OCEAN BEACH SURVEY

FINAL REPORT 2018 - 2020

A Report to the Dunedin City Council

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EXECUTIVE SUMMARY

This final report 2018 – 2020 is the fifth submitted by the University to the Dunedin City Council. The three previous reports were (i) year-end 2018; (ii) mid-year 2019; (iii) and year-end 2019; (iv) mid-year 2020. The current report presents up-to-date beach and dune elevation data from the 1st survey on 28th May 2018.

Beach and dune elevations were surveyed by RTK – GPS and digital surface models were developed using UAV (or 'drone') photogrammetry. Spatial and temporal patterns of erosion/accretion (i.e. volumetric sand gain/loss and average elevation change) are presented. Local 'sea level', uncorrected tide levels (tides + pressure effects), were recorded for periods using an RBR pressure transducer set into the rock platform beside the St. Clair Salt Water Pool.

Area 1 and 2 have been the most vulnerable to beach erosion since the commencement of the current monitoring programme. Winter storms (from 1st May to 26th July 2020) lowered the beach 1 – 2 m in these areas. There is evidence that the beach and dune in these Areas have been recovered during summer time.

Beach width and beach volumes in Area 3 and 4 are more stable. The elevation changes in these areas are within a range of ± 0.5 m. However the more severe erosion (from 1 – 2 m) might occur at Area 3 as it was observed from 1st May 2020 to 11th November 2020.

7-m dune erosion occurred on 8th August 2019 in Area 2 (Profile 5) has not yet fully recovered from these winter storms. However, no further dune erosion has occurred (up to the 11th November 2020).

The highest sea level recorded at St. Clair, between the 29th May and the 14th July 2020, was 6.7662 m (NZGD 2000) recorded at 3:58:00 p.m. 14/07/2020.

The time-lapse camera deploying that St. Kilda is under normal operation (up to 26th July 2020)

Constructing notches on the foredune at St Kilda has resulted in up to 2.5m sand deposition on the lee side of notched foredune. In the lee side of intact foredune, in contrast, there is little sand deposition. Notches appear to be an effective intervention to rollback the foredune at St Kilda.

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LIST OF ABBREVIATIONS

2D	2-dimensional
DCC	Dunedin City Council
DSM	Digital Surface Model
GCP	Ground Control Points
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HWM	High Water Mark
JWD	John Wilson Drive
MHWS	Mean High Water Spring
MSL	Mean Sea Level
NZGD2000	New Zealand Geodetic Datum 2000
NZTM2000	New Zealand Transverse Mercator 2000
PT	RBR pressure transducer
RMSE	Root Mean Square Error
RTK	Real Time Kinematic
SSI	Storm surge intensity
UAV	Unmanned Aerial Vehicle (or ‘drone’)
LINZ	Land information New Zealand
MSLP	Mean sea level pressure
SLSC	Saint Kilda Surf Club

GLOSARRY

Benchmark: A point of known elevation and location.

Digital surface models (DSM): A DSM is a topographic model of the earth's surface including vegetation and built objects.

Ground control points (GCPs): Defined as points on the surface of the earth of known location used to geo-reference aerial images. In this survey, 'GCPs' are used to geo-reference UAV images for Pix4D processing.

High water mark (HWM): The level reached by the sea at high tide.

Inverse barometric effect: The inverse barometric effect describes the relationship between atmospheric pressure and sea level. A decrease in mean sea level pressure of 1 hPa causes a temporary 1 cm rise in local sea-level (on average), and vice versa.

Mean High Water Spring (MHWS): The average level reached by spring high tides.

Mean Sea Level (MSL): The average sea-level. On a beach it is roughly the mid-point and level between mean low and mean high tides.

Mean Sea Level Pressure (MSLP): The atmospheric pressure at sea level.

Orthomosaic: Georeferenced image –mosaic from an image collection, where the geometric distortion has been corrected and spatially corrected.

Reference point: A point of known (and fixed) position and elevation relative to a coordinate system and vertical datum (e.g. NZGD2000).

Storm surge intensity (SSI): Storm surge intensity is a dimensionless index that indicates the relative magnitude and duration of a storm surge event.

1. BACKGROUND

This report is one of a series by the School of Geography, University of Otago to Dunedin City Council. It should be read in conjunction with previous reports including year-end 2018 report presented on the 13th December 2018; mid-winter 2019 reported on the 24th August 2019; year-end 2019 report presented on 11th December 2019, and mid-winter 2020 report presented on the 18th August 2020.

The background to this work, the objectives and methods employed, are discussed in these (earlier) reports.

This final report 2018 – 2020 presents up-to-date beach and dune elevation data. The data analysis is standardised to quantify the spatial beach elevation changes and volumetric sand accretion/erosion. The change in beach volume and average elevation are presented as time-series charts to clarify the circumstances in which accretion/erosion has occurred.

The sea levels recorded by an RBR pressure transducer at St. Kilda and St. Clair are also presented

The elevation changes on the lee side of notched foredune at St. Kilda since 2016 where the first notches were cut, and the evolution of hydrodynamic on the foredune during prevailing oblique onshore wind direction, are also presented.

2. SURVEY OVERVIEW

2.1. Survey areas

Figure 2.1 shows the location of the four survey areas at Ocean Beach, Dunedin. The shoreline in these four areas is characterised by:

(1) the geotextile tubes installed in May 2016[1];
(2) the playing fields and historic landfills (Hancock Park, Kettle Park);
(3) the western section of the foredune bordering John Wilson Drive (east of the St Kilda Surf Life Saving Club); and

[1] https://www.odt.co.nz/news/dunedin/dcc/sand-sausage-error-causes-further-delay-video

(4) the eastern section of the same foredune bordering John Wilson Drive (adjacent to Lawyers Head).

The length of each shoreline section is between 500 and 700 m. Oblique aerial views of these shorelines are shown in Figure 2.2 – 2.4.

