Rich Passage Long-Term Beach Monitoring: May to October 2021 Beach Response Report

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Executive Summary

Blue Coast Engineering (Blue Coast) has been contracted by Kitsap Transit to monitor the beaches within Rich Passage during the implementation of commercial service of the fast ferry M/V Rich Passage 1 (RP1) and subsequent vessels of the same class the M/V Reliance and M/V Lady Swift on the Bremerton to Seattle route. Beach photo observations and laser scanning surveys were completed in May and October 2021. Beginning in January 2005 and continuing through 2021, geo-referenced and time-stamped photographs were acquired approximately quarterly at several reference locations along the five sections of sensitive shorelines (Pleasant Beach, Point White, East Bremerton, Port Orchard, and Point Glover). Laser scanning surveys provide three-dimensional measurements of beach elevation over 500-foot-long sections on Point Glover, Point White, Pleasant Beach, and East Bremerton shorelines. The observations from the shorelines indicate that the seasonal and interannual patterns are consistent between 2017 to 2021, and years prior to vessel operations.

The 2021 measurements at Port Orchard and Pleasant Beach show small pockets of erosion and accretion which are consistent with years prior to vessel operations. East Bremerton also shows waves of sediment erosion and accretion, similar to those that have been identified previously at the site. Point White is the most dynamic shoreline reach (constantly changing) in the study area because of exposure to wind-waves and the lack of sediment supply to replenish sediment transported by wind-waves. Monitoring sites along Point White continue to exhibit long-term depletion of sediment as well seasonal cycles. Volumetric change analysis of beach elevations, as determined by laser scanning, at Point Glover and at Point White are within the typical seasonal and annual variability and no discernable change in the trend is apparent in the data over the past 9 years of monitoring.

The measurable beach response along the reaches monitored in 2021 cannot be correlated to Bremerton-Seattle Passenger Only Ferry (POF) operations. In other words, there is no correlation between the changes on the beaches and the beginning or changes to POF vessel operations in Rich Passage between 2017 and 2021. The beaches will be monitored again in May and October 2022 to record both the seasonal and interannual cycles of beach response during the sixth year of operation of Kitsap Transit Fast Ferry Service through Rich Passage.

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1.0 Introduction

Blue Coast Engineering (Blue Coast) has been contracted by Kitsap Transit to monitor the beaches within Rich Passage during the implementation of commercial service of the fast ferry M/V Rich Passage 1 (RP1) and subsequent vessels of the same class the M/V Reliance and M/V Lady Swift on the Bremerton to Seattle route. In accordance with the recommendation from the Rich Passage Wake Research conducted from 2004 to 2016, the service is being implemented with a phased approach to allow for continued monitoring and evaluation of beach response along the sensitive shorelines of Rich Passage (Golder 2013).

Commercial service began on July 10, 2017 with a preliminary level of service of 80 one-way trips per week. A summary of the operations since July 2017 is provided in Table 1. This report summarizes changes in operations and beach monitoring from January 2021 through December 2021. In 2021 Rich Passage class operation were at 130 one-way trips with the exception of the summer period when they were increased to 150 one-way trips, 6 days per week. In 2021, Kitsap Transit also added commercial service of a new vessel (M/V Enetai) operating between Southworth and Seattle with transit through Rich Passage from Bremerton each day (Table 2). The vessel operated between 20 to 22 one-way trips each week beginning on March 29, 2021.

Beach monitoring was conducted using ground-based geo-referenced photographs on May 26 and October 5, 2021, and laser scanning surveys on May 27 and October 10, 2021. See Figure 1 for the location of laser scanning areas and beach photo sites throughout the study area. This report documents the results of the 2021 beach monitoring and compares this data to baseline beach monitoring surveys recorded from 2004 to 2017 during intervals when RP1 was not operating and the first four years of operations from 2017 to 2020. The results provide insight into seasonal, inter-annual and long-term beach response trends.

Table 1. Rich Passage fast ferry operations service summary from 2017 through 2021.

Start Date	End Date	One Way Trips Per Week	Operation Days per Week
July 10, 2017	October 28, 2017	80	6
October 30, 2017	November 30, 2017	60	5
December 1, 2017	May 4, 2018	80	5
May 5, 2018	September 29, 2018	100	6
September 30, 2018	May 1, 2019	80	5
May 1, 2019	September 22, 2019	120	6
September 23, 2019	October 19, 2019	160	6
October 19, 2019	February 24, 2020	80	5
February 24, 2020	June 7, 2020	120	5
June 8, 2020	July 24, 2021	130	5
July 25, 2021	September 25, 2021	150	6
September 26, 2021	December 31, 2021	130	6

Table 2. M/V Enetai Rich Passage vessel transits summary in 2021.

Start Date	End Date	One Way Trips Per Week	Operation Days per Week
March 29, 2021	July 24, 2021	20	5
July 25, 2021	September 25, 2021	22	6
September. 26, 2021	December 31, 2021	20	5

2.0 Methodology

This section describes the methods used to collect measurements and observations to document the changes in beach morphology in May and October 2021 including beach response to operation of RP1. See Figure 2 for a timeline of beach observations documented in photographs and laser scanning surveys from 2013 through 2021.

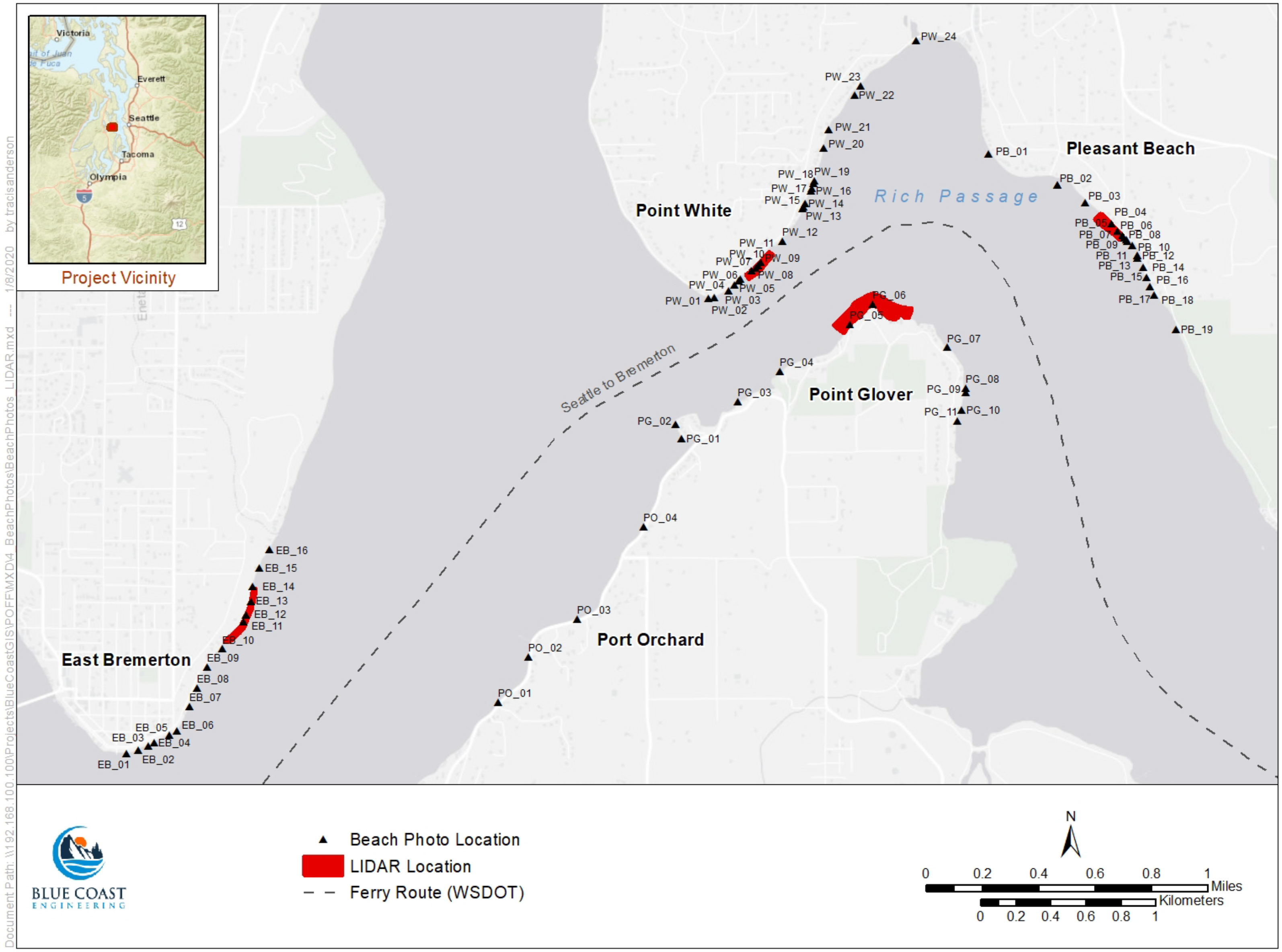

Figure 1. Beach photograph and laser scanning survey (LIDAR) locations along Bremerton to Seattle transportation route.

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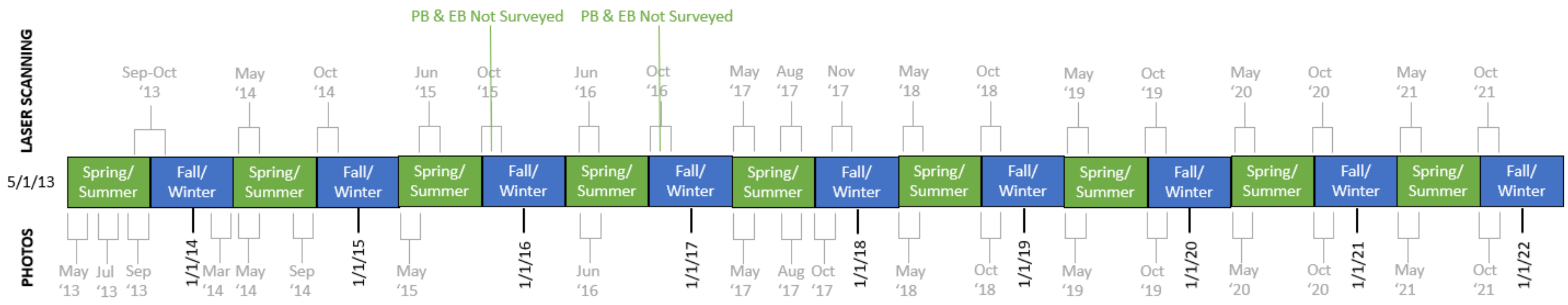

LEGEND
Fall/Winter = October through April   PB = Pleasant Beach
Spring/Summer = May through September   EB = East Bremerton

Figure 2. Timeline of beach photo observations and laser scanning surveys.

2.1 Beach Photo Observations

Observations of beach condition and beach elevations at bulkheads have been made along the shorelines of the Bremerton to Seattle ferry route since June 2004. Beginning in January 2005 and continuing through 2018, geo-referenced and time-stamped photographs were captured approximately quarterly at several reference locations along the five sensitive shoreline sections (Pleasant Beach, Point White, East Bremerton, Port Orchard, and Point Glover). The resulting time series of photographs and beach elevations relative to bulkheads for each shoreline have been analyzed in a series of reports:

1. Baseline beach photo observations in 2005 to 2012 were analyzed and documented as part of the Rich Passage Wake Research (Golder 2013).
2. Additional baseline beach photographs recorded from 2013 through May 2017 (performed to document the seasonal and annual changes in the beach morphology prior to commercial operation of RP1) were analyzed in Year 1 of the Long-Term Beach Monitoring Program (Confluence 2017).
3. Beach response to RP1 from May to November 2017 were recorded and analyzed during Year 1 of the Long-Term Beach Monitoring Program (Confluence 2018).
4. Beach response to RP1 from May to October 2018 were recorded and analyzed during Year 2 of the Long-Term Beach Monitoring Program (Blue Coast 2020a).
5. Beach response to RP1 from May to October 2019 were recorded and analyzed during Year 3 of the Long-Term Beach Monitoring Program (Blue Coast 2020b).
6. Beach response to RP1 from May to October 2020 were recorded and analyzed during Year 4 of the Long-Term Beach Monitoring Program (Blue Coast 2021).

