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North Cove Dynamic Revetment Monitoring: Winter 2018-2019

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Acknowledgements

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Abstract

A dynamic revetment, spanning over 2 km of shoreline, was constructed at North Cove, Washington in December 2018 in order to prevent further erosion of the land. The revetment consists of quarry spalls ranging in size from pea gravel to small boulders. The rocks are expected to fracture and round over time due to wave action. The Washington State Department of Ecology is conducting topographic surveys to monitor how the dynamic revetment, and the beach in front of the revetment, change over time. In addition, over 300 rocks have been tagged so their movement can be tracked. In the limited time it has been installed, the dynamic revetment has proven to be dynamic in nature—the rocks move and respond to the hydrodynamic forces, while dissipating wave energy, protecting the upland, and facilitating the deposition of sand at the toe of the revetment during moderate wave and water level conditions.

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Introduction

The shoreline of North Cove has experienced significant erosion for decades. Since 1871, the shoreline has retreated to the northeast by 4 km at a rate of up to 45 m/y (Talebi et al., 2017). Hundreds of homes have fallen into the ocean as a result, and State Route (SR)-105 was relocated. To prevent further loss of the North Cove community, quarry rock has been placed on the upper beach to protect the uplands from attack by ocean waves. This dynamic revetment simulates a natural cobble berm that absorbs wave energy and helps to stabilize the beach from further lowering and retreat. However, little to no data has been collected to evaluate the performance of dynamic revetments as an erosion control structure in Washington or around the world.

The purpose of this monitoring effort is to evaluate the effectiveness of the cobble placed on the upper beach in dissipating wave energy and reducing or preventing erosion of the uplands. In addition, the alongshore transport of individual cobbles are being tracked to quantify how far they move over time, a factor in determining the timescale for renourishment of the material. This report focuses on data collected to date, primarily over the winter of 2018-2019, when topographic surveys were collected quarterly between June 2018 and March 2019 and monthly during the winter from December 2018 through March 2019.

Survey site

North Cove is located on the north side of the entrance to Willapa Bay in southwest Washington. The monitoring surveys focus on the area between the SR-105 groin and Warrenton Cannery Rd, where the dynamic revetment was constructed in December 2018 (Figure 1). Cross-shore transects for topographic surveys are spaced at 100-m intervals over 3.1 km alongshore. Tagged rocks were placed for tracking at three locations where closer-spaced transects were defined: two sites east of Old SR-105 (213 and 216; five 10-m spaced transects with a 40-m alongshore extent) and an additional site west of Old SR-105 (219-220; ten 20-m spaced transects with a 180-m alongshore extent). In June 2018, prior to the quarterly dynamic revetment monitoring, a comprehensive beach and nearshore survey was conducted of a larger area spanning approximately 6.2 km alongshore, starting at the southeast extent of Graveyard Spit and ending 650 m north of Warrenton Cannery Rd (spanning transects 52-243 in Figure 1).

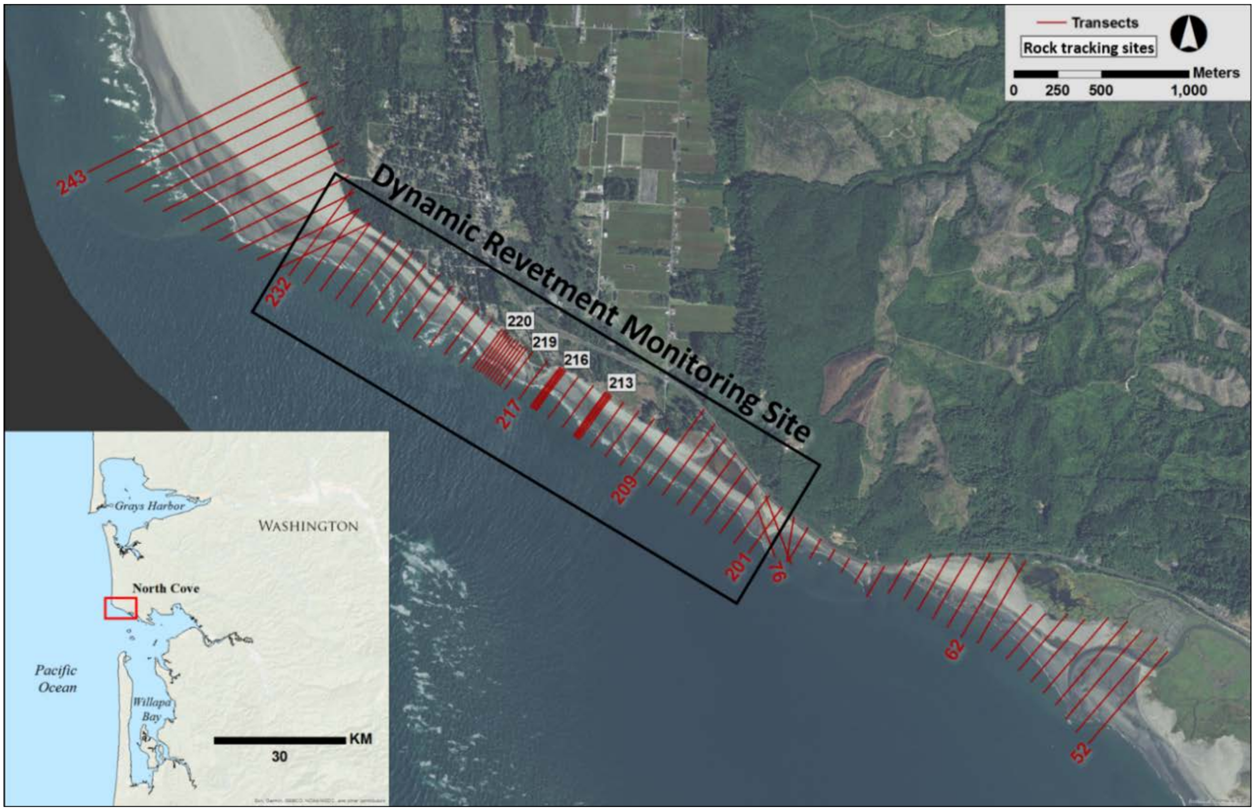

Figure 1: North Cove dynamic revetment monitoring survey site

Data Collection

Overview

In June 2018, an initial beach and nearshore survey was collected that included the surrounding area northwest and southeast of the dynamic revetment for geomorphic context (Figure 2). This survey used a combination of boat-based topographic lidar and multibeam bathymetry as well as ground-based beach topography data to create a 1-m digital elevation model (DEM) of the overall North Cove site.

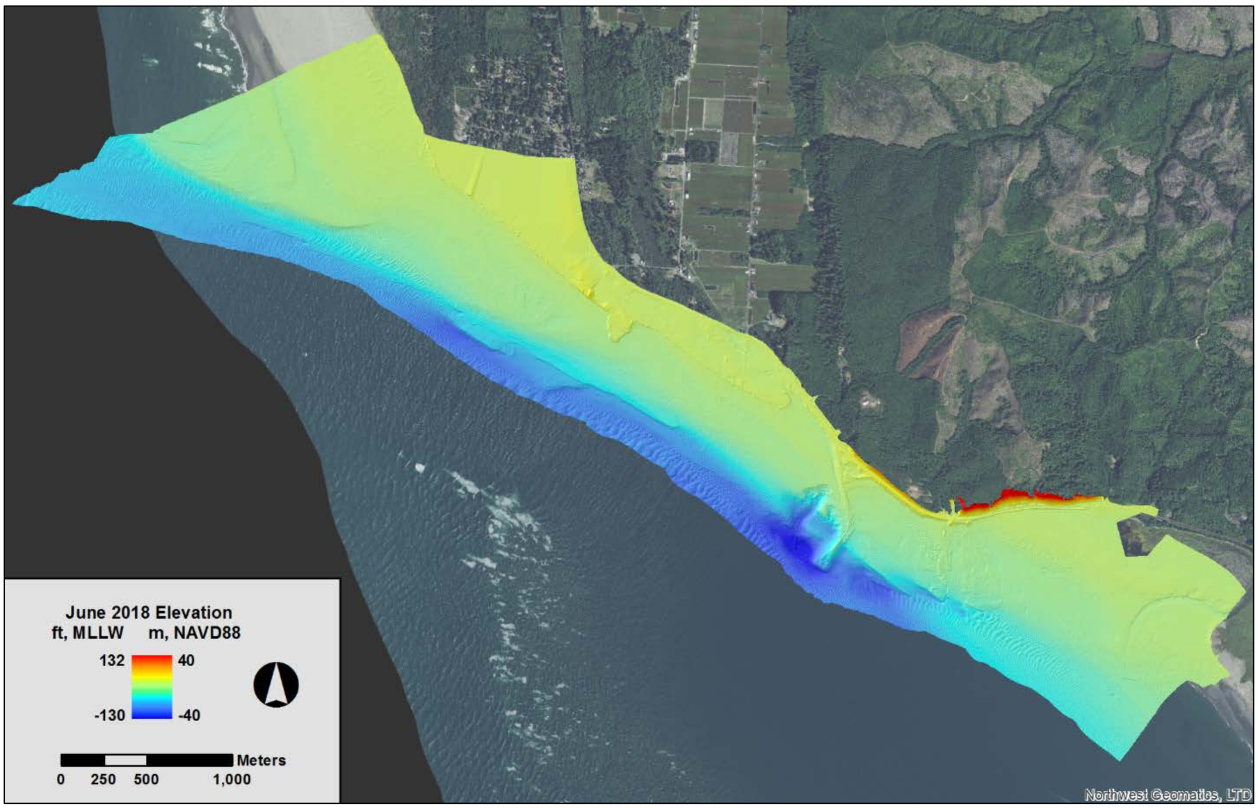

Figure 2: Topographic and bathymetric DEM (1-m resolution) of North Cove from June 2018

Beach topographic data have been collected quarterly since June 2018, with monthly surveys collected over the winter between December 2018 and March 2019 (Table 1). These surveys focus on the dynamic revetment location, from the SR-105 groin to Warrenton Cannery Rd. Rock tracking began in January 2019 after placing rocks at two sites east of Old SR-105. In February 2019, rocks were placed at an additional site west of Old SR-105. Rock tracking is performed during the same time as the quarterly and monthly topography surveys, though it requires three additional low tides.

Table 1: List of survey dates and activities

Survey Dates	Survey Activities
6/6 – 6/16/2018	Initial topographic survey with extended bounds, plus nearshore multibeam bathymetry and boat-based topographic lidar
9/10 – 9/11/2018	Quarterly topographic survey
12/20 – 12/21/2018	Quarterly topographic survey
1/17 – 1/19/2019	Monthly winter topographic survey and rock placement and tracking at sites 213 and 216
1/24 – 1/25/2019	Rock placement and rock tracking at sites 213 and 216
2/13/2019	Rock placement at site 219-220
2/18 – 2/20/2019	Monthly winter topographic survey and rock tracking
3/17 – 3/18/2019	Monthly winter/quarterly topographic survey and rock tracking
3/22 – 3/23/2019	Rock tracking

Survey methods

Beach topography data are collected with Real Time Kinematic Global Navigation Satellite System (RTK-GNSS) in two ways: on foot and using an all-terrain vehicle (ATV). A local base station set up on a nearby survey monument (Table 2) sends corrections to the GNSS receivers so that data are collected with 2-3 cm accuracy in real time. Surveyors wear backpacks with a mounted GNSS receiver to collect cross-shore transects and delineate the top and toe of the revetment (Figure 3). For more regional alongshore data, a GNSS receiver is mounted to an ATV and the surveyor drives along the beach (Figure 3). For locations that cannot be accessed on foot, such as areas with dense woody debris, a survey rod with an extendable arm is used to reach the ground (Figure 3).

