Morro Bay National Estuary Program

Sediment Monitoring Report
2016

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EXECUTIVE SUMMARY

The Morro Bay Estuary is impaired by accelerated sedimentation rates. Monitoring efforts underway by the Morro Bay National Estuary Program (Estuary Program) are intended to assess sedimentation in the watershed and the bay. To that end, four types of monitoring data are detailed in this report.

- Suspended sediment concentration: Samplers at three locations collect water during storm events for analysis for suspended sediment concentration. Due to a lack of storms of adequate size, no monitoring was conducted during the 2016 water year.
- Streambed Sediment Impairment Indicators: Utilizing a method under development by the Central Coast Water Quality Control Board and University of California researchers, watershed bioassessment data was assessed to determine the impacts of sedimentation on aquatic health. Of the five sites assessed by this method, four frequently have scores indicating some level of impairment.
- Sediment Elevation Tables: Permanent stations have been monitored periodically to assess sediment deposition and aggradation in the mudflat area of the bay. Measurements were repeated in October 2015 and are included in this report.
- Sediment Quality Assurance Measures: The Estuary Program participates in the USGS Sediment Lab Quality Assurance (SLQA) effort each spring and fall. The results for fall 2015 and spring 2016 are included. The program's results of analysis of blind samples were on par with results from other labs participating in the effort.

INTRODUCTION

The Central Coast Regional Water Quality Control Board adopted the Central Coast Basin Plan (Basin Plan) on March 14th, 1975. The Basin Plan included a broad array of water quality objectives, beneficial use designations, discharger implementation plans, and incorporated statewide plans and policies. Section 303(d) of the Clean Water Act requires that states create a list of water bodies that do not meet water quality objectives and establish load and waste load allocations. Total Maximum Daily Load (TMDL) documents detail the impairment of the listed water bodies and are incorporated into the Basin Plan upon approval. In California, this action is the responsibility of the Regional Water Quality Control Boards.

In 1998, the Central Coast Regional Water Quality Control Board (Water Board) identified Chorro Creek, Los Osos Creek and the Morro Bay Estuary as impaired by sediment and listed the water bodies under Clean Water Act Section 303(d). The TMDL identified accelerated sedimentation due to anthropogenic disturbance as the primary cause for listing. TMDL documentation cited the 1998 Tetra Tech report estimates that the Chorro and Los Osos Creeks sub-watersheds deliver an average of approximately 70,000 tons per year of sediment into the Morro Bay estuary. The report indicated that the Chorro Creek watershed was estimated to contribute 86 percent of the total sediment delivered to Morro Bay, approximately 60,689 tons.

The TMDL identified five numeric targets for monitoring and plans to track the progress of voluntary and required implementation actions. The Morro Bay National Estuary Program (Estuary Program) was identified as the lead monitoring and reporting agency. The *Morro Bay Total Maximum Daily Load for Sediment (including Chorro Creek, Los Osos Creek and the Morro Bay Estuary)* was formally adopted by the Environmental Protection Agency on December 3, 2003.

This report details progress on monitoring to assess sediment conditions in the Morro Bay watershed and estuary.

PROJECT BACKGROUND

The TMDL established four numeric targets for the streams in the Morro Bay watershed: pool volume, median gravel size diameter (D50), percent fines in substrate, and percent of course fines in substrate. The TMDL identified tidal prism volume as the primary numeric target for Morro Bay. The numeric targets are detailed in Table 1.

Table 1: Morro Bay Sediment TMDL Numeric Targets

Parameter	Numeric Target
Chorro and Los Osos Creeks and Tributaries Streambed Sediment	
Residual Pool Volume	v*= (a ratio) Mean values ≤ 0.21 (mean of at least 6 pools per sampling reach) Max values ≤ 0.45
Median Diameter (D50) of sediment Particles in Spawning Gravels	D50= Mean values ≥ 69 mm Minimum values ≥ 37 mm
Percent of Fine Fines (< 0.85 mm) in Spawning Gravels	Percent fine fines ≤ 21%
Percent of Course Fines (all fines < 6.0 mm) in Spawning Gravels	Percent course fine ≤ 30%
Morro Bay Estuary	
Tidal Prism Volume	4,200 acre-ft

The Estuary Program's Monitoring Program has been conducting regular on-going monitoring throughout the estuary and watershed for over ten years. Program volunteers are trained by staff to conduct on-going monitoring of water quality in the bay and creeks. The Estuary Program has collected ambient creek turbidity data from sites throughout the Morro Bay watershed either monthly or bi-weekly from 2002 through 2016 as part of ongoing water quality monitoring. Outside of storm events, the ambient turbidity levels rarely exceeded the Central Coast Basin Plan levels of concern of 25 NTU for protection of aquatic life in cold water (beneficial use COLD) and 40 NTU in warm waters (beneficial use WARM). Of the 3,041 turbidity readings collected since 2002, 2.3% exceeded 25 NTU and 1.1% exceeded 40 NTU. The Estuary Program has not conducted monitoring of the TMDL targets due to the cost and expertise required.

Multiple studies have analyzed the accuracy of measuring turbidity as a surrogate for monitoring total suspended solids (TSS) or suspended sediment concentration (SSC). Turbidity monitoring is significantly faster and less expensive than monitoring SSC or TSS. However, although turbidity data has generally proven to be more accurate than other surrogate measures (such as discharge), there are limitations to its usefulness in quantifying suspended sediment load in surface waters (Ankcorn, 2003).

In 2007, the Estuary Program launched an expanded monitoring effort to generate detailed measurements of suspended sediment and turbidity in the Chorro Creek watershed at three sites. The expanded monitoring generated a new dataset of SSC data using updated United States Geological Survey (USGS) approved laboratory methods. Turbidity was measured in the laboratory on a subset of samples analyzed for SSC. The findings can be used to characterize instantaneous and storm event suspended sediment loads and potentially assess the effectiveness of best management practices (BMPs) implemented throughout the Morro Bay watershed. This project built on total suspended solids (TSS) data collected during the National Monitoring Program (NMP) paired watershed study during the 1990s and early 2000s.

While suspended sediment concentration is not required in the Morro Bay Sediment TMDL, many recently adopted TMDLs include this type of monitoring, and it is one of the most effective ways to quantify instantaneous sediment loading. Additionally, this expanded effort investigated the relationship between turbidity and suspended sediment concentration at each monitoring site. The relationships developed by this project may enable the monitoring of turbidity as a surrogate for SSC under certain conditions. Further, this dataset illustrates a more comprehensive assessment of 'Wet Season' turbidity levels in the Chorro Creek watershed.

While substantial data has been collected throughout this effort, there were no storm events during the 2016 rain year that produced sufficient elevated stage to monitor for SSC. Future monitoring will be done on storms expected to exceed SSC of 300 mg/L or greater at San Luisito Creek and 1,000 mg/L or greater at Chorro Creek. Walters Creek will be monitored for all storm events when the creek is flowing.

As SSC data is not available for assessing sediment impacts in the 2016 rain year, this report will instead focus on other areas of the program that address sedimentation. Analysis was conducted of streambed sediment impairment indicators from 2016 utilizing data collected during Surface Water Ambient Monitoring Program (SWAMP) Bioassessment surveys. Methods under development by the Water Board and UC Davis researchers incorporate bioassessment and habitat survey scores to assess the impacts of sedimentation.

SUSPENDED SEDIMENT MONITORING EFFORT

No new SSC data was collected during the 2016 rain year due to lack of storms of adequate size. The hydrographs for 2016 are included, demonstrating the lack of storms meriting monitoring during the year.

For additional details on this monitoring effort, please refer to Estuary Program sediment reports from previous years.

2016 RAIN YEAR HYDROGRAPH

During the 2016 water year (October 1, 2015 to September 30, 2016), 14.24" of rain was measured at the Canet Road rain gauge. Average annual precipitation for this gauge is approximately 21 inches.

The only storm that may have merited SSC sample collection and analysis was the mid-January 2016 storm. This storm ended up being stronger than was predicted. The forecast indicated that the storm did not merit monitoring, and so unfortunately equipment was not deployed to monitor this storm.

The following graphs provide discharge data during the 2016 rain year (July 1, 2015 to June 30, 2016), which partly covers the 2017 water year (October 1, 2016 to September 30, 2017).

Figure 1: 2016 Rain Year Hydrograph-San Luisito Creek

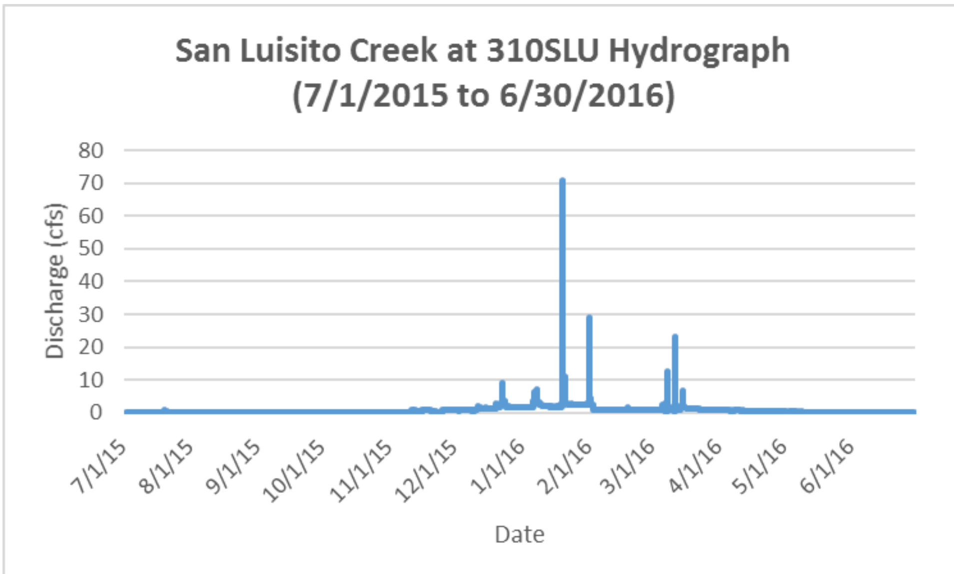


Figure 1 shows discharge (cfs) from July 1, 2015 to July 30, 2016 on San Luisito Creek on Adobe Road. Discharge values were calculated using stage heights from the SLO County FC & WCD stage recorder and the rating curve outlined in previous sediment reports.

FIGURE 2: 2016 RAIN YEAR HYDROGRAPH-CHORRO CREEK

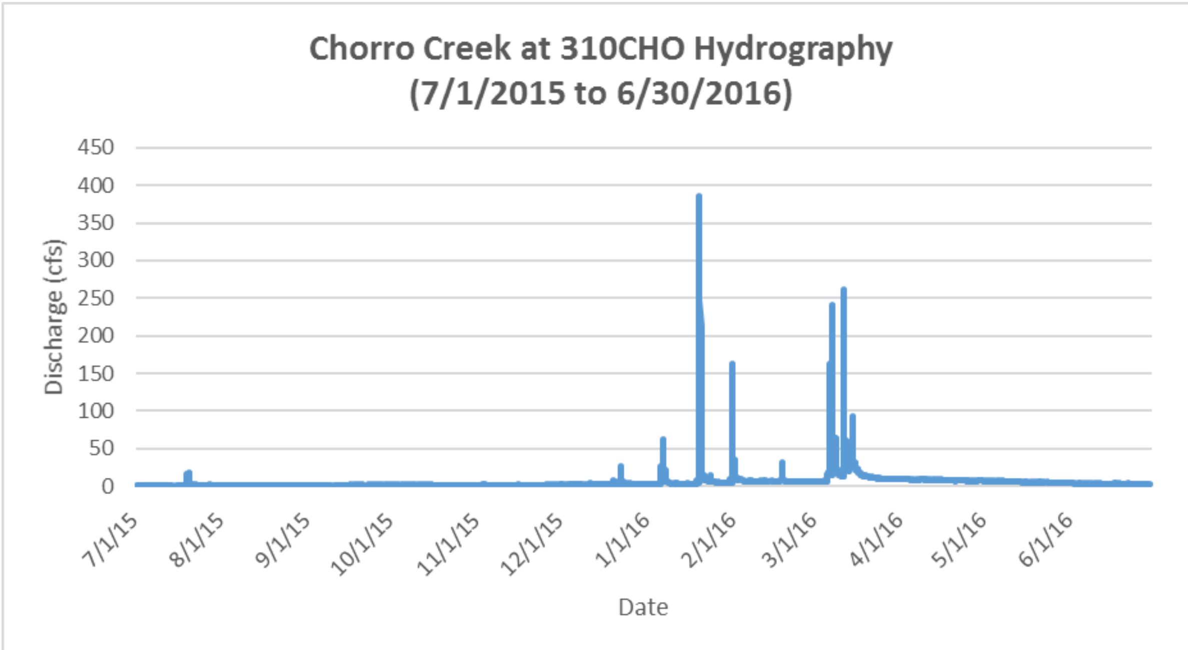


Figure 2 shows discharge (cfs) from July 1, 2015 to July 30, 2016 on Chorro Creek at Canet Road. Discharge values were calculated using stage heights from the SLO County FC & WCD stage recorder and the rating curve outlined in previous sediment reports.

As no storms during the 2016 rain year were large enough to generate flows on Walters Creek, an updated hydrograph was not created.

STREAMBED SEDIMENT IMPAIRMENT INDICATORS

The relationship between aquatic health in a watershed and impacts due to sediment loading is of great interest in the regulation of sediment. Over a three-year period, researchers from the Sierra Nevada Aquatic Research Laboratory (SNARL) (associated with the University of California) conducted research to develop numeric targets for sediment impairment and biological thresholds in riverine systems in the Central Coast region. Although these criteria were not specifically developed for the Morro Bay watershed, they are being evaluated for assessments throughout the Central Coast region. Initial analysis shows that the indicators are applicable in the Central Coast region.

An extensive number of indices were tested across a gradient of test sites. The final outcome included 16 indicators of sediment impairment on aquatic habitat. The indicators cover both the physical characteristics (sediment) and the biological community.

A significant data collection effort is required to determine the status of all 16 sediment and biological indicators for a study reach. The current SWAMP Bioassessment Protocol (SWAMP, 2007) metrics can be used to generate seven (in bold) of the nine sediment indicators, and six (in bold) of the seven biological indicators. Since Estuary Program monitoring is conducted per the SWAMP protocol, only the indicators in bold in the list below are available for analysis. There are three threshold criteria for comparison of each of these indicators, shown in Table 2.