The beach photographs presented in this report were recorded on May 26 and October 5, 2021 to characterize the changes in beach morphology during the fifth year of Bremerton-Seattle Fast Ferries commercial scale operations.

Appendix A contains beach photograph observations and measured elevations at the interface between the beach and bulkhead recorded during intervals without fast ferry operations from 2014 through May 2017 and intervals with Fast Ferries operations from July 2017 to October 2021. Each time series in Appendix A shows a photo from the spring and fall of each year in which they are recorded; the photo dates, a map of the photo locations, and a graph of relative elevation of the beach measured at the toe of the bulkhead as compared to the first elevations recorded in 2005. Measurement sites were strategically selected to determine the overall trends within different littoral drift cells. At some sites, photographs were recorded, but the relative elevation of the beach was not measured. Therefore, there is no graph of relative beach elevation for some sites, and changes in the beach are noted qualitatively.

2.2 Laser Scanning Surveys

eTrac Inc. has performed laser scanning surveys in Rich Passage semi-annually in May and October since 2011. These surveys provide three-dimensional measurements of beach elevation over 500-foot-long sections. On May 27 and October 10, 2021, eTrac performed laser scanning topographic surveys of four shorelines with a Riegl VZ400 scanner mounted on board the MV Especial vessel. Laser scanning survey sites are located on Point Glover, Point White, Pleasant Beach, and East Bremerton shorelines. Appendix B contains the report of this work, which includes details of the methods used, locations surveyed, and the quality control and post-processing performed. Sea conditions and a motion sensor failure resulted in “striping” of the elevation dataset collect in May 2021. Post-processing techniques were used to smooth the striping at all the sites except Point White. However, the remaining striping does not appear to change the overall ability to interpret the results at Point White.

The survey results are files containing latitude, longitude, and elevation (*.xyz) in a resolution of 0.25 feet (ft) by 0.25 ft. These files provide the coordinates and elevations for points collected during the survey in horizontal datum Washington State Plane North feet and vertical datum North American Vertical Datum 1988. These xyz files were converted to raster files using ArcGIS. Blue Coast used these raster files for all analysis presented in this report. For datasets where previous analysis was completed by others (Golder 2017), Blue Coast visually compared the datasets to evaluate methodology and results.

Raster files for spring surveys (May) were subtracted from fall surveys (October or November) to determine summer elevation change for two summer intervals prior to RP1 service (2013 and 2014) and five summer intervals with RP1 service (2017, 2018, 2019, 2020, and 2021). The resulting maps are clipped to include only changes in beach surface elevations. There may be some high value changes (darker red or blues) near the beach/upland interface that are artifacts of overhanging vegetation or complex shoreline armoring structures that are not measured consistently from survey to survey. Beach photo observations were used to determine if large changes in beach elevation shown adjacent to structures were real or were artifacts of the survey method.

The same process as described in the above paragraph was completed to determine the beach change on an annual basis; for this metric, the raster file for the fall survey from one year was subtracted from the fall survey for the next year. Annual beach change was calculated for at least one year without RP1 operations (2013 and/or 2014) and the most recent 3 full years with RP operations: November 2018 to October 2019, November 2019 to October 2020 and November 2020 to October 2021. Data recorded in 2017 and 2018 are available in previous beach monitoring reports (Blue Coast 2020a; Blue Coast 2020b).

At Point White and Point Glover, additional analysis was conducted to calculate the total volume of beach change that occurred during the summer seasons because the most noticeable change was observed at these sites. The total volume of change is the summation of all beach change (positive and negative) within a subset of the survey area, which was consistently surveyed in all years. The error associated with the volume change was calculated as twice the root sum of squares of the standard deviation of the survey (using a maximum of 0.10 ft) across the subset of the survey area (Schmid et. Al, 2014):

$$Volume\ error\ (one\ dataset) = 2 * \sqrt{Area * 0.1^2}$$

Two standard deviations have a 95% confidence interval, assuming the data fits a normal distribution, which is typical for open terrain laser scanning data. Table 3 provides a summary of the subset of survey areas, including the error associated with the volume change calculation. For reference, the volume of 1-inch-thick sediment across for the subset of the survey area where volume change was calculated is also provided. The potential error in volume calculations is small relative to the size in the survey area. Updates to the calculation methodology in 2020 (Blue Coast 2021) resulted in small changes to the volume change calculation results reported in previous years (Blue Coast 2020a; Blue Coast 2020b).

Table 3. Volume change area statistics.

Survey Area	Size (sq. feet)	Error Volume Change Calculation (cubic yards)	1-inch Thickness Volume (cubic yards)
Point Glover East	32,500	3.8	100
Point White North	25,500	3.3	78
Point White South	12,000	2.3	37

Note: [1]Represents volume of material 1-inch thick across enter volume change survey area

3.0 Beach Response Results

The beaches in Puget Sound are comprised of sediment derived from the erosion and re-working of landslides and sloughing from coastal bluffs and discharge from small streams. These sediment supplies are episodic in nature and depend on larger scale processes such as the amount of precipitation and upland land use activities. The beach morphology (slope and form) and sediment transport patterns along the shorelines in Puget Sound are controlled primarily by wind-wave attack along the middle to upper intertidal portion of the beach which transports mixed sand and gravel. Coarser sediments often found lower on the beach are mobilized during larger, more energetic storm events (Finlayson 2006). In addition, beach morphology along major transportation routes and in confined waterways of Puget Sound can be affected by vessel wakes.

Beaches are dynamic systems and change seasonally as well as annually and even longer time scales. A study of Puget Sound beaches suggest that beaches should be monitored for at least five years to observe the dynamic characteristics of the beaches (Finlayson 2006). The baseline studies of beach change conducted for the Rich Passage Wake Research Program between 2005 and 2016 have shown beaches along the Bremerton to Seattle ferry route exhibit change on an approximate four-year cycle (Golder 2013; Golder 2017a).

Sediment moves along the shorelines of Puget Sound within a littoral drift cell driven primarily by wind-wave energy. A littoral drift cell is stretch of shoreline where sediment moves alongshore until there is a divergence in drift typically at a major point or embayment where there is a change in the exposure of the shoreline to wind-waves. Sediment transport at any single location in a drift cell has an effect on and can be affected by changes to sediment transport at other locations within the drift cell.

Extensive research has been conducted over the last 10 years on the impact of shoreline erosion control structures (bulkheads) on the marine ecosystem in Puget Sound. Bulkheads placed below mean higher high water (MHHW) have shown to have direct negative impacts on sediment composition, wrack and wood accumulation, and fish usage (Dethier et al 2016). Bulkheads placed at any elevation impound sediment which would otherwise be contributing to the dynamic beach system (Shipman 2010; Dethier et al 2016). Drift cells with extensive armoring show an overall reduction in sediment within the cell, particularly updrift (in the direction of transport) of bulkheads (Dethier et al 2016). This means that bulkheads built along the shoreline interfere with coastal processes, can increase erosion, and reduces or sometimes eliminates the sediment available to replenish the beaches.

The beaches along the five shorelines of East Bremerton, Point White, Pleasant Beach, Port Orchard, and Point Glover exhibit some similar geomorphic patterns, as well as some important differences. Most of the beaches are backed by bulkheads; these bulkheads vary in construction and location with respect to tidal water elevations, but most are below MHHW. The beach slopes in front of the bulkhead along Point White, East Bremerton, and Port Orchard are typically steep with gravel overlying mixed sand and gravel that varies in thickness and grain size with increasing distance from the bulkheads. The beach slopes along Pleasant Beach are typically more gently sloping, and the sediment grain sizes are smaller, containing more sand and shell hash than the beaches on the adjacent shoreline of Point White. Beaches along Point Glover are pocket beaches bounded by bedrock outcrops and headlands; these beaches are composed of loose sand, silt, and broken shell overlying a hard-bottomed mudstone terrace. The pocket beaches tend to be gently sloping where there is sand, but transition abruptly to deep water where the bedrock outcrops dip seaward.

The condition of each of these beaches can be observed in the beach photo observations in Appendix A. The beach elevation changes at laser scanning survey sites during the summer are plotted as color contour maps, in which red colors represent erosion and blue colors represent accretion, and the darker color indicates a larger amount of erosion or accretion.

The results presented in the sections below describe the changes in beach morphology of each shoreline from May to October 2021 and relative to the October 2020 survey. The observations are compared to beach response patterns that have been observed from 2005 to 2020 through beach photo observations and 2011 to 2020 through laser scanning surveys. A series of technical reports submitted to Kitsap Transit have documented the seasonal and annual variability during the interval of 2012 to May 2017 when RP1 was not operating (Golder 2013, 2015, 2016, 2017a, 2017b; Confluence 2017, 2018).

3.1 East Bremerton

The beaches along East Bremerton tend to be coarse and depleted of sediment on the southern end of the shoreline as observed at sites EB_01 through EB_04 (Figure 3 and Appendix A, Figures A-1 through A-4). The beach elevations at these sites have gradually decreased since 2005 and experience small seasonal fluctuations of +/- 0.25 to +/- 0.5 ft (Golder 2013). Monitoring of beaches along East Bremerton in 2021 showed similar patterns at these sites, with a majority of the sites decreasing in beach elevation year-to-year. Three of the four sites along East Bremerton were lower in October 2021 compared to 2020, only EB_02 increased in elevation (by approximately 0.25 ft). All elevation changes at EB_01 to EB_04 were less than 0.25 feet.

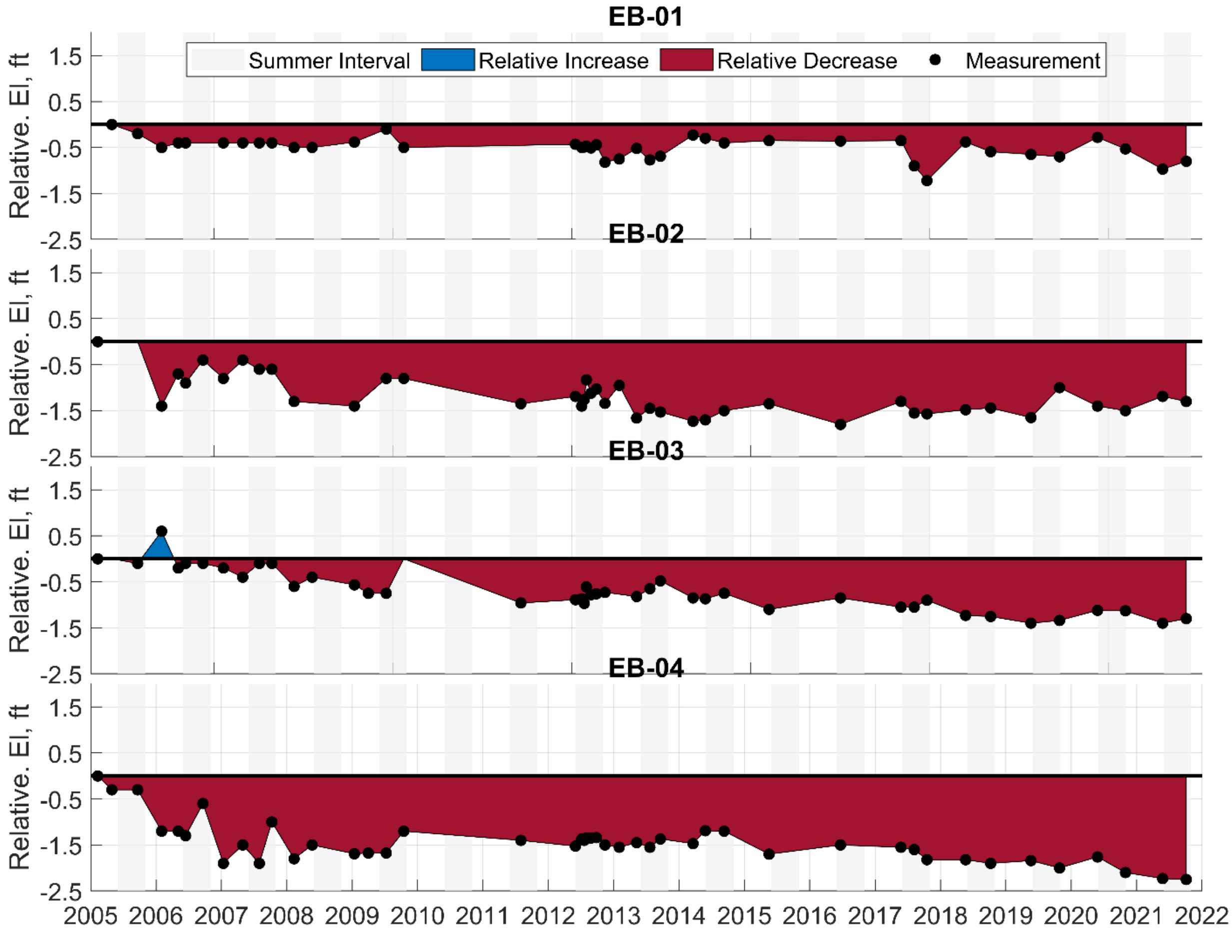

Figure 3. Time series of relative beach elevation from 2005 through 2021 at beach photo survey sites EB_01 to EB_04. Blue indicates accretion relative to the 2005 starting point and red indicates erosion relative to the 2005 starting point.

