Stillaguamish Estuary Habitat Change: 1886 - 2013

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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.

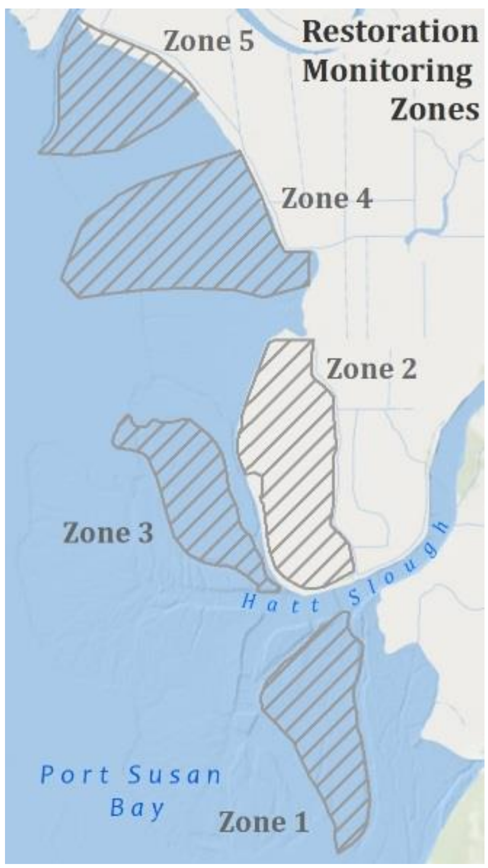

Figure 1. *Map showing the location of the five study zones in the Stillaguamish estuary. Zone 2 is the restoration site.*

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 three square, 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 Figure 8). 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 American 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.

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 aerials 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 aerials. 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 aerials. 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.

Tidal channel area is comparable because these channels tend to occur largely in the vegetated tidal zone which is always exposed in the aerials. Tidal channel area approximately doubled between 1964 to 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.

Table 1: *Habitat extent for the Stillaguamish estuary, based on historic aerials 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

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 aerials 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.