Sediment Indicators:

1. **Percent of Fines (F) on transects**
2. **Percent of Sand (S) on transects**
3. **Percent of Fines (F) + Percent of Sands (S) on transects**
4. **Percent of Fines, Sands and Gravels < 8mm on transects**
5. **D50 Median particle size**
6. Percent patch-scale grid Fines and Sands
7. Log Relative Bed Stability
8. **Percent of Fines (Steelhead)**
9. **Percent Cover of Fines and Sands (BMI Limits)**

Biological Indicators

1. **Total Richness**
2. **EPT Richness**
3. **%EPT**
4. **Biotic Index**
5. **Percent Tolerant**
6. **Sensitive Number**
7. Crayfish Number and Size

TABLE 2: SEDIMENT AND BIOLOGICAL INDICATOR CRITERIA

	Recommended Numeric Targets To Support Beneficial Uses	Recommended Numeric Targets to Support Preliminary 303(d) Listing (lower priority)	Recommended Numeric Targets To Support 303(d) Listing (high priority)
Sediment Indicators		**75/25**	**90/10**
Percent Fines on transects	<8.5%	8.5 to 15.2%	>15.2%
Percent Sands on transects	<27.5%	27.5 to 35.3%	>35.3%
Percent Fines + Sands on transects	<35.5%	35.5 to 42.0%	>42.0%
Percent Fines, Sands, Gravel <8mm on transects	<40.0%	40.0 to 50.2%	>50.2%
D50 median particle size	>15 mm	7.7 to 15 mm	<7.7 mm
Percent Fines (steelhead)	<6%	6 to 10%	>10%
Percent cover of FS (BMI limits)	<30%	30 to 40%	>40%
Biological Indicators		**75/25**	**90/10**
Total Richness	>50.0	<50.0	<44.2
EPT Richness	>16.5	<16.5	<11.6
Biotic Index	<5.48	>5.48	>5.92
Percent Tolerant	<26.3%	>26.3%	>37.7
Sensitive Number	>9.5	<9.5	<5.8

The Estuary Program, with the help of trained volunteers, has conducted SWAMP Bioassessment on an annual basis since 2007. Sites are selected for monitoring based on program data needs and hydrologic conditions. Thus, many sites are monitored on a rotating basis, and data is not available across all sites each year.

Five bioassessment monitoring sites were selected to be included in this analysis. These monitoring sites are located on Pennington Creek (310UPN), San Bernardo Creek (310MNO), San Luisito Creek (310LSL), Lower Chorro Creek (310TWB), and Middle Chorro Creek (310CER). See Figure 3 for a map of the monitoring locations. The selective scores between 2008 and 2016 were averaged for all sites in Table 3.

FIGURE 3: BIOASSESSMENT SITE MAP

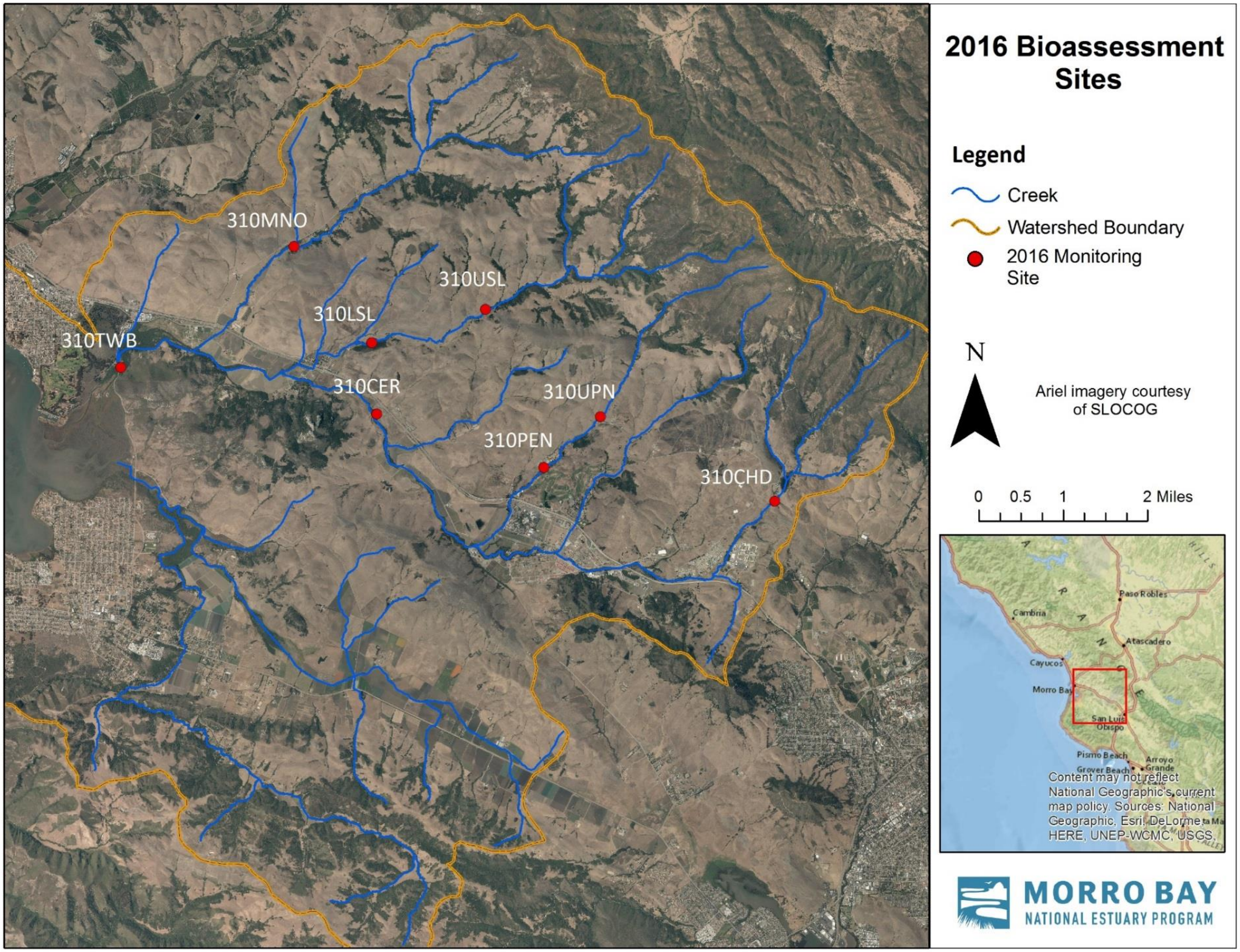


TABLE 3: SEDIMENT AND BIOLOGICAL INDICATOR SCORES 2008 - 2016

		Sediment Indicators							Biological Indicators					
Site Code	Survey Date	Percent Fines	Percent Sands	Percent <8mm	FS Sum Percent	D50 Median particle size	Percent Fines (steelhead)	Percent Cover of FS (BMI limits)	Total Richness	EPT Richness	Percent EPT	Biotic Index	Percent Tolerant	Sensitive Number
310MNO	2008	0.0	24.8	26.7	24.8	20.0	0	25	64.0	20.0	50.4	4.70	9.4	10.0
310MNO	2010	1.0	23.3	30.1	24.3	14.0	1	24	42.0	14.0	61.8	4.70	7.1	5.0
310MNO	2012	2.9	9.8	14.7	12.8	37.0	3	13	69.0	22.0	42.8	4.76	8.7	10.0
310MNO	2013	2.9	7.8	18.6	10.8	31.0	3	11	66.0	18.0	19.0	5.65	9.1	14.0
310MNO	2014	5.0	24.0	35.0	29.0	24.0	5	29	46.0	3.0	3.4	7.29	17.4	3.0
310MNO	2015	6.7	9.5	24.8	16.2	17.0	7	16	57.0	5.0	4.3	6.93	14.0	4.0
310MNO	2016	13.5	11.0	36.5	12.4	12.5	13	13	70.0	16.0	23.6	5.91	14.3	9.0
310LSL	2008	5.7	19.1	33.3	24.8	12.0	6	25	55.0	14.0	25.2	4.48	12.7	9.0
310LSL	2010	11.8	10.9	33.7	22.8	13.0	12	23	48.0	18.0	50.7	4.58	6.3	9.0
310LSL	2012	2.9	23.3	32.1	26.2	14.0	3	26	61.0	22.0	18.3	4.48	9.8	16.0
310LSL	2013	10.5	9.5	25.7	20.0	17.0	10	20	39.0	4.0	0.9	5.17	15.4	2.0
310LSL	2014	16.2	11.4	34.3	27.6	20.0	16	28	44.0	8.0	4.3	5.45	9.1	6.0
310LSL	2015	14.4	11.5	37.5	26.0	11.0	14	26	54.0	14.0	17.8	5.28	9.3	6.0
310LSL	2016	23.8	9.5	40.0	33.3	9.0	24	24	44.0	15.0	36.0	4.54	8.9	9.0
310UPN	2008	1.9	12.4	20.0	14.3	25.0	2	14	62.0	17.0	18.4	4.95	9.7	14.0
310UPN	2011	2.9	15.2	19.1	18.1	120.0	3	18	59.0	25.0	64.4	4.26	5.1	13.0
310UPN	2012	1.0	16.5	17.5	17.5	63.5	1	17	56.0	21.0	48.5	4.02	8.9	15.0
310UPN	2013	2.9	7.7	14.4	10.6	100.5	3	11	70.0	24.0	32.6	4.49	5.7	17.0
310UPN	2014	1.9	3.8	9.5	5.7	87.0	2	6	73.0	20.0	17.6	4.92	6.9	15.0
310UPN	2015	5.8	4.8	16.3	10.6	55.5	6	11	53.0	10.0	16.1	5.38	9.4	5.0
310UPN	2016	2.9	9.0	24.8	2.9	24.0	3	3	73.0	14.0	15.9	5.68	11.0	10.0
310TWB	2008	18.8	7.9	31.7	26.7	13.0	19	27	55.0	14.0	27.3	5.38	14.6	7.0
310TWB	2012	8.0	29.0	44.0	37.0	9.5	8	37	46.0	8.0	6.8	6.65	21.7	3.0
310TWB	2013	9.7	18.5	44.7	28.2	9.0	10	28	52.0	9.0	3.7	6.44	21.2	4.0
310TWB	2014	24.8	11.4	53.3	36.2	6.0	25	36	41.0	4.0	6.9	6.52	24.4	2.0
310TWB	2015	0.0	41.0	59.0	41.0	5.0	0	41	31.0	0.0	0.0	7.61	29.0	0.0
310TWB	2016	12.4	24.8	51.4	37.1	12.5	13	13	42.0	3.0	2.9	7.2	21.4	3.0
310CER	2008	15.2	15.2	30.5	30.5	24.0	15	30	48.0	6.0	14.6	6.22	14.6	1.0
310CER	2011	3.8	34.3	41.0	38.1	13.0	4	38	50.0	14.0	48.1	5.48	12.0	4.0
310CER	2012	15.3	11.2	26.5	26.5	20.0	15	27	42.0	12.0	35.6	5.48	16.7	2.0
310CER	2013	13.8	22.3	45.7	36.2	15.5	14	36	26.0	5.0	6.3	5.64	19.2	0.0
310CER	2014	26.7	15.2	47.6	41.9	9.0	27	42	34.0	6.0	3.2	6.64	20.6	1.0
310CER	2015	25.0	12.5	39.4	37.5	14.0	25	38	53.0	9.0	11.9	6.16	19.1	2.0
310CER	2016	33.3	17.1	54.3	50.5	1.0	33	33	47.0	5.0	12.9	6.11	14.9	1.0

Recommended numeric targets to support beneficial uses
Recommended numeric targets to support preliminary 303d Listing (low priority)
Recommended numeric targets to support 303d listing (high priority)

TABLE 4: SEDIMENT AND BIOLOGICAL INDICATOR SCORE AVERAGES 2008 – 2016

2016 Herbst Averages

	Sediment Indicators							Biological Indicators					
Site Code	Percent Fines	Percent Sands	Percent <8mm	FS Sum Percent	D50 Median particle size	Percent Fines (steelhead)	Percent cover of FS (BMI limits)	Total Richness	EPT Richness	Percent EPT	Biotic Index	Percent Tolerant	Sensitive Number
310UPN	2.7	9.9	17.4	11.4	67.9	2.7	12.8	62.2	19.5	32.9	4.7	6.8	13.2
310MNO	4.6	15.8	26.6	18.6	22.2	4.6	19.6	57.3	13.7	30.3	5.7	11.0	7.7
310LSL	12.2	13.6	33.8	25.8	13.7	12.2	24.4	49.3	49.3	13.6	21.9	4.9	10.2
310TWB	12.3	21.6	47.4	34.4	8.5	12.5	33.8	45.0	7.0	8.9	6.5	22.2	3.2
310CER	19.0	18.3	40.7	37.3	13.8	19.0	34.9	42.9	8.1	8.1	19.0	6.0	16.7

Recommended numeric targets to support beneficial uses
Recommended numeric targets to support preliminary 303(d) listing (low priority)
Recommended numeric targets to support 303(d) listing (high priority)

STREAMBED SEDIMENT IMPAIRMENT INDICATORS ANALYSIS

With the averaged data from 2008 through 2016, 310UPN and 310 MNO meet all sediment numeric targets that support beneficial use. Two sediment indicators met the lower priority listing criteria for 303(d) listing at 310LSL. 310CER and 310TWB had one indicator meet the high priority criteria for 303(d) listing, as well as multiple indicators meet the lower priority criteria for 303(d) listing.

Looking at the averaged data from 2008 through 2016, all biological indicators at 310UPN and 310MNO met all the targets to support beneficial use. At 310LSL, two biological indicators met the lower priority listing criteria. 310TWB and 310CER both had one indicator meet the lower criteria listing and three meet the high priority criteria for 303(d) listing.

California has been in a persistent drought since 2011. Lack of water as a result of this ongoing drought is believed to be a contributing factor to the increasing number of indicators showing impairment. San Bernardo and San Luisito Creeks, which tend to have the best bioassessment scores in the watershed, have showed a decrease in the quality of habitat since the drought began. All creeks except Pennington Creek had at least one indicator meet the high priority criteria listing in 2016. The 2015 survey was the first year that 310UPN had any indicators that met the criteria for 303(d) listing. Though some sites showed slight improvements in 2016, others decreased.

This preliminary analysis indicates that physical characteristics are variable across sites in the Morro Bay watershed and that some sites may indicate greater levels of impairment than others. It is important to consider that these results do not include the full suite of sixteen metrics that comprise the analytical approach.