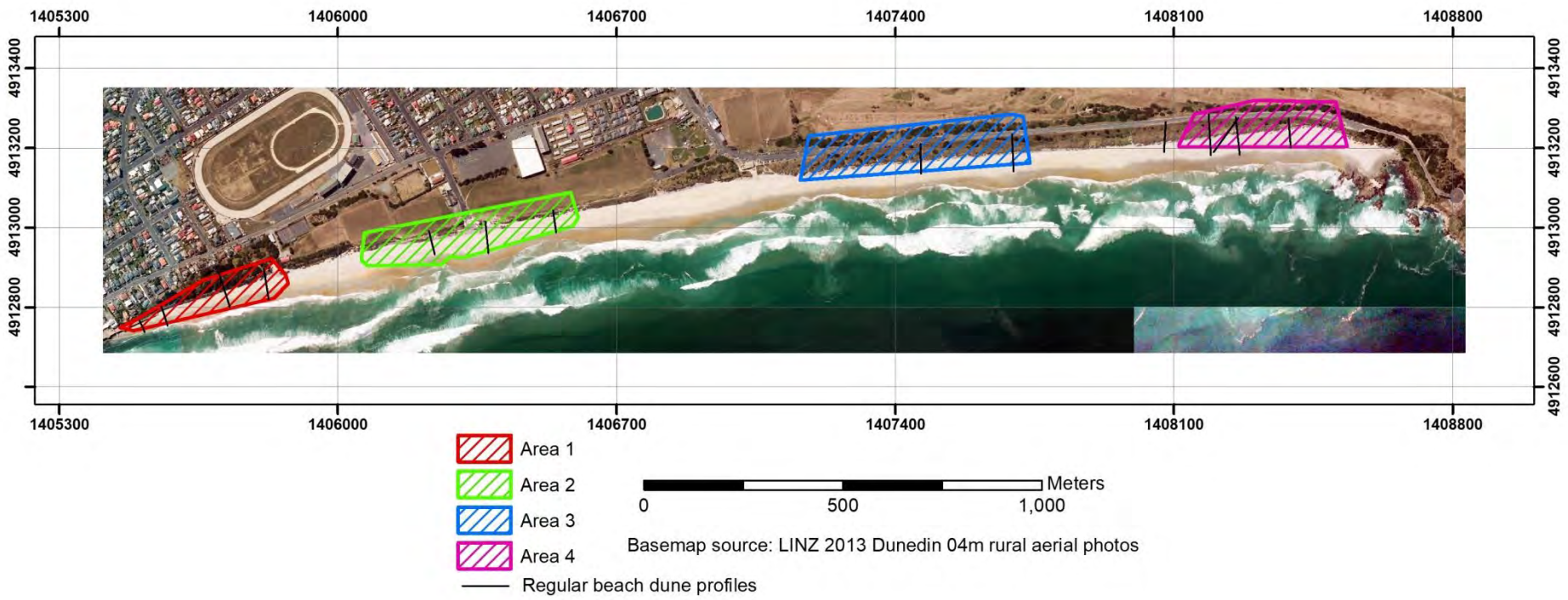

Figure 2.1: Ocean Beach survey areas

Figure 2.2: Oblique UAV photo of the Area 1 shoreline on the 25th November 2019.

Figure 2.3: Oblique UAV photo of the Area 2 shoreline on the 8th August 2019.

Figure 2.4: Oblique UAV photo of the Area 3&4 shoreline on the 4th November 2020.

Survey times & methods

Table 1 summarises the sea level record at St. Kilda and St. Clair from the 25th May 2018 to the 18th January 2021. Methods and results of sea level records are presented in Section 3.

Table 2 summarises topographic surveys that have been completed up to the 11th November 2020. Two survey methods have been employed: RTK-GPS and UAV – Photogrammetry. Details of each survey method are presented in Section 4 and 5, respectively. Surveys are timed to gather pre-winter (April – May) and post-winter (September – November) data and, secondly, to document shoreline change before and after storm events.

Table 1: Summary of sea level records deployment periods

Location	Sea level record periods
St. Kilda	25th May – 15th June 2018; 16th October to 23rd November 2018; 19th January to 8th May 2019; 18th May to 13th June 2019.
St. Clair	29th May to 13th July 2020; 14th November 2020 to 29th November 2020; 5th December 2020 – 18th January 2021

Table 2: Summary of surveys up to 11th November 2020.

Date	RTK – GPS survey	UAV – Photogrammetry survey
29th May 2018	Pre-winter	Pre-winter (4 Areas)
16th October 2018	Post-winter	Post-winter (4 Areas)
15th November 2018	Post-spring storm	
22nd January 2019	Post-summer storm	
15th January 2019	Post-summer storm	
3rd – 9th May 2019		Pre-winter (4 Areas)
29th May 2019	Post-autumn storm	
25th July 2019		Event-based survey (Area 4)
8th August 2019		Event-based survey (Area 1&2)
18th August 2019		Event-based survey (Area 2)
21st – 25th November 2019		Post-winter (4 Areas)
14th January 2020		Event-based survey (Area 4)
1st May 2020		Pre-winter (4 Areas)
26th July 2020	Post-winter storm	
11th September 2020		Event-based survey (Area 4)
11th November 2020		Post-winter (4 Areas)

3. SEA LEVEL RECORDS

3.1. Methods

Sea level at St. Kilda is measured by RBR Duet pressure transducer (PT)[2], sampling at an interval of 6 minutes. Sea level at St. Clair has been measured by PT RBR Solo[3], sampled at an interval of 5 minutes.

Sea level is calculated by Equation 1

$$Sea\ level\ = E_{rock} - G + D \quad (1)$$

Where:

E_{rock}: Elevation of rocky surface where the PT is deployed, measured by RTK – GPS

G: Distance between rocky surface and PT sensor

D: Water depth above the sensor, measured by PT.

Table 3 shows the coordinates and elevation of the rock surface and PT sensors. Sensors were placed at 0.02 m below the rocky surface in a vertical configuration (after the rock core had been removed), respectively. Figure 3.1 and 3.2 show the position of PTs in St. Kilda and St. Clair, respectively.

Table 3: Coordinates and elevations of pressure transducers at St. Kilda and St. Clair

Pressure Transducer	Northing (m)	Easting (m)	Elevation (rocky surface) (m)	Gap (G) (m)	Elevation of sensors (m)
St. Kilda	4913148.41	1408535.37	5.401	0.02	5.381
St. Clair	4912448.72	1405220.21	5.624	0.02	5.574

Note: Coordinate system: NZTM 2000; Vertical datum: NZGD 2000.

[2] https://rbr-global.com/products/compact-loggers/rbrduet-td
[3] (https://rbr-global.com/products/compact-loggers/rbrsolo

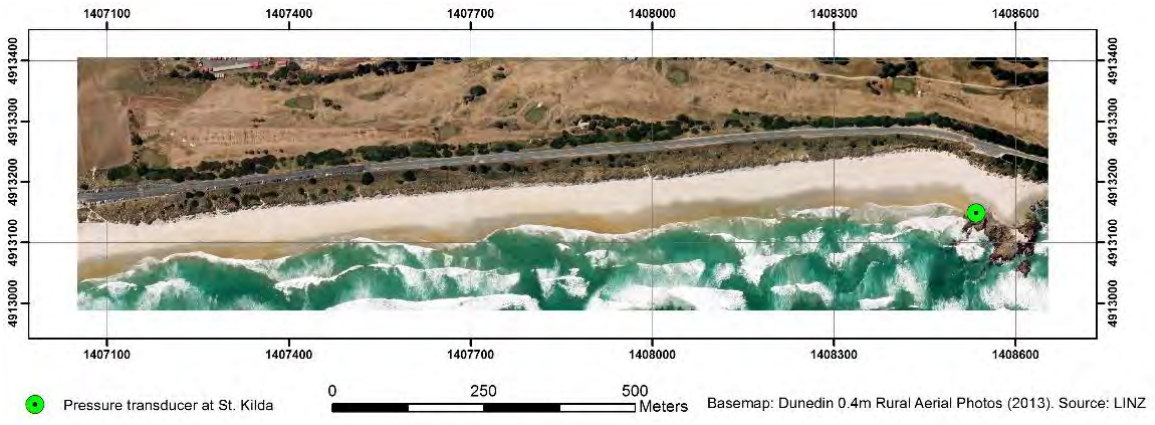

Figure 3.1: Pressure transducer location at St. Kilda

Figure 3.2: Pressure transducer location at St. Clair

3.2. Results

Figures 3.3 – 3.7 presents the sea level records at St. Kilda and St. Clair from 2018 - 2020. The maximum sea level recorded at St. Clair was 6.7662 m, recorded at 3:58:00 p.m. on the 14th July 2020.

