

Stillaguamish Estuary Monitoring Report Summary

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Field monitoring of biophysical conditions

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Monitoring Context

Key objectives of the Port Susan Bay restoration project were to restore self-sustaining tidal wetlands on the 60 ha project footprint, and to improve connectivity between the river and northern tidal habitats in order to increase the functions, services and resilience of the larger estuary system. These restoration objectives invoke two scales: site and ecosystem. Accomplishing both of these objectives requires changing the fundamental physical drivers of habitat formation in a way that facilitates the development and increased functionality of habitats. The project hypothesis was that removing the dike would change those physical drivers in a way that would deliver the desired habitat objectives.

The key physical drivers of habitat development include the distribution and dynamics of sediment accretion and erosion, the distribution of river flows (freshwater), the hydrodynamics of river and tidal interactions, and the role of disturbance in modifying those drivers. The habitat outcomes observed in the years that follow restoration result from the interaction of the physical drivers with vegetation. Different types of vegetation communities develop in response to the physical drivers, but the vegetation also modifies the physical processes. For example, seasonal changes in the vertical structure of vegetation will affect the amount of suspended sediment that gets captured for accretion.

This monitoring project focuses on measuring

- how the physical drivers operate at both site and system scales
- how vegetation patterns and physical drivers interact to affect long-term habitat development, and
- how restoration affects the outcomes of biophysical interactions.

Monitoring Design

Five Study Sites

We organized monitoring around five zones in the delta (Figure 1) in order to understand the dynamics at the restoration site and the effect of the restoration on different areas of the delta. The physical drivers of estuarine habitat development vary substantially over space, with the strongest patterns in relation to distance from the main river mouth at Hatt Slough. The five study zones allow us to capture this range of variability without having to sample the entire system. This structure also provides a great baseline that facilitates future monitoring and research related to long-term effects of old and new restoration projects, climate change impacts and basin-scale land use changes.

Each zone is a discrete area capturing, to the extent possible, the entire drainage basin of one or more blind tidal channel systems. The five study zones represent different points on a gradient of hydrogeomorphic connectivity with the river, and allow an analysis of the effects of landscape position on restoration response. As such, various biophysical characteristics are expected to differ among the five zones, including salinity and sediment dynamics, vegetation structure, hydraulic energy, water and soil quality, invertebrate and vertebrate composition, etc. The zones are numbered in order of the relative importance of river flow to their physical conditions, beginning with the southernmost zone. Detailed maps of sampling sites in each zone are provided in Appendix 1.

Zone 1 is an island to the south of the Hatt Slough mouth and is the zone under the greatest influence of the river's freshwater since two of the largest distributaries define the boundaries of the island. The zone has one major blind tidal channel that drains to the river's largest distributary. This zone was framed as the restoration reference site for the project (Woo et al. 2011). In hind sight, zone 3 described below is likely a more relevant reference site, but each of the four non-restoration zones together provide a reference spectrum within which we can better understand the outcomes of restoration.

Zone 2 is the restoration zone itself. Since it abuts the dike system, it is not a true marsh island, but it is drained by blind tidal channels as are the other sites. Hatt Slough runs along its southern edge, but no flow from Hatt Slough moves directly onto the site except at flood flows. A small distributary channel flows north along much of the western edge and is the channel feeding the two blind tidal channel systems that penetrate the restoration zone.

Zone 3 is an island just to the north of the mouth of Hatt Slough and west of the restoration site. This site is similar to zone 1 in that it is surrounded by two distributaries, though they are much smaller than those surrounding zone 1. Two major blind channel systems drain the island, along with a few small channels. Since this zone is on the same side of Hatt Slough as the restoration site, and is influenced by smaller distributaries than zone 1, it is likely a better reference site for the restoration. Early results of vegetation and sediment sampling confirm that the sites are likely more similar than zone 1.

Zone 4 occurs in the mid-delta region, about half way between the restoration site and South Pass. There are no distributaries in this area so the site includes a marsh plain drained by two blind tidal channel systems. Similar to the restoration site, this site abuts the dike system and so is not a true

Restoration Monitoring in the Stillaguamish Estuary

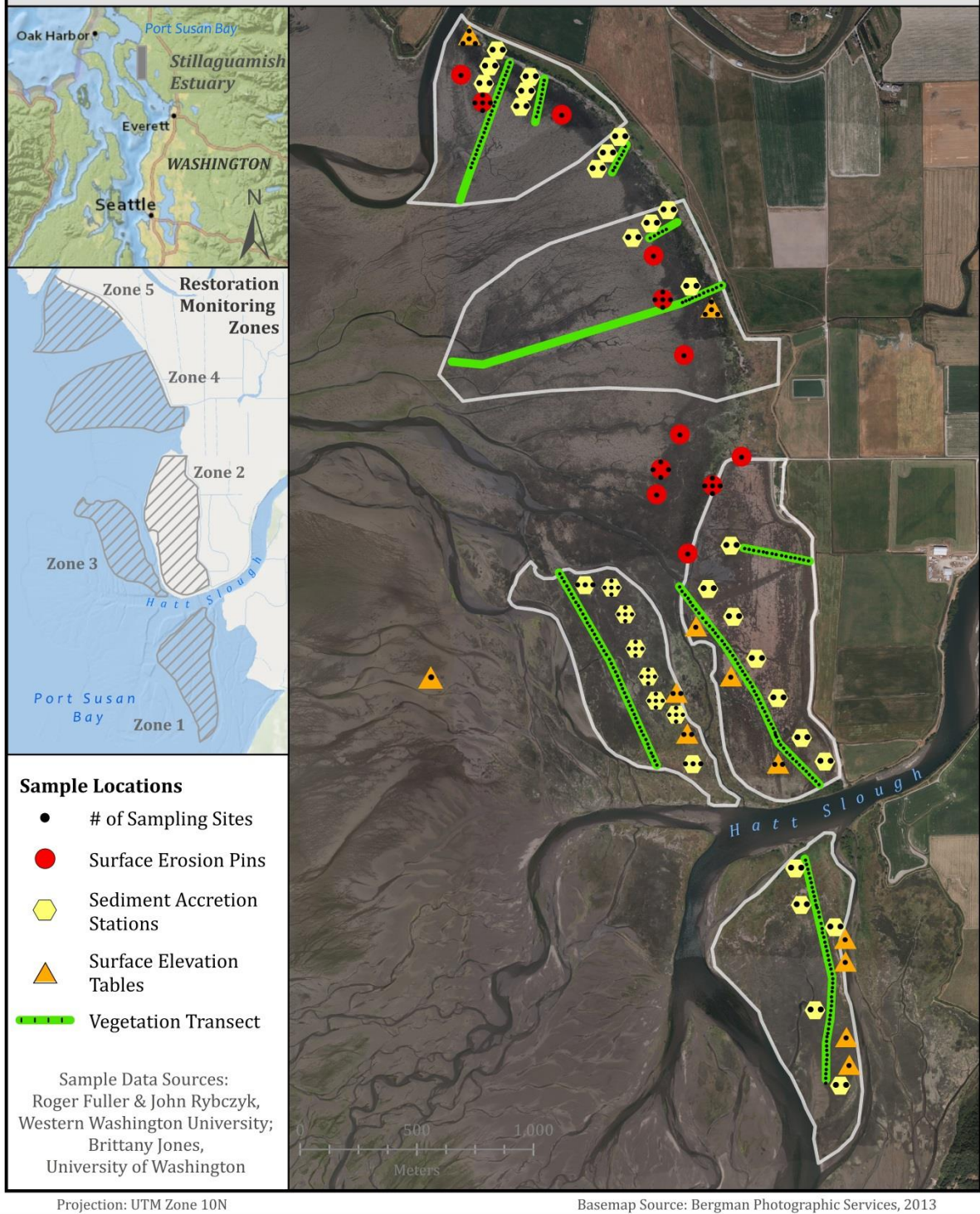


Figure 1. Approximate locations of monitoring sites in the five study zones of the Stillaguamish estuary.

marsh island. Zone 4 represents the mid-delta marshes that are most disconnected from the river and potentially the most vulnerable to accretion and salinity issues in light of climate impacts. The restoration project may result in improved connectivity for this zone.

Zone 5 is near South Pass which is under some level of influence from the Old Stilly channel and potentially from the south fork of the Skagit. However anecdotal observations and early monitoring results suggest that tidal dynamics dominate, and riverine influence is likely quite minor. In addition to shedding light on the effect of landscape position on restoration response, this last site will also provide a context for understanding the potential effects of future restoration at Leque Island and Matterand.

Sampling layout

Sampling is designed to study the interaction of key physical drivers and vegetation. Elevation, sediment dynamics, inundation and vegetation are closely associated and are monitored within each zone on transects that sample across gradients of elevation and habitat type. The proximity of an area to a major distributary also plays a key role in salinity, sediment particle size and other physical drivers. Distributary proximity is represented in the spatial distribution of the five study zones.

The monitoring at each site is organized similarly, with a series of SET's to capture high resolution long term trends in accretion, and a series of vegetation and short term accretion plots arranged across the elevation spectrum of the zone to capture biophysical conditions. Vegetation plots are positioned contiguously along transects that run parallel to the dominant topographic slope. Short term accretion plots are generally positioned alongside the vegetation transect at various elevations. Sample stations are positioned in the middle of the marsh plain, not immediately adjacent to channels, although some vegetation transects cross blind channels.

Field Data Collection

The draft field sampling methods are provided in Appendix 2.

Summary of physical, hydrological and vegetation patterns

All five zones were sampled extensively during the winter period to characterize the species and physical vegetation structure. Winter conditions are important because this is the season with the most dynamic sediment conditions. Winter experiences the highest river flows, greatest suspended sediment delivery, highest tides, and most dynamic wind-wave conditions. Vegetation structure interacts with flows to strongly influence the distribution of sediment and rates of accretion. Since these are key drivers of marsh development and resilience, it is important to understand how winter vegetation structure differs from summer structure.

In addition to the winter data, all zones are in the process of being sampled for summer peak growing season vegetation conditions. This report summarizes the winter data from all zones and summer data from zones 1, 2 and 5.

General physical conditions

The zones range in area from 100 to 200 acres (Table 1). Vegetation and accretion transects were arranged across the elevation gradient in each zone, running from the highest area of the marsh plain in each zone to the lowest area. In zones 1, 3, 4 and 5, the upper end of the transect began at approximately the upper log deposition zone, which is above MHHW, generally where the average winter storm pushes logs. Zone 2, the restoration zone, does not extend to that elevation, except at the south end where the narrow upper band of the old dike footprint approaches this elevation. Transect lengths ranged from 640 to 1265m. Zone 4 has the largest area and longest transect, in order to completely capture the drainage basin of two blind channel systems. Zone 2, the restoration zone has the second largest area and transect length.

Table 1. Physical characteristics of the five study zones and transects. Zone 2 is the restoration zone.

Zone	Area (ac)	Transect length (m)	Elevations (m, NAVD88)	Vegetated Elevations	Elevation range	Slope (cm/m)	Proportion of Transect by Inundation Zone			
							<MSL (<1.36)	MSL-MHW (1.37-2.50)	MHW-MHHW (2.51-2.77)	MHHW+ (2.78+)
1	119	1,000	1.71-2.93	1.71-2.93	1.22	0.122	0	80	8	12
2	156	1,080	1.50-2.32	1.83-2.32	0.82	0.076	0	100	0	0
3	98	940	1.54-2.85	1.54-2.85	1.31	0.139	0	89	9	2
4	199	1,265	1.1-3.19	1.23-1.4, 1.86-3.19	2.09	0.222	28	64	3	5
5	107	640	1.18-2.38	1.37-1.41, 1.62-2.38	1.2	0.188	28	72	0	0

The restoration area displays some key physical differences from all four natural areas. Estuarine marshes have, by nature, very gently, almost imperceptibly sloping topography. But even in that context, the restoration site has a slope that is 38-66% more gentle than the natural sites (Figure 2). Although it has the second longest transect, the range of elevations across the Zone 2 transect is much smaller than transects in the other zones (Figure 2). These differences will have significant effects on physical dynamics such as inundation periods, sedimentation and soil chemistry, and will likely affect biotic evolution of the site over time. The difference is likely driven by the legacy of farming and diking at the site. Decades of plowing and isolation from the river's sediment has contributed to topographic flattening. One opportunity from studying this site is to gain insight into the effects of restoration site topography and consider whether additional construction design elements such as reshaping the land might have improved future project ecological performance. The physical difference from the four "reference" areas is one of the reasons that the site is unlikely to look like any of the natural areas in the near future. It will develop in its own trajectory.

Another difference evident in the slopes of the zones is that the northerly zones, which have been losing marsh rapidly since 1990, have considerably steeper slopes than the southern marshes near the river mouth. Steeper slopes may be an indicator of an erosional environment in which the topography is adjusting to changes in driving factors such as reductions in sediment, changes in currents or wind/wave conditions, changes in water levels, or changes in disturbance regimes to sediment or vegetation.

Soils

The five zones have different soil characteristics that are important to tease apart in order to understand how they affect ecological functions and the effects of restoration. Soil comparisons are just being initiated, but some results of a test of soil firmness are shown in Figure 3. A penetrometer is dropped onto the sediment surface under controlled conditions and the depth that it penetrates the soil indicates the level of soil firmness. In wetlands, soil penetrability may be related to various factors such as particle size, compaction, biofilm development, organic content and goose foraging efficiency. The deeper the penetrometer penetrates, the softer the soil, and generally the finer the soil particle sizes.

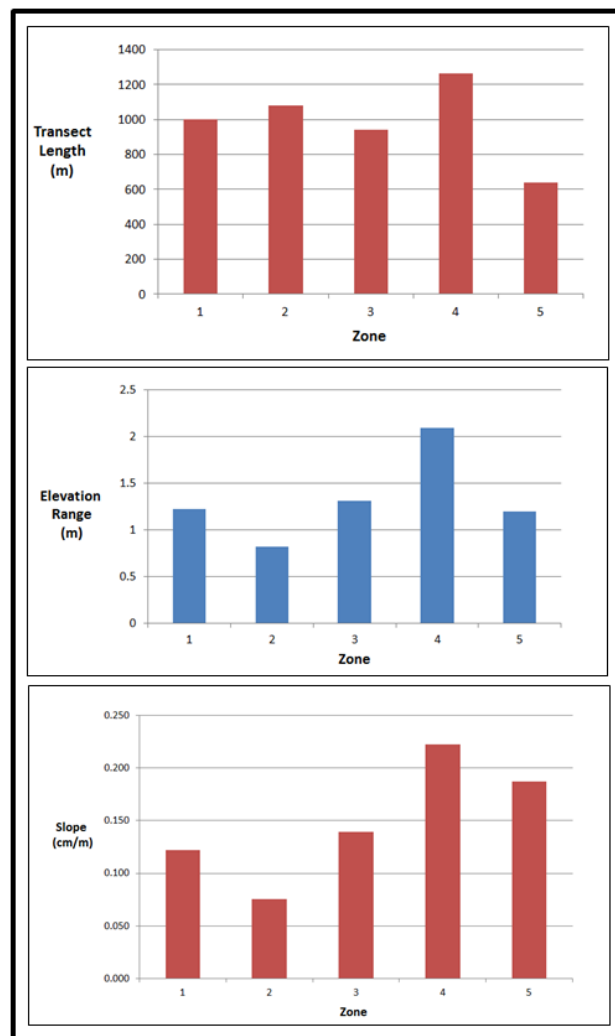


Figure 2. Physical characteristics of the five primary study zone transects.

Penetration testing has been completed in three zones and the restoration zone 2 has substantially less firm soils than zones 1 and 5 (Figure 3). The restoration area had softer soils before restoration as well,

but this characteristic could also be affected by greater sediment deposition rates than other zones, which accretion monitoring suggests is happening. Newly deposited sediment tends to be lighter and less compacted than older sediment which has had time to settle and eliminate some of the air and water that fills pore spaces. So a larger amount of newly deposited sediment could increase the softness and penetrability of the soil.

In all zones, penetration depths appear to follow a bell shape curve, with deeper penetration in middle elevations of the zone and shallower penetration at higher and lower elevations. Zone 1, surrounded by the river's two largest distributaries, has the firmer, more coarse sediment of the three zones, with more than half the samplings having firmer soil than any of the samples in the other two zones.

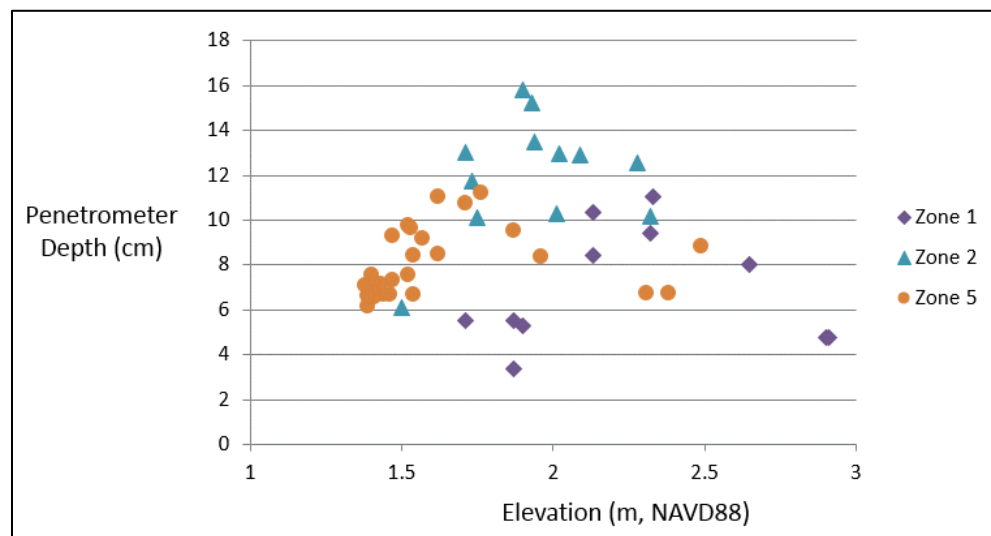


Figure 3. Soil firmness as measured by a penetrometer. The deeper the penetration, the softer the soil and finer the particle sizes.

On the Fraser River delta, penetrometers have been used to test soils for goose foraging efficiency where they have found that geese graze more intensely on softer soils from which it is easier to extract the rhizomes of bulrush and sedge. This pattern may help explain the pattern of tidal marsh in the north of Port Susan Bay where there is a short, sparse low elevation marsh of threesquare bulrush, a middle elevation zone that is bare of vegetation and a higher elevation tidal marsh of mixed threesquare and maritime bulrush. The lower elevation soils are sandier and firmer and may experience less intense grazing, while the middle elevations with slightly softer soils may be grazed intensively. The higher elevation marshes, with denser, taller maritime bulrush, maintain sufficient above ground biomass during the winter that may provide some resistance to meandering geese and thus reduce grazing intensity at the higher elevations. Anecdotal evidence does suggest there may be a correlation in zone 5, where the area with the most evidence of goose excavation is above approximately 1.6m elevation where the soils are generally softer (Figure 3) than at lower elevations. More intense herbivory in the softer soils would also make those soils even more vulnerable to wind-wave erosion during winter, enhancing marsh loss even further in the middle and upper elevation areas.

The hypothetical construct just described, linking vegetation, elevation, sediment particle size, geese and waves may be key to understanding the fate of the northern marshes and the restoration site, and to identifying potential adaptive management strategies that encourage more resilient tidal marshes. There are a number of ways in which this conceptual model should be tested and we hope to pursue this avenue of investigation further. Getting absolutely clear on the interaction of driving forces will enable us to identify the adaptive management strategies that will increase marsh resilience, slow the loss of marsh in the north, and improve ecological function of restoration projects.

Hydrology

Species distributions, vegetation structure and biophysical conditions are affected to a substantial degree by the inundation period, which can be characterized in part by the use of a tidal datum. River flow and landscape position relative to the river will modify inundation periods. The following are the definitions of tidal datum that are referenced here.

MLLW – Mean Lower Low Water is the average of the lowest of the two daily low tides

MLW – Mean Low Water is the average height of all the low tides. In this area there are two low tides per day, with one being lower than the other. MLW is the average of both.

MSL – Mean Sea Level is the average height of the water across all tides

MHW – Mean High Water is the average height of all the high tides. In this area there are two high tides per day, with one being higher than the other. MHW is the average of both.

MHHW – Mean Higher High Water is the average of only the highest of the two daily high tides.

A general rule of thumb is that emergent marsh vegetation begins at about Mean Sea Level (MSL). The lowest, most frequently inundated marsh lies between MSL and MHW and as a result, generally experiences both inundation and drying twice per day. Above MHW, the marsh may only be flooded once per day, resulting in smaller periods of daily inundation. This difference in inundation drives differences in vegetation and accretion. Above MHHW is tidal marsh that is inundated less frequently than daily. These areas may be inundated several times per week or as little as once per month during the largest tide of the lunar tidal cycle.

For the purposes of this study, we have separated wetland areas into four elevation bins that define relative periods of inundation. The bins are <MSL, MSL-MHW, MHW-MHHW, and >MHHW. These bins define boundaries that are associated with significant differences in vegetation composition and structure. We used the 2013 LiDAR and aerial photograph to determine how different habitat types are distributed among important inundation bins. The area of analysis was limited to the aerial extent of both the LiDAR and photograph, which is shown in Figure 4. The continuous marsh habitat type occupied 780 acres and was spread among the upper three inundation bins, between MSL and MHHW+, with 71% occurring in the MSL-MHW zone (Table 2). A small amount, less than 5 acres, occurred below MSL. Patchy marsh and sparse marsh are habitat types that tend to occur at the lower boundary of continuous marsh, and are often indicators of either expanding or retreating marsh. There were 188 acres of patchy and sparse marsh, with about 25% below MSL and 75% in the MSL-MHW zone.

Table 2. Summary of the distribution of different habitat types in different inundation zones.

Habitat Type	Inundation Zones																		
	< MSL (<u><1.37</u>)				MSL-MHW (1.37-2.50)				MHW-MHHW (2.51-2.77)				MHHW+ (2.78+)				All Inundation Zones		
	% of this inundation zone		% of the total area for this habitat		% of this inundation zone		% of the total area for this habitat		% of this inundation zone		% of the total area for this habitat		% of this inundation zone		% of the total area for this habitat				
	acres	m ²	acres		m ²	acres	m ²		acres	m ²	acres		m ²	acres	m ²		acres	m ²	%
Total Area	4220	17,077,510		1558	6,305,475			105	424,072			127	513,551			11154	24,320,609	100	
Continuous Marsh	4.8	19,442	0.1	0.6	555	2,246,762	35.6	71	98	397,121	93.6	13	122	494,583	96.3	16	780	3,157,908	13
Patchy Marsh	6.8	27,644	0.2	23	23	92,885	1.5	77	0.1	217	0.1	0.2	0.2	98	0.0	0.1	30	120,843	0
Sparse Marsh	40	161,453	0.9	25	118	475,767	7.5	74	0.7	2,998	0.7	0.5	0.0	57	0.0	0.0	158	640,274	3
Tidal Channel	39	156,870	0.9	60	26	104,181	1.7	40	0.5	2,162	0.5	0.8	0.1	335	0.1	0.1	65	263,549	1
River Channel	633	2,563,205	15.0	74	220	889,552	14.1	26	1.5	6,131	1.4	0.2	1.2	4,972	1.0	0.1	856	3,463,860	14
Tide Flat	3496	14,148,896	82.9	85	617	2,496,329	39.6	15	4	15,444	3.6	0.1	0	0	0.0	0	9264	16,660,670	69

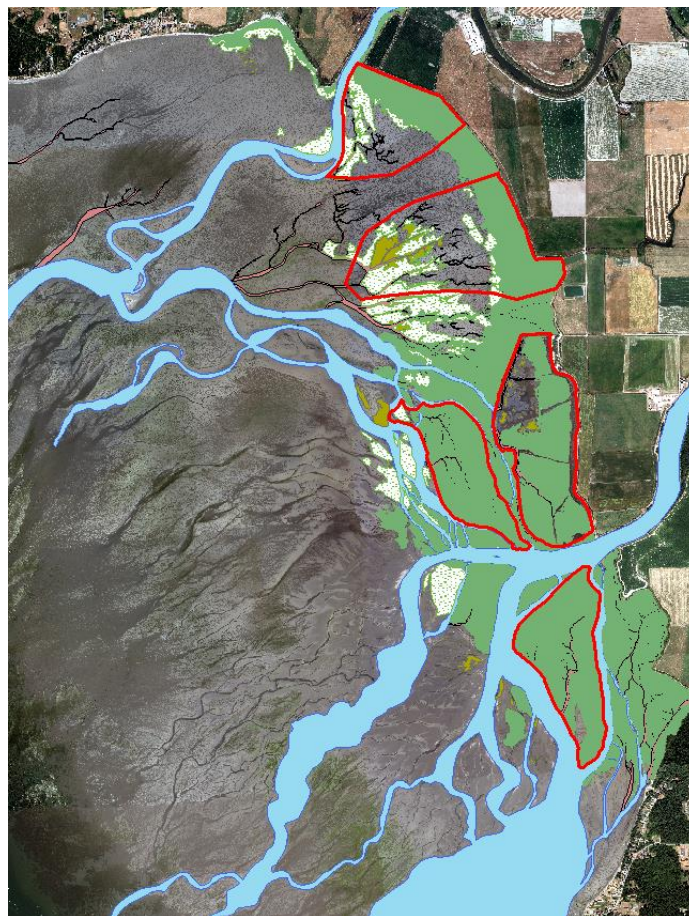


Figure 4. Aerial extent of the 2013 photograph used to digitize habitat and assess inundation bins using tidal datum boundaries (Table 2).

We also compared the five study zones with each other in terms of the distribution of inundation bins and habitat types. As expected, in all zones, the largest tidal marsh area occurs between MSL and MHW which spans a broader elevation gradient than the other inundation bins (Table 3, Figure 5). Zones 1 and 3, the natural marshes with the gentler sloping elevations, have substantially more marsh in the MHW-MHHW tidal range (12-14%) than other zones. The MHW-MHHW inundation range is an area of high productivity (tall plants with high stem densities). Zones 4 and 5, in contrast, have very little habitat in this tidal range (1.8-4.6%). Interestingly, though zones 4 and 5 have little habitat in the MHW-MHHW area, they are similar to zones 1 and 3 in terms of area above MHHW (10-12% in zones 1, 4, 5). In zones 4 and 5, it turns out that most of the MHHW+ area is in the highest elevations that are only tidally inundated a few times per year, during king tides and the larger storms. This part of the inundation area is upland of the log deposition zone that generally occurs well above MHHW. The log zone is also where shrubs begin to show up in the vegetation. In much of zone 5 where evidence of erosion extends throughout the marsh up to the shrub line, there is a 0.5-1m vertical cliff at the shrub line, which appears to be protected from erosion by the large wood deposits pushed up against the shrubs. The abrupt change in ground elevation is reflected in the fact that only 1.8% of zone 5 is in the MHW-MHHW inundation bin (in contrast to 14% in zone 1), while 12% of zone 5 is in the MHHW+ bin (same proportion as zone 1).

Table 3. Proportion of the study zones that fall within important inundation bins. Elevations are in meters, NAVD88.

Zone	Inundation Zone												Zone Total	
	<MSL (<1.36)			MSL-MHW (1.37-2.50)			MHW-MHHW (2.51-2.77)			MHHW+ (2.78+)				
	acres	m ²	% of zone	acres	m ²	% of zone	acres	m ²	% of zone	acres	m ²	% of zone	acres	m ²
1	1.2	4,876	1.0	86	346,687	72	17	69,061	14	15	59,422	12	119	480,045
2	0.9	3,677	0.6	149	603,381	95	2.0	8,090	1.3	4.4	17,962	2.8	156	633,109
3	3.6	14,571	3.7	77	310,119	78	11	45,969	12	6.4	25,880	6.5	98	396,539
4	37	151,024	19	133	538,735	67	9.1	36,702	4.6	20	79,411	10	199	805,873
5	15	59,962	14	78	315,234	72	1.9	7,688	1.8	13	51,926	12	107	434,811

The vegetation transects in the study zones are relatively similar in length, though a little shorter in zone 5, and they all run from above MHHW down to below MSL. However the steeper topographic slopes evident in zones 4 and 5 (Figure 2), and the reduction in the MHW-MHHW area, results in much larger areas that are below MSL (14-19%), in contrast to zones 1 and 3 with <4% below MSL. This pattern is reflected in both the overall zonal areas (Table 3), as well as on the vegetation transects within each zone (Figure 5).

Zone 2, the restoration zone, has the flattest topography, and this gentle slope is also reflected in the reduced diversity of elevation bins and marsh types in both the entire zone (Table 3), as well as on the vegetation transect specifically (Figure 5). In zone 2, despite having the second longest transect, the entire transect falls in the MSL-MHW range. There is no higher marsh in the restoration zone, in either the MHW-MHHW, or MHHW+ elevation ranges. The small area within zone 2 that falls above MHW occurs mostly in areas where farm and construction legacies left fill. Marshes that grow in the elevation

bins above MHW tend to produce more above-ground biomass and are more diverse, so the absence of elevation areas in the restoration zone that would support these marshes will affect the ecological functions of the site.

Table 4 provides more detail for each zone in terms of how much of the zone is comprised by different habitat types, and where those habitats occur with respect to inundation bins. In most estuaries, the inundation zone between MSL and MHHW is dominated by tidal marsh. We know from the distribution of threesquare bulrush in the Stillaguamish that it is capable of growing at all elevations from slightly below MSL to MHHW. And yet when we compare the zones there are remarkable differences in marsh area.

The natural habitat zones near the river mouth (zones 1 and 3) are very different from the natural habitat zones in the mid-delta and the north end of Port Susan Bay (zones 4 and 5). In all four zones, a similarly large proportion of their total area falls within the MSL-MHW area (67-78%, Table 3). However the habitat composition of that area is very different. Near the river, 88-90% of that area is dense continuous marsh (Table 4), while in zones 4 and 5 it only makes up 20-31%. In the northern zones, the MSL-MHW inundation area is instead dominated by barren tide flat 48-53%, which makes up less than 8% of the southern marshes. In addition, zones 4 and 5 have more amounts of sparse marsh, which is a low elevation habitat type with very short, sparse threesquare bulrush (see Figure 12), a habitat that occurs only at the lowest elevations on coarse substrates, and where heavy snow goose grazing occurs.

The restoration area, zone 2, falls 95% within the MSL-MHW inundation area (Table 3). It is 65% continuous marsh and 29% tidal flat (Table 4). The site is in transition, with new tide flat and sand bars forming at lower elevations and new marsh moving into the higher elevations that were not marsh prior to restoration. Much of the heavy construction traffic area remains bare and lower in elevation than surrounding marsh areas.

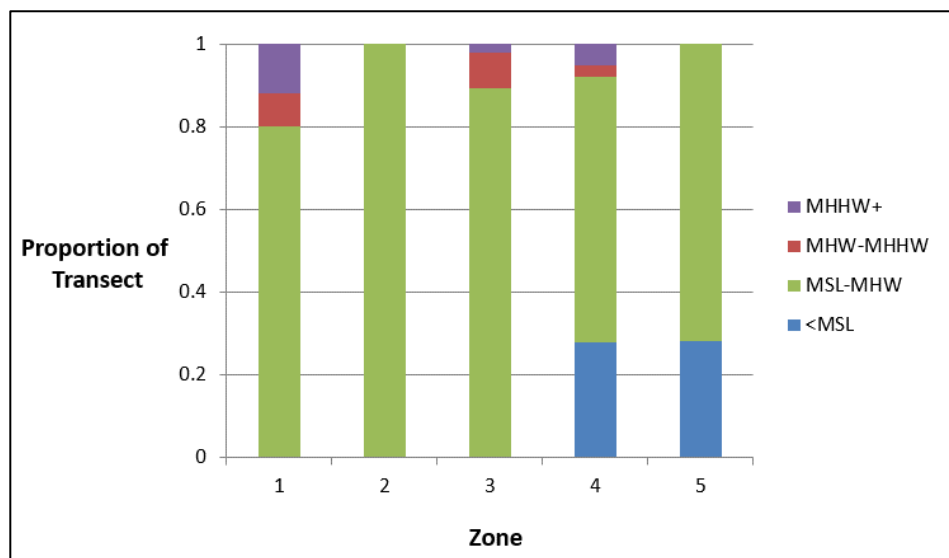


Figure 5. The proportion of each zone's transect that falls within four important inundation zones.