East Bremerton sites EB_05 through EB_16 (Appendix A, Figures A-5 through A-16) are mixed sand and gravel beaches that exhibit seasonal fluctuations from 0 to 1.0 ft. Beach photo observations at sites EB_05 through EB_13 show changes in beach elevation of less than 0.75 ft between October 2020 and October 2021. The largest change occurred at EB_15 which decreased 0.75 ft. A summary of the year-to-year elevation change at the beach bulkhead interface (October 2020 to October 2021) is provided for each observation site below:

- EB_06: 0.25 ft decrease
- EB_07: no change
- EB_08: 0.50 ft decrease
- EB_09: 0.25 ft increase
- EB_12: 0.25 ft decrease
- EB_13: 0.25 ft decrease
- EB_14: 0.5 ft decrease

- EB_15: 0.75 ft decrease
- EB_16: no change

The map of laser scanning survey differences for one-year intervals from 2013 to 2021 (Figure 4) shows that the beach experienced minimal net change (15 cubic yards [CY]) from 2020 to 2021, with small waves of sediment moving obliquely to the shoreline (illustrated by the pattern of elevation increase (red) and decrease (blue) across the scanned area. The areas of the greatest decrease in elevation up to 1 ft (dark red) occurred on the upper beach near the toe of structures. The map of laser scanning survey differences for the summer interval at East Bremerton (Figure 5) shows a similar pattern as the annual difference map, but with less pronounced waves (less than 0.5 ft of elevation change) of sediment. The summer interval also shows more accretion of sediment on the upper beach in comparison to the annual interval when mostly erosion occurred on the upper beach. The net change in sediment over the summer interval was a decrease of 46 CY.

All beaches which are measured within the study area along the Bremerton to Seattle ferry route fluctuate on the order of +/- 0.5 feet annually or interannually (Golder 2013b). Most beaches within the study area exhibit seasonal variation where the elevations are the lowest in the spring after winter storm events and highest in the fall after recovering through the summer. In 2021, the beaches along East Bremerton followed this pattern, with 10 of 13 monitoring sites decreasing in elevation through the winter and 9 of 13 increasing in elevation through the summer.

While not all beaches on East Bremerton responded the same, the patterns of beach response are consistent with historical observations in magnitude (elevation change) and spatial extent (location). This is readily evident by comparing laser scanning survey difference maps from 2021 to the interval prior to operations in 2013 to 2014 (Figures 4 and 5).

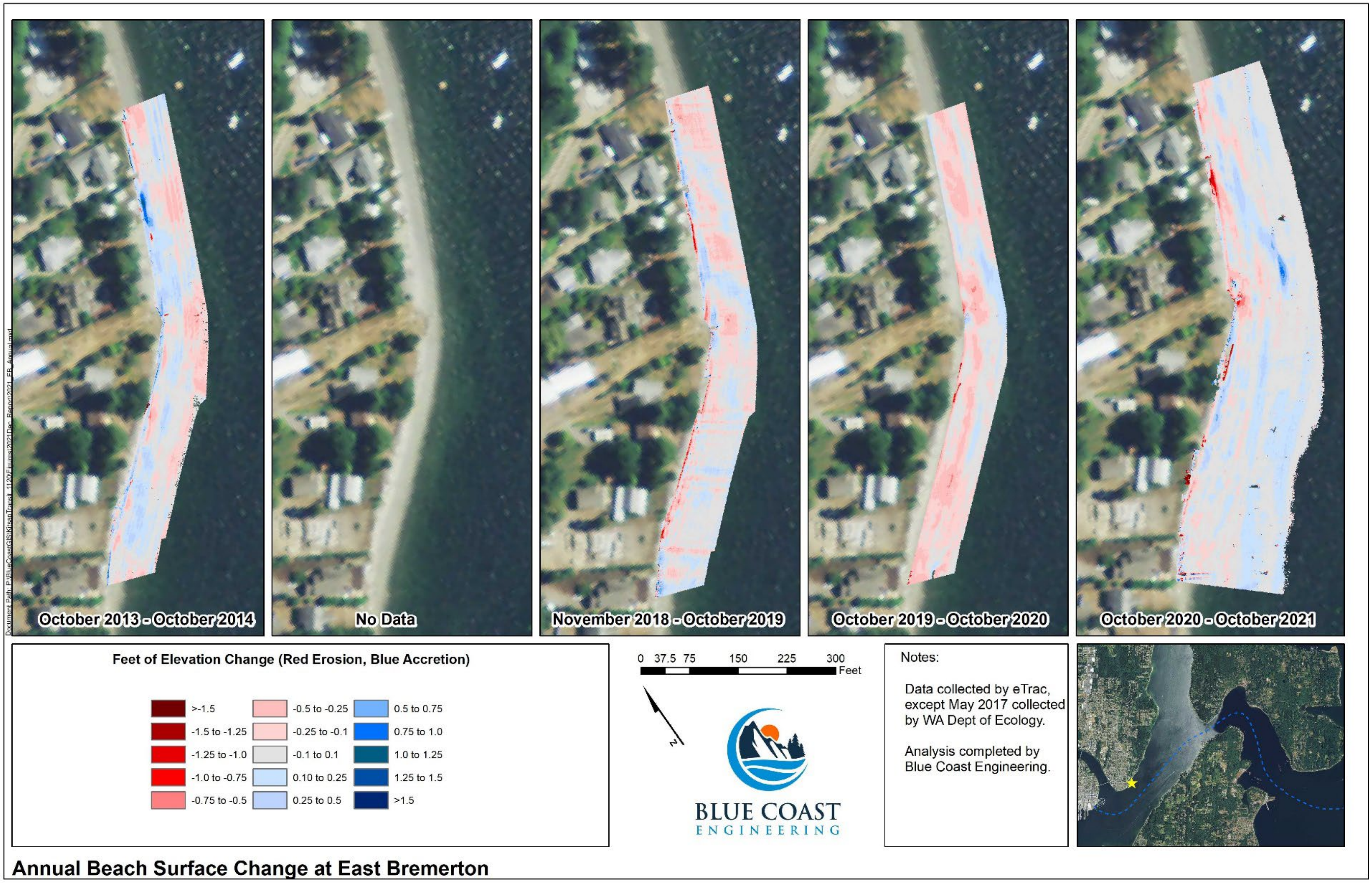

Figure 4. East Bremerton annual elevation change from 2013 to 2014, from 2018 to 2019, 2019 to 2020, and 2020 to 2021.

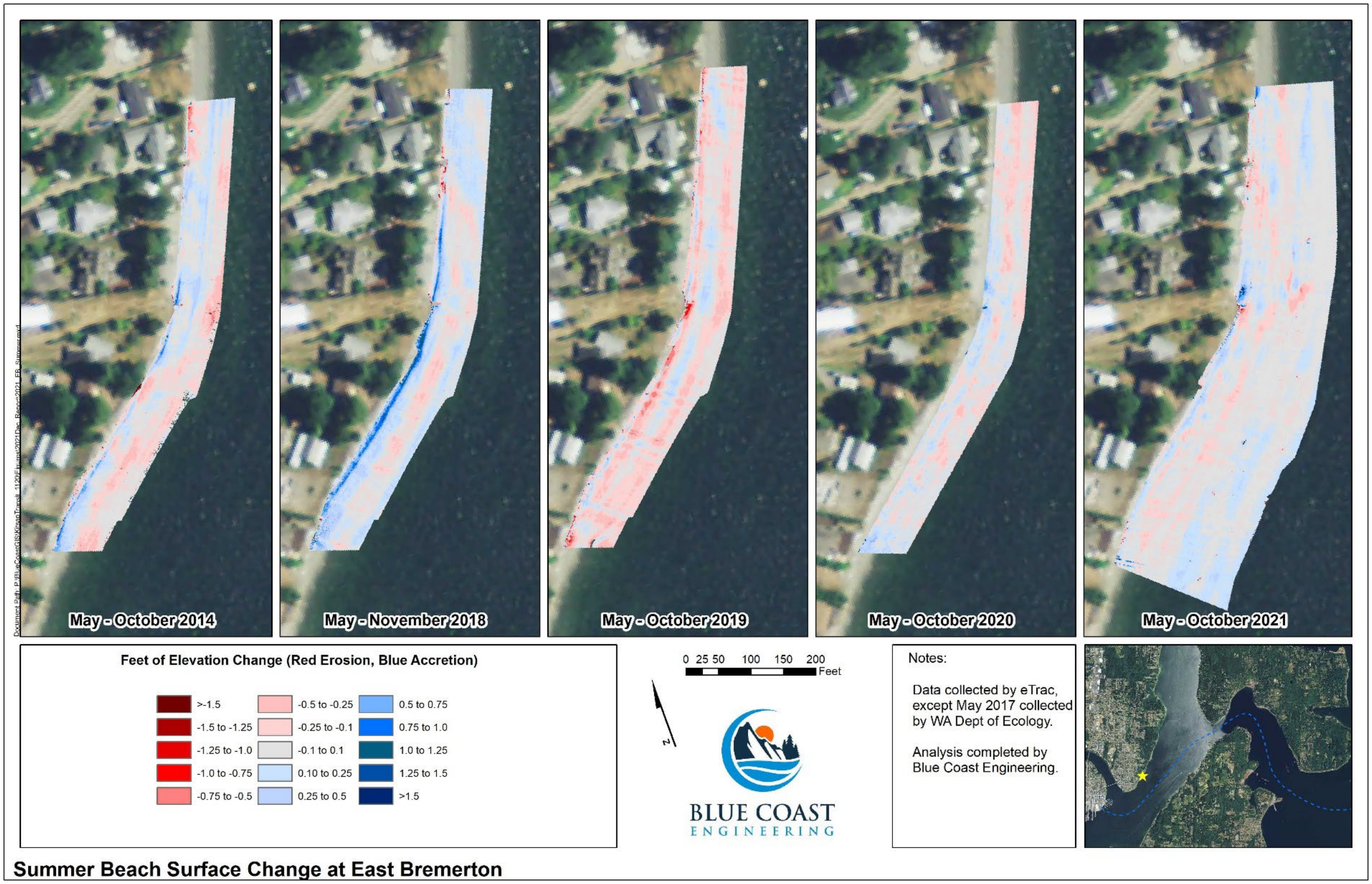

Figure 5. East Bremerton summer elevation change in 2014, 2018, 2019, 2020, and 2021.

3.2 Pleasant Beach

The beaches along Pleasant Beach are composed of mixed sand and gravel and exhibit seasonal variability ranging from +/- 0. 25 ft to +/- 0.5 ft (Golder 2013). Figure 6 (see also Appendix A, Figures A-17 through A-35) shows time series of beach elevation from 2014 to 2021 (relative to the first survey in 2005) at all observation sites along Pleasant Beach and highlights the small variability at these sites over several years. The largest changes have occurred at PB_06, which increased 0.75 ft after reaching its lowest point since 2005 in 2020. At PB_09 the beach elevation increased 0.5 ft from 2020 to 2021, while at PB_10 the beach elevation decreased 0.5 ft from 2020 to 2021. Overall, 8 of 11 monitoring sites recorded beach elevation increases year-to-year from 2020 to 2021.

