Rich Passage Long-Term Beach Monitoring: May to October 2022 Beach Response Report

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Executive Summary

Kitsap Transit has contracted Blue Coast Engineering (Blue Coast) to monitor the beaches within Rich Passage during the implementation of commercial service of the passenger only fast ferry (POFF) Motor Vessel (MV) *Rich Passage 1* (*RP1*) in 2017 and subsequent vessels of the same class the MV *Reliance* and MV *Lady Swift* on the Bremerton to Seattle route. Beach photo observations and laser scanning surveys were completed in May and October 2022. Beginning in January 2005 and continuing through 2022, 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 2022, and years prior to vessel operations.

The 2022 measurements at Port Orchard and Pleasant Beach show varying patterns of erosion and accretion which are consistent with years prior to vessel operations. East Bremerton monitoring sites continue to exhibit long-term depletion of sediment at the beginning of the drift cell and seasonal cycles of accretion and erosion of sediment along the middle to end of the drift cell. Point White is the most dynamic shoreline reach in the study area because of larger exposure to wind-waves, the lack of sediment supply to replenish sediment transported by wind-waves, and shoreline armoring within the intertidal which increases the erosion caused by wind-waves. Monitoring sites along Point White continue to exhibit long-term depletion of sediment and seasonal cycles downdrift of the point towards Lynnwood Bay. 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 prior to the interval of POFF vessel operations.

The measurable beach response along the reaches monitored in 2022 cannot be correlated to Bremerton-Seattle Passenger POFF operations. In other words, there is no correlation between the changes on the beaches and the beginning or changes to POFF vessel operations in Rich Passage between 2017 and 2022. The beaches will be monitored again in May 2023 to record both the seasonal and interannual cycles of beach response during the seventh year of operation of Kitsap Transit Fast Ferry Service through Rich Passage.

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1.0 Introduction

Kitsap Transit has contracted Blue Coast Engineering (Blue Coast) to monitor the beaches within Rich Passage during the implementation of commercial service of the POFF MV *Rich Passage 1* (*RP1*) and subsequent vessels of the same class the MV *Reliance* and MV *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, Table 1).

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 from January 2022 through December 2022 and beach monitoring in May 2022 through October 2022. In 2022 Rich Passage class operations ranged between 130 to 150 one-way trips with the exception of December when they were increased to 214 one-way trips, 6 days per week. In 2021, Kitsap Transit also added commercial service of a new vessel (MV *Enetai*) operating between Southworth and Seattle with transit through Rich Passage from Bremerton each day to dock in Bremerton (Table 2). The vessel operated between 20 and 22 one-way trips each week throughout 2022.

Beach monitoring was conducted using ground-based geo-referenced photographs on May 17 and October 6, 2022, and laser scanning surveys on May 17 and October 12, 2022. Figure 1 shows the location of laser scanning areas and beach photo sites throughout the study area. This report documents the results of the 2022 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 five years of operations from 2017 to 2021. 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 2022.

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
January 1,2022	June 3, 2022	130	5
June 4, 2022	September 24, 2022	150	6
September 26, 2022	November 30, 2022	130	5
December 1, 2022	December 31, 2022	214	6

Table 2. MV *Enetai* Rich Passage vessel transits summary in 2022.

Start Date	End Date	One Way Trips Per Week	Operation Days per Week
January 1, 2022	June 3, 2022	20	5
June 4, 2022	September 24, 2022	22	6
September 26, 2022	December 31, 2022	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 2022 including beach response to operation of *RP1*. Figure 2 presents a timeline of beach observations documented in photographs and laser scanning surveys from 2013 through 2022.

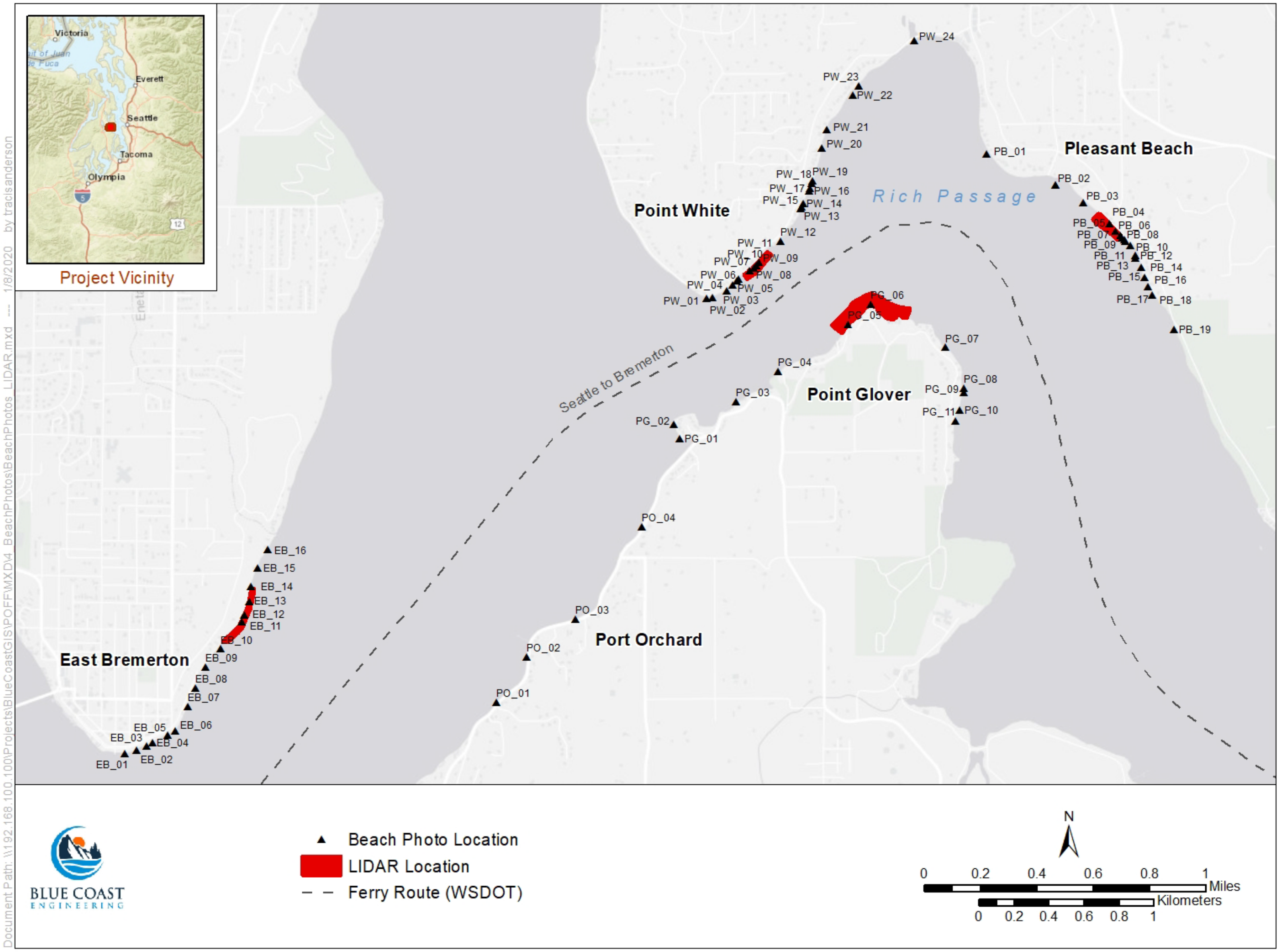


Figure 1. Beach photograph and laser scanning survey locations along Bremerton to Seattle transportation route.

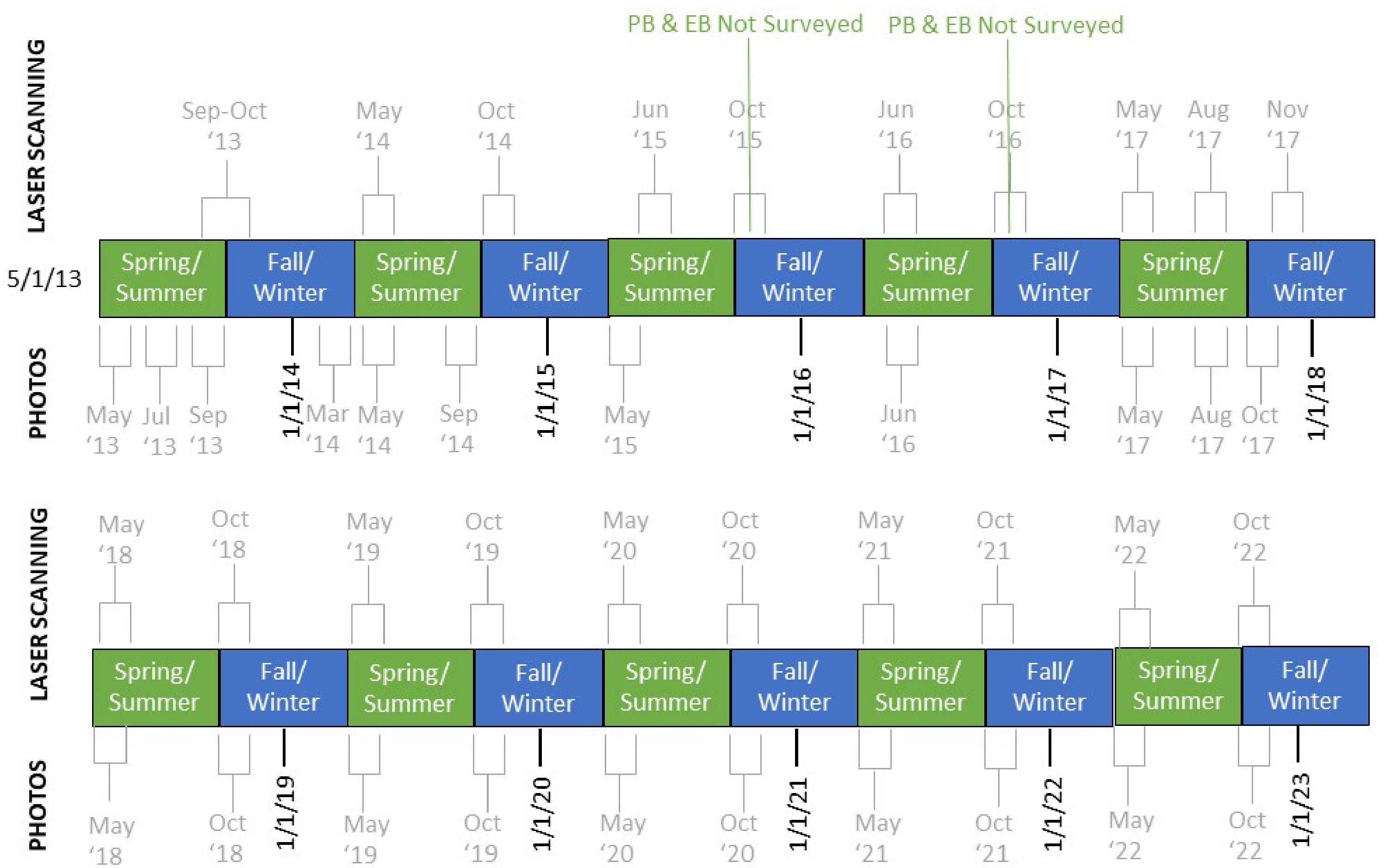


Figure 2. Timeline of beach photo observations and laser scanning surveys. Fall/Winter is approximately October thru April, Spring/Summer is approximately April thru October. PB is Pleasant Beach and EB is East Bremerton.