These indicator criteria are still being assessed for incorporation in the 303(d) listing process and TMDL assessment process in the Central Coast region. These criteria differ greatly from the D50 and percent sands/percent fines criteria listed in the approved sediment TMDL for Morro Bay. Further guidance is needed from the Water Board for future assessments of the status of the Morro Bay Sediment TMDL.

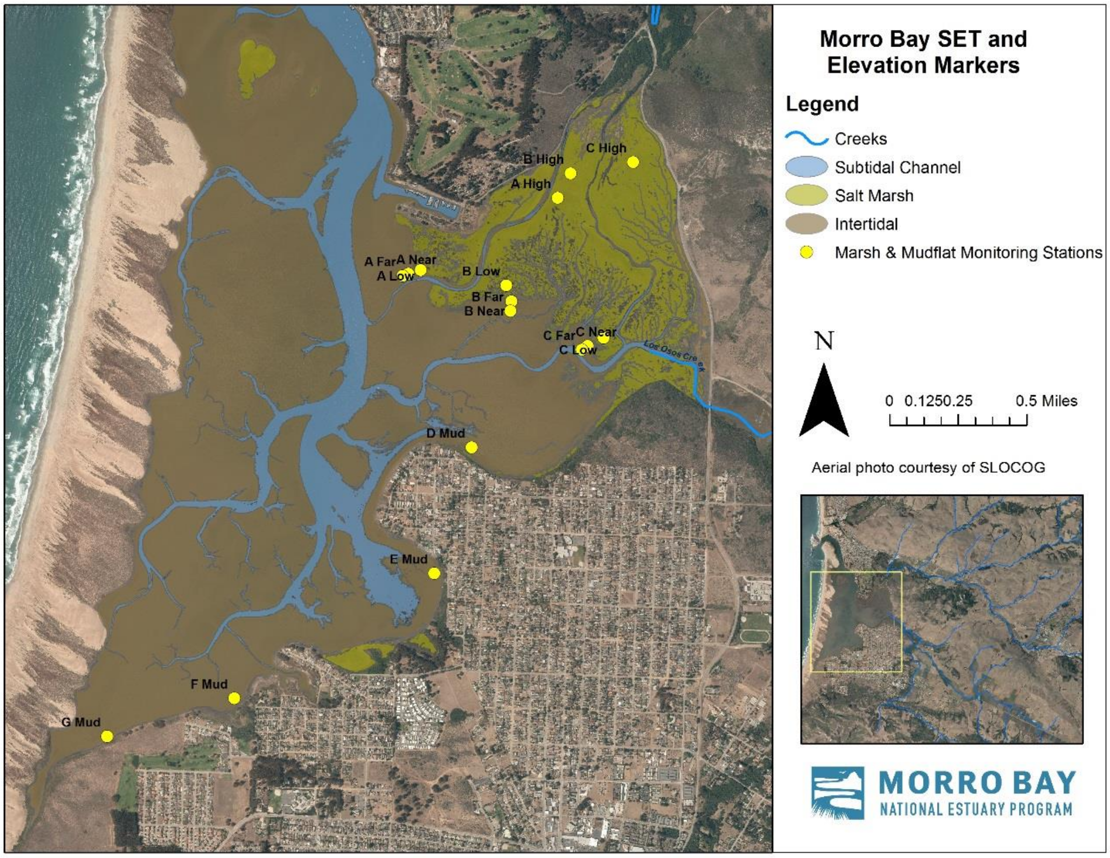
SEDIMENT ELEVATION TABLES

In addition to measurements of sediment transport and effects within the Morro Bay watershed, numerous sediment accretion sampling stations have been established in the salt marsh and mudflats. Surface Elevation Tables (SETs) and marker horizons were established in 2004 to measure sedimentation rates and establish a baseline for long term measurements.

Six surface elevation sampling stations were established in the salt marsh along three transects (A, B & C) in January of 2004. Additional sampling stations were constructed in the intertidal mudflats at elevations below each of the marsh sampling stations. Four additional mudflat stations were established around the shoreline of the bay in October of 2004. Stations are illustrated in Figure 4.

Measurements were conducted on a variable frequency by staff at the Department of Environmental Science from the University of San Francisco in 2004, 2007 and 2010. The results from these surveys were detailed in the Estuary Program's 2011 sediment report. Monitoring was conducted in October 2015 but results were not available for the 2015 Sediment Report. The report is included in Appendix A.

FIGURE 4: MAP OF ALL MORRO BAY SETS & HORIZON MARKERS



SSC QUALITY ASSURANCE MEASURES

As part of efforts to ensure the quality of SSC data, the Estuary Program participates in the SLQA Project with the USGS Branch of Quality Systems. The USGS lab creates single-blind samples for SSC analysis by labs across the country. USGS provides triplicate samples from three ranges of sediment concentrations, one of which needs to be analyzed using a sand/fine split procedure. The individual labs analyze the samples and send the results to the USGS, which then compiles a summary report with results from all participating labs. This biannual quality control check provides an opportunity to verify that lab protocols, techniques, supplies and equipment are not introducing errors into the sample analysis process. The Estuary Program has participated in this QA program since the spring of 2008. The results from the fall 2015 and the spring 2016 rounds of SLQA testing are provided in Appendix B.

USGS presents the results as a sediment concentration percent difference, which is a measure of the difference between the known concentration of sediment in the prepared sample compared to the amount of sediment recovered by the individual lab. The results are usually negative percentages because typically sample is lost in the measurement process, rather than contamination being added to the sample. The results also provide a median percent difference value of all of the results as compared to the known sediment concentrations.

TABLE 5: RESULTS FOR SLQA PROGRAM, FALL 2015 AND SPRING 2016

SLQA Effort	SSC Target of QA Sample (mg/L)	Sample Replicate #	SSC Percent Difference for Estuary Program Analysis Compared to Known Concentration (%)	Average SSC Percent Difference for Estuary Program Analysis (%)	Median SSC Percent Difference for Results from All Labs (%)
Fall 2015	75	1	24.99	13.83	-5.24
		2	-		
		3	2.66		
	550	1	1.07	1.16	-2.16
		2	12.14		
		3	-9.74		
	4,00	1	-0.16	-0.37	-0.82
		2	-0.55		
		3	-0.39		
Spring 2016	65	1	-4.23	-5.31	-4.26
		2	-6.72		
		3	-4.97		
	400	1	-1.83	-2.54	-1.94
		2	-2.94		
		3	-2.86		
	4,050	1	-0.45	-0.37	-0.65
		2	-0.26		
		3	-0.42		

No numeric targets are in place for assessing program accuracy. As demonstrated by the values in the above table, Estuary Program results were on par with the results from other labs across the country that participated in the SLQA Program.

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Sediment Accumulation Rates in Morro Bay Estuary:

Final Report 2015 Field Sampling

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Introduction

In Morro Bay, there has been on-going concern over high rates of sediment accumulation within the estuary, supported by the general observations that some areas within the Bay have been filling in over time. Despite these concerns there has been a lack of data to evaluate sedimentation rates in Morro Bay salt marshes and mudflats. In order to address this issue, sampling stations have been established in both marsh and mudflats to measure sedimentation rates and to establish a baseline for long-term measurements into the future. As described in the annual report from 2004, two approaches are being used: marker horizons to measure rates of sediment accretion and Surface Elevation Tables (SETs) to measure corresponding changes in sediment elevation. SETs were not established on the mudflats because of challenges for access and concerns about putting permanent SET pipes on the mudflats where they may impact canoeing and kayaking. In addition, heavy filter fabric (typically used for french drains) is being used as a marker on the mudflats because of high rates of bioturbation in this habitat.

Methods

Details for sampling methods are given in the annual report from 2004. As noted in that report, six sampling stations were established on the marsh plain along three transects (Table 1, Figure

1) in January 2004. In addition, sampling stations were set up on the mudflats at elevations just below each of the three low marsh sampling stations (A, B, and C, with stations near and far from marsh/mudflat transition) in January 2004 (Table 2, Figure 2). Four additional mudflat stations were established in the southern part of the Bay in October 2004 (mudflat stations D, E, F, G; Table 2, Figure 2).

Feldspar markers were used to measure accretion at the salt marsh stations, and heavy fabric was used as a marker at the mudflat stations. Accretion was measured in October 2004 at all salt marsh stations and at mudflat stations A-C. Accretion was measured at all stations in October 2005 and October and November 2007 (although some mudflat stations were not accessible or could not be relocated during the 2007 sampling). Sampling in 2010 was completed on July 16, 17, and 18. We were able to sample at all locations on the marsh and mudflat in 2010.

Sampling in 2015 was completed on October 2, 3 and 4. We sampled all six marsh stations in 2015. We were only able to sample the mudflat stations adjacent to transect B (only the Near stations) and transect C (both Near and Far stations) because of relatively high tidal levels.

Accretion data are cumulative values, relative to the time period when the marker was established (January 2004 for salt marsh and mudflat stations A-C; October 2004 for mudflat stations D-G; some mudflat stations have washed out and been re-established; see 2010 report for additional details). We added tables to this year's summary that include "annual rates" of accumulation and elevation change over each time period sampled in order to facilitate comparisons across sampling periods (Tables 4, 7, and 9). SETs were measured during initial establishment in January 2004, and on all subsequent sampling periods. Field sampling in 2015 was completed by Evyan Borgnis, Julia Elkin, and John Callaway.

Results

Marsh marker horizons and SETs

Based on the marker horizon data over more than 11 years, sediment continues to accumulate at a relatively constant rate at all marsh stations (Tables 3 and 4, Figures 3 and 4). Low marsh stations were more variable than high marsh stations (as expected); total sediment accumulation at these stations ranged from 30 to 68 mm from 2004 to 2015. A large component of the variation in accretion dynamics at the low marsh stations is due to station B Low, where sampling indicated erosion from 2007 to 2010 but accretion during other periods. Accretion rates at stations A Low and C Low have remained relatively constant over the course of the study, with a slight decrease in the mean annual rates of accretion over time (Table 4). This decrease in measured rates over longer time periods is typical for salt marsh sites because material that accretes on the marsh surface slowly consolidates over time; most salt marsh sites show elevated accretion rates with short-term measurements and slower rates over long periods.

Accretion at high marsh stations has remained very consistent with little variation across transects or over time. Total accretion from 2004 to 2015 at the three high stations ranges from 13.7 to 14.0 mm, for annual rates over the entire period of 1.2 to 1.3 mm/yr. As with the low marsh stations that has been a slight decrease in the measured rates over the 11 year period, likely due to surface consolidation of sediments.

As in previous years, changes in marsh surface elevation (measured with the SET) were more variable than sediment accretion data (Tables 5, 6, and 7; Figures 5 and 6). Changes in elevation over each sampling interval are given in Table 5 with cumulative changes since January 2004 in Table 6 and Figures 5 and 6, and annual rates in Table 7. All stations show the same general trends over the most recent sampling interval compared to previous intervals (Figures 5 and 6). Changes in relative elevation were greater for the low stations compared to the high stations, reflecting greater rates of sediment accretion. Most stations show similar trends in the two variables, with slightly lower rates of elevation change as is to be expected due to slight compaction of surface sediments over time (Figures 7 to 12). Average annual rates of elevation change ranged from 0.65 to 3.85 mm/yr over the entire period (Table 7), and as with accretion rates, rates tend to decrease over longer periods of measurement (although there was some variation in initial SET measurements).

The rates of accretion and elevation change in the low marsh are similar to recent rates of global sea-level rise (2-3 mm/yr); while those in the high marsh are slightly lower than sea-level rise. The high marsh rates also are slightly lower than rates from other well-developed salt marsh systems (see 2004 Annual Report for a compilation of data from other sites around the world). Given the relatively high elevation of the marsh plain within Morro Bay, low rates of accretion and elevation change are not unexpected (accretion rates are inversely related to elevation because low elevation sites receive greater flooding and sediment input from tidal water (i.e., higher accretion rates at low elevations and lower accretion rates at high elevations). Even if the marsh continues to lose elevation relative to rising sea level, the loss in elevation is likely to be very slow, and, due to the relatively high elevation of the marsh, it has a substantial amount of "elevation capital" (i.e., the marsh has a substantial "capital" of elevation that it could lose before it would be "lost" or converted to mudflat conditions). Given this, the low accretion rates are not cause for immediate alarm.

Mudflat marker horizons

We were able to sample plots on transect B (Near only) and transect C (Near and Far). Mudflat accretion rates from 2010 to 2015 were similar to previously measured rates at stations B Near and C Near (Tables 8 and 9). A total of 68.2 mm accumulated at B Near (compared to 30.4 mm in July 2010), and 47.1 mm accumulated at C Near (compared to 26.1 mm in July 2010). Very slight erosion occurred at station C Far, with a loss of 1.3 mm of sediment over the 5 year period from 2010 to 2015 and a total accretion of 21.6 mm in 2015. Given these changes, annual rates increased at B Near (from 4.7 to 5.9 mm/yr); stayed constant at C Near (4.0 mm/yr), and decreased at C Far (from 3.5 to 1.9 mm/yr; Table 9). The mudflat stations are expected to be more variable than marsh stations; however, with only three stations measured it is difficult to evaluate overall variability. From the limited data collected in 2015, it appears that there have been no dramatic changes in mudflat sediment dynamics compared to previous sampling periods. In addition, we were somewhat surprised that all mudflat stations that we could access remained intact after eleven years and with no sampling for over five years.

Conclusions and Next Steps

As indicated above, accretion rates in the low marsh are comparable to global rates of sea-level rise, and these areas are keeping pace with sea-level rise. The data from the high marsh stations indicate a slight loss in high marsh elevation relative to sea level, with accretion rates below current rates of sea-level rise (1.2-1.3 mm/yr of accretion vs 2-3 mm/yr of sea-level rise); however, the difference is quite small (0.7 to 1.7 mm/yr), so even over a 10-year period, the total loss in elevation in the high marsh would be only 7 to 17 mm (0.7 to 1.7 cm over a decade). Because the range of high marsh vegetation is on the order to 10 to 30 cm, this is not an immediate concern (this concept is referred to as elevation capital above). However, rates of sea-level rise have already been increasing over the recent decades; if sediment input remains low and sea-level rates begin to accelerate more rapidly in the coming decades, the marsh could lose elevation more rapidly than it has in the past. Given this longer-term concern for sea-level rise, it would be worthwhile to continue to monitor sedimentation and elevation dynamics at a moderate frequency (every 3-5 years), with more frequent monitoring if substantial sediment inputs occur (e.g., as is anticipated during El Niño years). This would allow for identification of longer-term shifts in marsh elevation. If the marsh continues to loss elevation, management activities should take place sooner rather than later. It is more practical to maintain a relatively high elevation marsh than to increase elevations from lower elevation conditions, because once a site drops to lower elevations, plants are likely to be stressed by increased inundation. If plants remain stressed for extended periods and die, this could cause erosion of sediment and further loss of elevation.

