# Ecological Change in Lake Clark, Alaska's Salt Marshes from 1940-2010

Thomas S. Walker *Department of Resource Analysis, Saint Mary's University of Minnesota, Winona, MN 55987*

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## Abstract

This research explores salt marshes changes in Lake Clark National Park (LACL), Alaska (USA). Of primary concern is the health of the salt marshes which are a unique part of Alaska's ecosystem. Objectives included identifying physiography, landscape formation, and changes occurring between years. Three years of aerial photography/satellite imagery were examined. Analyses determined vegetation development and expansion in the intertidal area was the most common change occurring on average 12.05% from 1950 to 1980 in all of the salt marshes, and 10.63% of the time from 1980 to 2010. These results show vegetation growth was more prominent from 1950 to 1980 than it was from 1980 to 2010.

## Introduction

The geomorphology of coastal areas in LACL was shaped by a variety of erosional and depositional processes that are a function of waves, winds and currents (Jorgenson, Frost, Miller, Spencer, Shephard, Mangipane, Moore, and Lindsay, 2010). Salt marsh communities represent one type of coastal geomorphic unit in LACL and are characterized by tidal flats interspersed with channels, levees, basins and pools (Jorgenson *et al.*, 2010).

Despite salt marsh communities, which occupy less than one percent of the total land area of LACL, they have great importance to the park's ecosystems (NPS, 2014). Salt marshes are among the most productive ecosystems in the world and provide habitat and food for a variety of the park's species including coastal brown bears, salmon, and resident and migratory birds (NPS, 2014). The critical relationship between salt marshes and the wildlife they support prompted the Southwest Alaska Network Inventory and Monitoring program to label them as "sensitive communities" and identify them as a Vital Sign for LACL (Nagorski, Hood, Eckert, and Pyare, 2008). These communities are primarily congregated along a 200 km (124 mi) stretch of coastline from Chinitna Bay to Redoubt Point (Bennett, 1996), including Tuxedni Bay (**Error! Reference source not found.**).

Photo interpretation was used to better understand and identify the changes that occur over extended periods of time within the salt marshes of LACL. Using imagery from 1940, 1980, and 2010, it is possible to delineate vegetation, mudflat, and other features of the salt marshes at a point in time as a reference point. This reference point can then be compared to others giving a representation of the change. The line work, shown in red

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in all of the figures, denotes what the
photo interpreter delineated


Figure 1. Three coastal salt marsh areas mapped and delineated in LACL. From left to right Chinitna Bay Southwest. Chinitna Bay Northeast, Shelter Creek, and Silver Salmon Creek.

as the physiography and landscape formation of all three year classes. Each polygon has a specific physiography, landscape formation, and landscape change class for each year.

This assessment focused on three salt marsh communities which include: Silver Salmon Creek, Chinitna Bay, and Shelter Creek. Shelter Creek (Figure 2) is a more difficult salt marsh to access for LACLs' visitors, thus making it less frequently visited as compared to the other salt marshes examined. Shelter Creek comprises 3,218 km$^2$ (1,242 mi$^2$) along the LACL shoreline.

Silver Salmon Creek (Figure 3) is easily accessible and is well known to LACL visitors for its fishing, bear viewing, clam digging, backpacking, and hiking. This salt marsh hosts Coho (silver) salmon and Humpback (pink) salmon as well as a Dolly Varden run in the late summer. Visitors can also walk the tidal flats which are filled with razor, little-neck, and butter clams (NPS, 2015b). Silver Salmon Creek salt occupies an area of 1830 km$^2$ (706 mi$^2$) along LACL's shoreline. Finally, Chinitna Bay (Figure 4) is well known by visitors for its brown bear viewing. The bears congregate in high numbers in the estuaries where rivers flowing out of the mountains meet the sea in Chinitna Bay. Late spring through mid-summer bears feed on sedges that are high in protein as well as other edible plants that grow in the salt marshes (NPS, 2015a). For the purpose of this project, Chinitna Bay was split into two areas due to its large area and how the salt marsh community starts and stops: Chinitna Bay Southwest (Figure 4) and Chinitna Bay Northeast (Figure 4). The Southwestern portion comprises 8,658 km$^2$ (3,342 mi$^2$) of shoreline area; the Northeastern part has 1,202 km$^2$ (464 mi$^2$) shoreline area.

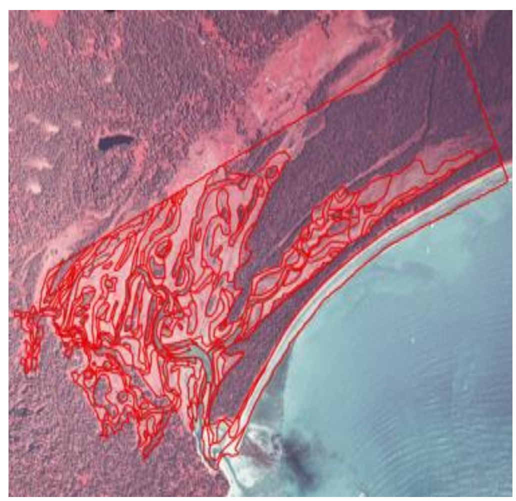

Figure 2. IKONOS (2010) imagery of Shelter Creek with salt marsh delineations in red.

## Methods

Data were digitally photo-interpreted using the photography from three years: the 1950s (BW/1952-1957), the 1980s


Figure 3. Above graphic: Aerial photo of Silver Salmon Creek salt marsh (Photo by Jalone). Below graphic: IKONOS (2010) imagery of Silver Salmon Creek with delineation lines in red.

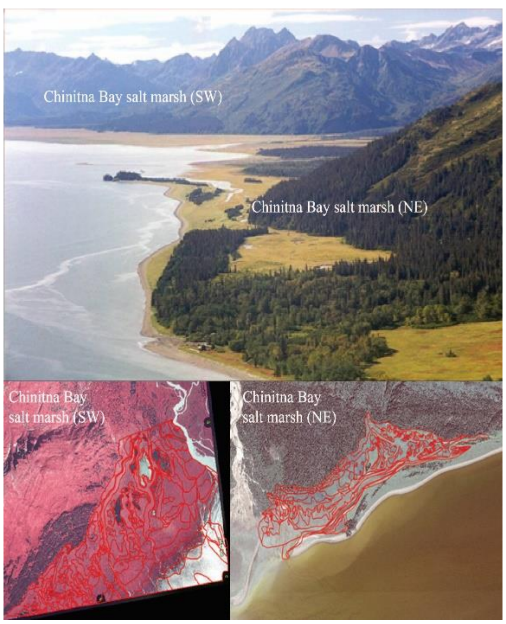


Figure 4. Above graphic: Aerial Photo of the northeast and southwest Chinitna Bay salt marshes. Bottom left: IKONOS (2010) imagery of Chinitna Bay (SW) with delineation lines. Bottom Right graphic: IKONOS (2010) imagery of Chinitna Bay (NE) with salt marsh delineations in red.