Table 4. Distribution of habitat types and inundation bins in study zones. Elevations are in meters, NAVD88.

	Zone Total	Inundation Bin											
		<MSL (<1.36)			MSL-MHW (1.37-2.50)			MHW-MHHW (2.51-2.77)			MHHW+ (2.78+)		
		acres	m2	% of zone	acres	m ²	% of bin	acres	m ²	% of bin	acres	m ²	% of bin
Zone 1	Total Area	119	480045	100	1.2	4876		86	346687		17	69061	
	Continuous Marsh	107	433913	90	0	111	2	76	306544	88	17	68435	99
	Patchy Marsh	0	0	0	0	0	0	0	0	0	0	0	0
	Sparse Marsh	0	0	0	0	0	0	0	0	0	0	0	0
	Tidal Channel	3.1	12472	3	0.3	1167	24	2.8	11297	3	0.0	8.0	0
	Tide Flat	8	33664	7	1	3598	74	7	28849	8	0	617	1
Zone 2	Total Area	156	633109	100	0.9	3677		149	603381		2.0	8090	
	Continuous Marsh	98	395193	62	0	21	1	97	393297	65	0	1532	19
	Patchy Marsh	5.4	21783	3	0	0	0	5.4	21783	4	0	0	0
	Sparse Marsh	0	0	0	0	0	0	0	0	0	0	0	0
	Tidal Channel	4.3	17326	3	0.7	2819	77	3.6	14507	2	0	0	0
	Tide Flat	49	198810	31	0	836	23	43	173797	29	1.6	6558	81
Zone 3	Total Area	98	396539	100	3.6	14571		77	310119		11	45969	
	Continuous Marsh	86	349502	88	0.1	326	2	69	278279	90	11	45383	99
	Patchy Marsh	0	0	0	0	0	0	0	0	0	0	0	0
	Sparse Marsh	1.9	7771	2	0.1	398	3	1.8	7372	2	0	0	0
	Tidal Channel	2.2	8793	2	0.3	1199	8	1.8	7331	2	0.1	221	0
	Tide Flat	7.5	30482.0	8	3.1	12647.4	87	4.2	17145.3	6	0.1	365.1	1
Zone 4	Total Area	199	805873	100	37	151024		133	538735		9.1	36702	
	Continuous Marsh	55	221997	28	0	0	0	26	105884	20	9.1	36702	100
	Patchy Marsh	13	50814	6	5.8	23565	16	6.7	27249	5	0	0	0
	Sparse Marsh	40	162646	20	15	62045	41	25	100601	19	0	0	0
	Tidal Channel	10	39940	5	5.4	21877	14	4.5	18055	3	0	8.0	0
	Tide Flat	82	330565	41	11	43537	29	71	287027	53	0	0	0
Zone 5	Total Area	107	434811	100	15	59962		78	315234		1.9	7688	
	Continuous Marsh	39	157369	36	0	7.3	0	24	97753	31	1.9	7688	100
	Patchy Marsh	0	70	0	0	0	0	0	70	0	0	0	0
	Sparse Marsh	20	79497	18	4.8	19498	33	15	59999	19	0	0	0
	Tidal Channel	2.5	10135	2	1	4387	7	1.4	5748	2	0	0	0
	Tide Flat	46	187739	43	9	36070	60	37	151665	48	0	0	0

Vegetation

There are a few major species that dominate the tidal marshes of the Stillaguamish estuary. The low marsh below MHW (~2.5m) is dominated by two bulrush species, *Schoenoplectus americanus* (threesquare or American bulrush) and *Bolboschoenus maritimus* (maritime bulrush). Above 2.0m, several other species can be common and even dominate some areas. These include *Carex lyngbyei* (Lyngbye's sedge), *Juncus balticus* (Baltic rush), *Schoenoplectus tabernaemontani* (softstem bulrush), *Agrostis alba* (creeping bentgrass), *Typha latifolia* (broad-leaved cattail), *Distycklis spicata* (saltgrass), *Triglochin maritimum* (seaside arrow grass), *Potentilla anserina* (silverweed), and *Symphotrichum subspicatum* (Douglas aster).

Some of the vegetation differences among zones are shown in Figure 6 which shows where the two most common plant species are dominant members of the species assemblage during winter. Threesquare bulrush has the broadest distribution across the elevation spectrum and the distribution of maritime bulrush falls completely within the elevation range of threesquare (Figure 7). In zone 1, threesquare dominates much of the vegetation transect and maritime only co-dominates in a small area. Maritime doesn't achieve sole dominance in any part of the transect. In zone 3, a similar though broader distribution pattern is seen, but maritime grows more densely and tall and achieves greater dominance in the upper portion of its elevation range. In the restoration zone 2, due to the site legacy, the transect is dominated by maritime bulrush which occurs at a much broader elevation range than in any other zone. Threesquare has not begun to establish in substantial numbers on the transect, though it does show up in bare areas along the old dike footprint and other areas that were not covered by maritime bulrush prior to restoration. In zones 4 and 5, maritime bulrush dominates the higher marsh during winter (Figure 6) though threesquare is common and mixed in with the maritime.

Soil qualities likely result in the different patterns shown by maritime and 3-square bulrush. Maritime bulrush appears to be most robust in areas with finer sediments. In zone 1 where sediments are more firm (Figure 3), it doesn't achieve the level of dominance and vigor as in other zones. At the elevations with the softer soils in zones 2 and 5 (Figure 3), maritime bulrush dominates (Figure 6).

As indicated, the elevation range of threesquare is broader than and completely encompasses the range of maritime bulrush (Figure 7), except in the restoration zone. Prior to restoration, a very robust non-tidal maritime bulrush marsh established in zone 2. It was essentially a monoculture and its response to restoration will be interesting to watch. Currently it dominates not just at its typical elevations in zone 2 but also at lower elevations than it does in any other zone (Figure 7).

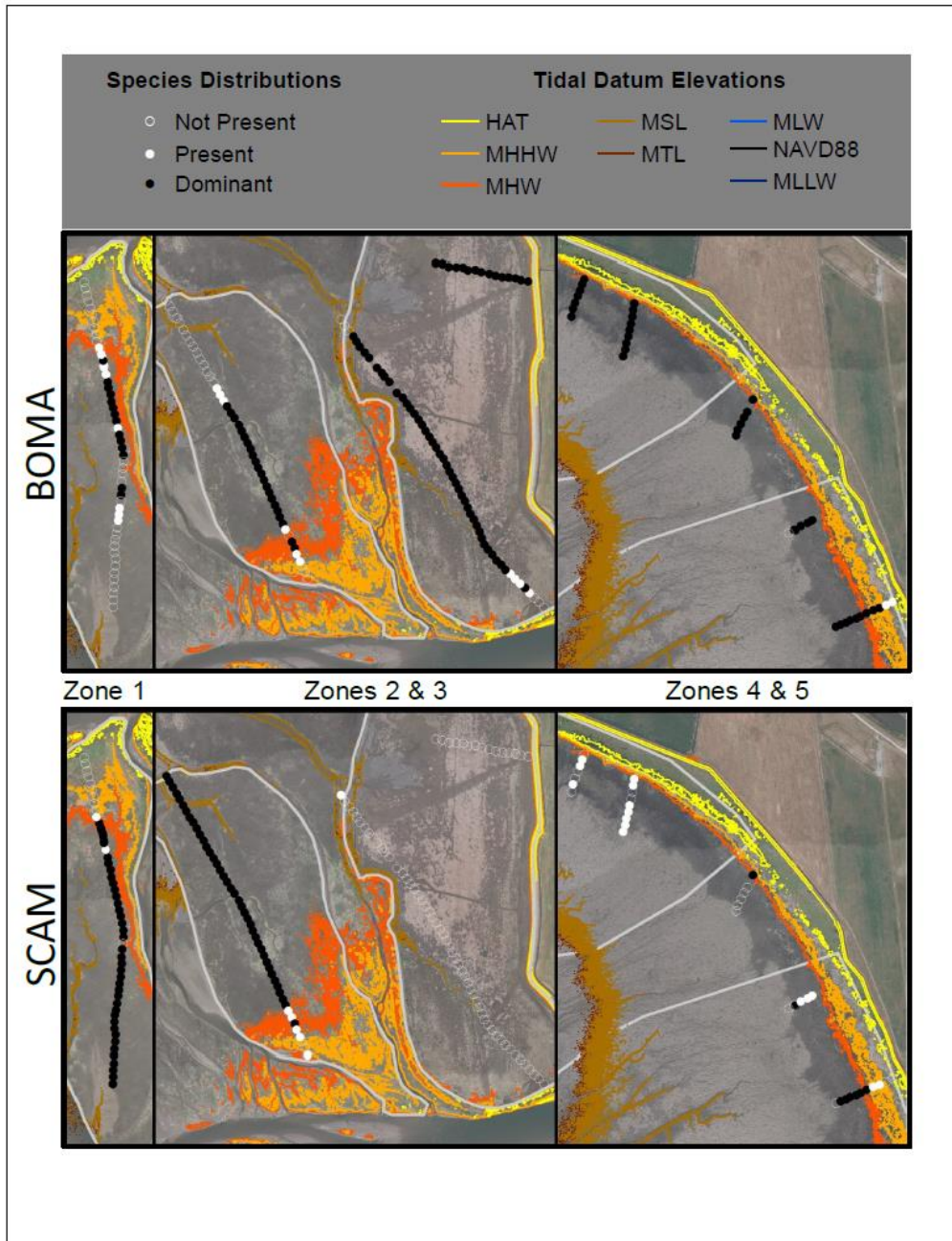


Figure 6. Distribution of common marsh plant species during winter. Scam is *Schoenoplectus americanus* (threesquare bulrush), Boma is *Bolboschoenus maritimus* (maritime bulrush).

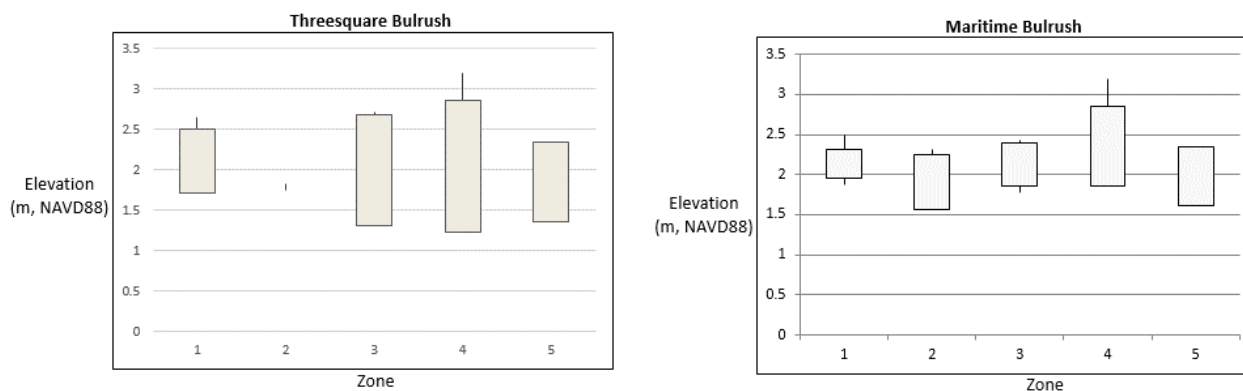


Figure 7. The distribution of threesquare and maritime bulrush across elevations in the 5 study zones. The boxes indicate the elevations at which the species is common (dominant or sub-dominant), and the whiskers indicate elevations at which it is present but not common.

Lyngbye's sedge is common across a broad elevation zone in zone 1, extending well below the MHW line at 2.5m (Figure 8). In zone 3 it occupies a considerably narrower zone at about MHW. It is uncommon on the transect in the restoration zone, occurring at particularly low elevations possibly having established prior to restoration. It is establishing new clones in peripheral bare areas such as near the old dike footprint. In zone 4 it occurs in the high marsh well above MHW, and in zone 5 it occurs on a few eroding pedestals of high marsh that are surrounded by low marsh, so the elevations shown in Figure 8 for zone 5 are likely artificially low in that they show the elevation of the plot where it occurs, not necessarily the elevation of the pedestal on which the sedge was located.

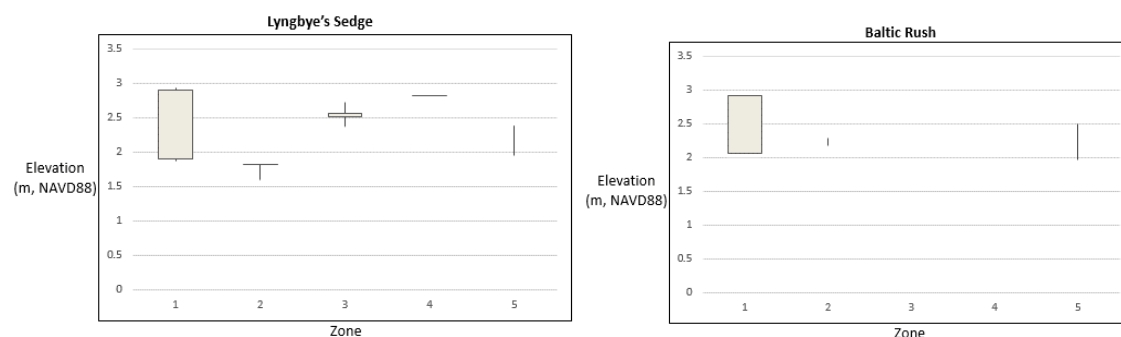


Figure 8. Distribution of Lyngbye's sedge and Baltic rush across elevations in the 5 study zones. The boxes indicate the elevations at which the species is common (dominant or sub-dominant), and the whiskers indicate elevations at which it is present but not common.

Baltic rush is similar to Lyngbye's sedge in that it is common in zone 1 across a relatively broad elevation spectrum that dips down to almost 0.5m below MHW (Figure 8). In zone 2 it is establishing at the higher elevations of the zone, between 2-2.5m. In zone 3, it was common in the high marsh above MHW, though was rare on the sampling transect so is absent from the graph. Similarly with zone 4, it commonly forms large clones in the high marsh but happened to be rare on the transect. In zone 5 it was present in the highest elevations of the transect (below MHW), particularly on the eroding high marsh pedestals.

Creeping bentgrass (*Agrostis alba*) is a dominant species in the high marsh and in zone 1 extended well below MHW to about 2m (Figure 9). In the restoration zone it was common in the higher elevations, though still below MHW. It had established broadly and densely before restoration in the higher elevations of the site, but it appears to be dying back substantially from the areas where it dominated prior to restoration. In zone 3 it was common above MHW, and in zone 4 it was common only in the high marsh above MHHW. It was rare in zone 5. The distribution pattern of bentgrass does not appear to follow patterns of substrate particle size like maritime bulrush. Bentgrass distribution may instead relate more to soil salinity. It's elevation range increases from south (freshest water) to north (saltier water).

Saltgrass (*Distycklis spicata*) had a narrower elevation band than bentgrass (Figure 9) and was consistently in the high marsh above MHHW, except in zone 5 where it occurred on the eroding high marsh pedestals. As with the sedge distribution in zone 5, the saltgrass elevations shown in the figure for zone 5 may be artificially low since the elevations represent the plot rather than the pedestals where the saltgrass was growing.

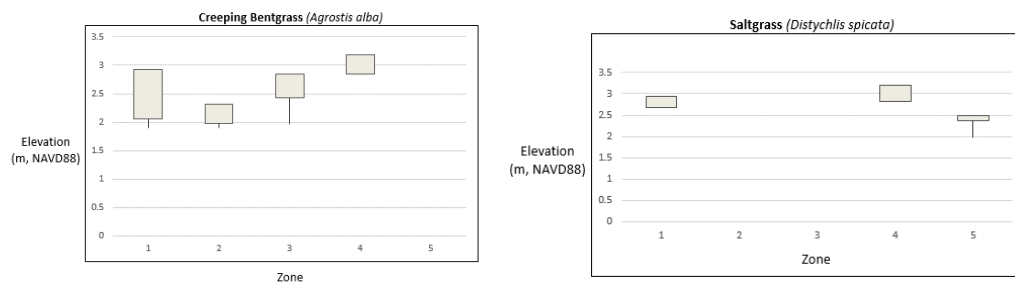


Figure 9. Distribution of creeping bentgrass and saltgrass across elevations in the 5 study zones. The boxes indicate the elevations at which the species is common (dominant or sub-dominant), and the whiskers indicate elevations at which it is present but not common.

Vegetation structure

Vegetation height and density was measured in winter and summer to evaluate community composition, relative aboveground productivity, and potential effects on sediment accretion and wind/wave dynamics. Winter structure was measured in all 5 study zones. Summer structure has been measured at 3 zones so far. As expected, aboveground structure is substantially lower in winter than summer (Figure 10). The effect differs by species. Threesquare bulrush is a smaller species with shorter and smaller diameter stems. In the fall it rapidly gets knocked prostrate by the tides and quickly begins to decompose. In contrast, maritime bulrush stems often stay erect aboveground throughout the winter and continue to affect hydro and sediment dynamics. At lower elevations it begins to break down though the stem generally breaks in pieces, leaving part of the stem erect in place. This is in contrast to threesquare whose stem is usually knocked flat all at once and never remains partially erect. As a result, threesquare marshes are essentially barren aboveground in winter while mixed marshes and maritime marshes can maintain substantial aboveground structure.

In all zones, the height of the vegetation approaches something like a bell curve, with the middle elevations having higher vegetation than either the lower or higher elevations (Figure 10). The middle elevations also correspond to the areas most likely to have maritime bulrush, softstem bulrush, and cattails, the tallest tidal marsh species.

In zone 1, winter height seldom got above 30cm and was generally much lower than that. This zone is dominated by threesquare bulrush, the species that essentially disappears in the winter. Maritime bulrush doesn't form the dense very tall stands that it does in zone 3, and it tends to be more scattered in zone 1 rather than forming broad, dense stands. Regularly inundated tidal marsh, below MHHW, is much taller than the higher marsh above MHHW.

The restoration zone 2, dominated by maritime bulrush, has higher vegetation structure of 30-50cm in winter, compared to zone 1. In zone 2, maritime bulrush occurs at lower elevations than in other zones because the bulrush established prior to dike removal. Both height and density at the lower elevations have decreased substantially since the restoration. Prior to restoration, the low area of the diked field supported the tallest and most dense maritime meadow in the estuary. Currently, at 2.0m elevation, summer height was over 120cm while it was 50cm at 1.5m elevation. In zone 1, no maritime bulrush grew that low, and in zone 5 the only maritime near that elevation was less than 20cm tall. At the lower elevations in zone 2, large bare areas are forming and the density of maritime in other areas is dropping as well. It will be interesting to see if threesquare moves into these areas or if they remain barren.

In zone 5, vegetation height is lower than in zones 1 and 2, even in the maritime bulrush zone, reaching a maximum of 100cm at one plot. In contrast, both zones 1 and 2 supported maritime bulrush that was higher than 120cm across several plots.

The winter height of vegetation across all five zones is shown in Figure 11. Zones 1 and 5 have the lowest heights. Zone 1 is more dominated by threesquare bulrush and hence loses more of its structure in the winter. Zone 5 marsh is actively eroding away and is exposed to the longest fetch for winter's southerly wind storms. Waves break down the vegetation structure and zone 5 likely experiences the strongest wave environment.

Zones 2-4 all show a substantial area with vegetation 50cm or taller (Figure 11). These are also the areas with the softest soils and the most dominant maritime bulrush areas. The taller winter vegetation is more likely to influence sediment dynamics and likely increase accretion rates.

All zones show a similar bell curve pattern, with highest structure in the middle elevations where maritime bulrush is more likely to dominate, and lower structure at lower and higher elevations (Figure 11). Zones 2 and 5 show the weakest pattern in this respect, and both zones lack any substantial area of high marsh which is characterized by the low growing graminoids like grasses, sedges and rushes.

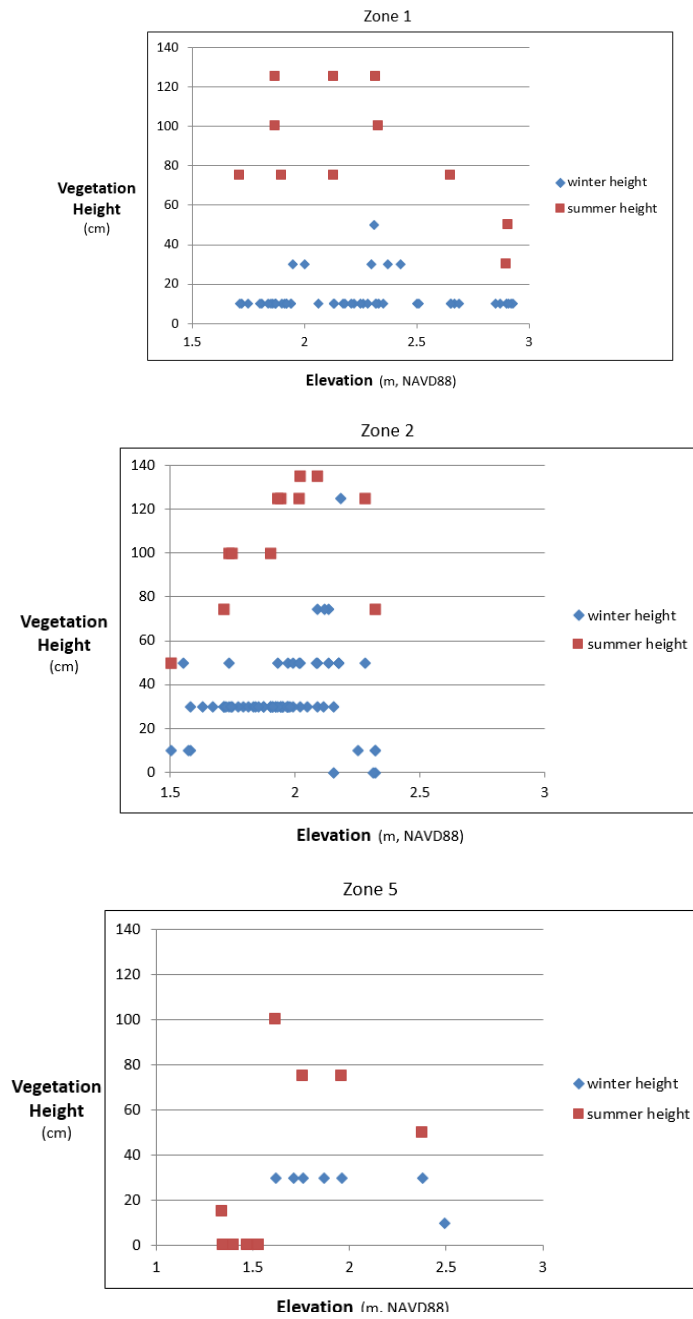


Figure 10. The height of vegetation during summer and winter, for zones 1, 2 and 5.

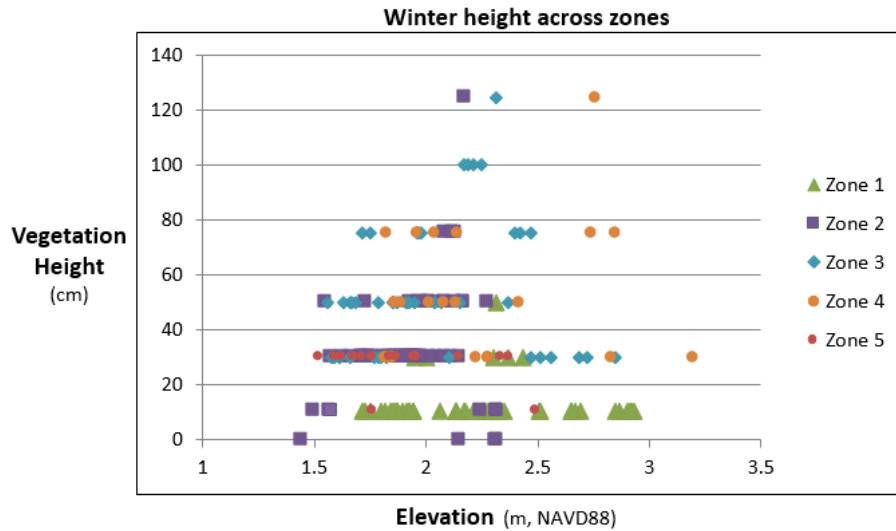


Figure 11. Winter vegetation height across all zones.

Summer height has been measured in zones 1,2 and 5 so far, and the results are shown in Figure 12. Zones 1 and 2 have the highest summer vegetation. In contrast to winter when zone 1 had considerably shorter vegetation than zone 2, in summer zones 1 and 2 have similar heights, at least where their elevation ranges overlap. This is surprising since zone 2 has more maritime bulrush and softer soils which are sometimes associated with taller vegetation. Summer monitoring is ongoing and will help us paint a more complete picture.

Zone 5, which includes elevations below MSL, shows some of the extreme low elevation, short, sparse threesquare bulrush marsh that grows at about 1.35m elevation. In zones 4 and 5, this marsh type is disconnected from the higher marsh, separated by a stretch of bare tide flat, as evident in Figure 12 by the stretch of no vegetation between about 1.35m and 1.6m elevation.

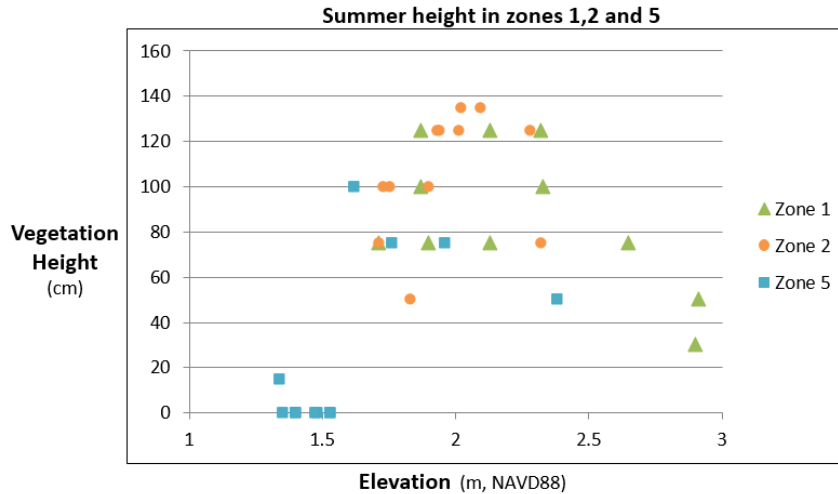


Figure 12. Summer vegetation height in zones 1, 2 and 5.

The extreme low elevation marsh type grows throughout the system near or slightly below MSL, on sandy, firm soils. In the south, these low marshes are adjacent to and extend out from the dense higher marshes. Zones 1 and 3 are islands that don't extend below MSL, so they lack the extreme low marshes to compare with zones 4 and 5, but we are in the process of mapping the extreme low marshes throughout the system. We need to better understand the extreme low marshes since they appear to be persisting in the northern areas even as the middle and higher elevation marshes are disappearing. Plants in the MSL marshes rarely reach 50cm height and grow very sparsely (Figure 13). This area of marsh is very difficult to detect in aerial photos due to its low density (see the report on historic aerial imagery analysis for more details).



Figure 13. Examples of threesquare bulrush marsh. The left is dense, middle elevation (~1.8-2.7m) marsh with an average height exceeding 100cm. The right is the extreme low elevation (~1.1-1.5m) marsh that rarely reaches 50cm and grows very sparsely.

Accretion

Short-term accretion stations have been installed in all five study zones, with a series of stations in each zone at intervals alongside the vegetation transect. A combination of feldspar and grid stations have

been installed in zones 1, 4 and 5. In zones 2 and 3 an intensive assessment of alternative methods is being conducted in a collaboration with graduate student Brittany Jones from the University of Washington. In these zones, each station has four methods installed, feldspar, grids, ceramic plates and PVC pins. A statistical and logistical comparison of the methods will be made to assess the relative effectiveness, costs and benefits of the different methods in different kinds of tidal marsh. Early sampling results suggest a relatively high level of variability among methods.

Data from four of the zones have been collected, after 17-30 weeks of installation. These early data should not be used to compare accretion rates between zones, because they represent different time periods, and very recent deposits such as these, will be undergoing a process of compaction that will result in very different results after just a few more months. However, relative comparisons within a zone, where methods, timeframes and personnel have been consistent, may provide an early glimpse of how accretion varies across elevation and between different vegetation types.

For reporting early data here, only the results from sediment pins are provided for zones 2 and 3. For sediment pins, four readings were taken for each pin and averaged. These zones were sampled in mid to late April.

For zones 1 and 5, early results for feldspar layers are reported. These zones were sampled in early July. For feldspar stations, generally five readings were taken in different parts of the feldspar plot, and averaged. For zones 1, 2 and 5, each accretion site included two replicates, and the reported number is an average of the two. For zone 3, six of the accretion sites had five replicates each and the remaining two sites had three replicates each. The reported numbers are averages of the replicates. All of the reported accretion numbers were collected at least a few weeks after the massive Oso landslide on March 22.

Accretion rates are shown in Figure 14. In the natural marshes sampled in zones 1, 3 and 5, all of the highest marsh sites had substantially lower accretion rates than the other sites in their respective zones.

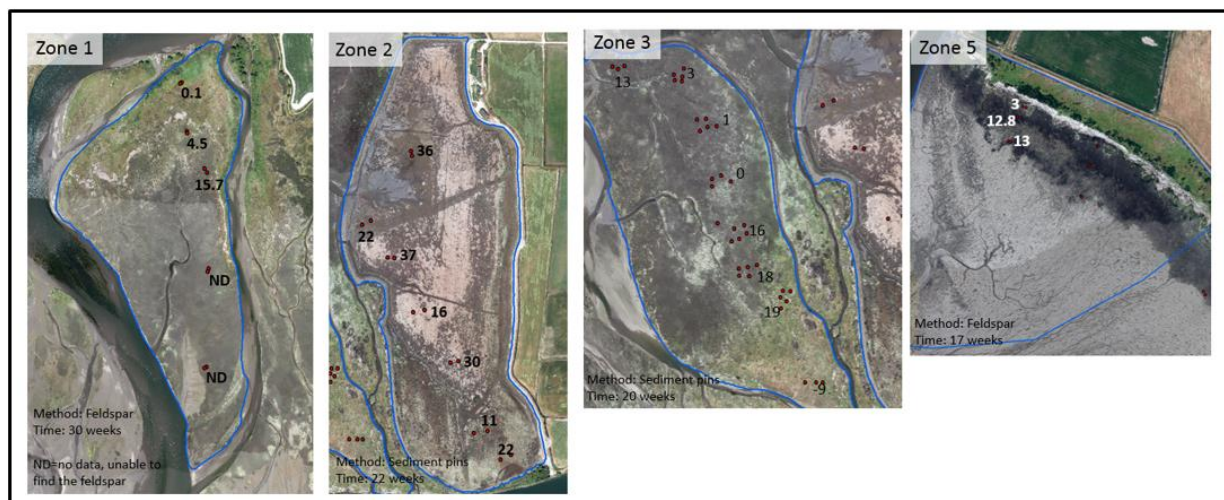


Figure 14. Early accretion rates for zones 1-3 and 5. Rates should not be compared between zones at this time, except at a gross level. All units are mm.