Table 2: Grid and local geographic coordinates established for monument Citronella; NAD83(2011) Washington State Plane South, NAVD88 (GEOID12B)

Easting (m)	Northing (m)	Elevation (m)	Latitude (DMS)	Longitude (DMS)	Height (m)
230974.708	160533.458	4.845	46 43 24.96493	124 01 13.98942	-19.240

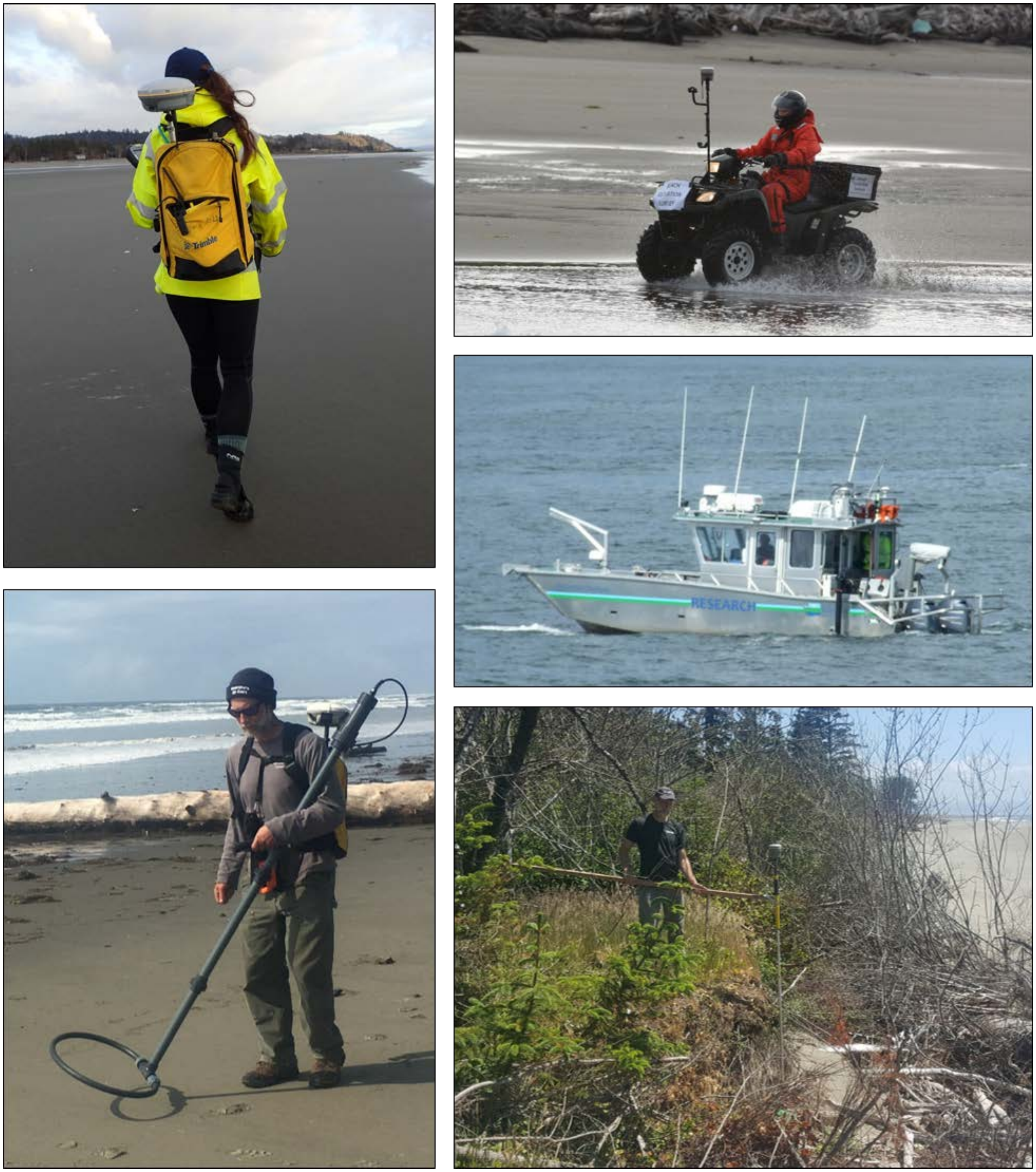

Figure 3: Photos showing various survey methods: backpack-based surveying, ATV surface mapping, the R/V George Davidson, survey rod in dense brush, and rock tracking

Rocks used for tracking are made up of angular cobbles taken from the revetment and rounded cobbles from off-site. Rocks are tracked by first installing Passive Integrated Transponder (PIT) tags in selected cobbles and boulders. Each electronic tag has a unique code that is used to identify the rock. Tagged cobbles were placed at pre-determined elevations along transects on the revetment at each site, and several boulders were tagged in-situ.

A radio-frequency identification (RFID) antenna is used to locate the rocks on the beach (Figure 3). The RFID antenna sends out electromagnetic pulses which charge nearby PIT tags and prompt a return signal. Once a tagged rock is located, its position is surveyed with a GNSS receiver mounted to a survey rod. Depending on the size of the tag and its orientation to the antenna, tags can be identified up to 1-1.5 m away, even if buried by sand.

Multibeam bathymetry and mobile lidar data are collected aboard Ecology's research vessel, *George Davidson* (Figure 3). Two R2Sonic 2022 multibeam echosounders are deployed from either side of the vessel for swath coverage of up to 6.5 times water depth. The sonars are operated at 400 kHz using alternating pings. Data are collected with 100% overlap at a survey speed of around 3.5 kt to maintain coverage of a 0.5-m grid. Sound velocity casts are collected at hourly intervals and applied to the data in real time.

The lidar system scans the shoreline in a vertical line pattern as the vessel moves alongshore. The angular interval between laser pulses is 0.09° such that at a distance of 100 m, the vertical point spacing is 1.6 cm. Typically, the vessel is 20-100 m from the shoreline while scanning, depending on water depth and breaking waves.

Ground control targets (1 m^2 sheet metal, spray-painted flat white) are set up on the beach for checking positional alignment of the laser point cloud with independently surveyed GNSS points. High-resolution digital photos of the shoreline are taken from the vessel simultaneously to document the landscape.

Results

Morphology change

Topographic data collected during each quarterly and monthly survey are compiled into a single digital elevation model (DEM) of the survey area. These DEMs can be differenced to quantify change between the surveys for understanding how the beach and dynamic revetment change on a monthly and seasonal time scale. The DEMs and change surfaces for each quarterly or monthly time period for the survey area are shown in two sub-regions, west (Figures 4-5) and east (Figures 6-7) of Old SR-105. For each change surface shown, blue areas indicate accretion and red shows erosion of ± 0.1-1 m (0.3-3.3 ft). Note that volume change calculations are based on the common area between the two surveys being compared and are not directly comparable across all surface change analyses. While surveys are typically conducted during the lowest tides available, wave and water level conditions at the time of each survey determine the area of beach that is accessible to surveyors (Appendix; Figures A-1 and A-2).

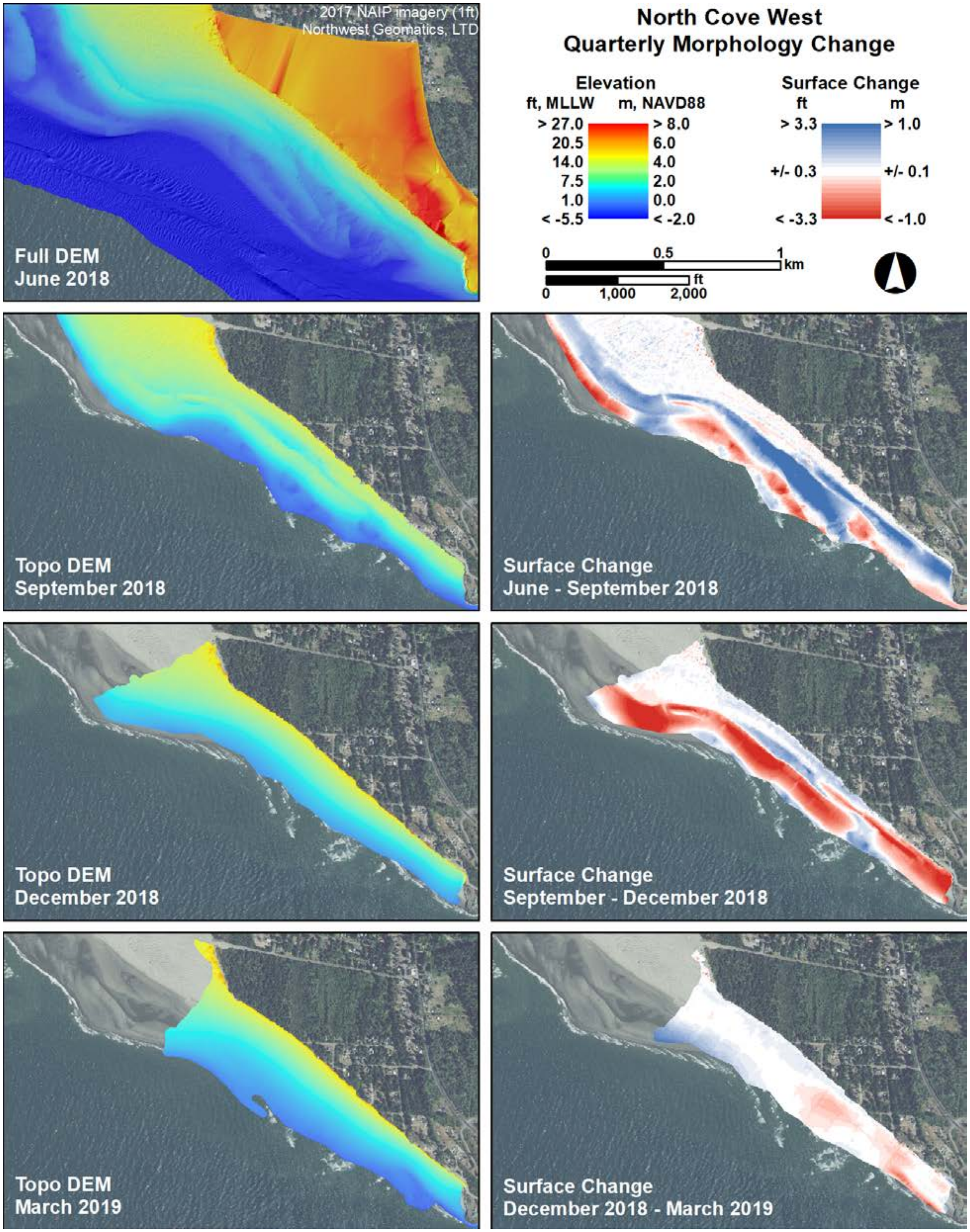

Figure 4: Digital elevation models (DEMs) produced from quarterly surveys for the west half of the survey area and morphology change measured between each survey; 1-m DEM resolution

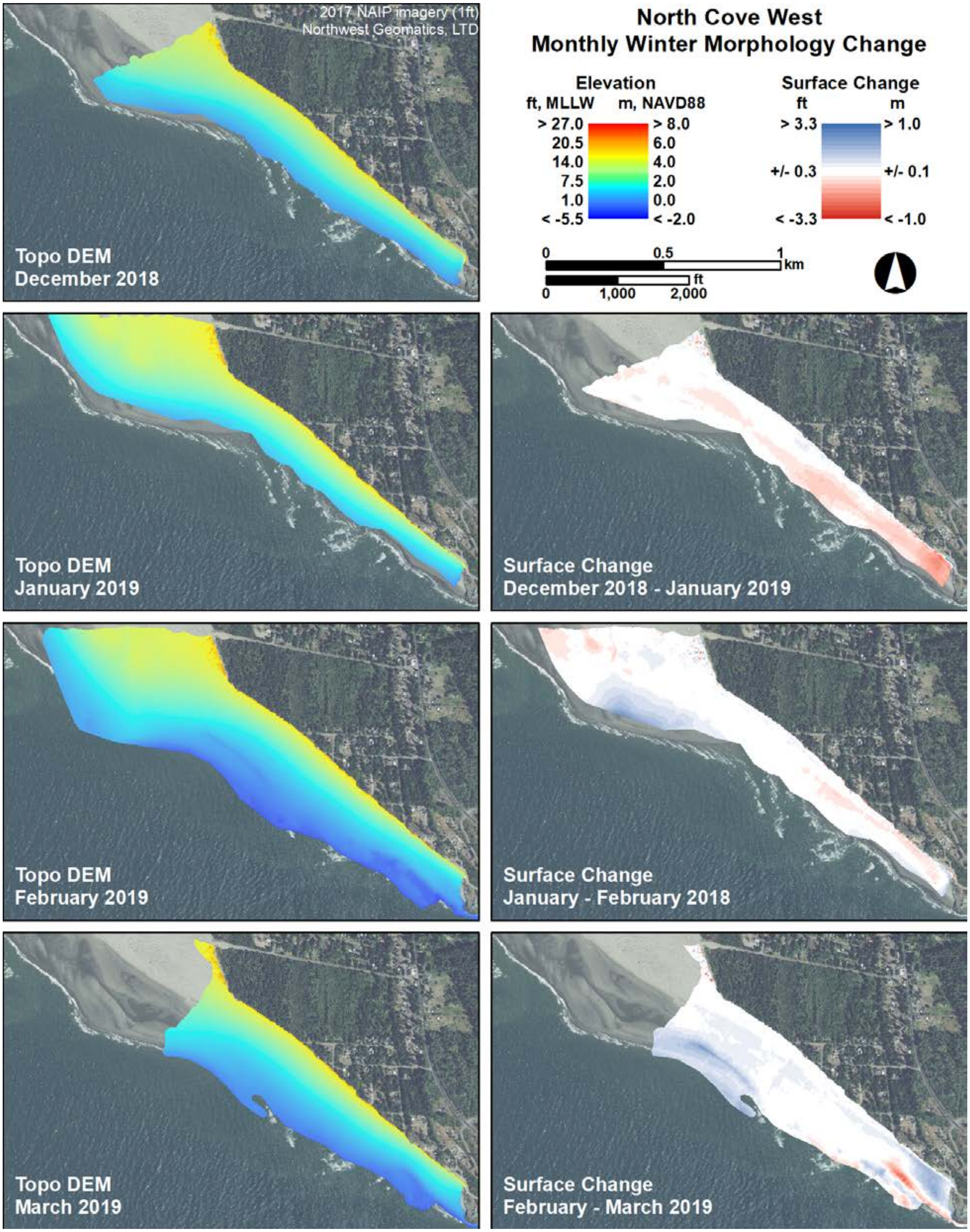

Figure 5: Digital elevation models (DEMs) produced from monthly winter surveys for the west half of the survey area and morphology change measured between each survey; 1-m DEM resolution