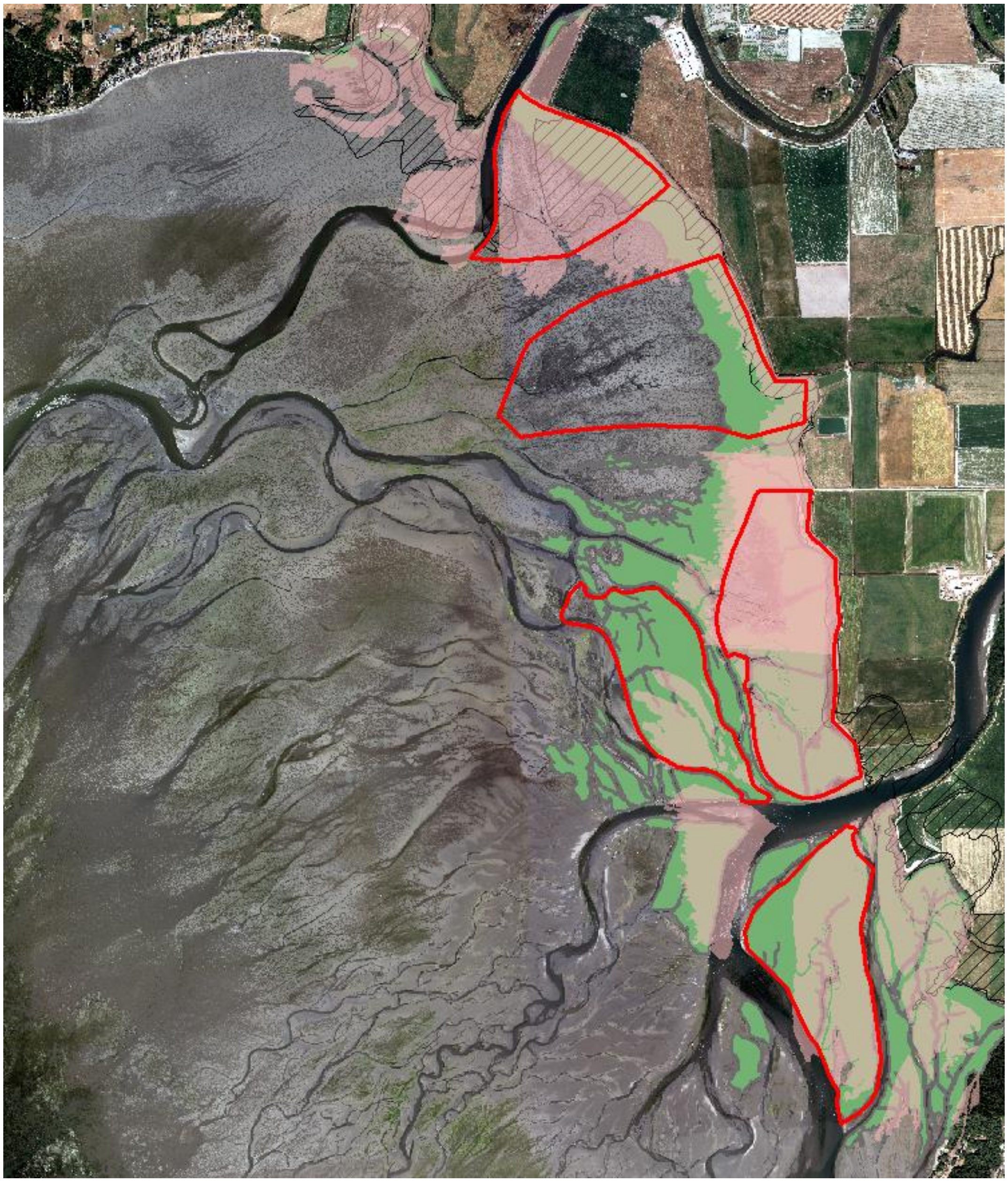

Figure 3. *Changes in the extent of continuous marsh habitat, 1886 to 2013. Three time periods are shown overlaying the 2013 aerial photograph. 1886 tidal marsh is shown as cross-hatched. 1933/1947 is shown as translucent pink, and 2013 is shown as solid green.*

All of the changes in the configuration of continuous marsh habitat over the years is summarized in Figure 4. The map classifies each distinct area of marsh according to the number of aerials 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.