In zones 1 and 3, the highest sites were above MHHW and their accretion rates were 0.1mm and -9mm respectively. In zone 5, the highest accretion site was below MHHW and it had a rate of 3mm over 17 weeks. In zone 1, the remaining two sites had rates of 4.5-15.7mm after 30 weeks. In zone 3, accretion ranged from 0 to 19mm after 20 weeks. The highest accretion rates (16-19mm) were in the middle elevations where maritime bulrush dominates. Below this, where threesquare becomes gradually more prevalent, accretion rates were 0-13mm. Threesquare is essentially absent during winter, in contrast to maritime bulrush whose vertical structure can still act to trap sediment during the winter. In zone 5, the two lower accretion sites had accretion rates near 13mm. The high rates at these lower sites were a surprise since there is ample evidence in the area of erosion. The microscale topography in zone 5 is highly varied compared to other zones, as a result of erosion and deposition of eroded sediment. It is likely that accretion and erosion rates are highly variable over small spatial scales. Sampling this dynamic area in a way that adequately captures sediment dynamics will be challenging.

Zone 2, the restoration zone, had higher accretion rates than other sites, ranging from 11-37mm over 22 weeks. The accretion rates should not be compared among zones except at a gross level. The substantially higher rates seen on the restoration site are likely a real phenomenon. Due to subsidence and its proximity to the river, the site is expected to trap more sediment than other areas. In addition, the bath tub geomorphology of the site, slow draining times, and dense vegetation will enhance this accretion rate. In the restoration area, the higher accretion rates tended to be lower in elevation and closer to the channel connections.

Observations and Emerging Lessons

Improving our understanding of the restoration site

The restoration site is a bathtub.

The restoration site is substantially subsided compared with adjacent natural marsh areas. Even though the dike has been removed and two channel connections excavated, the site still behaves like a bathtub with two small drains. In contrast to the natural reference marshes where substantial tidal flows move across the tidal flat and marsh surfaces, almost all flow into and out of the restoration site much flow through the two channel connections. Because of the level of subsidence, up to 1.5m or more, it is likely to take many decades, probably more than 100 years for the site to catch up with the elevations of adjacent natural marshes.

There are several implications of the “bathtub” effect. First, all hydraulic energy focuses flows through the two excavated openings. The two openings are insufficient in size or number to convey the full tidal prism of the site in a manner similar to reference sites, which has several significant implications for habitat development. The newly developing channel network on site is likely to extend from those two principal channels. Because most of the hydraulic energy is focused on those two openings, it is unlikely that other channels will form across the border from the old marsh to the restoration site, as would happen in a normal site that isn’t a bathtub with two drains. This is likely to have a long-term effect on reducing the number of channel connections with the rest of the estuary. Examination of old aerials

suggests that at least 8 blind tidal channels of various sizes drained the marsh in the restoration area before it was diked.

Another implication of the bathtub effect is that the site drains much more slowly than a natural site would (Figure 15). In the 2013 aerial shown in Figure 15, standing water can be seen throughout much of the restoration area at the same marsh elevations that have completely drained in never-diked areas with natural channel systems. There are only two drains in the tub and their collective size is too small for the area drained. In addition, the restoration area is much more level than the natural marsh, an artefact of decades of plowing and isolation from the river's sediment load. The flat topography, the dense maritime bulrush marsh that established before restoration, the absence of a complex blind channel network, and the presence of a hard pan layer that may be limiting the depth of newly developing channels all significantly retard the rate at which water can drain off the land. Combined with the fact that all the water must flow into the two evacuation channels, the site likely experiences inundation periods that are more typical of places much lower in the tidal frame. In fact some areas of the marsh appear to never drain completely even though water levels in adjacent channels may be several feet lower than the marsh surface. These conditions are likely to affect the rate of sedimentation, though in possibly complex ways. First, accretion is expected to be higher because the site is densely vegetated and inundated longer than normal, allowing more time for suspended sediment to be captured. However the persistent inundation may make the effective elevation, in terms of vegetation growth, considerably lower than the actual elevation. In addition, the inundation may affect sediment chemistry in ways that could reduce marsh vigor and density, and alter its composition, for example by increasing risk of sulfide toxicity. Both of these effects would reduce the marsh structure in ways that would lessen sediment capture over time.

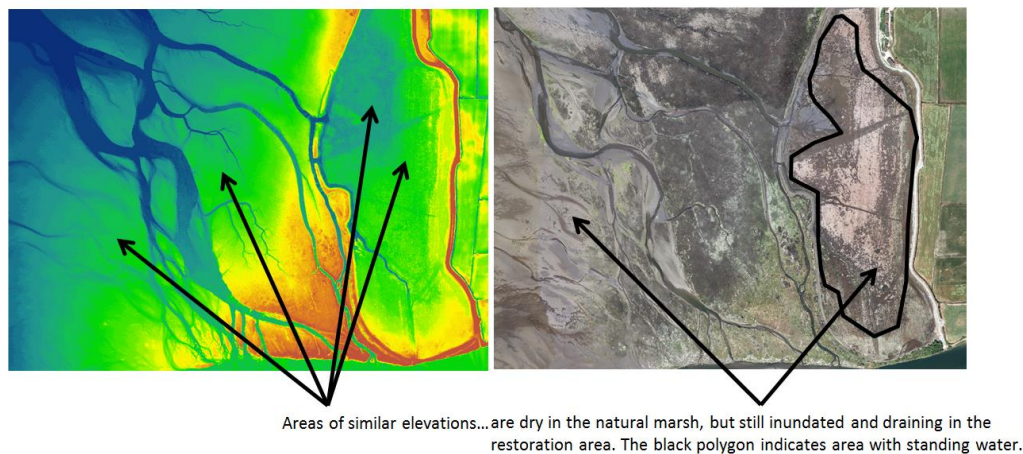


Figure 15. *Insufficient channel connectivity with the estuary, a flatter topography, and the presence of an under layer of hardpan that limits the depth of new tidal channels appears to cause the restoration site to drain substantially more slowly than natural areas at the same elevation.*

Reduced hydrologic connectivity with the rest of the estuary also has biological implications such as lower access opportunity for fish. During the ebb tide, velocities in the two channel breaches are quite

high and a substantial portion of the channel cross sectional area is likely flowing too fast to allow juvenile fish access during the ebb. These conditions may last for considerably longer in the breach channels than would be found in similar natural channels. The absence of any smaller channel connections with the adjacent marsh substantially reduces the options for low-velocity access to the site. In addition, simple arithmetic suggests that two channel connections provides many fewer access opportunities than eight channel connections, and this level of connectivity is unlikely to change much for many decades.

The restoration site appears to have a surface layer of 15-30cm very soft sediment overlaying a hard, erosion-resistant surface. The hard surfaces are evident where erosion has begun excavating tidal channels, such as immediately upstream of the channel breach connections, and on the footprints of the major construction truck routes. The latter were areas of compacted soil that, after demolition of the old dike, were disked to reduce compaction. The traffic routes have now eroded down to hard pan and are serving as new drainage channels. In addition, the tidal channels immediately upstream of the excavated channel connections have eroded down to the hard pan layer. This hardpan layer is higher in elevation than the channel bottom in the adjoining distributary. As a result, at lower tide levels there is a shallow sill, and in some places even a small waterfall as water drains off the marsh plain sill into the main channel near the breach openings. This hard sill further reduces fish accessibility, inhibits site drainage and will affect the development of the blind tidal channel system.

In retrospect it would likely have been better to excavate more channel connections across the old dike footprint. There are at least six other sites where small blind tidal channels (~1-3m width) come close to the restoration area where a small amount of excavation across the dike footprint could allow those channels to connect to the site and improve channel connectivity. In addition, other larger connections could be created with nearby distributary channels, or the existing openings could be enlarged. This is a potential avenue for exploring adaptive management options in the future. Another option for adaptive management that could help with site drainage and connectivity with adjacent marshes is to accelerate accretion and development of a more natural marsh slope by using dredged sediment as fill to raise site elevations. There are several different ways of using sediment addition to improve site conditions. As we learn more about habitat development on the site, these options should be explored for their potential to substantially improve site function over the next several decades.

The sediment surface in the restoration site is different

As a result of the legacy of agricultural use and recent years as a non-tidal wetland, the site has different soil characteristics than the natural marsh areas. There is a top layer of up to 30cm of very soft, finely textured, and apparently highly organic sediment. Zone 2 has the highest soil penetrability values of all zones. Fine textured, soft soils are favored by maritime bulrush, which is indeed the dominant species in the restoration zone. Fine soils are also favorite grazing grounds for snow geese. The degree to which geese grazing will affect marsh development in the restoration area is a significant question that needs to be addressed and is not currently part of the monitoring program. North of the restoration area, substantial areas of intermediately soft soils are completely barren at elevations that would normally support a mixed maritime-threesquare bulrush meadow, and there is ample evidence during the winter of heavy goose grazing along the lower boundary of the maritime marsh in that area. It is possible that

geese will be the most significant factor that determines how the tidal marsh on the restoration site changes over time.

Below this top layer of very soft soil is a hard pan layer that is highly erosion resistant. The origin of this layer is unknown. It may be a natural hard pan layer, or it may be the result of compaction from years of management with heavy agricultural vehicles. Where developing tidal channels have carved down to this layer, further deepening of the channels appears to be substantially slowed. As a result of this, channels may develop different morphologies, remaining more shallow and broad than might otherwise be expected.

Early results from short term accretion monitoring suggest that accretion rates in the site may be considerably higher than other zones, up to twice as high in some places. This likely results from a number of factors including relative position to river, impaired drainage due to insufficient channel connections, bath tub effects, low topographic slope, and the legacy of the pre-restoration dense maritime bulrush marsh.

A broad and deep sandbar has formed inside the restoration area near the mouth of the excavated channel connections. The sand splay is up to a meter thick in places and covers over 3.5 acres in area. The sand appears to have come from the distributary channel downstream of the site which has increased by close to 75% in width and has also deepened substantially since the restoration (Figure 16).

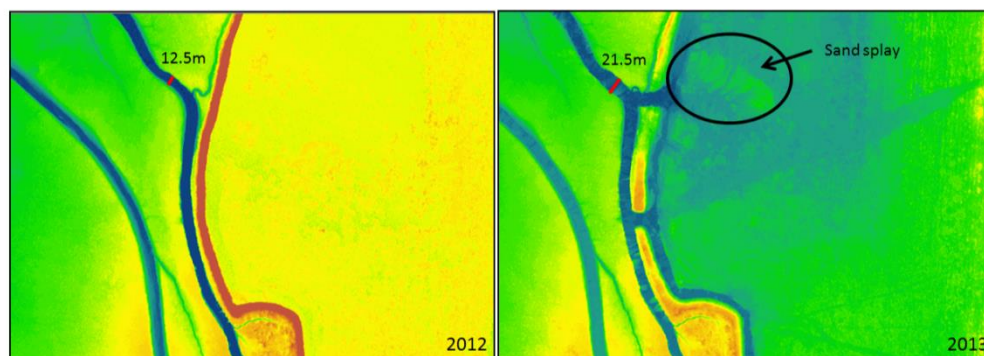


Figure 16. LiDAR imagery of restoration site elevations from pre and post restoration. The width of the distributary channel downstream of the restoration area is shown for the red cross-section. A sand bar is growing inside the restoration area, where it appears the strong flood tides may be depositing coarse sediment carved from the enlarging channel downstream.

Improving our understanding of marsh loss in north Port Susan Bay

Our understanding of the dynamics driving both marsh loss and marsh gain in the Stillaguamish estuary is evolving as we learn more about the estuary. West and north of the restoration area we have mapped threesquare bulrush growing at considerably lower elevations than we expected. There is a banded pattern in the habitat in this area, with a densely vegetated upper marsh of mixed maritime and threesquare bulrush, a barren tide flat seaward of this, and a sparsely vegetated, low growing

monotypic stand of threesquare bulrush farther out and at a lower elevation. The lower area of marsh is almost impossible to detect on aerial photographs because it is less dense than most marsh, and the threesquare bulrush stems are essentially short, erect and leafless, so an aerial orthophoto view is like looking at needles on end from far away. Although there is a broad barren area between the two marsh areas, the presence of the lower threesquare bulrush zone indicates that the species is capable of growing throughout the elevation spectrum including the broad barren areas.

Our original hypothesis for the vegetation patterns we see in the north was that there was a combination of insufficient supply of sediment from the river and rising salinities, both as a result of the gradual shift of river flows farther and farther to the south. We also thought that overgrazing from snow geese and swans was contributing. As a result of our more detailed observations over the past year, and after discussions with Sean Boyd (Canadian Wildlife Service), a researcher in the Fraser estuary, we're now beginning to develop a better conceptual model for the marsh loss in the north.

From our accretion data in the long term SET study area near South Pass, it appears that the higher marsh area is accreting and increasing in elevation faster than moderate projections of sea level rise. However the lower end of the upper mixed marsh does appear to be losing elevation, and there is extensive evidence of marsh erosion throughout the area including even the highest marsh areas. This finding suggests that the ongoing erosion and loss of marsh in the north may be more complicated than we originally hypothesized. The high accretion in the upper SETs may suggest that the supply of river sediment is not limiting marsh persistence and growth, contrary to our original hypothesis. Alternatively, the high accretion rates in the high marsh may be due to erosion at lower elevations, and the waves transport the sediment into the high marsh which has enough vegetation structure to trap it. Regardless of the answer, it is clear that the wide spread loss of marsh in the north is likely due to complex biophysical interactions.

In the northern marshes, the higher marsh areas have very soft soils that consist of finer particles carried there by the tide. The isolated, low elevation (MSL) threesquare bulrush marsh occurs on firmer, sandier soils. On the Fraser delta they see a similar vegetation pattern of low elevation threesquare bulrush, barren middle elevations, and a higher, mixed bulrush marsh area. They have found that the pattern relates to ease of beak probing by geese and the relative metabolic cost of grazing (Sean Boyd, CWS, personal communication). Excavating bulrush rhizomes from sandier soils requires much more energy than probing the softer soils. Rhizomes in sandier soils where the bulrush is shorter and less dense may also be less frequent and smaller in size, reducing the energy reward for foraging. So the geese focus on the middle zone where soils are softer and food reward greater. We hypothesize that the lower marshes are grazed less intensively due to the higher metabolic cost of foraging, the middle marshes are just right, and that the higher mixed marsh zone may be grazed less heavily because of the amount of senescent above ground biomass that remains in the winter. The higher maritime bulrush zone is sufficiently robust that the tall, stiff and dry winter stems are able to withstand winter waves and present an physical impediment to roving geese.

We think the vegetation and physical patterns we see are the result of winter grazing by snow geese that remove the roots that hold the soil in place, loosen and disturb the soil so that tidal action and storm waves can re-suspend the sediment and move it higher into the upper marsh area. The north of

Port Susan Bay has one of the longest storm wind fetches in Puget Sound. The bulrush has disappeared from the intermediate elevation zone and the seaward edge of the upper mixed bulrush marsh, where soils are soft and fine in texture, shows widespread signs of erosion, such as exposed rhizomes and deep eroded rills. At the far north end of Port Susan Bay, these signs of erosion extend throughout the upper marsh all the way to the shrub line where there is a vertical cliff of 0.5-1.0m. The lower elevation marsh, at about MSL, has firmer soil and is likely less prone to erosion due to coarser, less mobile particle sizes and to less grazing intensity. The combination of grazing disturbance and winter wave environment combine to reduce the marsh biomass and move sediment. Although the barren intermediate areas could support both threesquare and maritime bulrush, its absence suggests that chronic disturbance by both birds and waves prevents it from reoccupying the space.

This emerging conceptual model suggests some interesting possible characteristics of resilient marshes in Port Susan. Soil of sufficient coarseness can resist goose bill probing and thereby suffer less disturbance. In addition, marshes with finer soils that are more protected from wave attack may be able to survive heavier grazing pressure than areas more exposed to waves. The lower level of wave disturbance may allow enough above-ground biomass to persist through winter to reduce the ease of goose access. These characteristics may point to potential adaptive management actions in the future if marsh loss continues.

Improving our understanding of the dominant plant species

The two most prevalent species in the tidal marshes of Port Susan Bay are threesquare and maritime bulrushes. Threesquare bulrush is smaller and essentially leafless, consisting primarily of a green vertical triangular stem. Its stem is less thick than maritime bulrush and it does not persist long into the fall. As it senesces its stem rapidly weakens, falls prostrate and is washed away or decomposed. In contrast maritime bulrush is leafy, grows taller and can have a stem often twice as thick or more. Its stems are more robust and can persist through the entire winter, though at lower elevations the wave energy is sufficient to knock much of it down by mid-winter. However the above ground biomass seldom disappears completely.

Threesquare bulrush has the broadest distribution and appears to entirely overlap the distribution of maritime bulrush. It grows at the lowest elevations of all native brackish marsh emergent species, even dipping below MSL (1.35m NAVD88). It grows from that elevation up to approximately MHHW (2.78m NAVD88). In contrast, maritime bulrush grows only in the higher area of low marsh, between about 2.0 and 2.8 m NAVD88. Furthermore maritime bulrush appears to prefer finer soils. In zone 3 where soils are finer, it grows tall and densely, and dominates a large portion of the vegetation. In zone 1 which we thought would be very similar to zone 3, we found firmer soils and maritime bulrush never reached the height, density or extent as is seen in zone 3. Similarly, it grows very high and densely in the upper marshes north of the restoration area where the soils are softer and smaller in particle size.

Our understanding of the full spatial distribution of major tidal marsh plant species is not complete. In particular, threesquare bulrush occurs considerably farther seaward in the area west and north of the

restoration zone than was expected. Straight west from the restoration area, the threesquare bulrush appears to have recently expanded seaward rapidly, compared with previous surveys. This may have occurred since 2009, when a major flood resulted in significant sediment deposition at the west end of Hatt Slough, and a shift in the channel away from the northwest towards the southwest. This change may have both increased elevations and decreased disturbance in the area northwest of Goose Island, which was formerly subject to more hydraulic energy and frequently shifting intertidal channels.

In addition, the lower elevation areas of threesquare are often undetectable in aerial photographs, leading to underestimates of the amount of tidal marsh in the Stillaguamish system. The inability of aerial photos to pick up the lower elevation threesquare may be due to several factors including the decreasing stature and density of the plant as it approaches the lower tolerance threshold of its elevation and salinity range, the physiognomy of the plant (essentially leafless, with a single vertical green stem, resulting in relatively little cover when viewed from directly above), and the timing of aerial flights. The Stillaguamish is relatively heavy with sediment and the stems of American bulrush begin to become covered with a thin film of sediment in July. Sparsely distributed, short, vertical, greenish brown stems may be very difficult to see in an aerial photo, particularly if the aerial is taken near mid-day when there is little shadow.

As a result of our 2013-14 sampling, it was noted that we lack a comprehensive map of the lower and upper elevation boundaries of the major marsh zones and species, and that aerial photos are inadequate for demarcating some of these boundaries. The boundary areas in particular are expected to change in response to restoration, climate change, herbivory and other changes in key physical drivers. The spatial pattern of change in the boundary will be important to detect, as it will provide key information on changes in the spatial distribution of key physical drivers such as inundation, salinity, sediment deposition and wave erosion. The pattern of change in the marsh zone boundaries may also help us understand the effect of restoration on system-wide processes.

As we assemble the data on both the distribution of species and their relative productivity in different areas, we can begin to understand the drivers that will determine habitat distribution in the future. For example, we know that neither threesquare nor maritime bulrush occupies the entire potential area that they could occupy, and we know that their relative height and density varies considerably in different areas. By mapping these characteristics in relation to factors such as inundation period, sediment quality, landscape position, chemistry, and physical and biotic disturbance, we begin to understand why species are more resilient in some areas of the estuary, how they will respond to restoration actions and climate change impacts, and what management actions to increase system resilience are possible.

Implications for the response of habitats to restoration

The implications of these emerging ideas for monitoring of restoration impacts are important. It suggests some characteristics that could help determine the long term fate of habitat development on the restoration site. It could also help us better predict the effect of restoration on the northern marshes. Some key things for greater future focus include soil particle size distributions, transport

patterns of different particle sizes, snow goose grazing patterns, the wave environment, and vegetation response to soil particle size, soil chemistry and grazing.

For example, better characterization of the spatial patterns of soil particle sizes is very important, and understanding the conditions under which different particle sizes are transported, including both suspended particles as well as the bed load of coarser particles. The subsided restoration site is expected to be a sediment sink, capturing more sediment and accreting more rapidly than other marsh areas. It was originally hypothesized that there was enough sediment coming out of the river that the restoration site would not reduce accretion in other marsh areas, and would actually increase sediment delivery to the north. However the patterns may differ for different particle sizes and it might be possible that during major floods, the restoration site captures a larger proportion of the coarser sediments heading north, thereby altering the average particle size of sediments reaching the north.

Monitoring snow goose grazing could help us confirm where grazing intensity is highest and begin to link the biophysical feedbacks we hypothesize. In addition, we are now seeing some evidence of erosion along the western and northern boundaries of the restoration site which suggests that the subsided restoration site may be low enough to allow substantial wave development during southerly winds, enough to trigger erosion into adjacent marsh. It is also possible that snow geese congregate on the conveniently barren and firm dike footprint, resulting in more intensive grazing of the marsh immediately adjacent to the site, despite the physical interference from maritime bulrush stems. In addition, physical conditions on the restoration site are changing quickly, and the response of the vegetation will be very informative. For example, there is rapid sand accretion in some areas near the blind channel mouths, fine particle accretion in other areas, and some areas where the marsh never drains completely. Failure to drain completely is a factor sometimes linked with chemical changes in the soil, such as accumulation of hydrogen sulfide which can inhibit vegetation growth. Understanding how these different areas develop over time will improve our ability to plan future restoration projects, and will also inform the development of potential adaptive management options for the Groeneveld site that could improve habitat development.

Recommendations for monitoring

The monitoring and observations we have completed to-date suggest a number of areas for more targeted research that will improve our understanding of site and system scale effects of both restoration and climate change impacts. In addition, this recommended research will specifically identify and inform adaptive management actions at both scales.

Restoration site adaptive management

Early evidence suggests that the site will likely function at a substantially reduced level compared to natural marshes for many decades as a result of its subsided nature, with only two undersized channel connections. Much of this evidence is still anecdotal at this point, but there are a number of potential adaptive management choices that could be considered in the future to improve ecological function.

We recommend that these adaptive management options be fully fleshed out in order to define the kind of data needed to determine whether adaptive management would be likely to substantially improve ecological function or not. With the right data, these options could be modeled and compared with existing conditions to evaluate potential ecological benefit and cost. Candidate adaptive management actions could be implemented at smaller experimental pilot scales to test them before implementing across the entire site. Some potential future actions might include:

- Increase hydrological connectivity with the rest of the system by carving multiple, small connections with existing small blind tidal channels that come close to the site.
- Improve drainage of the site by widening the existing breaches or adding one or two more larger breach connections to the distributary.
- Improve connectivity of the site, and the northern marshes, with the river by creating a small breach connection with Hatt Slough.
- Improve drainage on-site by excavating more extensive networks of sinuous channels, cutting down through the hard pan layer which appears to be hindering natural channel development. This could also lessen the chance of the arrow-straight construction traffic routes from becoming the new primary channel systems. New channel systems are developing, though the hard pan layer seems to hinder their downcutting, so these proto-channels could serve as the template for where to enhance downcutting by active excavation.
- Add submerged LWD in deeper channels that remain flooded at low tide, to provide fish cover. Evidence from other systems suggests that marshes drained by channels that have subtidal wood for fish cover are used more extensively for feeding than are marshes drained by channels that lack submerged wood. This could be a good site for a management experiment that would inform the use of wood in future estuary projects.
- Re-use dredged sediment to accelerate the rate of accretion, and raise site elevations more rapidly. This could also help increase the slope to a more natural marsh slope, improving drainage, site hydraulics and channel formation.

Snow geese and the wind-wave environment

It has become clear that the effect of snow goose grazing is complex and dependent on factors such as soil particle size distribution, plant rhizome size, and the exposure of a site to erosive wind-driven waves. We need data on snow goose grazing preferences spatially and with reference to soil conditions. We also need to better understand the interaction of grazing disturbance with wave and current conditions in different areas of the estuary. For example, are marshes in soft-soiled areas that are more protected from wind waves able to withstand higher rates of grazing than are similar marshes that are more exposed? The answers will help us understand the likely trajectory on the restoration site, as well as how to improve resilience in the mid-delta and northern marshes.

Soil chemistry

We have begun to gather data on soil salinity to inform our understanding of vegetation response. However, in the restoration zone where much of the marsh surface never fully drains, there may be

chemical changes happening that could stress the plants, such as increasing levels of hydrogen sulfides. These chemicals should be monitored in the restoration site and in at least some of the reference areas as comparisons.

Erosion in the northern marshes

The highly variable microtopography of the northern marshes that are eroding make it difficult to monitor accretion/erosion dynamics in a way that accurately describes what is happening at scale. On the ground dynamics vary widely across seasons as well, with stronger evidence of erosion in the winter, while summer tides re-sort the sediment and fill in some of the eroded rills. We recommend using ground survey techniques, such as with laser levelers and rods, to accurately track the marsh front to understand the spatial and temporal dynamics. This improved knowledge of the physical dynamics driving erosion will help us determine whether there are adaptive management actions that can slow erosion.

Comprehensive tidal marsh map and system-wide photopoint system

Although much of the marsh has been sampled with plots in the past, and marsh areas digitized from aerial photos, we have found that some types of marsh are almost impossible to detect in aeriels. The sparse marshes that grow at low elevation and on coarse sediments are important because they occur in threshold areas where future changes from climate change or restoration may first become evident. Having an accurate baseline, comprehensive map of tidal marsh is important to recognize when things change. We also recommend establishing photopoints throughout the estuary, not just at the restoration site. This will make it easier to track and understand broader changes in the system. We took photos throughout all of our transects and some of these could become permanent photopoints. We have also begun to take photos at specific, GPS'd locations where significant structures occur, such as channel bifurcation points.

Sediment event sampling

Most sediment is delivered during flood events when distribution patterns are likely very different than at other times because of extensive over-bank flows. Sediment traps or short-life isotopes can be used to track event-based sediment distribution and particle size distribution. This will help us better understand how sediment is delivered to the northern marshes and what role the subsided restoration site plays in capturing sediment and possibly affecting the particle sizes delivered to the northern marshes.

Appendix 1 Detailed maps of study zones

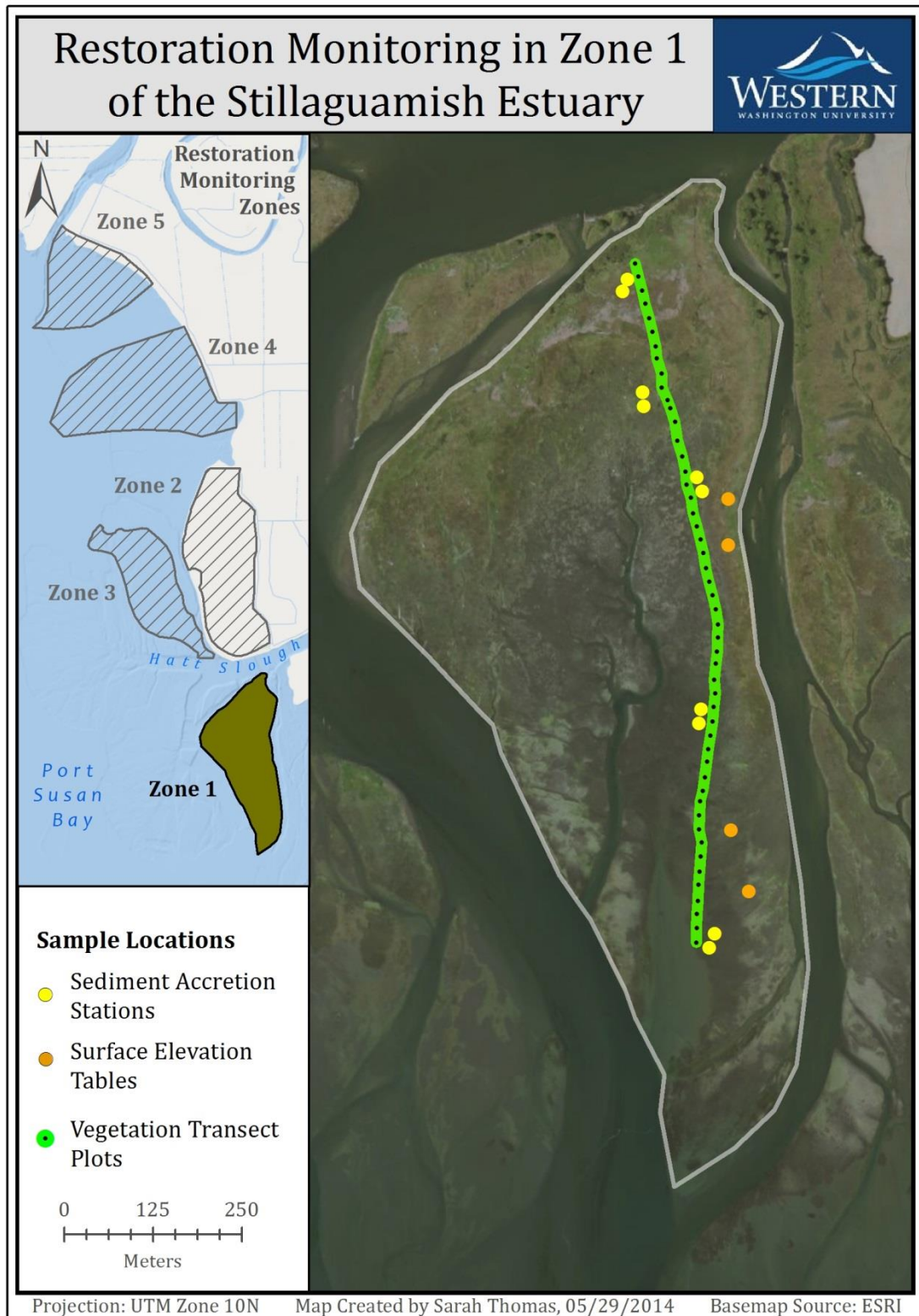


Figure 1. Sampling locations in zone 1.

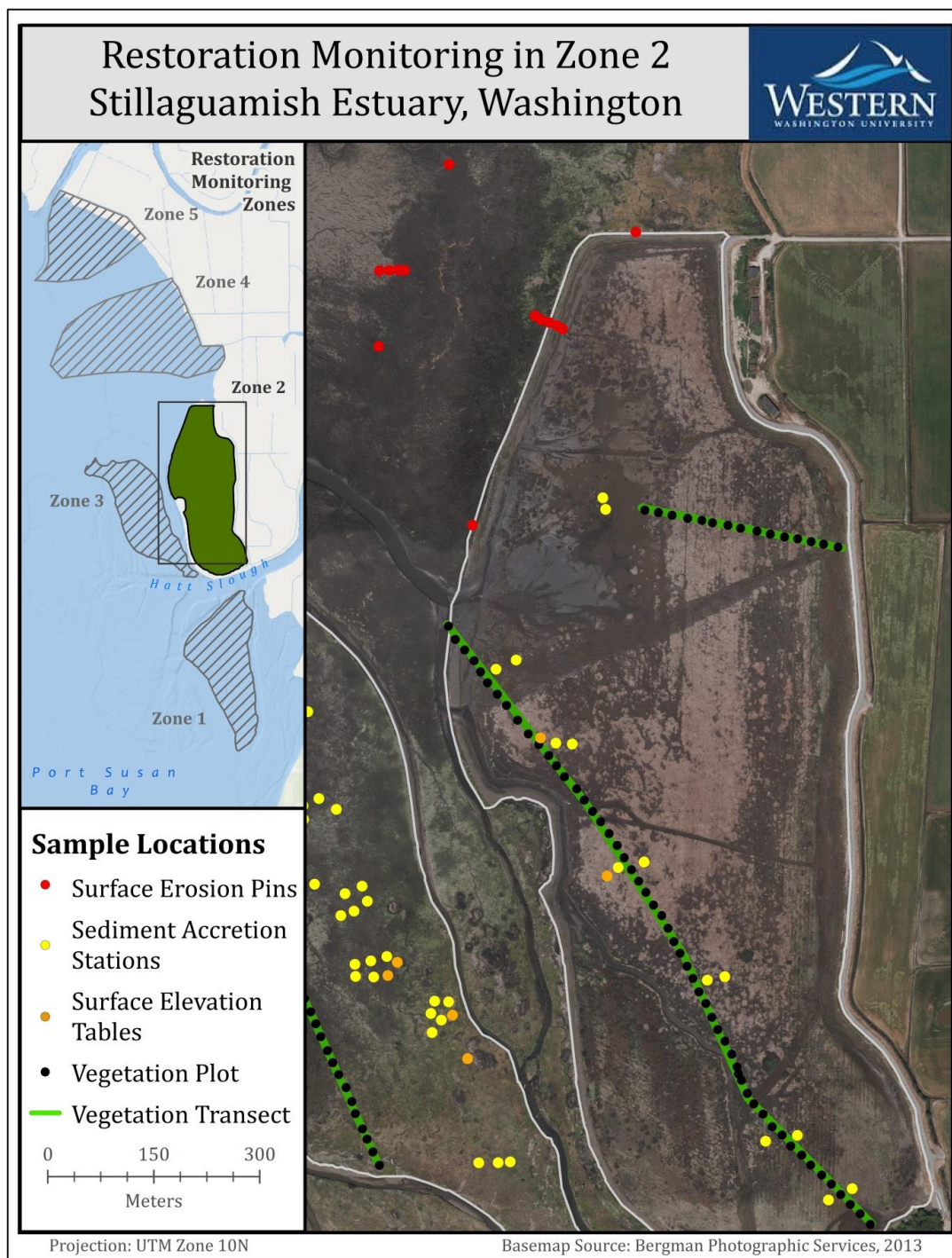


Figure 2. Sampling locations in zone 2.