On the mudflats, although we were only able to sample a limited number of locations, it appears that accretion rates continue at a relatively moderate and consistent rate. While there have been historic concerns within Morro Bay that mudflats were being “filled in” with high rates of sediment input, this does not appear to be the case at the sites were we have long-term data over the last decade. If general observations in other locations in the Bay indicate that mudflats are building elevation and converting to marsh, it may be worthwhile to do more targeted measurements in those locations; however, given both the slow rate of sediment accumulation in the marsh and the moderate rates in the mudflats that have been measured, it does not seem likely that high rates of sediment inputs into the Bay would be converting mudflats in other areas.

Literature Cited

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Table 1. Latitude and longitude for salt marsh sampling stations in Morro Bay Estuary (coordinates are based on NAD83; GPS points collected with Garmin GPSmap76S). Stations were established in January 2004.

	Latitude		Longitude	
	deg	min	deg	min
A Low	35	20.510	120	50.532
A High	35	20.751	120	50.099
B Low	35	20.469	120	50.198
B High	35	20.830	120	49.962
C Low	35	20.311	120	49.816
C High	35	20.872	120	49.721

Table 2. Latitude and longitude for mudflat sampling stations in Morro Bay Estuary (coordinates are based on NAD83; GPS points collected with Garmin GPSmap76S). Stations A-C were established in January 2004; stations D-G were established in October 2004.

	Latitude		Longitude	
	deg	min	deg	min
A Near	35	20.497	120	50.580
A Far	35	20.490	120	50.602
B Near	35	20.419	120	50.177
B Far	35	20.388	120	50.180
C Near	35	20.284	120	49.877
C Far	35	20.272	120	49.899
D Mud	35	19.952	120	50.316
E Mud	35	19.549	120	50.447
F Mud	35	19.134	120	51.208
G Mud	35	19.002	120	51.697

Table 3. Mean sediment accretion (and standard error) for Morro Bay Estuary salt marsh stations from January 2004 to October 2004, October 2005, October 2007, July 2010, and October 2015. Means are based on samples from four plots at each sampling station with two plugs within each plot.

	Sediment Accretion (mm)				
Sampling Station	**January 2004 through October 2004**	**January 2004 through October 2005**	**January 2004 through October 2007**	**January 2004 through July 2010**	**January 2004 through October 2015**
A Low	5.10 (1.30)	8.94 (1.49)	19.55 (5.73)	30.26 (6.19)	49.36 (3.56)
B Low	1.71 (0.43)	8.23 (0.48)	15.40 (0.90)	9.75 (3.88)	30.06 (1.91)
C Low	4.58 (0.38)	12.45 (1.14)	23.75 (2.35)	35.72 (5.19)	68.00 (2.76)
A High	1.02 (0.07)	2.69 (0.43)	5.88 (0.66)	7.93 (0.78)	13.66 (0.76)
B High	1.60 (0.11)	4.23 (0.18)	8.26 (0.51)	10.26 (0.89)	15.03 (0.56)
C High	1.25 (0.07)	4.02 (0.25)	7.42 (0.53)	11.58 (0.63)	14.74 (1.57)

Table 4. Mean annual rates of sediment accretion for Morro Bay Estuary salt marsh stations from January 2004 to October 2004, October 2005, October 2007, July 2010, and October 2015. Means are based on samples from four plots at each sampling station with two plugs within each plot; annual rates are based on time interval since 2004.

Annual Rate of Sediment Accretion (mm)

Sampling Station	**January 2004 through October 2004**	**January 2004 through October 2005**	**January 2004 through October 2007**	**January 2004 through July 2010**	**January 2004 through October 2015**
A Low	7.6	5.1	5.1	4.7	4.2
B Low	2.6	4.7	4.0	1.5	2.6
C Low	6.9	7.1	6.2	5.5	5.8
A High	1.5	1.5	1.5	1.2	1.2
B High	2.4	2.4	2.2	1.6	1.3
C High	1.9	2.3	1.9	1.8	1.3

Table 5. Mean change in surface elevation (and standard error) for Morro Bay Estuary salt marsh stations over each sampling interval from January 2004 to October 2015. Means are based on SET measurements from four directions at each sampling station, with nine measurements for each direction.

	Change in Elevation (mm)				
Sampling Station	**January 2004 through October 2004**	**October 2004 through October 2005**	**October 2005 through October 2007**	**October 2007 through July 2010**	**July 2010 through October 2015**
A Low	-3.83 (0.42)	7.00 (2.56)	0.61 (2.67)	9.09 (2.13)	11.89 (2.62)
B Low	-0.72 (0.75)	3.58 (1.03)	1.00 (1.52)	5.75 (1.00)	2.69 (5.43)
C Low	7.31 (1.99)	0.39 (1.72)	13.64 (2.76)	7.33 (4.35)	16.28 (1.44)
A High	-4.22 (0.45)	3.89 (0.89)	1.44 (0.57)	0.86 (0.18)	7.67 (1.53)
B High	-1.19 (1.39)	4.19 (1.53)	4.08 (0.84)	2.08 (0.83)	4.83 (0.96)
C High	-0.75 (1.34)	0.75 (0.33)	3.94 (0.76)	2.06 (0.46)	1.53 (2.47)

Table 6. Mean cumulative change in surface elevation (and standard error) for Morro Bay Estuary salt marsh stations since January 2004. Means are based on SET measurements from four directions at each sampling station, with nine measurements for each direction.

	Cumulative Change in Elevation (mm)				
Sampling Station	**January 2004 through October 2004**	**January 2004 through October 2005**	**January 2004 through October 2007**	**January 2004 through July 2010**	**January 2004 through October 2015**
A Low	-3.83 (0.42)	3.17 (2.49)	3.78 (1.29)	12.87 (2.21)	24.76 (4.19)
B Low	-0.72 (0.75)	2.86 (1.65)	3.86 (1.10)	9.61 (1.13)	12.31 (4.53)
C Low	7.31 (1.99)	7.69 (0.66)	21.33 (3.18)	28.67 (3.48)	44.94 (3.57)
A High	-4.22 (0.45)	-0.33 (0.69)	1.11 (0.30)	1.97 (0.34)	9.64 (1.29)
B High	-1.19 (1.39)	3.00 (0.46)	7.08 (0.74)	9.17 (1.04)	14.00 (1.96)
C High	-0.75 (1.34)	0.00 (1.59)	3.94 (0.86)	6.00 (1.32)	7.53 (3.69)

Table 7. Mean annual rate of change in surface elevation for Morro Bay Estuary salt marsh stations since January 2004. Means are based on SET measurements from four directions at each sampling station, with nine measurements for each direction; annual rates are based on time interval since 2004.

Sampling Station	Annual Rate of Change in Elevation (mm) January 2004 through October 2004	January 2004 through October 2005	January 2004 through October 2007	January 2004 through July 2010	January 2004 through October 2015
A Low	-5.75	1.81	0.99	1.98	2.12
B Low	-1.08	1.63	1.01	1.48	1.05
C Low	10.96	4.40	5.57	4.41	3.85
A High	-6.33	-0.19	0.29	0.30	0.83
B High	-1.79	1.71	1.85	1.41	1.20
C High	-1.13	0.00	1.03	0.92	0.65

Table 8. Mean sediment accretion (and standard error) for Morro Bay Estuary mudflats stations that were sampled in 2015. Means are based on samples from four fabric marker plots at each sampling station with two locations within each plot.

	Sediment Accretion (mm)				
Sampling Station	**January 2004 through October 2004**	**January 2004 through October 2005**	**January 2004 through October 2007**	**January 2004 through July 2010**	**January 2004 through October 2015**
Plots established in January 2004					
B Near	10.3 (1.3)	26.88 (5.63)	37.5 (6.7)	30.4 (5.9)	68.2 (12.7)
C Near	7.0 (2.3)	14.9 (4.4)	18.5 (2.4)	26.1 (5.6)	47.1 (4.0)
C Far	9.3 (1.0)	13.9 (1.9)	17.0 (3.0)	22.9 (2.9)	21.6 (3.6)

Table 9. Mean annual rates of sediment accretion for Morro Bay Estuary mudflats stations that were sampled in 2015. Means are based on samples from four fabric marker plots at each sampling station with two locations within each plot; annual rates are based on time interval since 2004

	Annual Rate of Sediment Accretion (mm/yr)	
Sampling Station	**January 2004 through July 2010**	**January 2004 through October 2015**
B Near	4.7	5.9
C Near	4.0	4.0
C Far	3.5	1.9

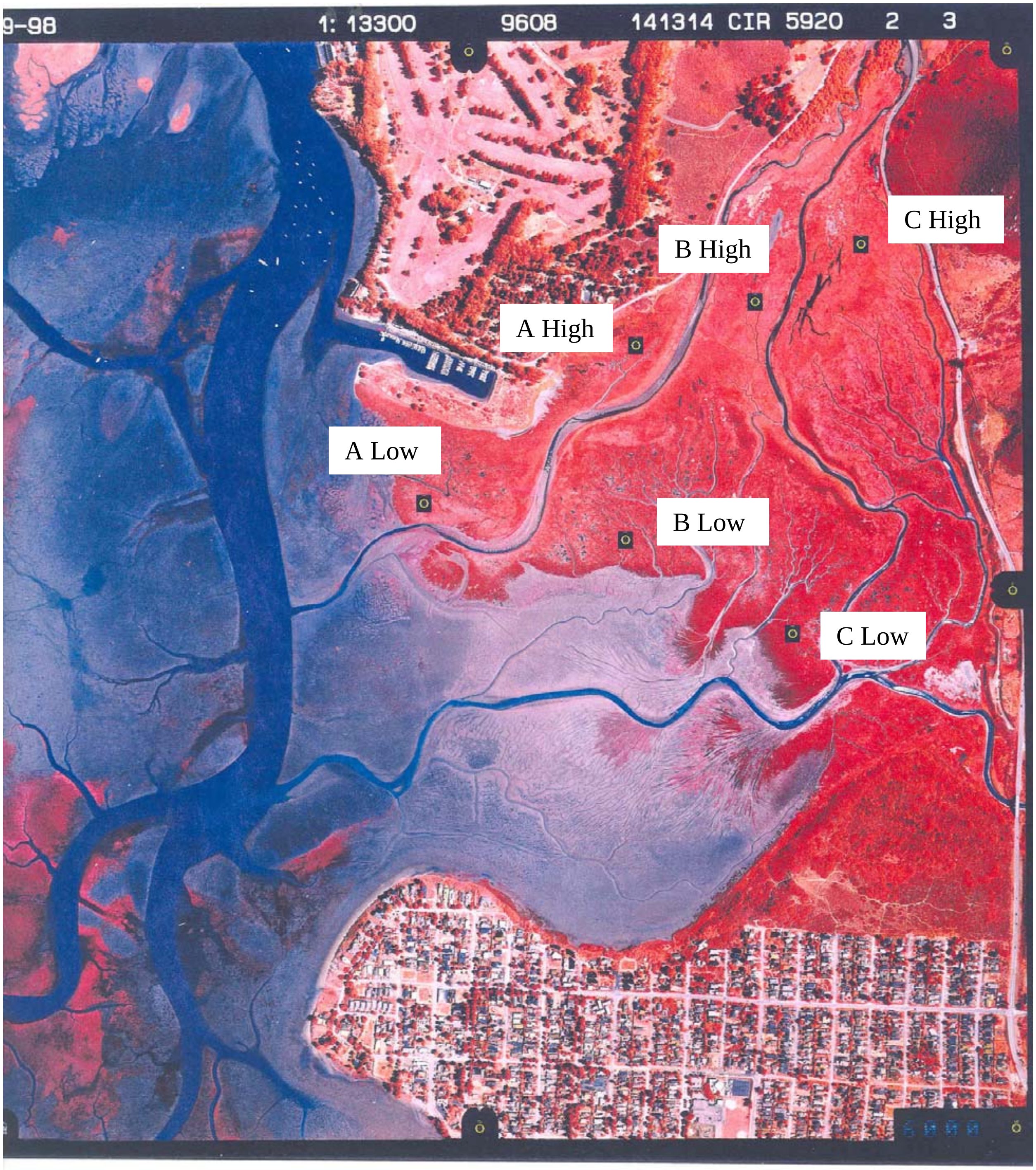


Figure 1. Six salt marsh sampling stations in Morro Bay Estuary (designated with a yellow circle within a small black square). Mudflat sampling stations A, B, & C are just below each low marsh station and are identified in Figure 2. Exact locations of salt marsh stations (latitude and longitude) are given in Table 1.

Figure 2. Mud flat sampling stations in Morro Bay Estuary. Near and Far stations are identified for stations adjacent to the marsh (Stations A, B, & C). A single sampling station was set up at each station in the southern portion of the Bay (Stations D, E, F, & G). Exact locations of mudflat stations (latitude and longitude) are given in Table 2.