This maximum sea level is indicated in the beach-dune profiles in Section 4.

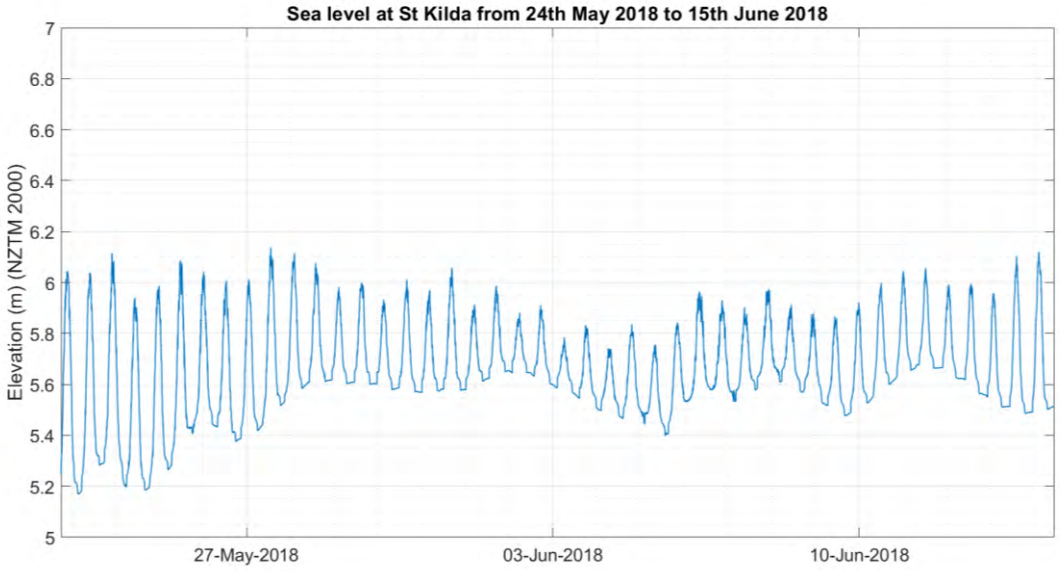

Figure 3.3: Sea level records at St. Kilda from the 24th May to 15th June 2018 (Vertical datum: NZGD 2000)

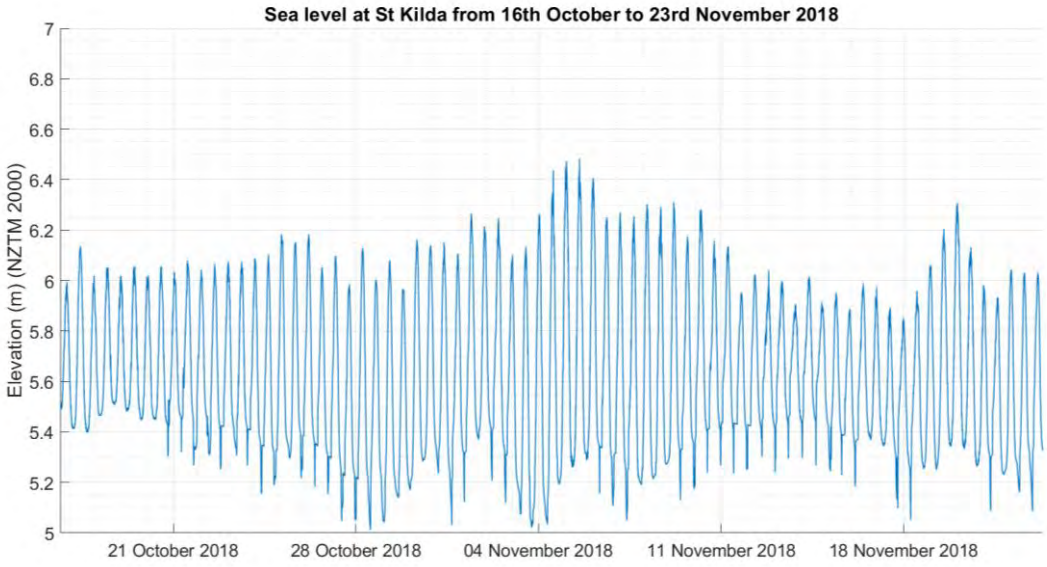

Figure 3.4: Sea level records at St. Kilda from the 16th October to 23rd November 2018 (Vertical datum: NZGD 2000)

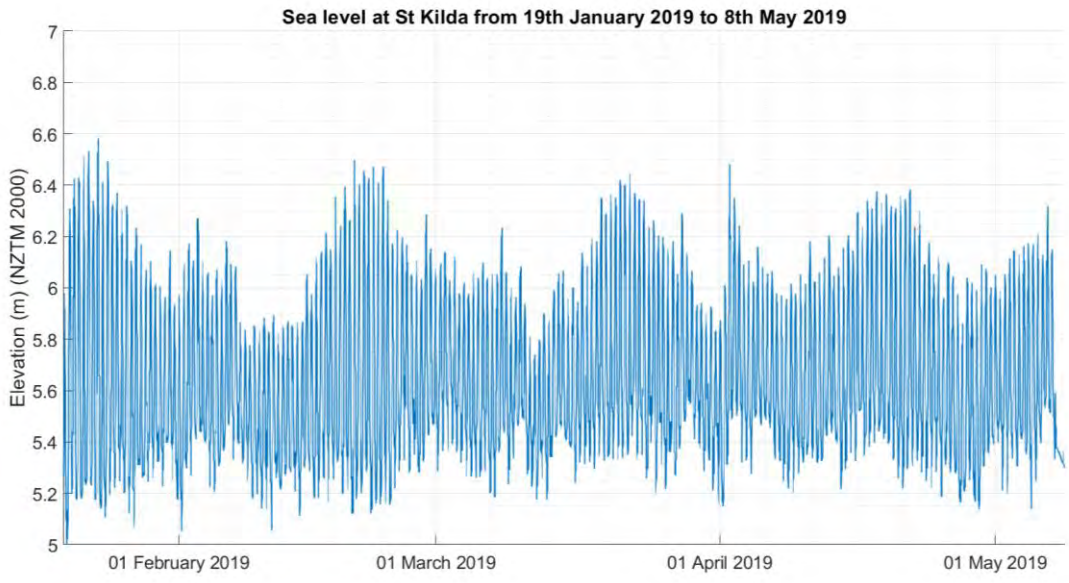

Figure 3.5: Sea level records at St. Kilda from the 19th January to 8th May 2019 (Vertical datum: NZGD 2000)