(CIR/1978-1980), and an IKONOS (CIR/2005-2009) and SPOT5 (CIR/2011) image composite. The 1950's imagery was black and white with some pixilation and of medium to low quality. This imagery was viewed at a scale of 1:15,000 in ArcMap during the interpretation process. The 1980's Alaska High Altitude Photography (AHAP) imagery was color infrared and was interpreted at 1:10,000 scale. The 2010's data, high-resolution, IKONOS/SPOT5 composite color infra-red satellite imagery was interpreted at a scale of 1:5,000.

### *Data Classification*

The mapping and classification of the salt marshes delineated for this assessment were adapted from Tande (1996). Specific attributes interpreted for each marsh were limited by the quality of the aerial imagery and included physiography type, site moisture, and landscape formation values (Table 1).

Table 1. Possible classification/identification values for salt marshes (adapted from Tande, 1996).

| Physiography | Site Moisture | Landscape Formation |
|---|---|---|
| Upland | Moist | Upland |
| Coastal High Marsh | Wet | Meadow |
| Coastal Mid Marsh | | Levee Meadow |
| Coastal Low & Mid Marsh | | Levee |
| Coastal Low Marsh | | Interlevee Basin&Channel Basin |
| | | Interlevee Ponded Basin |
| | | Interlevee Pond |
| | | Interlevee Basin Meadow |
| | | Pond or Lake |
| | | Mudflat |
| | | Mudflat and Panne |
| | | Open Water |
| | | Unconsolidated Shore |
| | | Eroding Levee Meadow |

## Results

Result were divided into the three image classification values referenced in the methods and each was divided and compared across year classes.

### *Physiography*

The physiographic location for each polygon that was delineated within the salt marshes was assessed for each of the time periods. As per Tande (1996), "Barren" values were assigned to a physiography that had a landscape formation value of "Mudflat" since this community was not considered to be a category of the vegetated salt marsh community. A physiography of "Ocean" was assigned to community types that changed from salt marsh to water.

Silver Salmon Creek

The most common physiographic change in the Silver Salmon Creek area (

Table 2) between the 1950s to the 1980s was "Upland" to "Barren" which comprised 6.29% of the area in Silver Salmon Creek.

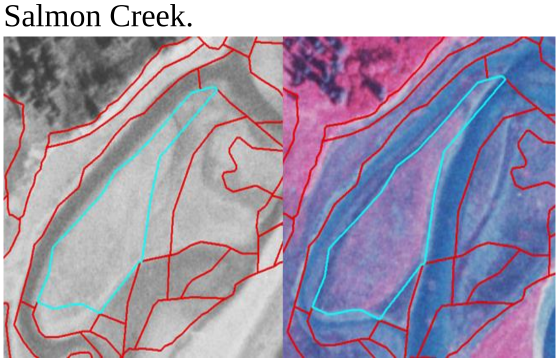

Figure 2 shows change from 1950 to 1980, which was "Barren" to "Coastal Mid Marsh", perhaps due to uplift following the 1964 earthquake (Miller, 2015). The analysis demonstrates 67.29% of the area did not change between these two time periods.

Table 2. Summary of physiographic change from 1950 to 1980 in Silver Salmon Creek.

| Physiography 1950 | Physiography 1980 | Area(ha) | Percent Area |
|---|---|---|---|
| No Change | No Change | 123.15 | 67.29% |
| Upland | Barren | 11.51 | 6.29% |
| Coastal Low & Mid Marsh | Coastal Mid Marsh | 10.07 | 5.50% |
| Barren | Coastal Mid Marsh | 8.91 | 4.87% |
| Barren | Upland | 5.77 | 3.15% |
| Barren | Coastal Low Marsh | 5.68 | 3.10% |

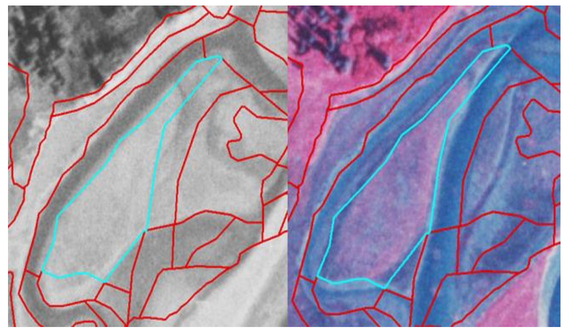

Figure 2. As seen in the blue outlined area, Vegetation growth allowed for a physiographic change in Silver Salmon Creek from Barren in 1950 (left) to Coastal Mid Marsh in 1980 (right) at a scale of 1:2,000.

Results illustrate that the change from "Ocean" to "Barren" was the most common change between the 1980's and 2010's but only involved 4.24% of the Silver Salmon Creek area (Table 3). Analysis demonstrated 78.40% of the physiography did not experience any change between the 1980's and 2010's. **Error! Reference source not found.** shows representation of "Mass Wasting" from 1980 to 2010 where the physiography changed from "Upland" to "Ocean."