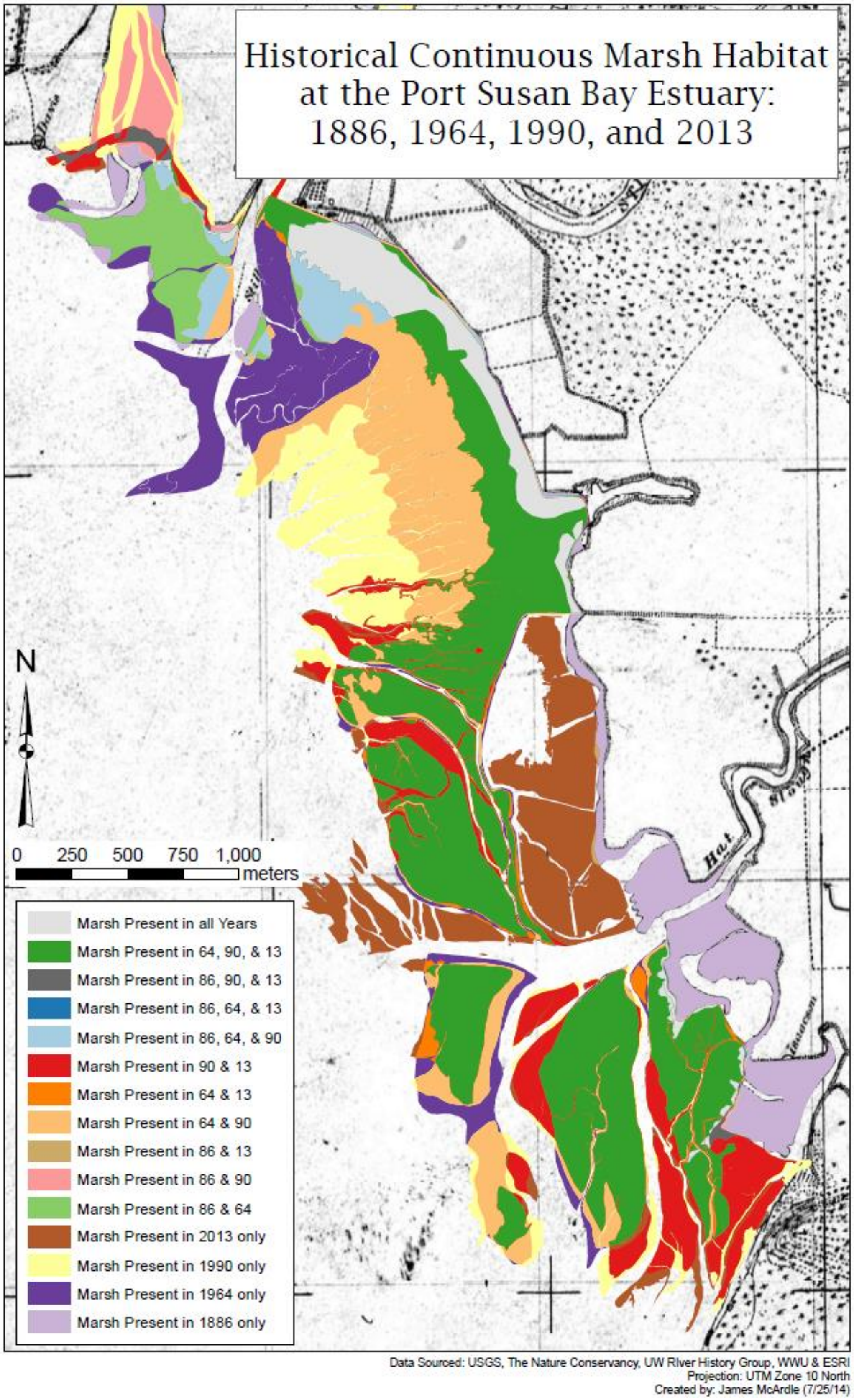

Figure 4. *Historical changes in the configuration of continuous marsh.*

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.

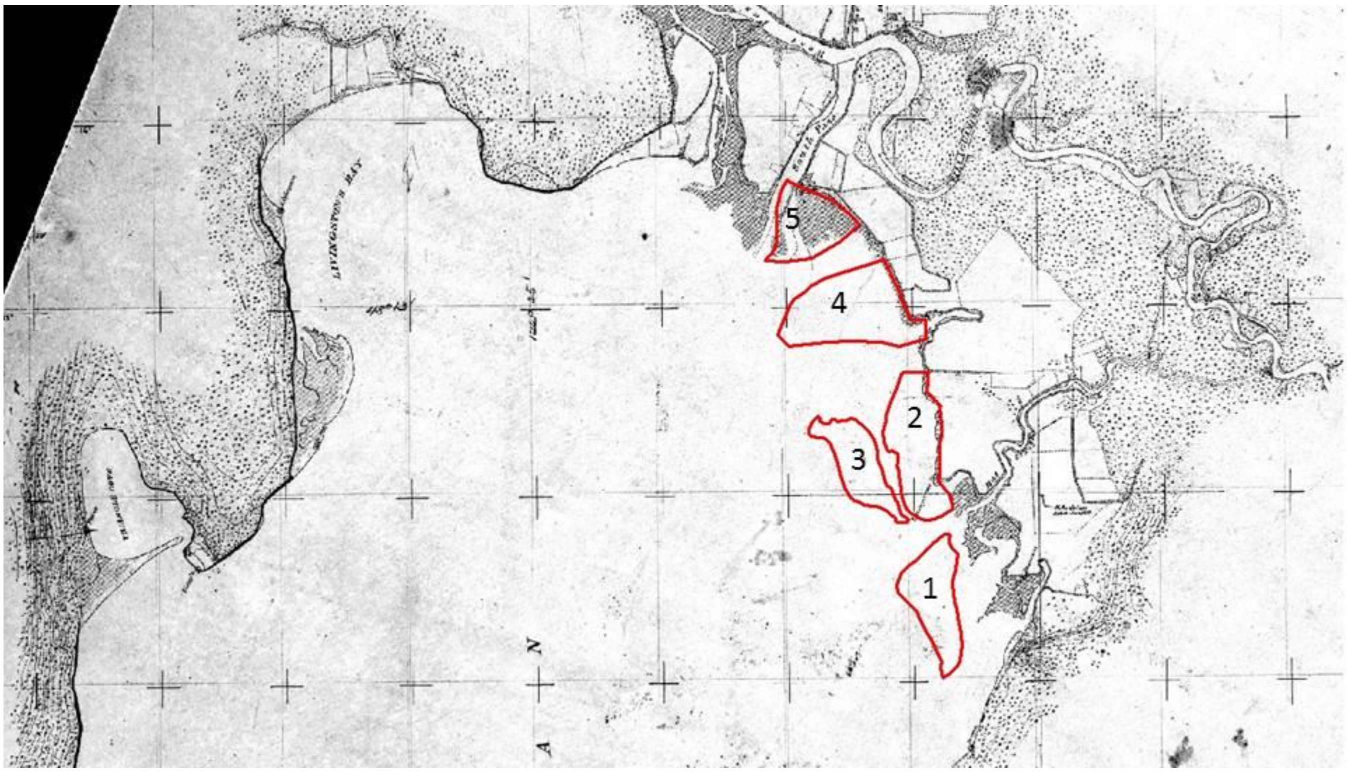

Figure 5. *1886 survey map of the Stillaguamish delta (U.S. Coast and Geodetic Survey). The five study zones are indicated.*

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.

Menno Groeneveld built his dike in the late 1950's, eliminating the marsh in zone 2. Tidal marsh in zones 3 and 4 increased substantially by 1964, and held steady in zones 1 and 5 (Figure 6).