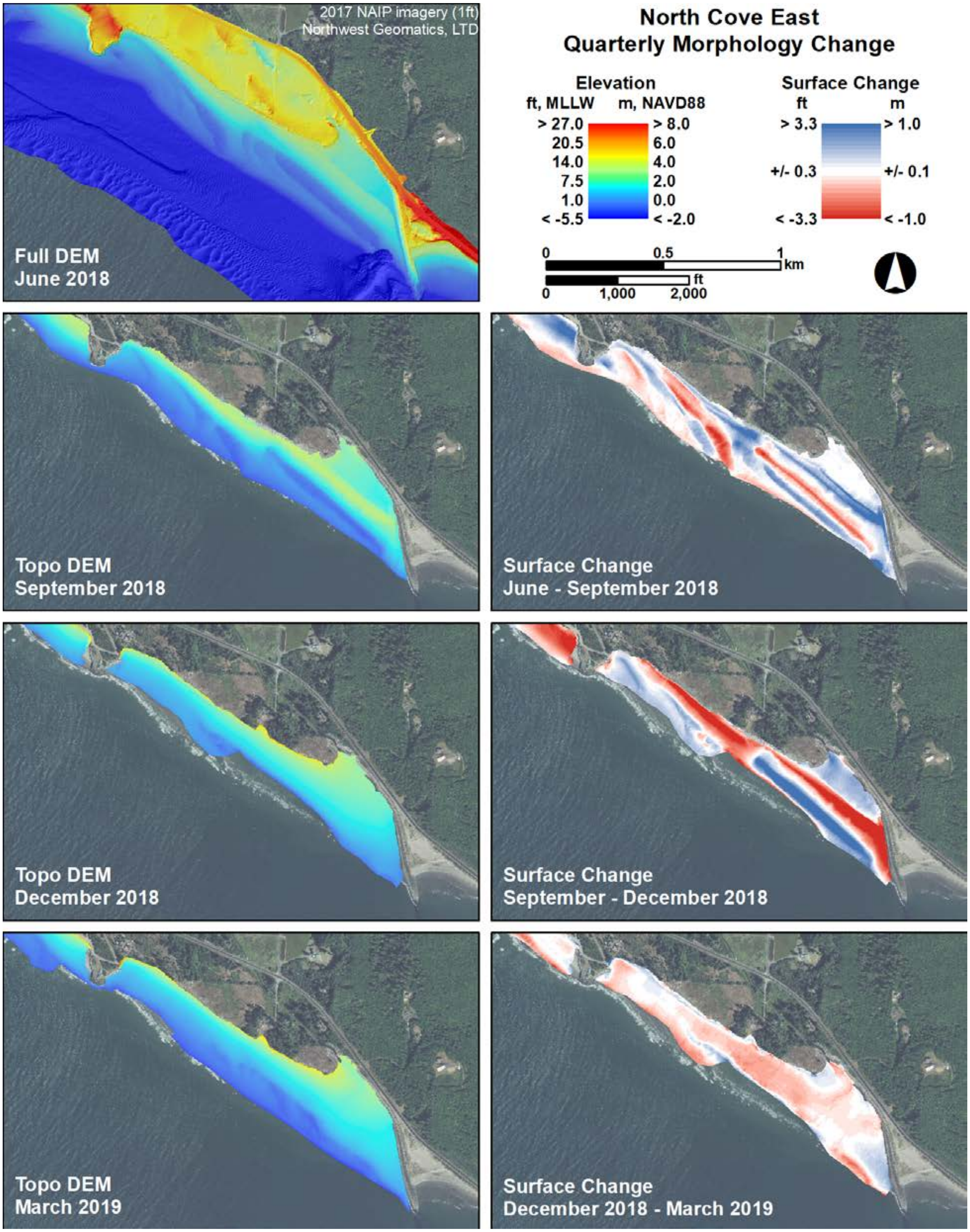

Figure 6: Digital elevation models (DEMs) produced from quarterly surveys for the east half of the survey area and morphology change measured between each survey; 1-m DEM resolution

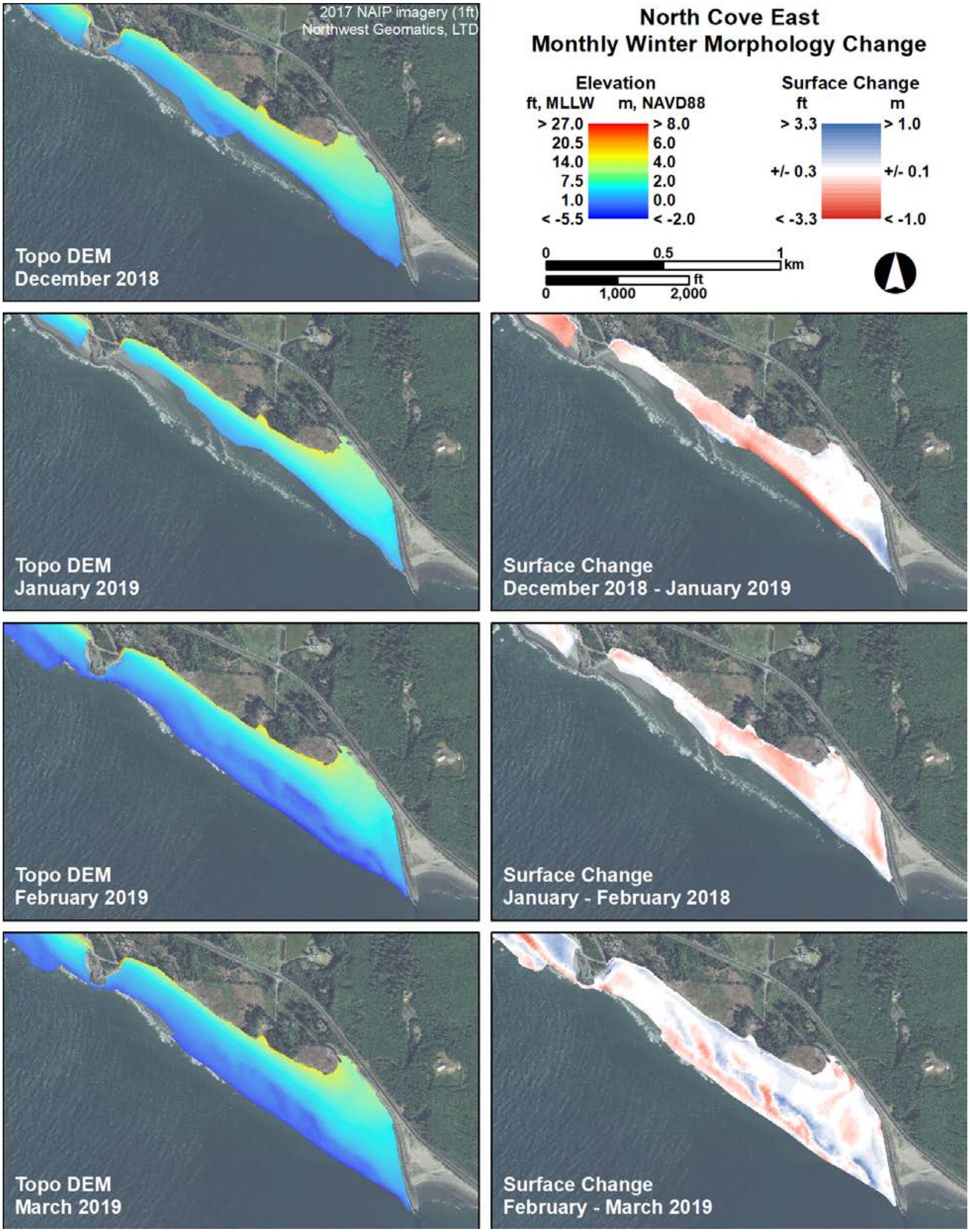

Figure 7: Digital elevation models (DEMs) produced from monthly winter surveys for the east half of the survey area and morphology change measured between each survey; 1-m DEM resolution

Over the entire survey period from June 2018 to March 2019, June to September showed the largest gain in sediment across the survey area, with 143,800 m^3 of net accretion (Figures 4 and 6). Most of this accretion is attributed to a large intertidal sand bar that formed on the west end of the survey area in September below 1.5 m NAVD88 (5.8 ft MLLW) (Figure 8). The sand bar was approximately 1.5 m high at its peak and 90 m wide, stretching for almost 1.5 km alongshore.

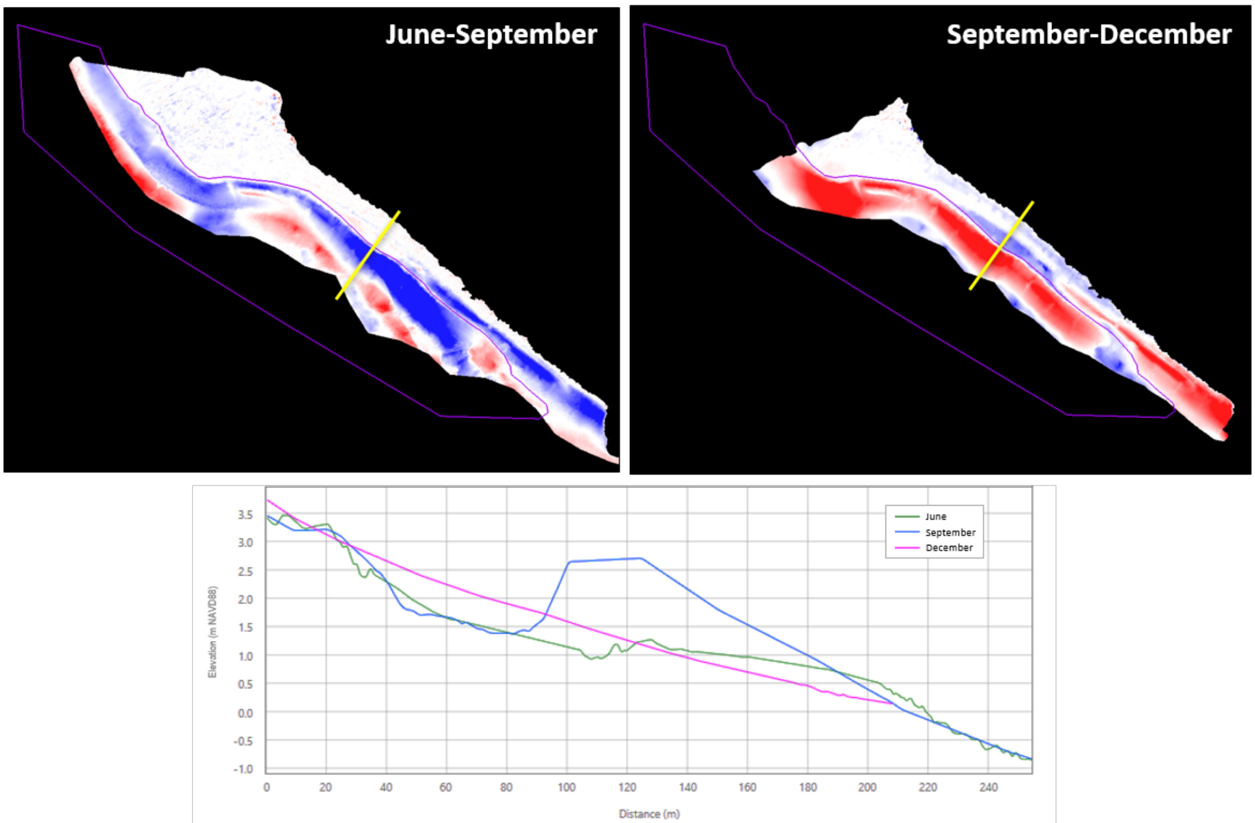

Figure 8: Intertidal sand bar evolution from June to December 2018 west of SR-105

During fall, there was an increase in the wave energy between September and December (Appendix; Figure A2). A large storm with mean wave heights of 8.14 m (26.7 ft) struck the coast on December 20th after the dynamic revetment was constructed, and just before the December survey. The large sandbar on the west side of the survey area was smoothed out to create a uniformly-sloping beach face (Figure 8). Between September and December, a net sediment loss of 99,300 m^3 was measured over the entire survey area, though no significant retreat of the uplands was observed. About 32,400 m^3 of sediment was lost from the beach immediately west of Old SR-105 where the dynamic revetment was constructed, and beach lowering of up to 2.1 m (6.9 ft) was measured (Figure 9). These numbers are almost identical to those observed on the east side of Old SR-105 for the same period, where a loss of 31,500 m^3 of sediment was measured, with a maximum lowering of 2.1 m (6.9 ft) as well.