2.1 Beach Photo Observations

Observations of beach condition and beach elevation 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 2022, geo-referenced and time-stamped photographs were captured approximately bi-annually 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).
7. Beach response to RP1 from May to October 2021 were recorded and analyzed during Year 5 of the Long-Term Beach Monitoring Program (Blue Coast 2022).

New beach photographs presented in this report were recorded on May 17 and October 6, 2022 to characterize the changes in beach morphology during the sixth year of Bremerton-Seattle Fast Ferries commercial scale operations (Appendix A).

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 October 2017 to October 2022. 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 as compared to elevations recorded in 2013. 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 due to lack of a permanent reference location such as a bulkhead, stairs, or other fixed point on the beach. Therefore, there is no graph of relative beach elevation for some sites.

2.2 Laser Scanning Surveys

eTrac Inc. has performed laser scanning surveys in Rich Passage bi-annually in May and October since 2011. These surveys provide three-dimensional measurements of beach elevation over 500-foot-long sections. On May 17 and October 12, 2022, 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 quality control report for this work, which includes details of the methods used, locations surveyed, and the post-processing performed.

The survey results are XYZ files containing easting, northing, and elevation in a resolution of 1 foot (ft) by 1 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. A raster file is a digital grid surface with a continuous elevation across each grid cell, which in this case is 1 ft by 1 ft. 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 POFF service (2013 and 2014) and six summer intervals with POFF service (2017 to 2022). 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 POFF operations (2013 and/or 2014) and the most recent 3 full years with POFF operations: November 2018 to October 2019, November 2019 to October 2020, and October 2020 to October 2021, and October 2021 to October 2022. Data recorded in 2017 to 2018 are available in previous beach monitoring reports (Blue Coast 2020a; Blue Coast 2020b).

At Point White and Point Glover, where the most noticeable change was detected, additional analysis was conducted to calculate the total volume of beach change that occurred during the summer seasons. (Figure 13 and 21). The total volume of change is the summation of all beach change (addition of beach sediment and removal of beach sediment) 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. Also, the potential error in volume calculations is small relative to the size in the survey area. 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 of sediment across for the subset of the survey area where volume change was calculated is also provided, i.e. the volume change that would occur if 1 inch of sediment was added or removed from the surface of the area being analyzed. 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 statistics by shoreline area.

Survey Area	Size (sq. feet)	Error Volume Change Calculation (cubic yards)	1-inch Thickness Volume (cubic yards)[1]
East Bremerton	48,500	4.6	173
Pleasant Beach	56,000	5.0	149
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 (transport of sediment offsite) 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 forces along the middle to upper intertidal portion of the beach which transports mixed sand and gravel along and across the shoreline. 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, annually, and over 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 eleven year baseline study of beach change conducted for the Rich Passage Wake Research Program between 2005 and 2016 has 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 and availability at other locations within the drift cell.

Extensive research has been conducted over the last 20 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 had direct and indirect 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 sediment volume on the beach (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, may increase erosion, and reduce or eliminate 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 (addition of sediment onsite), 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 2022 and relative to the October 2021 survey. The observations are compared to beach response patterns that have been observed from 2005 to 2021 through beach photo observations and 2011 to 2021 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 POFF vessels were 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). This is likely due to direct exposure to southerly wind-waves and their position at the start of a drift cell with limited sediment supply due to shoreline armoring. 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 2022 showed that all four of the sites are at or near historic lows relative to 2005. However, between October 2020 and October 2021, two of the sites increased in beach elevation (EB_02 and EB_04) , one remained unchanged (EB_03), and one decreased (EB_01). EB_02 and EB_04 increased slightly in elevation (less than 0.5 feet) during the summer interval. The East Bremerton sites are at the updrift end (beginning) of a relatively long drift cell and exhibit long-term depletion of sediment due to the lack of sediment supply to the drift cell.

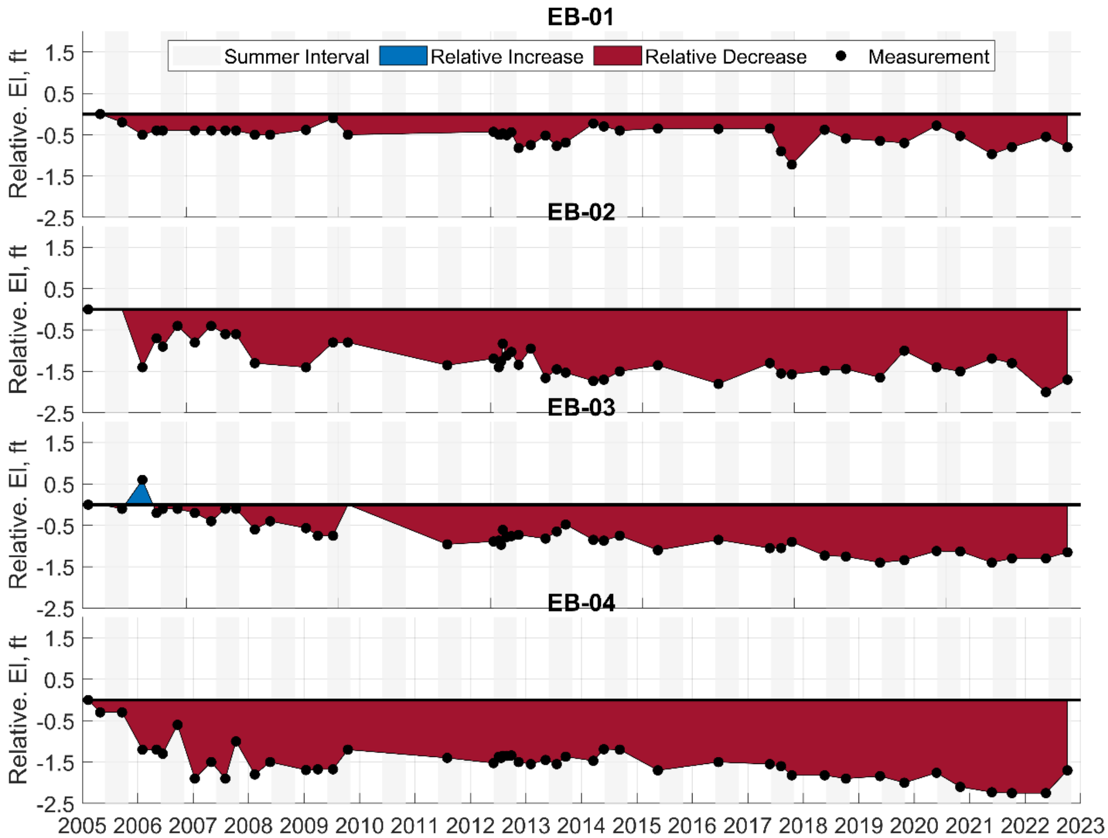


Figure 3. Time series of relative beach elevation from 2005 through 2022 at beach photo survey sites EB_01 to EB_04. Blue indicates accretion relative to the 2005 starting point and red indicates erosion relative to the 2005 starting point.

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. In 2022 the largest change in beach elevation occurred at EB_12 which decreased almost 1 ft between the October 2021 and October 2022 surveys. Photo observations at this site show the loss of a gravel berm at the toe of the bulkhead. Also in 2022, a strong seasonal signal was observed at EB_08, with a winter and summer fluctuation of +/- 1 ft. A summary of the year-to-year elevation change at the beach bulkhead interface (October 2021 to October 2022) is provided for each observation site below. All but two of the sites measured year-to-year elevation increases which may be reflective of these sites being in the middle of the drift cell and less sediment-starved than sites at the end of the drift cell, EB_01 through EB_04 to the southwest along East Bremerton.

October 2021 to October 2022 beach elevation change:

- EB_06: 0.50 ft increase
- EB_07: 0.25 ft increase
- EB_08: 0.50 ft increase
- EB_09: 0.25 ft decrease

- EB_12: 1.0 ft decrease
- EB_13: 0.25 ft increase
- EB_14: 0.5 ft increase
- EB_15: 0.75 ft increase
- EB_16: 0.5 ft increase

The map of laser scanning survey differences for one-year intervals from 2013 to 2021 shows that the beach accreted sediment (151 cubic yards [CY] net change) from 2021 to 2022 over much of the survey area (Figure 4). The observations of accretion in this area of East Bremerton is consistent with the photo observations between sites EB_10 and EB_14 (Figures A-10 through A-14). The areas of the greatest increase in elevation up to 1 ft (dark blue) occurred on the upper beach near the toe of structures. The map of laser scanning survey differences for the summer interval at East Bremerton shows a similar pattern as the annual difference map, but with more pronounced accretion of sediment on the upper beach in comparison to the annual interval (Figure 5). The net change in sediment over the summer interval was significantly more than in past years with an increase of 299 CY. The laser scanning survey area is on the northeastern end of the East Bremerton monitoring reach and the structures are setback higher on the beach and do not interact with wind-waves and vessel wakes as frequently as the structures on the southwest end of East Bremerton. Therefore, this area is more likely to accrete sediment during intervals of low wave energy in the summer.

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 2022, the beaches along East Bremerton followed this pattern, with 10 of 13 monitoring sites decreasing (or not changing) in elevation through the winter and 11 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 evident by comparing laser scanning survey difference maps from 2022 to the interval prior to operations in 2013 to 2014 (Figures 4 and 5).