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. Zone 4 continued to rise sharply after 1964, peaking in 1990 at 179 acres (2.6 ac/yr), then fell sharply by 70% to 54 acres in 2011 (-5.9 ac/yr). 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. Zone 5 dropped after 1964, declining 34% in 26 years (-1.7 ac/yr for a total decline of 34 acres) by 1990. It continued to drop between 1990 and 2011, declining a further 28 acres in 21 years (-1.3 ac/yr). Currently zone 5 has 39 acres of tidal marsh, down from its 1933-1964 peak of 99 acres.

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

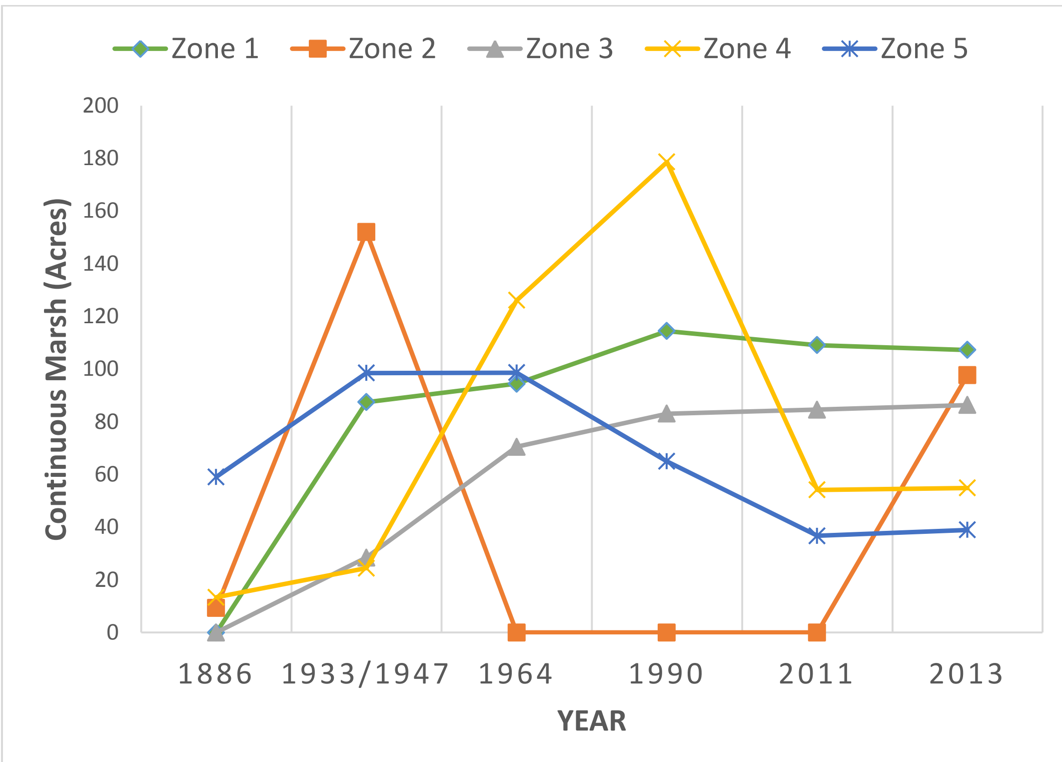

Figure 6. *Trends in the area of continuous tidal marsh in the 5 study zones. 1933 and 1947 data are lumped because 1933 aerials only cover zones 4 and 5, and 1947 aerials only cover zones 1-3.*

Aerials and maps showing the changes in tidal 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 Marsh, Patchy Marsh or Low Density Marsh, and channels are categorized as River Channels 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.

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

Patchy marsh appears more prevalent in earlier years, especially in zones 4 and 5. It appears to form 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 American 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.

The high density continuous marsh begins to substantially recede in zones 4 and 5 by 1990. This corresponds with the rapid expansion of the wintering snow goose population, which feeds heavily on bulrush rhizomes in soft soils. 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.

Low density marsh is difficult to detect in aerials (Figure 10) 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 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 American 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 11), 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 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 12). 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.