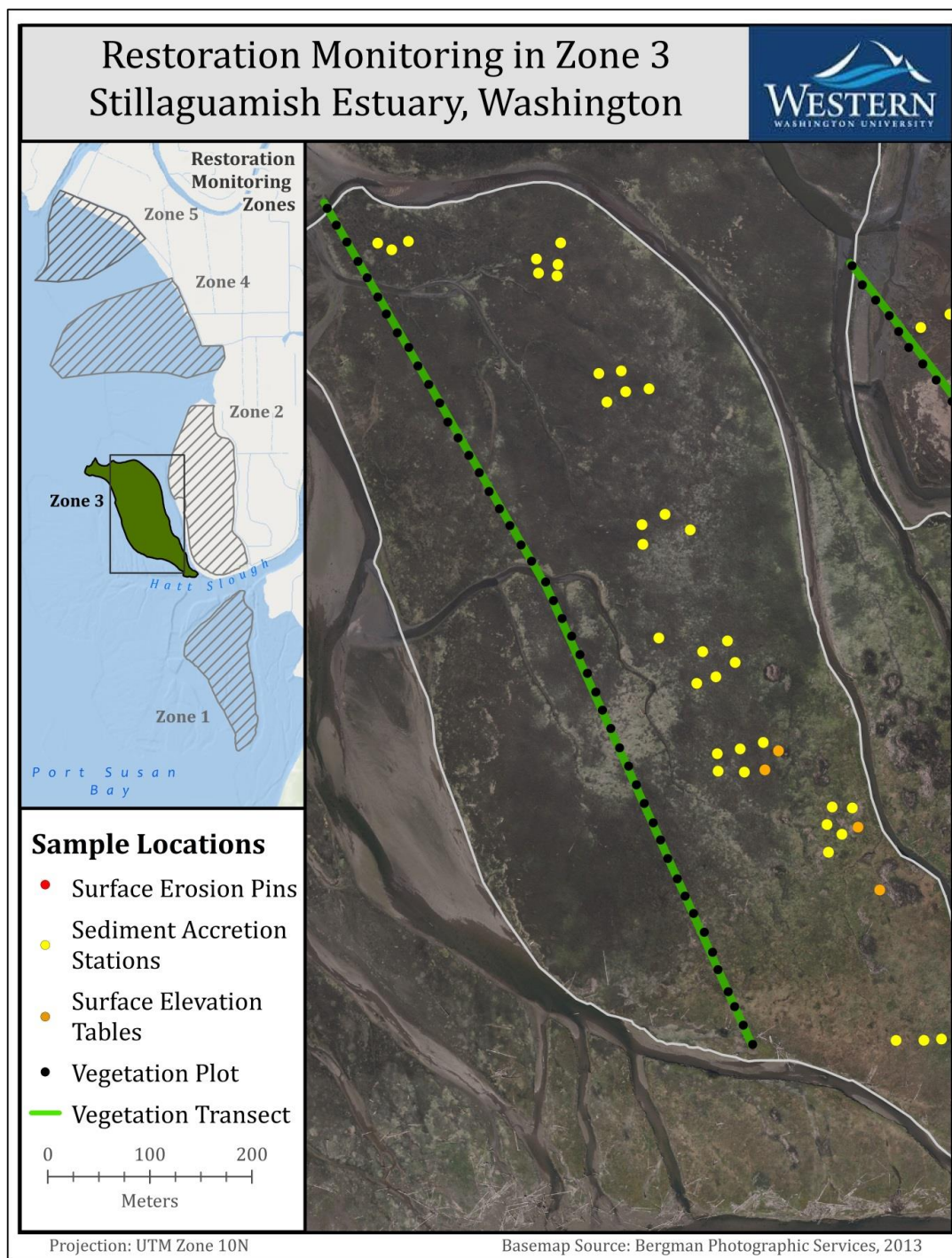


Figure 3. Sampling locations in zone 3.

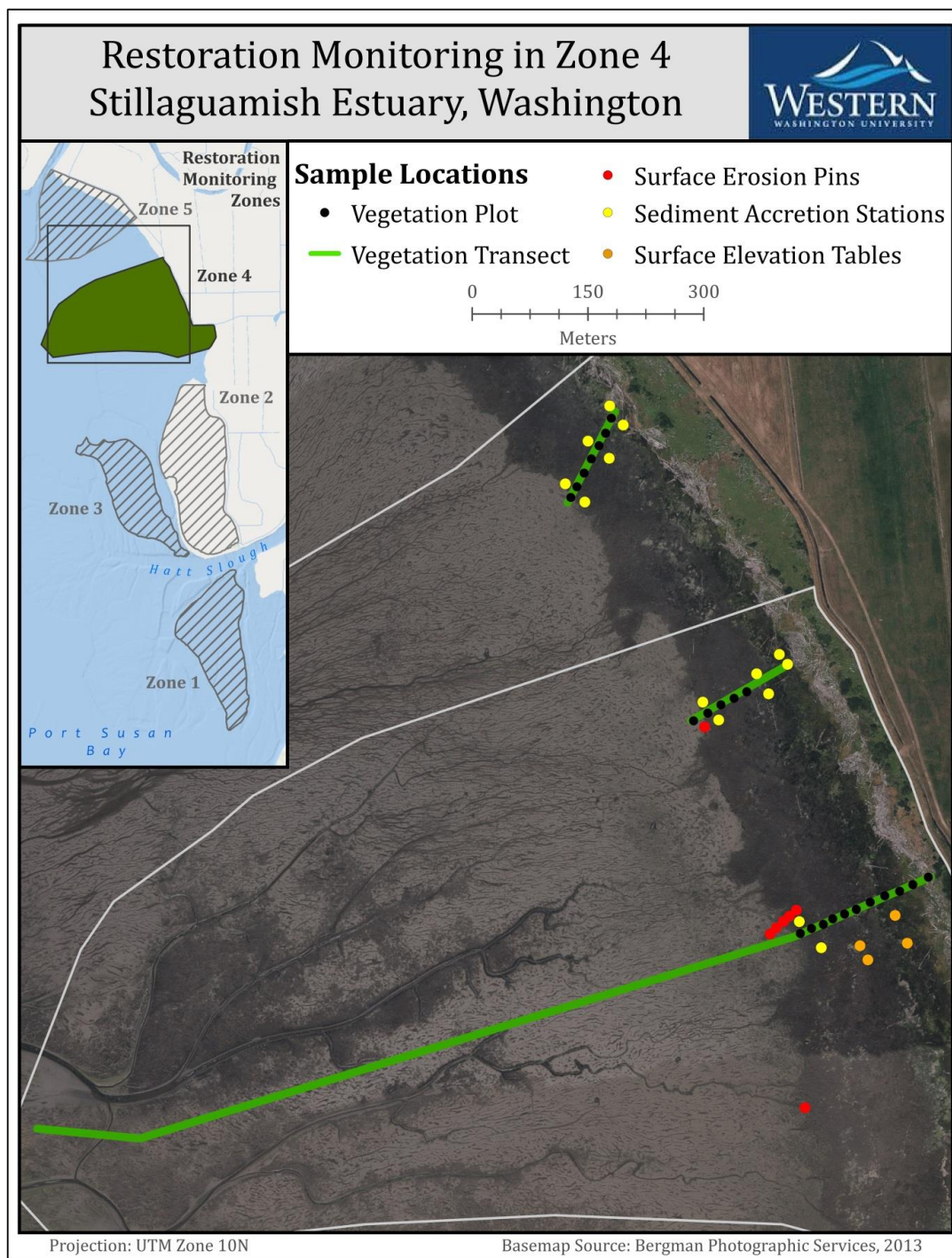


Figure 4. Sampling locations in zone 4.

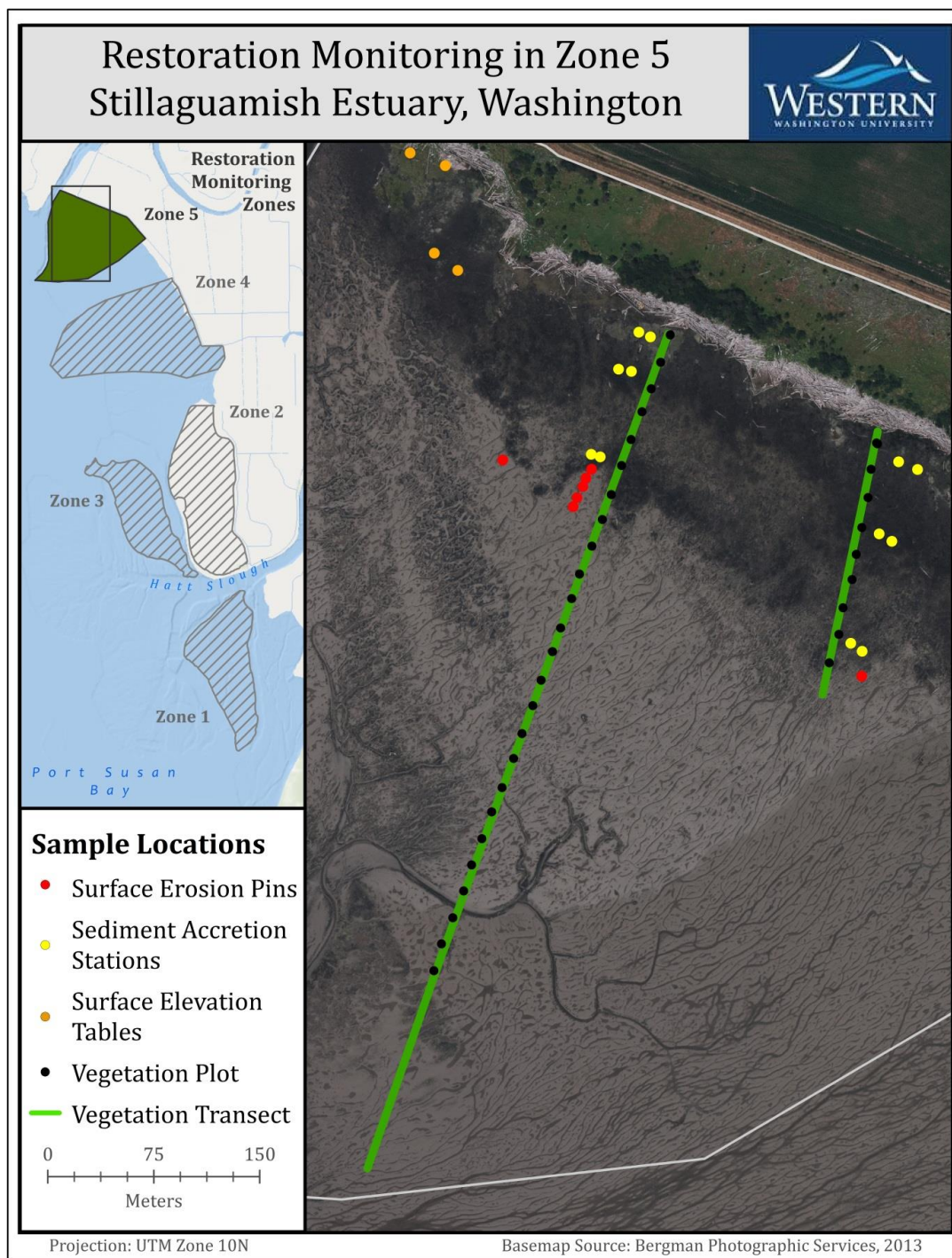


Figure 5. Sampling locations in zone 5.

Appendix 2 Draft field sampling methods

Stillaguamish Estuary

Field Methods – Vegetation

Start

Record date, crew names, GPS id#, Camera id#

Record Plot number, GPS waypoint (try for +/- 2m accuracy or less), and coordinates

Take and record photo numbers. Take four photos at each plot, pointing approximately in cardinal directions in the order South, West, North, East.

General plot data:

Species: note which species occur under the following categories:

dom: dominant, the species with the most cover

co-dom: co-dominant, sometimes there may be 2-4 species that all have +/- the same cover (there can't be both a dom and a co-dom species)

sub-dom: species that cover at least 20% of the plot, but not as much as the dominant species

present: species that are present, but at sufficiently low cover that they are unlikely to affect the overall physical structure of the habitat compared to the other species

It isn't necessary to capture every single, low-cover species that is present since the objective of this sampling is vegetation structure and dominant species, so don't spend too much time searching for rare species.

Notes: make a note of anything unique to the plot, such as the presence of large wood or channels in the plot, or large parts of the plot that are different than other parts (e.g. if 25% of plot is bare, or if there are signs of recent disturbance, etc.)

Sub-plot data

Measure vegetation structure in 5 sub-plots (a-e), chosen randomly by tossing a flag or something blindly over the shoulder. Place at least one sub-plot within each quadrant of the plot.

Height (1m² subplot): record the bin number for the average full height of plants. Don't record the height of the tallest plant, just the height that appears to be the average for the dominant species. Record the actual structural height of the vegetation biomass regardless of time of year. During the fall/winter the plant biomass may be bent over or prostrate.

Height bin numbers:

Old	New
1 = mid-calf (30cm)	0 = 0
2 = knee (50cm)	1 = prostrate (<10cm) (=old 1-)

3 = waist (100cm)	2 = mid-calf (30cm) (=old 1 and 2-)
4 = chest (130cm)	3 = knee (50cm) (=old 2)
5 = head (160cm)	4 = thigh (75cm) (=old 2+ and 3-)
	5 = waist (100cm) (=old 3)
	6 = diaphragm (125cm) (=old 3+)
	7 = chest (>130cm) – note if it is head height or higher (=old 4 and 5)

Density (50cm² subplot): For larger species (Scam, Boma, Scta, Tyla, Tyan). Record the density of stems of the taller plant species in half of the 1m² subplot. It is not necessary to count every stem in every subplot, once your density “eye” has been well calibrated with counting. However, even once the eye is calibrated, at least 1 in 10 subplots should be counted to keep the density “eye” calibrated correctly.

Density bins:

Old	New
	0 = 0
1- = 1-25	1 = 1-25
1 = 26-50	2 = 26-50
2 = 51-100	3 = 51-100
3 = 101-150	4 = 101-150
4 = 151-200	5 = 151+ (if more than 200, note approx. actual density)
5 = 201+	

For shorter or lax species (grasses, Carex, Juncus, etc.), record the following data:

Density (10cm² subplot): Record the number of stems of Carex, Juncus, Triglochin, etc. in a small 10cm² subplot approximately in the center of the 50cm² plot. Record the species next to the stem count.

Mat: (50cm² subplot): For lax species such as grasses that provide a dense, tangled matrix of thin stems, mostly in height bin 1, occasionally may reach a 2.

Record the height of the mat, whether it is dense or loose, and note if it covers less than ½ of the 50cm² subplot.

Stillaguamish Estuary Habitat Change: 1886 - 2013

Roger Fuller and James McArdle
Western Washington University

Historic habitat changes were assessed using aerial photos and the 1886 US Coastal and Geodetic Survey map. Tidal marsh and channel habitats were digitized as polygons and their area and extent were quantified. Habitat totals were calculated for the entire estuary and also for the five study zones (Figure 1).

Aerial imagery from the years 1933, 1947, 1964, 1990, 2011, and 2013 were digitized for analysis. The aerial imagery for some years did not cover the entire estuary. Data that was not available from the aerials is indicated in this report with an * symbol. The digitization of aerials and the 1886 survey map was done at a scale of no greater than 1:2,500. For the purpose of comparing the historic aerials, only the Stillaguamish tidal marsh south of the Stanwood-Camano bridge was digitized since the area north of the bridge was not always available in the photographs. While the 1886 survey maps include tidal marshes, it should be noted that the methods used by the surveyors to define and map tidal marsh habitat are unknown and may not exactly match how we have mapped tidal marsh in subsequent aerials.

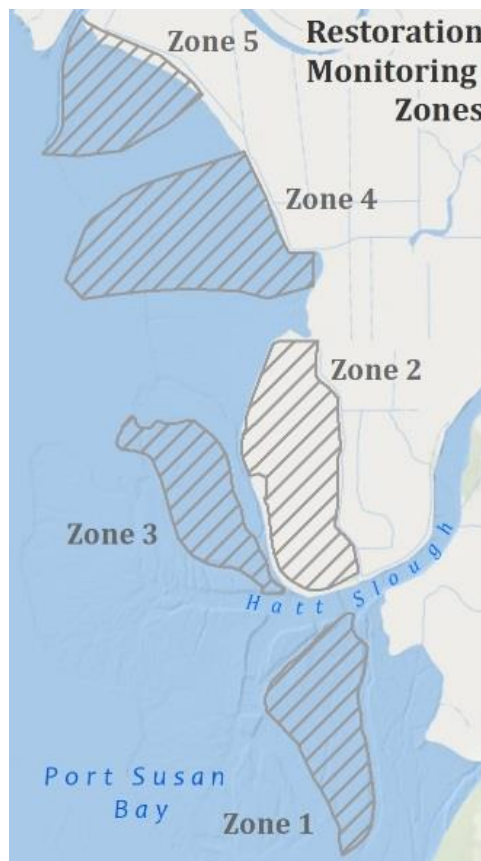


Figure 1. Map showing the location of the five study zones in the Stillaguamish estuary. Zone 2 is the restoration site.

Tidal Marsh

Tidal marsh was categorized as Continuous Marsh, Patchy Marsh, or Low Density Marsh.

Continuous Marsh was defined as large stretches of high density marsh vegetation unbroken by bare tidal flat (Figure 2). Continuous marsh generally extended seaward from the dike or from the highest tidal elevations. Some continuous marsh was divided by tidal or river channels, but was designated as continuous marsh as long as it was not interrupted by bare tide flat.

Patchy Marsh was defined as high density marsh separated from continuous marsh by areas of bare tide flat. These areas mainly consisted of lone circular colonies of distinct vegetation or the merging of multiple circular colonies.

Low Density Marsh was deemed any area where vegetation was still present but sufficiently sparse that large areas of bare sediment were visible throughout the marsh (Figure 2). These areas did not appear patchy but tended to be in larger continuous stretches.

Both Patchy and Low Density Marsh generally occurred at the seaward edge or the lowest elevations of the low marsh areas.

Low Density Marsh can be very difficult to see in aerial imagery, likely affected by factors such as photo resolution, month and day of the aerial (which affects the plant growth phase and the seasonal likelihood of wrack or wind/wave flattened vegetation), as well as time of day (which affects shadows that can reveal otherwise cryptic vegetation). Based on our field work, the Low Density Marsh appears to be largely American, or threesquare bulrush (*Schoenoplectis americanus*), which is essentially leafless, consisting of a vertical green stem that is very difficult to see at low densities from an aerial perspective. The marsh in these areas also tends to be much shorter than most Continuous Marsh areas (Figure 2). The stems begin to become coated with sediment starting in July, which would make them even more difficult to see from above.

Due to the difficulty of seeing Low Density Marsh in aerials, the data on this marsh type is provided here only for future reference. Older aerials may not have had sufficient resolution to detect Low Density Marsh, so its absence from older aerials does not necessarily mean that it was absent from the system. Even with modern aerials, it can be very difficult to detect, as can be seen by comparing the 2011 and 2013 aerials (Table 1 and Figures 8 and 9). Areas that appear bare in 2011 have low density marsh visible in 2013. The patterns of marsh in older photos, as well as on-the-ground data and plot photos indicate that the bare areas in 2011 had low density marsh in earlier years. Their absence in 2011 aerials is almost certainly due to issues related to the timing and environmental context when the aerial was collected. For these reasons, further analysis is needed to determine when it is appropriate to compare digitized low density marsh between various aerials. It may be necessary to document photo resolution, timing and environmental context before determining which aerials can be used for comparisons.

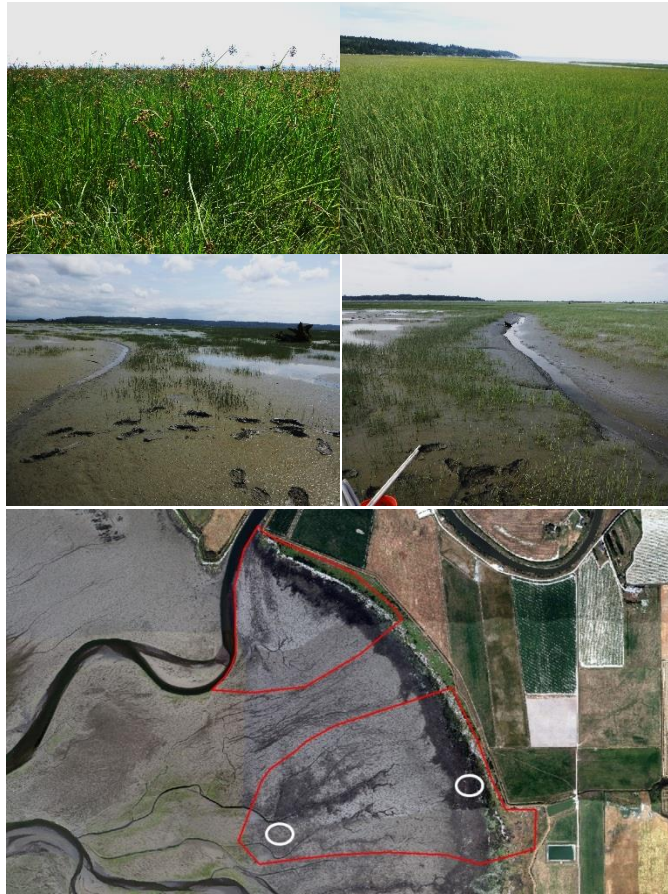


Figure 2. The top two photos illustrate high density marsh and the middle two illustrate low density marsh. The top left photo is of soft stem bulrush and the other three photos are of threesquare bulrush. The bottom aerial photograph from 2013 illustrates how high density marsh (right circle) and low density marsh (left circle) differ in appearance in the aerials.

Channels

Channels were categorized as either River Channels or Tidal Channels.

River Channels carried water from the Stillaguamish River to the bay and are also called distributary channels. River channels had well defined banks and generally were wetted, carrying river water, even at low tide.

Tidal Channels were deemed any “blind” channels not directly connected to the river. These convey water as the tide moves in and out and are key to tidal marsh connectivity, moving water, sediment, fish, organic matter and other materials around the estuary. Tidal channels generally occur in the marsh zone. Below this elevation, in the bare tide flat zone, they tend to become more broad, variable and with ill-defined banks, often disappearing entirely. We digitized only channels that had clearly defined banks that appeared moderately stable.

Results and Discussion

Estuary-wide trends

The 1886 survey map was drawn after most of the levees and dikes had been built, resulting in the conversion of most of the system's tidal marsh. As a result, the lowest amount of tidal marsh (329 acres) was in the 1886 map (Table 1), and it nearly tripled in area by 1964. The peak was reached in 1990 at 1,063 acres, after which it declined 37% by 2011. The 17% increase between 2011 and 2013 is largely due to the restoration project at Hatt Slough.

The invasion of *Spartina anglica*, or cordgrass, is a historical event that may have affected rates of marsh change, but for reasons discussed later we do not think it was a major factor in the areas we discuss. Additional information on spartina extent when control began would be helpful in interpreting the aerals. In aerial photos, it is not possible to discern different species without a contemporary on-the-ground survey. The introduction of spartina to Puget Sound occurred on Menno Groeneveld's property. It may have been introduced to lessen wave erosion of his new dike, which would have placed the introduction sometime after 1959, likely in the early 1960's. Intensive control of spartina occurred after 2000, but some control efforts likely occurred during the 1990's.

Overall, marsh expanded at a rate of 6-8 acres per year on average until 1990, after which it declined at a rate of 19 acres per year until the 2012 restoration project.

Low density marsh is difficult to detect in aerals and should not be compared between years until further analysis. The data is provided here for information purposes only, but can be used in future analyses now that we have a baseline of on-the-ground data to inform interpretation of aerals. Similarly, river channel data should not be compared between years because the extent of river channels in an aerial depends on the tide height and photo extent, which varies significantly among the aerals. Future analysis could determine the year of smallest extent and use that to clip the river channel layers for other years, allowing at least a partial comparison.

Table 1: *Habitat extent for the Stillaguamish estuary, based on historic aerals and maps. Units are acres. For this analysis, only tidal marsh south of the Stanwood-Camano bridge was included. * indicates that data were not available from the 1886 survey map. Low density marsh and river channel area should not be compared between years. See the text for details.*

Year	1886	1964	1990	2011	2013
Continuous Marsh	329	916	1,063	669	784
Patchy Marsh	*	8	1	1	30
Low Density Marsh	*	0	0	122	158
Total Marsh	329	924	1,064	792	972
Avg Annual Rate of Change		8	6	-19	58
River Channels	*	1,413	850	470	906
Tidal Channels	*	30	65	69	65

Tidal channel area is comparable because these channels tend to occur largely in the vegetated tidal zone which is always exposed in the aerals. Tidal channel area approximately doubled between 1964 and 1990. This was largely as a result of the consolidation of the South Pass channel from two distributary forks into a single fork, converting one of them into a blind channel system. Since then, overall tidal channel area has remained constant.

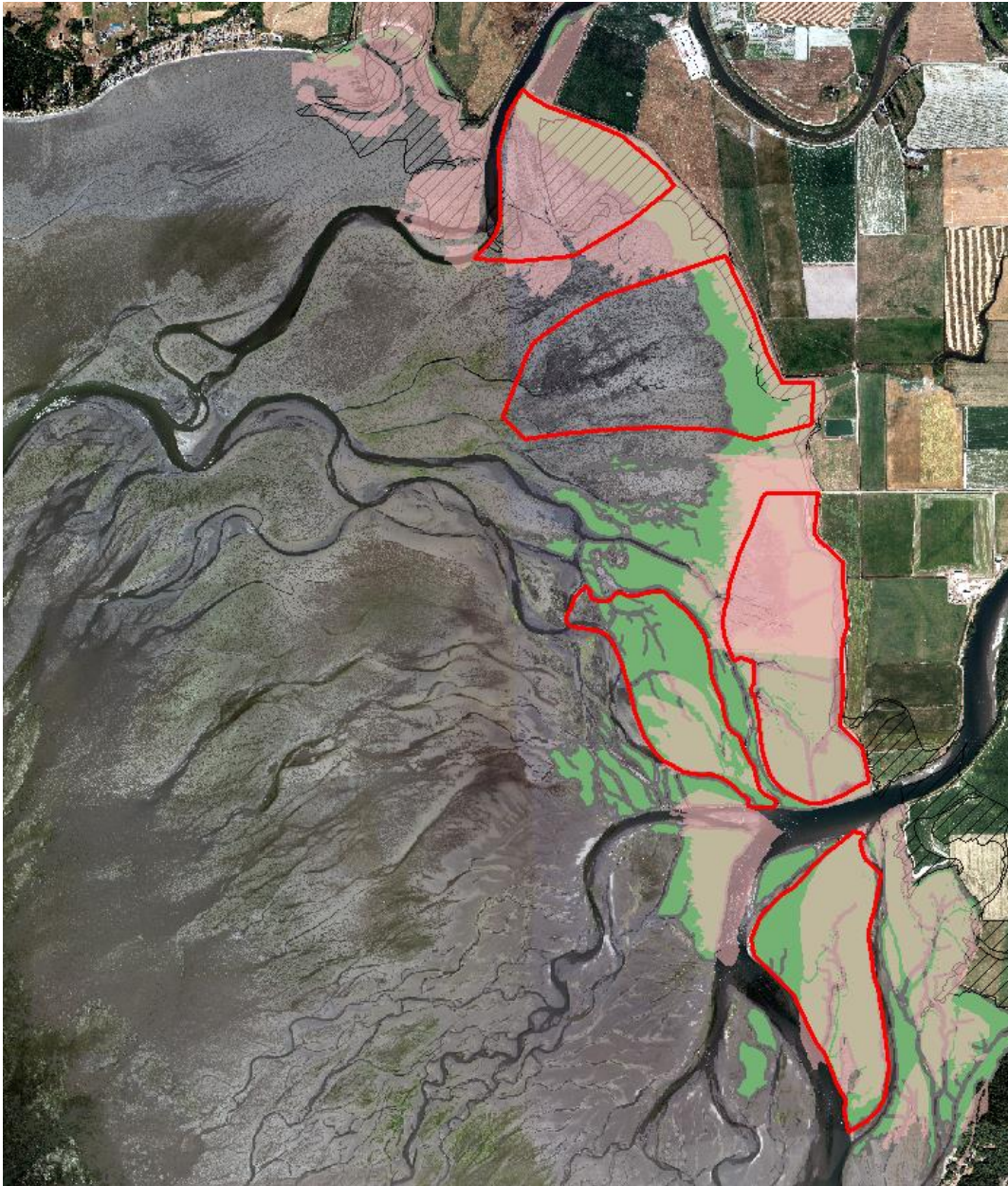


Figure 3. Changes in the extent of continuous marsh habitat, 1886 to 2013. Three time periods are shown overlaying the 2013 aerial photograph. 1886 tidal marsh is shown as cross-hatched. 1933/1947 is shown as translucent pink, and 2013 is shown as solid green.

A summary of the historic changes in continuous marsh extent is shown in Figure 3, which maps the marsh in 1886, 1933/1947, and 2013. Neither of the aerals for 1933 and 1947

covered the entire estuary, so they were combined in a single layer to represent conditions before the Groeneveld dike was built. The 1933 extent covers the northern half of the estuary and the 1947 extent covers the southern half. The general pattern can be seen of early marsh expansion in the north followed by substantial losses, while in the south there has been sustained expansion since 1886.

All of the changes in the configuration of continuous marsh habitat over the years are summarized in Figure 4. The map classifies each distinct area of marsh according to the number of aerals in which it was found, beginning with marsh that was present in all years and ending with marsh that was present in only one of the time periods.