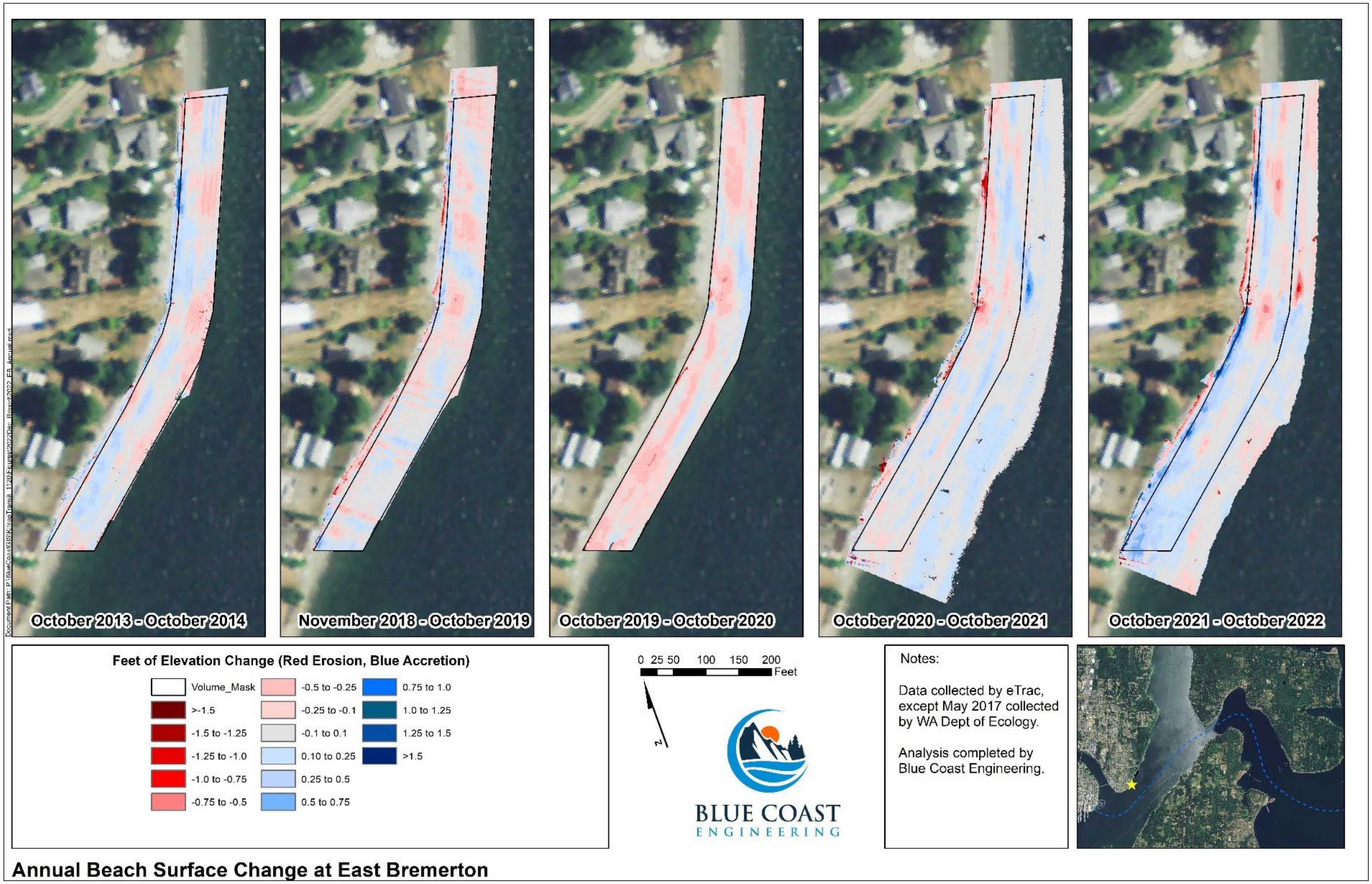


Figure 4. East Bremerton annual elevation change from 2013 to 2014, from 2018 to 2019, 2019 to 2020, 2020 to 2021, and 2021 to 2022.

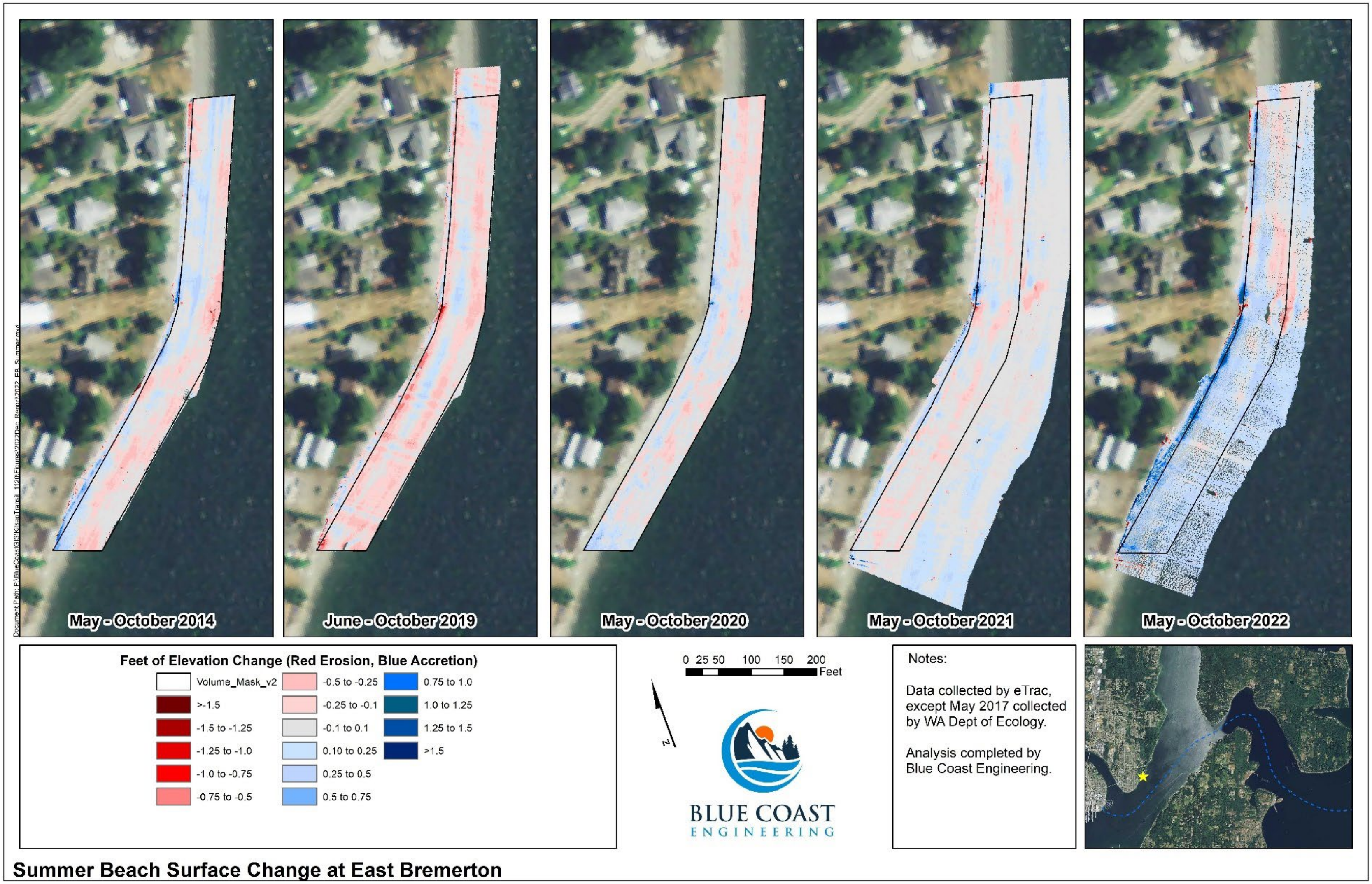


Figure 5. East Bremerton summer elevation change in 2014, 2019, 2020, 2021, and 2022.

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 2022 (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. Elevation at all but one site (PB_15) decreased during the winter interval from October 2021 to May 2022. The largest change occurred at PB_11, which decreased 0.75 ft. A strong seasonal signal was observed at PB_05, PB_07, PB_09, and PB_10 with a decrease in elevation over the winter interval and subsequent increase in elevation over the summer interval. On a year-to-year basis, six sites recorded beach elevation increases and 5 recorded beach elevation decreases from 2021 to 2022.

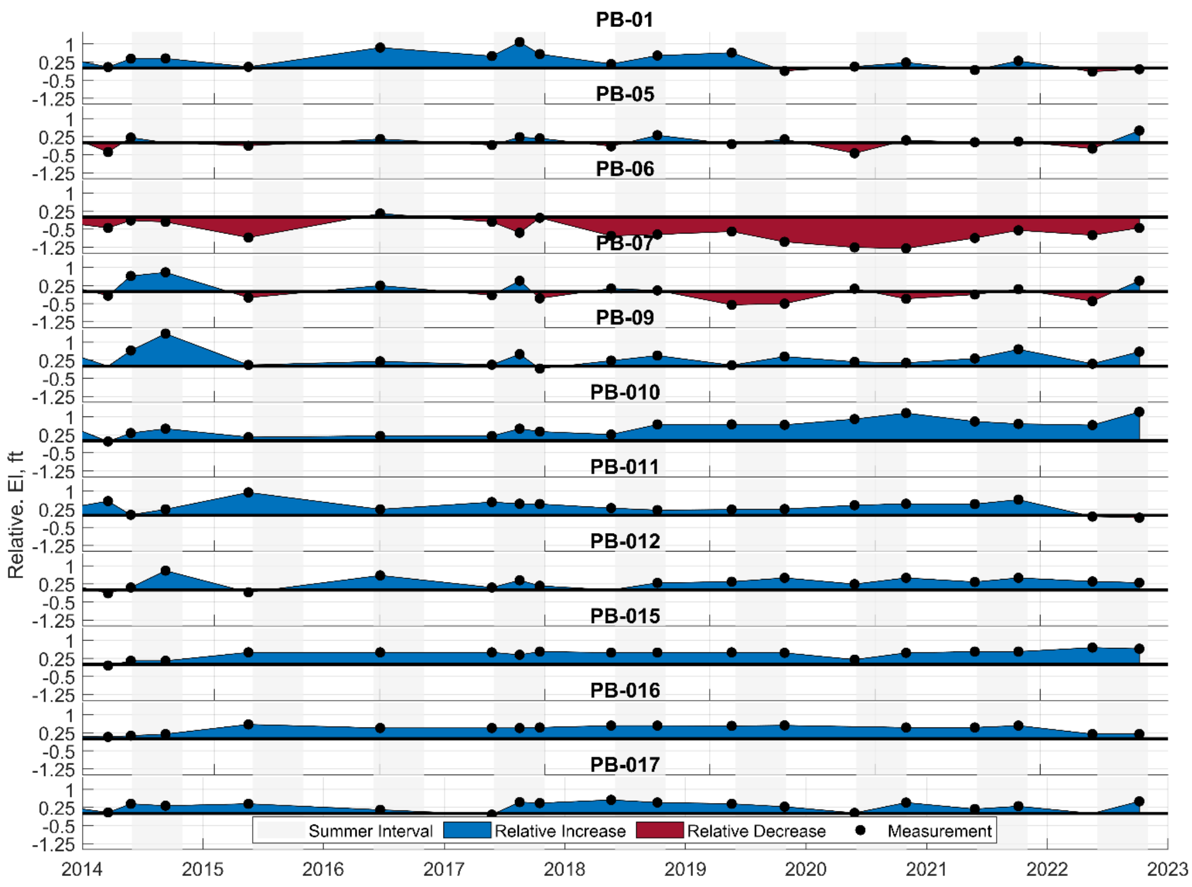


Figure 6. Time series of relative beach elevation from 2014 through 2022 at all beach photo survey sites along Pleasant Beach. Blue indicates accretion relative to the 2005 starting point and red indicates erosion relative to the 2005 starting point.

The map of laser scanning survey differences for the one-year interval from October 2021 to October 2022 at Pleasant Beach (Figure 7) shows mostly erosion (<0.5 ft) across the entire surveyed beach with a few areas near the upper beach exceeding 1 ft of erosion. There are a few small pockets of accretion on the upper beach (<0.5 ft). The same map for the summer interval shows mostly accretion across the beach, with two small areas of erosion (up to 1 ft) in the center of the survey area (Figure 8). Pleasant Beach exhibits less change than the other monitoring areas because there is a wide low sloping terrace offshore of the beach pushing the navigation channel towards Port Orchard, i.e., the navigation channel is further from the shoreline along Pleasant Beach than in other areas. In addition, Pleasant Beach is relatively sheltered from wind-wave energy. The laser scanning survey results are consistent with the measurements at the nearby beach photo sites (PB_04 to PB_08) which predominantly measured increases in beach elevation during the same interval.

The comparison of summer elevation changes against the previous surveys shows that beach elevation changes in 2022 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.