Table 3. Summary of physiographic change from 1980 to 2010 in Silver Salmon Creek.

| Physiography 1980 | Physiography 2010 | Area(ha) | Percent Area |
|---|---|---|---|
| No Change | No Change | 143.72 | 78.40% |
| Ocean | Barren | 7.75 | 4.24% |
| Coastal Low Marsh | Barren | 5.62 | 3.07% |
| Upland | Barren | 4.52 | 2.47% |
| Barren | Upland | 4.34 | 2.38% |
| Barren | Coastal Low Marsh | 2.58 | 1.41% |

## Chinitna Bay

The most common physiographic change in Chinitna Bay Southwest between the 1950's and the 1980's was "Barren" to "Coastal Low Marsh" (Figure 7). This comprised 12.4% of the overall change to "Coastal Low Marsh" (Figure 7). This comprised 12.4% of the overall change to

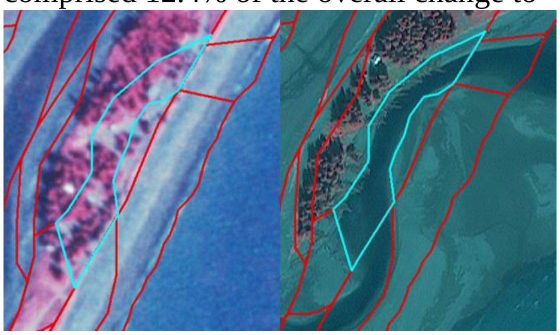

Figure 6. As seen in the blue outlined area physiographic change in Silver Salmon Creek from Upland in 1980 (left) to Ocean in 2010 (right) at a scale of 1:2,000.

physiography in Chinitna Bay Southwest (Table 4). Of the total area 85.23% was unchanged.

Table 4. Summary physiographic change from 1950 to 1980 in Chinitna Bay South West.

| Physiography 1950 | Physiography 1980 | Area(ha) | Percent Area |
|---|---|---|---|
| No Change | No Change | 737.91 | 85.23% |
| Barren | Coastal Low Marsh | 107.32 | 12.40% |
| Barren | Coastal Low & Mid Marsh | 13.14 | 1.52% |
| Coastal Low & Mid Marsh | Coastal Mid Marsh | 4.13 | 0.48% |
| Coastal High Marsh | Barren | 3.27 | 0.30% |

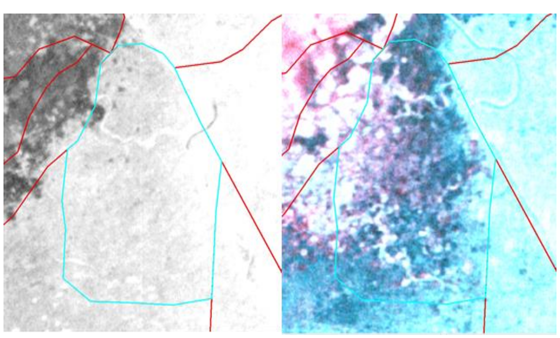

Figure 7. As seen in the blue outlined area, vegetation change within the mudflat allowed for a physiographic change in Chinitna Bay Southwest from Barren in 1950 (left) to Coastal Low Marsh in 1980 (right) at a scale of 1:2,000.

Similar results can be seen in Table 5, where 78.14% of the area did not experience any change between the 1980's and the 2010's. The most common change in Chinitna Bay Southwest between the 1980's and the 2010's was from "Coastal Low Marsh" to "Coastal Low & Mid Marsh" at 10.77%.

Table 5. Types of physiographic change from 1980 to 2010 in Chinitna Bay Southwest.

| Physiography 1980 | Physiography 2010 | Area(ha) | Percent Area |
|---|---|---|---|
| No Change | No Change | 676.55 | 78.14% |
| Coastal Low Marsh | Coastal Low & Mid Marsh | 93.23 | 10.77% |
| Barren | Coastal Low & Mid Marsh | 64.93 | 7.50% |
| Coastal High Marsh | Barren | 10.64 | 1.23% |
| Barren | Coastal Low Marsh | 8.19 | 0.90% |
| Coastal Mid Marsh | Coastal High Marsh | 3.72 | 0.43% |

Table 6 shows the most common change in Chinitna Bay Northeast between the 1950's and the 1980's was "Mudflat" (null) to "Coastal Low Marsh." This change comprised 9.22% of the overall change to the physiography in Chinitna Bay Southwest. The analysis demonstrated that 84.98% of the physiography did not change.

Table 6. Summary of physiographic change from 1950 to 1980 in Chinitna Bay Northeast.

| Physiography 1950 | Physiography 1980 | Area(ha) | Percent Area |
|---|---|---|---|
| No Change | No Change | 95.67 | 79.61% |
| Barren | Coastal Low Marsh | 11.07 | 9.22% |
| Coastal Low Marsh | Coastal Low & Mid Marsh | 4.53 | 3.77% |
| Barren | Coastal Low & Mid Marsh | 4.41 | 3.66% |
| Coastal Low Marsh | Ocean | 1.27 | 1.02% |
| Barren | Ocean | 1.35 | 0.84% |

Similar results can be seen in Table 7, where 76.46% of the area did not experience change between the 1980's and the 2010's in Chinitna Bay Northeast. The most common change in Chinitna Bay Northeast between the 1980's and the 2010's was "Coastal High Marsh" to "Upland" (Figure 8), at 4.74%.

Shelter Creek

Table 8 illustrates the most common change in Shelter Creek from the 1950's to the 1980's was "Coastal Mid Marsh" to "Coastal Low & Mid Marsh". In this instance, stream formation caused the physiographic change (Figure 9). This change occurred in 2.43% of the Shelter Creek area. Analysis demonstrated 91.09% of the area was unchanged between the 50's and 80's.

Table 7. Summary of physiographic change from 1980 to 2010 in Chinitna Bay Northeast.

| Physiography 1980 | Physiography 2010 | Area(ha) | Percent Area |
|---|---|---|---|
| No Change | No Change | 91.85 | 76.46% |
| Coastal High Marsh | Upland | 5.69 | 4.74% |
| Coastal Mid Marsh | Coastal High Marsh | 5.62 | 4.68% |
| Coastal Mid Marsh | Upland | 3.21 | 2.67% |
| Barren | Coastal Low Marsh | 3.13 | 2.61% |
| Barren | Coastal Low & Mid Marsh | 2.81 | 2.34% |

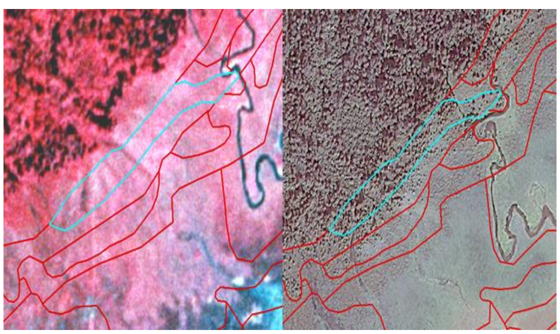

Figure 8. As seen in the blue outlined area, there is some image shift in the 1980 (left) photo, a physiographic change from in Chinitna Bay Northeast Coastal High Marsh in 1980 (left) to Upland in 2010 (right) can still be seen at a scale of 1:2,000.