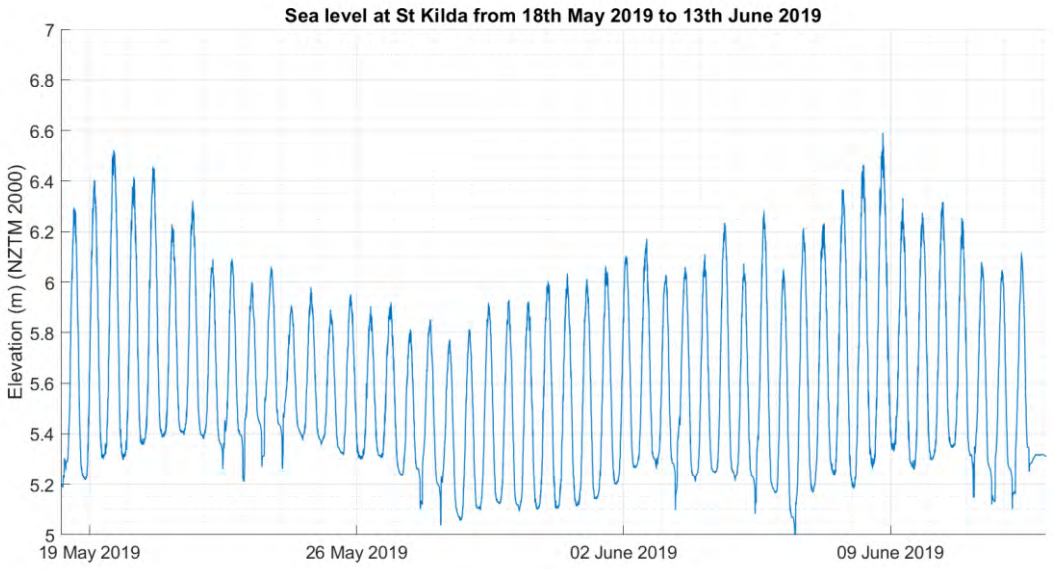

Figure 3.6: Sea level records at St. Kilda from the 18th May to 13th June 2019 (Vertical datum: NZGD 2000)

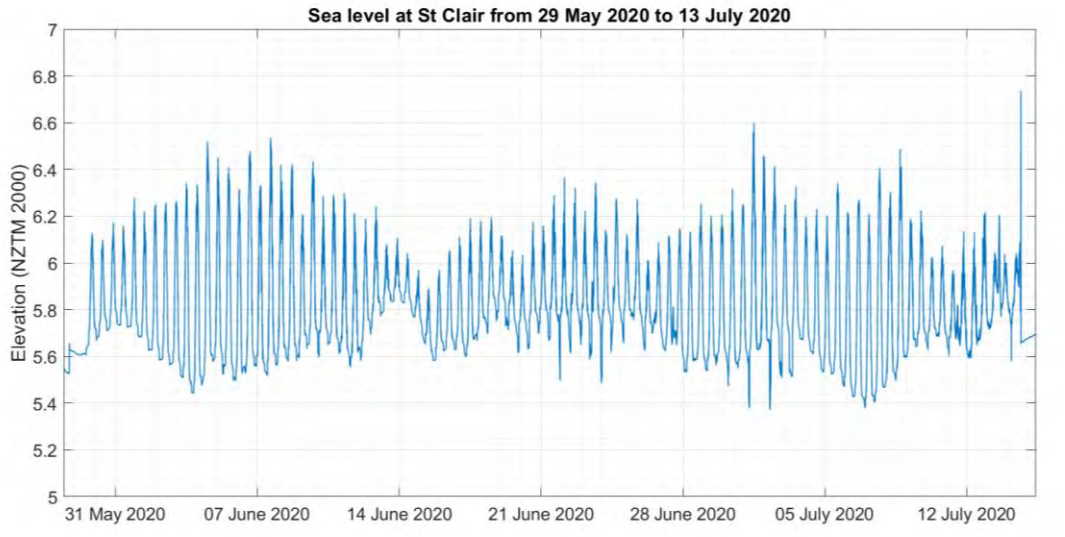

Figure 3.7: Sea level records at St. Clair from the 29th May to 13rd July 2020 (Vertical datum: NZGD 2000)

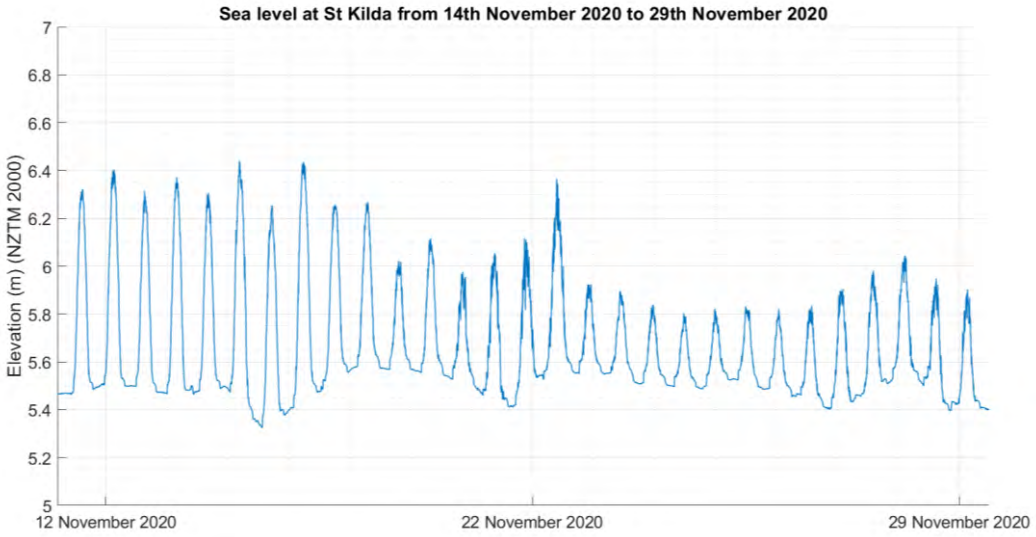

Figure 3.8: Sea level records at St. Clair from the 14th November to 29th November 2020 (Vertical datum: NZGD 2000)

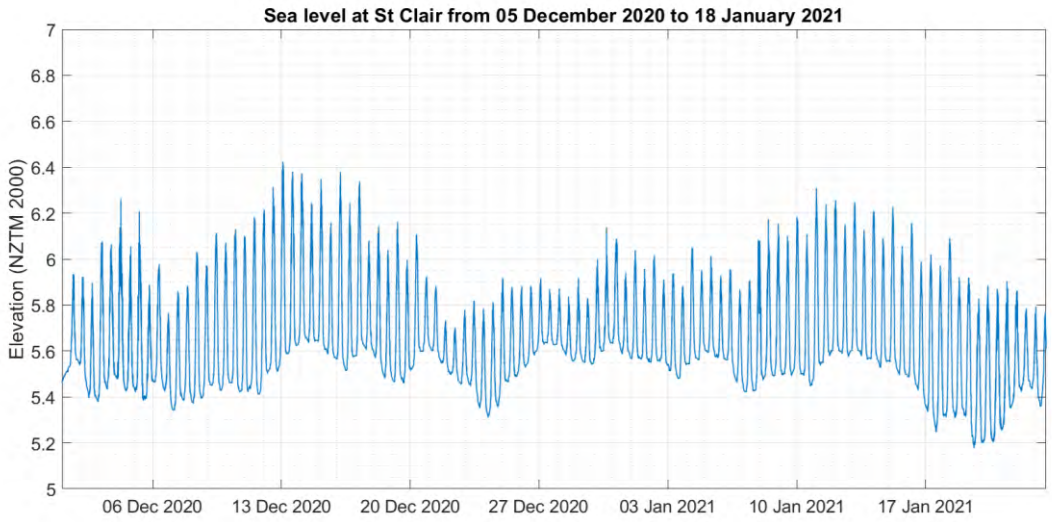

Figure 3.9: Sea level records at St. Clair from the 5th December 2020 to 18th January 2021 (Vertical datum: NZGD 2000)