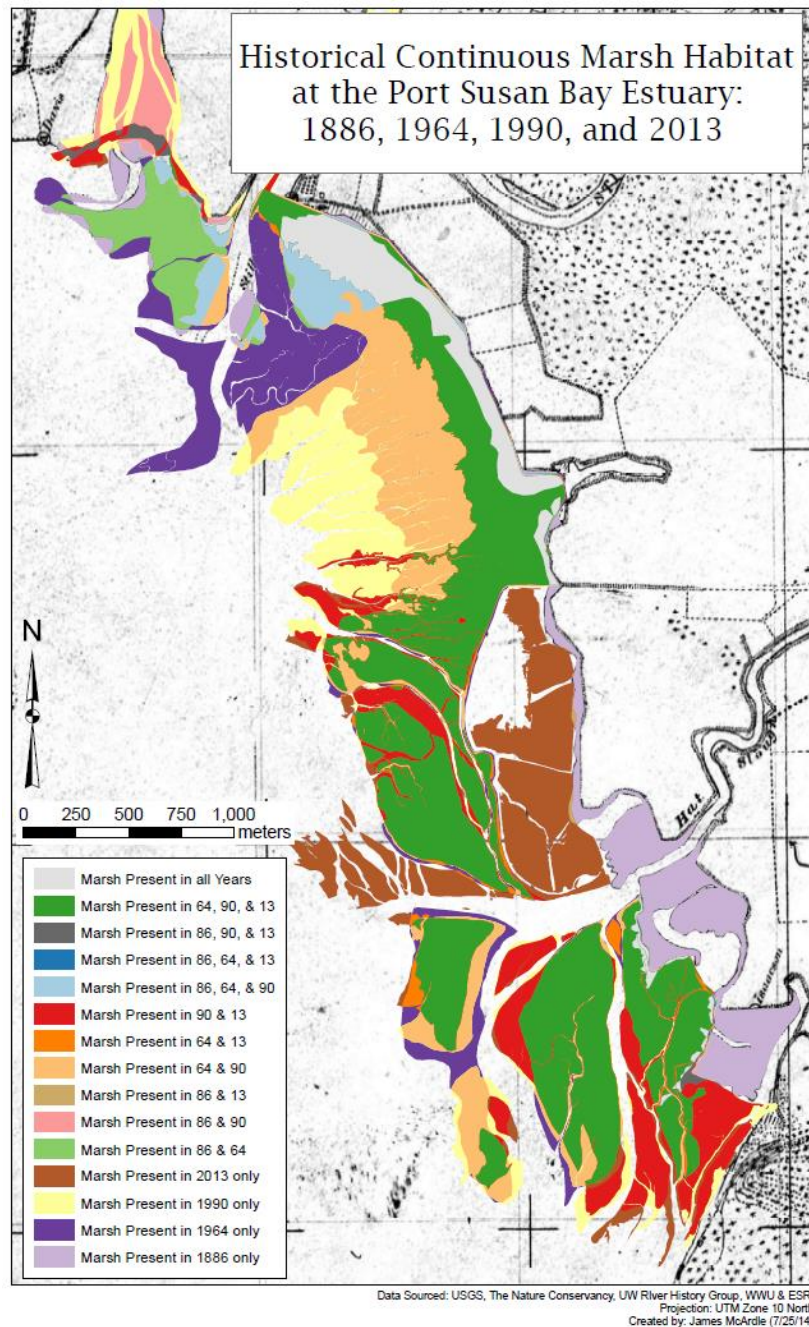


Figure 4. Historical changes in the configuration of continuous marsh.

Habitat trends in the five study zones

In 1886, zone 5 had the most tidal marsh (59 acres) of all five zones, and zones 1 and 3 had no marsh (Figures 5 and 6). At this time, the main channel of the Stillaguamish was still the Old Stilly channel, so most of the freshwater and sediment was delivered at the north end of the bay. Hatt Slough was the smaller of the two main distributaries. This arrangement changed in the early 1900's when the log jam at the mouth of Hatt Slough was removed and a flood pushed the main flow into Hatt Slough where it has remained.

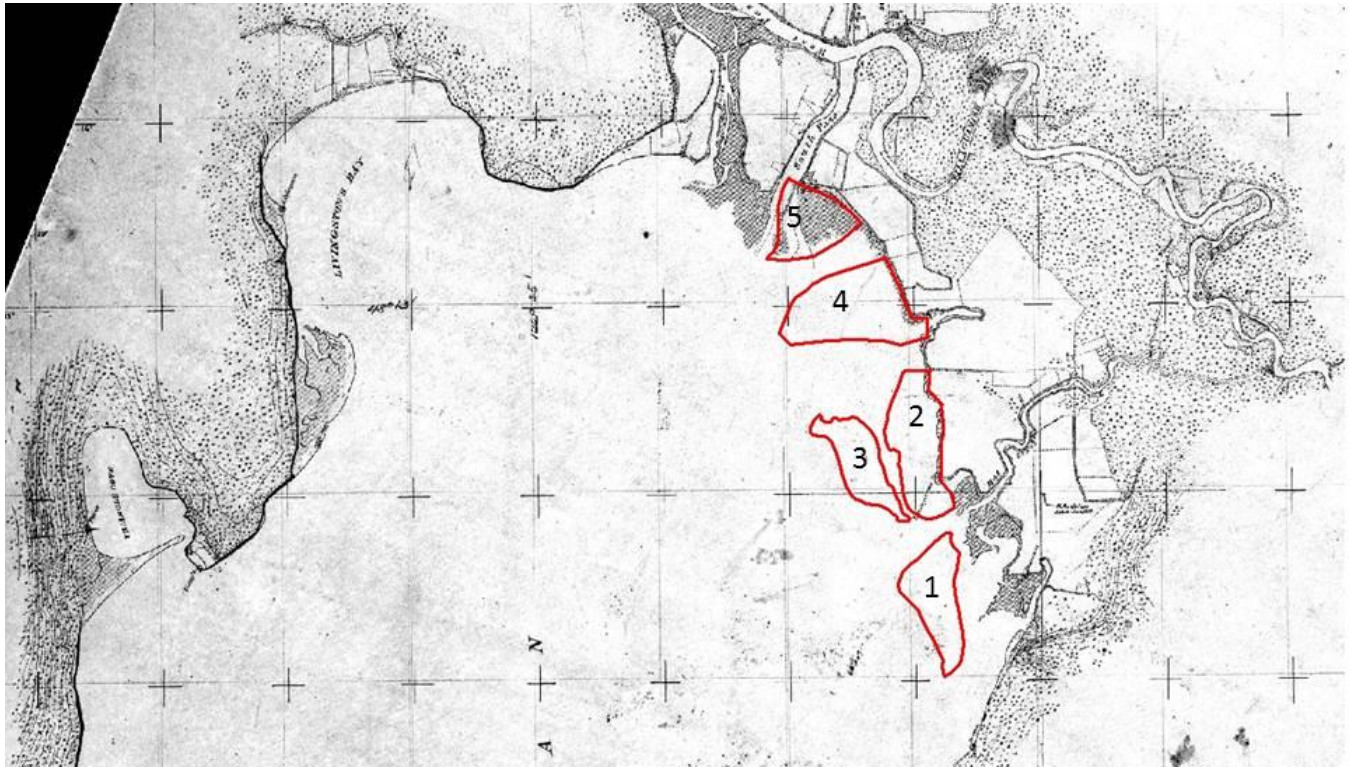


Figure 5. 1886 survey map of the Stillaguamish delta (U.S. Coast and Geodetic Survey). The five study zones are indicated.

The change in dominant flow from the Old Stilly channel to Hatt Slough had a profound effect on the pattern of delivery of sediment and freshwater to the estuary, and the resulting development of tidal marsh. Between 1886 and the aerials of 1933 and 1947, the tidal marsh in all zones increased in area (Figure 6), though zones 1 and 2 at the mouth of Hatt Slough expanded considerably faster than zones 4 and 5 which were no longer at the mouth of the main channel. Between 1886 and now, zone 5 went from having the most marsh to having the least, and zone 1 went from having the least to having the most, illustrating the importance of proximity to freshwater and a sediment source.

Trends in Continuous Marsh

Tidal marsh in zones 3 and 4 increased substantially by 1964, and held steady in zones 1 and 5 (Figure 6). Menno Groeneveld built his dike in the late 1950's, eliminating the zone 2 marsh. The rate of expansion in zone 3 was 2.47 acres per year leading up to 1964, and 3.28 ac/yr in zone 4. Zone 1 increased by less than 0.5 ac/yr and zone 5 stayed essentially the same.

Zone 1 increased by 20% (20 acres) from 1964 to 1990, peaking at 114 acres. Since then it has declined slightly by 5% to 107 acres. Between 1964 and 1990, zone 3 increased by 18% (13 acres, or 0.5 acre/year), then slowed down, growing 2% (2 acres, 0.07 ac/yr) between 1990 and 2011.

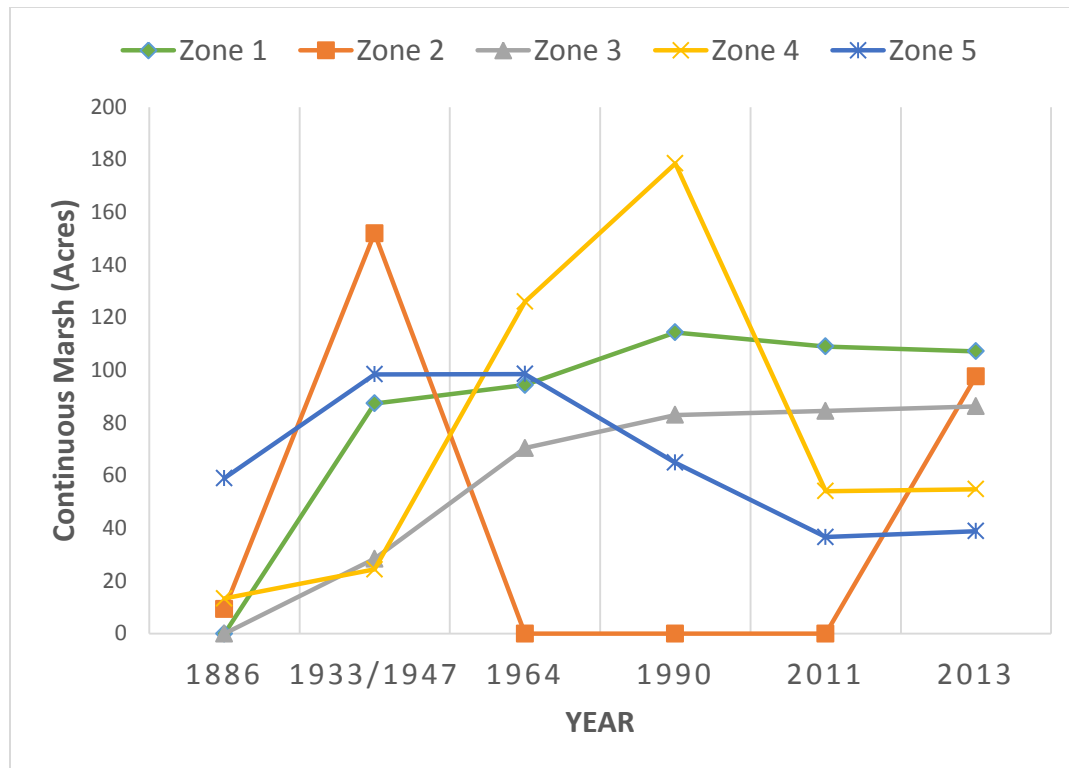


Figure 6. Trends in the area of continuous tidal marsh in the 5 study zones. 1933 and 1947 data are lumped because 1933 aerials only cover zones 4 and 5, and 1947 aerials only cover zones 1-3. Note that the X axis shows photo years and is not to scale.

Zone 4 continued to rise sharply after 1964, peaking in 1990 at 179 acres (2.02 ac/yr), then fell sharply by 70% to 54 acres in 2011 (-5.9 ac/yr). The dynamics of spartina invasion and control may have played a role in zone 4, however it is our view that the patterns of marsh expansion and retreat are not consistent with spartina history as we understand it. The rate of growth after 1964 (2.02 ac/yr) was slower than the rate of growth prior to 1964 (3.28 ac/yr). If spartina was introduced in the early 60's we would expect to see a rise in the rate rather than a decline.

Intensive control efforts after 2000 found spartina mixed with the native species throughout the upper marsh in zone 4, however it did not form broad monotypic stands as it did in south Skagit Bay and in Triangle Cove. Treatment during the 2000's in this area of the marsh consisted of spot spraying of individual patches. If this was also the case in the years before 2000, than control efforts should have altered the species composition of the marsh, but not have significantly reduced the overall marsh area. Furthermore, during the 2000's spartina was present but not common in the lower, sparse marsh area where the greatest marsh loss has

been seen. It is conceivable that the lower marsh was dense spartina in 1990 and was heavily sprayed with herbicide during the 1990's, wiping out all the vegetation in the lower marsh which then developed sparse threesquare marsh. We are not aware of any treatment records from the '90s though they may exist. However the only herbicide legally available for marshes prior to the mid 2000's was glyphosate, which was only effective at wiping out vegetation after continuous use over many years. It is our understanding that this level of effort did not begin until after 2000, and spartina did not begin to be wiped out until the herbicide imazapyr was approved in the mid to late 2000's. We think it unlikely therefore that extensive loss of marsh in the 1990's was due to treatment.

Finally, though we have not digitized habitats from aerials in the late 1990's to early 2000's, examination of available aerials suggests a broad, gradual thinning of the marsh over time, rather than a sudden disappearance. A sudden loss of marsh would be consistent with treatment, as can be seen in Triangle Cove. Instead we see the lower marsh thin out, most of it transitioning to what we call sparse marsh by 2003, and the sparsest areas in 2003 become barren by 2013. Unlike threesquare bulrush, which occupies the sparse lower marsh and which does not grow in dense clones, spartina grows very densely. It should appear as either dense continuous marsh, or if in the process of being controlled, as scattered, but relatively dense patches.

In zone 5, the high density continuous marsh begins to substantially recede after 1964, falling by 1.29 ac/yr through 1990, and by 1.35 ac/yr between 1990 and 2011. The marsh in the 1990 aerial can be difficult to discern in zone 5, so the loss rate prior to 1990 may have been less, but that would only increase the rate of loss after 1990. Currently zone 5 has 39 acres of tidal marsh, down from its 1933-1964 peak of 99 acres. If spartina has played a role in zone 5, we would have expected to see an expansion of marsh after 1964 throughout that area, and this is not evident.

The heavy loss of marsh in zones 4 and 5 after 1990 corresponds with the rapid expansion of the wintering snow goose population, which feeds heavily on bulrush rhizomes, particularly in soils with finer particle sizes. This is also when the flow from Hatt Slough shifts away from the north and towards the south, likely affecting the amount and particle size of sediment that is delivered to the northern marshes. These effects likely combine with winter storm waves to cause the substantial loss in dense continuous marsh.

The only significant change in tidal marsh between 2011 and 2013 was the increase of 98 acres after restoration in zone 2.

The habitat changes are quantified for each year in each zone and provided in Table 2.

Aerials and maps showing the changes in marsh and channel habitats are provided in Figure 7 for zone 1, Figure 8 for zones 2 and 3, and Figure 9 for zones 4 and 5. Marsh is categorized as Continuous, Patchy or Low Density, and channels are categorized as River or Tidal Channels. At the scale of these figures, tidal channels are difficult to see, but details can be seen in the ArcGIS files that accompany this report.

A summary of the historical changes in continuous marsh boundaries for each zone is shown in Figure 10.

Table 2. Habitat areas and rates of change in each study zone. The rates of change are in acres per year, calculated since the previous photo date.

Zone 1

	1886				1947				1964				1990				2011				2013			
				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)
	m2	acres	% of Zone		m2	acres	% of Zone		m2	acres	% of Zone		m2	acres	% of Zone		m2	acres	% of Zone		m2	acres	% of Zone	
Continuous Marsh	0	0.00	0.00		353,749	87.40	73.60	1.40	382,076	94.41	79.59	0.41	463,065	114.43	96.46	0.77	441,491	109.10	91.97	-0.25	433,913	107.22	90.39	-0.94
Patchy Marsh	*	*	*	*	4,204	1.00	0.80		0	0.00	0.00	-0.06	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00
Low Density Marsh	*	*	*	*	0	0.00	0.00		0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00
River Channels	*	*	*	*	100,881	24.90	21.00		92,354	22.82	19.24	-0.12	10,380	2.57	2.16	-0.78	6,628	1.64	1.38	-0.04	19,228	4.75	4.01	1.56
Tidal Channels	*	*	*	*	11,046	2.70	2.30		5,349	1.32	1.11	-0.08	6,600	1.63	1.37	0.01	12,466	3.08	2.60	0.07	124,712	30.82	25.98	13.87
Total Area of Zone	480,045	118.60	100.00	0.00	480,045	118.60	100.00	0.00	480,045	118.60	100.00	0.00	480,045	118.60	100.00	0.00	480,045	118.60	100.00	0.00	480,045	118.60	100.00	0.00

* Data not available for given year in Zone 1

Zone 2

	1886				1947				1964				1990				2011				2013			
				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)
	m2	acres	% of Zone		m2	acres	% of Zone		m2	acres	% of Zone		m2	acres	% of Zone		m2	acres	% of Zone		m2	acres	% of Zone	
Continuous Marsh	37,785	9.40	6.00		615,348	152.00	97.00	2.30	0	0.00	0.00	-8.94	0	0.00	0.00	0.00	0	0.00	0.00	0.00	395,193	97.66	62.42	48.83
Patchy Marsh	*	*	*	*	0	0.00	0.00		0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	21,905	5.41	3.46	2.71
Low Density Marsh	*	*	*	*	0	0.00	0.00		0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00
River Channels	*	*	*	*	0	0.00	0.00		0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00
Tidal Channels	*	*	*	*	17,729	4.40	2.80		0	0.00	0.00	-0.26	0	0.00	0.00	0.00	0	0.00	0.00	0.00	17,326	4.28	2.74	2.14
Total Area of Zone	633,109	156.50	100.00	0.00	633,109	156.50	100.00	0.00	633,109	156.50	100.00	0.00	633,109	156.50	100.00	0.00	633,109	156.50	100.00	0.00	633,109	156.50	100.00	0.00

* Data not available for given year in Zone 2

Zone 3

	1886				1947				1964				1990				2011				2013			
				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)
	m2	acres	% of Zone		m2	acres	% of Zone		m2	acres	% of Zone		m2	acres	% of Zone		m2	acres	% of Zone		m2	acres	% of Zone	
Continuous Marsh	0	0.00	0.00		115,178	28.46	29.05	0.46	285,207	70.48	71.92	2.47	336,164	83.07	84.77	0.48	342,288	84.58	86.32	0.07	349,502	86.37	88.14	0.89
Patchy Marsh	*	*	*	*	3,129	0.77	0.79		0	0.00	0.00	-0.05	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00
Low Density Marsh	*	*	*	*	0	0.00	0.00		0	0.00	0.00	0.00	0	0.00	0.00	0.00	21,781	5.38	5.49	0.26	7,771	1.92	1.96	-1.73
River Channels	*	*	*	*	116,683	28.83	29.43		108,588	26.83	27.38	-0.12	22,000	5.44	5.55	-0.82	12,844	3.17	3.24	-0.11	20,282	5.01	5.11	0.92
Tidal Channels	*	*	*	*	0	0.00	0.00		5,516	1.36	1.39	0.08	7,831	1.94	1.97	0.02	9,757	2.41	2.46	0.02	8,793	2.17	2.22	-0.12
Total Area of Zone	396,539	98.00	100.00	0.00	396,539	97.99	100.00	0.00	396,539	98.00	100.00	0.00	396,539	98.00	100.00	0.00	396,539	98.00	100.00	0.00	396,539	98.00	100.00	0.00

* Data not available for given year in Zone 3

Table 2, continued.

Zone 4

	1886				1933				1964				1990				2011				2013			
				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)
	m2	acres	% of Zone		m2	acres	% of Zone		m2	acres	% of Zone		m2	acres	% of Zone		m2	acres	% of Zone		m2	acres	% of Zone	
Continuous Marsh	53,950	13.30	6.70		98,922	24.40	12.30	0.24	510,115	126.05	63.31	3.28	722,600	178.56	89.67	2.02	219,143	54.15	27.20	-5.92	221,997	54.86	27.55	0.35
Patchy Marsh	*	*	*	*	60,673	15.00	7.50		17,909	4.43	2.22	-0.34	0	0.00	0.00	-0.17	0	0.00	0.00	0.00	50,814	12.56	6.31	6.28
Low Density Marsh	*	*	*	*	0	0.00	0.00		0	0.00	0.00	0.00	0	0.00	0.00	0.00	1,188	0.29	0.15	0.01	162,646	40.19	20.18	19.95
River Channels	*	*	*	*	0	0.00	0.00		0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00
Tidal Channels	*	*	*	*	10,884	2.70	1.40		35,447	8.76	4.40	0.20	60,440	14.94	7.50	0.24	30,793	7.61	3.82	-0.35	39,932	9.87	4.96	1.13
Total Area of Zone	805,800	199.00	100.00	0.00	805,800	199.00	100.00	0.00	805,800	199.00	100.00	0.00	805,800	199.00	100.00	0.00	805,800	199.00	100.00	0.00	805,800	199.00	100.00	0.00

* Data not available for given year in Zone 4

Zone 5

	1886				1933				1964				1990				2011				2013			
				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)				Average Change per Year (ac/yr)
	m2	acres	% of Zone		m2	acres	% of Zone		m2	acres	% of Zone		m2	acres	% of Zone		m2	acres	% of Zone		m2	acres	% of Zone	
Continuous Marsh	239,045	59.10	54.90		398,665	98.50	91.60	0.84	399,089	98.62	91.72	0.00	262,873	64.96	60.41	-1.29	148,460	36.69	34.12	-1.35	157,672	38.96	36.24	1.14
Patchy Marsh	*	*	*	*	0	0.00	0.00		0	0.00	0.00	0.00	0	0.00	0.00	0.00	0	0.00	0.00	0.00	71	0.02	0.02	0.01
Low Density Marsh	*	*	*	*	0	0.00	0.00		0	0.00	0.00	0.00	0	0.00	0.00	0.00	19,130	4.73	4.40	0.23	79,497	19.64	18.27	7.46
River Channels	*	*	*	*	26,861	6.60	6.20		28,817	7.12	6.62	0.02	21,957	5.43	5.05	-0.07	1,030	0.25	0.24	-0.25	4,651	1.15	1.07	0.45
Tidal Channels	*	*	*	*	4,994	1.20	1.20		6,560	1.62	1.51	0.01	4,933	1.22	1.13	-0.02	5,598	1.38	1.29	0.01	10,135	2.50	2.33	0.56
Total Area of Zone	435,122	107.50	100.00	0.00	435,122	107.50	100.00	0.00	435,122	107.50	100.00	0.00	435,122	107.50	100.00	0.00	435,122	107.50	100.00	0.00	435,122	107.50	100.00	0.00

* Data not available for given year in Zone 5

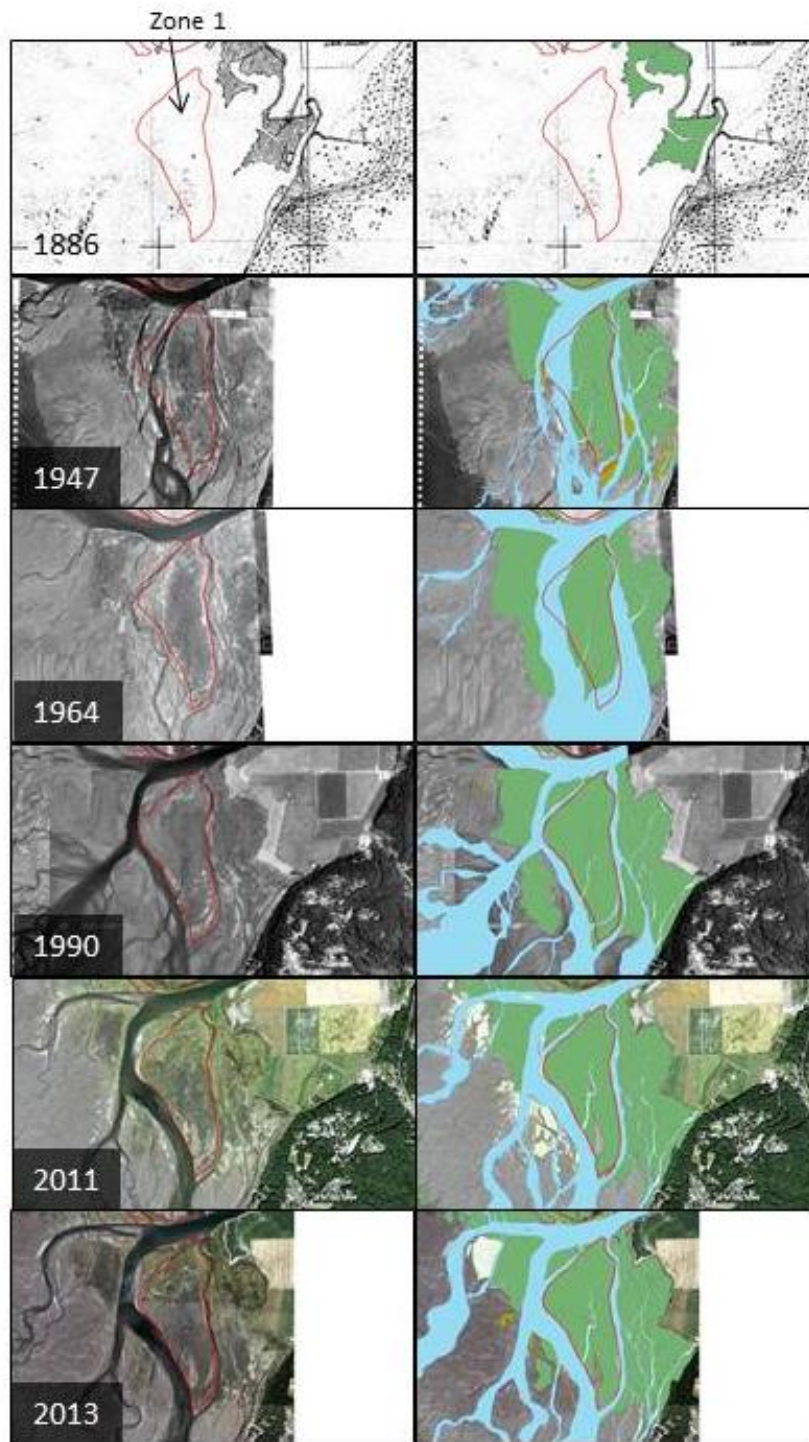


Figure 7. Habitat trends in zone 1 (outlined in red). The left column shows the aerials and the right column shows the digitized habitat. Green polygons show Continuous Tidal Marsh, olive green polygons show Patchy Marsh and white polygons show Low Density Marsh. Blue polygons show the River Channels and turquoise polygons show the Tidal Channels.

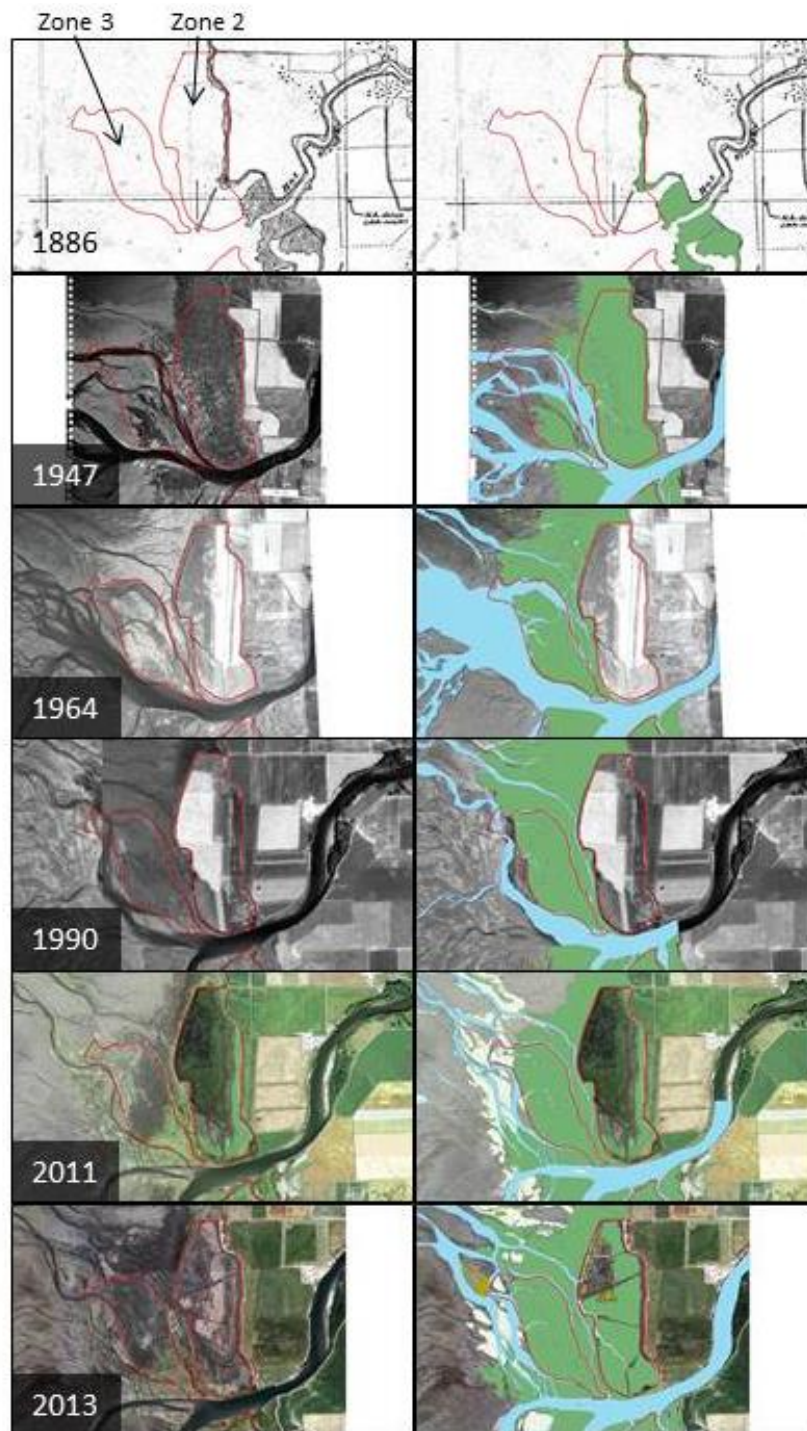


Figure 8. Habitat trends in zones 2 and 3 (outlined in red). The left column shows the aerials and the right column shows the digitized habitat. Green polygons show Continuous Tidal Marsh, olive green polygons show Patchy Marsh and white polygons show Low Density Marsh. Blue polygons show the River Channels and turquoise polygons show the Tidal Channels.