Table 8. Summary of physiographic change from 1950 to 1980 in Shelter Creek.

| Physiography 1950 | Physiography 1980 | Area(ha) | Percent Area |
|---|---|---|---|
| No Change | No Change | 293.22 | 91.09% |
| Coastal Mid Marsh | Coastal Low & Mid Marsh | 7.81 | 2.43% |
| Coastal High Marsh | Coastal Mid Marsh | 4.01 | 1.25% |
| Coastal Mid Marsh | Coastal High Marsh | 2.66 | 0.83% |
| Coastal High Marsh | Coastal Low & Mid Marsh | 2.65 | 0.83% |
| Barren | Coastal Low Marsh | 2.46 | 0.77% |

Table 9 illustrates change from "Coastal Mid Marsh" to "Upland" was the most common change between the 1980's and 2010, reflected in 1.76% of the Shelter Creek area. Figure 10 shows expansion of shrub and sapling between the 1980's and 2010. Analysis revealed 91.70%

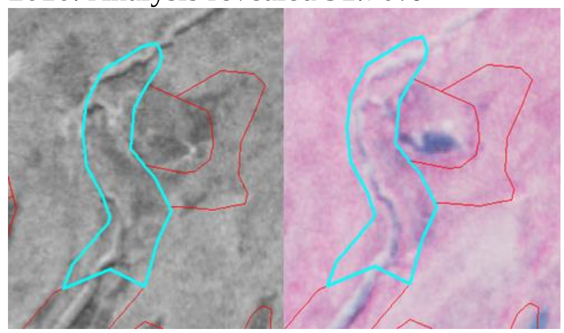

Figure 9. As seen in the blue outlined area, the presence of stream formation allowed for a physiographic change in Shelter Creek from Coastal Mid Marsh in 1950 (left) to Coastal Low & Mid Marsh in 1980 (right) at a scale of 1:2,000.

Table 9. Summary physiographic change from 1980 to 2010 in Shelter Creek.

| Physiography 1980 | Physiography 2010 | Area(ha) | Percent Area |
|---|---|---|---|
| No Change | No Change | 295.11 | 91.70% |
| Coastal Mid Marsh | Upland | 5.66 | 1.76% |
| Coastal Low & Mid Marsh | Coastal Mid Marsh | 4.59 | 1.43% |
| Coastal High Marsh | Upland | 4.11 | 1.28% |
| Ocean | Barren | 2.64 | 0.82% |
| Barren | Coastal Low Marsh | 1.77 | 0.55% |

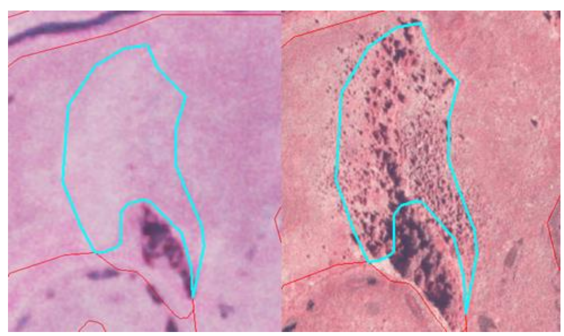

Figure 10. As seen in the blue outlined area, physiographic change in Shelter Creek from Coastal Mid Marsh in 1980 (left) to Upland in 2010 (right) at a scale of 1:2,000.

of the area did not experience change between the 80's and 2010's.

### *Landscape Formation*

Change was assessed over time to identify habitat creation. The assessment codes were adapted from Tande's (1996) land cover codes that were field verified.

Silver Salmon Creek

The Landscape within Silver Salmon Creek experienced noticeable change between the 1950's and the 1980's (Table 10). The largest single change was "Upland" to "Mudflat" due to mass wasting from tide and water expansion (Figure 11). This occurred in 6.29% of the area of Silver Salmon Creek. The change was due primarily to mass wasting along the shore line. Analysis demonstrated 63.76% of the landscape did not change.

Table 10. Summary of landscape formation changes from 1950 to 1980 in Silver Salmon Creek.

| Landscape Formation 1950 | Landscape Formation 1980 | Area(ha) | Percent Area |
|---|---|---|---|
| No Change | No Change | 116.72 | 63.76% |
| Upland | Mudflat | 11.51 | 6.29% |
| Mudflat | Interlevee Basin Meadow | 10.12 | 5.53% |
| Open Water | Open Water | 6.85 | 3.74% |
| Meadow | Interlevee Ponded Basin | 5.59 | 3.06% |
| Mudflat | Upland | 5.39 | 2.95% |

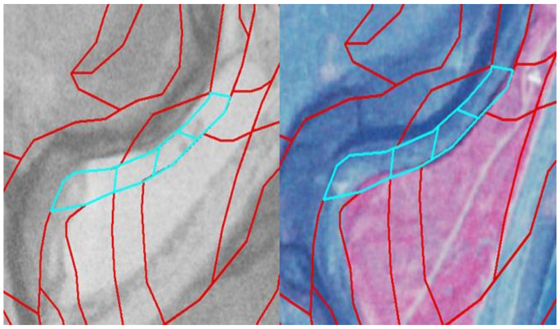

Figure 11. As seen in the blue outlined area, depiction of the river actively cutting away at the shoreline allowed for a landscape formation change in Silver Salmon Creek from Upland in 1950 (left) to Mudflat in 1980 (right), viewed at a scale of 1:2,000.

Between the 1980's and the 2010's most change occurred from sediment deposition and changed "Open Water" to "Mudflat" (Figure 12). This change occurred in 4.24% of the Silver Salmon Creek area. Analysis demonstrated 70.83% of the landscape did not change (Table 11).

