.94	1.40	40.65
22-24	1.62	98.85	1.15	61.14	1.64	37.22
24-26	1.56	98.98	1.02	58.79	1.39	39.82
26-28	1.53	98.94	1.06	57.80	1.42	40.78
28-30	1.44	98.30	1.70	54.09	2.15	43.76
30-32	1.59	98.68	1.32	59.74	1.84	38.42

Table C.12. Sediment characteristics at site 10.

section	Bulk Density (g/cm³)	% Mineral matter by weight	% Organic matter by weight	% Volume mineral matter	% Volume organic matter	% Volume pore space
0-2	0.75	97.07	2.93	27.85	1.93	70.21
2-4	1.24	97.58	2.42	46.04	2.62	51.34
4-6	1.29	98.29	1.71	48.39	1.94	49.67
6-8	1.34	99.01	0.99	50.56	1.16	48.28
8-10	1.61	98.98	1.02	60.83	1.44	37.73
10-12	1.42	99.14	0.86	53.61	1.07	45.31
12-14	1.53	99.05	0.95	57.75	1.27	40.98
14-16	1.48	98.78	1.22	55.92	1.58	42.50
16-18	1.62	98.91	1.09	61.21	1.55	37.24
18-20	1.50	98.76	1.24	56.39	1.63	41.98
20-22	1.54	98.79	1.21	58.15	1.63	40.22
22-24	1.61	98.69	1.31	60.48	1.85	37.67
24-26	1.72	98.72	1.28	64.86	1.93	33.21
26-28	1.83	98.88	1.12	69.06	1.79	29.15
28-30	1.67	98.91	1.09	63.03	1.60	35.37
30-32	1.38	99.00	1.00	52.11	1.21	46.68

Table C.13. Sediment characteristics at site 11.

section	Bulk Density (g/cm³)	% Mineral matter by weight	% Organic matter by weight	% Volume mineral matter	% Volume organic matter	% Volume pore space
0-2	0.92	97.20	2.80	34.06	2.26	63.68
2-4	0.99	97.37	2.63	36.77	2.28	60.95
4-6	1.09	97.87	2.13	40.70	2.04	57.27
6-8	1.36	98.23	1.77	50.83	2.11	47.06
8-10	1.28	98.43	1.57	48.02	1.76	50.21
10-12	1.53	98.39	1.61	57.54	2.17	40.29
12-14	1.46	98.33	1.67	54.65	2.13	43.22
14-16	1.39	98.37	1.63	52.11	1.99	45.90
16-18	1.47	98.34	1.66	55.34	2.15	42.51
18-20	1.53	98.48	1.52	57.43	2.04	40.53
20-22	1.52	98.55	1.45	57.20	1.94	40.86
22-24	1.56	98.76	1.24	58.82	1.70	39.48
24-26	1.42	98.72	1.28	53.67	1.60	44.73
26-28	1.54	98.41	1.59	57.70	2.14	40.16
28-30	1.64	98.76	1.24	61.71	1.78	36.51
30-32	1.67	98.72	1.28	62.89	1.88	35.23

Table C.14. Sediment characteristics at site 12.

section	Bulk Density (g/cm³)	% Mineral matter by weight	% Organic matter by weight	% Volume mineral matter	% Volume organic matter	% Volume pore space
0-2	0.82	97.21	2.79	30.40	2.01	67.59
2-4	1.16	98.18	1.82	43.63	1.86	54.51
4-6	1.32	98.56	1.44	49.55	1.67	48.78
6-8	1.58	98.93	1.07	59.83	1.49	38.68
8-10	1.48	99.07	0.93	56.07	1.21	42.72
10-12	1.36	99.00	1.00	51.20	1.19	47.61
12-14	1.55	99.15	0.85	58.59	1.16	40.25
14-16	1.65	99.27	0.73	62.70	1.06	36.24
16-18	1.59	98.88	1.12	59.85	1.56	38.59
18-20	1.63	99.21	0.79	61.66	1.13	37.21
20-22	1.59	98.86	1.14	59.86	1.59	38.55
22-24	1.60	98.87	1.13	60.45	1.59	37.96
24-26	1.56	98.68	1.32	58.59	1.81	39.61
26-28	1.74	98.94	1.06	65.83	1.62	32.55
28-30	1.57	98.85	1.15	59.11	1.58	39.31
30-32	1.71	98.81	1.19	64.53	1.79	33.68

Table C.15. Sediment characteristics at site 13.