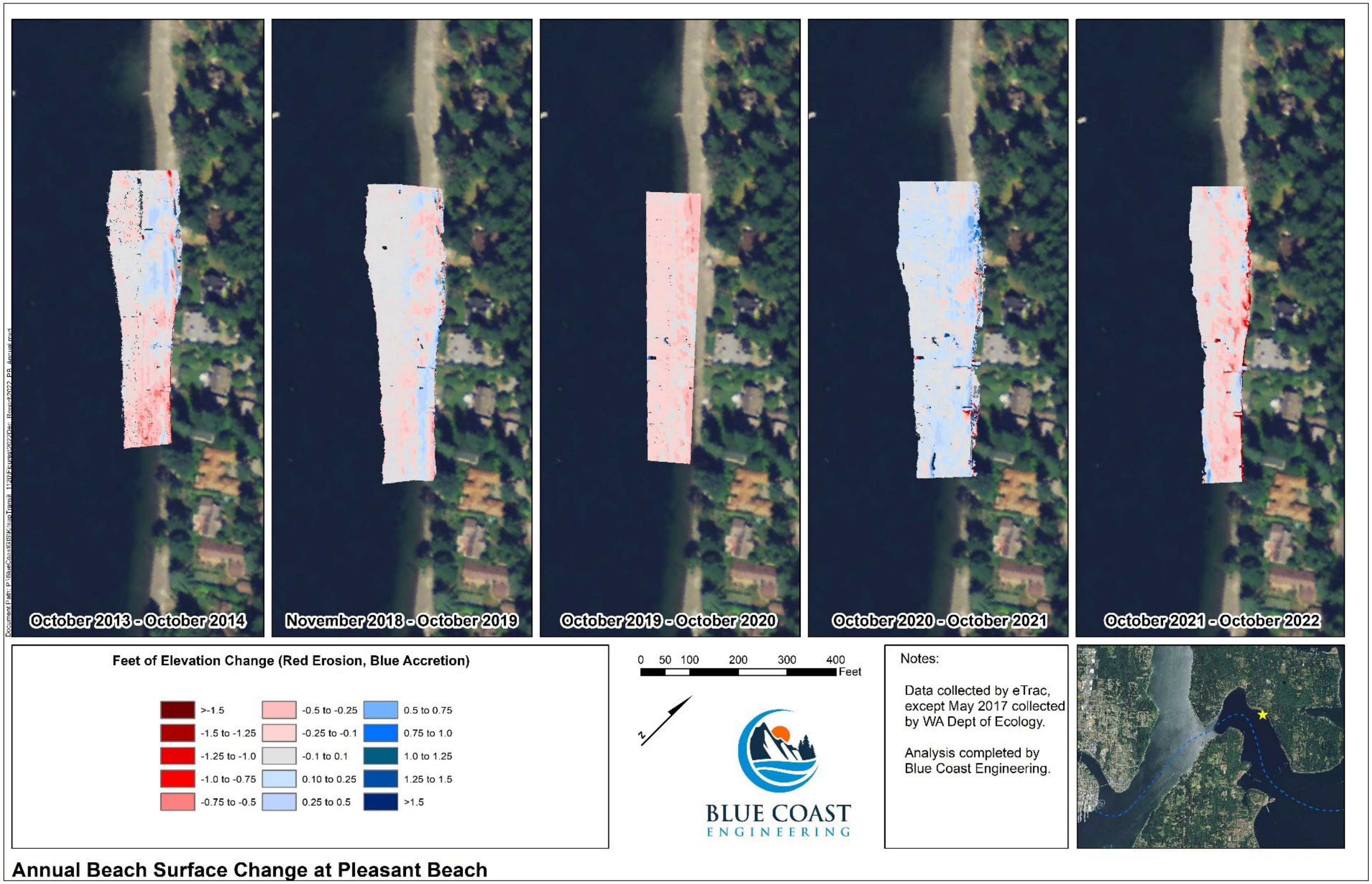


Figure 7. Pleasant Beach annual elevation change from 2013 to 2014, from 2018 to 2019, 2019 to 2020, 2020 to 2021, and 2021 to 2022.

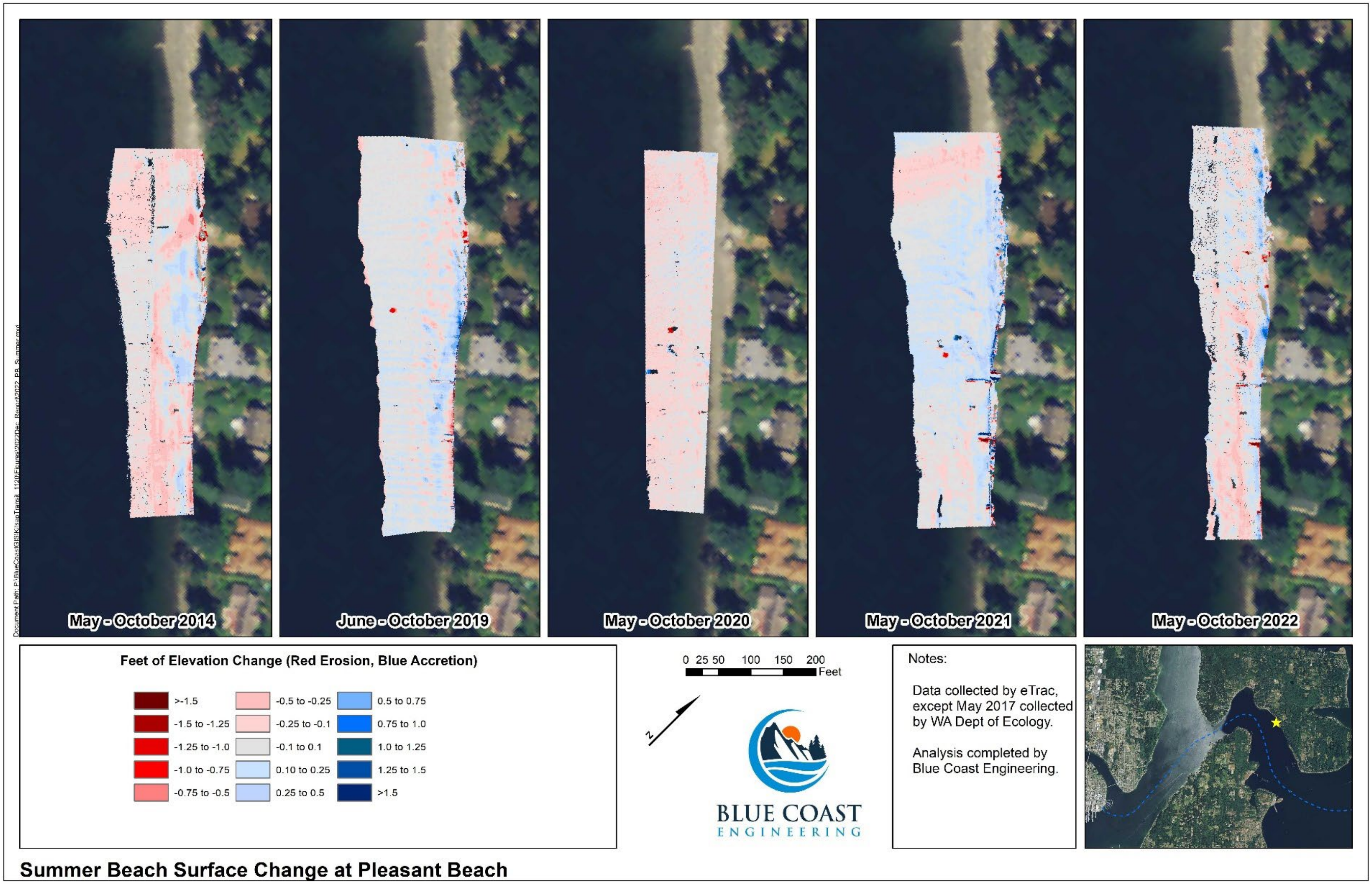


Figure 8. Pleasant Beach summer elevation change in 2014, 2019, 2020, 2021, and 2022.

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 contain along-shore sediment transport between the outcrops. 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, due to these sediment shifts is typically on the order of +/- 0.5 ft on the west side of Point Glover. From 2021 to 2022, the map of laser scanning survey differences , shows minor accretion or negligible change across most of the upper beach (Figure 9). Accretion and erosion are visible on the north and south sides, respectively, of the three shore-perpendicular groins in the survey area. The map of laser scanning survey differences for the summer interval shows the accretion and erosion trend more clearly along the groins and generally higher amounts of change in the beach elevation across the site compared to the annual difference survey (Figure 10). Accretion (up to 1.0 ft) is visible on the updrift (north) side of the groins and on the downdrift (south) side of the groins erosion (up to 1.0 ft) is visible. Groins are placed to block alongshore sediment transport and retain sediment between two groins and this is the phenomena observed at west Point Glover.

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) and erosion of sediment on the lower beach over the summer interval, similar to previous summers (Figure 12). 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 and an increase in elevation on the lower beach of up to 1.0 ft (Figure 11). This is a similar annual trend during the past annual interval (2020-2021), but the opposite from some previous years (2018-2019 and 2019-2020). The pattern at this location appears to be sensitive to discharge and sediment input from the creek outlet within the pocket beach. Discharge (volume of water) is not measured in this small stream and so observations correlated with stream flow are qualitive based on the geomorphology rather than quantitative based on measured stream flow. Localized accretion on the upper beach (dark blue) has been associated with the 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). This summer trend is evident in all monitoring intervals (Figure 12).

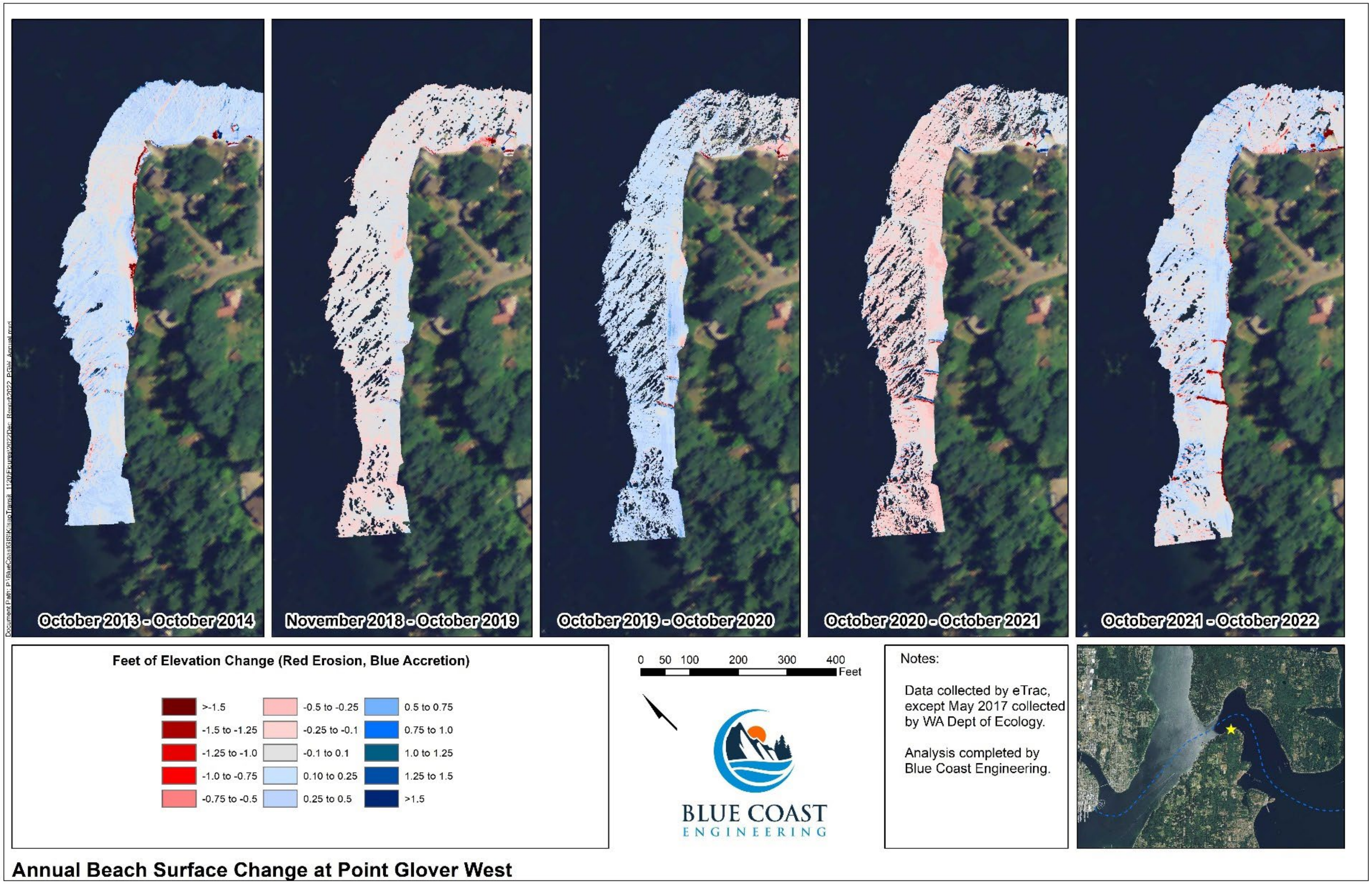


Figure 9. Point Glover West elevation change over five 1-year intervals from 2013 to 2022.