4. RTK – GPS SURVEYS

4.1. Methods

The RTK-GPS survey method was described in the first beach and dune monitoring report (Adam et al. 2018). Figures 4.1, 4.2, 4.3 and 4.4 show the positions of RTK-GPS survey lines in Area 1, 2, 3 and 4, respectively. These lines were surveyed relative to benchmarks on John Wilson Drive (Table A1 in Appendix). Observations of beach/dune morphology were recorded at about 1-meter intervals. These points were joined together to create beach – dune profiles. There are 14 profiles in total across the four areas. The position of the seaward edge of the vegetation and the last HWM/LWM is recorded on each beach – dune profile.

The elevation of Mean High Water Spring tides (MHWS) and the maximum sea level recorded by PT at St Clair (Section 3.2) are also marked on each profile.

All RTK-GPS surveys were completed using a Trimble R10. This instrument provides a horizontal and vertical accuracy of 10 mm +/-1 ppm RMS and 20 mm +/- 1 ppm RMS, respectively.

4.2. Results

The beach profiles are graphed in Figure 4.5 - 4.18 (Profiles 1 – 14). The vertical datum is NZGD 2000.

In addition, profiles surveyed on the 9th May 2019 (1 – 7), 3rd May 2019 (8 – 14); 25th July 2019 (10 – 14), 8th August 2019 (1 – 7), 18th August 2019 (5 – 7), 21st November 2019 (8 – 14) and 25th November 2019 (1 – 7), 14th January 2020 (10 – 14), 30th April – 1st May 2020 (1 – 14), 11th September 2020 (10 – 14), 11th November 2020 (1 – 14) were derived from UAV – photogrammetry. Only the elevation of points on the beach (i.e. seaward of the toe of the foredune) are reported to avoid DSM errors related to vegetation.

The elevation of Mean High Water Spring (MHWS) of 6.16 m is taken from Land Information New Zealand[4].

[4] https://www.linz.govt.nz/sea/tides/tide-predictions/standard-port-tidal-levels

Appendix 1 provides the coordinates of reference points and benchmark points used for the 14 RTK-GPS surveys.