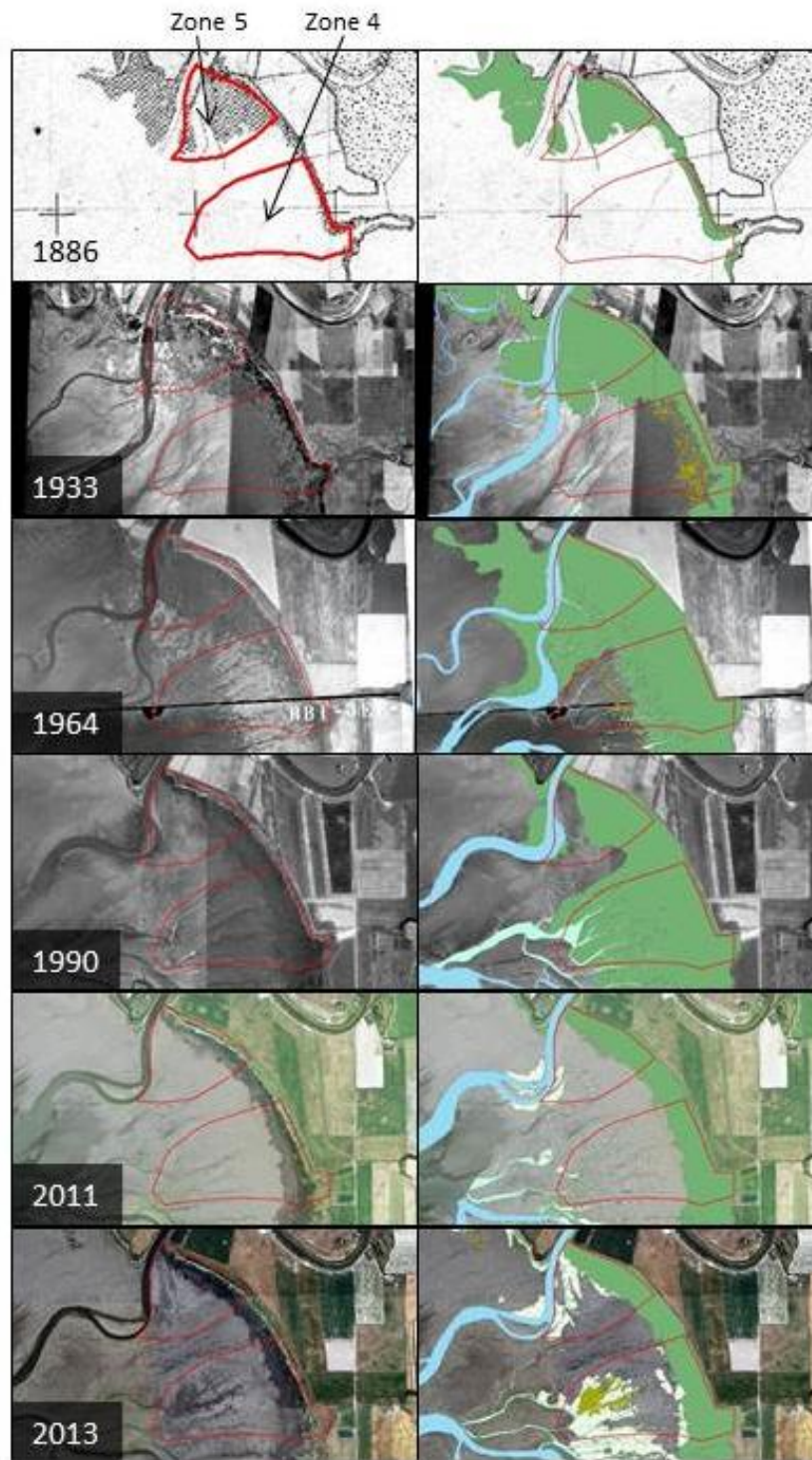


Figure 9. Habitat trends in zones 4 and 5 (outlined in red). The left column shows the aerials and the right column shows the digitized habitat. Green polygons show Continuous Tidal Marsh, olive green polygons show Patchy Marsh and white polygons show Low Density Marsh. Blue polygons show the River Channels and turquoise polygons show the Tidal Channels.

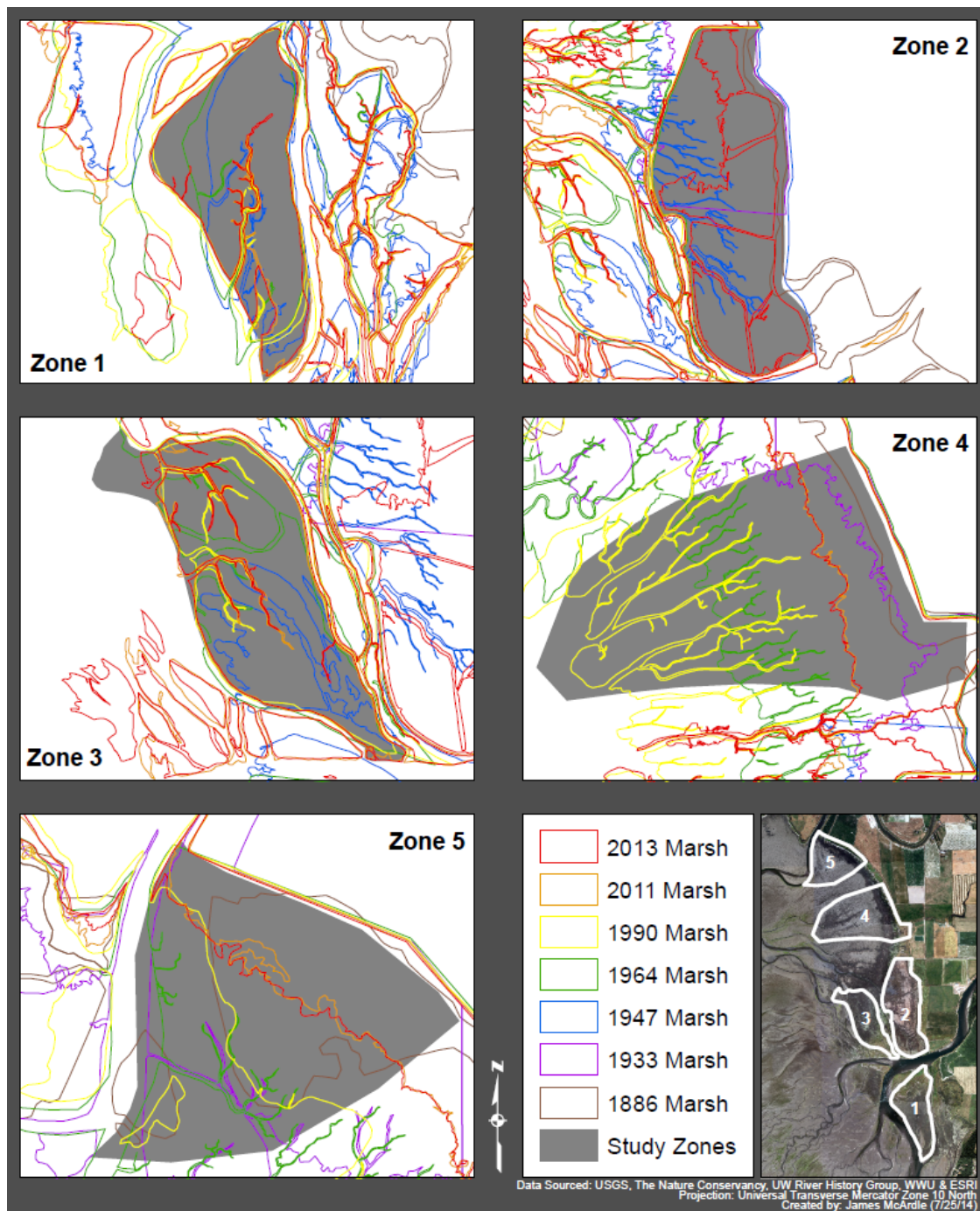


Figure 10. Historical changes in continuous marsh boundaries in the 5 study zones.

Trends in Patchy Marsh

Patchy marsh appears more prevalent in earlier years, especially in zones 4 and 5. In the 1933, 1947 and 1964 aerials there are many patchy circular clones forming on the tideflat seaward of the dense continuous marsh in the mid-delta region. In subsequent aerials, these areas have coalesced into dense marsh. Patchy marsh forms in advance of expansion of the continuous marsh and likely represents the establishment of new clones of bulrush, or possibly

Spartina, which then expand and coalesce into continuous marsh. Current observations of vegetation suggests that maritime bulrush (*Bolboschoenus maritimus*) and soft-stem bulrush (*Schoenoplectus tabernaemontani*) follow this growth pattern, while threesquare bulrush (*Schoenoplectus americanus*) does not seem to form dense circular clones from which it expands. Instead, it appears to establish thinly across broad areas and gradually increase in density. As a result, the early growth of patchy marsh may represent the expansion of maritime and soft-stem bulrush. If spartina introduction did not occur until the early 1960's, then the early clonal expansion patterns must represent bulrush expansion. It is possible that the circular clones evident in the 1964 aerial are spartina, and there is a substantial increase in marsh area between 1964 and 1990 in the mid-delta area. However, records from the intensive control efforts in the 2000's suggest that spartina was mixed with native species in the upper marsh area, but was not extensive in the lower marsh area. For this reason, it seems unlikely that the lower marsh clones in 1964 and subsequent expansion in that area was the result of spartina.

Trends in Low Density Marsh

Low density marsh is difficult to detect in aerials (Figure 11) and further analysis is needed to determine the conditions under which we can safely delineate low density marsh in aerials. We only digitized it in the 2011 and 2013 aerials, but there appear to be substantial differences between the years that are likely the result of issues with the photos rather than actual differences in vegetation. Both photos were taken in summer, but even a month difference in

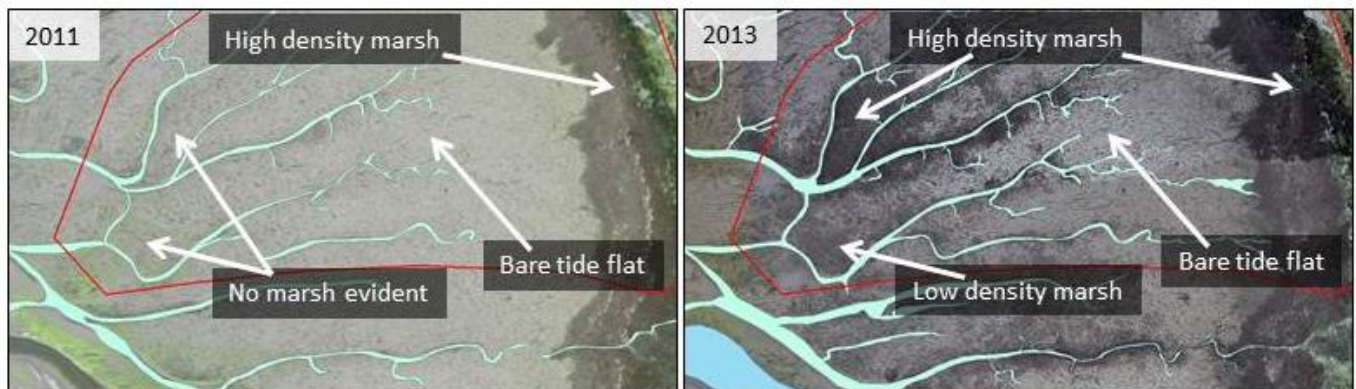


Figure 11. Example of the difficulty in seeing low density marsh in aerial photos. In the 2011 photo on the left, there is no marsh evident in areas where both low density and high density American bulrush marsh is evident in the 2013 aerial. Field data from previous years indicate that the missing American bulrush marshes were present since at least 2004 and were therefor likely present in 2011 but not detected in the aerials. Both the sparse and dense American bulrush marshes that are missing in 2011 are very short compared to other areas of marsh (knee high compared to waist high or greater).

timing could affect the detectability of low density marsh. Over the course of the growing season, a number of factors that would affect detectability change quickly, including plant height, growth of algae on and around the plants, sediment coating on the plant stems, capture of wrack in the marsh, and the area of marsh that is flattened due to wind or wave action. On-the-ground observations suggest that the low density marsh is threesquare bulrush. Low density marsh may only occur at the lowest elevations of tidal marsh where conditions are sufficiently challenging to limit plant height and stem density. However, low density marsh may

also occur in areas that are heavily grazed by snow geese. Further analysis is in progress to attempt to determine the conditions that result in low density marsh.

It is possible that low density marsh is symptomatic of both expanding marsh on the prograding southern delta (Figure 12), and receding marsh on the eroding northern delta. On the southern prograding delta, the low density marsh occurs adjacent to and lower in elevation than the high density continuous marsh, suggesting a pattern of expansion. In contrast, in the

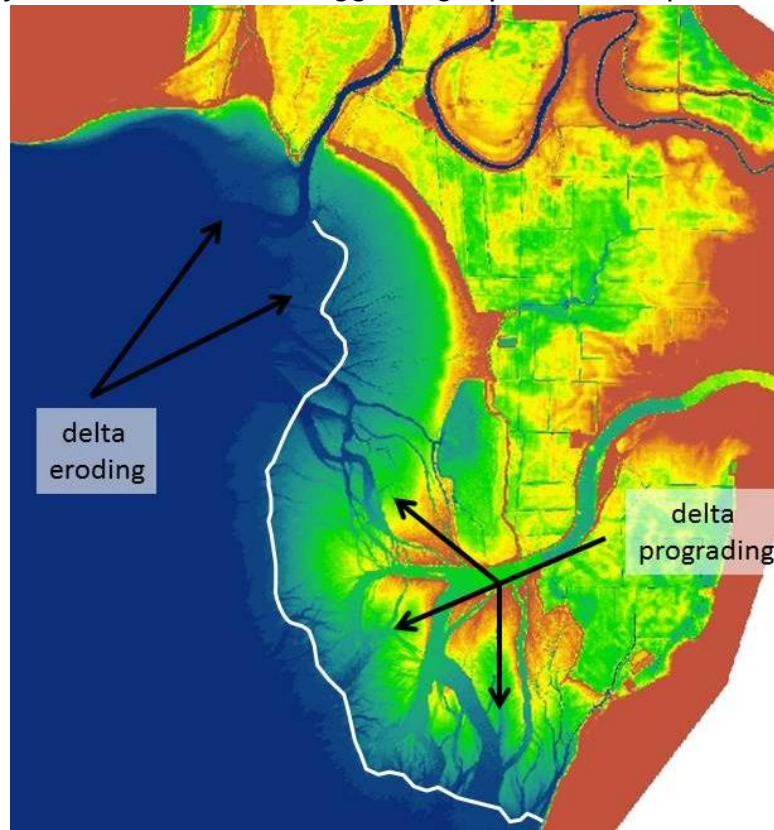


Figure 12. Elevations of the Stillaguamish delta, from LiDAR. There is a new delta prograding at the mouth of Hatt Slough, while the northern area of the historic delta is eroding. Warm colors are the highest elevations, cool colors are the lowest.

northern area of erosion, the lower elevation low density marsh appears to be separated from the higher elevation continuous marsh by an area of bare tide flat (Figure 13). Since the barren areas are intermediate in elevation, they should be covered with vegetation. Our current hypothesis is that the northern pattern of vegetation is due to differential grazing by snow geese. Preliminary data suggest that the lower elevations have coarser, sandier soil which is harder to penetrate with a goose bill, increasing the energetic cost of grazing. As a result, we expect that grazing is more intense on soils of fine and intermediate particle size, higher in elevation. This same pattern of soils, vegetation and goose grazing has been documented on the Fraser delta. The lower elevation marsh may be low density due to lower productivity on coarser soils, lower grazing intensity than occurs on higher elevations, or a combination of those and other factors.



Figure 13. In the northern estuary, the low elevation, low density marsh (stippled white polygons) are separated from the higher elevation continuous marsh (green polygons) by bare tide flat. This is the 2013 habitat delineation.

Changes in Marsh Width

Another way of comparing the 5 study zones in terms of marsh changes is to measure the width of the marsh from the dike or highest marsh elevation to the lowest elevation at which marsh occurs. Table 3 shows how the width of marsh has changed over time in each of the zones. Zone 1 grew substantially between 1886 and 1990, at about 5m per year on average. In 1990 it essentially filled the zone completely with marsh, so is no longer expanding.

Zone 2, the restoration zone, grew rapidly, at about 11m/yr between 1886 and 1933 when the entire zone was covered with marsh. It was then diked and converted, declining to zero, then was restored in 2012 to nearly complete marsh.

Zone 3 grew rapidly after 1886, with the highest rate between 1947 and 1964 at 9.4m/yr. Since 1964 it has increased slightly, but is essentially completely filled with marsh so is no longer expanding.

Zone 4 decreased slightly until 1933 but then grew very rapidly through 1990 at an average annual rate of 20m/year. Since 1990 most of the growth was reversed and marsh width declined at an average rate of 40m/year. It should be noted that these numbers are for the continuous marsh category. Some of the lost continuous marsh in zone 4 was undetectable in the 2011 aerial but was detected in the 2013 aerial as low density marsh (Figure 13 and Figure 2) which is not represented in this analysis.

Zone 5 increased at an average annual rate of 5m/yr until 1933. It held essentially steady through 1964, then has been declining rapidly at about 10.5m/yr until the present. As with zone 4, the lost continuous marsh was undetectable in the 2011 aerial, but some of it was detectable in the 2013 aerial as low density marsh (Figure 13 and Figure 2).

Table 3. Historic changes in the width of continuous marsh in the 5 study zones.

Year	Interval in years	Zone 1		Zone 2		Zone 3		Zone 4		Zone 5	
		max width	avg change per year	max width	avg change per year	max width	avg change per year	max width	avg change per year	max width	avg change per year
1886		0		60		0		238		516	
1933	47	*	*	578	11	*	*	211	-0.6	752	5
1947	14	321	5.3 ^a	578	0	273	4.5 ^a	*	*	*	*
1964	17	416	5.6	0	-34	432	9.4	831	20 ^b	766	0.5 ^b
1990	26	533	4.5	0	0	424	-0.3	1,339	19.5	494	-10.5
2013	23	549	0.7	475	20.7	437	0.6	421	-39.9	257	-10.3

Units are meters

* Data not available

^a Interval of 61 years

^b Interval of 31 years

Acknowledgements

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Systematic Qualitative Monitoring at the Stillaguamish Estuary

2014 Field Report

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Systematic qualitative monitoring (SQM), is an enhanced version of photomonitoring in which photos are accompanied by an information-rich narrative. The narrative documents key elements of the habitat, such as vegetation, channel and other habitat conditions, with educated speculation about the biophysical dynamics reshaping the site. A SQM protocol was developed earlier as part of this project and is provided in Appendix 1.

Consistency with Original Photopoints

Prior to restoration, The Nature Conservancy established 18 photopoints around the restoration site. We obtained from the Conservancy a spreadsheet of spatial coordinates for the photopoints and a pdf aerial map showing locations of the photopoints. Other than these, no specific record of methods or field notes are known to exist from the original sampling event(s). We assume that the Conservancy has the photos from the earlier sampling events.

WWU resampled the 18 points using the new protocol we developed, and established several new photopoints to better document key ecological areas. Since the original sites were established prior to restoration, it was likely difficult to anticipate exactly where some of the key places of change would be. As a result, we moved a few of the original photopoints short distances in order to better document post-restoration dynamics. We also moved all photopoints so that they were at the highest elevation point nearest the original location. The highest point is generally at the edge of the adjacent pre-existing marsh, at the outer edge of the original dike footprint. Most of the original photopoints appear, from the GPS locations, to have been taken from the interior edge of the dike or possibly from the interior foot of the dike. On the new east dike, we placed the photopoints to be on the western edge of the dike top where the top gravel driving surface meets the external boulder armoring.

New photopoints were added in places where key geomorphic changes appeared to be occurring such as the development of new channels, or where unique features were developing such as the construction traffic routes where soil was compacted relative to other areas. In addition, there are a number of small blind tidal channels adjacent to the restoration area that may form connections to the site in the future, and these points were added to the photopoint list. There are at least eight places where small tidal channels come very near the restoration site. These places are candidates for potential adaptive management action in the future, such as excavation of channel connections in order to improve hydrologic connectivity between the restoration site and the rest of the estuary.

Photomonitoring with narratives may help determine whether these sites are developing connections naturally and/or whether active management may be recommended in the future.

We renamed all photopoints so that the “final” series of photopoints for future monitoring would be named consistently and in consecutive order. The photopoint spreadsheet and map provided by The Nature Conservancy had different names for the photopoints and not all of the photopoints overlapped exactly. To cross reference our final photopoints with the numbers and names previously used by The Nature Conservancy, Table 1 includes the new names and the previously used names.

Table 1. Photopoint names, locations and cross references to former names.

Photo Point	Former photo point names	Photopoint location		Former location		Notes
		Latitude	Longitude	Latitude	Longitude	
R1		48.21050654	-122.3666841			
R2	PP1, photopoint project site	48.21051685	-122.3671743	48.210415°	-122.367161°	
R3	PP2, photopoint project site	48.20968453	-122.3695644	48.209491°	-122.369561°	
R4		48.20775602	-122.3707009			
R5		48.20679118	-122.3711826			
R6	PP3, photopoint channel at levee	48.20610805	-122.3714319	48.205944°	-122.371367°	Moved about 20m N because original was in middle of breach
R7		48.20580304	-122.3715149			
R8		48.20457157	-122.3716702			
R9		48.20423076	-122.3715877			
R10	PP3B, photopoint excavation levee	48.20352433	-122.3712206	48.203798°	-122.371265°	Moved 30m S to better capture curve in channel and because we are setting up a new one nearby at the breach mouth.
R11	PP3A, photopoint LWD channel at levee	48.20322367	-122.3699455	48.203381°	-122.370070°	Moved 22m SE to better capture newly forming channels
R12		48.20176757	-122.3697487			
R13	PP4, photopoint breach site	48.20130078	-122.3695707	48.201338°	-122.369513°	
R14		48.20031649	-122.3694862			
R15	PP5, photopoint channel	48.19954653	-122.3693576	48.199573°	-122.369244°	
R16	PP6, photopoint high elevation project site	48.19875914	-122.3690583	48.198809°	-122.368927°	
R17	PP7	48.19811566	-122.3684863	48.198180°	-122.368395°	
R18	PP8	48.19752842	-122.3673228	48.197618°	-122.367266°	
R19	PP9, PP10, photopoint south ditch fill tidegate	48.19721729	-122.3659558	48.197304° 48.197303°	-122.366228° -122.365698°	PP9 and 10 were next to each other and redundant. A replacement photopoint was placed between them, also capturing a cattail swale and small blind channel to south, a potential place to carve a new connector channel.
R20		48.19753538	-122.3642335			
R21	photopoint tree graveyard aldergedden	48.19816553	-122.3624884			
R22	PP11	48.19907421	-122.3628333	48.199086°	-122.362833°	
R23	PP12, photopoint east levee	48.20015925	-122.3635841	48.200156°	-122.363600°	
R24	PP13, photopoint east levee 2	48.20118704	-122.3642537	48.201199°	-122.364235°	
R25		48.20233972	-122.3640774			
R26	PP14, photopoint east levee 3	48.20506568	-122.3638849	48.205059°	-122.363878°	
R27	PP15, photopoint east levee 4	48.20653712	-122.3640299	48.207355°	-122.364042°	Moved about 90m S to track development on the compacted construction truck route
R28	PP16, photopoint east levee 5	48.20813614	-122.3658118	48.208540°	-122.365876°	

Photopoint Database

We have developed a photopoint database using an interactive web map application that facilitates storage and visualization of the photos along with the narratives. The web map is at <http://bit.ly/1rNLc7f>. Viewing the application requires an ArcGIS account which is simple to obtain. To sign up for a free public account, go to <http://www.esri.com/software/arcgis/arcgisonline/features/free-personal-account>, or you may use the following log-in:

U=TNC_PSB

P=rE5t0rEd2012

The web map application has two main parts, a left panel that includes text and photopoint photos, and a right panel that includes a site map (Figure 1). Navigating through the photopoints is accomplished by scrolling up or down through the left panel.

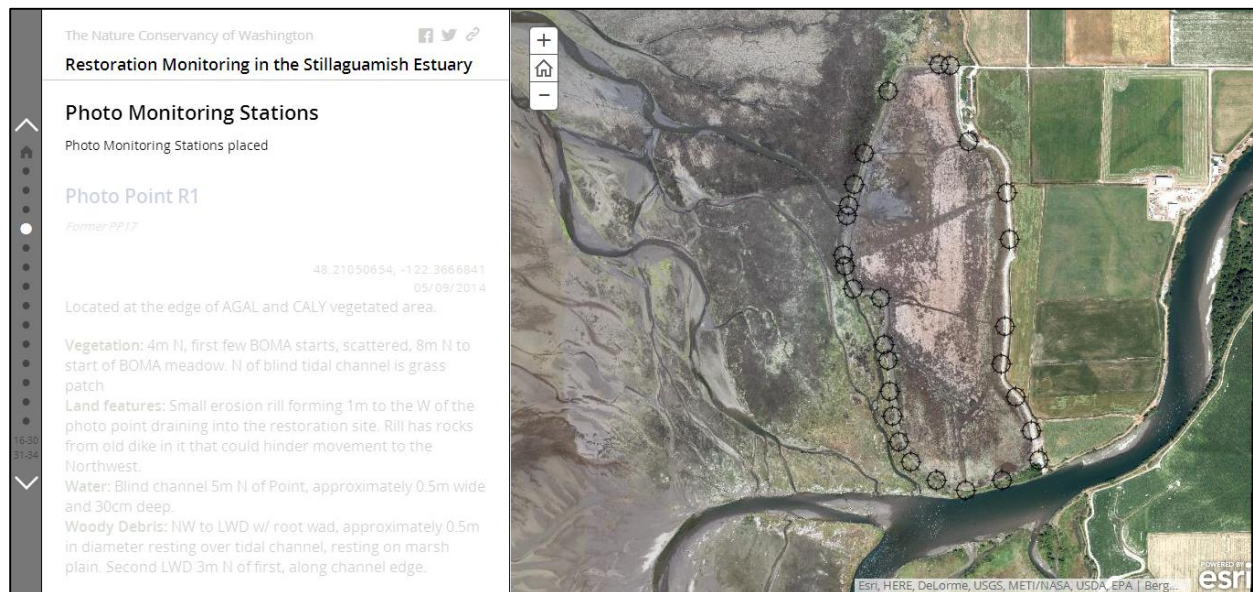


Figure 1. Screen shot from the interactive web map, showing the location of all photopoints at the restoration site.

At each photopoint, we took photos in a continuous 360° series. On the app, the photos are provided individually. We have also stitched them together into a single panoramic photo but have not included them yet. Creating a panoramic tends to warp the perspective in individual photos. Each photo is taken at a different angle and so represents a slightly different spatial plane. Combining them into a single panoramic tends to flatten them into a single spatial plane and in the process creates false corners or curves in the landscape features. Panoramics are useful in some situations but can also be misleading or confusing.

In the web app, each photopoint section begins with narrative information about the photopoint (Figure 2), including information on physical location, land characteristics, vegetation, water and wood. Following this, each photo is shown in order, beginning with the southerly photo and moving clockwise to west, then north and east. The right hand side of the screen shows an aerial photo with the location of the subject photopoint in the middle of the aerial.

In the future, this tool can be built out to include both pre-restoration and future photos, and additional tools added to facilitate comparisons across time or space.

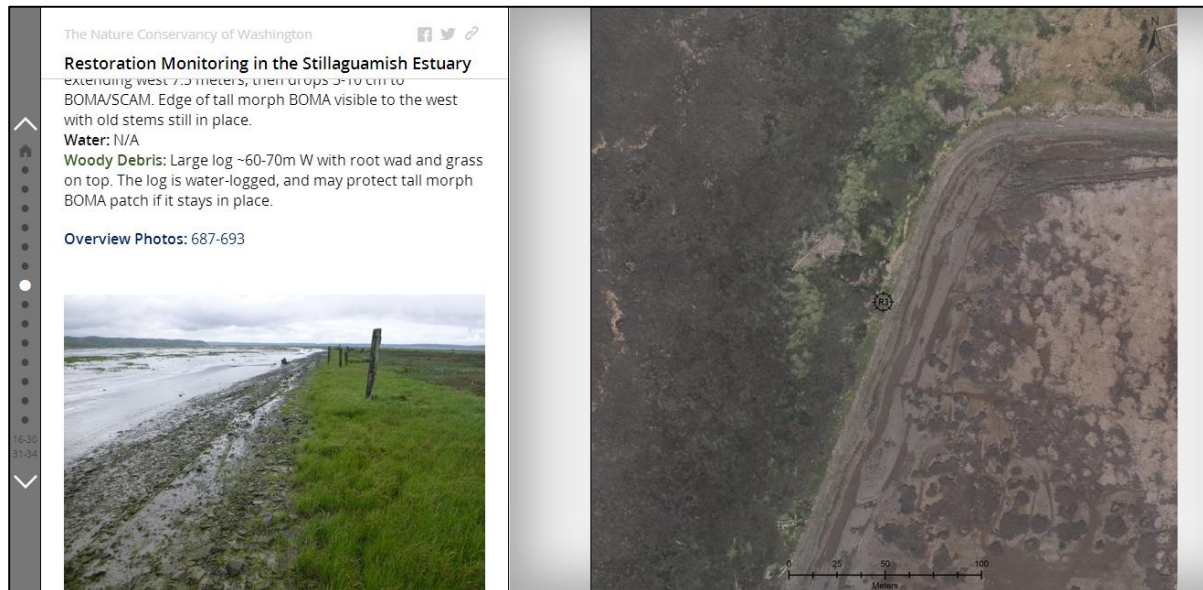


Figure 2. Screen shot from the web app showing part of the section on photopoint R3. The last part of the narrative is shown, and the first photo for that point.

Personnel Involved

All personnel are from Western Washington University's Huxley College of the Environment.

Method development by Roger Fuller.

Field data collection by Roger Fuller, Sarah Thomas, James McArdle.

Geoprocessing, interactive web map and photo database developed by Sarah Thomas.

Technical assistance provided by Jacob Lesser.

Appendix 1

Systematic Qualitative Monitoring Methods

Roger Fuller
Western Washington University
Huxley College of the Environment

Systematic Qualitative Monitoring (SQM) is intended to provide a rapid, systematic, repeatable and information-rich method of documenting restoration site development in a way that can inform adaptive management decisions and test underlying project assumptions. SQM generally has lower cost and time requirements than a statistically robust quantitative monitoring or research program. It is intended to complement a quantitative monitoring program, increasing the amount and utility of information that can be gathered with scarce monitoring funds. Qualitative monitoring does not replace quantitative monitoring because the two methods are intended for different purposes, but using the two together allows the overall monitoring program to be more efficient and to generate more useful information for the practitioner, funder and the broader restoration learning community.

SQM is a “narrative and photographic observation of site development based on specific speculation about dynamics and driving factors” (ESRP). It consists of permanent photopoints where regular photos are taken and accompanied by a detailed, expert narrative describing vegetation, channel and other habitat conditions, with educated speculation about the biophysical dynamics reshaping the site. Since these photos are accompanied by expert narrative, sampling should be conducted by someone with specific expertise in the restored habitat. This characteristic is what differentiates SQM from many photo point sampling programs that consist only of collecting photos. The expert should be someone well versed in the main plant species and their biophysical interactions, as well as in the physical properties and dynamics of habitats such as soil qualities, accretion, channel formation, etc.

In addition to monitoring restoration effects, SQM can also be used to monitor long-term change over broad areas where the cost of quantitative monitoring is prohibitive. This may be particularly relevant in the context of detecting early habitat response to climate change impacts.

Overview of SQM at the Stillaguamish estuary

WWU evaluated the existing photopoints along the old dike footprint of the Port Susan Bay restoration site, added some additional points to adequately capture potential areas of significant change, took panoramic photos at all sites, and recorded a narrative of habitat conditions. Using this process, WWU developed these guidelines for developing and using a Systematic Qualitative Monitoring program to track habitat response to restoration. The guidelines will be revised and updated as experience is gained.

The project context for selecting photopoints

Photopoints should be established at places where a change due to restoration, or other factors, would be expected to happen or would be important to document. The selection of photopoints should be informed by the project objectives, the restoration methods, and by potential future management decisions.

Project objectives are important because they define the expected outcomes of the project, and therefore they can be used to identify the underlying expectations, assumptions, and hypotheses about how the site will respond to management. Those underlying issues, whether explicitly documented by the project team or not, are all associated with varying levels of uncertainty. Photopoints should be located in a way that will document site development in relation to the project objectives. Photopoints can also specifically address the underlying assumptions and are perhaps most valuable when they are used to test those assumptions that have higher levels of uncertainty. In this way, the results of SQM can allow for practitioner and institutional learning that improves future efforts.

Future management decisions will be made for the restoration site, even if the decision is to do nothing more. However there may be many kinds of adaptive management actions in the future that could improve the ecological or socio-economic functions of the site. To the extent that those decisions can be anticipated, they should inform the use of photopoint monitoring.

Good places for photopoints

Photopoints should be placed to document changes that result from restoration, both on the site footprint itself and offsite areas that may be directly affected. Some suggestions for determining photopoint locations include the following.