section	Bulk Density (g/cm³)	% Mineral matter by weight	% Organic matter by weight	% Volume mineral matter	% Volume organic matter	% Volume pore space
0-2	0.94	96.69	3.31	34.86	2.74	62.40
2-4	1.23	97.64	2.36	45.99	2.56	51.46
4-6	1.22	97.72	2.28	45.54	2.44	52.02
6-8	1.42	98.49	1.51	53.56	1.89	44.55
8-10	1.48	98.50	1.50	55.81	1.95	42.24
10-12	1.56	98.55	1.45	58.79	1.99	39.22
12-14	1.37	98.55	1.45	51.53	1.74	46.73
14-16	1.66	98.68	1.32	62.50	1.92	35.59
16-18	1.51	98.68	1.32	56.81	1.74	41.44
18-20	1.62	98.57	1.43	60.83	2.02	37.15
20-22	1.54	98.78	1.22	58.02	1.65	40.33
22-24	1.29	98.69	1.31	48.68	1.48	49.84
24-26	1.42	98.43	1.57	53.28	1.96	44.76
26-28	1.47	98.79	1.21	55.37	1.56	43.08
28-30	1.46	98.56	1.44	55.02	1.84	43.13
30-32	1.45	98.37	1.63	54.30	2.07	43.63

Table C.16. Sediment characteristics at site 14.

section	Bulk Density (g/cm³)	% Mineral matter by weight	% Organic matter by weight	% Volume mineral matter	% Volume organic matter	% Volume pore space
0-2	0.85	96.91	3.09	31.37	2.30	66.33
2-4	1.09	96.93	3.07	40.16	2.92	56.92
4-6	1.08	97.06	2.94	40.15	2.80	57.05
6-8	1.09	97.58	2.42	40.66	2.32	57.02
8-10	1.46	98.35	1.65	54.69	2.11	43.20
10-12	1.48	98.18	1.82	55.63	2.37	42.00
12-14	1.53	98.62	1.38	57.70	1.85	40.45
14-16	1.54	98.39	1.61	57.95	2.18	39.87
16-18	1.42	98.47	1.53	53.36	1.90	44.73
18-20	1.54	98.53	1.47	58.01	1.99	40.00
20-22	1.41	98.24	1.76	52.69	2.17	45.14
22-24	1.38	98.04	1.96	51.77	2.38	45.85
24-26	1.50	98.34	1.66	56.43	2.19	41.37
26-28	1.44	98.56	1.44	54.01	1.81	44.18
28-30	1.52	98.36	1.64	57.09	2.19	40.72
30-32	1.50	98.30	1.70	56.18	2.23	41.59

Table C.17. Sediment characteristics at site 15.

section	Bulk Density (g/cm³)	% Mineral matter by weight	% Organic matter by weight	% Volume mineral matter	% Volume organic matter	% Volume pore space
0-2	0.63	95.05	4.95	22.92	2.74	74.33
2-4	0.82	95.68	4.32	29.98	3.11	66.91
4-6	0.94	96.22	3.78	34.44	3.11	62.46
6-8	1.01	96.47	3.53	37.05	3.11	59.84
8-10	1.08	96.62	3.38	39.97	3.21	56.82
10-12	1.05	96.65	3.35	38.83	3.10	58.07
12-14	1.25	96.86	3.14	46.28	3.45	50.27
14-16	1.20	96.94	3.06	44.53	3.23	52.24
16-18	1.17	96.91	3.09	43.21	3.16	53.63
18-20	1.15	96.97	3.03	42.39	3.05	54.56
20-22	1.10	97.21	2.79	40.66	2.69	56.66
22-24	1.09	96.85	3.15	40.30	3.01	56.68
24-26	1.00	97.27	2.73	37.10	2.40	60.50
26-28	1.00	97.10	2.90	37.16	2.55	60.29
28-30	1.00	96.97	3.03	37.05	2.66	60.29
30-32	1.03	97.29	2.71	38.29	2.45	59.26

Table C.18. Sediment characteristics at site 16.

section	Bulk Density (g/cm³)	% Mineral matter by weight	% Organic matter by weight	% Volume mineral matter	% Volume organic matter	% Volume pore space
0-2	0.81	96.11	3.89	29.73	2.77	67.50
2-4	0.91	96.60	3.40	33.42	2.71	63.87
4-6	0.86	96.54	3.46	31.72	2.61	65.67
6-8	0.98	96.52	3.48	36.06	2.99	60.95
8-10	1.01	96.63	3.37	37.26	2.98	59.75
10-12	1.00	96.50	3.50	36.66	3.05	60.29
12-14	0.99	96.62	3.38	36.65	2.95	60.41
14-16	1.12	96.93	3.07	41.31	3.01	55.67
16-18	1.08	96.97	3.03	39.94	2.87	57.19
18-20	1.12	97.26	2.74	41.64	2.69	55.66
20-22	1.22	97.35	2.65	45.46	2.84	51.70
22-24	1.10	97.47	2.53	41.03	2.45	56.52
24-26	1.17	97.33	2.67	43.28	2.73	53.99
26-28	1.16	97.44	2.56	42.98	2.60	54.43
28-30	1.18	97.39	2.61	43.95	2.70	53.34
30-32	1.13	97.19	2.81	42.00	2.79	55.21