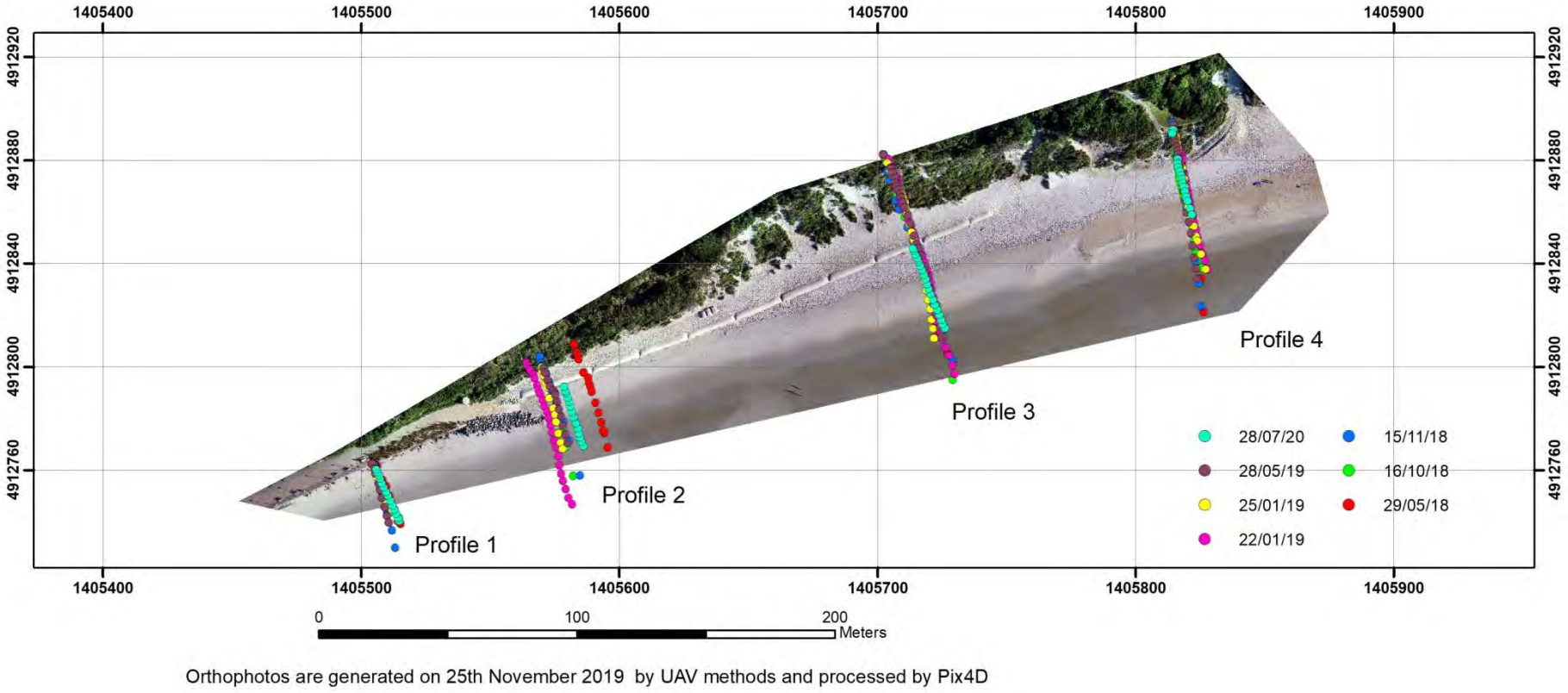

Figure 4.1: Location of RTK-GPS profiles in Area 1

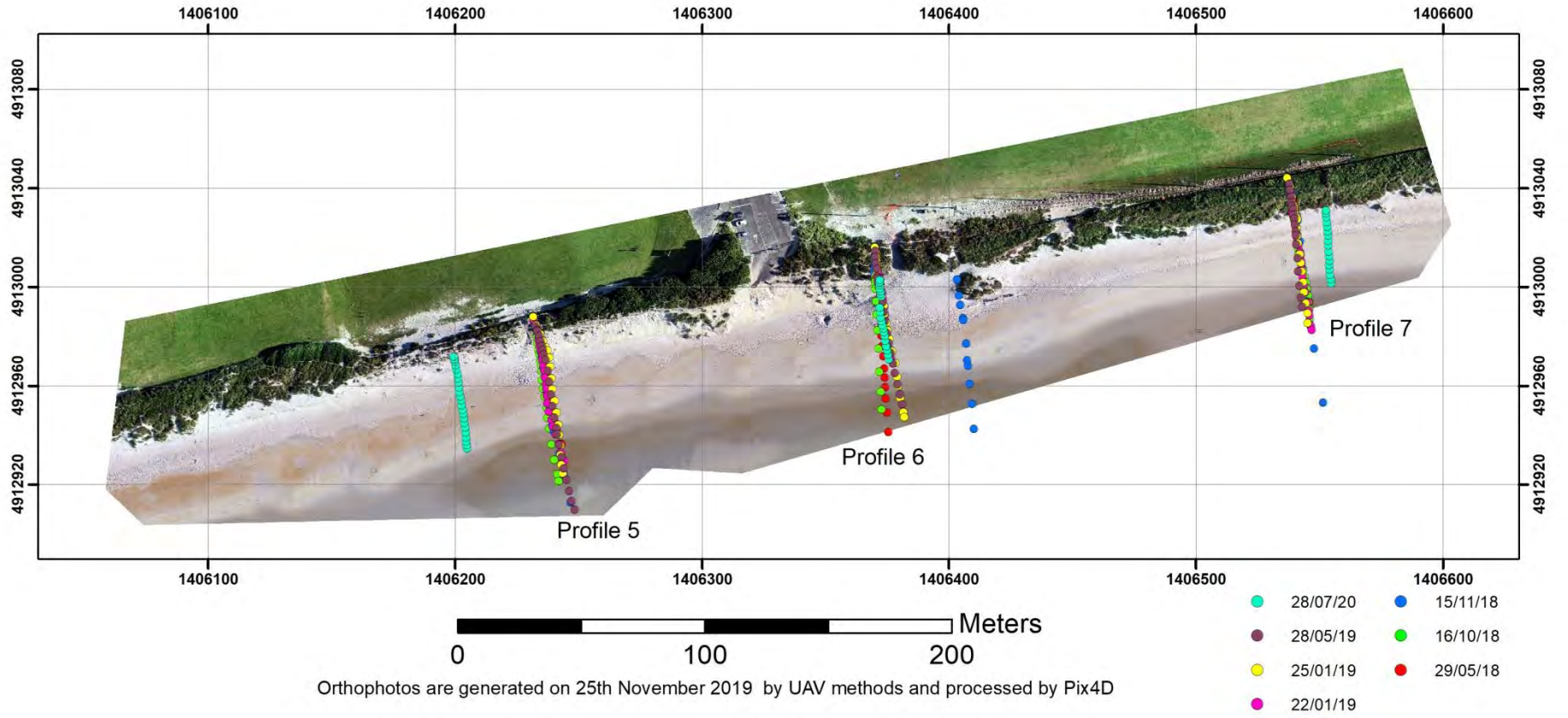

Figure 4.2: Location of RTK-GPS profiles in Area 2