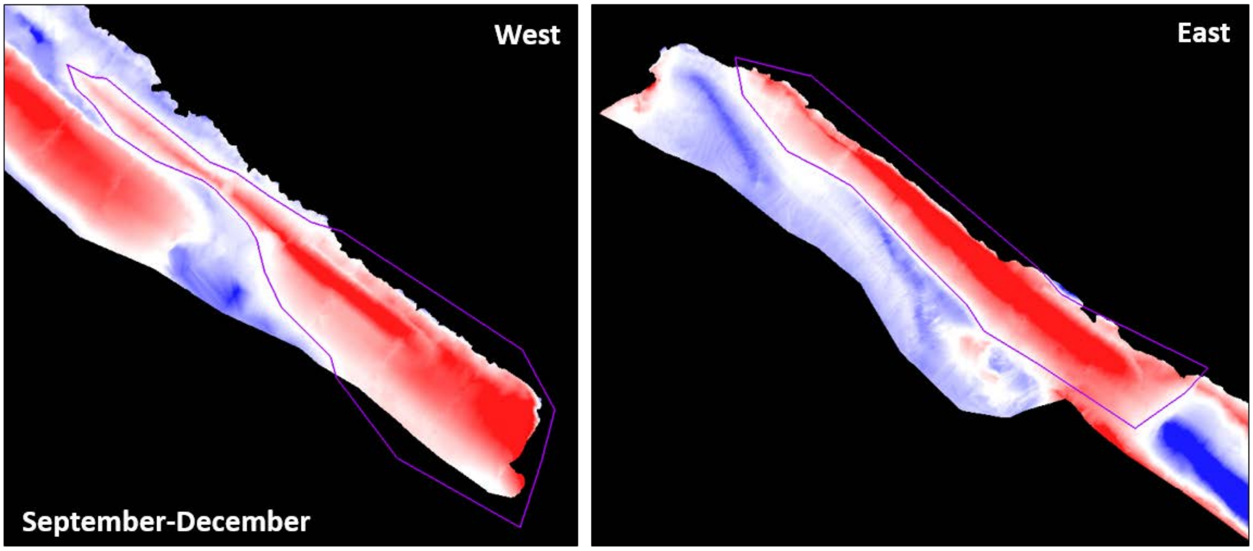

Figure 9: Areas of erosion on either side of Old SR-105 between September and December 2018

During the time when the revetment was in place from December 2018 through March 2019, the beach eroded from December to January (net loss of 38,500 m^3) and then accreted from January to March (net gain of 23,000 m^3). Prior to the January 2019 survey, two large wave events with mean wave heights around 6 m (19.6 ft) or more occurred on January 4th and again January 18th and 19th, which resulted in the January survey being the most eroded beach state out of the 9 months surveyed.

Between December and January, erosion was measured on both sides of Old SR-105 adjacent to the large riprap peninsula, with more extensive erosion on the west side (Figures 10 and 11). The accumulation measured at the top of the revetment at sites 219 and 216 is due to additional rock material placed on site between the two surveys.

West of Old SR-105, at least 5,200 m^3 of sediment was lost from the beach face, with a maximum elevation loss of 0.8 m (2.6 ft) on the beach near the riprap, tapering off to the west (Figure 10). At site 219-220, erosion was observed at the revetment toe and on the upper beach just below the toe, causing the revetment toe to shift seaward by an average of 5.6 m (18.4 ft), from mean elevation of 3.17 m to 2.58 m NAVD88 (11.3 ft to 9.4 ft MLLW) (Table 3). The revetment toe marks the upper limit of sand accumulation on the revetment face and is an indicator of beach state. A bar chart of the change in average toe elevation at the three rock tracking sites is shown in Figure 12.

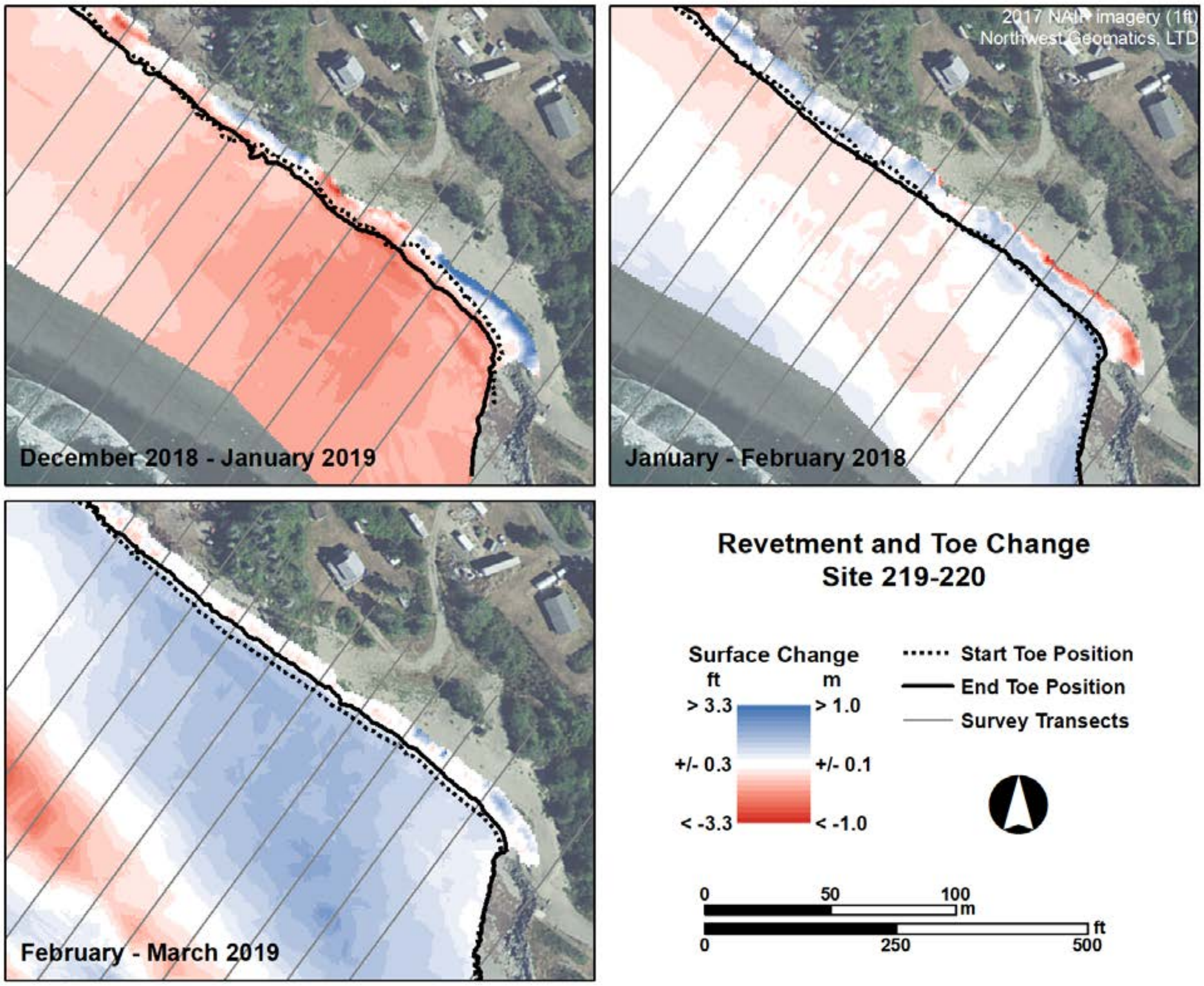

Figure 10: Monthly change in dynamic revetment morphology and toe position at site 219-220 during the winter between December 2018 and March 2019

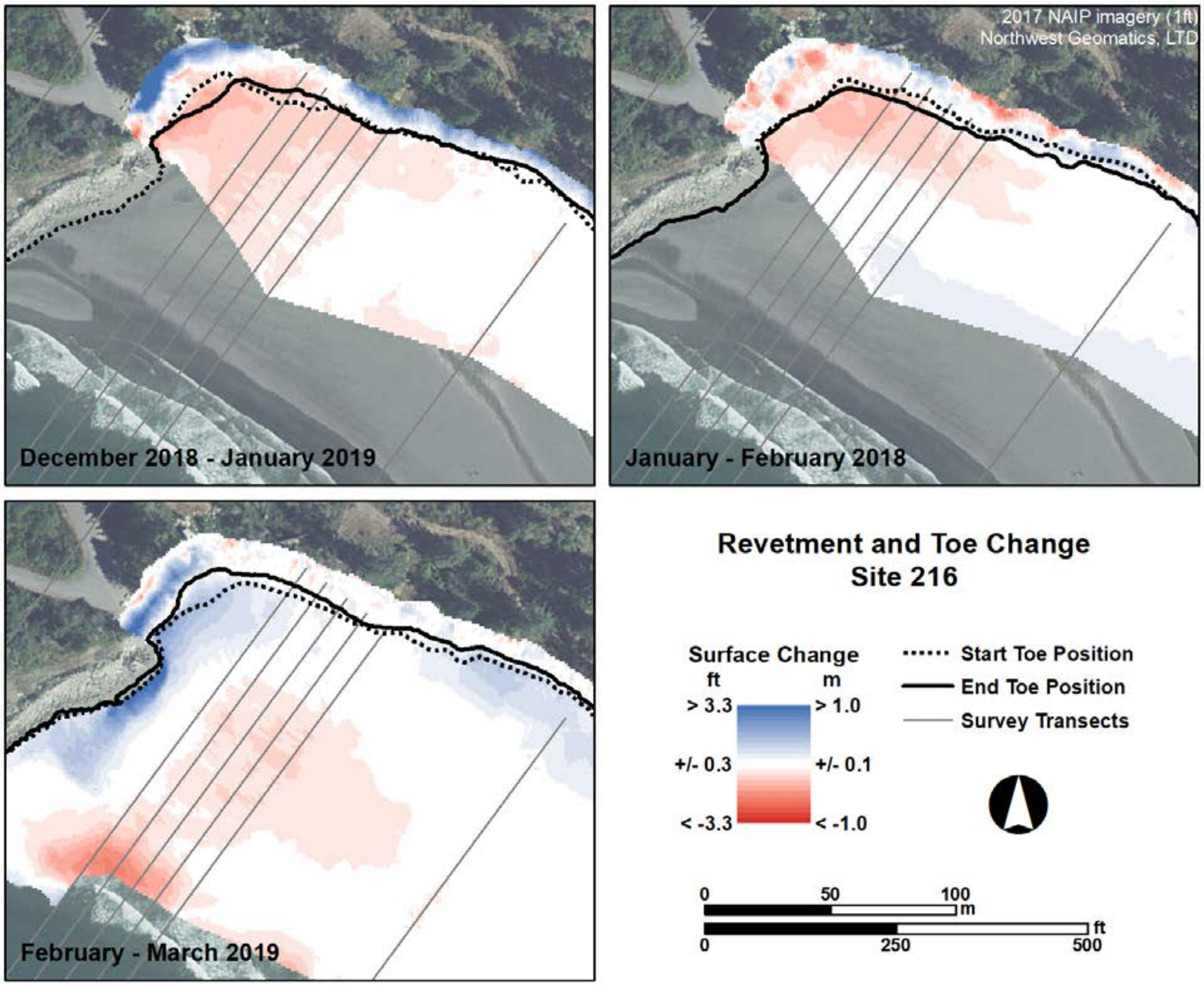

Figure 11: Monthly change in dynamic revetment morphology and toe position at site 216 during the winter between December 2018 and March 2019

Table 3: Change in elevation of dynamic revetment toe for each rock tracking site between December 2018 and March 2019

Site	Month	Revetment Toe Elevation (m NAVD88)			
		Average	St Dev	Min	Max
219-220	December	3.17	0.19	2.58	3.54
	January	2.58	0.27	1.85	2.92
	February	2.51	0.11	2.08	2.82
	March	3.17	0.12	2.84	3.38
216	December	2.33	0.11	2.07	2.54
	January	2.26	0.10	2.08	2.47
	February	1.80	0.07	1.66	1.95
	March	2.11	0.05	2.02	2.20
213	December	1.43	0.12	1.09	1.61
	January	1.77	0.10	1.57	2.02
	February	1.95	0.04	1.86	2.08
	March	2.53	0.06	2.36	2.64

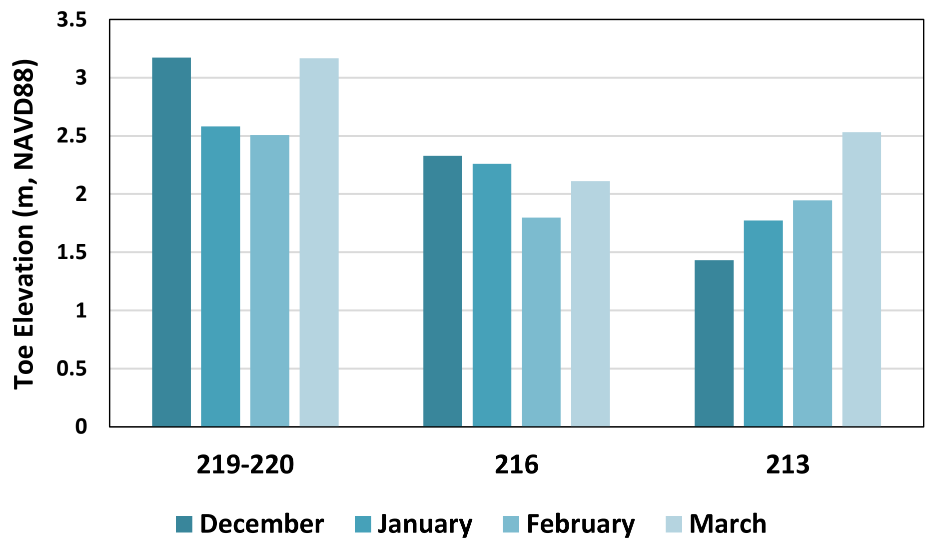

Figure 12: Bar chart showing change in mean revetment toe elevation for each rock tracking site between December 2018 and March 2019

The area east of Old SR-105 lost 1,300 m^3 of sediment from the beach face between December and January, though the revetment toe held relatively steady at sites 213 and 216, with some minor realignment of the toe position (Figures 11 and 13). At site 216, the revetment toe stayed at a mean elevation of 2.3 m NAVD88 (8.5 ft MLLW), while at site 213, the toe moved slightly landward from a mean elevation of 1.43 m NAVD88 (5.6 ft MLLW) in December to 1.77 m NAVD88 (6.7 ft MLLW) in January (Table 3; Figure 12).