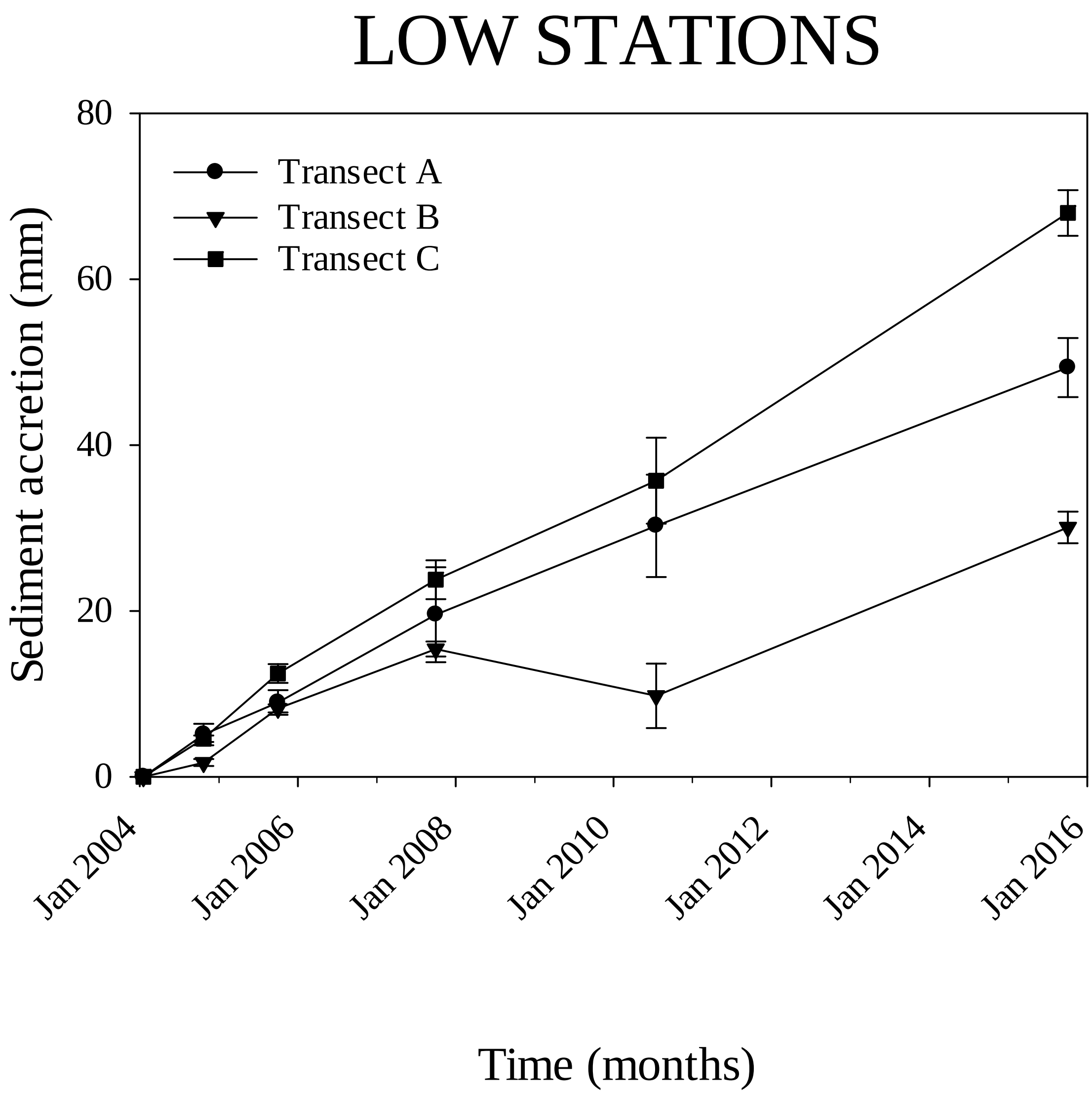


Figure 3. Mean sediment accretion (and standard error) for low stations in the Morro Bay salt marsh from January 2004 to October 2015. Data are also presented in Table 3. Transect locations are shown on Figure 1.

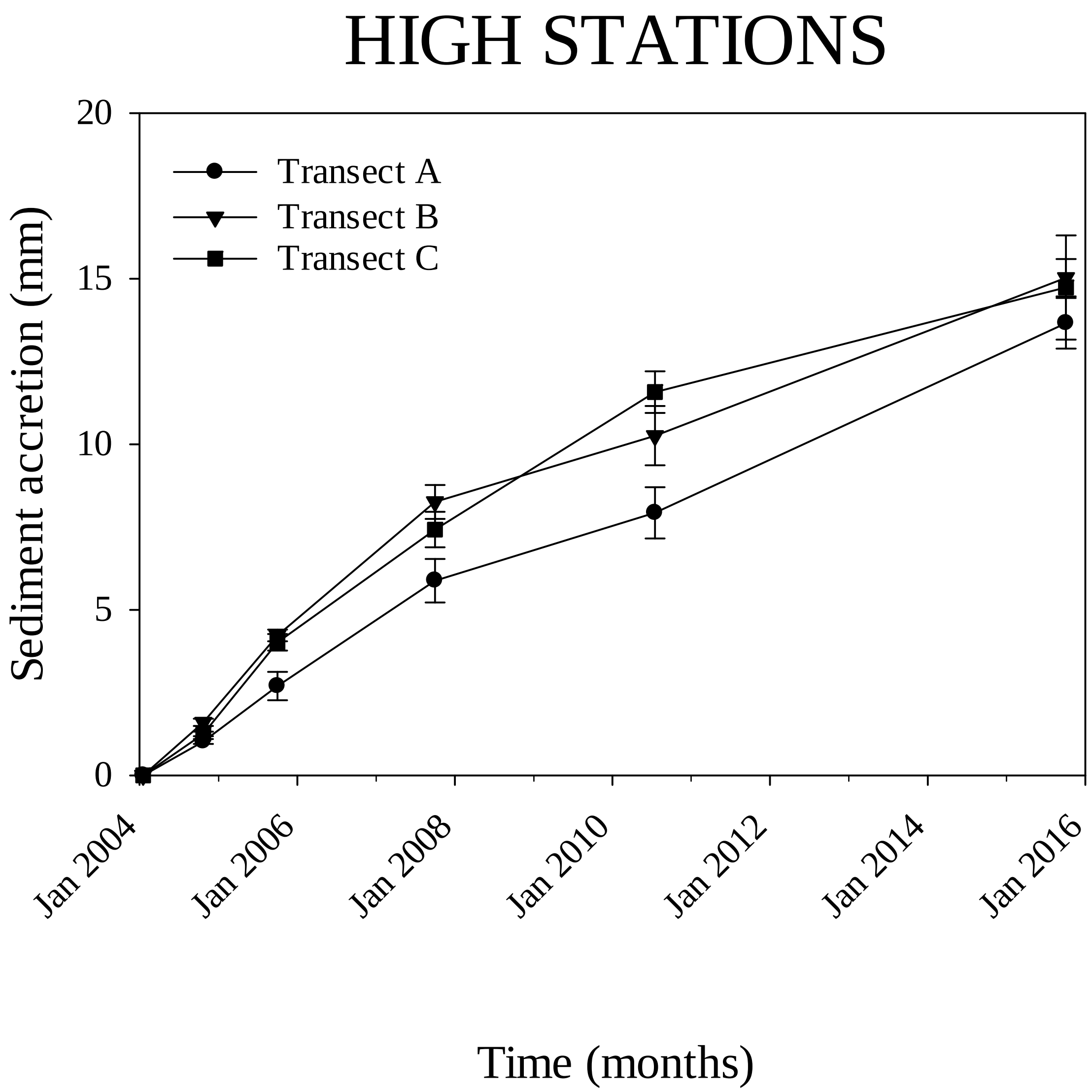


Figure 4. Mean sediment accretion (and standard error) for high stations in the Morro Bay salt marsh from January 2004 to October 2015. Data are also presented in Table 3. Transect locations are shown on Figure 1.

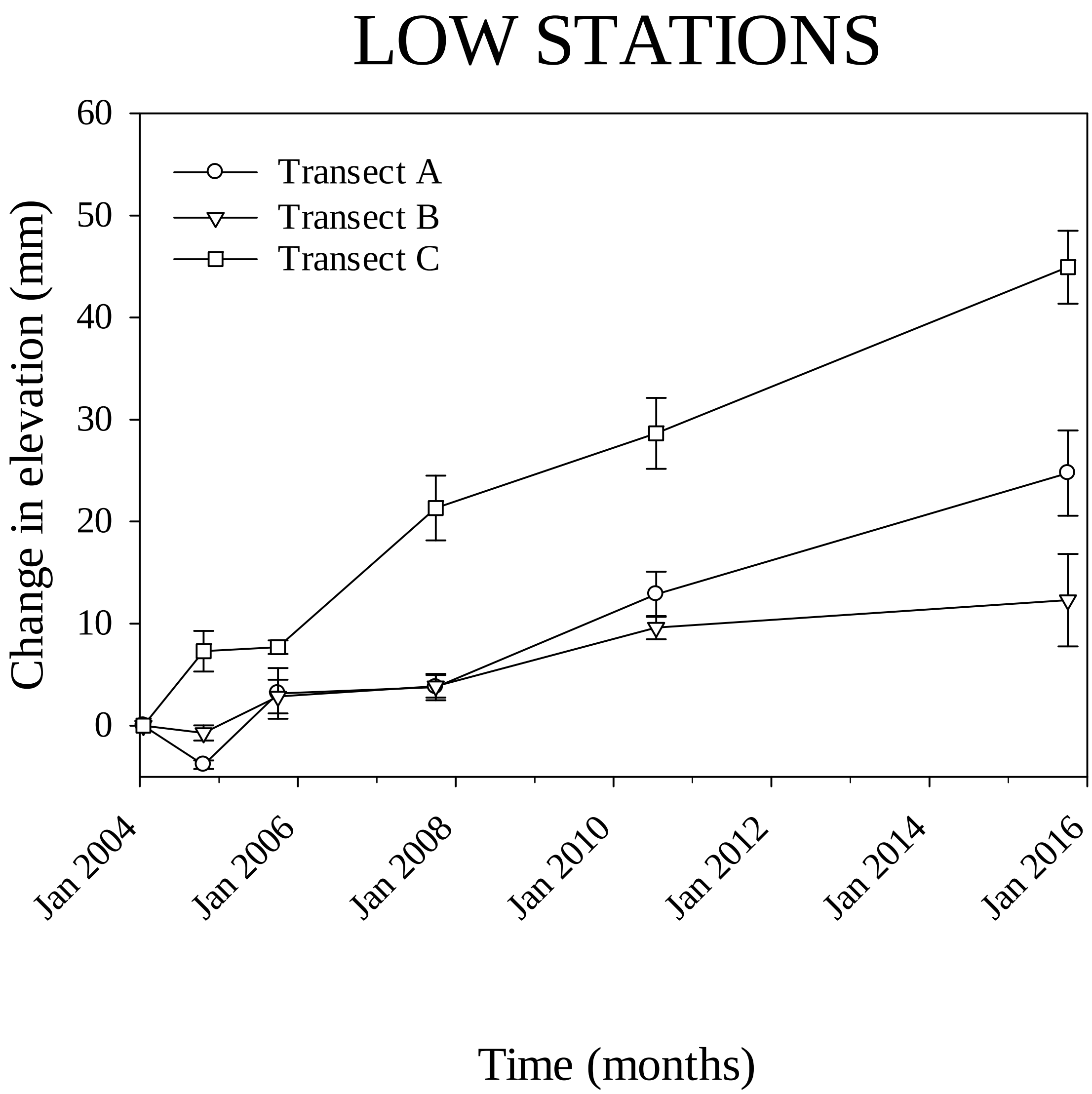


Figure 5. Mean change in surface elevation (and standard error) for low stations in the Morro Bay salt marsh from January 2004 to October 2015. Data are also presented in Table 6. Transect locations are shown on Figure 1.

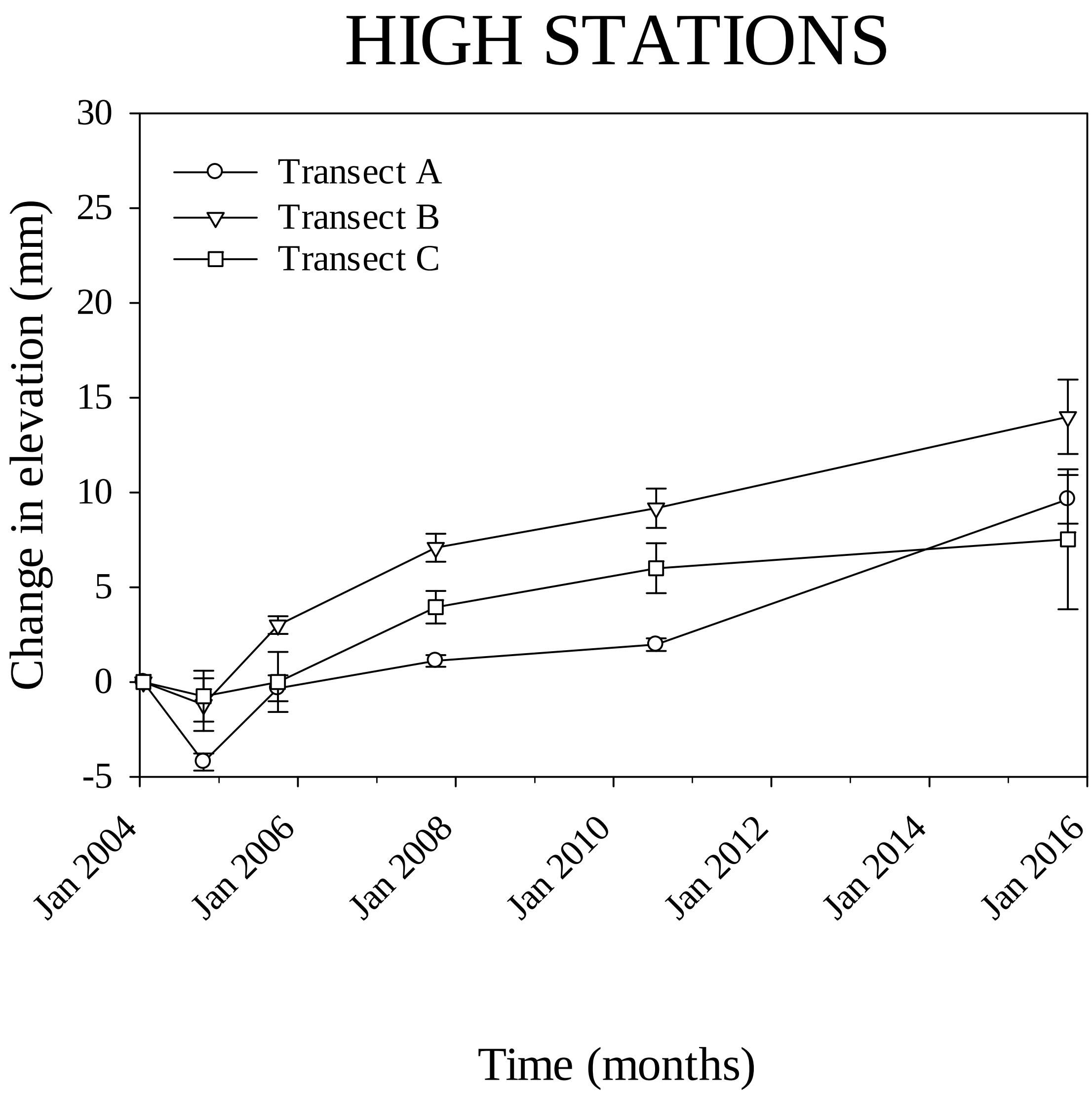


Figure 6. Mean change in surface elevation (and standard error) for high stations in the Morro Bay salt marsh from January 2004 to October 2015. Data are also presented in Table 6. Transect locations are shown on Figure 1.