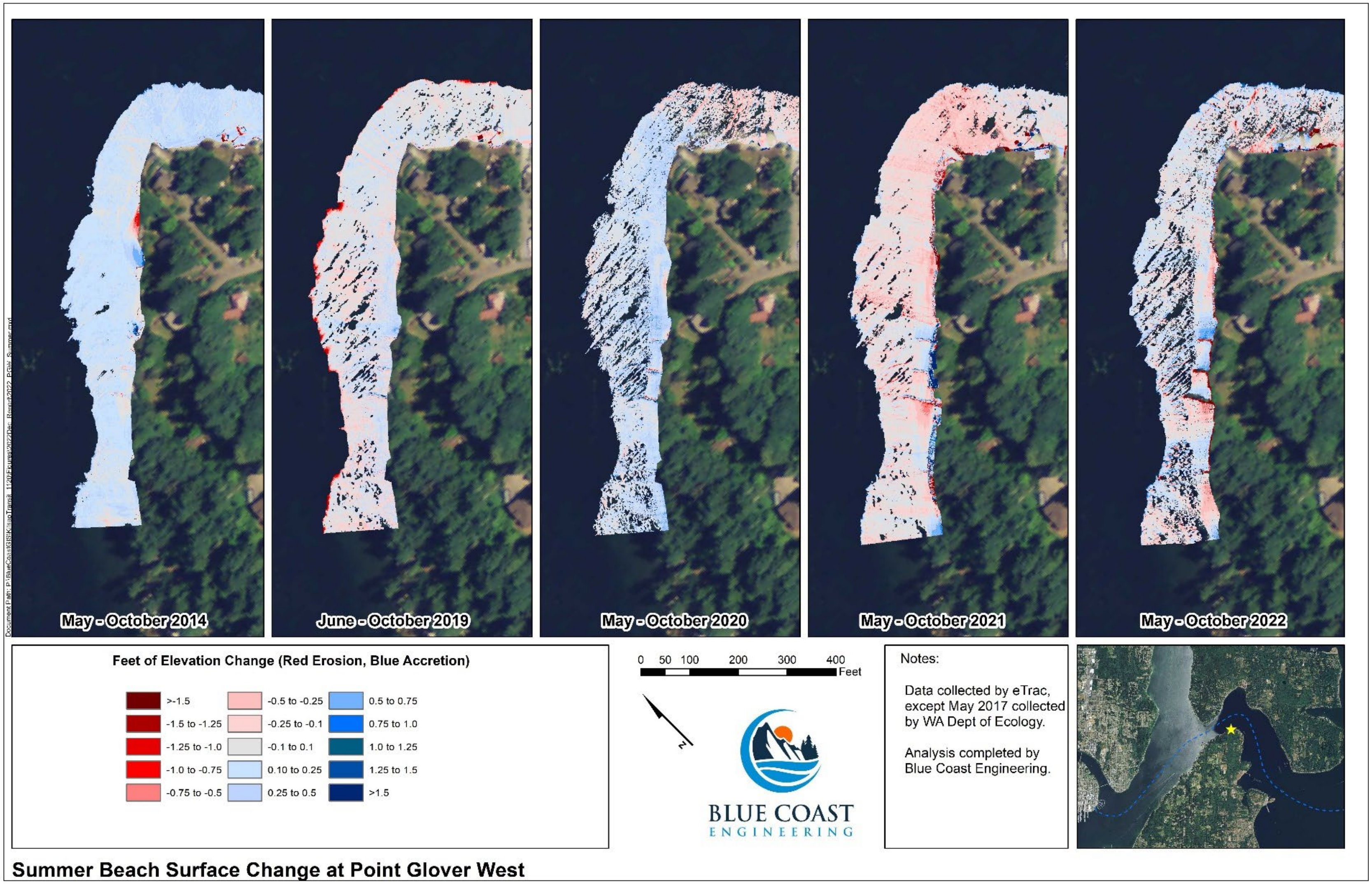


Figure 10. Point Glover West summer elevation change in 2014, 2019, 2020, 2021, and 2022.

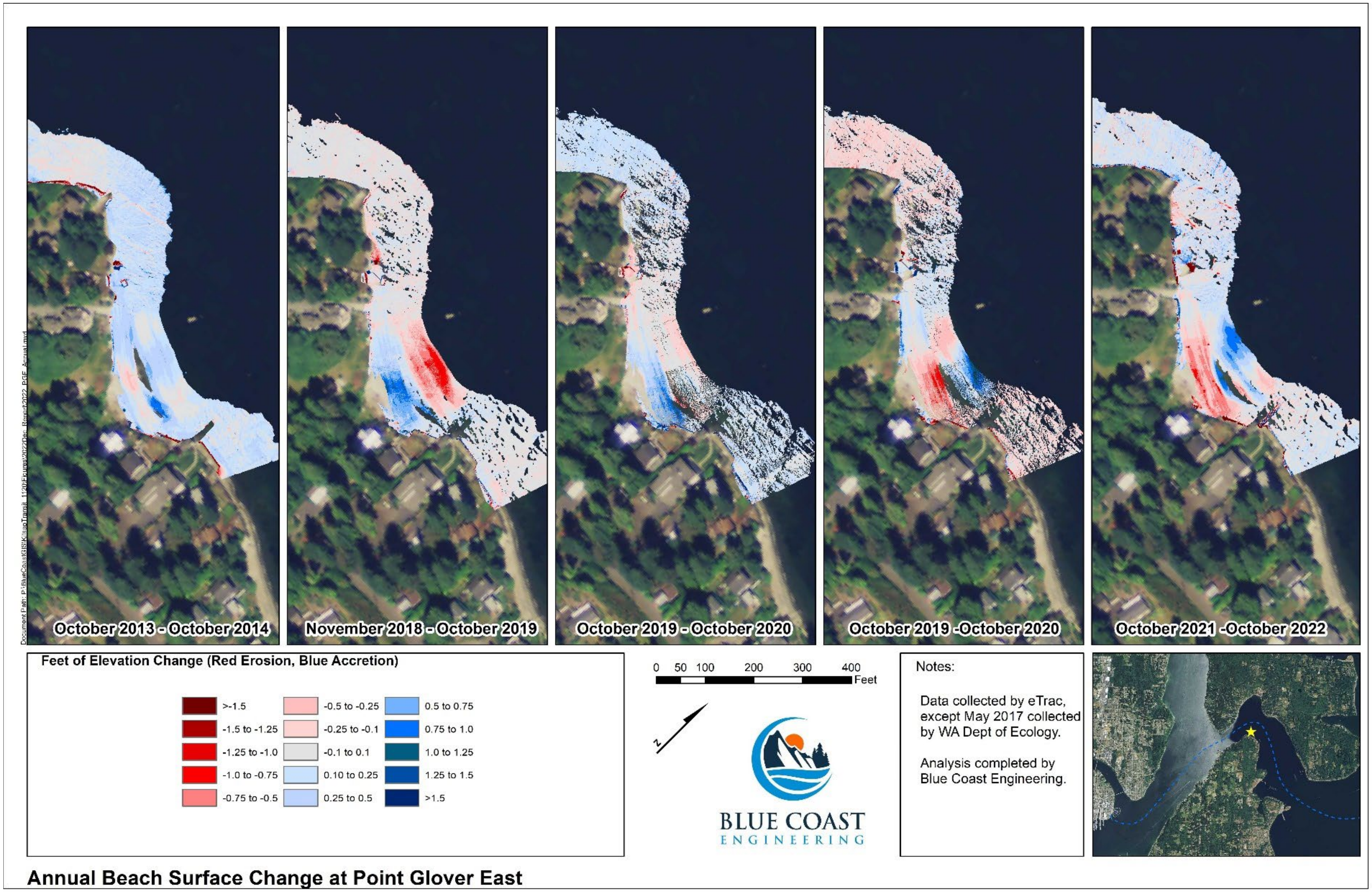


Figure 11. Point Glover East change over five 1-year intervals from 2013 to 2022.