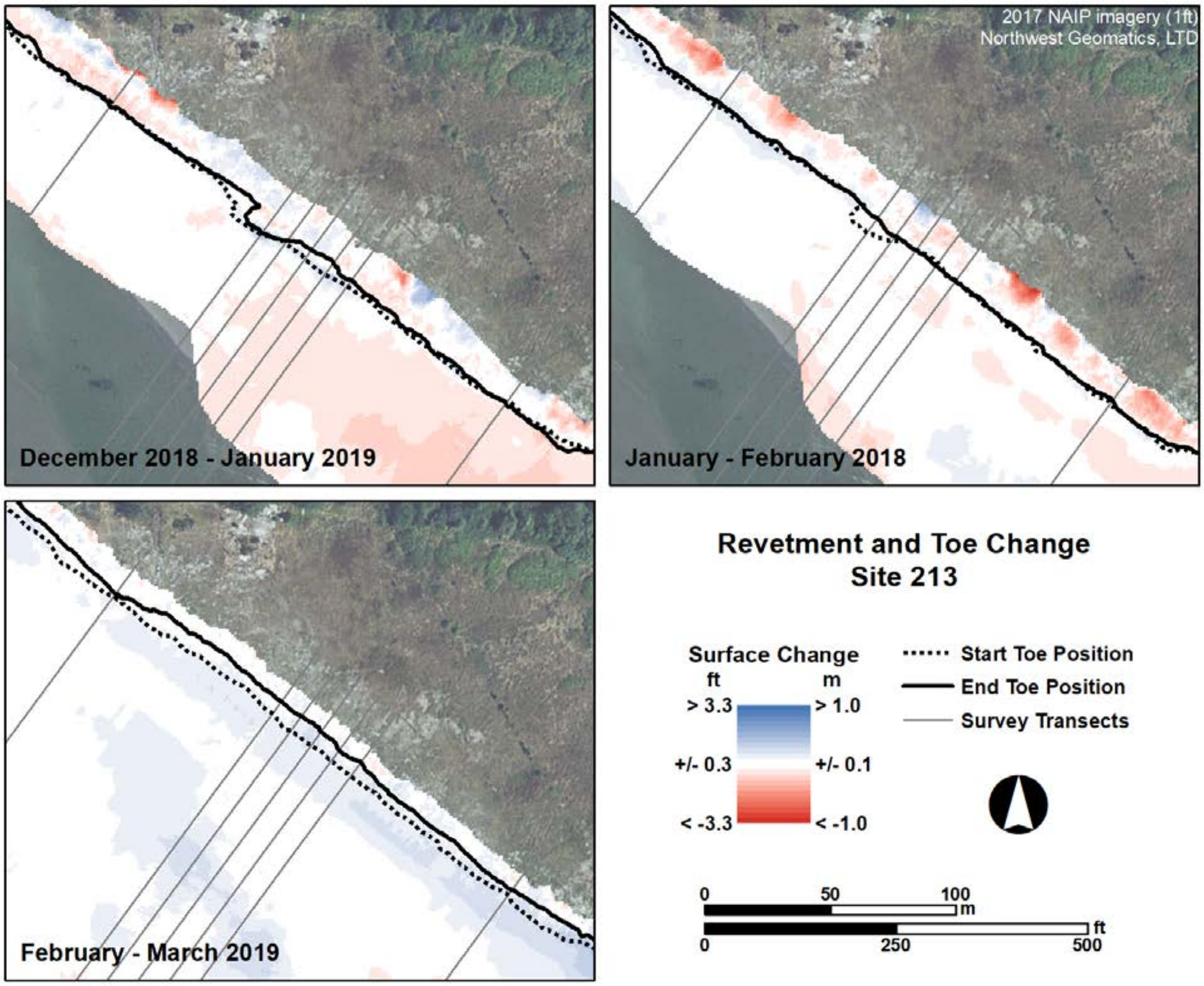

Figure 13: Monthly change in dynamic revetment morphology and toe position at site 213 during the winter between December 2018 and March 2019

The overall change trend reversed after January, and 4,500 m^3 of accretion was measured over the entire survey area between January and February (Figures 5 and 7). The area west of Old SR-105 showed accretion adjacent to the riprap between January and February, with a maximum vertical elevation gain of 0.6 m (2 ft), as well as on the upper beach and lower portion of the revetment (Figure 10). Sediment loss from the upper part of the revetment and a gain on the lower suggests cross-shore redistribution of the cobbles seaward. No significant change in the position of the revetment toe was observed at site 219-220, where it stayed around 2.5 m NAVD88 (9.1 ft MLLW) (Table 3; Figure 12).

While most areas started to show a net accumulation of sediment between January and February, the area east of Old SR-105 at site 216 continued to erode, losing an additional 700 m^3 of sediment, with a maximum elevation loss of 0.4 m (1.3 ft) (Figure 11). The position of the revetment toe at site 216 shifted seaward by an average of 3.9 m (12.8 ft), from 2.26 m NAVD88 (8.3 ft MLLW) in January to 1.80 m NAVD88 (6.8 ft MLLW) in February (Figures 11 and 12; Table 3). Farther to the east, site 213 showed further alignment of the toe position between

January and February, moving slightly landward from 1.77 m to 1.95 m NAVD88 (6.7 ft to 7.3 ft MLLW) (Figures 12 and 13; Table 3).

Net accretion continued into March, with 51,200 m^3 of net sediment gain for the entire survey area between the February and March surveys. In February and March, mean wave heights decreased to an average of 2 m (6.7 ft) from 2.9 m (9.5 ft) in December and January, but the average period remained about 13 s (Appendix; Figure A2). Because of this, sand was able to accumulate at the toe of the revetment and on the upper beach below the revetment between February and March, causing the position of the toe to translate upward and landward at all locations (Figures 10 – 13; Table 3).

West of Old SR-105, between February and March, 9,700 m^3 of accretion was measured along the length of the revetment to Willow Ln and on the upper beach at site 219-220, with a maximum vertical elevation gain of 1.3 m (4.3 ft) immediately adjacent to the riprap and 0.8 m (2.6 ft) on the beach face (Figure 14).

In March, the revetment toe was buried by up to 0.55 m (1.8 ft) of sand, relative to February, with an average depth of 0.36 m (1.2 ft) (Figure 10). The toe position at site 219-220 translated landward by an average of 3.5 m (11.5 ft), from 2.51 m to 3.17 m NAVD88 (9.1 ft to 11.3 ft MLLW) (Figures 10 and 12; Table 3). Figure 15 shows photos of the site, looking west from Old SR-105, from the February and March surveys.

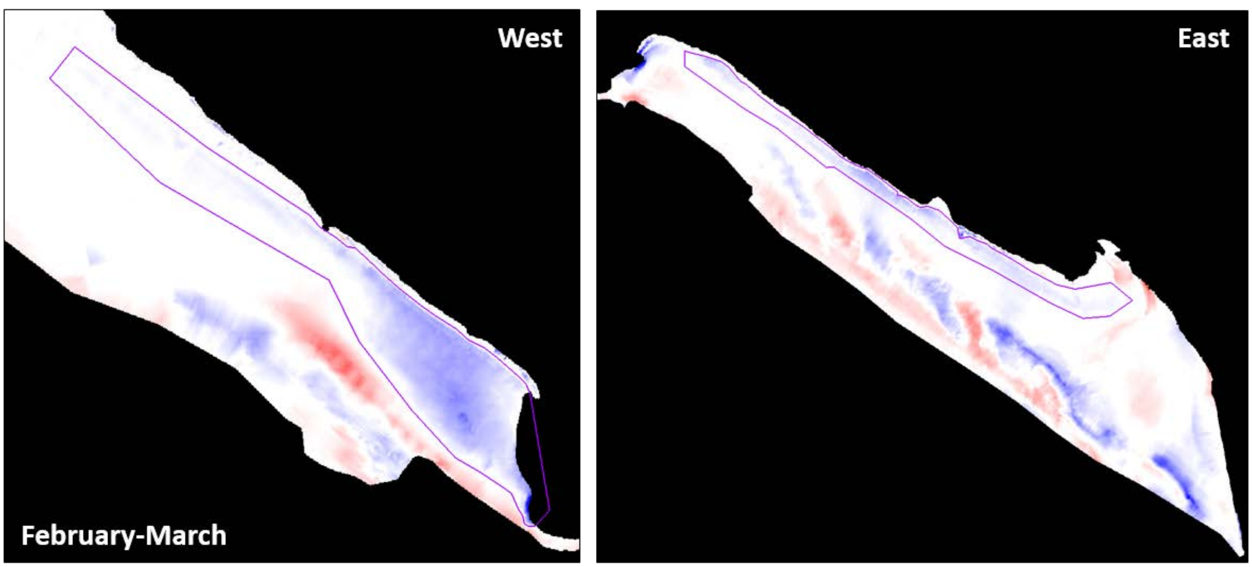

Figure 14: Areas of accretion on either side of Old SR-105 between February and March 2019

Figure 15: Photos looking west of site 219-220 from February and March 2019

On the east side of Old SR-105, 6,100 m^3 of accretion was measured between February and March along the length of the revetment toe from Old SR-105 to the east end of the revetment (including both sites 216 and 213), with a maximum vertical elevation gain of 0.6 m (2 ft) (Figure 14). The revetment toe was buried by up to 0.8 m (2.6 ft) of sand, relative to February, with an average of 0.25 m (0.8 ft), along the same extent.

At site 216, the average elevation of the revetment toe increased from 1.80 m to 2.11 m NAVD88 (6.8 ft to 7.8 ft MLLW), resulting in a landward translation of about 2.7 m (8.9 ft), on average (Figure 11; Table 3). Farther east, at site 213, the revetment toe elevation increased from 1.95 m to 2.53 m NAVD88 (7.3 ft to 9.2 ft MLLW), and translated landward by an average of 6.5 m (21.3 ft) (Figure 13; Table 3).

Figure 16 shows photos of site 216 from the February and March surveys. A large log on the left side of the photos can be used as a reference to see the change in the position of the revetment toe.

Figure 16: Photos looking east of site 216 from February and March 2019

To summarize the morphology change observed over the total period of surveys, Figure 17 shows the difference between the June 2018 and March 2019 surveys. The net volume change between these two surveys is +74,900 m^3, meaning the erosion that took place over the 2018-2019 winter was not enough to outweigh the accumulation experienced over the 2018 summer and 2019 late winter/early spring months.