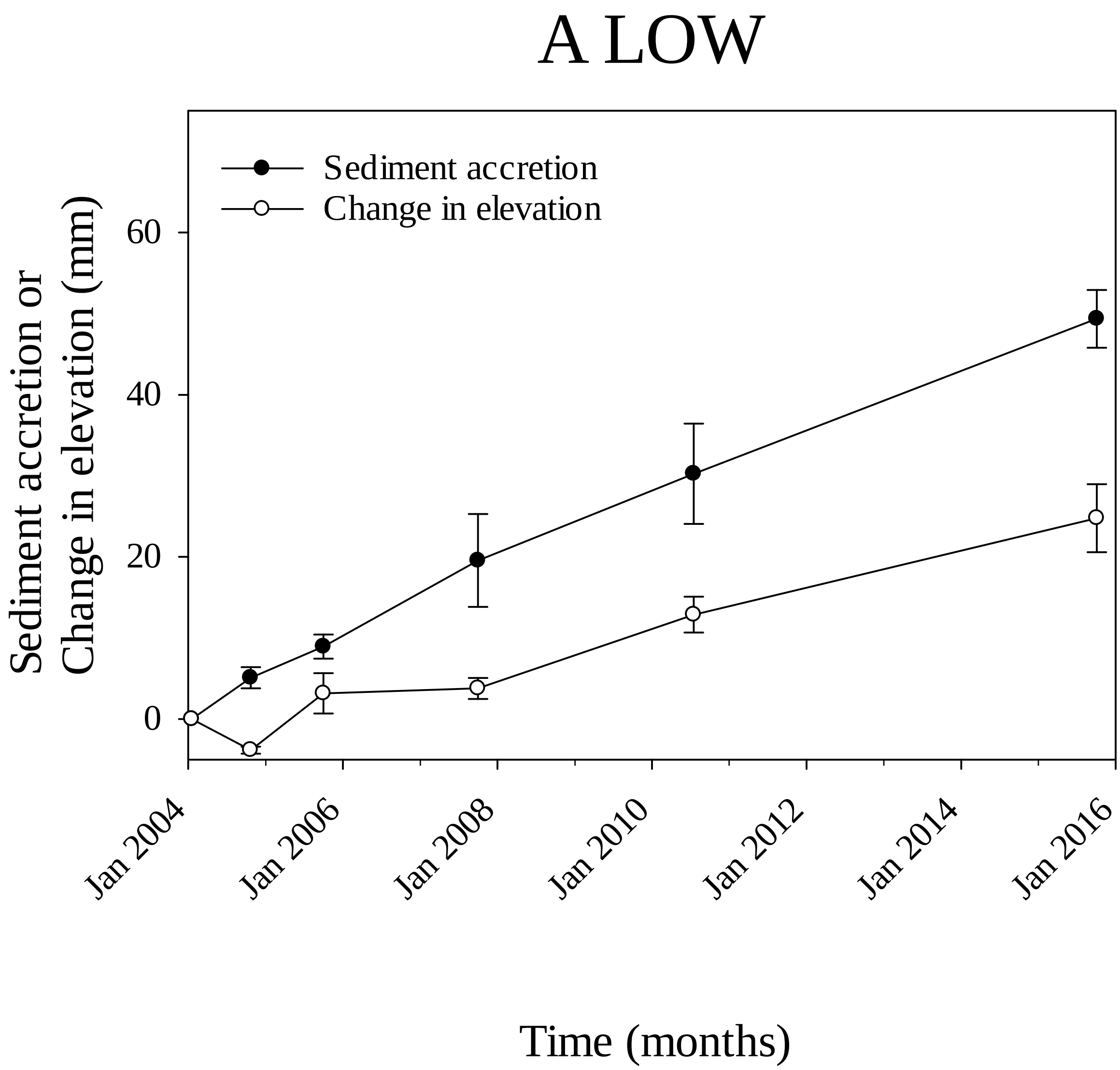


Figure 7. Comparison of sediment accretion and change in surface elevation for station A Low in the Morro Bay salt marsh from January 2004 to October 2015.

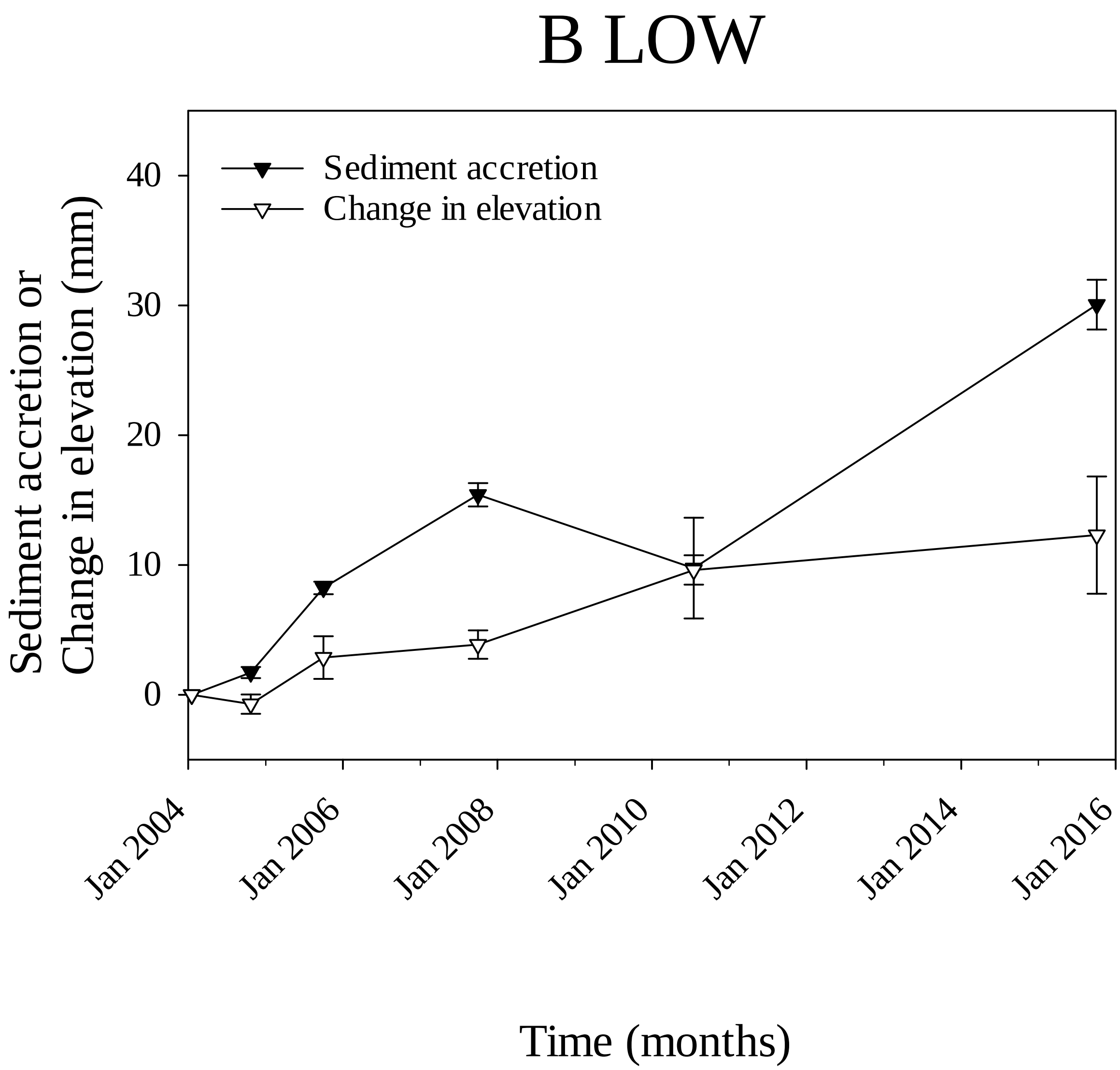


Figure 8. Comparison of sediment accretion and change in surface elevation for station B Low in the Morro Bay salt marsh from January 2004 to October 2015.

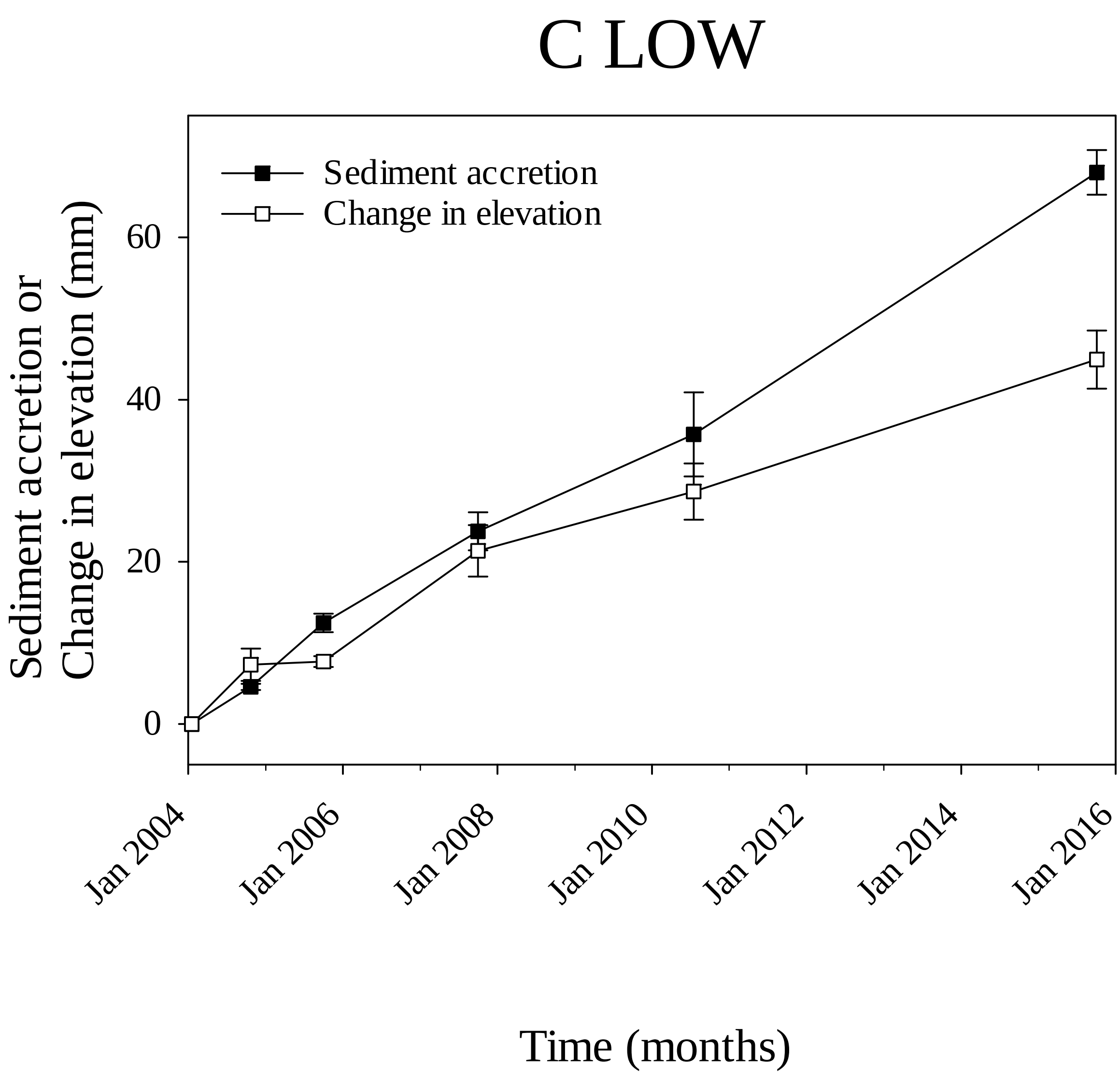


Figure 9. Comparison of sediment accretion and change in surface elevation for station C Low in the Morro Bay salt marsh from January 2004 to October 2015.

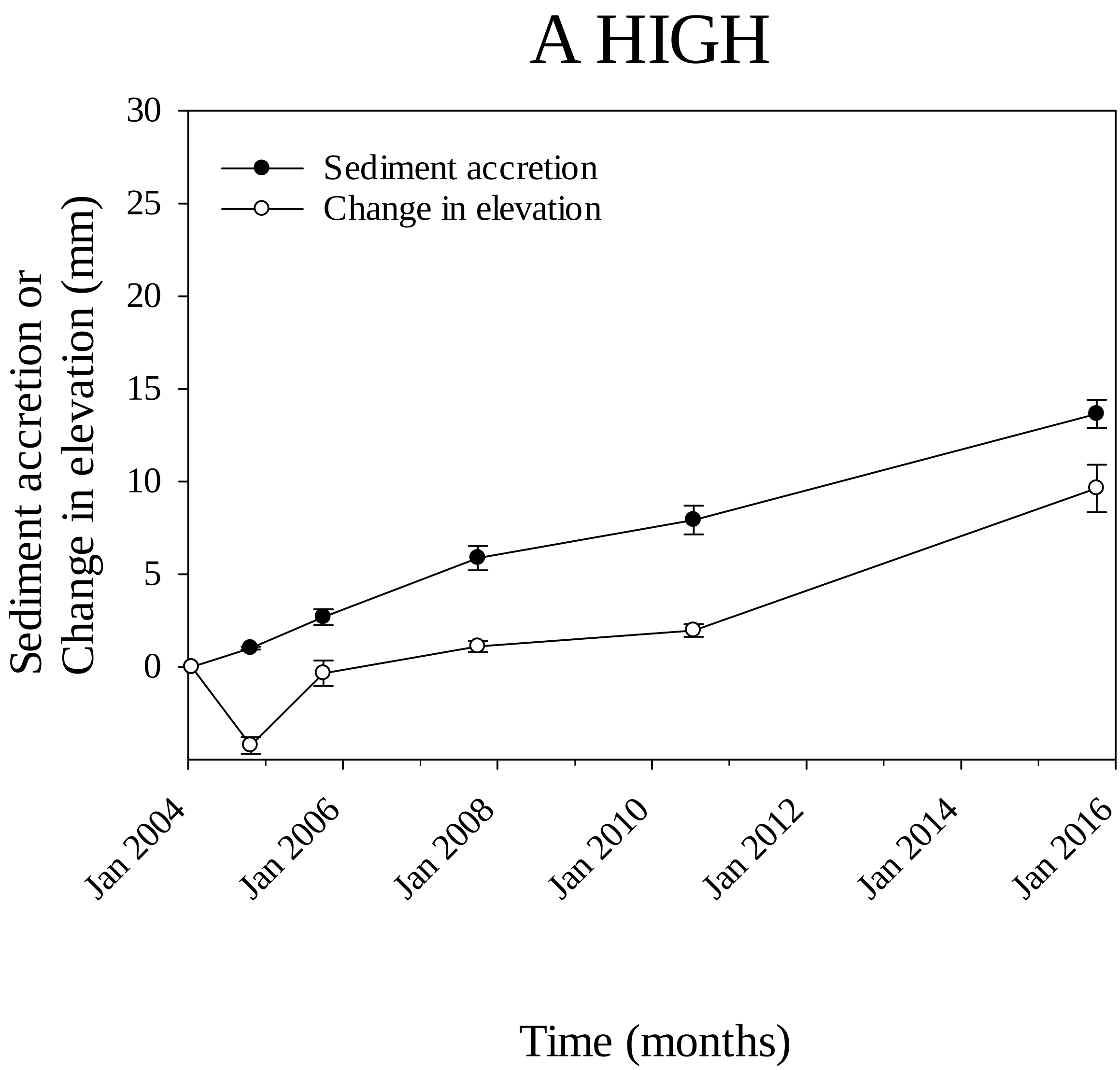


Figure 10. Comparison of sediment accretion and change in surface elevation for station A High in the Morro Bay salt marsh from January 2004 to October 2015.