Table C.19. Sediment characteristics at site 17.

section	Bulk Density (g/cm³)	% Mineral matter by weight	% Organic matter by weight	% Volume mineral matter	% Volume organic matter	% Volume pore space
0-2	1.12	97.52	2.48	41.53	2.43	56.04
2-4	1.36	97.81	2.19	50.68	2.61	46.72
4-6	1.38	98.05	1.95	51.64	2.36	46.00
6-8	1.48	97.86	2.14	55.28	2.78	41.94
8-10	1.42	98.03	1.97	53.24	2.46	44.30
10-12	1.48	98.22	1.78	55.43	2.31	42.25
12-14	1.55	98.15	1.85	57.99	2.51	39.50
14-16	1.42	98.06	1.94	53.11	2.41	44.47
16-18	1.57	97.85	2.15	58.45	2.95	38.60
18-20	1.58	98.36	1.64	59.33	2.28	38.39
20-22	1.46	97.77	2.23	54.48	2.85	42.67
22-24	1.41	97.89	2.11	52.60	2.60	44.79
24-26	1.36	98.18	1.82	51.15	2.17	46.68
26-28	1.33	98.07	1.93	49.87	2.26	47.88
28-30	1.36	98.32	1.68	50.87	2.00	47.13
30-32	1.34	98.02	1.98	50.20	2.33	47.47

Table C.20. Sediment characteristics at site 18.

section	Bulk Density (g/cm³)	% Mineral matter by weight	% Organic matter by weight	% Volume mineral matter	% Volume organic matter	% Volume pore space
0-2	0.92	96.61	3.39	34.07	2.75	63.19
2-4	1.08	97.03	2.97	40.17	2.82	57.01
4-6	1.05	96.90	3.10	38.67	2.84	58.49
6-8	1.08	96.52	3.48	39.93	3.31	56.76
8-10	1.13	96.71	3.29	41.60	3.25	55.15
10-12	1.09	96.71	3.29	40.37	3.16	56.47
12-14	1.25	96.68	3.32	46.28	3.65	50.07
14-16	1.20	96.91	3.09	44.46	3.25	52.28
16-18	1.24	97.07	2.93	45.87	3.18	50.95
18-20	1.32	96.99	3.01	48.92	3.49	47.60
20-22	1.26	96.93	3.07	46.76	3.40	49.84
22-24	1.17	97.32	2.68	43.41	2.75	53.84
24-26	1.27	97.38	2.62	47.03	2.90	50.07
26-28	1.12	97.59	2.41	41.90	2.37	55.72
28-30	1.22	97.60	2.40	45.39	2.56	52.05
30-32	1.14	97.31	2.69	42.37	2.69	54.94

Table C.21. Sediment characteristics at site 14B.

section	Bulk Density (g/cm³)	% Mineral matter by weight	% Organic matter by weight	% Volume mineral matter	% Volume organic matter	% Volume pore space
0-2	0.73	97.34	2.66	27.27	1.71	71.02
2-4	1.27	98.00	2.00	47.59	2.23	50.19
4-6	1.24	97.88	2.12	46.25	2.30	51.45
6-8	1.23	97.89	2.11	45.95	2.28	51.76
8-10	1.24	98.11	1.89	46.60	2.06	51.34
10-12	1.34	98.06	1.94	50.03	2.27	47.70
12-14	1.42	98.50	1.50	53.28	1.87	44.85
14-16	1.38	98.43	1.57	51.79	1.90	46.31
16-18	1.51	98.58	1.42	56.74	1.88	41.39
18-20	1.53	98.52	1.48	57.57	1.99	40.43
20-22	1.42	98.42	1.58	53.34	1.96	44.70
22-24	1.49	98.44	1.56	55.86	2.03	42.11
24-26	1.53	98.52	1.48	57.48	1.98	40.53
26-28	1.57	98.38	1.62	58.97	2.23	38.79
28-30	1.44	98.19	1.81	54.13	2.30	43.57
30-32	1.40	98.32	1.68	52.72	2.07	45.21

Table C.22. Sediment characteristics at site 16B.