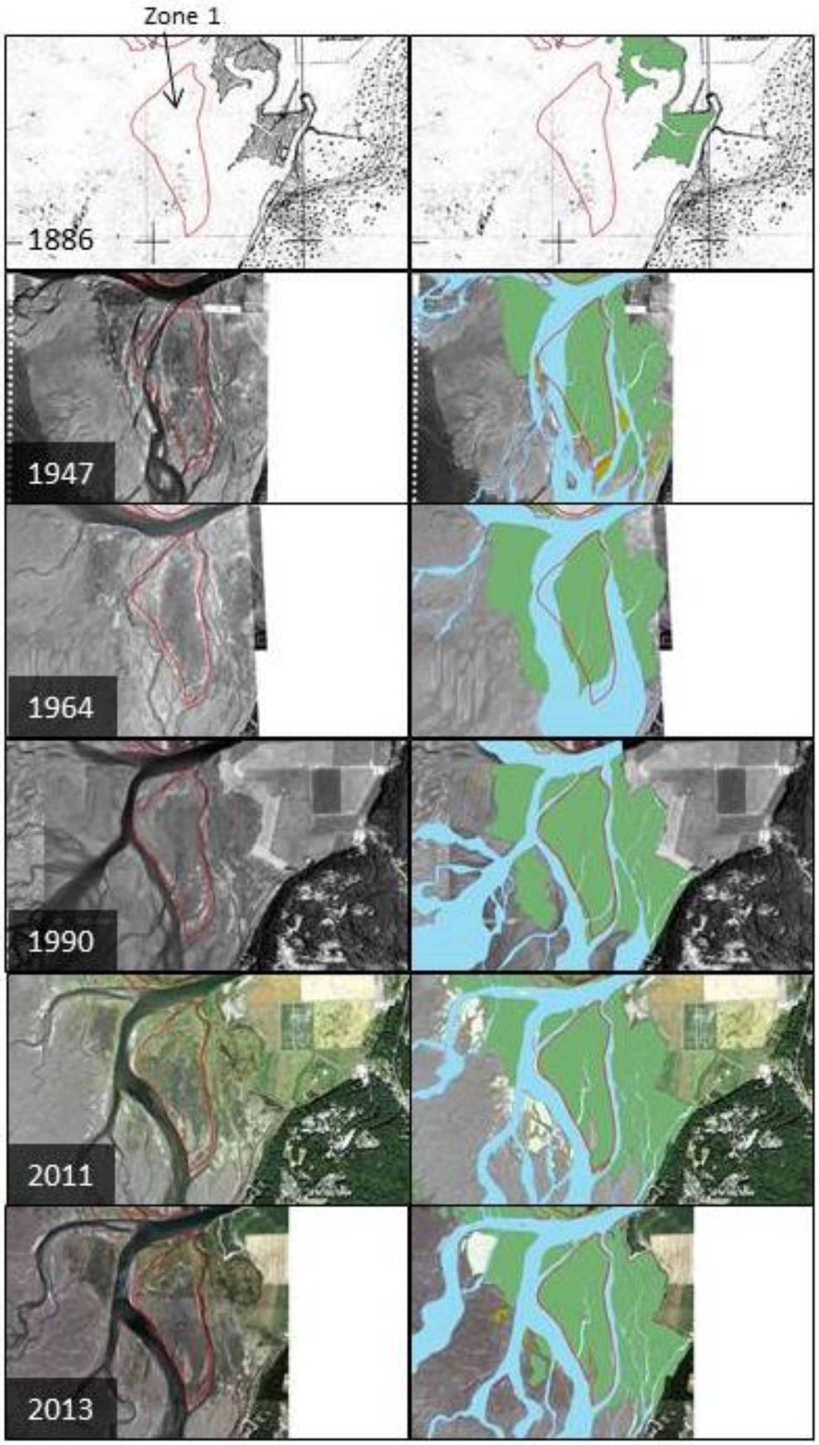

Figure 7. *Habitat trends in zone 1 (outlined in red). The left column shows the aerials and the right column shows the digitized habitat. Green polygons show Continuous Tidal Marsh, olive green polygons show Patchy Marsh and white polygons show Low Density Marsh. Blue polygons show the River Channels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