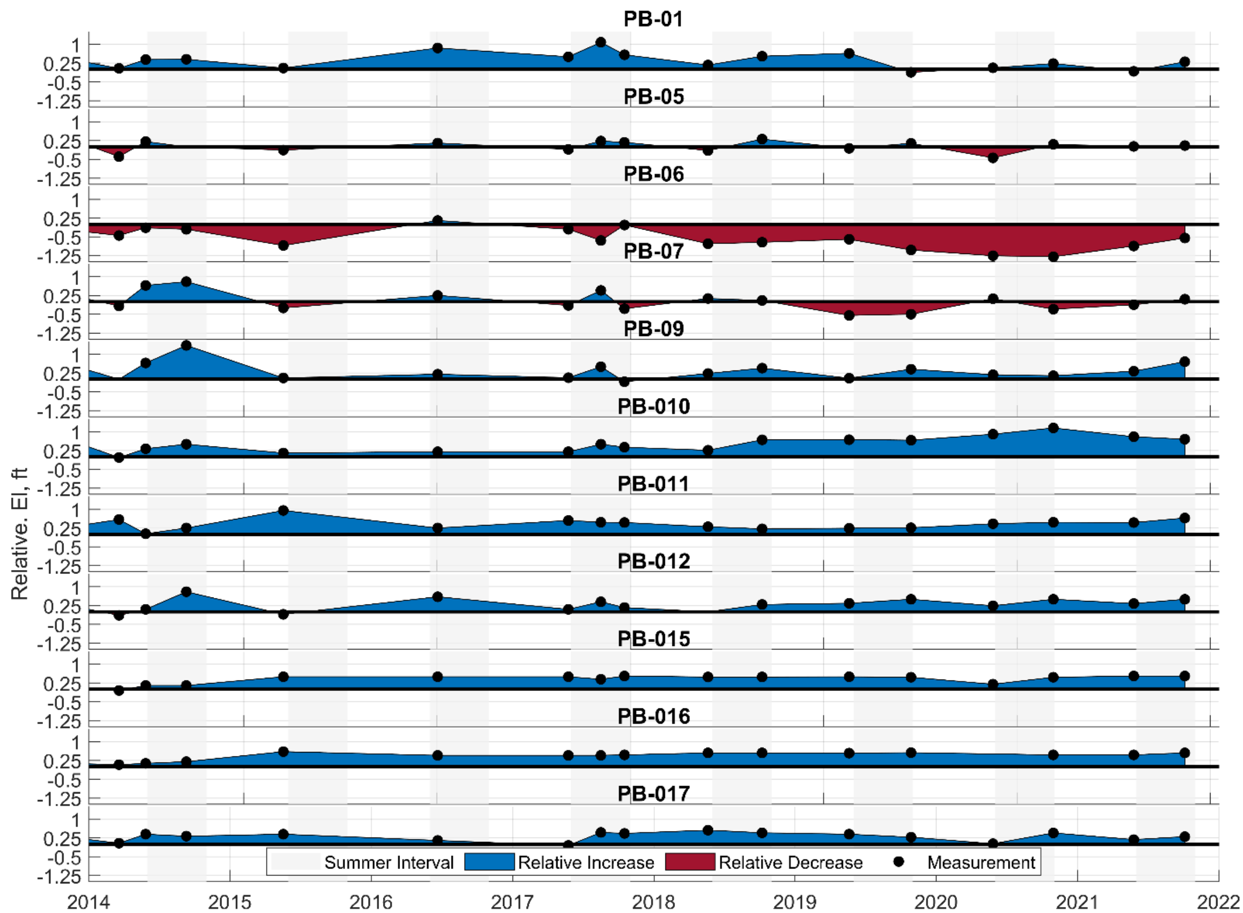

Figure 6. Time series of relative beach elevation from 2014 through 2021 at all beach photo survey sites along Pleasant Beach. Blue indicates accretion relative to the 2005 (not shown) starting point and red indicates erosion relative to the 2005 starting point.

The map of laser scanning survey differences for the one-year interval from October 2020 to October 2021 at Pleasant Beach (Figure 7) shows a few small areas of erosion (<0.5 ft) on the upper beach and mostly accretion (<0.5 ft) across the entire surveyed beach. The same map for the summer interval (Figure 8) shows mostly accretion across the beach, with some minor erosion (<0.25 ft) at the south and north ends of the survey area. The laser scanning survey results are consistent with the measurements at the nearby beach photo sites which predominantly measured increases in beach elevation.

The comparison of summer elevation changes over four years (2014, 2018, 2019, and 2020) shows that beach elevation changes in 2021 were consistent in (elevation change) and spatial extent (location) with previous years, including May to October 2014, when Rich Passage Class vessels were not operating.

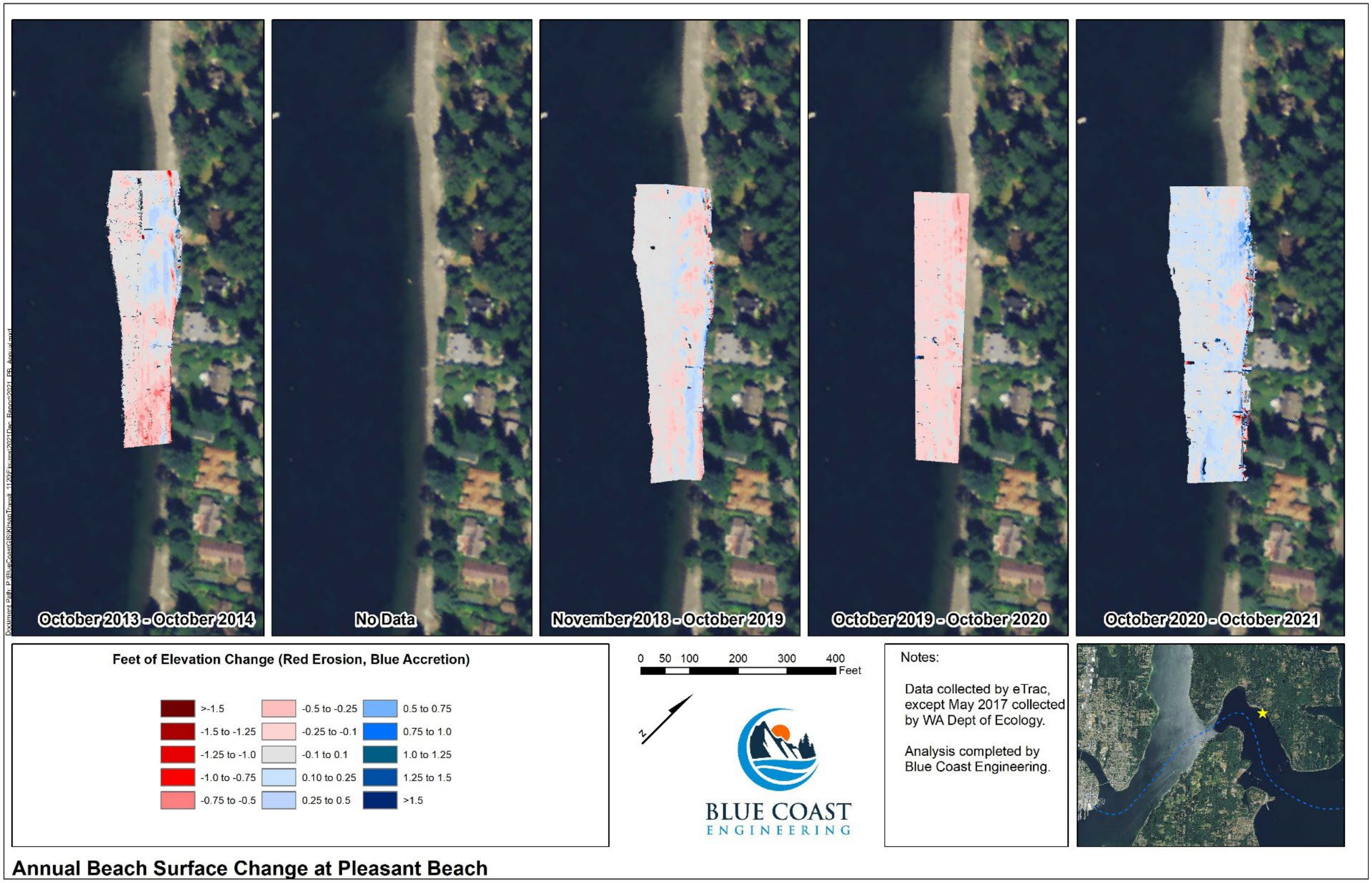

Figure 7. Pleasant Beach annual elevation change from 2013 to 2014, from 2018 to 2019, 2019 to 2020, and 2020 to 2021.

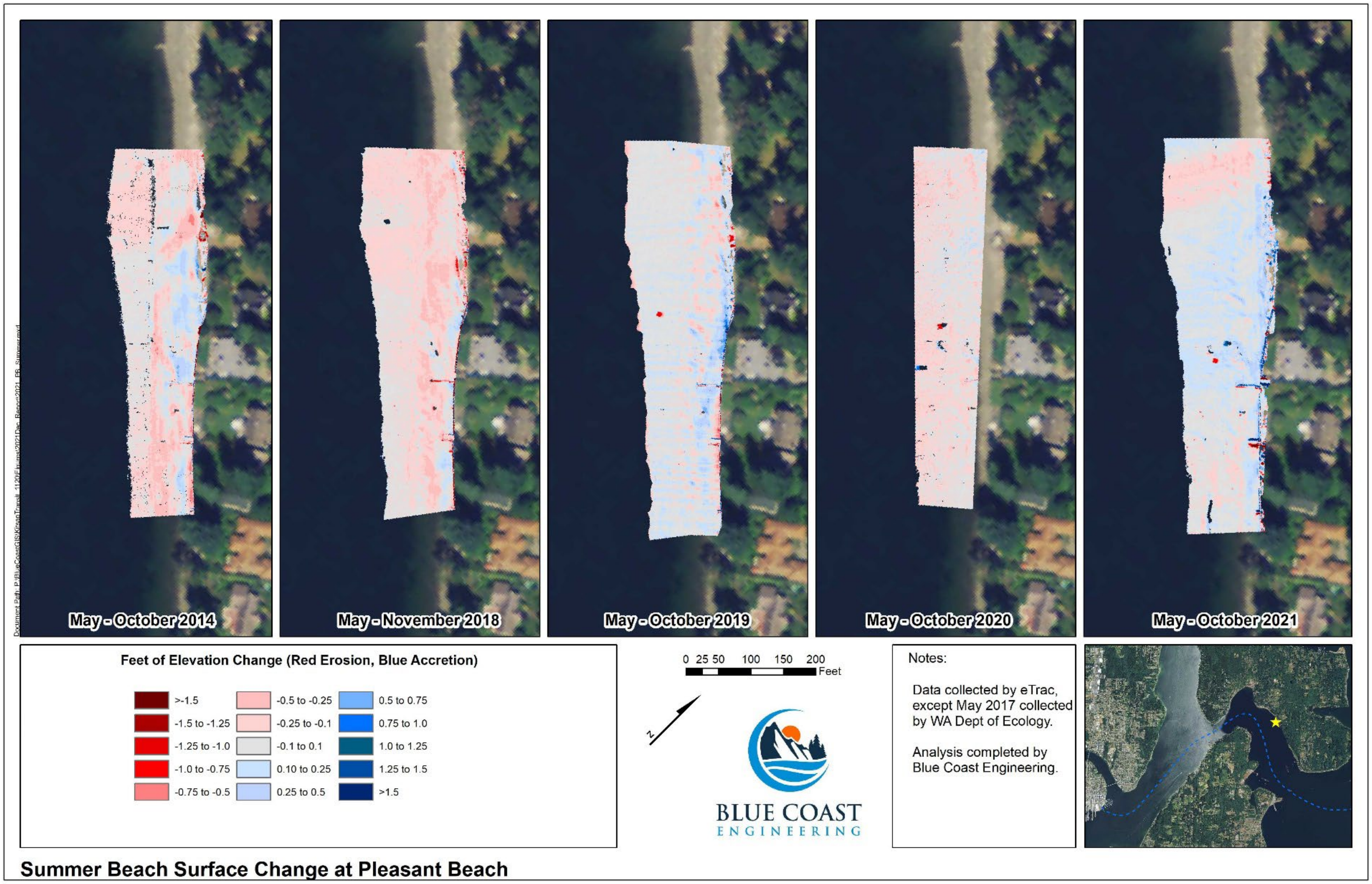

Figure 8. Pleasant Beach summer elevation change in 2014, 2018, 2019, 2020, and 2021.