section	Bulk Density (g/cm³)	% Mineral matter by weight	% Organic matter by weight	% Volume mineral matter	% Volume organic matter	% Volume pore space
0-2	1.18	97.99	2.01	44.07	2.07	53.85
2-4	1.39	98.41	1.59	52.11	1.93	45.96
4-6	1.44	98.37	1.63	54.23	2.07	43.71
6-8	1.45	98.46	1.54	54.53	1.96	43.51
8-10	1.44	98.36	1.64	54.19	2.07	43.73
10-12	1.46	98.48	1.52	54.80	1.94	43.26
12-14	1.37	98.21	1.79	51.38	2.15	46.47
14-16	1.30	97.72	2.28	48.38	2.59	49.03
16-18	1.17	97.41	2.59	43.49	2.66	53.85
18-20	1.33	97.60	2.40	49.69	2.81	47.50
20-22	1.37	97.79	2.21	51.24	2.67	46.10
22-24	1.34	97.65	2.35	49.78	2.75	47.47
24-26	1.26	97.60	2.40	46.93	2.65	50.41
26-28	1.47	97.62	2.38	54.89	3.07	42.04
28-30	1.37	97.75	2.25	51.06	2.70	46.25
30-32	1.46	97.80	2.20	54.32	2.81	42.87

Appendix D. Biomass data. Quadrat area = 0.1501 m².

Table D.1. Biomass in May/June.

		total eelgrass biomass (g DW)			
site	date	1	2	3	Zostera species
1	5/15/2010	0	0	0	
2	5/15/2010	10.896	7.845	10.637	marina
3	5/15/2010	0	0	0	
4	5/15/2010	14.293	10.923	8.71	mixed
5	6/13/2010	7.785	6.835	7.358	japonica
6	6/13/2010	13.794	13.805	27.94	marina
7	6/11/2010	10.993	18.985	11.203	japonica
8	6/12/2010	24.99	10.301	2.178	marina
9	5/17/2010	19.589	14.623	19.224	marina
10	5/17/2010	25.27	21.79	20.526	marina
11	5/17/2010	2.917	2.404	2.494	japonica
12	5/17/2010	13.839	13.917	15.338	marina
13	5/13/2010	13.803	8.588	10.38	marina
14	6/11/2010	18.978	16.592	14.811	marina
15	6/10/2010	0	0	0	
16	6/10/2010	0	0	0	
17	5/12/2010	0	0	0	
18	5/12/2010	11.615	12.575	16.688	marina
4B	6/14/2010	0	0	0	
5B	6/14/2010	24.98	17.921	21.56	marina
12B	6/14/2010	21.15	22.72	11.95	marina
14B	5/14/2010	16.361	17.262	13.586	marina
16B	5/14/2010	0	0	0	

Table D.2. Biomass in August.

		total eelgrass biomass (g DW)			
site	date	1	2	3	Zostera species
1	8/10/2010	0	0	0	
2	8/10/2010	9.48	10.04	12.6	marina
3	8/6/2010	0.25	0.91	0.27	japonica/mudflat
4	8/6/2010	14.35	11.87	14.67	mixed
5	8/5/2010	16.01	16.08	13.35	japonica/mixed
6	8/5/2010	14.86	6.82	16.27	marina
7	8/7/2010	13.73	24.62	22.43	japonica
8	8/7/2010	11.69	5.8	7.51	marina
9	8/7/2010	13.71	14.97	10.4	mixed
10	8/8/2010	22.87	17.26	20.62	marina
11	8/8/2010	16.1	12.91	14.57	japonica/mixed
12	8/8/2010	26.54	28.69	17.03	marina
13	8/6/2010	16.04	15.05	12.3	marina/mixed
14	8/7/2010	14.54	14.61	17.43	marina
15					
16					
17	8/9/2010	0.29	4.44	0.45	mudflat/japonica
18	8/9/2010	10.21	15.56	8.21	marina
4B					
5B					
12B					
14B	8/9/2010	15.55	12.55	7.2	marina
16B	8/9/2010	2.65			mudflat/marina

Table D.3. Biomass in January.

		total eelgrass biomass (g DW)			
site	date	1	2	3	Zostera species
1	1/3/2011	0	0	0	
2	1/3/2011	5.43	4.29	3.4	marina
3	1/2/2011	0	0	0	
4	1/2/2011	0.63	4.4	2.16	mixed
5					
6					
7					
8					
9	1/2/2011	1.01	1.54	0.78	marina
10	1/2/2011	1.57	2.69	2.14	marina
11					
12					
13	1/1/2011	3.2	2.52	4.52	marina
14	1/1/2011	3.1	4.55	9.53	marina
15					
16					
17					
18					
4B					
5B					
12B					
14B					
16B					