Places where the substrate or vegetation was directly altered during restoration:

- Footprints of excavated dikes or fill
- Vehicle traffic patterns where substrate may have been compacted
- Re-graded marsh plain or areas where fill was placed
- Drainage ditches or tiles that were filled
- Areas that were planted during restoration

Major areas of hydrologic connectivity with the estuary:

- Excavated channel connections, with photopoint views of both the restoration side and the external channel to which it connects, that allow for changes in channel size to be detected
- Places where natural channel connections with the outside might be expected to form, such as where existing blind tidal channels come close to the site

Areas within the site that have different substrates, management histories or physical structure:

- Historic land uses, such as agricultural fields, buildings, equipment staging areas, roads, ditches, forested areas, etc., may have different substrate conditions that could result in different habitat development trajectories after restoration

- Areas with topographic slopes that are unnatural for tidal marshes, for example where a restoration area has subsided, the slope between the adjacent natural marsh plain and the restored marsh plain may be unnaturally steep

Areas where substantial change is expected in physical and biological conditions:

- Places where substantial change is expected in vegetation, particularly in physical structure, such as significant changes in height, density or relative productivity.
- Bare, unplanted areas where natural invasion is expected to cover the site
- Places where particularly rapid sediment accretion or erosion might be expected
- Border areas where different habitat types may be expected to develop, such as the transition area above MHHW where low marsh may transition to high marsh, scrub-shrub, or riparian habitat.
- Channel mouths that might change in size or shape, or trap wood
- Channel bifurcation points where channels might enlarge, fill in or change directions
- Areas whose elevation and orientation suggest that woody debris may accumulate

Visitor vantage points:

- If the public will be able to access the site, they will be interested in documentation of changes they can see from their accessible vantage points.

Methods

Materials

Camera, preferable weather proof. Check to be sure the time and date are correct on each field day, and the correct mode is selected.

Compass. Photos taken at each photopoint should be taken in the same order for easy processing, so pick a cardinal direction for starting. In some cases, panoramic photos may not be desired, only photos in certain directions such as at the cardinal directions, or at a specific structure such as a channel mouth. Compasses are key for insuring that the right directions are identified and that different users or the same user in different years always takes photos in the same directions. Even when taking photos of specific structures, it can be important to use a compass for standardization so that key reference points are always visible. This also helps to detect structure movement, such as if a channel or log jam shifts. Set your compass for true north using the magnetic declination for your site. Because declination changes from year to year, it is better to always use true north rather than magnetic north, so that photo positions are easily comparable in the future. For 2014 the approximate declination for Stanwood is 16°.

Ladder or mast. Often photos are more informative if they have a little height to them, to provide better perspective of conditions on the ground. This may also be useful for comparing pre- and post-restoration photos when the pre-restoration photos were taken from the top of a dike that has been removed. Another option that has been used is camera balloons or small drones. If a ladder or mast is used, be sure to document the height between the ground level and either the ladder step used, or the top of the mast. And if you will be on soft ground, bring along a board or panel of some kind to help distribute the weight and keep the ladder from sinking too much.

Notebook or fieldsheets for recording photo data, site narrative and sketches if any.

Tape measure. Use the tape to measure distances from the photo point to key structural elements within 20m or so, or at least to calibrate your pace to approximate 1m so you can estimate distance. Distance measurements don't need to be exact, so paces are adequate as long as each sampler can directly relate their pace scale to 1m, and report their distances in meters. Even expert field people should recalibrate their paces frequently using a tape, to maintain relative accuracies.

Tidecharts. In general you will want to take photos at low tide to capture as much geomorphic and vegetation information as possible. Depending on site elevations, tides near either the full or new moons (spring tides) may be desirable to capture the lowest low tides.

Timing and frequency of photo sampling

The frequency and timing of photo sampling may vary over time, and the narrative level of detail may also vary. At the beginning, photos should be collected during summer growing season (preferably July to mid-August) and during the winter. Since vegetation structure, such as stem densities and heights, is important to physical processes such as sediment trapping and organic matter production, capturing the vegetation at maximum growth will be informative. However the vegetation is likely to hide much of the geomorphic detail such as channel formation, sediment deposition, evidence of hydrodynamics, and even large woody debris. Winter photos will capture these elements, as well as winter vegetation structure. Winter is the flood and storm wave season when sediment movement and delivery are most dynamic. But vegetation structure, which captures sediment and reduces wave energy, is very different than during the summer when most monitoring programs assess vegetation characteristics. Some perennial species such as *Schoenoplectus americanus* essentially disappear completely above ground during winter, while others in the same habitat zone, such as *Bolboschoenus maritimus*, may maintain most of their senescent above ground structure during the winter and thus influence sediment and wave dynamics.

Twice annual photo sampling is encouraged for at least the first three years to document rapid initial changes and to establish a background level of change that can inform the scheduling of future sampling. Based on the information needs for the project team, and the level of change experienced at individual photopoints, future sampling frequency and narrative detail could be scaled back by evaluating conditions and needs at each photopoint.

Looking through the viewfinder.

Photos should capture as much of the foreground as possible, but should almost always include the horizon at the top of the photo to allow photos to be easily georeferenced with previous photos. Photos with no horizon or no stable reference structure may make it very difficult to detect some changes such as whether a channel has shifted, enlarged or filled in, or whether bare spots have enlarged or moved.

In most cases, a panoramic series of photos that captures 360° views is most useful. This is true even if much of the photo sequence looks off site because sometimes documenting how things change

immediately adjacent to the site can be very useful for future reference. Photopoints should include reference structures in them that make it easy to align photos from different times. These might include trees, channels, structures on the horizon, or other relatively stable reference points.

Expert Narrative

The purpose of photopoints is to document change, or lack of it. However a photo essentially documents a one dimensional record of a site, and leaves out much of what a human sees and interprets while standing at the spot. For example, a small channel, or the presence of a key plant species, may be visible to the observer on site, but be hidden by the 1D perspective of the photo. A habitat expert can read the vegetation, shape of the land and biophysical context, and speculate on the dynamics and processes that may be at work. In addition, by recording a few physical measurements, such as the distance from the photopoint to a key feature, some of the limitations to the 1D photo format can be overcome. Some narrative details, such as things that remain relatively stable, may not need to be recorded at every photo interval. Over time, specific instructions for resampling can be developed for each photopoint to make recording most efficient.

The key things to record include details that might not be evident in the photo about vegetation, non-plant cover (such as wood, mud, or algae), and the physical environment. Measuring the distance to key structural elements such as channels or vegetation boundary changes will help with interpreting the photo, and provide a way of measuring change from one sample event to the next. If photopoints are along a border between restored and adjacent intact habitat, such as along the footprint of a removed dike, it is helpful to pace off distances to different habitat zones along transects perpendicular to the boundary, so that one transect heads into the restoration area, and the other heads into the intact habitat.

Vegetation

- General vegetation types that dominate the foreground of photos (e.g. low marsh, high marsh, unvegetated tide flat, shrub, riparian, etc.)
- Positions of each vegetation type relative to the photopoint. Estimate or pace off distances to key elements along the perpendicular transects.
- Relative condition of the vegetation type (is it substantially less dense than normal, are most plants new and just establishing, or are there well established clones and robust growth). Is there evidence of decline (fewer new stems than last year's senescent stems, or exposed rhizomes where sediment appears to be eroding away). Is the vegetation continuous or patchy, with extensive bare ground in between. Etc.
- Evidence of herbivory, such as goose pits and exposed rhizomes, or extensive grazing of above ground vegetation by birds, mammals or invertebrates.
- Estimate patch sizes if there are discrete new vegetation patches within about 20m that are expected to change in size. For example, species such as *B. maritimus*, *Schoenoplectus tabernaemontani*, *Typha latifolia* and *Typha angustifolia*, often establish as single clones that grow outwardly forming dense often circular patches until the patches begin to coalesce.

- List species that are dominant (majority of cover), sub-dominant (very common but not dominant), or present, as visible from the photopoint. If more than one species appears to co-dominate at roughly equal proportions, list them as co-dominants
- Estimate general overall vegetation structure for the dominant vegetation types
 - Estimate average total height, using 3-5 height bins, such as prostrate, 25cm, 50cm, 100cm, 150cm. The latter four correspond on a 5'10" person to about shin, knee, waist, and shoulder height).
 - Estimate average stem density, using 3-5 bins such as low, medium, high

Non-plant cover

- Note the location and approximate areas of bare ground, algae, wrack, open water, or other significant things.
- Note the location and estimate size of the largest logs, or consider using size bins for logs. Note whether root wad is present or not. Note the location (on marsh, in channel, part of channel, on dike face, etc.)
- Note approximate number and distribution of other smaller logs and woody debris

Physical environment

- Approximate size and location of channels. Note if channel appears to be changing, such as might happen with a changed tidal prism. Note if there is wood present in channel.
- Is there ponding present, or areas that appear to be draining much more slowly than other areas.
- Relative firmness of soil surface on transects from the photopoint. Is the substrate different in the restored vs. natural area?
- Note unique substrate areas, such as compacted former dike footprint or traffic route, rock or sandy deposits.
- Evidence of recent geomorphic change (erosion, sediment deposition, channel movement, panne formation, biogenic change such as excavations for food or domicile).
- Note evidence of overland water flow, such as areas across the old dike footprint where surface flows appear to be more focused and where new channels might form in future

Resources

<http://tidalmarshmonitoring.org/monitoring-methods-photo-points.php>

Erosion Stake Protocol

Objective: To track erosion and changes in the location of the marsh edge in areas that appear to be eroding. At the Stillaguamish estuary, stakes were established in 12 areas representing two kinds of erosional dynamics.

- (a) Stakes were placed in three areas along the former dike footprint of the restoration zone (zone 2), where the slope of the surface is steeper than would naturally occur in this estuary due to the subsidence of the restored area. The objective is to track whether erosion occurs into the old marsh, as a result of hydrodynamics attempting to reduce the slope steepness across the old dike footprint.
- (b) Stakes were placed in nine areas along the seaward boundary of the *Bolboschoenus maritimus* vegetation zone, which appears to be eroding from South Pass down to the northernmost tributary of Hatt Slough.

Figure 1 shows the approximate locations of the erosion stakes. There are 12 erosion monitoring locations, distributed in four areas of the estuary. The four areas include the South Pass area (Zone 5), mid-delta area (Zone 4), the restoration area (Zone 3), and the marsh area seaward of the northwest corner of the restoration area. The latter represents the southernmost area of the estuary where erosion along the edge of the *B. maritimus* zone is clearly evident. Each of the four erosion monitoring areas has three monitoring locations, two of which consist of a single stake placed at the marsh edge and the third of which consists of 5 stakes. The more intensive sites are designed to provide greater detail on the dynamics of erosion. At these sites, the middle stake is installed at the marsh edge, and adjacent stakes are installed every 5m along a transect in either direction, with two stakes seaward of the marsh edge and two stakes landward of the marsh edge. This results in a transect of five stakes that span 20m.

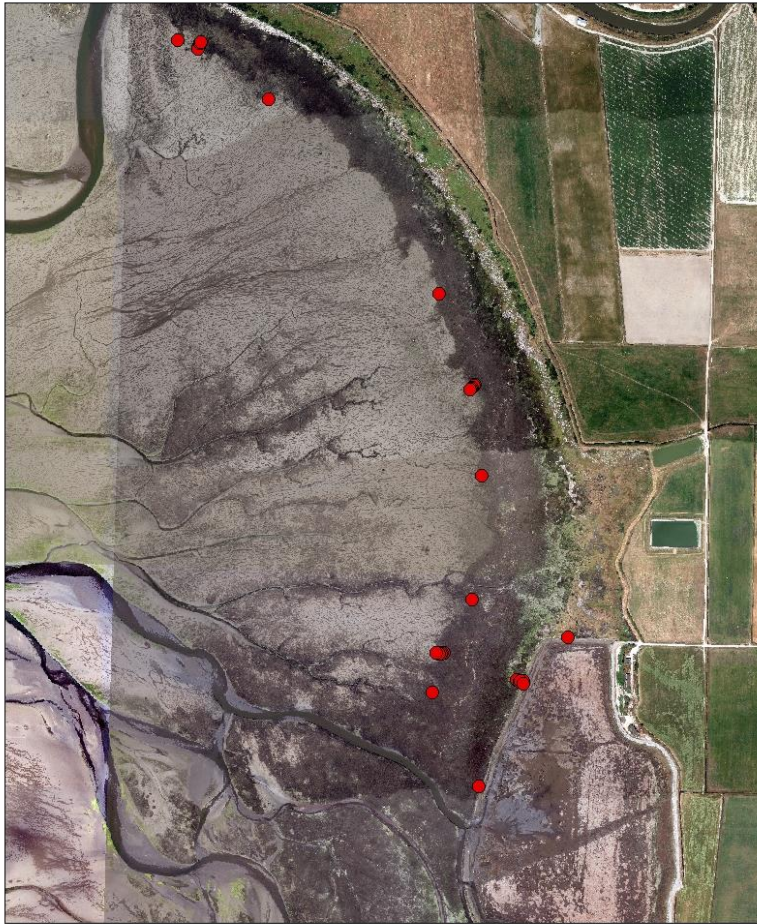


Figure 1: Locations of the 12 erosion monitoring locations. Eight locations consist of a single erosion stake, and four locations consist of a short transect of five erosion stakes.

Methods

1. Stakes are 3' long $\frac{3}{4}$ " PVC, and are driven into the sediment, leaving 15-25cm showing above ground.
2. The height of the stake above ground is measured to the nearest millimeter on two sides (east and west) of the stake. A ruler is held next to the stake as shown in figure 1, so that one edge of the ruler is against the stake and the opposite edge is as far from the stake as possible. This avoids measuring any compression or scour effects immediately adjacent to the stake. In the photo, you can see that the outer edge of the ruler touches the sediment but the inner edge next to the stake is not touching sediment due to a slight depression around the stake.



Figure 1. Position of the ruler next to the stake, so that any scour or compression of the sediment surface next to the stake is avoided during measurement.

3. Photos are taken at the stake location, pointing in four directions approximately parallel and perpendicular to the marsh. This roughly corresponds to the cardinal directions north, east, south, west, so those directions are used to name the photo files. Photos are taken when standing about 2m away from the stake so that the stake shows up in one of the photos that looks parallel to the marsh edge (in zone 5 in the north this is the west facing photo, in the other zones this is the north-facing photo). Views are framed so that the horizon is just visible in the top of the photo, to help with orientation. This allows the bottom of the photo to be as close as possible to the area around the stake.

4. A sketch of the stake area is created, to describe the relative location of vegetation and microtopography near the stakes. This is a rapid method, with no more than 5 minutes spent sketching.

Notes are made about evidence of erosion and deposition, such as:

- exposed rhizomes
- erosion rills (generally steep-sided linear features in the marsh, near the seaward edge of the marsh and running perpendicular to the marsh edge, with exposed rhizomes)
- ridges (the higher un-eroded areas between rills)
- pedestals (un-eroded islands surrounded by lower areas)
- swales (generally shallow, broad “protochannels” that are not connected to a channel or drainage system)
- ledges (vertical “cliffs” of >5cm, marking an abrupt habitat boundary, such as marsh to channel, high marsh to low marsh, or shrub to high marsh).

Task 1.a. Sediment Elevation Tables

Submitted by

**John Rybczyk, Alec Barber and Katrina Poppe
Western Washington University**

WWU has now installed a total of 21 Sediment Elevation Tables (SETs) in the Stillaguamish estuary in all five monitoring zones (Figure 1). This report summarizes the results obtained thus far.

A SET is a device developed for high precision measurements of long-term surface elevation change over time in wetlands. The SET is a portable leveling device attached to a permanent benchmark rod driven into the marsh surface to the point of refusal (Figure 2). The rod is then assumed to be a stable datum from which repeated measurements, over many years, can be taken. SETs allow for high resolution, long-term monitoring of accretion dynamics including deposition of suspended sediments, sub surface compaction, and in-situ organic matter accretion and decomposition. Because it integrates all process, it is one of the best ways to accurately measure long-term rates of accretion.

For this project, the first SETs were installed during the summer of 2011 and the last SETS were established in the newly restored area, zone 2, during the summer of 2014. In zones 1, 3, 4 and 5, two SETs were established each in the high marsh and the low marsh in each zone (4 zones x 2 marsh types x 2 replicates = 16 SETS). The high marsh sites are infrequently flooded and dominated by Baltic Rush (*Juncus balticus*). American Bulrush (*Schoenoplectis americanus*) and Maritime Bulrush (*Schoenoplectis maritimus*) dominate the low marsh sites. In the high marsh a thick mat of dead vegetation persists throughout the winter. In the lower marsh winter storms break off and remove much of the above ground biomass.

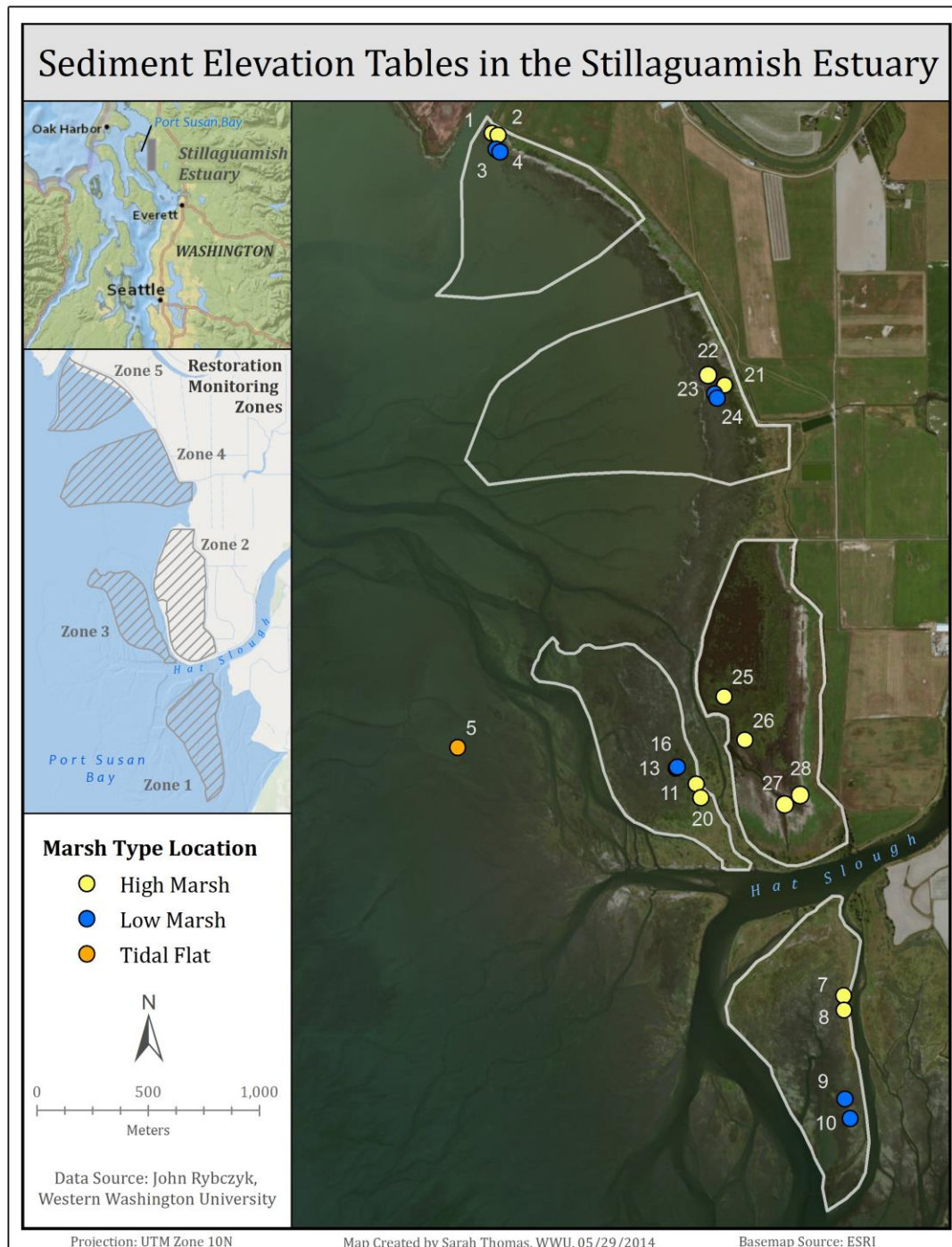


Figure 1. Sediment Elevation Tables locations and study zones in the Stillaguamish Delta restoration site.

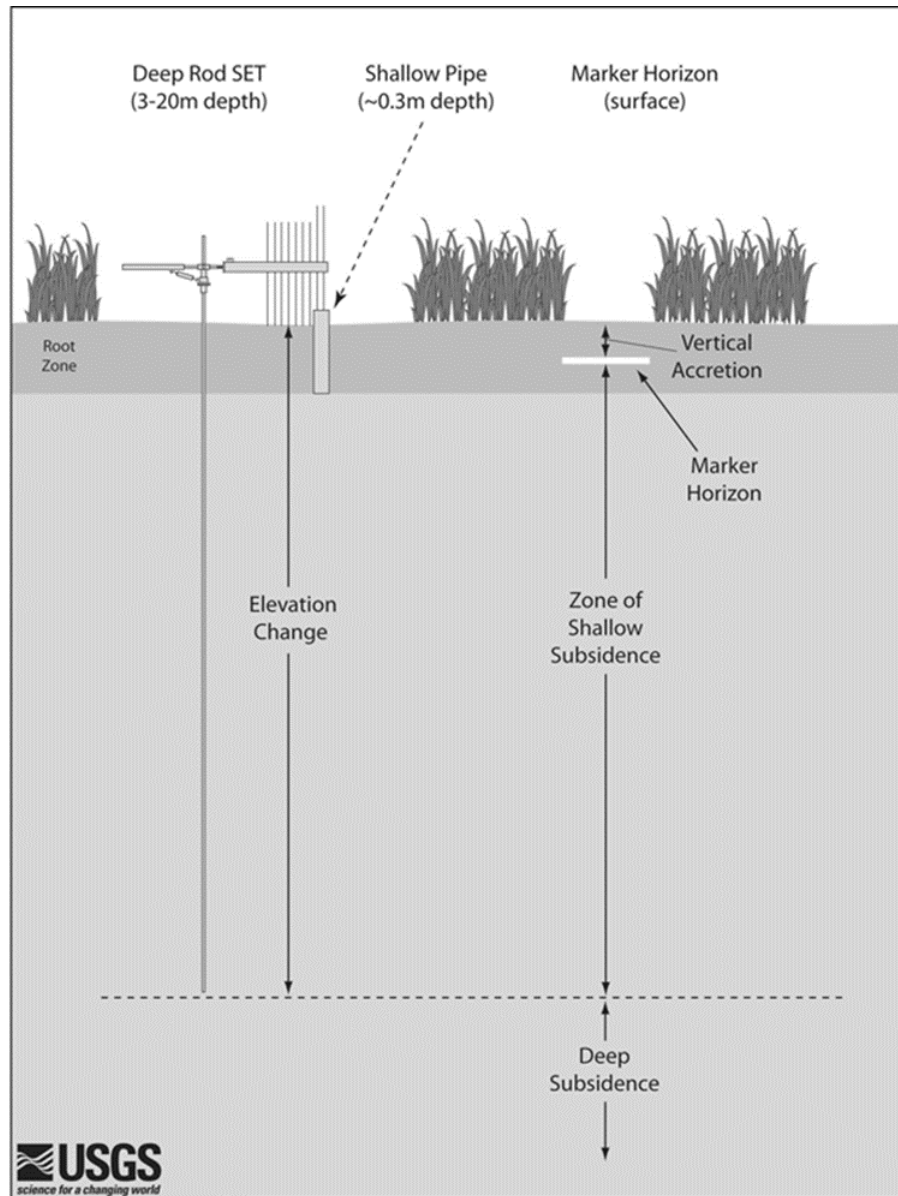


Figure 2. Measurements of surface elevation change are made using sediment elevation tables (SETs). SETs integrate all shallow surface processes into a single measure of elevation change (depositional or erosional). Figure courtesy of USGS Patuxent Wildlife Research Center

In the restoration area (Zone 2) there was no analogous high marsh/low marsh delineation, this being formerly diked farmland. Furthermore, we were not permitted to install the SETs before or during the restoration. Instead, we installed 4 sets along a transect running approximately south to north in the restoration area (Figure 1). This is the same transect used for vegetation monitoring in Zone 2. The southern end of this transect is located near a low area in the levee that borders the Stillaguamish River. We have observed river water flowing directly from the Stillaguamish River into the restoration site during high water levels in the river. The northern end of the transect is located near the northernmost breach in the former seaward levee. The removal of the outer levee was completed in Sept. of 2012.

We also established one SET (SET 5), outside of all zones, approximately 1 kilometer from the restoration site (Zone 2), on the seaward mudflats. This was largely an exploratory SET. Previous experience has shown us that we have little success with mudflat SETs due to excessive SET-induced scour in unvegetated, lower intertidal flats.

RESULTS AND DISCUSSION

1. SETs 1 – 4 (Zone 5)

SETs 1 and 2 are the replicate SETs located in the high marsh of Zone 5. The baseline data for both SETs were collected on August 26, 2011 and elevation has been measured yearly since then through 2014 (Figures 3 and 4 and Table 1). Both SETs showed a relatively constant rate of accretion over the three years that data were collected, with SET 1 accreting at a rate of 0.35 cm/year and SET 2 accreting at 0.54 cm/year. Persistent overwintering aboveground biomass at this site likely serves to protect the sediment surface from erosion associated winter storms and waves and also traps sediments in the winter. It is important to note, however, that while this site is accreting vertically, it is eroding at the high marsh edge.

SETs 3 and 4 are the replicate SETS located in the low marsh of Zone 5. The baseline data for both SETs were collected on August 26, 2011 and elevation has been measured yearly since then through 2014 (Figures 5 and 6 and Table 1). Visually, the sediment surface at this site is highly variable, with shifting erosional channels, ridges and swales. The surface also features shallow ponds that shift and expand over time. These observations are reflected in the SET data. For the first two years there was little elevation change recorded at either SET. In year 3, the surface at SET 3 eroded 2.5 cm and the surface at SET 4 accreted approximately 1.5 cm. Even within SETs there was much variation between arms (see the raw data files). Over three years, SET 3 showed an overall erosion rate of 0.98 cm/year and SET 4 showed an overall accretion rate of 0.58 cm/year. Continued measurements over time should allow us to distinguish the signal from the noise at this site.

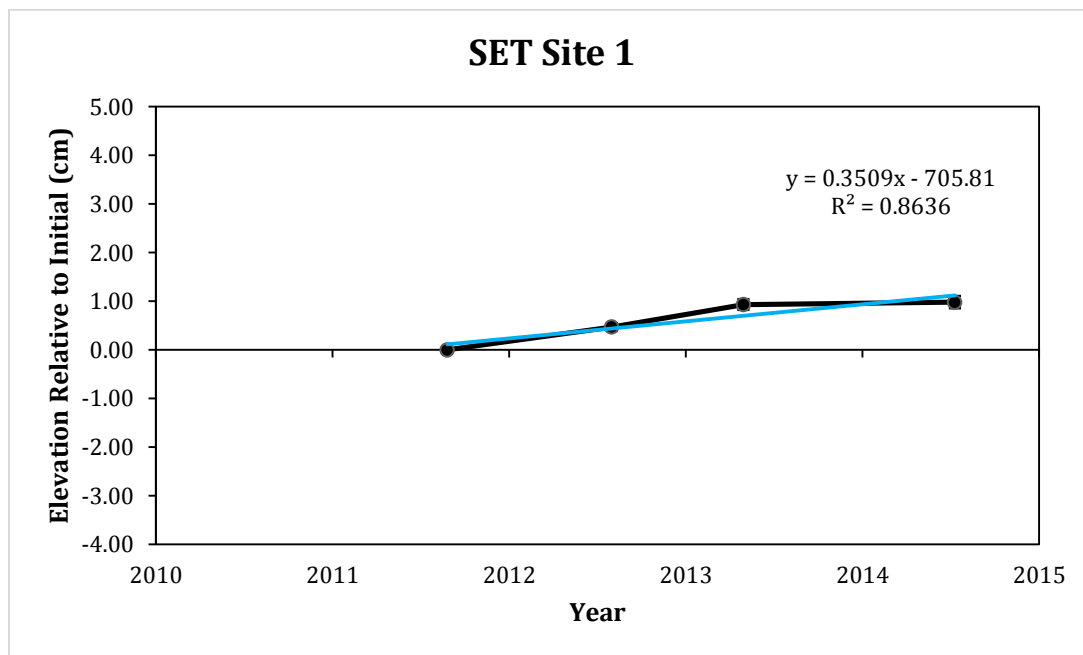


Figure 3. Mean elevation change over time, Set 1, Zone 5, high elevation marsh.

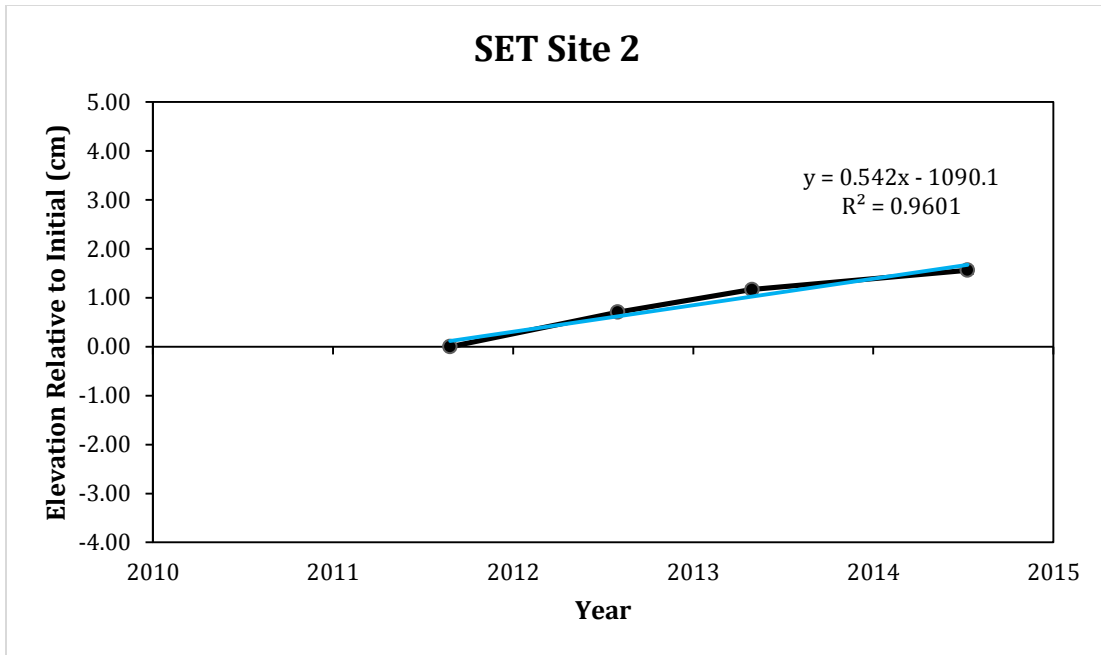


Figure 4. Mean elevation change over time, Set 2, Zone 5, high elevation marsh.

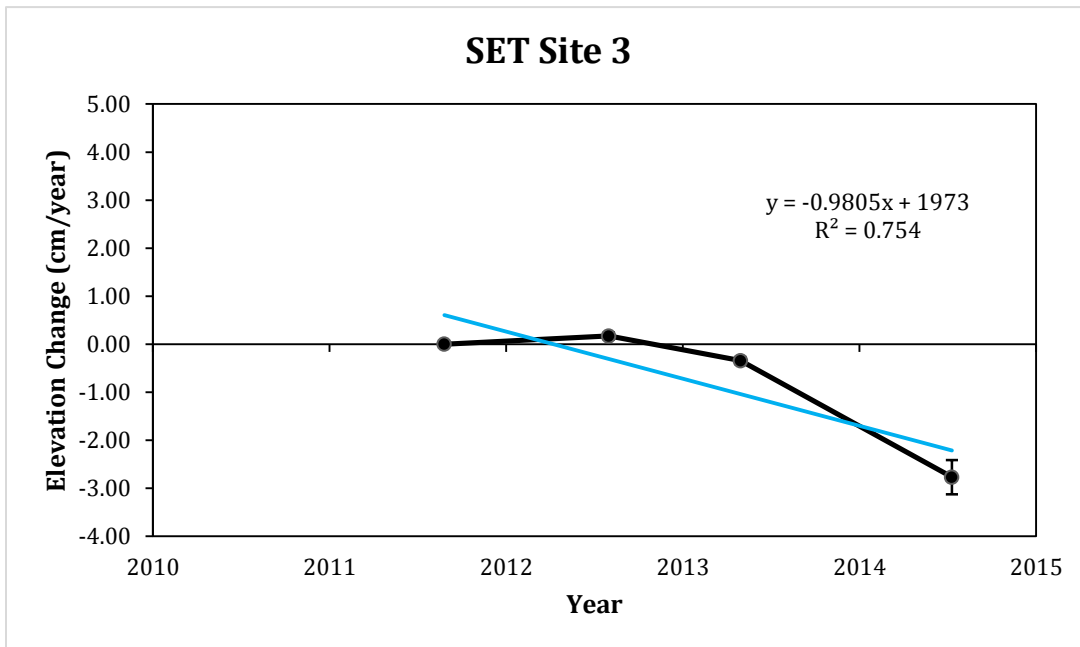


Figure 5. Mean elevation change over time, Set 3, Zone 5, low elevation marsh.