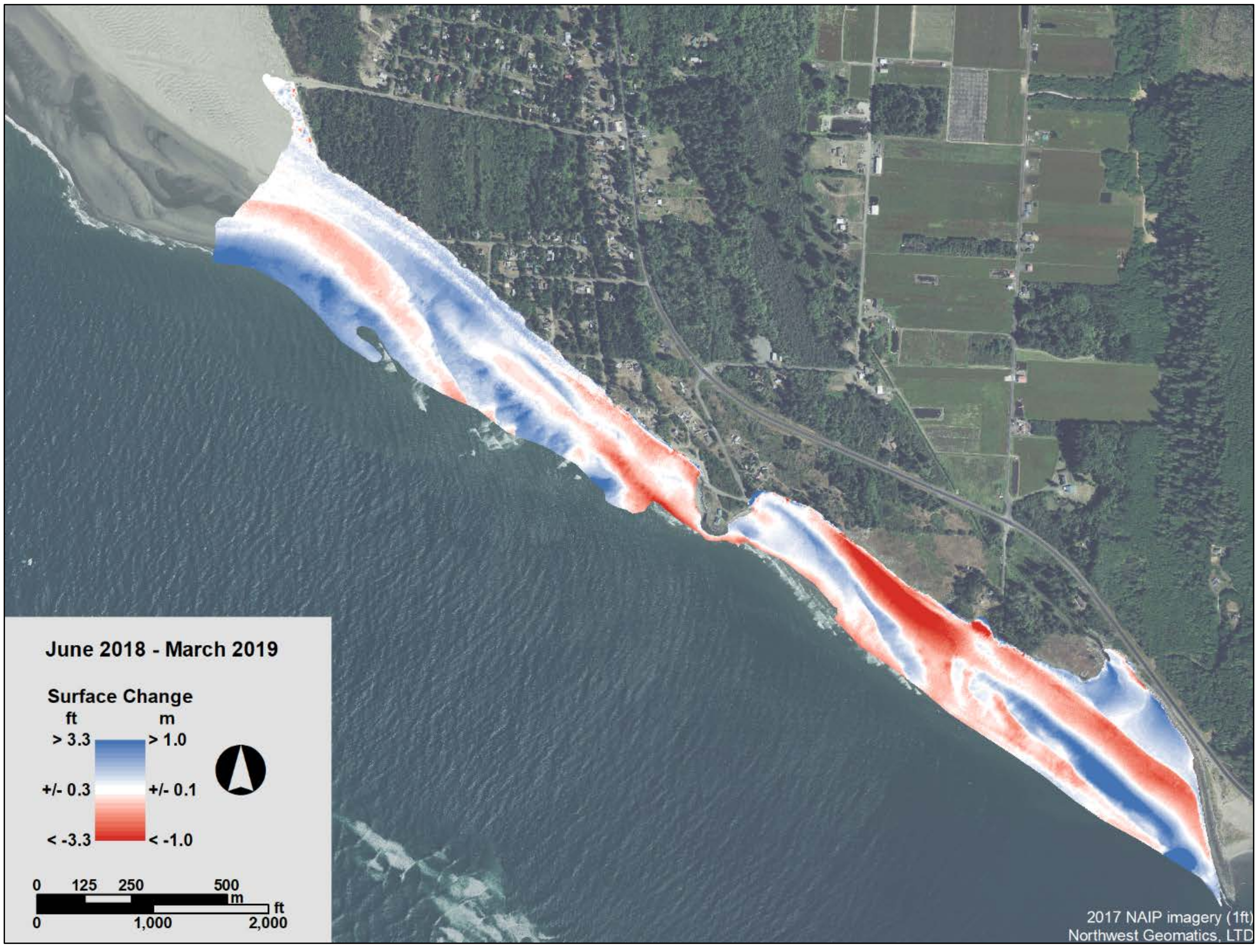

Figure 17: Net change for the entire survey area between June 2018 and March 2019

Over the time period surveyed, the maximum signal of erosion was measured between September 2018 and January 2019, where 219,200 m^3 of sediment was lost for a net volume change of -132,300 m^3 (Figure 18). This equates to an average volume change rate of -33,075 m^3/mo. After January, the beach shows an initial recovery of sand, especially on the west side of SR-105. Between January and March 2019, 41,200 m^3 of sediment was gained over the entire survey area for a net volume change of +23,000 m^3, equating to an average volume change rate of +11,500 m^3/mo.

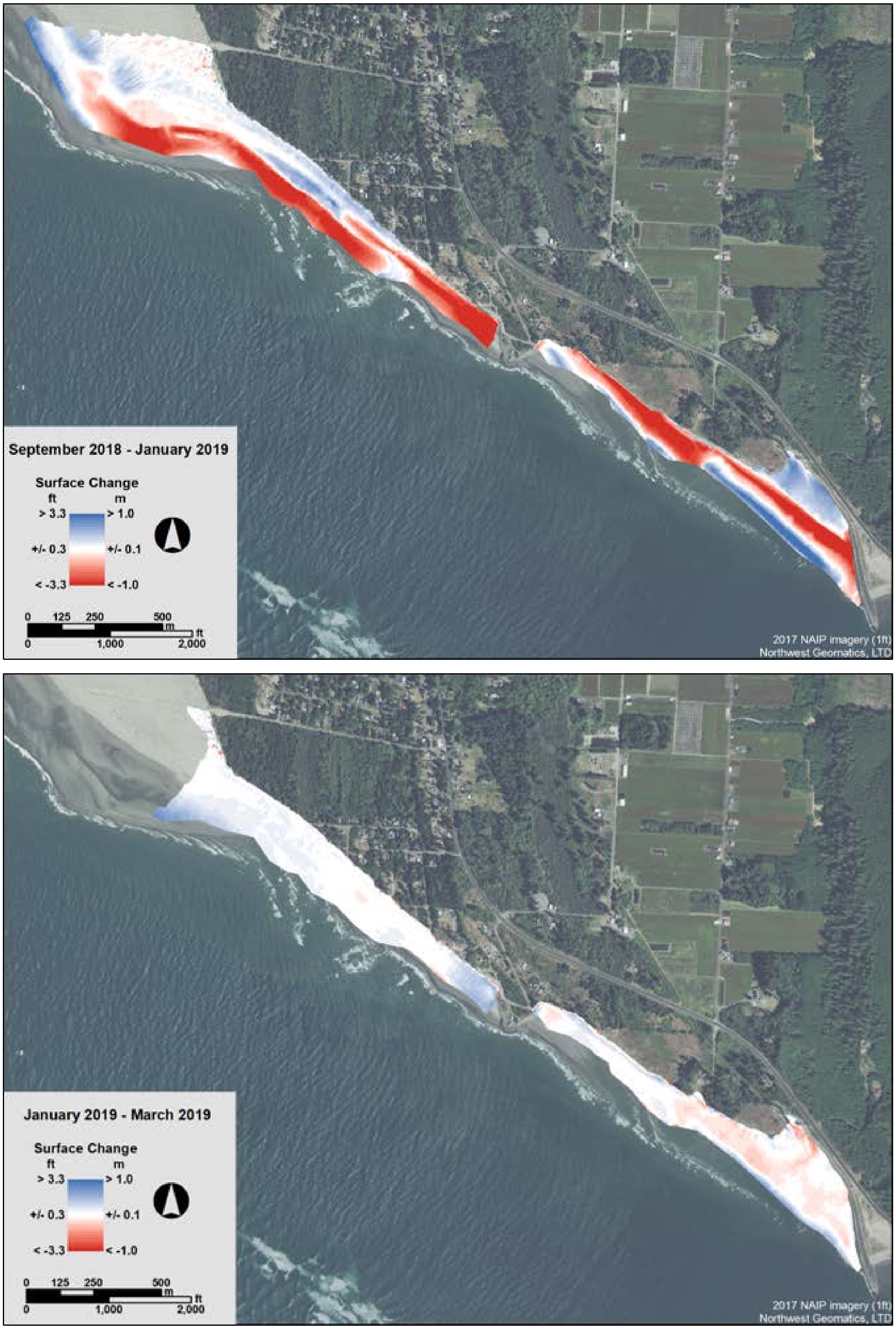

Figure 18: Morphology change for entire survey area for period of maximum erosion (September 2018 through January 2019) and initial recovery (January through March 2019)

Beach width and slope

The beach width and slope affect wave dissipation and help to describe the state of the beach. For this report, these parameters are calculated between the seawardmost occurrence of mean low water (MLW; 0.15 m NAVD88) and the landwardmost occurrence of mean high water (MHW; 2.17 m NAVD88). Figures 19 and 20 show the variation in beach width and beach slope, respectively, along every transect for each survey between June 2018 and March 2019, except for January 2019, where high water levels during the storm event did not allow surveyors to walk low enough on the beach to capture MLW. The beach width and slope for Transect 217, located in front of the riprap at the end of Old SR-105, were only calculated in June 2018 during an extreme low tide because the riprap is typically impassable.

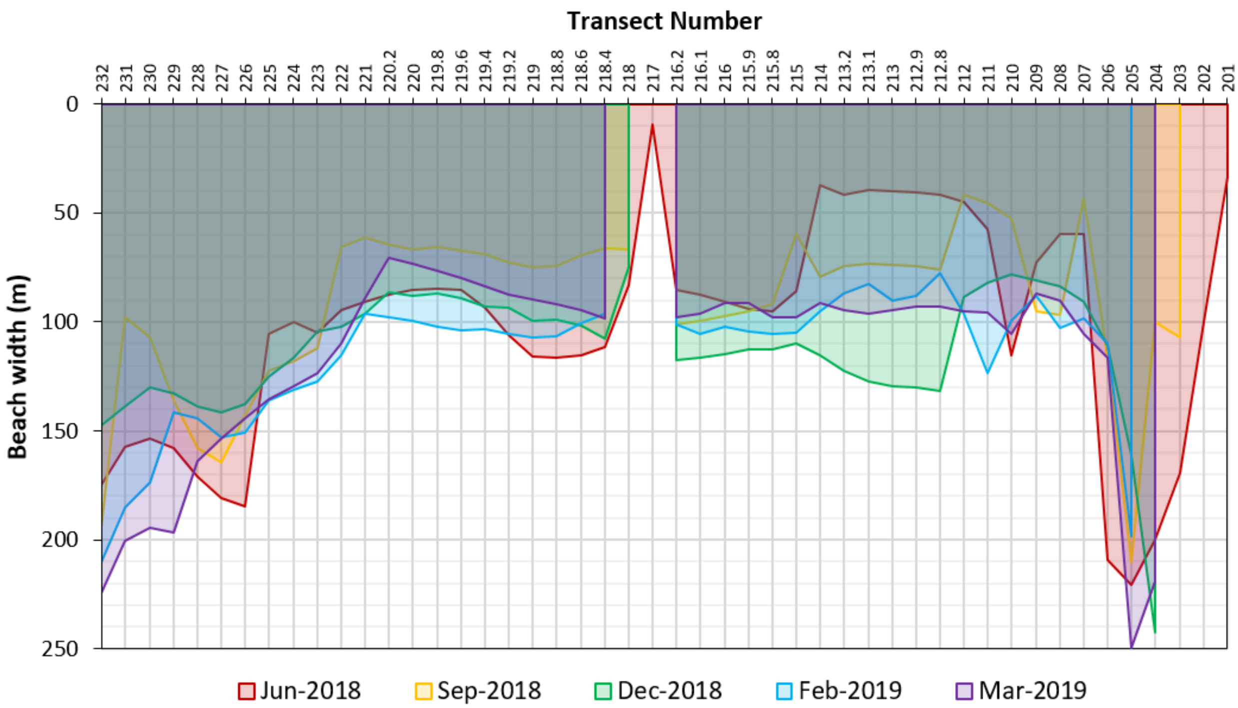

Figure 19: Beach width per survey transect, measured as the distance between MHW and MLW

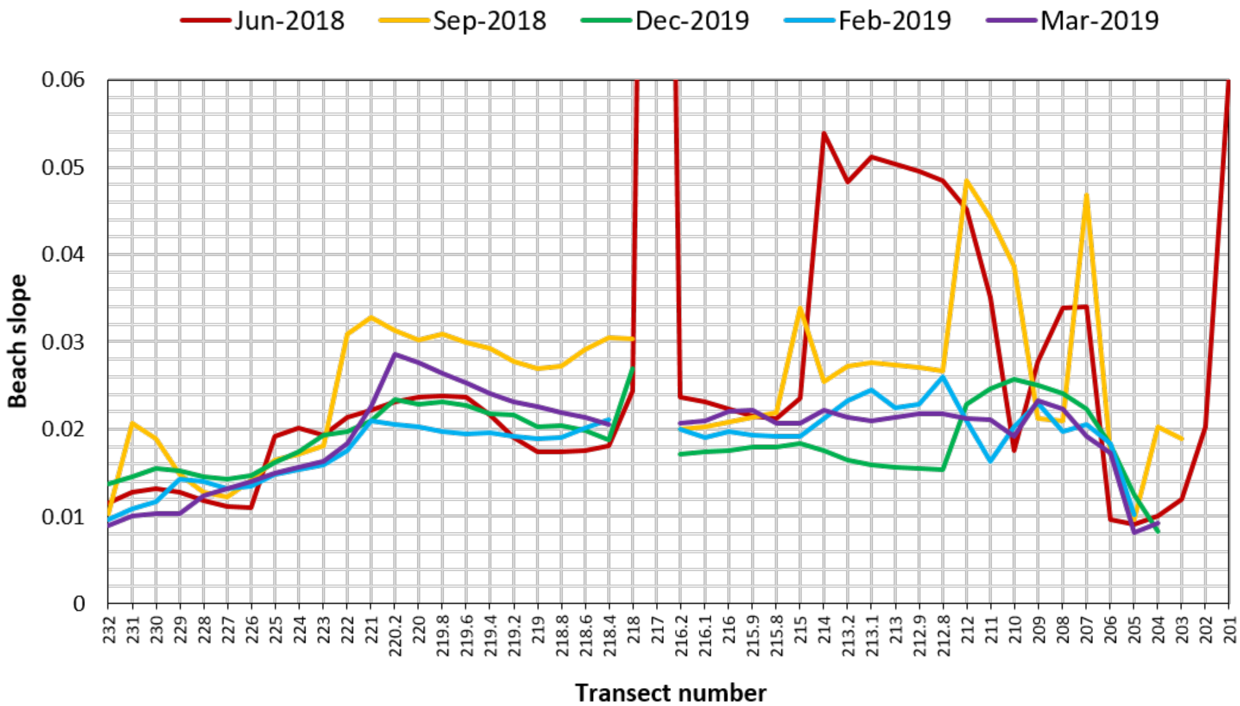

Figure 20: Beach slope per survey transect, measured as the rise in elevation over the distance between MHW and MLW

In June 2018, on the west side of Old SR-105 at site 219-220, the beach was wider and flatter closer to the riprap (width = 113 m; slope = 0.018) and slightly narrower and steeper at the west end of the site (width = 86 m; slope = 0.024). From June to September, the MHW contour moved seaward due to accretion on the upper beach, while the MLW contour stayed about the same, causing the beach width to decrease and the slope to increase. During the September 2018 survey, the narrowest and steepest beach face was measured, with an average beach width of 70 m and slope of 0.029.