3.2 Point Glover

The beaches along Point Glover are composed of loose sand, silt, and broken shell overlying a mudstone hard bottom. These beaches form in pockets between outcrops of bedrock and harder mudstone, which protrude into the intertidal zone and limit along-shore sediment transport. The beaches at the interface with bulkheads exhibit a seasonal variability ranging from +/- 0. 25 ft to +/- 0.5 ft as observed in the beach photo observations (Appendix A, Figures A-36 to A-46). Lower portions of the beach in the intertidal zone vary in elevation on a seasonal basis by as much as +/- 1.5 ft as observed in the laser scanning difference plots (Figures 9 through 12).

The changes in beach elevations within the pocket beaches of Point Glover vary from beach to beach depending on local effects. The sediment within the pocket beaches on the west side of Point Glover tends to shift back and forth seasonally due to wind-waves in the winter and vessel wakes (from all size and class of vessels) in the summer. The net change in beach elevation over a one-year interval because of these shifts in sediment is typically on the order of +/- 0.5 ft on the west side of Point Glover. From 2020 to 2021, the map of laser scanning survey differences (Figure 9), shows minor erosion or negligible change across most of the upper beach (<0.25 ft elevation change). Minor accretion is also visible on the north side of the three shore-perpendicular groins in the survey area. The map of laser scanning survey differences for the summer interval (Figure 10) shows higher amounts of change in the beach elevation across the site compared to the annual difference survey. Accretion (up to 1.0 ft) is visible to the north of the groins and downdrift of the southern-most groin erosion (up to 1.0 ft) is visible. The magnitude of change in the summer difference survey is greater than in previous years, however the annual difference survey is consistent with the results from the previous years. This indicates the changes in the winter (October 2020 to May 2021) were opposite and approximately equal to the slightly greater transport observed in the summer (May 2021 to October 2021), and therefore the net annual change is similar to other years.

At the east Point Glover laser scanning survey site (a small pocket beach), the map of elevation differences shows an area of accretion of sediment on the upper beach (blue) with an increase in elevation of 0.5 to 1.0 ft (Figures 11 and 12) over the summer interval. Over the one-year interval, the map of elevation differences shows erosion on the upper beach (red) with a decrease in elevation of 0.5 to 1.25 ft. This is opposite the trend in past annual intervals at the site in which accretion occurred over the same interval. Localized accretion on the upper beach (dark blue) has been associated with a creek outlet, where sediment accumulates at the mouth of the creek during the summer and is then dispersed throughout the pocket beach during high creek flows and storms in the fall and winter (Golder 2015, 2016, 2017a,b). The erosion documented in the annual difference survey on the upper beach may be a result of an exceptionally wet September and October in 2021, resulting in high runoff and erosion of the upper beach. In the same area, erosion low on the beach during the summer (red), is typically replenished with sediment over the winter from the process described above, however, in 2021 this process started earlier in the fall than previous years. This cycle is also observed in the photo surveys at PG_06 (Figure A-41).

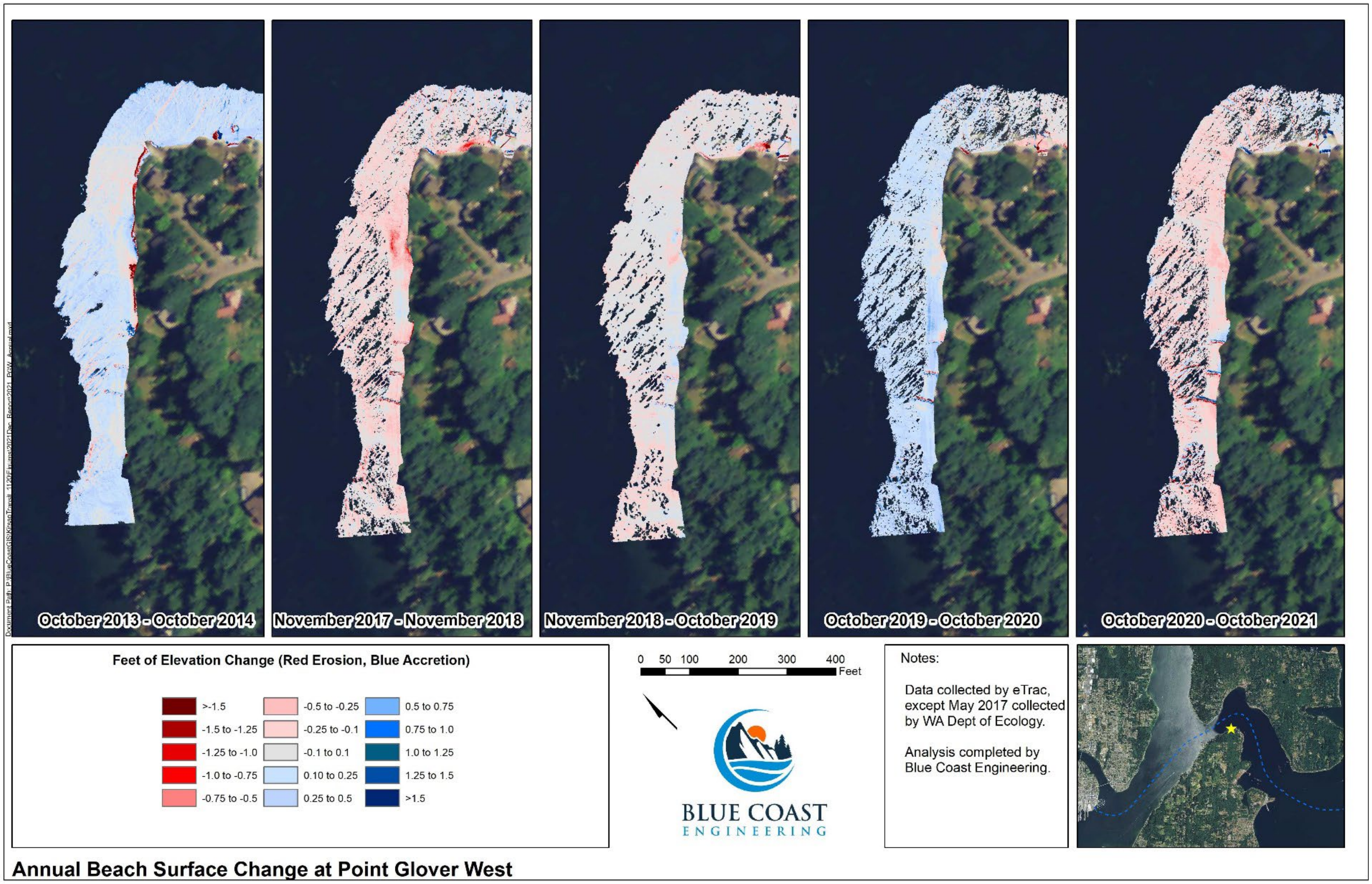

Figure 9. Point Glover West elevation change over five 1-year intervals from 2013 to 2021.

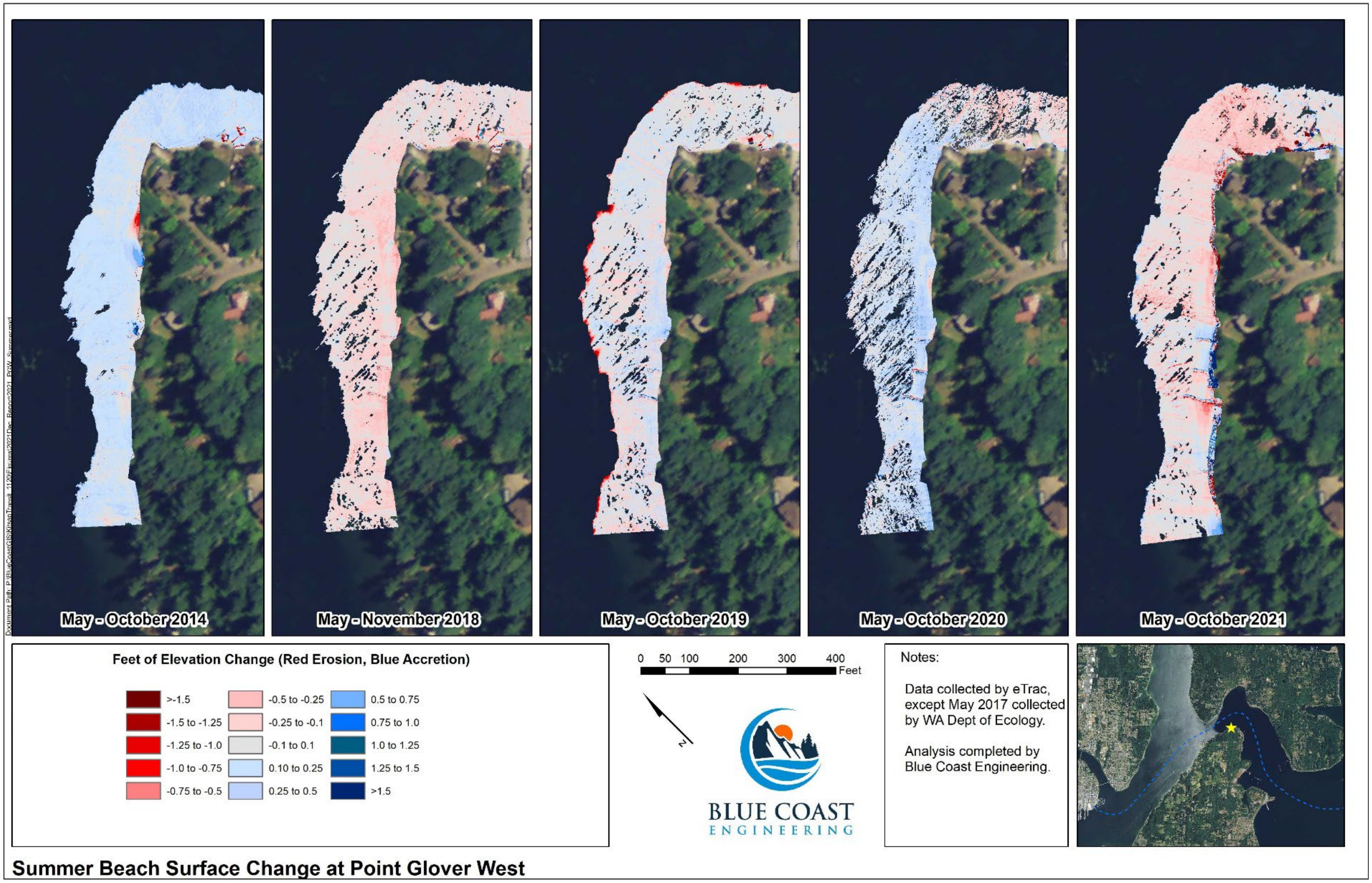

Figure 10. Point Glover West summer elevation change in 2014, 2018, 2019, 2020, and 2021.