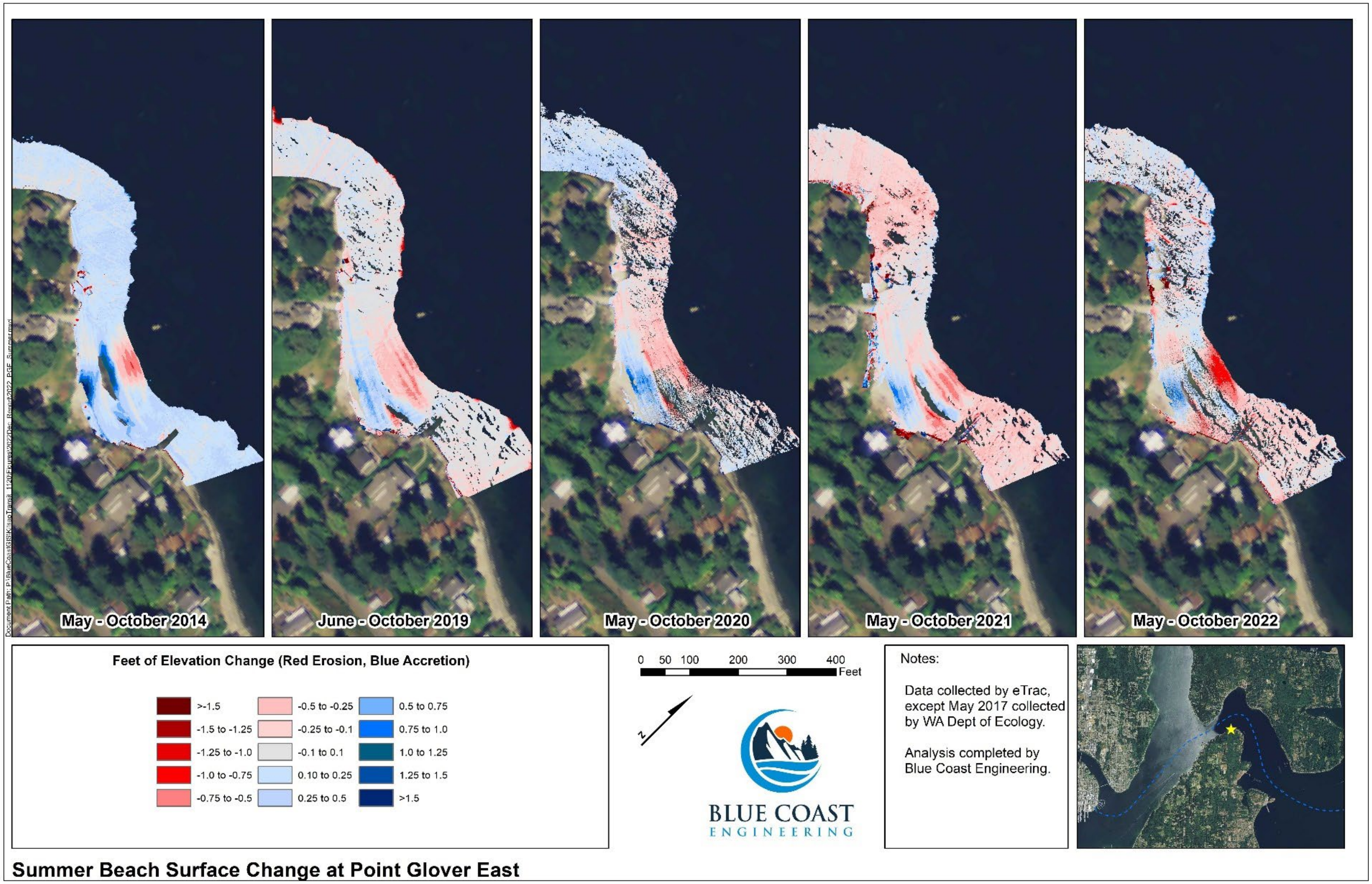
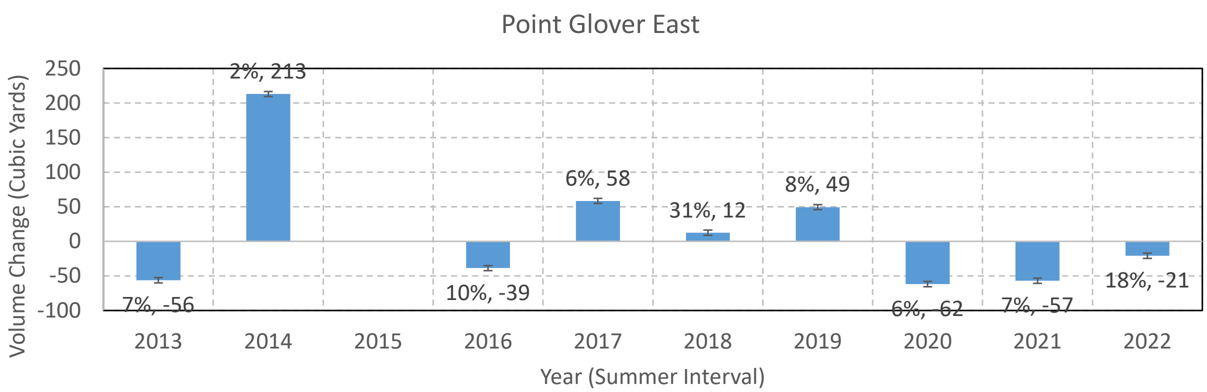


Figure 12. Point Glover East summer elevation change in 2014, 2019, 2020, 2021, and 2022.

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).In other words, the amount of material gained (accretion) or lost (erosion) within an area of the beach outlined in blue in Figure 13 is different from one year to the next primarily because of changes in weather patterns from one year to the next. 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 a net increase in volume of sediment within the calculation area and a negative number indicates net decrease in volume over the interval of calculation (summer or annual).

The total beach volume change between May and October 2022 (summer interval) was a net loss of 21 cubic yards (CY), compared to a net decrease of 57 CY during the summer interval in 2021 (Figure 14, top); so less material was lost in summer 2022 as compared to summer 2021. The volume change in 2022 is consistent with the magnitude of volume decrease which occurred in 2013, 2016, 2020, and 2021. On an annual basis the volume change was a net loss of 21 CY which is also smaller decrease than in 2021 (-48 CY) and within the range of change during previous years (2014-2015 and 2017-2018).



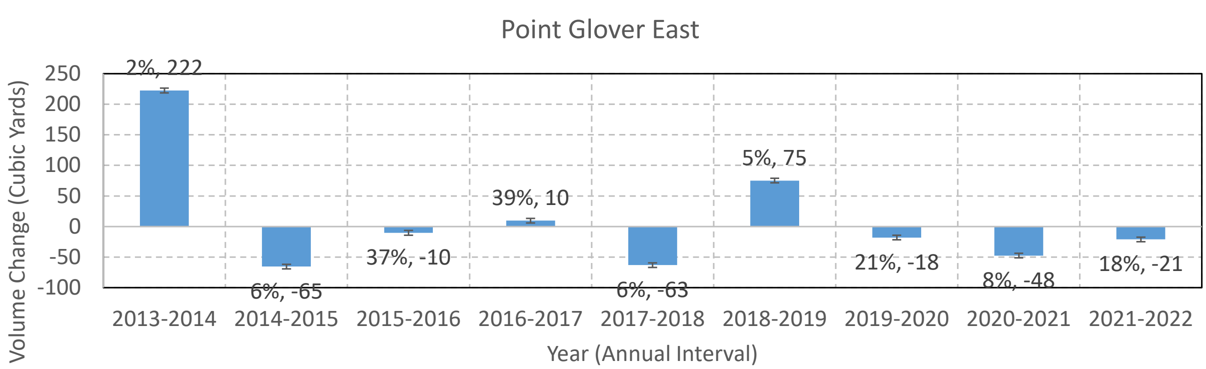


Figure 14. Volume change (cubic yards, CY) in calculation area at Point Glover East. The volume change (CY) and error as a percentage of the total change are shown for each measurement.

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). Laser scanning surveys are not conducted along Port Orchard.

The beach photo observations at sites PO_02 and PO_03 recorded in May and October 2022 are consistent with the seasonal and annual variability. Figure 15 shows time series of beach elevation from 2014 to 2022 (relative to the first survey in 2005) at PO_02 and PO_03. At PO_02 there was erosion of over 1 foot of beach between May 2016 and May 2019, the elevation of the beach has changed by less than 0.5 feet since May 2019 (Figure 15 upper plot). The beach elevation at PO_02 decreased by approximately 0.25 ft from October 2021 to October 2022. The photos of site PO_02 clearly show the beach has become coarser as the smaller sediment has been eroded. This is likely because this site is exposed to wind-waves from the southwest and there is a shoreline structure which reflects waves and can exacerbate erosion.

At PO_03, there was also a significant change in beach elevation beginning in May 2016 which resulted in a net increase of 0.5 feet in beach elevation by May 2017, but there has been less than 0.25 feet of beach elevation change since 2017.The beach elevation did not change at PO_03 from October 2021 to May or October 2022. PO_03 is in a small cove, is sheltered from wind waves, and has a natural shoreline, therefore the beach elevations and substrate do not vary over time as much as site PO_02.

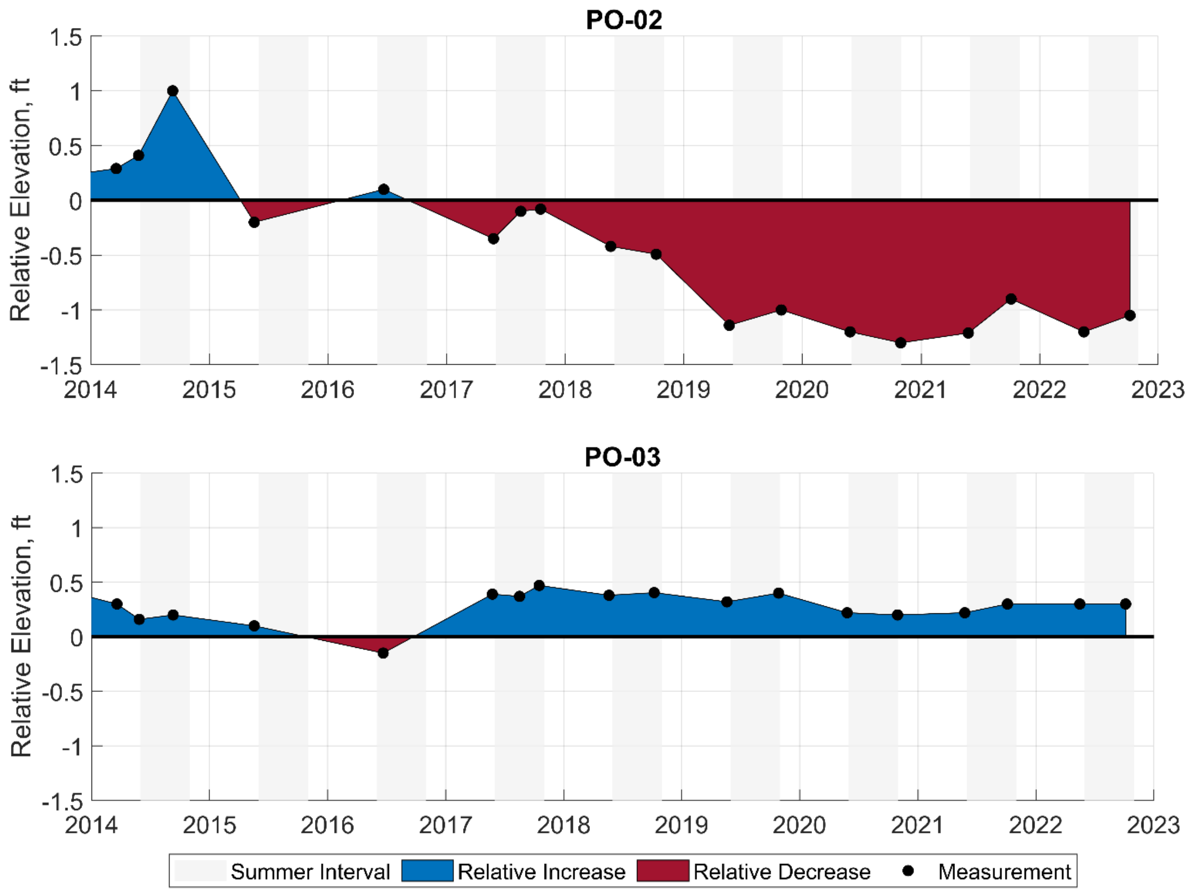


Figure 15. Time series of relative beach elevation from 2014 through 2022 at beach photo survey sites PO_02 and PO_03. Blue indicates accretion relative to the 2005 starting point and red indicates erosion relative to the 2005 starting point.

3.3 Point White

Point White is the most dynamic shoreline reach in the study area because of a larger degree of exposure to wind-waves, the lack of sediment supply, and placement of shoreline structures lower on the beach. 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 2022 at PW_05 and PW_06 which are representative of conditions at Point White. The beach elevations at both of these sites decreased and are at the lowest level since 2005. All of these sites (PW_01 through PW_06) are at the start of the drift cell and are sediment-starved.