In December, the MHW contour west of Old SR-105 moved landward to approximately the June position, showing an increase in the beach width and flattening of the slope. This trend continued into February where the beach at site 219-220 was 102 m wide with a slope of 0.020. February 2019 marks the widest and flattest beach observed at the west end of site 219-220. In March, the MHW contour moved seaward back to the December position as accretion buried the toe of the revetment, effectively narrowing the beach width.

On the east side of Old SR-105 at sites 213 and 216, the beach was narrowest and steepest during the June 2018 survey. In fact, at site 213, the beach was significantly narrower and steeper than most of the survey area (width = 41 m; slope = 0.050). The beach width increased from June to September and again to December, with the beach being widest and flattest during the December 2018 survey (width = 128 m; slope = 0.016). The beach width decreased from December to March as the slope increased and the toe of the revetment became buried, therefore increasing the toe elevation.

Rock tracking

A total of 344 rocks were tagged, weighed, measured, and placed on the North Cove dynamic revetment during January and February 2019. Angular and rounded cobbles were placed along 20 transects at 4 elevations on either side of Old SR-105 to compare rock transport. Rocks were placed on the east side of Old SR-105 in January and on the west side in February. On average, 84% of the rocks have been recovered during each tracking survey.

More rocks were mobilized from January to February than February to March due to larger waves and stormy weather (Figure 21). From January to February, 53% of the rocks found had moved over 1 m (54 out of 101) compared to only 26% from February to March (66 out of 255). In addition, more rocks moved farther from January to February than from February to March: from January to February, 13% of the rocks found moved over 20 m (13 out of 101), compared to 4% from February to March (9 out of 255).

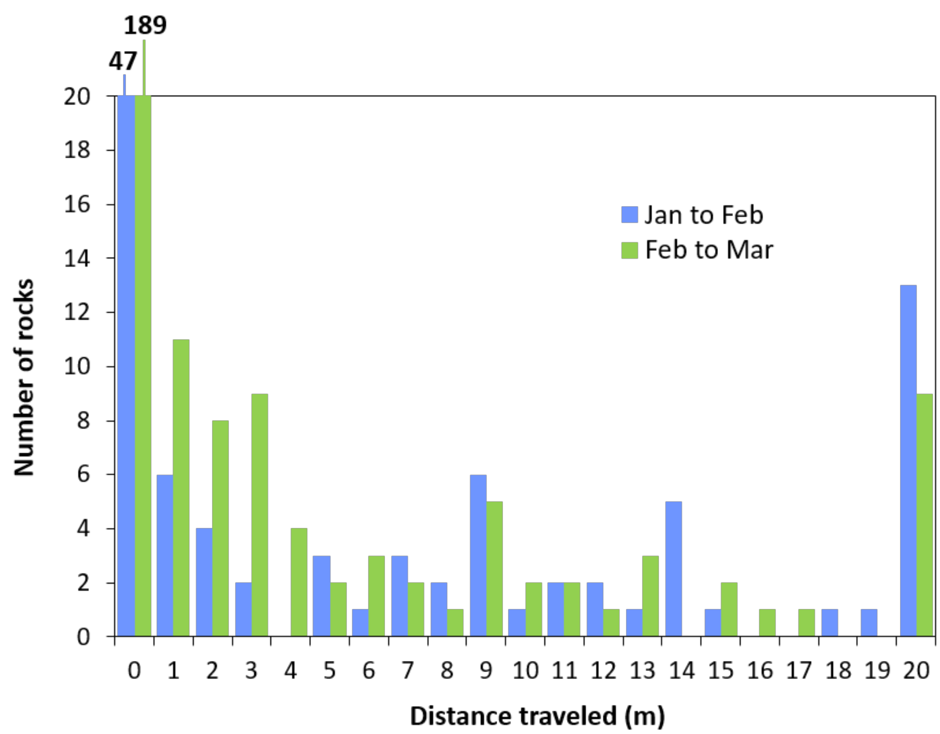

Figure 21: Bar chart showing rock transport distance by month between January and March 2019

Rocks weighing less than 10 kg (22 lb), which roughly equates to a 20 cm (8 in) intermediate axis, moved further than those that were heavier (Figure 20). The five rocks that traveled over 50 m weighed less than 4 kg (8.8 lb), with an approximately 14 cm (5.5 in) intermediate axis.

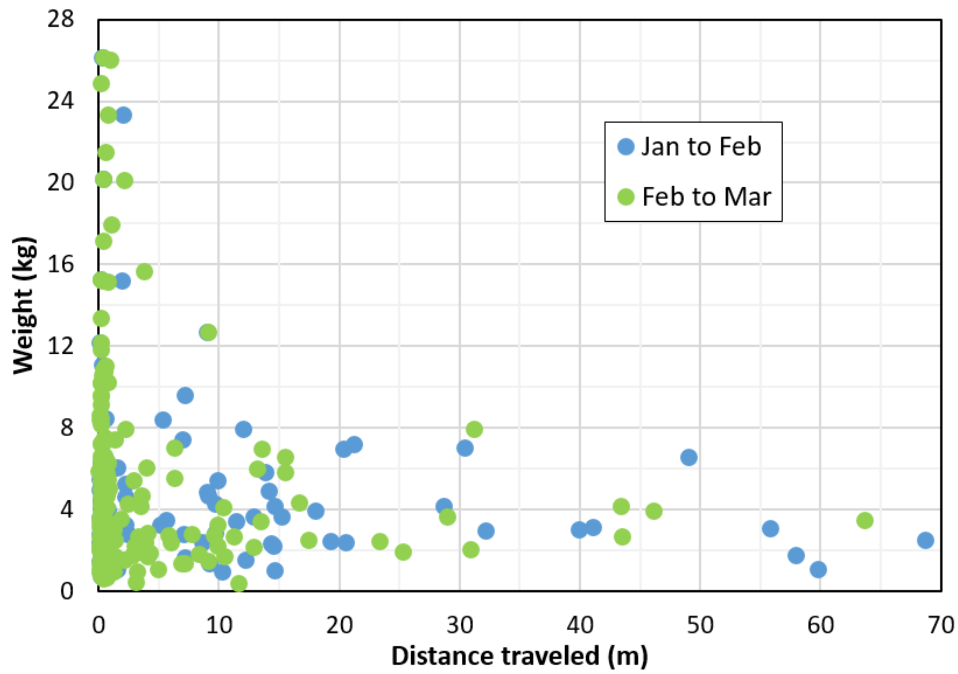

Figure 22: Rock transport distance by weight, comparing rock movement from January to February with February to March

Of the rocks found in both January and February at sites 213 and 216, about half (N = 47) stayed within 1 m of their January position. Of the 53% of cobbles that moved greater than 1 m, 27% moved over 10 m (N = 27) and 13% moved over 20 m (N = 13), with an average distance of 9 m (29.5 ft) eastward and slightly offshore. On average, the cobbles at site 216 (on the east side of Old SR-105) moved 15.9 m (52.2 ft) compared to only 2.9 m (9.5 ft) at site 213, further to the east (Figure 23).

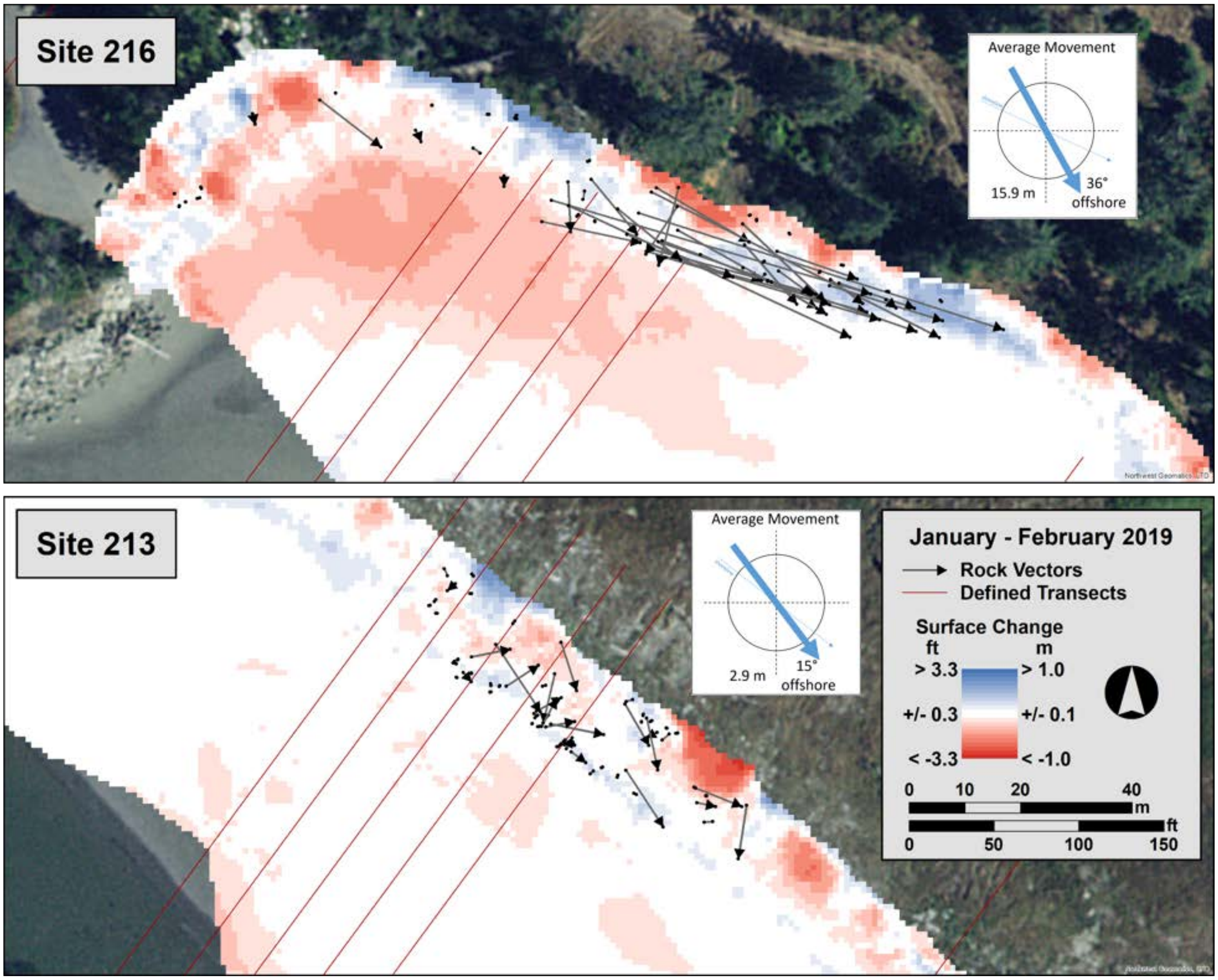

Figure 23: Vectors representing rock movement between January and February 2019 overlaid on corresponding change in the beach and revetment surface

Of the rocks found in both February and March at all 3 sites, 74% (189 out of 255) stayed within 1 m of their February position. On average, the cobbles at site 216 (east of Old SR-105) moved more than those at 213 and 219-220: 9.9 m (32.4 ft) vs. 2.5 m (8.2 ft) and 1.2 m (3.9 ft), respectively. Though the overall trend of cobble movement is eastward, when cobbles that moved over 1 m are excluded, the trend at site 219-220 is to the west (Figure 24). To date, there is no significant difference between the distance traveled by angular and round cobbles.