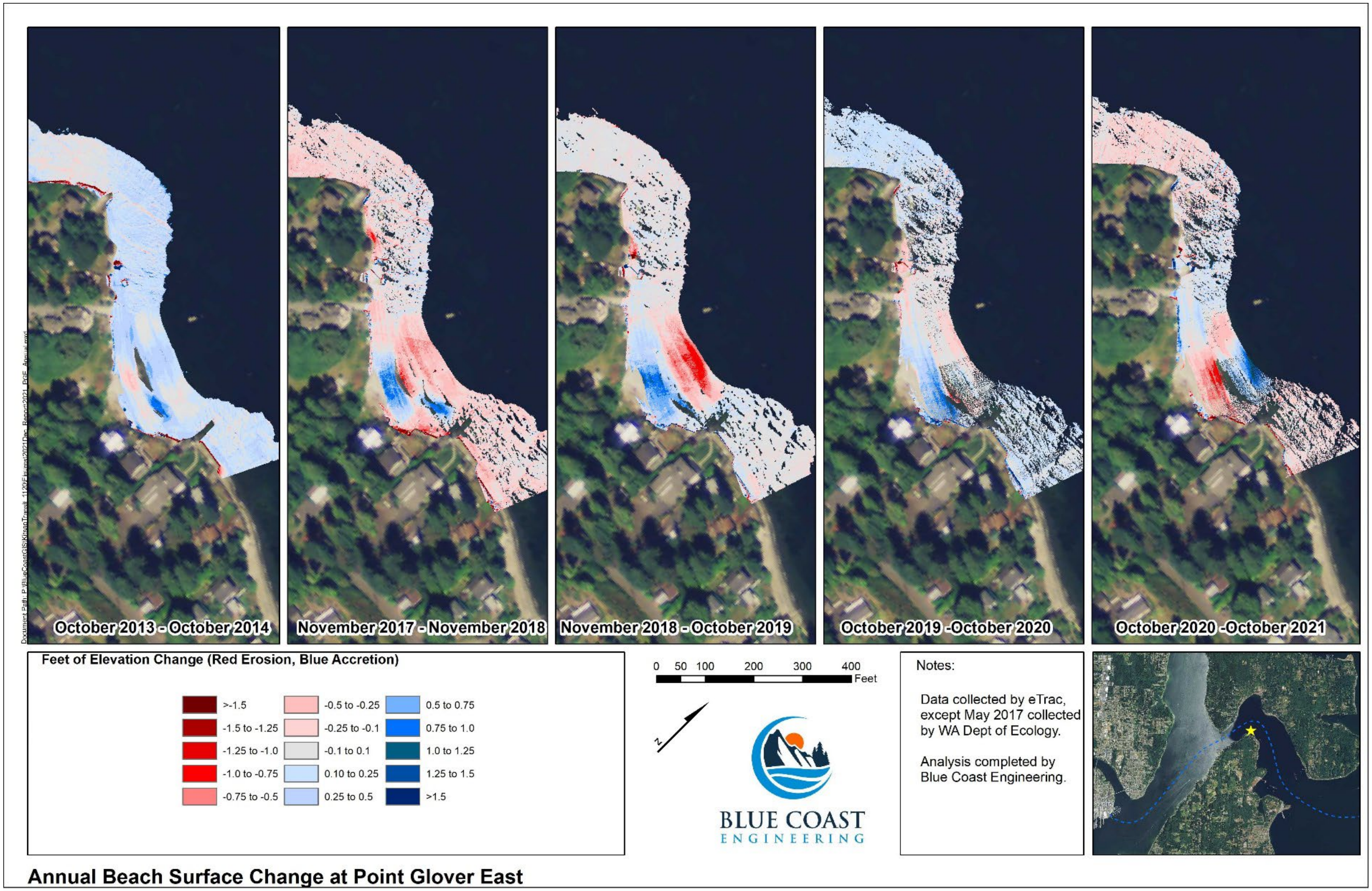

Figure 11. Point Glover East change over five 1-year intervals from 2013 to 2021.

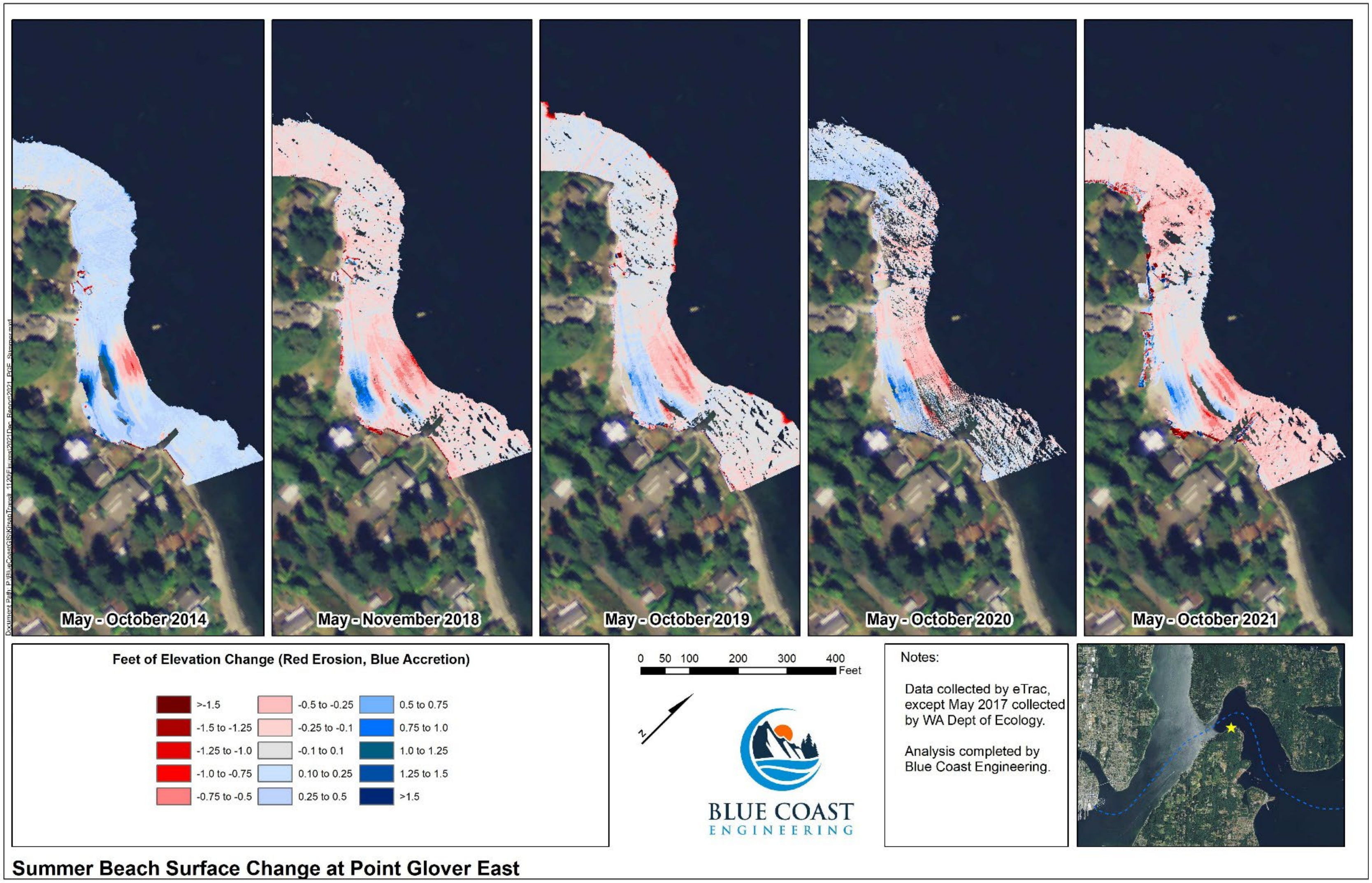

Figure 12. Point Glover East summer elevation change in 2014, 2018, 2019, 2020, and 2021.

Figure 13. Area of Point Glover East where volume changes were calculated.

The magnitude and spatial extent of the erosion and accretion patterns along the east side of Point Glover vary extensively from year to year (Figures 11 and 12). To quantify and better understand the geomorphic patterns, Blue Coast conducted further analysis to calculate the total volumetric change within a subset of the survey area (Figure 13). The results of this analysis are shown in Figure 14; a positive number indicates net increase in volume within the calculation area and a negative number indicates net decrease in volume.

The total beach volume change between May and October 2021 (summer interval) was a net loss of 57 cubic yards (CY), compared to a net decrease of 62 CY during the summer interval in 2020. The volume change is consistent with the magnitude of volume decrease which occurred in 2013, 2016, and 2020. On an annual basis the volume change was a net loss of 48 CY which is a larger decrease than in 2020 but within the range of change during previous years (2014-2015 and 2017-2018).

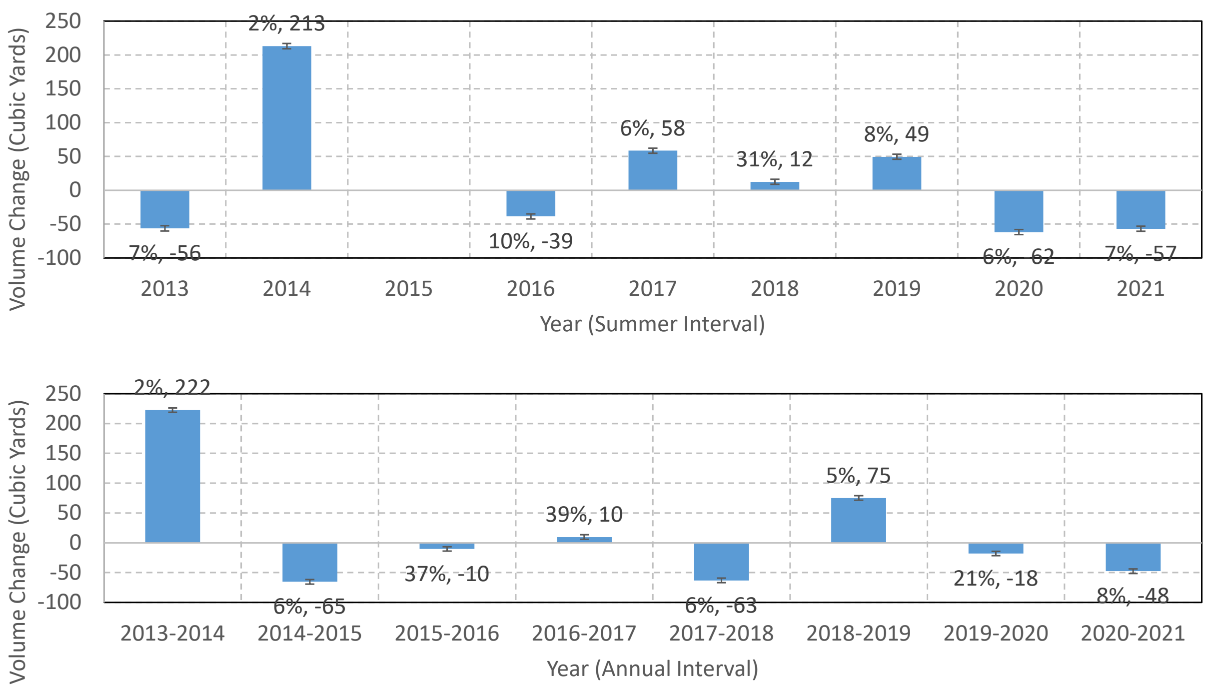

Figure 14. Volume change (cubic yards) in calculation area at Point Glover East. The volume change and error as a percent of the total change are shown for each measurement.

3.3 Port Orchard

The beaches along Port Orchard tend to be coarse and depleted of sediment as observed at sites PO_01 through PO_04 (Appendix A, Figures A-47 through A-50). The beach elevations at these sites experience small seasonal fluctuations of 0.25 to 0.5 ft (Golder 2013).

The beach photo observations at sites PO_02 and PO_03 recorded in May and October 2021 are consistent with the seasonal and annual variability. Figure 15 shows time series of beach elevation from 2014 to 2021 (relative to the first survey in 2005) at PO_02 and PO_03. The beach elevation at PO_02 increased 0.5 ft from October 2020 to October 2021 from a low point since 2014 at the site. The beach elevation increased slightly (<0.25 ft) at PO_03 from October 2020 to October 2021. Laser scanning surveys are not conducted along Port Orchard.