Table 11. Types of landscape formation changes from 1980 to 2010 in Silver Salmon Creek.

| Landscape Formation 1980 | Landscape Formation 1910 | Area(ha) | Percent Area |
|---|---|---|---|
| No Change | No Change | 129.65 | 70.83% |
| Open Water | Mudflat | 7.76 | 4.24% |
| Interlevee Ponded Basin | Interlevee Ponded Basin | 5.87 | 3.21% |
| Mudflat and Panne | Mudflat | 5.62 | 3.07% |
| Upland | Mudflat | 4.53 | 2.47% |
| Mudflat | Upland | 4.35 | 2.38% |

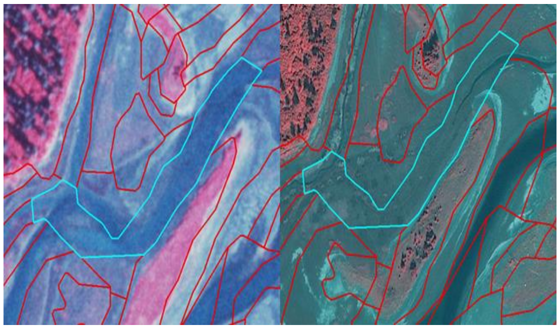

Figure 12. Seen within the light blue outlined area, landscape formation change in Silver Salmon Creek from Open Water in 1980 (left) to Mudflat in 2010 (right) at a scale of 1:2,000.

Chinitna Bay

The largest single landscape formation change for Chinitna Bay Southwest between the 1950's and the 1980's was "Mudflat" to "Mudflat and Panne" (Figure 13). Change occurred in 12.4% of the area in Chinitna Bay Southwest. Analysis demonstrated 77.22% of the landscape did not change (Table 12).

Table 12. Summary of landscape formation change from 1950 to 1980 in Chinitna Bay Southwest.

| Landscape Formation 1950 | Landscape Formation 1980 | Area(ha) | Percent Area |
|---|---|---|---|
| No Change | No Change | 668.60 | 77.22% |
| Mudflat | Mudflat and Panne | 107.33 | 12.40% |
| Interlevee Ponded Basin | Meadow | 26.05 | 3.01% |
| Unconsolidated Shore | Mudflat and Panne | 21.84 | 2.52% |
| Meadow | Interlevee Ponded Basin | 16.22 | 1.87% |
| Mudflat | Interlevee Ponded Basin | 13.14 | 1.52% |

Greater change was visible between the 1980's and the 2010's in Chinitna Bay Southwest, where roughly 30% of the area experienced landscape change (Table 13). The most common changes between the 1980's and the 2010's were the formation of "Interlevee Ponded Basins" (e.g., from "Mudflat" to "Interlevee Ponded Basin" (7.88%) and "Mudflat and Panne" to "Interlevee Ponded Basin" (7.52%) and meadow development (e.g., from "Interlevee Ponded Basin" to "Meadow" (3.84%) and "Mudflat and Panne" to "Meadow" (2.45%)).

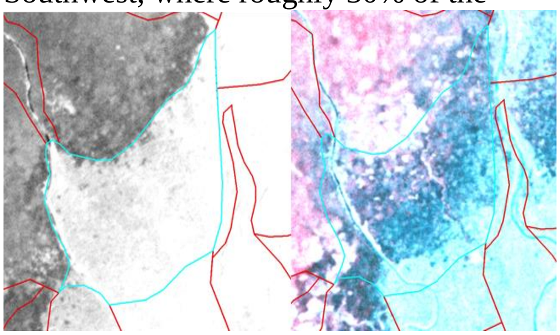

Figure 13. As seen in the blue outlined area, landscape formation change in Chinitna Bay Southwest from Mudflat in 1950 (left) to Mudflat and Panne in 1980 (right) at a scale of 1:2,000.

Table 13. Summary of landscape formation change from 1980 to 2010 in Chinitna Bay South West.

| Landscape Formation 1980 | Landscape Formation 2010 | Area(ha) | Percent Area |
|---|---|---|---|
| No Change | No Change | 606.13 | 70.01% |
| Mudflat | Interlevee Ponded Basin | 68.21 | 7.88% |
| Mudflat and Panne | Interlevee Ponded Basin | 65.14 | 7.52% |
| Interlevee Ponded Basin | Meadow | 33.23 | 3.84% |
| Mudflat and Panne | Meadow | 21.23 | 2.45% |
| Unconsolidated Shore | Mudflat and Panne | 13.89 | 1.60% |

Changes in Chinitna Bay Northeast were comparable to those in Chinitna Bay Southwest. Table 14 illustrates the most common change in Chinitna Bay Northeast between the 1950's and the 1980's, was "Mudflat" to "Mudflat and Panne". This change occurred in 9.22% of the area; the analysis also demonstrated 76.79% of the landscape did not change between these two time periods.

Table 14. Summary of landscape formation change from 1950 to 1980 in Chinitna Bay Northeast.

| Landscape Formation 1950 | Landscape Formation 1980 | Area(ha) | Percent Area |
|---|---|---|---|
| No Change | No Change | 92.27 | 76.79% |
| Mudflat | Mudflat and Panne | 11.08 | 9.22% |
| Mudflat | Interlevee Basin & Channel Basin | 4.87 | 4.05% |
| Mudflat and Panne | Interlevee Basin & Channel Basin | 4.69 | 3.90% |
| Interlevee Ponded Basin | Interlevee Pond | 2.22 | 1.85% |
| Mudflat | Open Water | 1.36 | 1.13% |

Similar results can be seen in Table 15 where 73.12% of the area did not experience any change between the 1980's and the 2010's in Chinitna Bay Northeast (Figure). In contrast to Chinitna Bay Southwest, the most common change between the 1980's and the 2010's time steps was "Meadow" to "Upland", accounting for 6.51% of the landscape formation change that occurred in Chinitna Bay Northeast. Analysis demonstrated 73.12% of the landscape did not change.

Table 15. Summary of landscape formation change from 1980 to 2010 in Chinitna Bay North East.

| Landscape Formation 1980 | Landscape Formation 2010 | Area(ha) | Percent Area |
|---|---|---|---|
| No Change | No Change | 87.86 | 73.12% |
| Meadow | Upland | 7.82 | 6.51% |
| Mudflat and Panne | Interlevee Basin & Channel Basin | 6.94 | 5.77% |
| Mudflat | Interlevee Basin & Channel Basin | 4.14 | 3.45% |
| Interlevee Ponded Basin | Interlevee Basin & Channel Basin | 2.11 | 1.76% |
| Open Water | Mudflat | 1.60 | 1.33% |

Shelter Creek

The Landscape within Shelter Creek did not experience significant change between the 1950's and the 1980's (**Error!**

**Reference source not found.**). The largest single landscape change occurring from "Meadow" to "Interlevee Basin & Channel Basin". This occurred in 1.8% of the area of Shelter Creek. This change was primarily due to the channel formation (Figure 15.) Analysis demonstrated 89.36% of the landscape was unchanged.