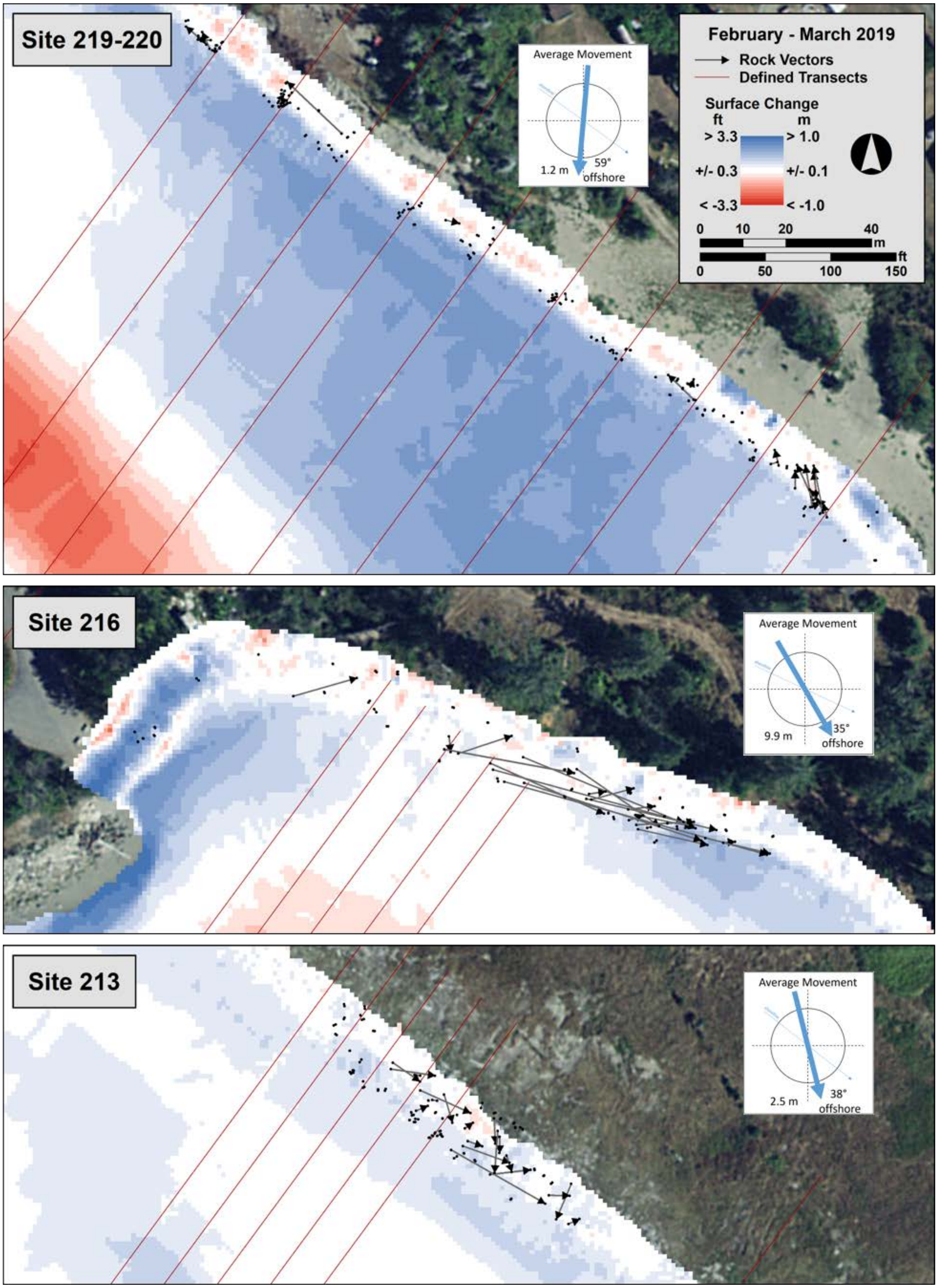

Figure 24: Vectors representing rock movement between February and March 2019 overlaid on corresponding change in the beach and revetment surface

Conclusions

Construction of the dynamic revetment just prior to the onset of winter storms appears to have prevented significant loss of the uplands from December 2018 to March 2019. Topographic surveys show the revetment was remarkably resilient to storm waves and high water levels, with little to no landward retreat. The beach fronting the revetment was observed to erode between September 2018 and January 2019. Winter storms removed sand from the upper beach and caused the revetment toe elevation to decrease at two of the three rock tracking sites, suggesting that without the dynamic revetment, the uplands may have experienced significant erosion between December and January. The beach fronting the revetment was able to rebound by March with onshore migration of the revetment toe due to sand deposition across the lower revetment face.

Between February and March, relatively large, long period waves allowed sand to be transported onto the revetment, accumulating at the revetment toe and upper beach. As the revetment toe is buried, and the toe elevation increases, the beach width between MLW and MHW is effectively decreased and the slope between these contours becomes steeper.

As expected, the larger the waves, the more movement of rocks on the revetment. More rocks were mobilized from January to February than February to March due to larger storm waves in January that were able to transport the rocks farther alongshore. However, over the three months of rock tracking from January to March, most rocks stayed within 1 m of their initial placement location. The rocks that moved farthest weighed between 1 and 10 kg (2.2 and 22 lb), which would have an intermediate axis of about 10 to 20 cm (4 to 8 in).

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References

Talebi, B., Kaminsky, G.M., Ruggiero, P., Levkowitz, M., McGrath, J., Serafin, K., and McCandless, D., 2017. Assessment of coastal erosion and future projections for North Cove, Pacific County. Shorelands and Environmental Assistance Program, Washington State Department of Ecology, Olympia, WA. Publication #17-06-010. https://fortress.wa.gov/ecy/publications/documents/1706010.pdf

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Appendix A

Environmental conditions

Local tide and wave conditions for the North Cove survey site from June 2018 through March 2019 are presented below. Figure A1 shows the hourly water levels for NOAA tide station 9440910 located at Toke Point, Washington (data available at: https://tidesandcurrents.noaa.gov/waterlevels.html). While the highest tide was expected on January 21, 2019, a higher water level was measured during a storm on December 20, 2018, with a height of 12.74 ft MLLW (3.63 m NAVD88).

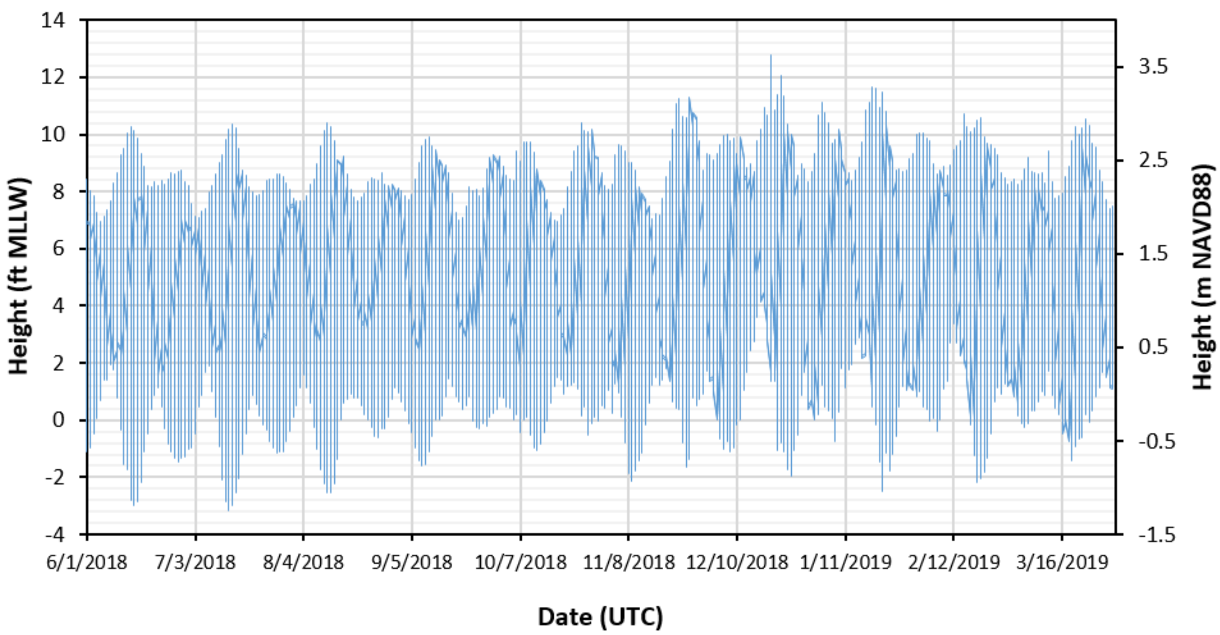

Figure A-1: Hourly water levels at Toke Point from June 2018 through March 2019

Figure A2 shows the offshore wave conditions for the same period. These data were downloaded from the NOAA National Data Buoy Center for the Grays Harbor Buoy, station 46211 (available at: https://www.ndbc.noaa.gov/station_page.php?station=46211). The average significant wave height for the survey period from June 1, 2018 to March 31, 2019 (UTC) is 1.97 m (6.5 ft) with a period of 11 s.

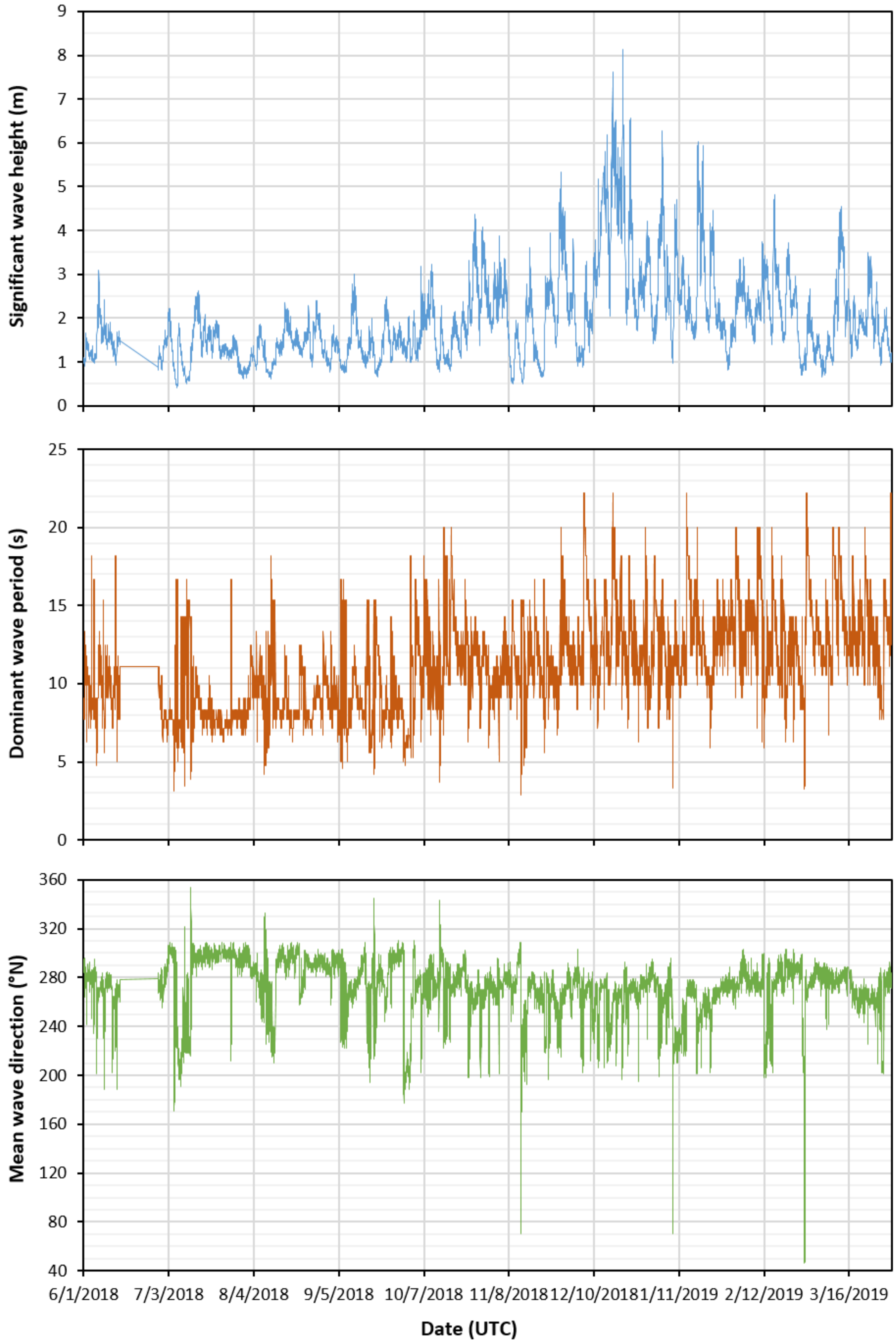

Figure A-2: Wave conditions offshore of North Cove from June 2018 through March 2019

As expected, the largest waves occur during the winter months from October to March. On average, December 2018 had the largest waves during the survey period with a mean significant wave height of 3.22 m (10.6 ft) at 13 s out of the west, followed by January with a mean of 2.58 m (8.5 ft) also at 13 s, though slightly WSW. The smallest waves, on average, were recorded in July and August, both of which had a mean significant wave height of 1.32 m (4.3 ft) at 8 and 9 s, respectively, and slightly WNW.

The largest waves recorded during the survey period occurred during a storm on December 20, 2018 with a significant wave height of 8.14 m (26.7 ft) and a dominant wave period of 12 s from the southwest. There were also large wave events at the beginning and middle of January with wave heights of 6.27 m (20.5 ft) at 15 s from WSW on January 4, 2019 and then around 6 m (19.6 ft) at 14 s on the 18th and 19th also from the SW/WSW.