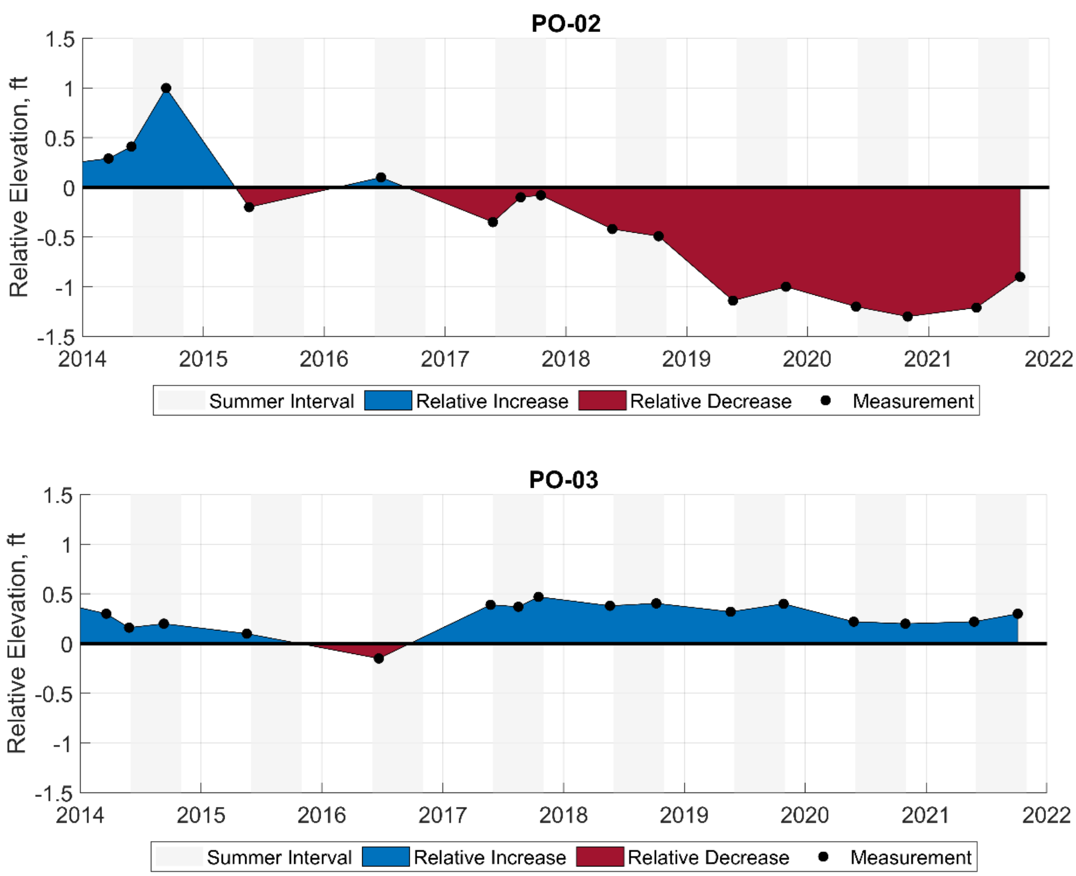

Figure 15. Time series of relative beach elevation from 2014 through 2021 at beach photo survey sites PO_02 and PO_03. Blue indicates accretion relative to the 2005 (not shown) starting point and red indicates erosion relative to the 2005 starting point.

3.3 Point White

Point White is the most dynamic shoreline reach in the study area because of exposure to wind-waves and the lack of sediment supply. The beaches along Point White tend to be coarse and depleted of sediment on the southern end of the shoreline, as observed at sites PW_01 through PW_06 (Appendix A, Figures A-51 through A-56).

The beach elevations at these sites have gradually decreased since 2005 and experience small seasonal fluctuations of 0.25 to 0.5 ft (Golder 2013). Photos of sites PW_01 to PW_03 show the beach is still at very low elevations and the footings of the bulkheads remain exposed; the beach elevation is not measured at these three sites. Figure 16 shows time series of beach elevation from 2005 to 2021 at PW_05 and PW_06 which are representative of conditions at Point White. At PW_05, the beach elevation decreased over the winter interval and increased over the summer interval (consistent with previous years). At site PW_06, the beach elevation increased nearly a foot during the summer interval from May to October 2021.

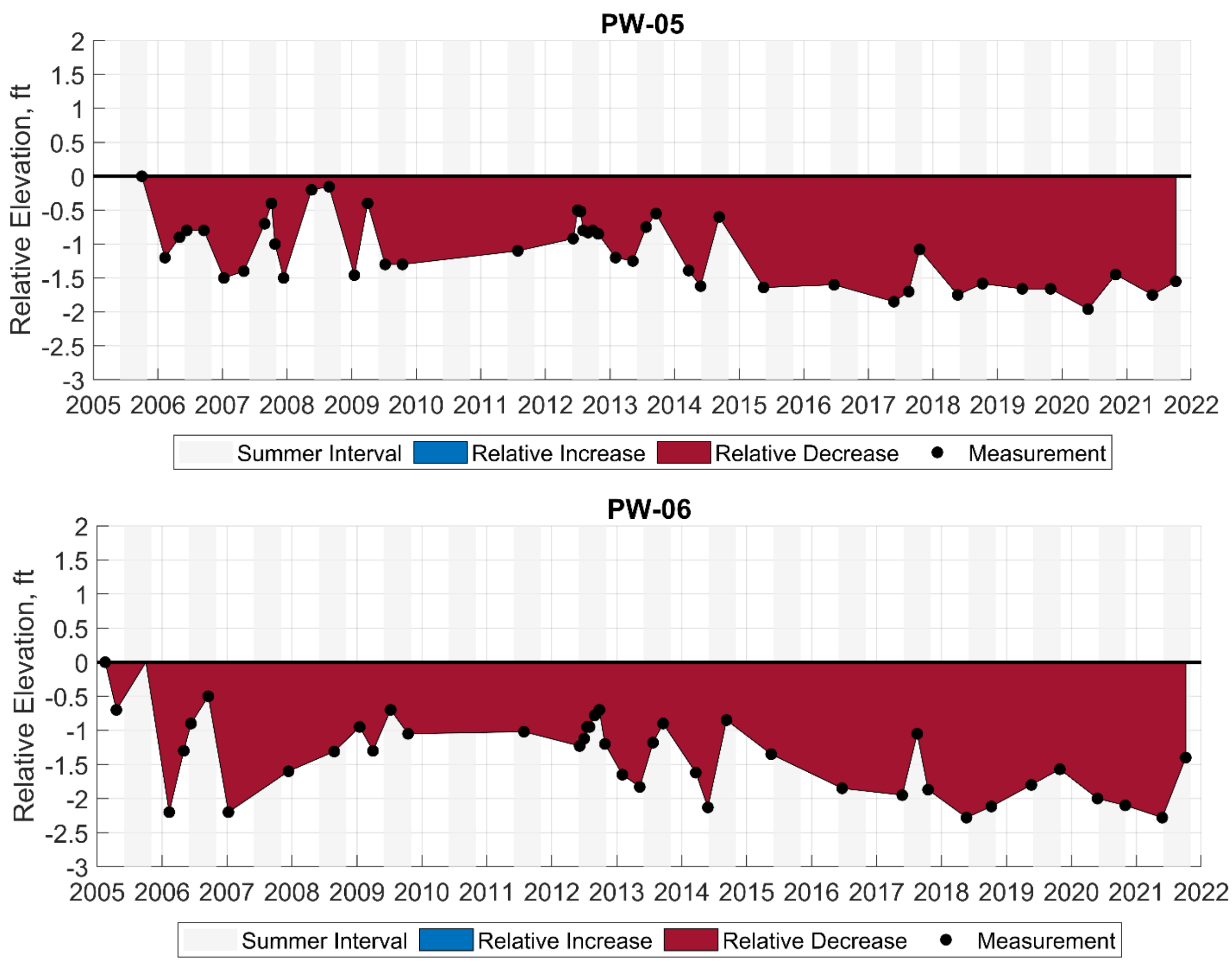

Figure 16. Time series of relative beach elevation from 2005 through 2021 at beach photo survey sites PW_05 and PW_06. Blue indicates accretion relative to the 2005 starting point and red indicates erosion relative to the 2005 starting point.

Despite the erosional trend at PW-05 and PW-06, occasional accretionary events are observed at these sites as is characteristic of other areas along Point White. Point White sites PW_07 through PW_18 (Figures A-57 through A-68) exhibit seasonal and annual fluctuations on the order of 1 ft. Waves of gravel move from the south to the north along Point White over an approximately 4-year cycle (Golder 2013) and result in localized highs and lows in beach elevation between sites PW_07 and PW_18 during different years. For example, beach elevation measurements at PW_14 have fluctuated over 1 ft from 2017 to 2019 (Figure 17). In 2020, there was minimal change to the elevation at the bulkhead. In 2021, the beach elevation at the bulkhead trended higher, with an increase over 0.5 ft from October 2020 to October 2021. At PW_18, the beach elevation continued the trend of increasing, with a change of over 0.25 ft from October 2020 to October 2021 and is now above the baseline level from 2005.

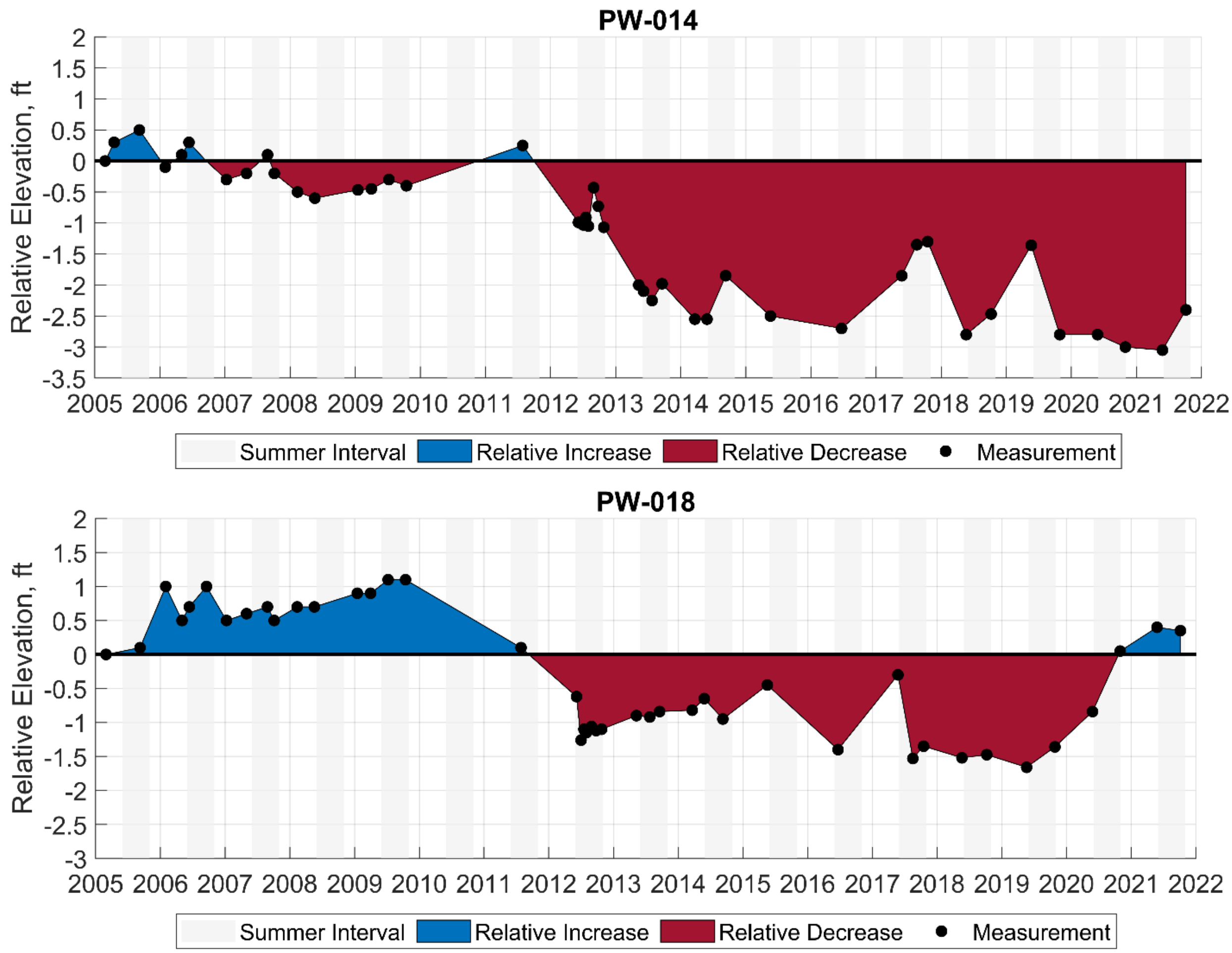

Figure 17. Time series of relative beach elevation from 2005 through 2021 at beach photo survey sites PW_14 and PW_18. Blue indicates accretion relative to the 2005 starting point and red indicates erosion relative to the 2005 starting point.