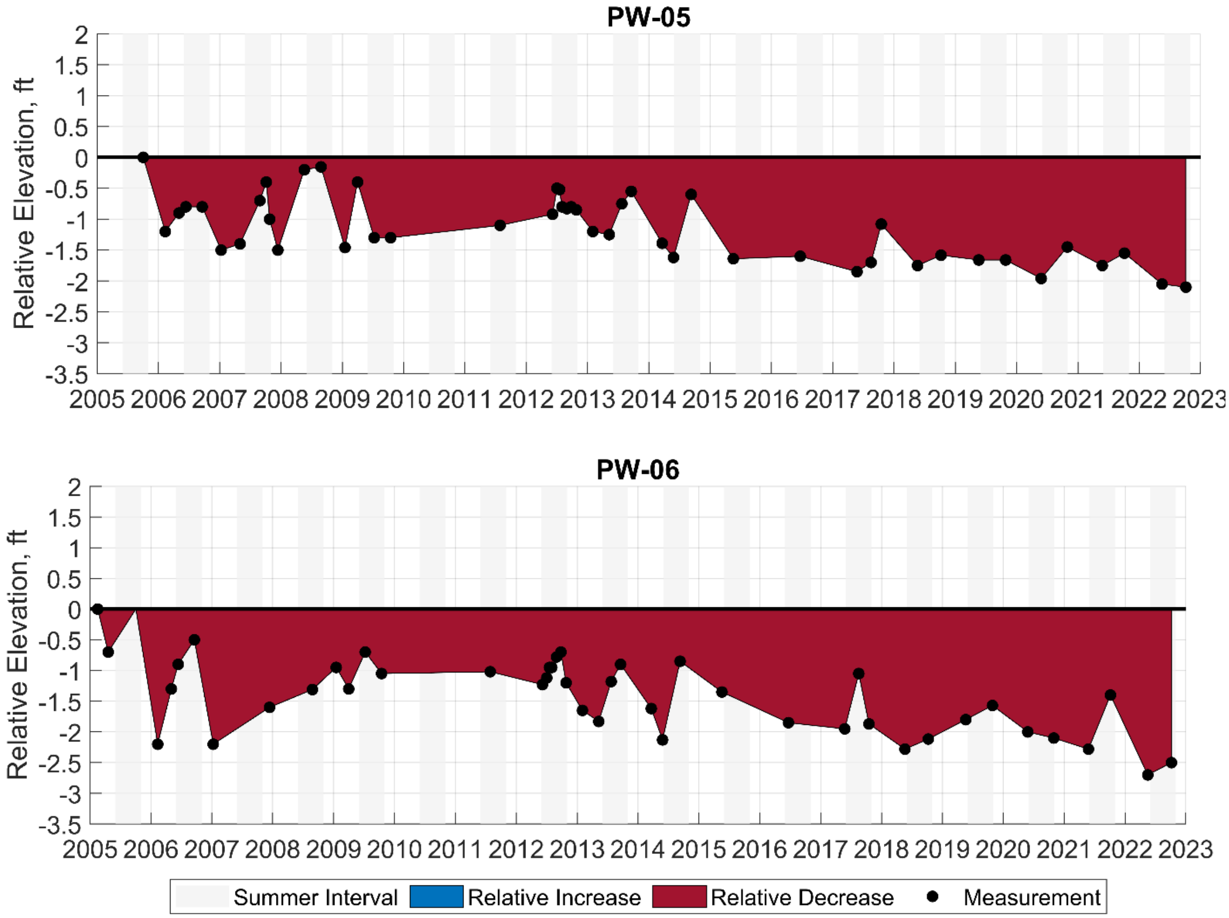


Figure 16. Time series of relative beach elevation from 2005 through 2022 at beach photo survey sites PW_05 and PW_06. Blue indicates accretion relative to the 2005 starting point and red indicates erosion relative to the 2005 starting point.

Point White sites PW_07 through PW_18 exhibit seasonal and annual fluctuations on the order of 1 ft (Figures A-57 through A-68). 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. Beach elevation measurements at PW_14 have fluctuated over 1 ft from 2017 to 2019 but in 2022 there was minimal change and photo observations indicate very low levels of beach sediment at the bulkhead interface (Figure 17). At site PW_17, the beach elevation decreased by 1.5 ft during the October 2021 to May 2022 winter interval and then increased by 1 ft during the 2022 summer interval, indicating a strong seasonal cycle at this site. At PW_18, the beach elevation decreased 0.75 ft in 2022 even though in 2021, the beach had increased in elevation to the highest it had been since 2017.

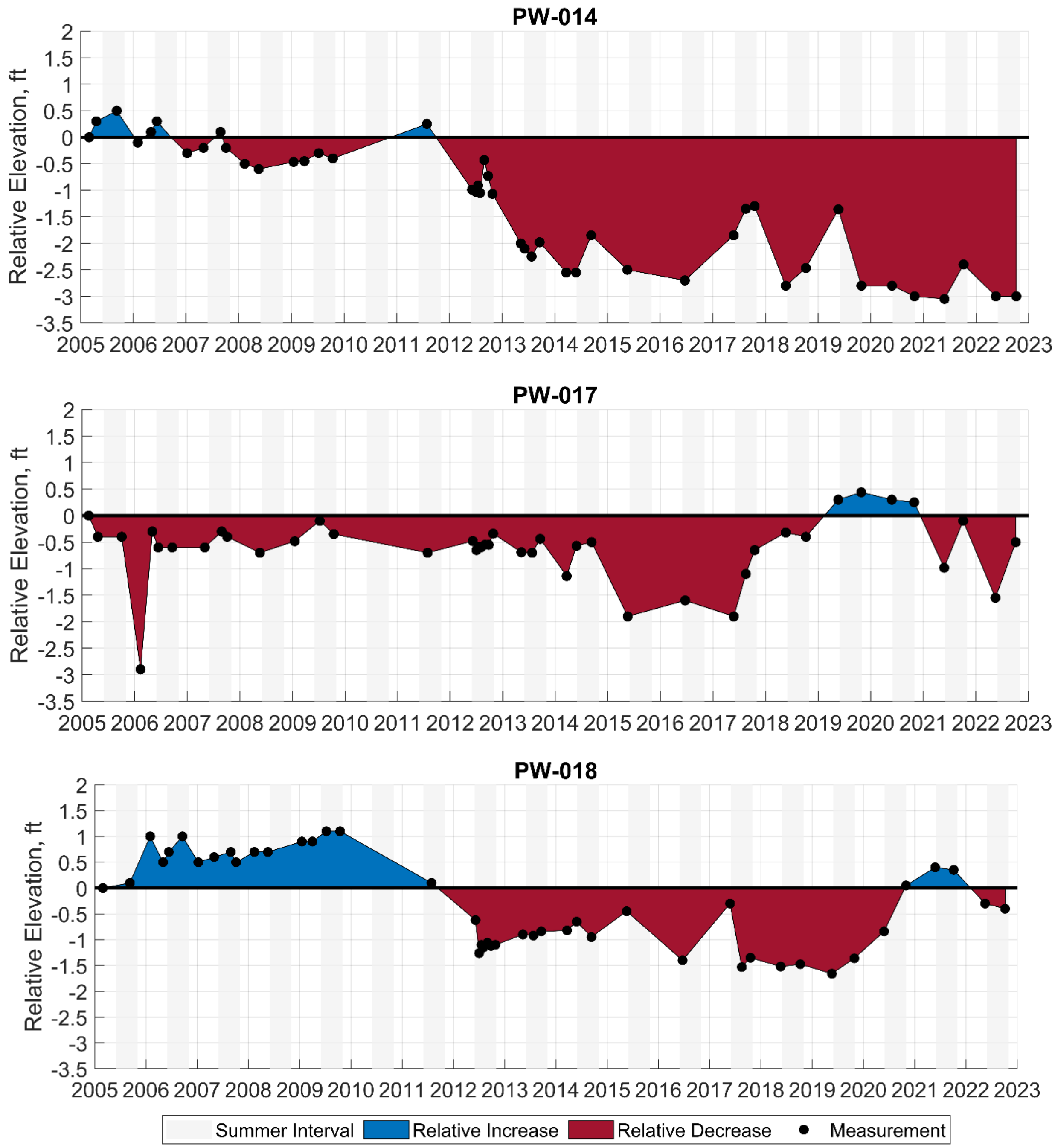


Figure 17. Time series of relative beach elevation from 2005 through 2021 at beach photo survey sites PW_14 and PW_18. Blue indicates accretion relative to the 2005 starting point and red indicates erosion relative to the 2005 starting point.

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 being farther from the entrance to Rich Passage with less exposure to wind-waves and vessel wakes as well as shallower sloping beaches with a wider low tide terrace that is farther from the navigation channel. In 2022, at PW_21 and PW_24 the beach elevation decreased by 0.5 ft during the 2021 to 2022 winter interval and increased slightly (0.1 ft) during the summer interval of 2022 (Figure A-74 and A-75).

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 shows waves of sediment moving obliquely relative to the shoreline, whereas the summer survey difference map shows primarily accretion on the upper beach and erosion on the mid-beach, a typical seasonal pattern (Figures 18 and 19). Elevation changes are negligible on the mid- to lower beach during the summer interval. The annual change shows more erosion than during the previous interval (2020 to 2021) but is similar to the 2018 to 2020 intervals.

The magnitude and spatial extent of the erosion and accretion patterns along Point White vary from year to year and there is not a readily observable pattern, 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 a 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 2022 (summer) was an increase of 37 CY at Point White South and a decrease of 13 CY at the Point White North survey site. The beach changes are consistent with the previous measurements at the two sites. The volume change during the summer at Point White South has been positive or no change over the last five intervals, reflecting a strong seasonal signal on this part of the shoreline due to its proximity to the ferry sailing route and exposure to southwesterly wind-waves in the winter. Accumulation of sediment in this area may also be aided by the groin-like concrete structure in the middle of the survey area. Point White North has measured similar net losses of sediment in 8 of 10 survey years since 2013 because of lack of sediment supply and extensive shoreline armoring within the littoral drift cell which both contribute to erosion. On an annual interval there was a net decrease at Point White South of 34 CY and a net decrease at Point White North of 9 CY.