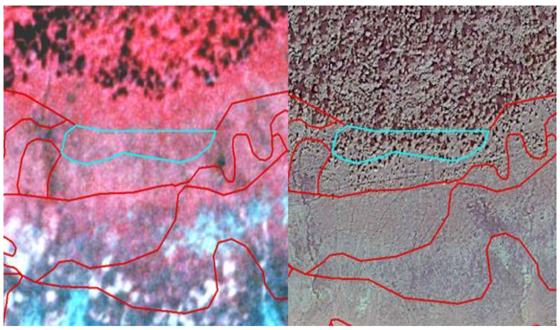

Figure 14. As seen in the blue outlined area, some image shift occurred in the 1980 (left) photo but the landscape formation change in Chinitna Bay Northeast still showed change from Meadow in 1980(left) to Upland in 2010 (right) at a scale of 1:2,000.

Table 16. Summary of landscape formation change from 1950 to 1980 in Shelter Creek.

| Landscape Formation 1950 | Landscape Formation 1980 | Area(ha) | Percent Area |
|---|---|---|---|
| No Change | No Change | 287.59 | 89.36% |
| Meadow | Interlevee Basin&Channel Basin | 5.78 | 1.80% |
| Interlevee Ponded Basin | Interlevee Basin&Channel Basin | 4.67 | 1.45% |
| Meadow | Interlevee Ponded Basin | 2.45 | 0.76% |
| Interlevee Basin&Channel Basin | Interlevee Ponded Basin | 2.45 | 0.76% |
| Interlevee Ponded Basin | Meadow | 2.15 | 0.67% |

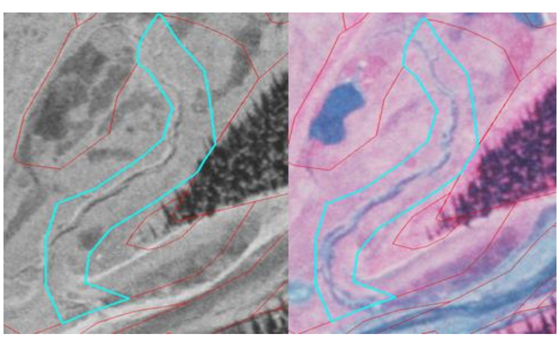

Figure 15. As seen in the blue outlined area, due to the expansion of the stream and the percentage of the polygon it makes up a landscape formation change in Shelter Creek from Meadow in 1950 (left) to Interlevee Basin & Channel Basin in 1980 (right) can be seen, viewed at a scale of 1:2,000.

Between the 1980's and the 2010's, Table 17 shows that the most common change occurred due to uplift from "Meadow" to "Upland" (Figure 16), occurring in 3.22% of Shelter Creek. The analysis demonstrated that 82.49% of the landscape did not change. The relative stability of the Shelter Creek complex may be due to the greater proportion of the area in uplands relative to the other study areas (Silver Salmon Creek, Chinitna Bay). In addition, the forested shoreline which likely protects the interior marshes from storm surges and other incursion (Miller, 2015).

Table 17. Summary of landscape formation change from 1980 to 2010 in Shelter Creek.

| Landscape Formation 1980 | Landscape Formation 2010 | Area(ha) | Percent Area |
|---|---|---|---|
| No Change | No Change | 265.47 | 82.49% |
| Meadow | Upland | 10.37 | 3.22% |
| Open Water | Open Water | 9.65 | 3.00% |
| Levee Meadow | Levee Meadow | 7.40 | 2.30% |
| Interlevee Ponded Basin | Interlevee Basin Meadow | 4.72 | 1.47% |
| Open Water | Mudflat | 2.65 | 0.82% |

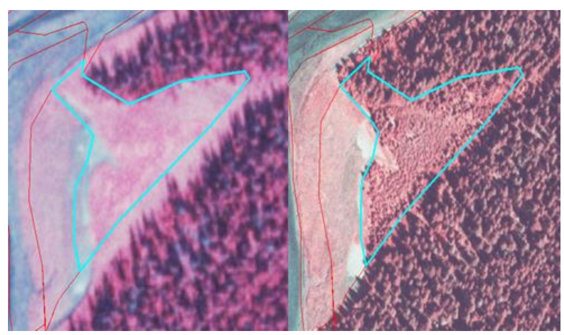

Figure 16. As seen in the blue outlined area, landscape formation change in Shelter Creek from Meadow in 1980 (left) to Upland in 2010 (right) at a scale of 1:2,000.

### *Landscape Change*

Landscape change codes were assigned where landscape formation change occurred between all time periods. This code reflects the type of change and was assigned at the discretion of the photo interpreter. Codes were adapted from the

LACL land cover report (Burchiel, Maffitt, Robertson, Rokus, and Stark, 2014) (Table 18).

## Silver Salmon Creek

The most common landscape changes within the Silver Salmon Creek area between the 1950's and the 1980's is

Table 18. Landscape change codes adapted from LACL land cover report.

| Landscape Change |
|---|
| Spruce Closure |
| Spruce Establishment/Expansion |
| Spruce Dieback |
| Shrub Closure |
| Shrub Establishment |
| Shrub Loss |
| Hardwood Forest Closure |
| Hardwood Forest Establishment |
| Hardwood Forest Dieback |
| Channel Formation |
| Channel Abandonment |
| Pond Drying |
| Wetland Loss |
| Wetland Creation |
| Mass Wasting |
| Coastal Subsidence/Flooding |
| Coastal Uplift |
| Ash Deposit |
| Alluvial Deposit |
| Pond/Lake Formation |
| Colluvial Deposit |
| Rill Formation |
| Rill Abandonment |
| Vegetation Development/Expansion in Intertidal Area |
| Ice Loss/Glacial Retreat |
| Aquatic Bed Formation/Expansion in Palustrine Area |
| Open Water Formation/Marine Intrusion |
| Beaver Activity |
| Annual Snow Increase |
| Annual Snow Decrease |
| Perennial Snow Increase |
| Perennial Snow Decrease |
| Vegetation Loss/Decrease in Intertidal Area |
| Lake Drainage |
| Mixed Forest Establishment |
| Shadows/Mosaic/Image Shift/Image Smear |

shown in Table 19. The largest single landscape change was "Vegetation Development/Expansion in Intertidal Area", involving 13.29% of the area in Silver Salmon Creek (Figure 17). 72.73% of the landscape did not change.