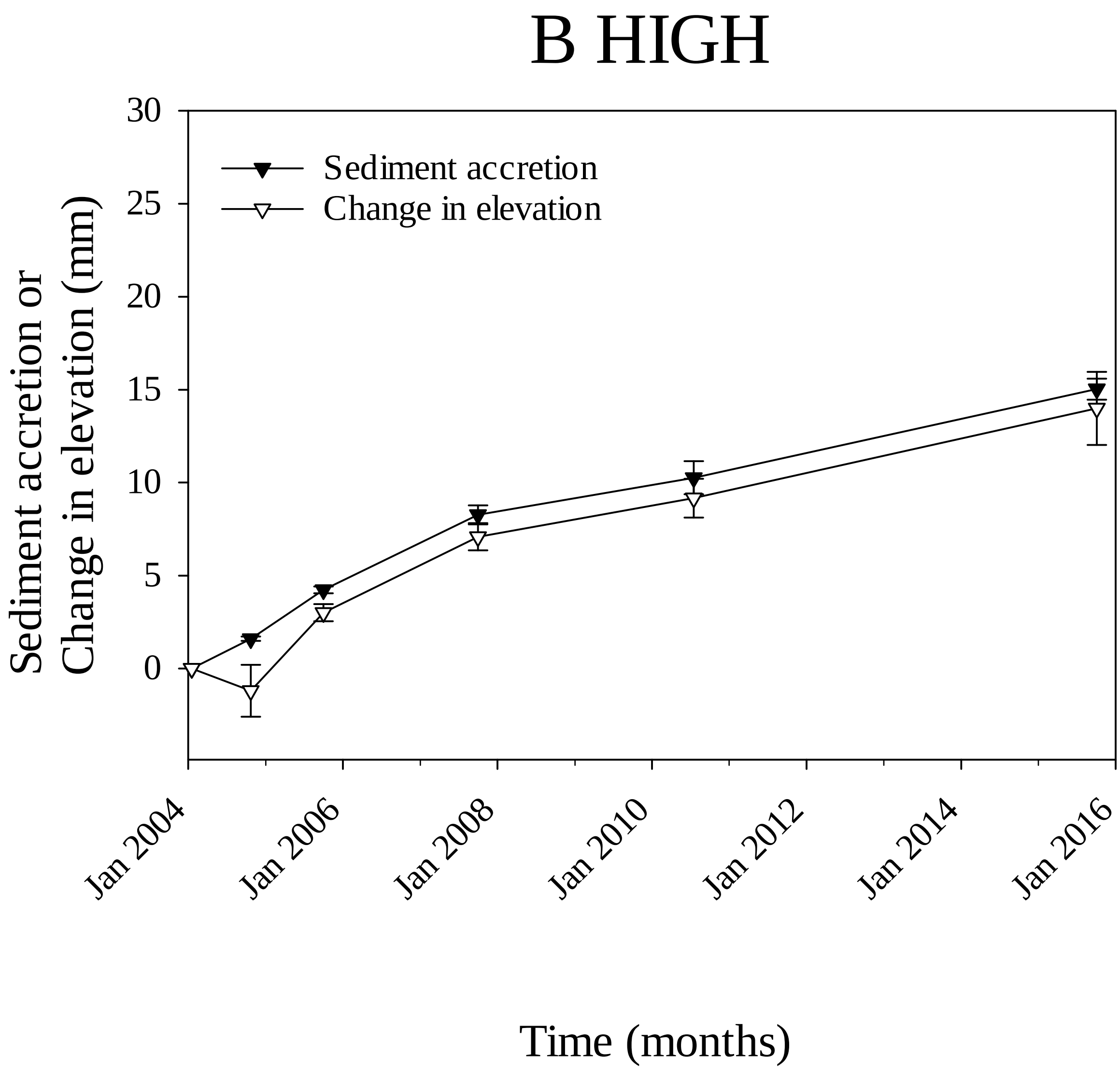


Figure 11. Comparison of sediment accretion and change in surface elevation for station B High in the Morro Bay salt marsh from January 2004 to October 2015.

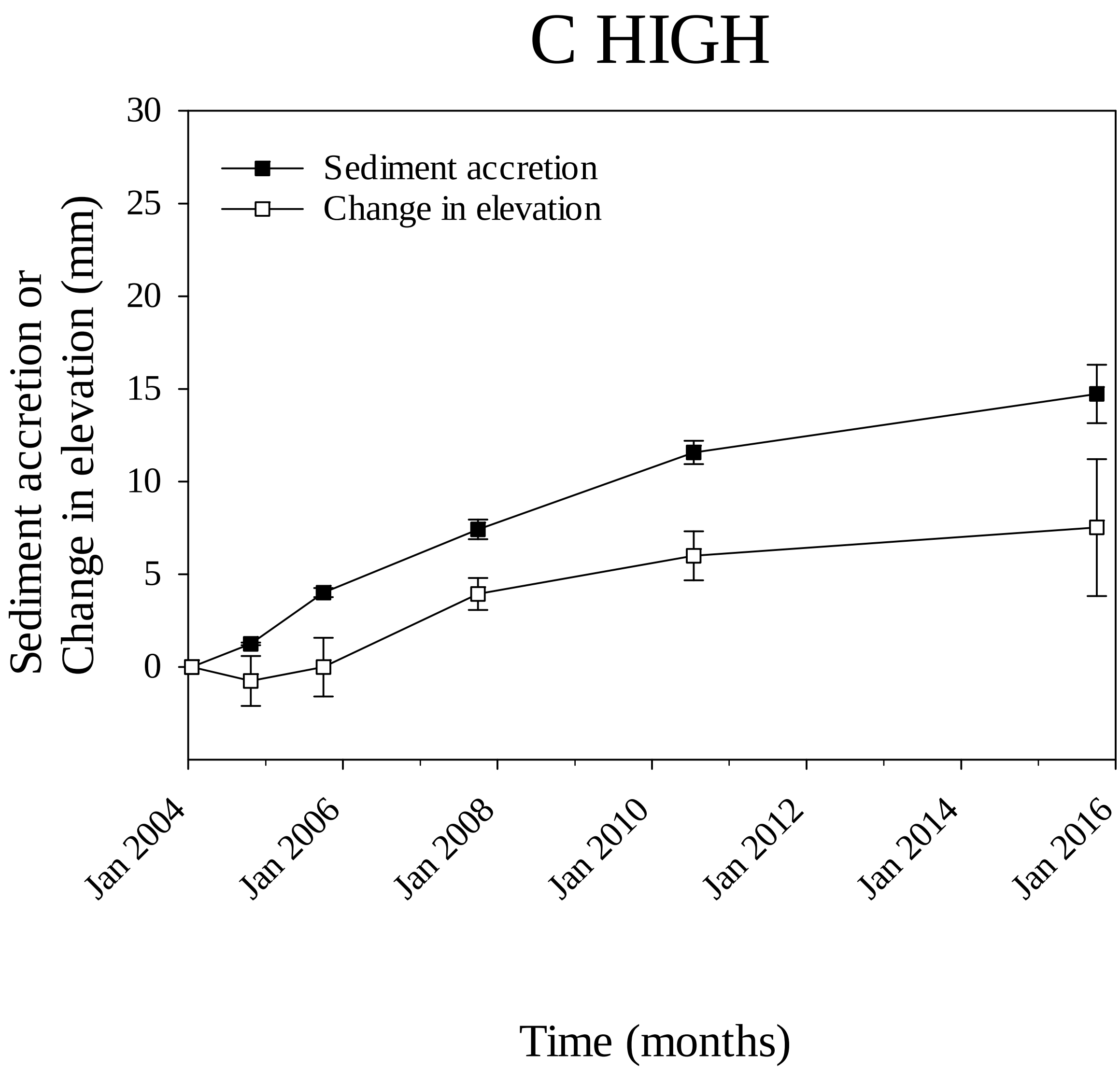
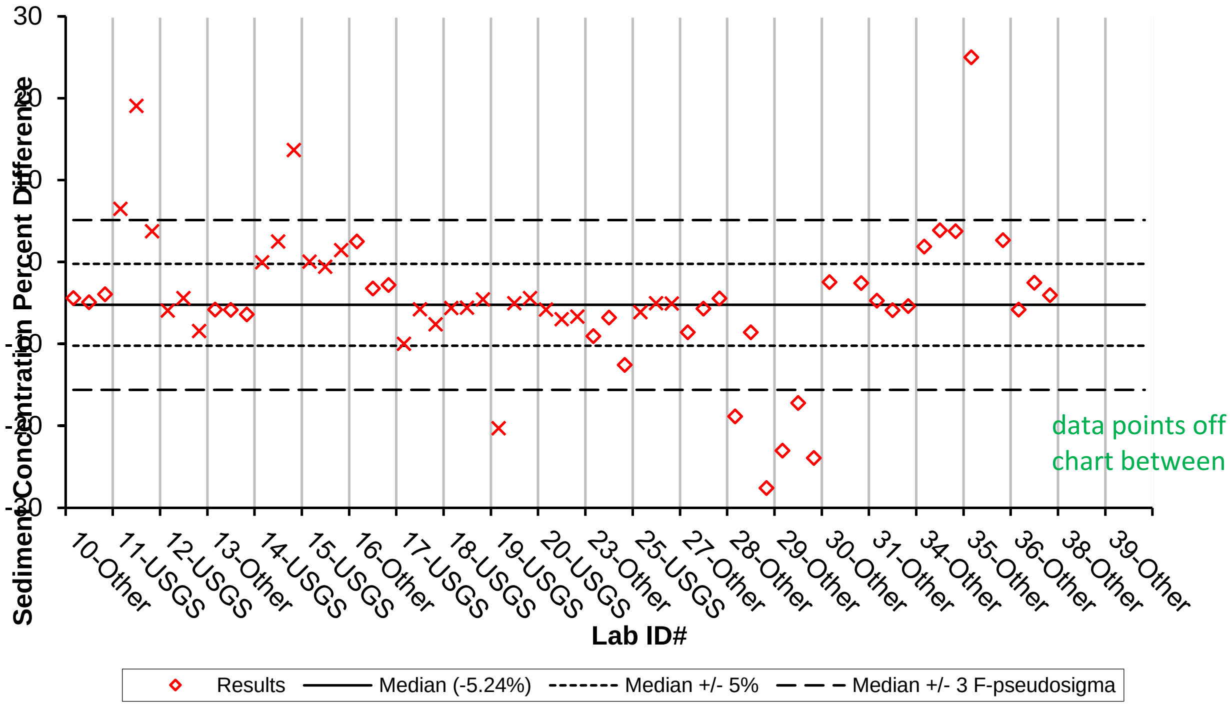


Figure 12. Comparison of sediment accretion and change in surface elevation for station C High in the Morro Bay salt marsh from January 2004 to October 2015.

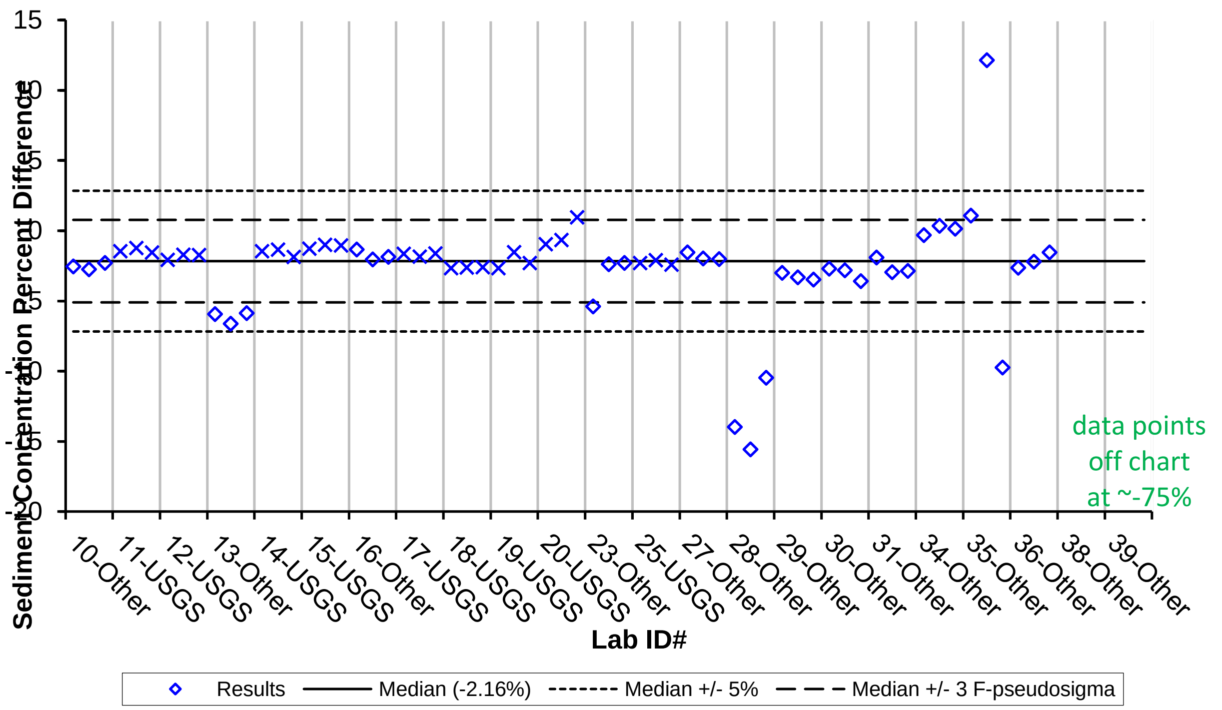
APPENDIX B. USGS SLQA RESULTS

Note: MBNEP's results are labeled as "35-Volunteer."