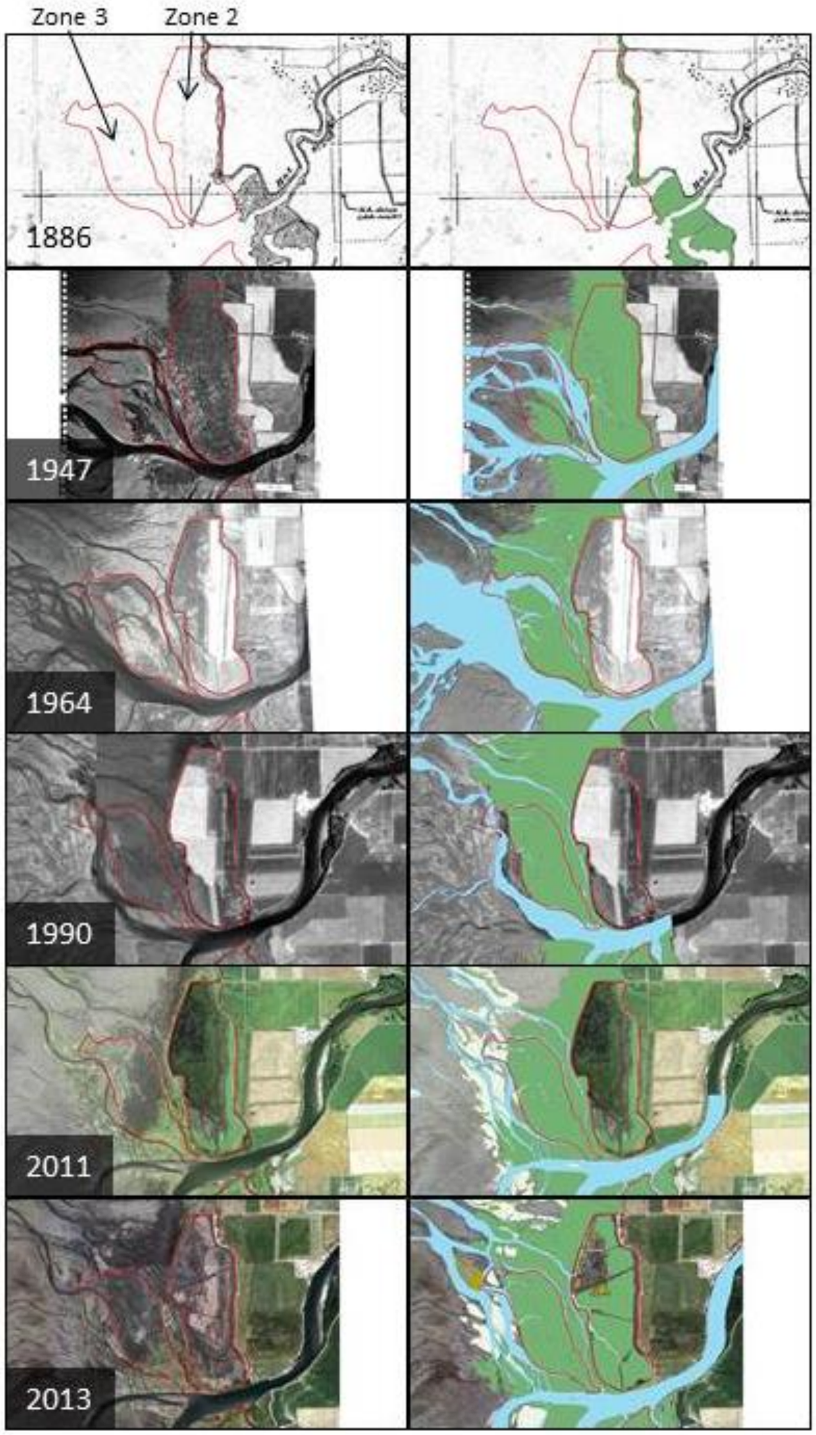

***Figure* 8.** *Habitat trends in zones 2 and 3 (outlined in red). The left column shows the aerials and the right column shows the digitized habitat. Green polygons show Continuous Tidal Marsh, olive green polygons show Patchy Marsh and white polygons show Low Density Marsh. Blue polygons show the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