Table 19. Summary of land change from 1950 to 1980 in Shelter Creek.

| Change Code from 1950 to 1980 | Area(ha) | Percent Area |
|---|---|---|
| No Change | 133.15 | 72.73% |
| Vegetation Development/Expansion in Intertidal Area | 24.34 | 13.29% |
| Vegetation Loss/Decrease in Intertidal Area | 12.86 | 7.03% |
| Wetland Creation | 5.59 | 3.06% |
| Channel Abandonment | 4.19 | 2.29% |
| Channel Formation | 2.44 | 1.33% |
| Spruce Establishment/Expansion | 0.49 | 0.27% |

Between the 1980's and the 2010's, landscape changes are shown in Table 20. The largest single landscape change was "Vegetation Development/Expansion in Intertidal Area", involving 6.68% of the

area in Silver Salmon Creek (Figure 18). The analysis demonstrated 78.96% of the landscape did not change.

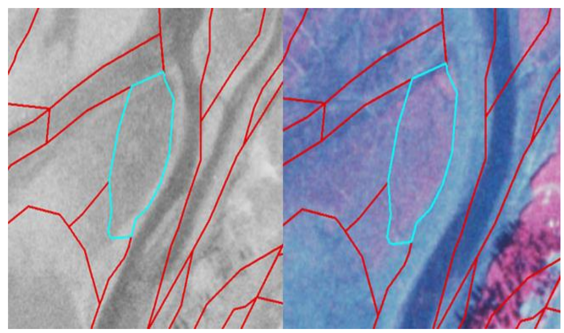

Figure 17. As seen in the blue outlined area Vegetation Development/Expansion in Intertidal Area in Silver Salmon Creek from 1950(left) to 1980(right) at a scale of 1:2,000.

Table 20. Summary of land change from 1980 to 2010 in Shelter Creek.

| Change Code from 1980 to 2010 | Area(ha) | Percent Area |
|---|---|---|
| No Change | 144.54 | 78.96% |
| Vegetation Development/Expansion in Intertidal Area | 12.24 | 6.68% |
| Vegetation Loss/Decrease in Intertidal Area | 10.65 | 5.82% |
| Mixed Forest Establishment | 4.24 | 2.31% |
| Wetland Creation | 4.05 | 2.21% |
| Channel Abandonment | 3.97 | 2.17% |
| Channel Formation | 3.37 | 1.84% |

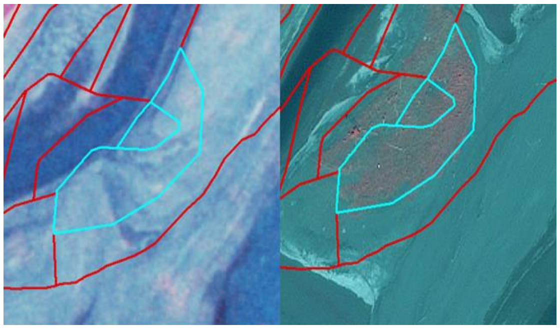

Figure 18. As seen in the blue outlined area, Vegetation Development/Expansion in Intertidal Area in Silver Salmon Creek from 1980 (left) to 2010 (right) at a scale of 1:2,000.

## Chinitna Bay

The most common landscape changes within Chinitna Bay Southwest between the 1950's and the 1980's can be seen in Table 21. The largest single landscape change was "Vegetation Development/Expansion in Intertidal Area", involving 14.92% of the area in Chinitna Bay Southwest (Figure 19). The cause of this change most likely was due to the tidal difference over time as the tied changed, this allowed for vegetation to grow in the nutrient rich mudflat. 78.77% of the landscape did not change.

Table 21. Summary of land change from 1950 to 1980 in Chinitna Bay South West.

| Change Code from 1950 to 1980 | Area(ha) | Percent Area |
|---|---|---|
| No Change | 682.03 | 78.77% |
| Vegetation Development/Expansion in Intertidal Area | 129.17 | 14.92% |
| Wetland Loss | 26.05 | 3.01% |
| Wetland Creation | 18.07 | 2.09% |
| Pond/Lake Formation | 7.24 | 0.84% |
| Pond Drying | 3.28 | 0.38% |

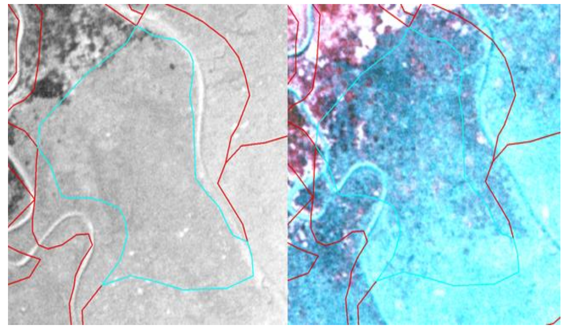

Figure 19. As seen in the blue outlined area, Vegetation Development/Expansion in Intertidal Area from 1950 (left) to 1980 (right) in Chinitna Bay South West.

Between the 1980's and the 2010's, the most common landscape changes are summarized in Table 22. The largest single landscape change was "Wetland Creation", involving 15.53% of the area in Chinitna Bay Southwest. Analysis demonstrated 73.66% of the landscape did not change.

The most common landscape changes within Chinitna Bay Northeast between the 1950's and the 1980's is presented in Table 23. The largest single landscape change was "Vegetation Development/Expansion in Intertidal Area", 17.46% of the area in Chinitna Bay Northeast. 72.99% of the landscape did not change.

Table 22. Summary of land change from 1980 to 2010 in Chinitna Bay South West.

| Change Code from 1980 to 2010 | Area(ha) | Percent Area |
|---|---|---|
| No Change | 637.75 | 73.66% |
| Wetland Creation | 134.50 | 15.53% |
| Vegetation Development/Expansion in Intertidal Area | 50.54 | 5.84% |
| Pond Drying | 19.96 | 2.31% |
| Wetland Loss | 17.61 | 2.03% |
| Pond/Lake Formation | 2.84 | 0.33% |
| Spruce Establishment/Expansion | 2.62 | 0.30% |

Table 23. Summary of land change from 1950 to 1980 in Chinitna Bay Northeast.

| Change Code from 1950 to 1980 | Area(ha) | Percent Area |
|---|---|---|
| No Change | 87.71 | 72.99% |
| Vegetation Development/Expansion in Intertidal Area | 20.98 | 17.46% |
| Mixed Forest Establishment | 11.37 | 9.46% |
| Aquatic Bed Formation/Expansion in Palustrine Area | 0.10 | 0.08% |

Between the 1980's and the 2010's, landscape change was significant (Table 24). The largest single landscape change was "Vegetation Development/Expansion in Intertidal Area", 26.69% of the area in Chinitna Bay Northeast (Figure 20). Analysis demonstrated 57.15% of the landscape did not change.