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

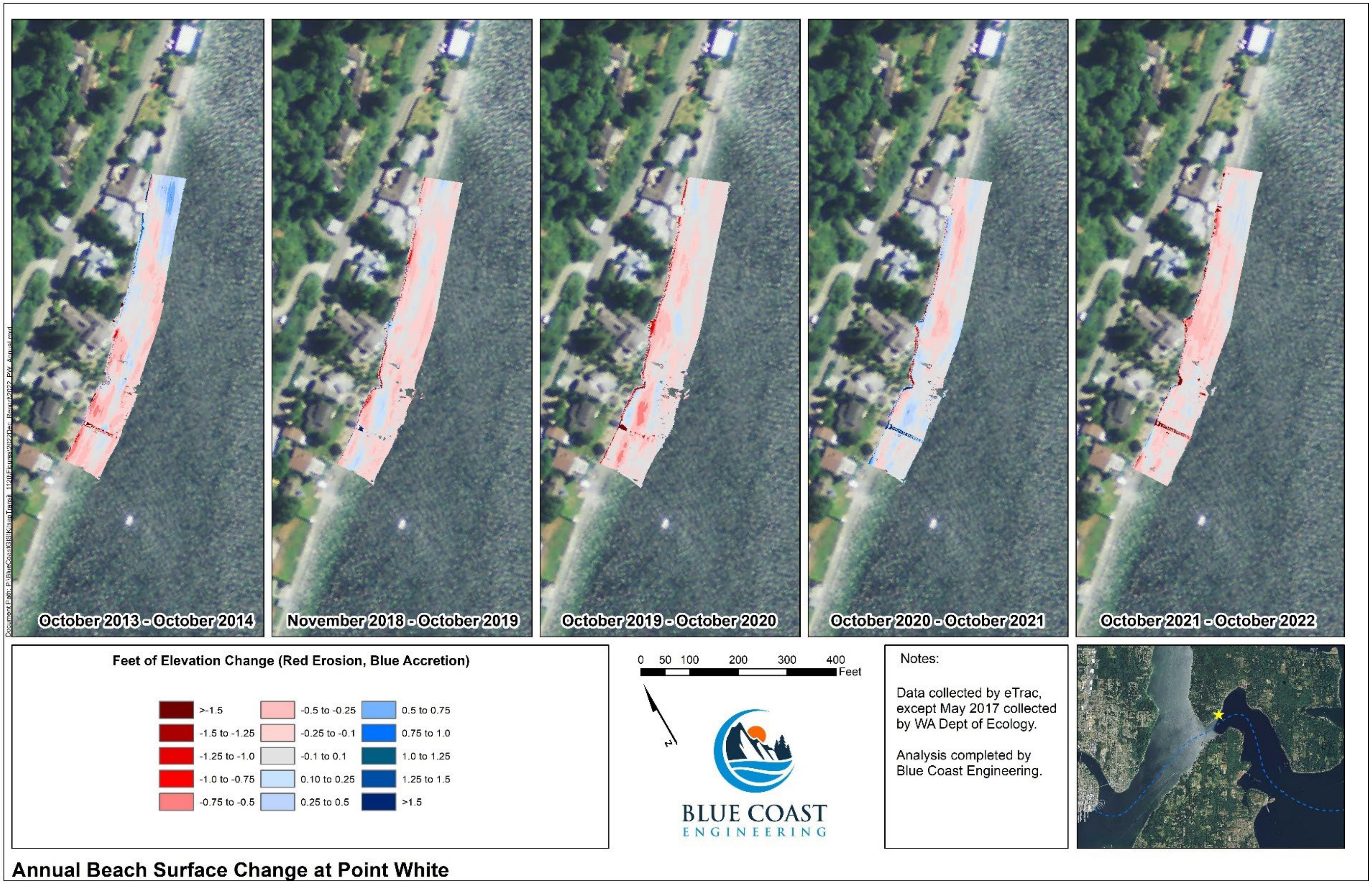


Figure 18. Point White elevation change over four 1-year intervals from 2013 to 2022.

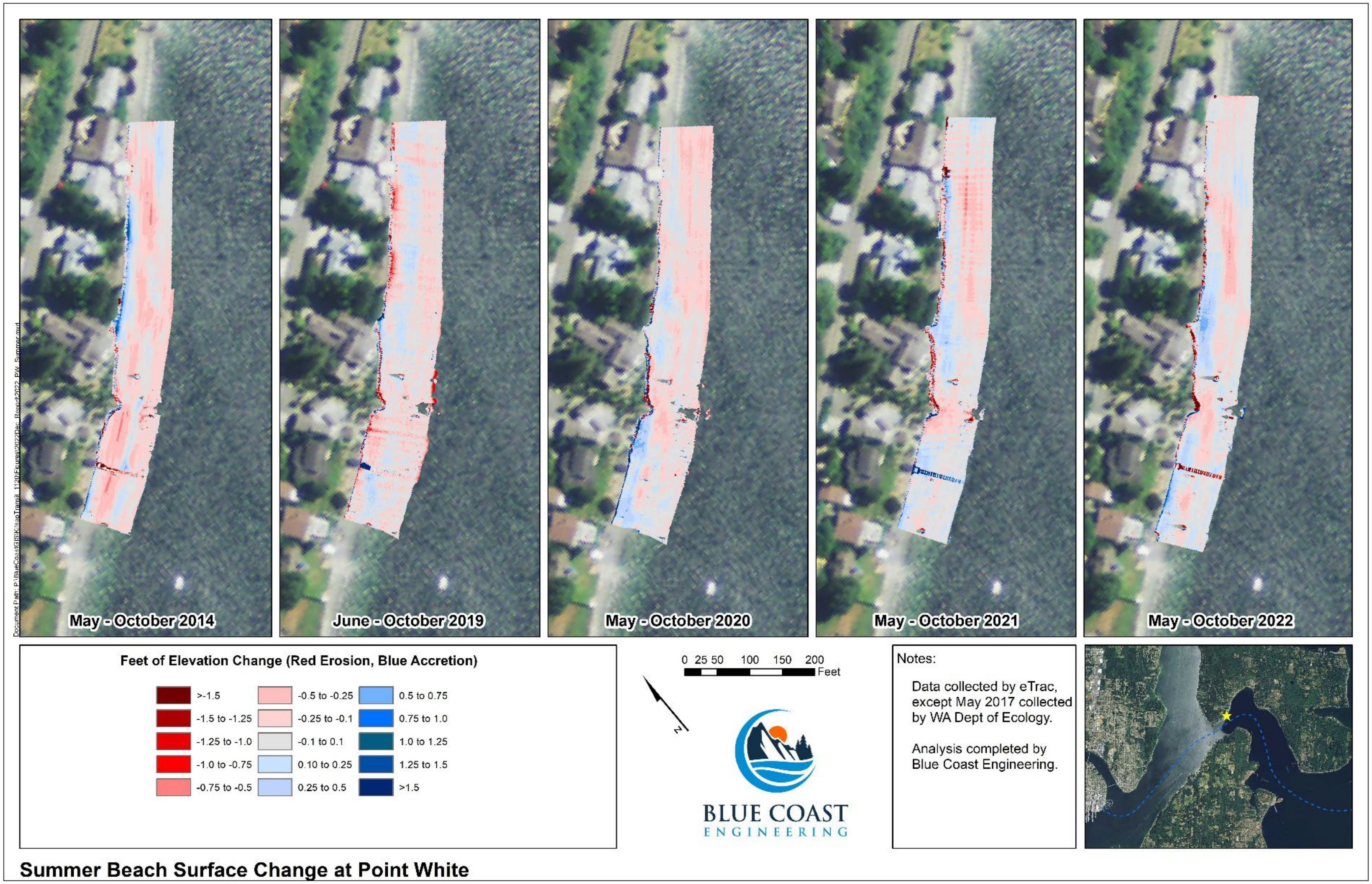


Figure 19. Point White summer elevation change in 2014, 2019, 2020, 2021, and 2022.

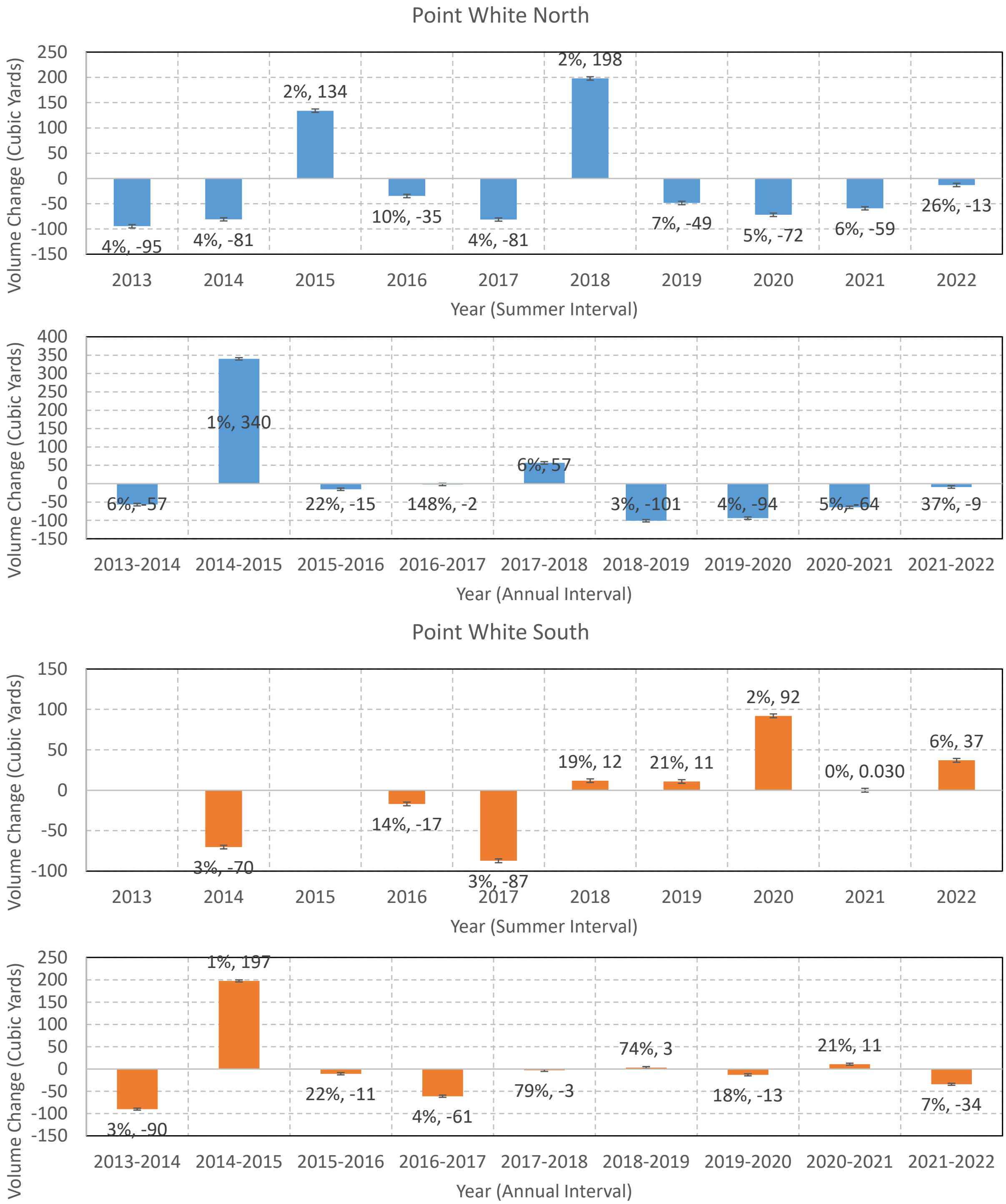


Figure 4. Volume change (cubic yards) in calculation area at Point White South and North. The volume change and error as a percentage of the total change are shown for each measurement.

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

4.0 Conclusions

Beach photo observations and laser scanning surveys were completed during the sixth year of MV *RP1* (and sister vessels) operations in May and October 2022. The observations indicate that the seasonal and interannual patterns are consistent between 2017 through 2022 and years prior to vessel operations.

The 2022 measurements at Port Orchard and Pleasant Beach show varying patterns of erosion and accretion which are consistent with years prior to vessel operations. East Bremerton monitoring sites continue to exhibit long-term depletion of sediment at the updrift end of the drift cell and seasonal cycles of accretion and erosion of sediment along the middle to end of the drift cell.

Point White is the most dynamic shoreline reach in the study area because of exposure to wind-waves, the lack of sediment supply, and the presence of shoreline armoring. Monitoring sites along Point White continue to exhibit long-term depletion of sediment near the updrift end of the drift cell (similar to East Bremerton) as well seasonal cycles downdrift, towards Lynwood Bay. Volumetric change analysis of beach elevations at Point White are within the range of expected results and no discernable trend is apparent in the data over the past 10 years of monitoring.

At Point Glover, localized effects within pocket beaches, such as changes in creek flows, result in variable sediment transport patterns. In 2022, the net change in sediment volume at the Point Glover East monitoring site are within the range of expected results and no discernable trend is apparent in the data over the past 10 years of monitoring.

The measurable beach response along the reaches monitored in 2022 cannot be correlated to Bremerton-Seattle POFF operations. The beaches will be monitored again in May 2023 to record both the seasonal and interannual cycles of beach response during the seventh year of operation of Kitsap Transit POFF operations through Rich Passage.

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