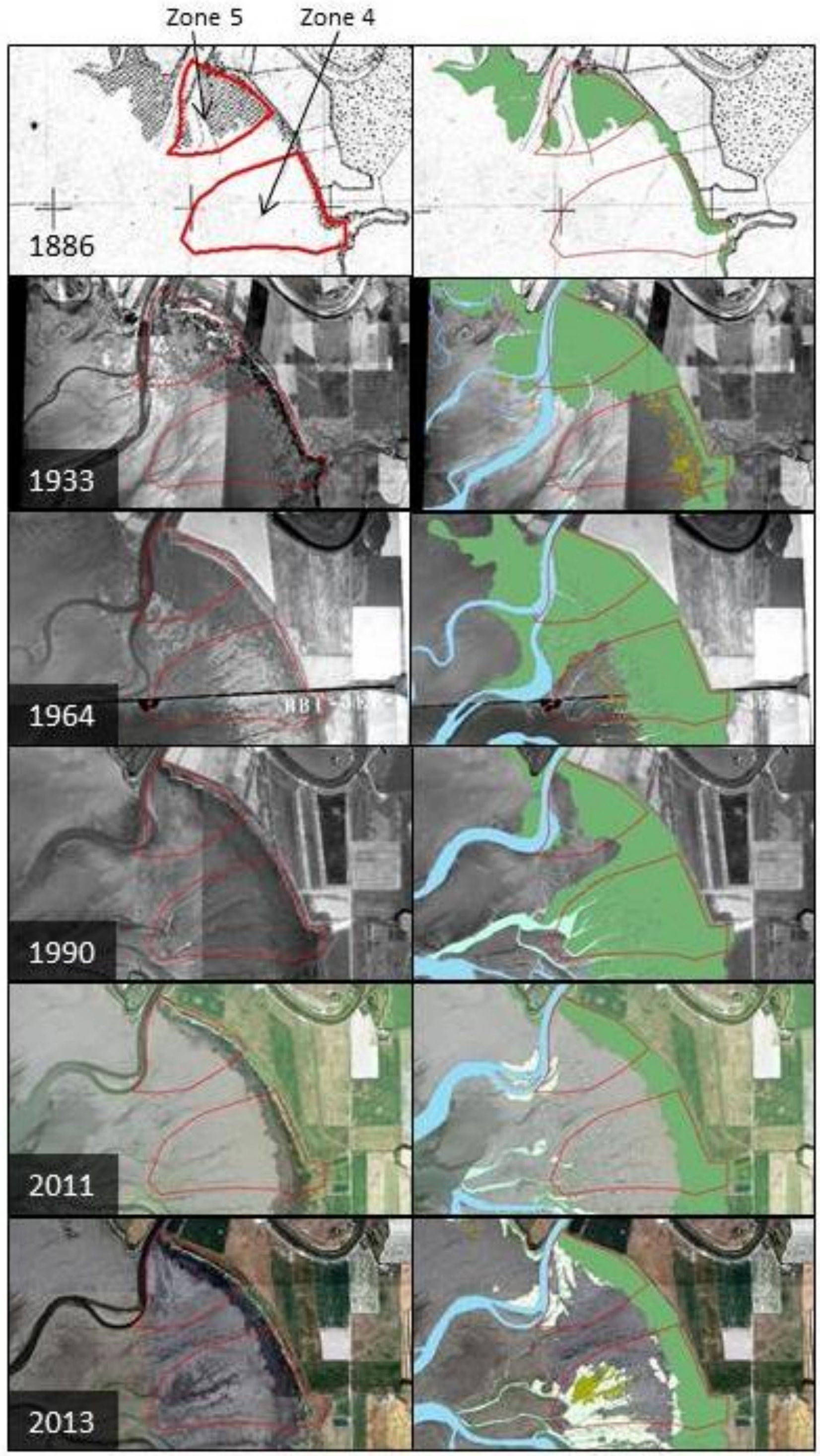

Figure 9. *Habitat trends in zones 4 and 5 (outlined in red). The left column shows the aerials and the right column shows the digitized habitat. Green polygons show Continuous Tidal Marsh, olive green polygons show Patchy Marsh and white polygons show Low Density Marsh. Blue polygons show the River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

Figure 10. *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).*

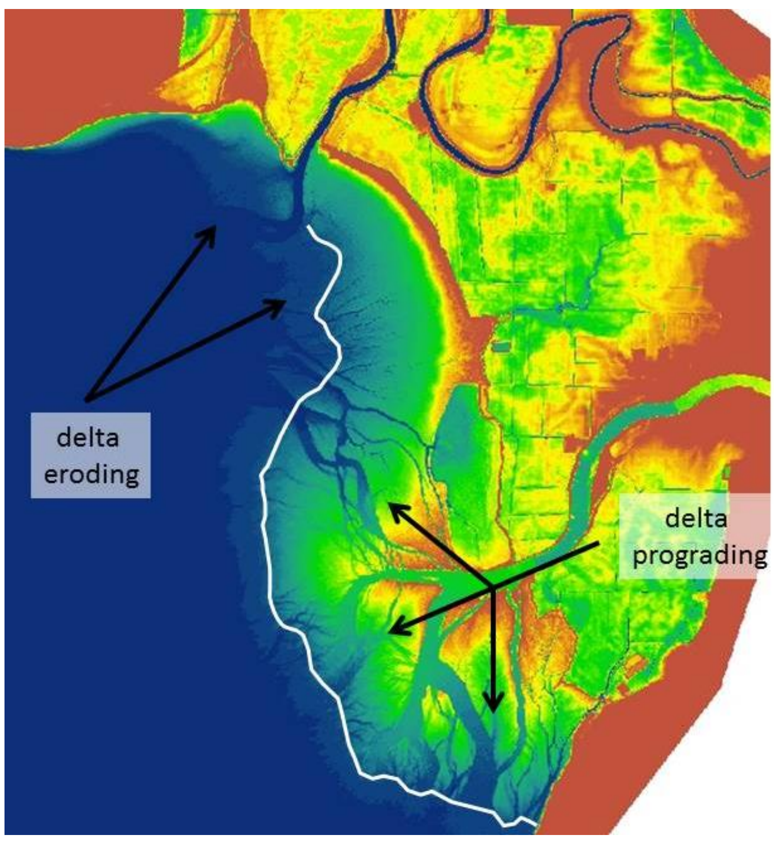

Figure 11. *Elevations of the Stillaguamish delta, from LiDAR. There is a new delta prograding at the mouth of Hatt Slough, while the northern area of the historic delta is eroding. Warm colors are the highest elevations, cool colors are the lowest.*

Figure 12. *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.*

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			
	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)
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			
	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)
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			
	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)
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			
	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)
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			
	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)	m2	acres	% of Zone	Average Change per Year (ac/yr)
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

A summary of the historical changes in continuous marsh boundaries for each zone is shown in Figure 13.