Table 24. Summary of land change from 1980 to 2010 in Chinitna Bay Northeast.

| Change Code from 1980 to 2010 | Area(ha) | Percent Area |
|---|---|---|
| No Change | 68.67 | 57.15% |
| Vegetation Development/Expansion in Intertidal Area | 32.07 | 26.69% |
| Mixed Forest Establishment | 19.43 | 16.17% |

Shelter Creek

The most common landscape changes within the Shelter Creek area between the 1950's and the 1980's are shown in Table 25. The largest single landscape change was "Channel Formation" (Figure 21), involving 3.53% of the area in Shelter Creek. 91.14% of the landscape did not change.

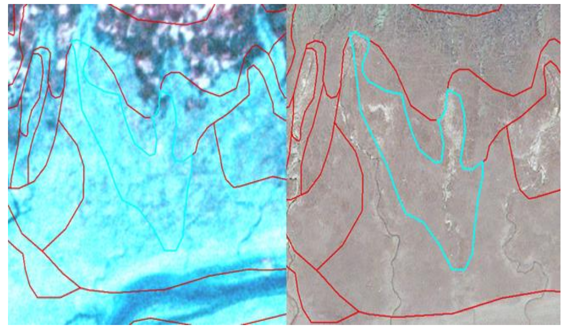

Figure 20. As seen in the blue outlined area, Vegetation Development/Expansion in Intertidal Area from 1980 (left) to 2010 (right) in Chinitna Bay North East.

Table 25. Summary of land change from 1950 to 1980 in Shelter Creek.

| Change Code from 1950 to 1980 | Area(ha) | Percent Area |
|---|---|---|
| No Change | 293.33 | 91.14% |
| Channel Formation | 11.37 | 3.53% |
| Vegetation Development/Expansion in Intertidal Area | 8.15 | 2.53% |
| Open Water Formation/Marine Intrusion | 1.90 | 0.59% |
| Pond/Lake Formation | 1.63 | 0.51% |
| Wetland Creation | 1.62 | 0.50% |

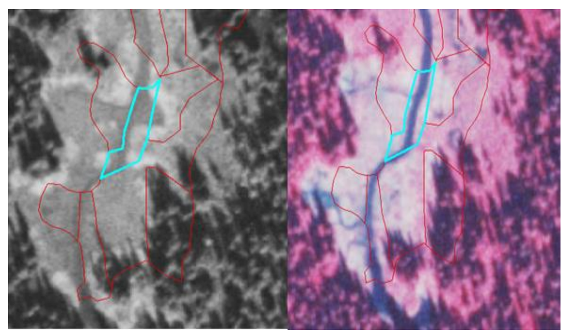

Figure 21. s seen in the blue outlined area Channel Formation in Shelter Creek from 1950(left) to 1980(right) at a scale of 1:2,000.

Changes between 1980's and the 2010's are contained in Table 26. The largest single landscape change was "Vegetation Development/Expansion in Intertidal Area" (Figure 22). This was 3.33% of the area in Shelter Creek. The analysis demonstrated that 91.48% of the landscape did not change.

Table 26. Summary of land change from 1980 to 2010 in Shelter Creek.

| Change Code From 1980 to 2010 | Area(ha) | Percent Area |
|---|---|---|
| No Change | 294.43 | 91.48% |
| Vegetation Development/Expansion in Intertidal Area | 10.70 | 3.33% |
| Coastal Subsidence/Flooding | 3.02 | 0.94% |
| Channel Abandonment | 2.97 | 0.92% |
| Pond/Lake Formation | 2.58 | 0.80% |
| Aquatic Bed Formation/Expansion in Palustrine Area | 1.74 | 0.54% |

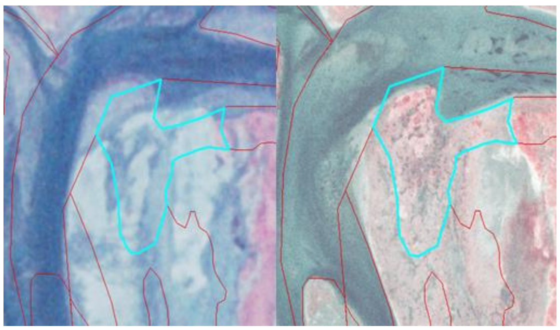

Figure 22. As seen in the blue outlined area, Vegetation Development/Expansion in Intertidal Area in Shelter Creek from 1980 (left) to 2010 (right) at a scale of 1:2,000.

## Discussion

Similar results were observed in all of the study areas, vegetation development and expansion in an intertidal area was the most common change occurring on average 12.05% of the time from 1950 to 1980 and 10.63% of the time from 1980 to 2010. Vegetation growth was more prominent from 1950 to 1980 then it was from 1980 to 2010.

As expected for both physiography and landscape formation the most common result was no change which occurred 72.63% of the time. The change codes that were assigned for each polygon were based on the landscape formation and how it changed between study periods. Because of this, the most common landscape formation change seen was the expansion of vegetation throughout the salt marshes, whether it was mudflat to mudflat and panne, or meadow to upland.

Although photointerpretation is a valuable tool in an analysis such as this it does have errors. Human error is the most common error; no matter how many people work on interpreting one photograph all the interpretations will be a little different. This is why this method would not be recommended for projects requiring extreme accuracy. But because LACL is looking for a general consensus of the salt marshes this method was ideal to help save time and resources for the project.

## Conclusion

The importance of these salt marshes to Alaska’s ecosystem is undeniably great due to their uniqueness. By better understanding how they change over time, it can help national park managers to better understand the health of these ecosystems with a goal of sustaining them for the future. This study shows that salt marshes change at different rates over varying intervals of time and that this change is represented in both specific physiography as well as landscape formation.

The most common change seen in this study was vegetation expansion which was likely caused due to the lack of tidal influence or channel creation/loss. Because the ocean tide is constantly changing, changes in the salt marshes are expected.

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