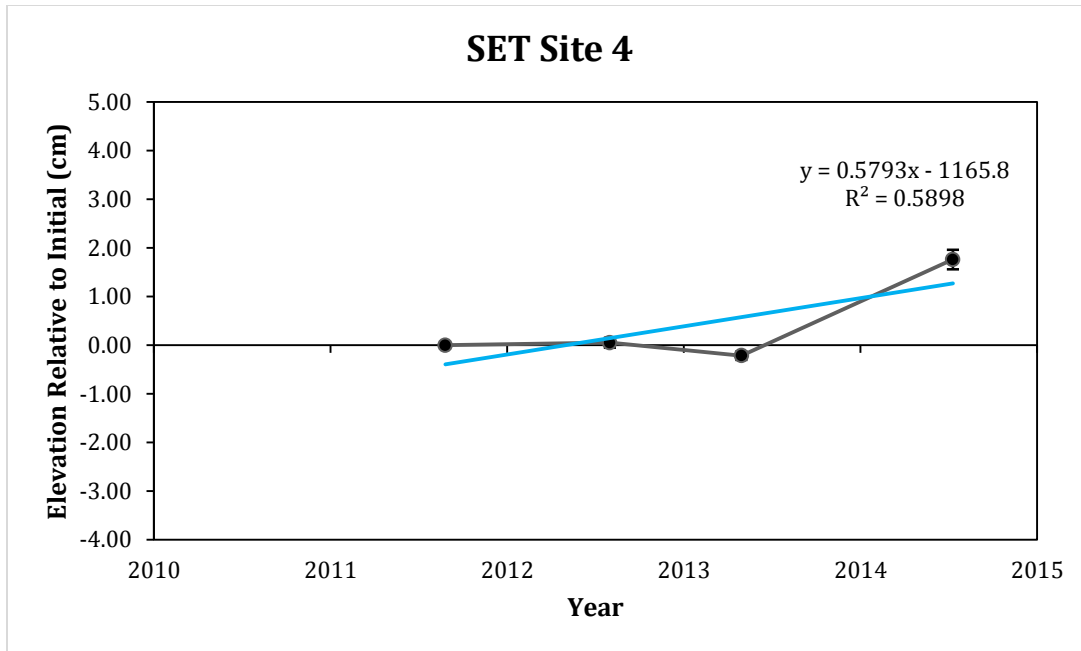


Figure 6. Mean elevation change over time, Set 4, Zone 5, low elevation marsh.

2. SET 5 (Mudflat outside of Zone 2)

As discussed previously, we deployed one SET outside of all zones, approximately 1 kilometer from restoration site (Zone 2), on the seaward mudflats. This was largely an exploratory SET. Previous experience has shown us that we have little success with mudflat SETs due to excessive SET-induced scour in unvegetated, lower intertidal flats. The baseline data for this SET was collected on August 26, 2011 and elevation was measured in 2012 and again in 2014. The data show that the surface has eroded at a rate of 0.73 cm/year (Figure 7). We did, in fact, observe SET induced scour at this site, so this is likely an overestimate of the actual rate of erosion.

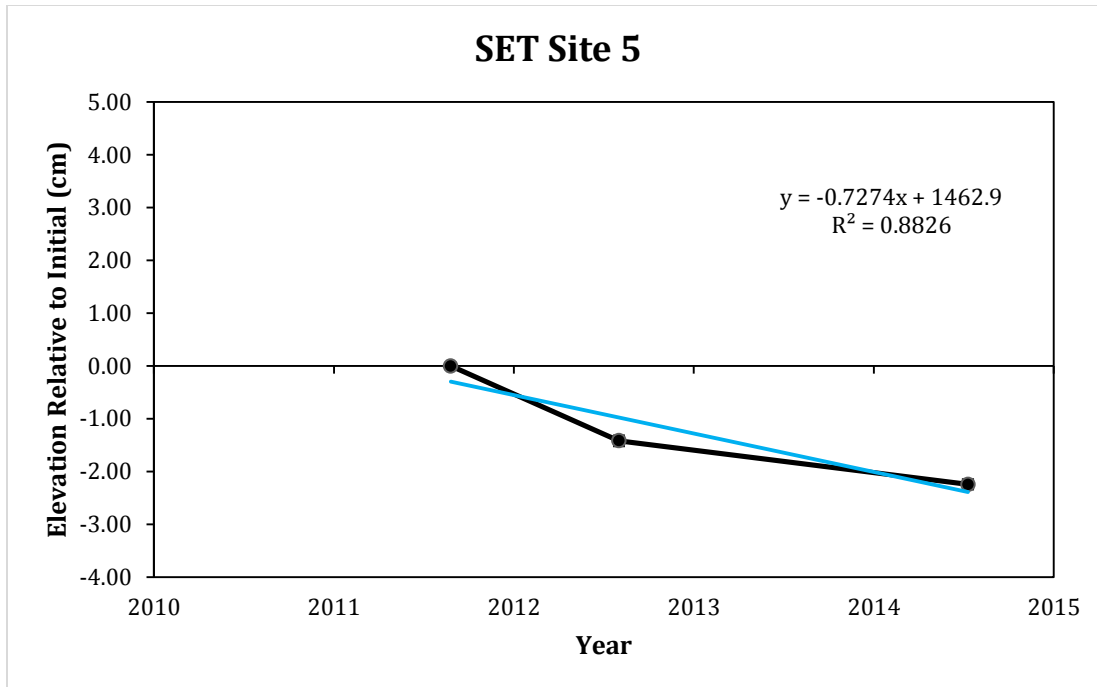


Figure 7. SET 5, mean elevation change over time, mudflat area 1 km west and seaward of the restoration site, Zone 2.

3. SETs 7 – 10 (Zone 1)

SETS 7 – 10 are located in the original reference marsh area, Zone 1. The marsh here is not hydrologically isolated from either the river or tides by dikes or levees.

SETs 7 and 8 are the replicate SETs located in the high marsh of Zone 1. The baseline data for both SETs were collected on Sept. 9, 2011 and elevation has been measured yearly since then through 2014 (Figures 8 and 9 and Table 1). Both SETs showed a relatively constant rate of accretion over the three years that data were collected with SET 7 accreting at a rate of 0.90 cm/year and SET 8 accreting at 0.74 cm/year. Persistent overwintering aboveground biomass at this site likely serves to protect the sediment surface from erosion associated winter storms and waves and also traps sediments in the winter.

SETs 9 and 10 are the replicate SETs located in the low marsh of Zone 1. The baseline data for both SETs were collected on Sept 9, 2011 and elevation has been

measured yearly since then through 2014 (Figures 10 and 11 and Table 1). As with the high marsh sites, both SETs showed of accretion over the three years that data were collected, both SETS accreting at a rate of 0.44 cm/year. As opposed to the high marsh sites, much of the aboveground biomass does not overwinter in the low marsh, subjecting this site to wintertime erosion, which would explain the lower rates of accretion in the low marsh compared to the high marsh. It would instructive to measure the SETs in Zone two in the early spring and then again in the late summer to determine if we could detect a seasonal signal.

All four of these sites are accreting at rates that far exceeds the current and predicted rates of eustatic sea-level rise, indicating that they are not sediment limited and that this zone is likely expanding at this time. It also suggests that restoring hydrologic connectivity to the restoration area (Zone 2) by levee removal would allow Zone 2 to keep also pace with current rates of sea level rise.

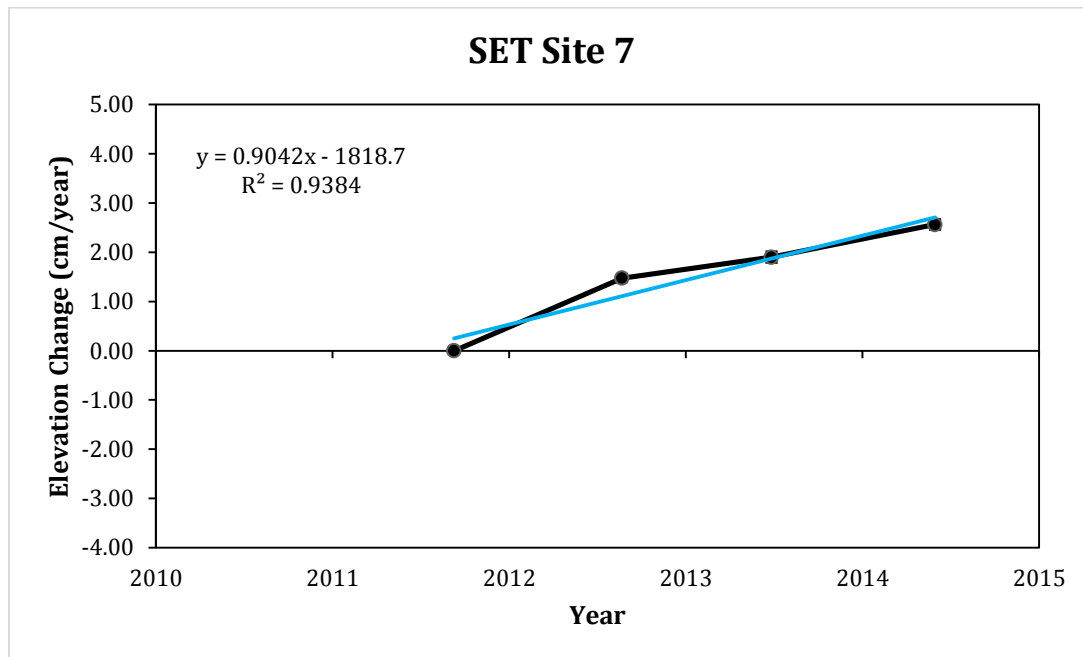


Figure 8. Mean elevation over time, Set 7, Zone 1, reference site, high marsh.

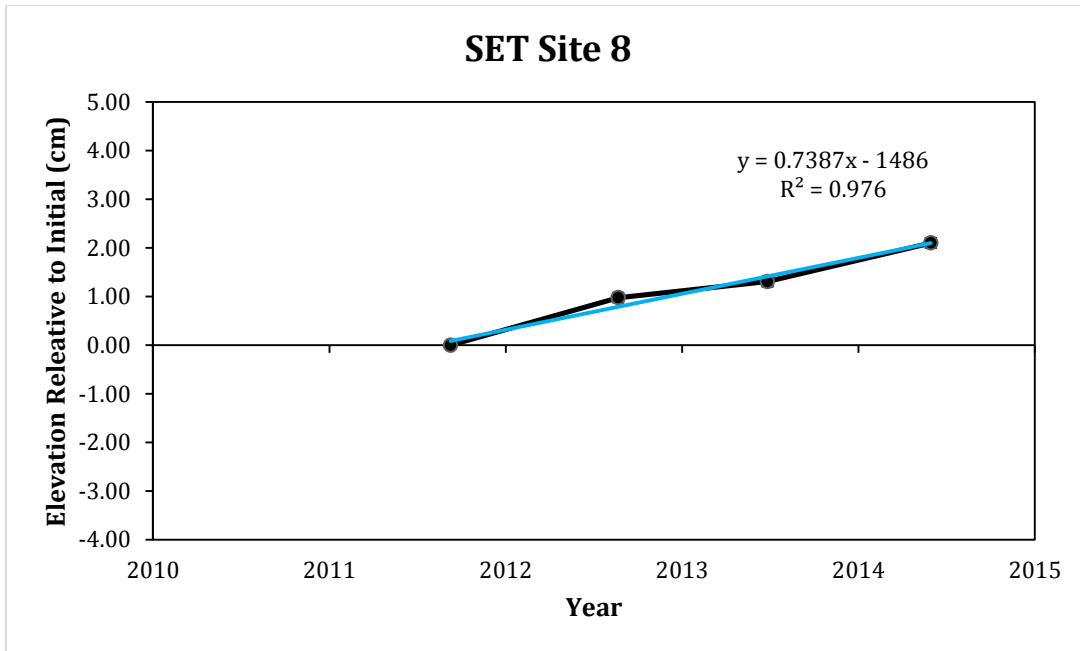


Figure 9. Mean elevation over time, Set 8, Zone 1, reference site, high marsh.

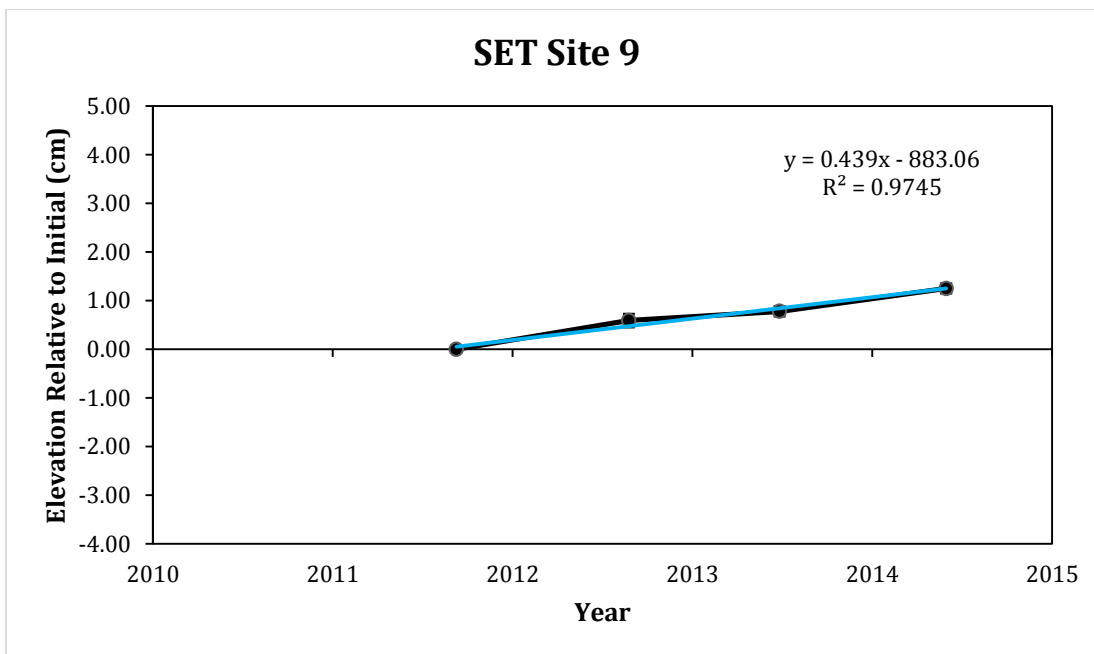


Figure 10. Mean elevation over time, Set 9, Zone 1, reference site, low marsh.

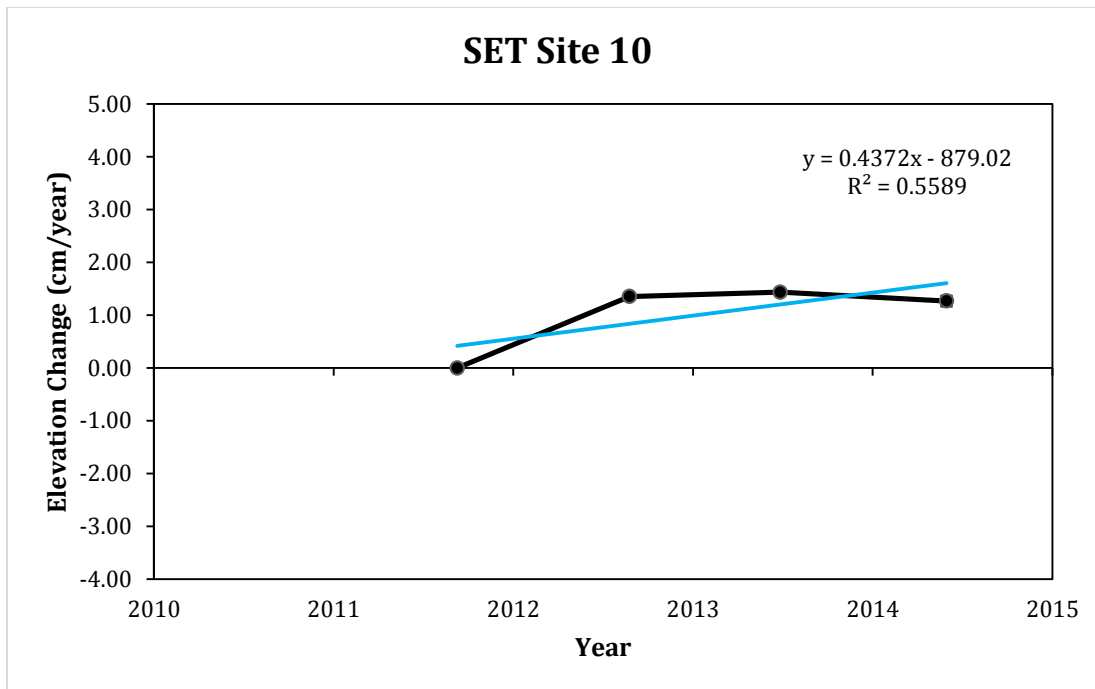


Figure 11. Mean elevation over time, Set 9, Zone 1, reference site, low marsh.

4. SETs 11, 13, 16 and 20 – 10 (Zone 3)

SETs 11 and 20 are the replicate SETS located in the high marsh of Zone 3, located immediately seaward and adjacent to the restoration area. The baseline data for both SETs were collected on August 26, 2011 and elevation has been measured yearly since then through 2014 at SET 11 (Figure 12 and Table 1). SET 20 was destroyed by a large log after baseline measurements and we were unable to obtain any data from it.

In the first year (pre-restoration), SET 11 showed a decrease in elevation of almost 1 cm, however the site was accretionary after the first year, the net result being a 3-year average rate of accretion of 0.11 cm/year.

SETs 13 and 16 are the replicate SETS located in the low marsh of Zone 3, located immediately seaward and adjacent to the restoration area. Unlike the other low marsh sites, the vegetation here is dominated by the bulrush, *Schoenoplectus acutus*. The baseline data for both of these SETs were collected on August 26, 2011 and elevation has been measured yearly since then through 2014 (Figure 13 and 14

and Table 1). Both SETs showed accretion over the three years that data were collected with SET 13 accreting at a rate of 1.05 cm/year and SET 8 accreting at 1.47 cm/year. However, the rate of accretion was not constant. Both SETs show a marked increase the rate of accretion after 2013. It is unclear at this time if this increase was due to restoration effects or due to some pulsing event such as the Oso slide.

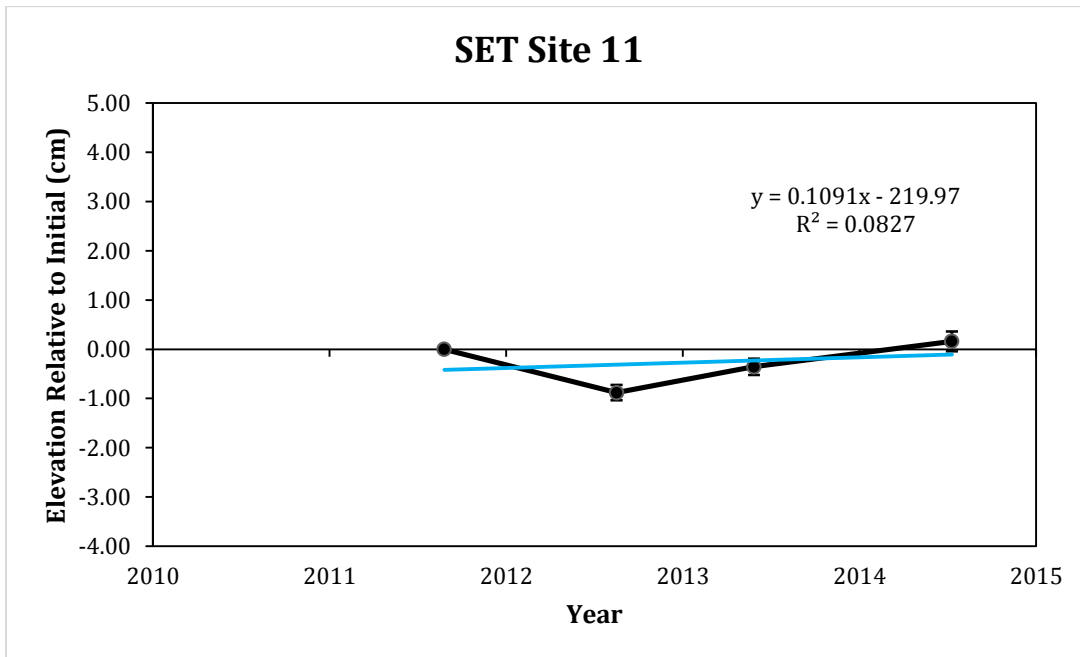


Figure 12. Mean elevation over time, Set 11, Zone 3, high marsh.

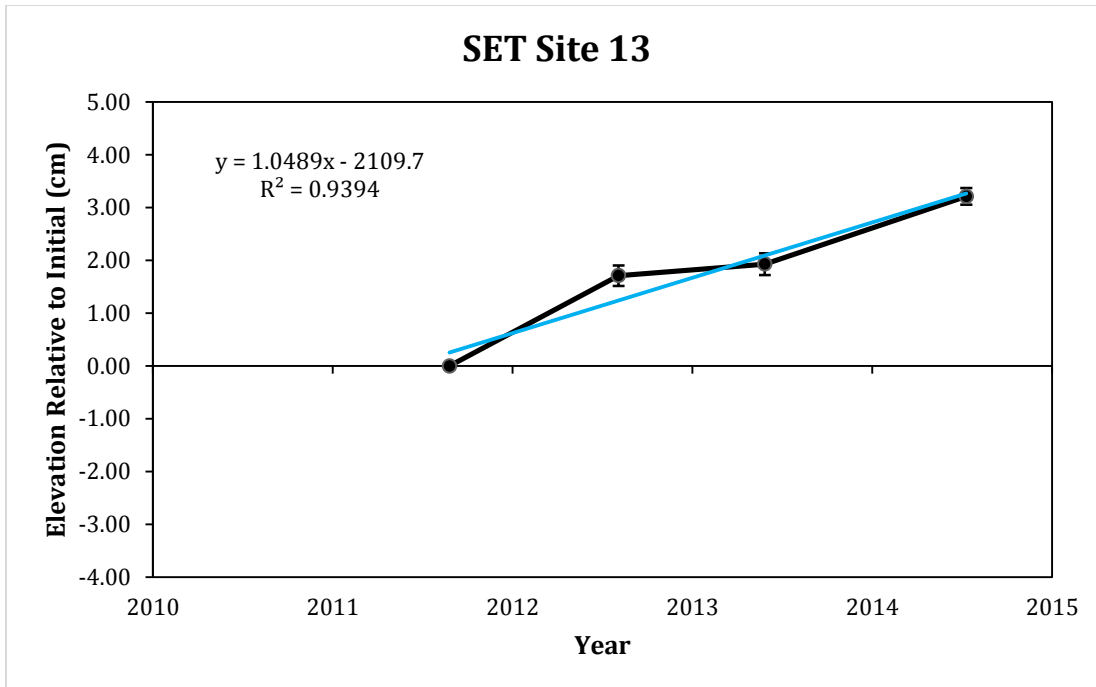


Figure 13. Mean elevation over time, Set 13, Zone 3, low marsh.

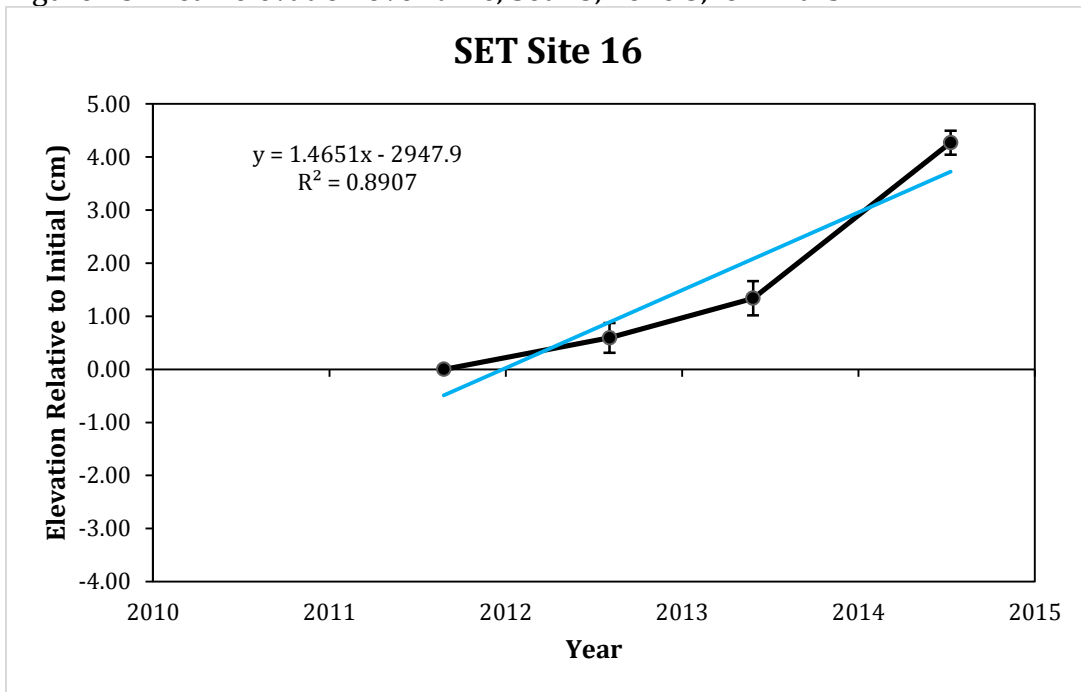


Figure 14. Mean elevation over time, Set 16, Zone 3, low marsh.

5. SETs 21 - 24 (Zone 4)

Zone 4 is a newly established zone, located between the restoration area (Zone 2), and the zone furthest north (Zone 5). As with other Zones, replicate SETs were positioned in the high marsh (SETS 21 and 22) and in the low marsh (SETs 23 and 24). Baseline measurements were collected in 2014 (Table 1) and our first elevation change measurements will come in 2015.

5. SETs 25 - 28 (Zone 2)

In the restoration area (Zone 2) there was no analogous high marsh/low marsh delineation, this being formerly diked farmland. Furthermore, we were not permitted to install the SETs before or during the restoration. We installed 4 sets along a transect running approximately south to north in the restoration area after the restoration was complete (Figure 1). This is the same transect used for vegetation monitoring in Zone 2. The southern end of this transect is located near a low area in the levee that borders the Stillaguamish River. We have observed river water flowing directly from the Stillaguamish River into the restoration site during high water levels in the river. The northern end of the transect is located near the northernmost breach in the former seaward levee. The removal of the outer levee was completed in Sept. of 2012. Baseline measurements were collected in 2014 (Table 1) and our first elevation change measurements will come in 2015.

Table 1. Average SET sediment elevation change over three years. HE = high elevation marsh, LE = low elevation marsh, UT = unvegetated tide flat, RET = Restoration Zone transect marsh, NA = no post baseline measurements.

SET #	Zone	Type	Location LAT/LON	Elevation (meters)	Mean Yearly Rate (cm)	Baseline Measure	Last Measure
1	5	HE	N48°13'37.2" W122°23'01.3"	2.66	0.35	8/26/2011	7/10/2014
2	5	HE	N48°13'36.9" W122°23'00.1"	2.73	0.54	8/26/2011	7/10/2014
3	5	LE	N48°13'34.9" W122°23'00.5"	1.82	-0.98	8/26/2011	7/10/2014
4	5	LE	N48°13'34.5" W122°22'59.7"	1.85	0.58	8/26/2011	7/10/2014
5	Mud	UT	N48°12'07.8" W122°23'09.9"	1.50	-0.73	8/26/2011	7/10/2014
7	1	HE	N48°11'31.2" W122°21'47.3"	2.40	0.90	9/9/2011	5/30/2014
8	1	HE	N48°11'29.1" W122°21'46.2"	2.39	0.74	9/9/2011	5/30/2014
9	1	LE	N48°11'16.1" W122°21'46.2"	2.01	0.44	9/9/2011	5/30/2014
10	1	LE	N48°11'13.3" W122°21'45.0"	1.99	0.44	9/9/2011	5/30/2014
11	3	HE	N48°12'02.2" W122°22'18.0"	2.63	0.11	8/26/2011	7/10/2014
13	3	LE	N48°12'04.5" W122°22'22.4"	2.22	1.05	8/26/2011	7/10/2014
16	3	LE	N48°12'04.7" W122°22'22.1"	2.21	1.47	8/26/2011	7/10/2014
20	3	HE	N48°12'00.2" W122°22'17.0"	2.55	NA	8/26/2011	5/27/2013
21	4	HE	N48°13.004' W122°22.184'	-	NA	5/16/2014	NA
22	4	HE	N48°12.997' W122°22.178'	-	NA	7/14/2014	NA
23	4	LE	N48°12.983' W122°22.221'	-	NA	5/16/2014	NA
24	4	LE	N48°12.973' W122°22.213'	-	NA	5/16/2014	NA
25	2	RET	N48°12.248' W122°22.197'	-	NA	7/11/2014	NA
26	2	RET	N48°12.142' W122°22.122'	-	NA	7/11/2014	NA
27	2	RET	N48°11.927' W122°21.912'	-	NA	7/11/2014	NA
28	2	RET	N48°11.909' W122°21.873'	-	NA	7/11/2014	NA

DISCUSSION

Elevation data collected from the reference area (Zone 1) and the area immediately seaward and adjacent to the restoration area (Zone 3), indicate that there is enough sediment available in the zones nearest to the river mouth to allow these marshes to accrete at a rate that exceeds the current and predicted rates of SLR. Both of these zones are open to riverine and tidal pulsing and sediments. This bodes well for the restoration area (Zone 2) now that the levees have been removed and hydrologic connectivity has been restored.

Elevation data collected from Zone 5, the area furthest from the river mouth, suggests that wave induced erosion, due to sediment starvation, is affecting the lower marsh, and eroding the boundary between low marsh and high marsh. However, in the vertical dimension, there is enough sediment capture in the high marsh, where mats of dead emergent vegetation persists through the winter, to keep pace with sea level rise.

Additional year(s) of elevation data will need to be collected to factor out the signal (long term trends), from the noise (seasonal and pulsing events), and to determine a restoration effect.

RECOMMENDATIONS FOR SECOND YEAR MONITORING

- Continued SET monitoring at all Zones. The first year of data will be collected in Zones 2 and 4.
- Twice-yearly SET measurements from Zones 1 and 5 (late spring and late summer) to detect seasonal variation due the presence/absence of plants.
- Currently, sediment data at the Stillaguamish are being collected by WWU, UW and the USGS? It would be instructive to have us get together for a one-day workshop to piece together the entire sediment story.
- Tie in the new SETS (21 – 28) to the elevation benchmark.

RAW DATA FILE

All SET raw data is contained in the Excel spreadsheet file, Port_Susan_Set_Data.xls, located on the external drive. The data files are set up such that each page represents a single SET.