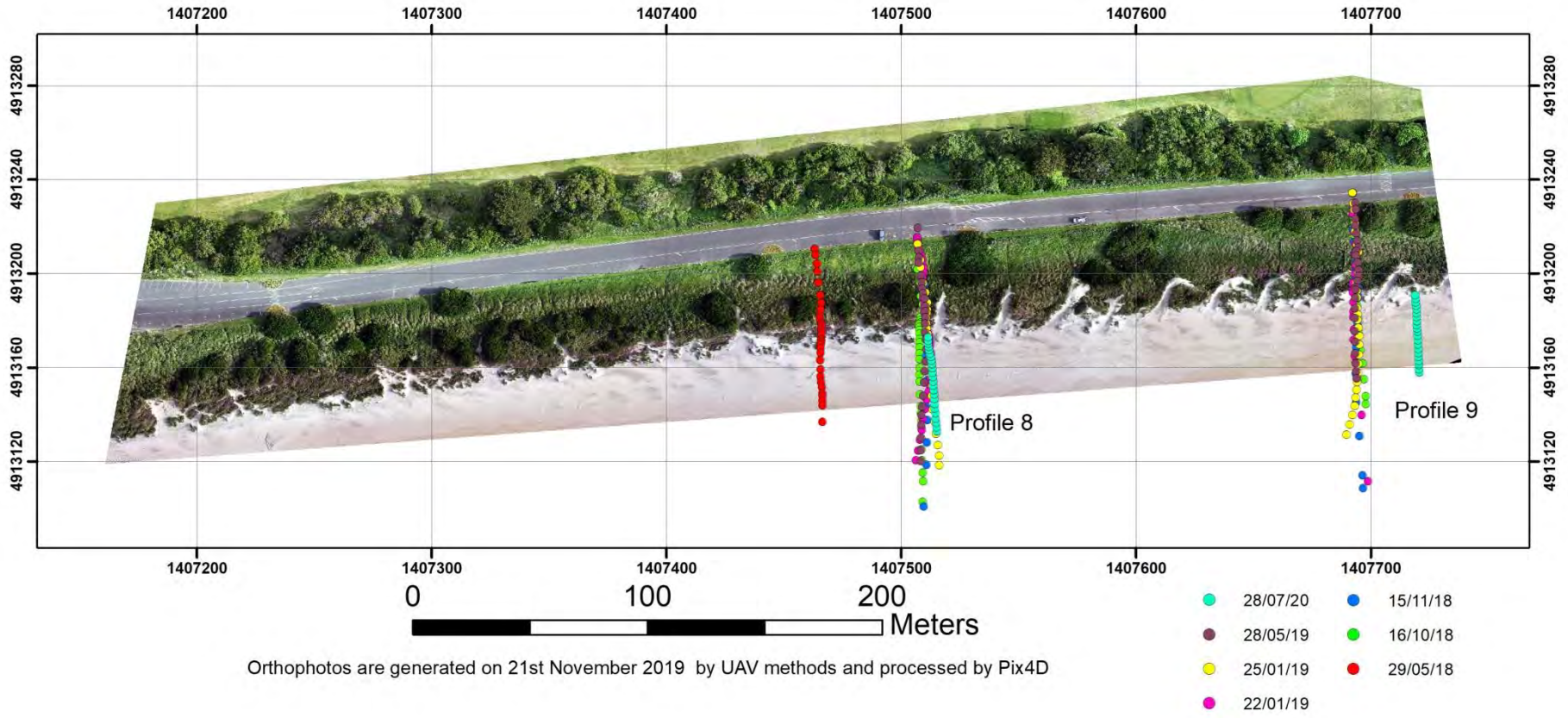

Figure 4.3: Location of RTK-GPS profiles in Area 3

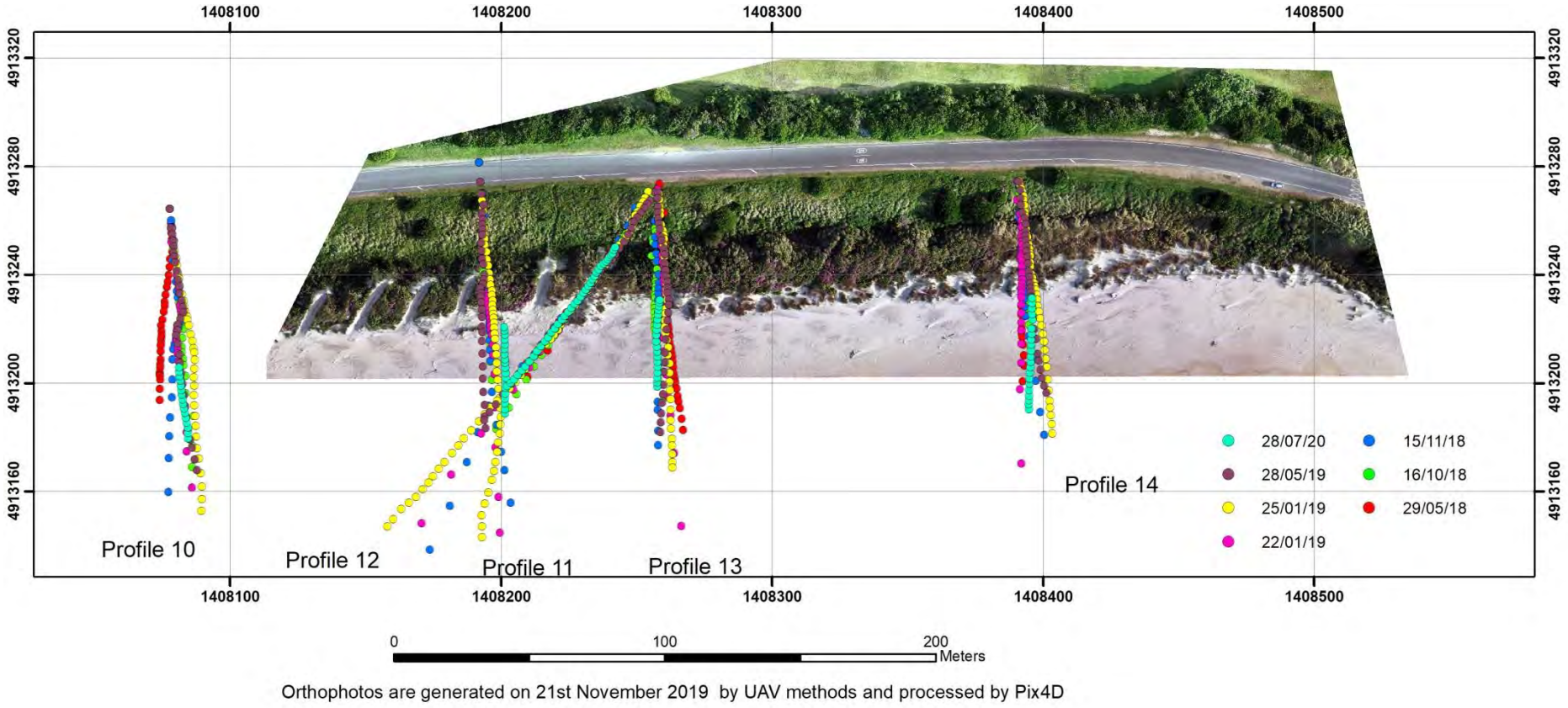

Figure 4.4: Location of RTK-GPS profiles in Area 4