Beach photo observations at sites PW_19 through PW_24 typically show smaller changes (less than 0.5 ft) due to the location of these sites farther from the entrance to Rich Passage with less exposure to wind-waves and vessel wakes. In 2021, at PW_21 (Figure A-74) and PW_24 (Figure A-75) the beach elevation increased from October 2020 to October 2021 and during the summer interval of 2021. These increases in elevation are likely the result of the waves of gravel being transported across these sites and the elevations will likely decrease again in 2022.

The maps of laser scanning survey differences for Point White which overlap with photo sites PW_7 to PW_11 show 0.25 to 0.5 ft of erosion across most of the survey area. The annual survey difference map (Figure 18) shows waves of sediment moving obliquely relative to the shoreline, whereas the summer survey difference map (Figure 19) shows primarily accretion on the upper beach and erosion on the mid-beach, a typical seasonal pattern. Elevation changes are negligible on the mid- to lower beach. The annual change is similar to the extent measured in previous years.

The magnitude and spatial extent of the erosion and accretion patterns along Point White vary from year to year, so further analysis was conducted to calculate the total volumetric change within two subsets of the survey area (Point White North and Point White South [Figure 21]). The results of this analysis are shown in Figure 20, where a positive number indicates net increase in volume within the calculation area and a negative number indicates net decrease in volume.

The total beach volume change between May and October 2021 was no net change at Point White South and a net decrease of 59 CY at the Point White North survey site. The beach changes are consistent with the previous measurements at the two sites. Volume change at Point White South are typically small due to the limited sediment supply near the start of the littoral cell. Point White North has measured similar net losses of sediment in 7 of 9 survey years since 2013 and due to it being within a transport zone in the shoreline littoral cell. On an annual interval there was a small net increase at Point White South of 11 CY and a net decrease at Point White North of 64 CY.

The volumetric change at both sites is consistent with the magnitude of change measured in previous years prior to RP1 operation. No differences in trends in beach response can be discerned from the volumetric change data.

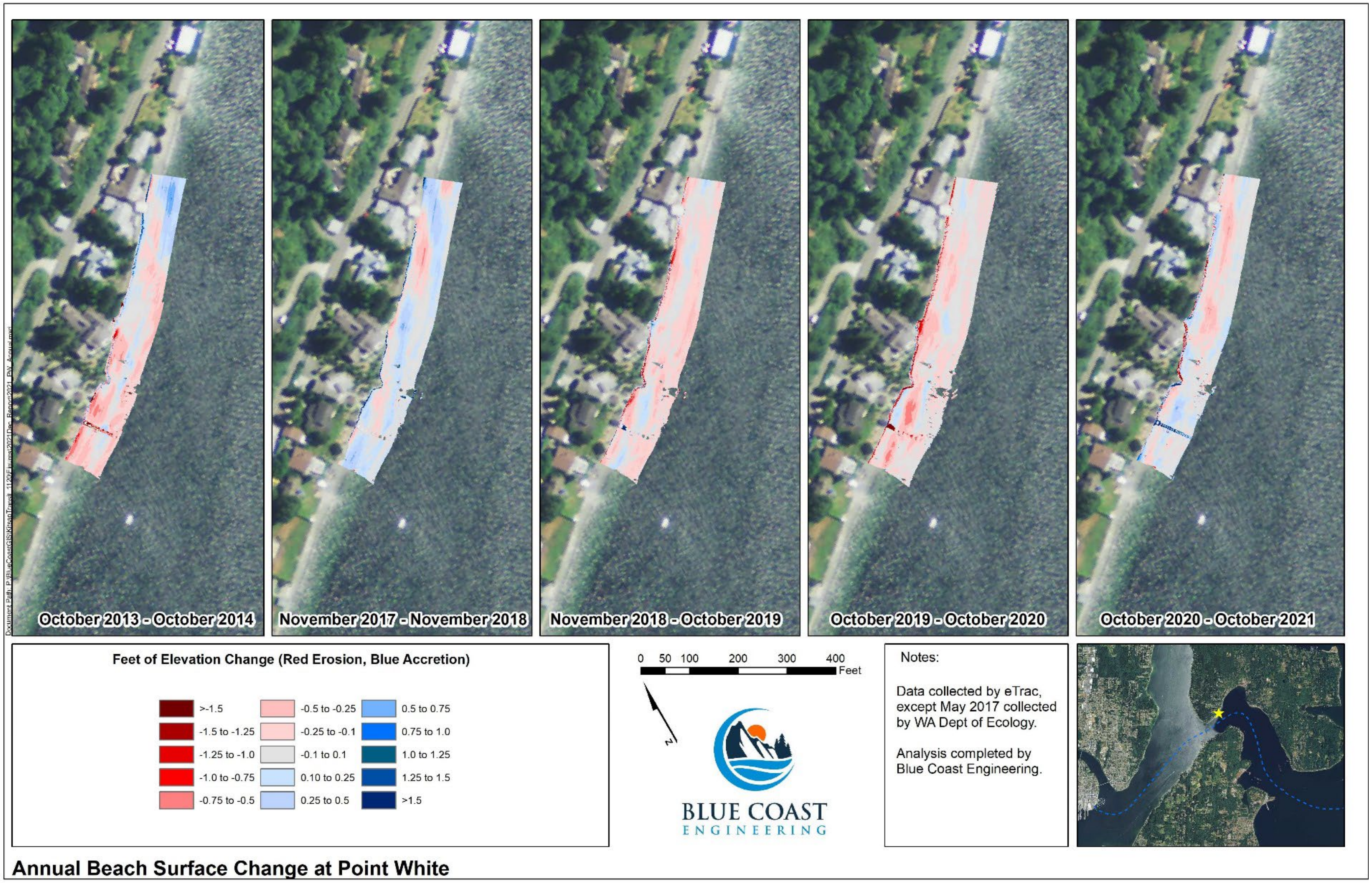

Figure 18. Point White elevation change over four 1-year intervals from 2013 to 2021.

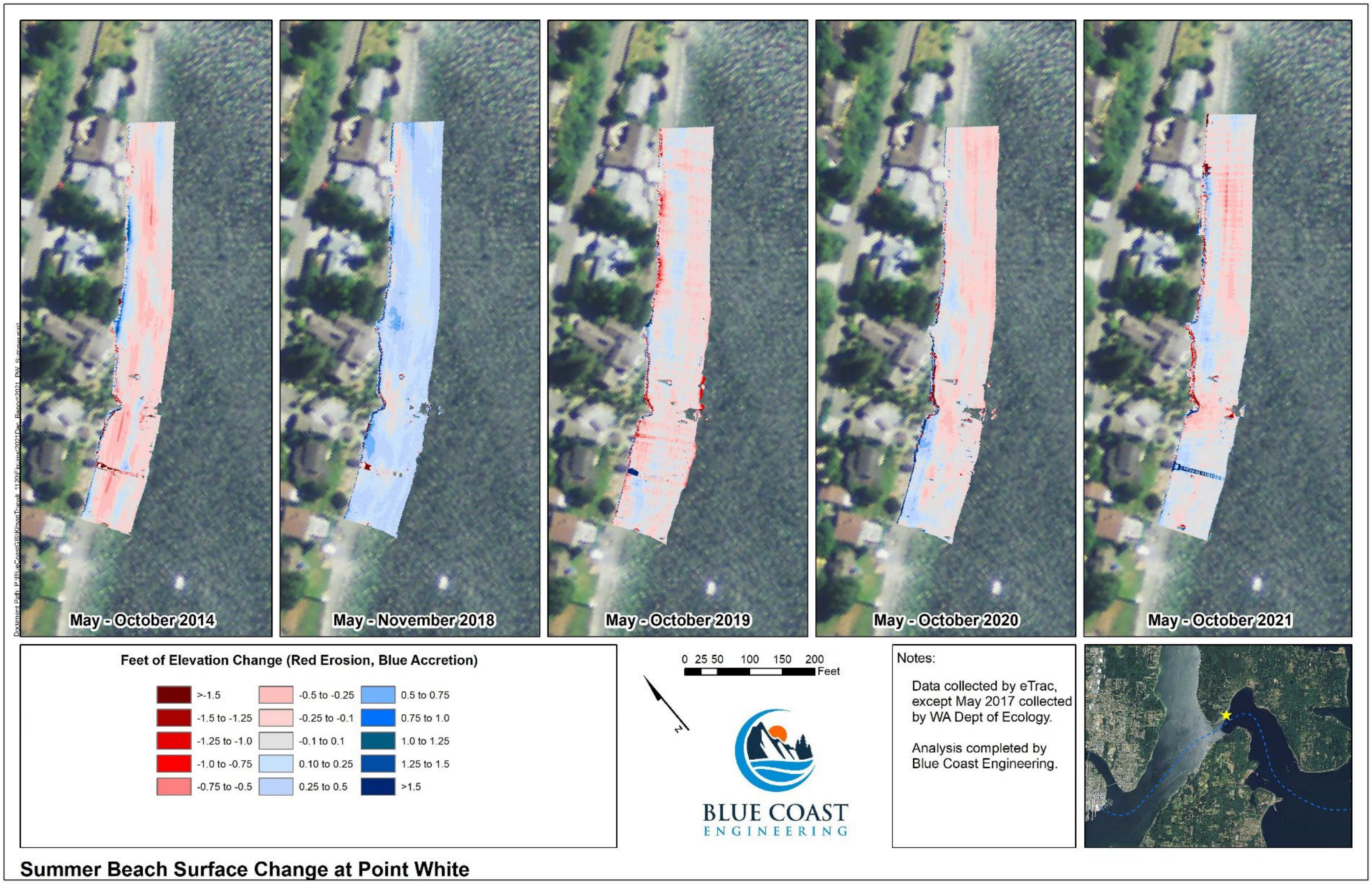

Figure 19. Point White summer elevation change in 2014, 2018, 2019, and 2020.

Figure 4. Volume change (cubic yards) in calculation area at Point White South and North. The volume change and error as a percent of the total change are shown for each measurement.

Figure 21. Calculation area for volume changes at Point White.

4.0 Conclusions

Beach photo observations and laser scanning surveys were completed during the fifth year of M/V RP1 (and sister vessels) operations in May and October 2021. The observations indicate that the seasonal and interannual patterns are consistent between 2017 through 2021 and years prior to vessel operations.

The 2021 measurements at Port Orchard and Pleasant Beach show small pockets of erosion and accretion which are consistent with years prior to vessel operations. East Bremerton shows waves of sediment erosion and accretion, similar to those that have been previously identified at the site.

Point White is the most dynamic shoreline reach in the study area because of exposure to wind-waves and the lack of sediment supply. Monitoring sites along Point White continue to exhibit long-term depletion of sediment as well seasonal cycles. Volumetric change analysis of beach elevations, as determined by laser scanning, at Point Glover and at Point White are within the range of expected results and no discernable trend is apparent in the data over the past 9 years of monitoring.

At Point Glover, which is also sediment supply-limited, local effects such as changes in creek flows result in variable sediment transport patterns. In 2021, the net change in sediment volume was a net loss of 48 CY, within the range of change during previous years.

The measurable beach response along the reaches monitored in 2021 cannot be correlated to Bremerton-Seattle POF operations. The beaches will be monitored again in May and October 2022 to record both the seasonal and interannual cycles of beach response during the sixth year of operation of Kitsap Transit POF operations through Rich Passage.

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