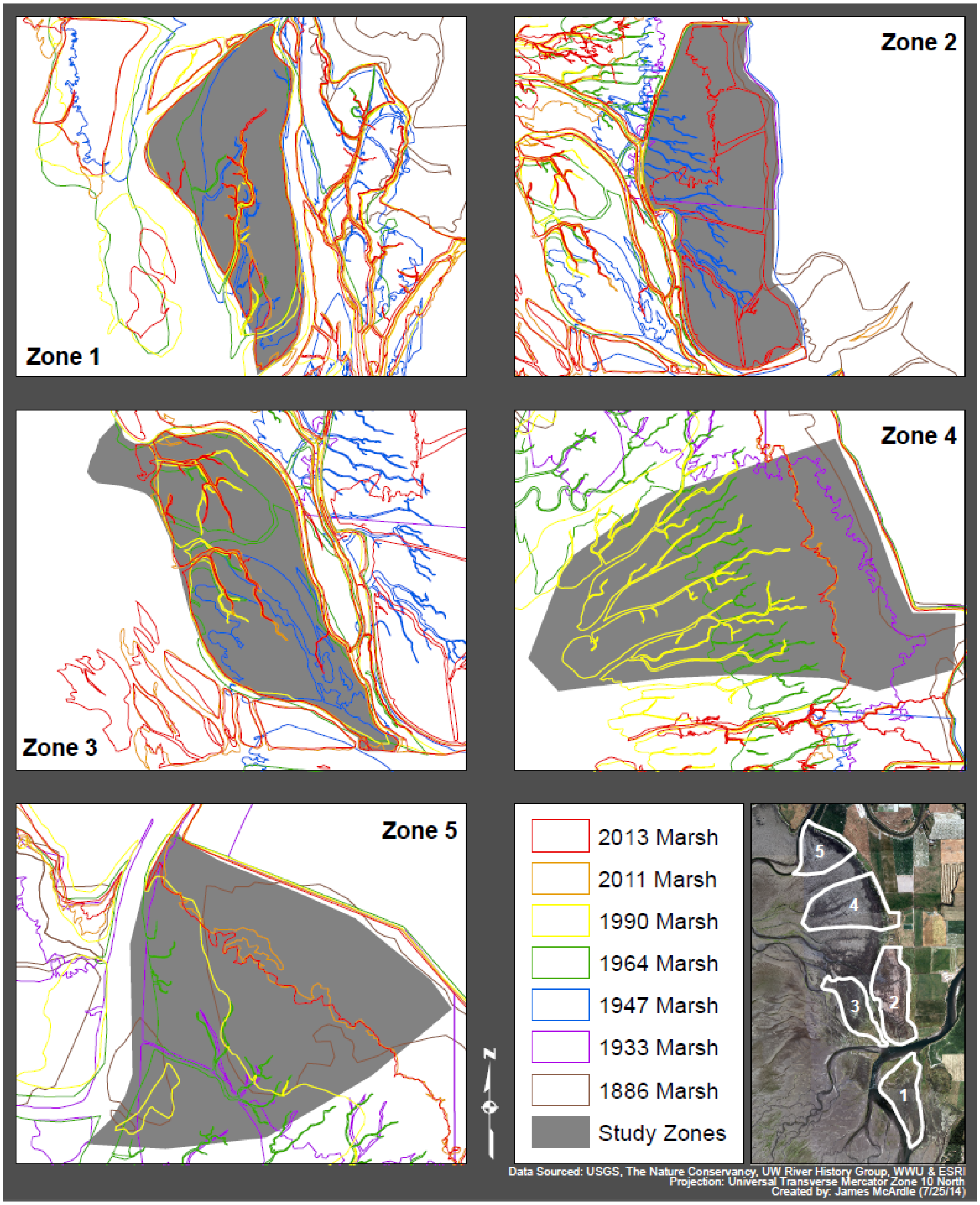

Figure 13. *Historical changes in continuous marsh boundaries in the 5 study zones.*

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 10 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 10 and Figure 2).

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

		Zone 1		Zone 2		Zone 3		Zone 4		Zone 5	
Year	Interval in years	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

Kaylee Guetle and Sarah Thomas provided additional assistance with geoprocessing and cartography.