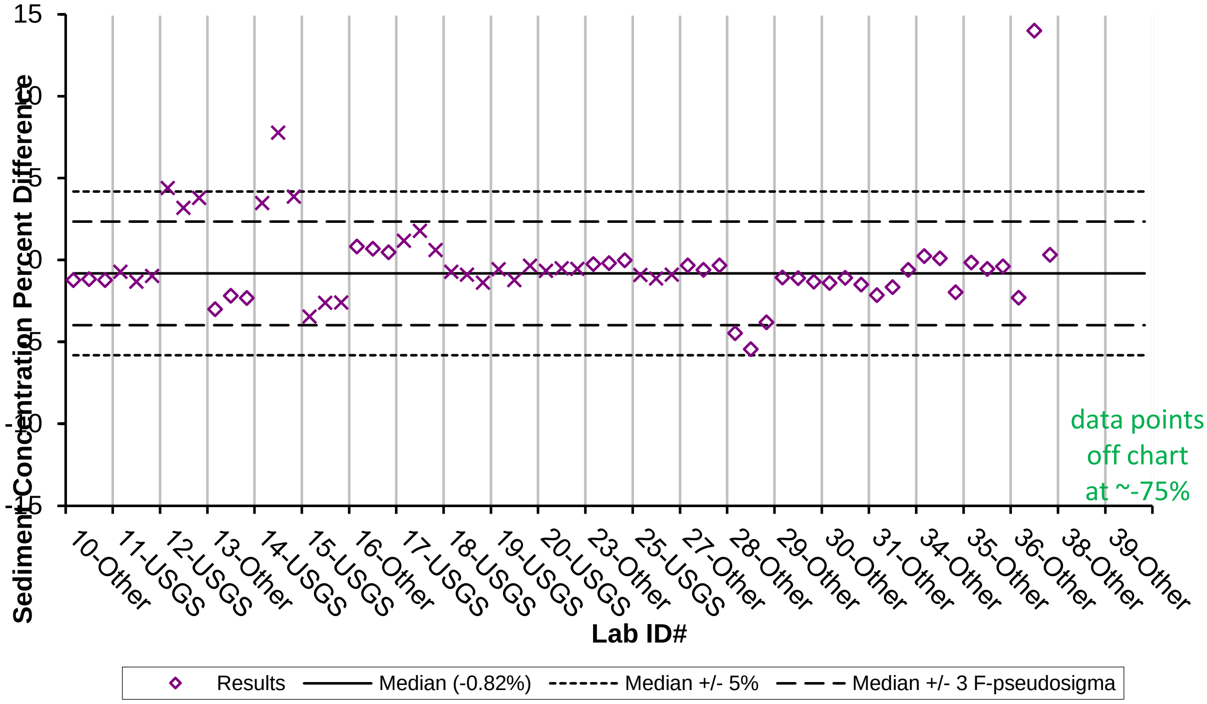
USGS Sediment Laboratory Quality Assurance Project - Study 2, 2015
Suspended Sediment Concentration Percent Difference Results
Class 1 Target SSC = 217 mg/L



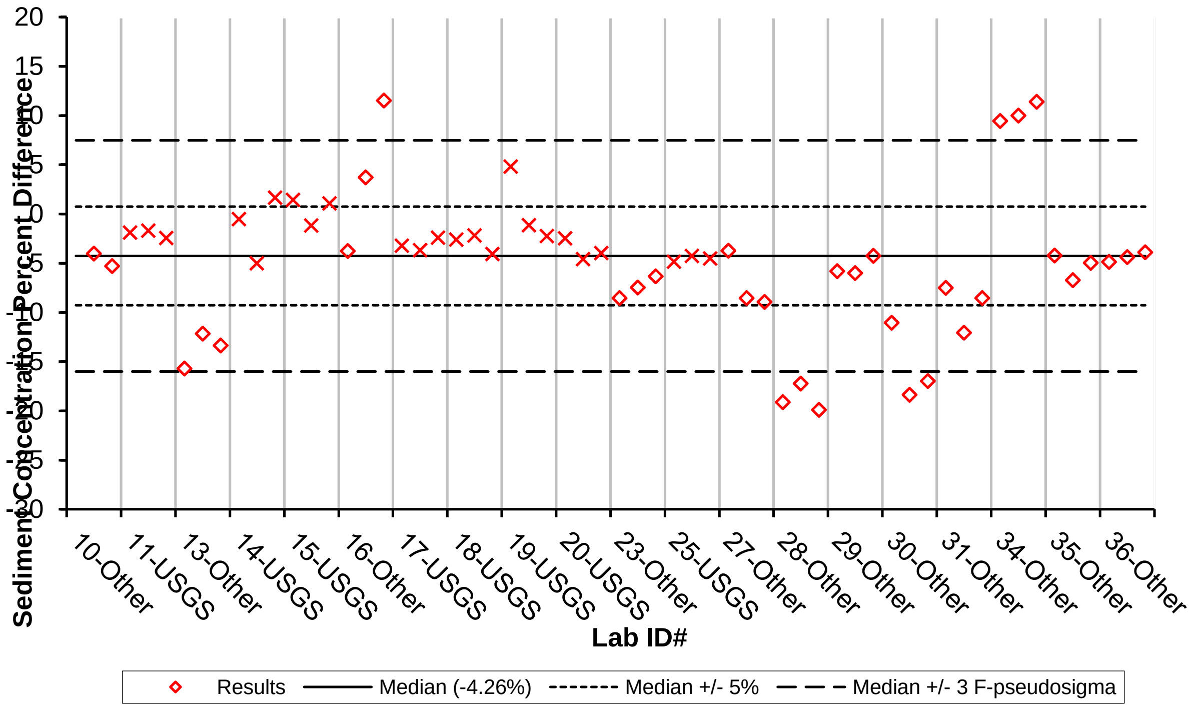
USGS Sediment Laboratory Quality Assurance Project - Study 2, 2015
Suspended Sediment Concentration Percent Difference Results
Class 2 Target SSC = 1467 mg/L

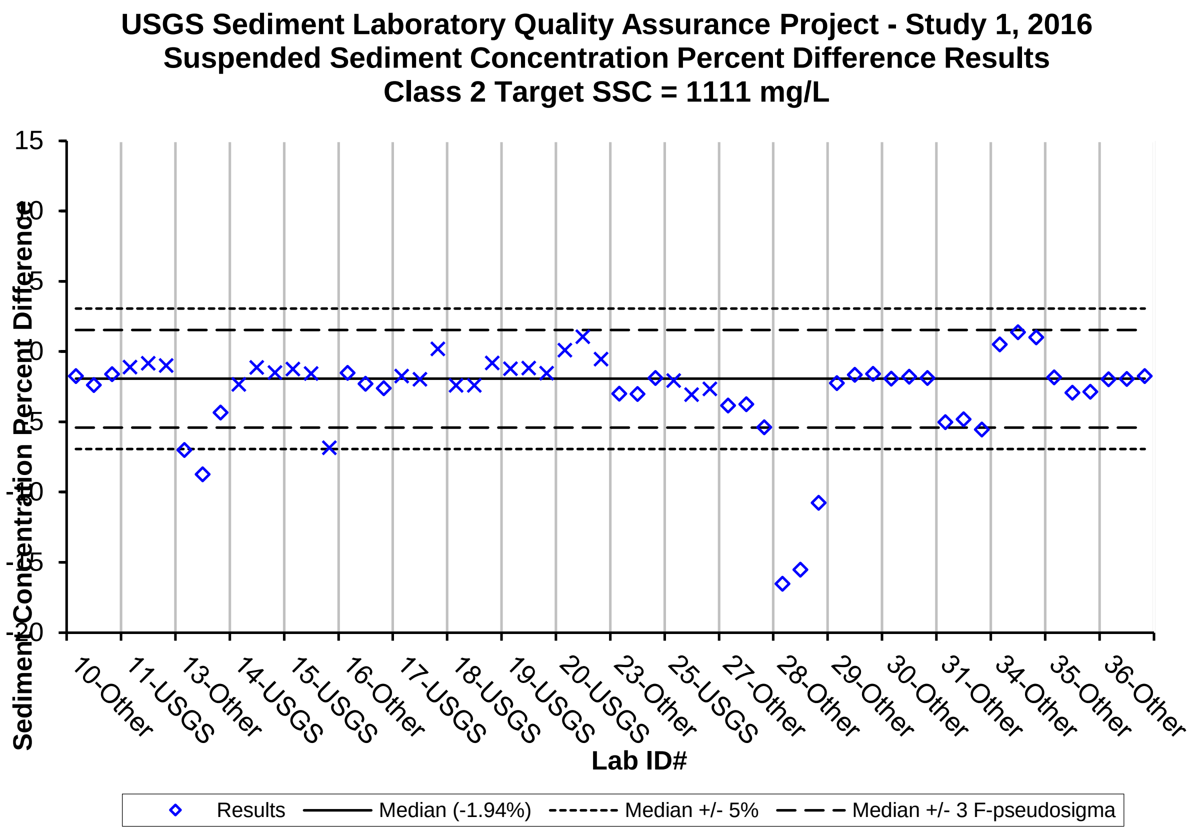


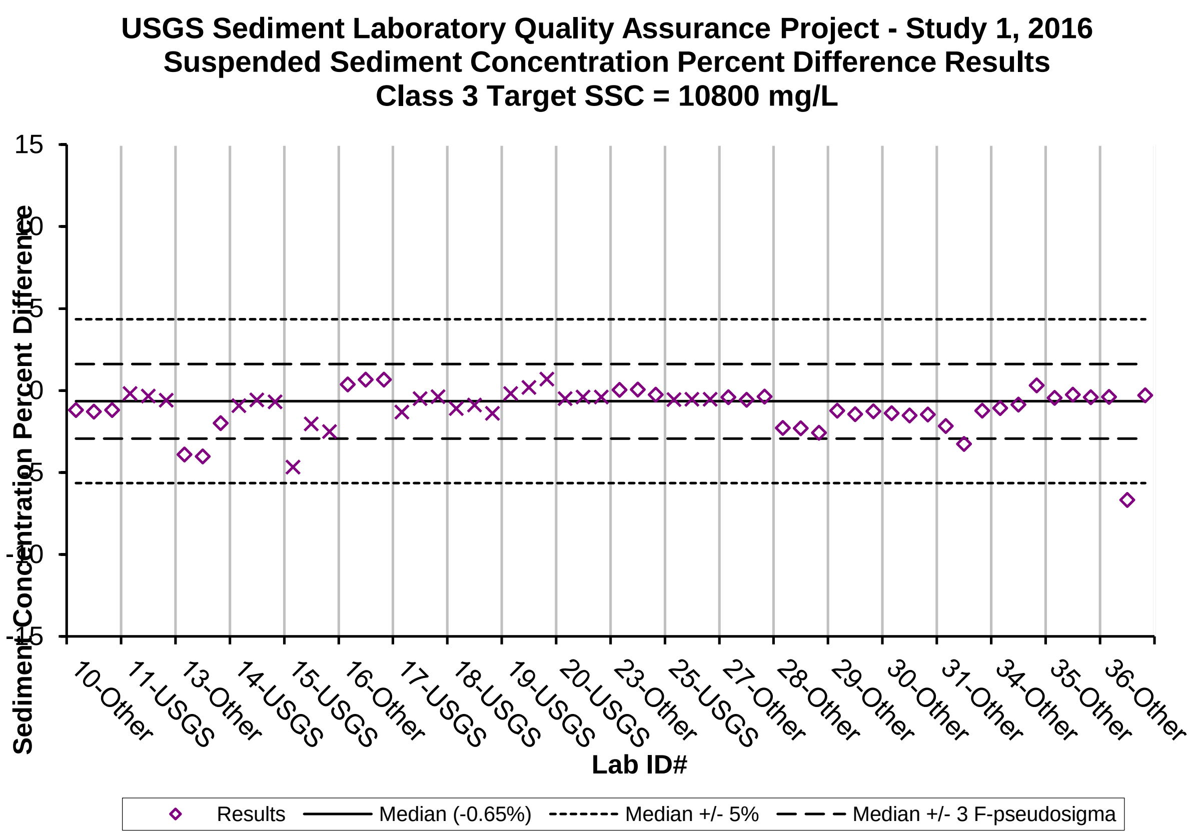
USGS Sediment Laboratory Quality Assurance Project - Study 2, 2015
Suspended Sediment Concentration Percent Difference Results
Class 3 Target SSC = 9778 mg/L



USGS Sediment Laboratory Quality Assurance Project - Study 1, 2016
Suspended Sediment Concentration Percent Difference Results
Class 1 Target SSC = 188 mg/L




USGS Sediment Laboratory Quality Assurance Project - Study 1, 2016
Suspended Sediment Concentration Percent Difference Results
Class 2 Target SSC = 1111 mg/L
Sediment Concentration Percent Difference
15
10
5
0
-5
-10
-15
-20
10-Other
11-USGS
13-Other
14-USGS
15-USGS
16-Other
17-USGS
18-USGS
19-USGS
20-USGS
23-Other
25-USGS
27-Other
28-Other
29-Other
30-Other
31-Other
34-Other
35-Other
36-Other
Lab ID#
Results
Median (-1.94%)
Median +/- 5%
Median +/- 3 F-pseudosigma


USGS Sediment Laboratory Quality Assurance Project - Study 1, 2016
Suspended Sediment Concentration Percent Difference Results
Class 3 Target SSC = 10800 mg/L
Sediment Concentration Percent Difference
15
10
5
0
-5
-10
-15
10-Other
11-USGS
13-Other
14-USGS
15-USGS
16-Other
17-USGS
18-USGS
19-USGS
20-USGS
23-Other
25-USGS
27-Other
28-Other
29-Other
30-Other
31-Other
34-Other
35-Other
36-Other
Lab ID#
Results
Median (-0.65%)
Median +/- 5%
Median +/- 3 F-pseudosigma