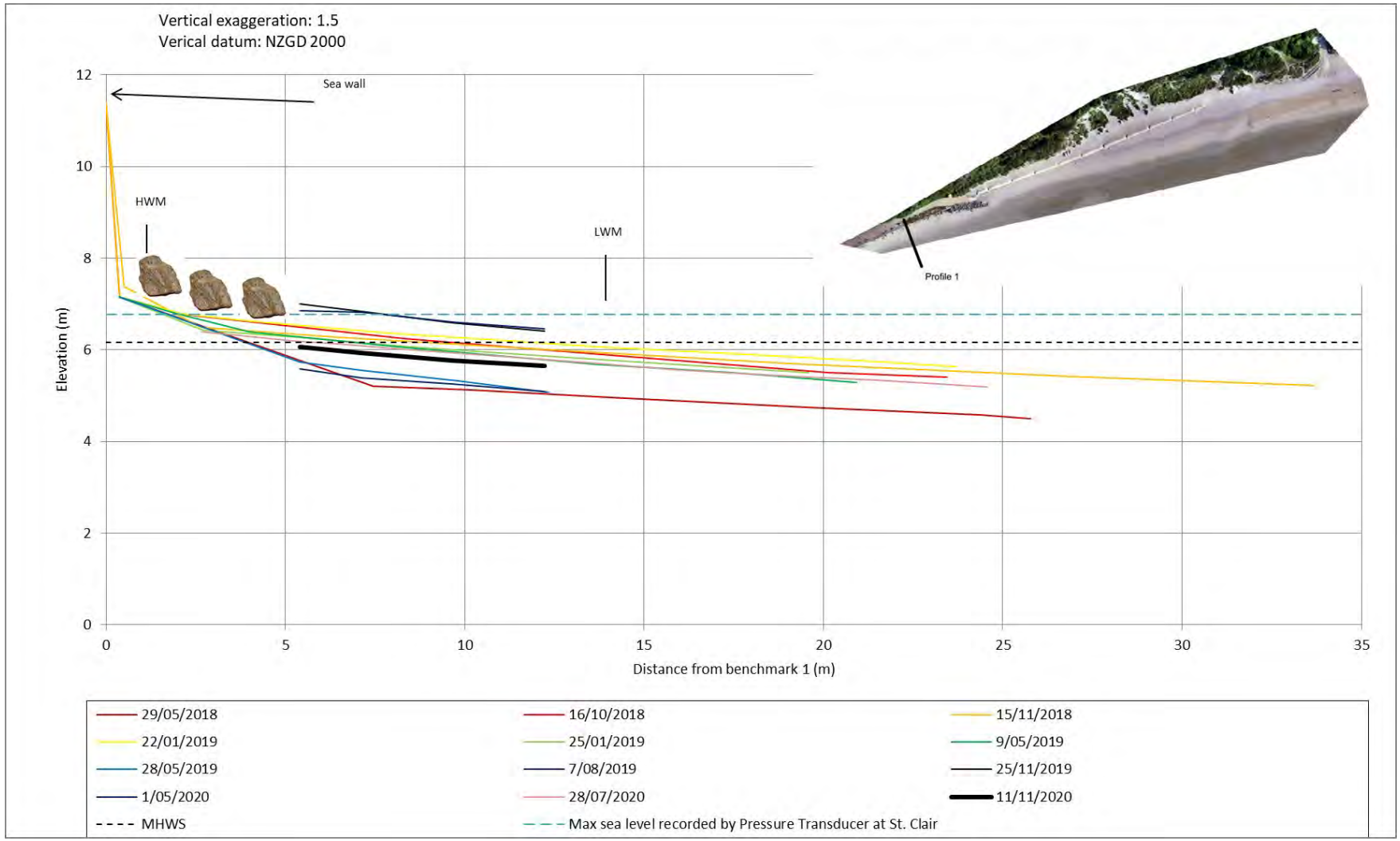

Figure 4.5: Profile 1

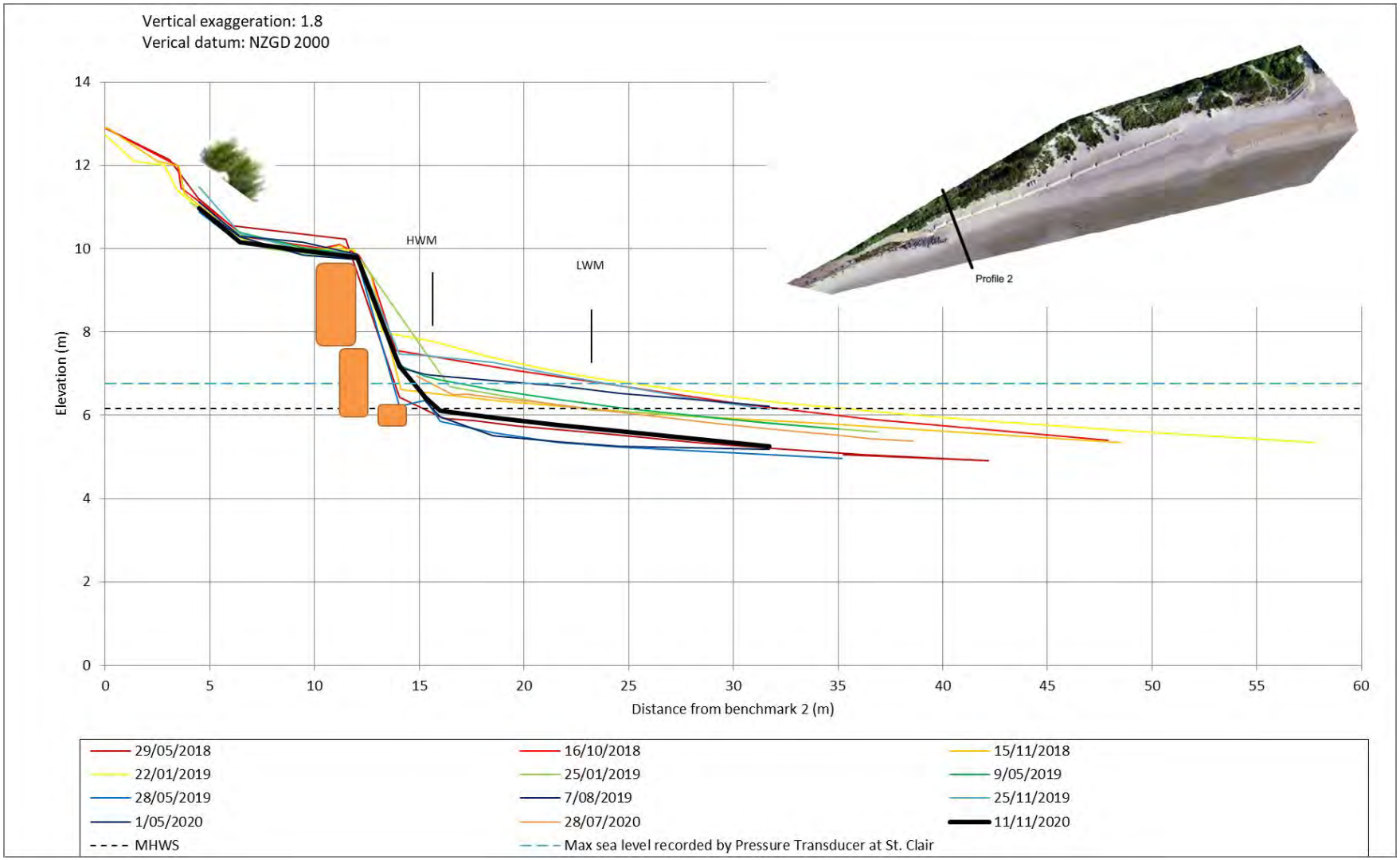

Figure 4.6: Profile 2

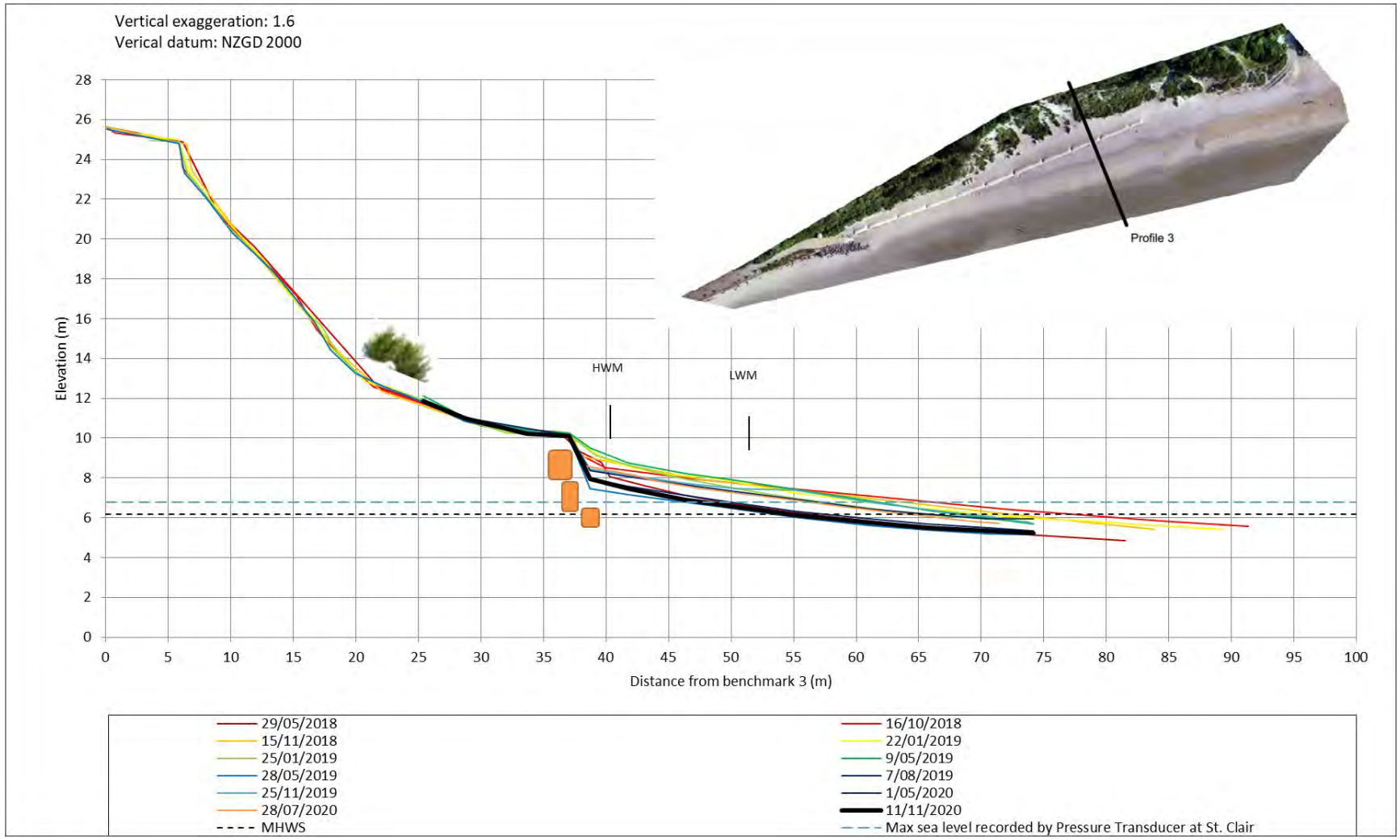

Figure 4.7: Profile 3

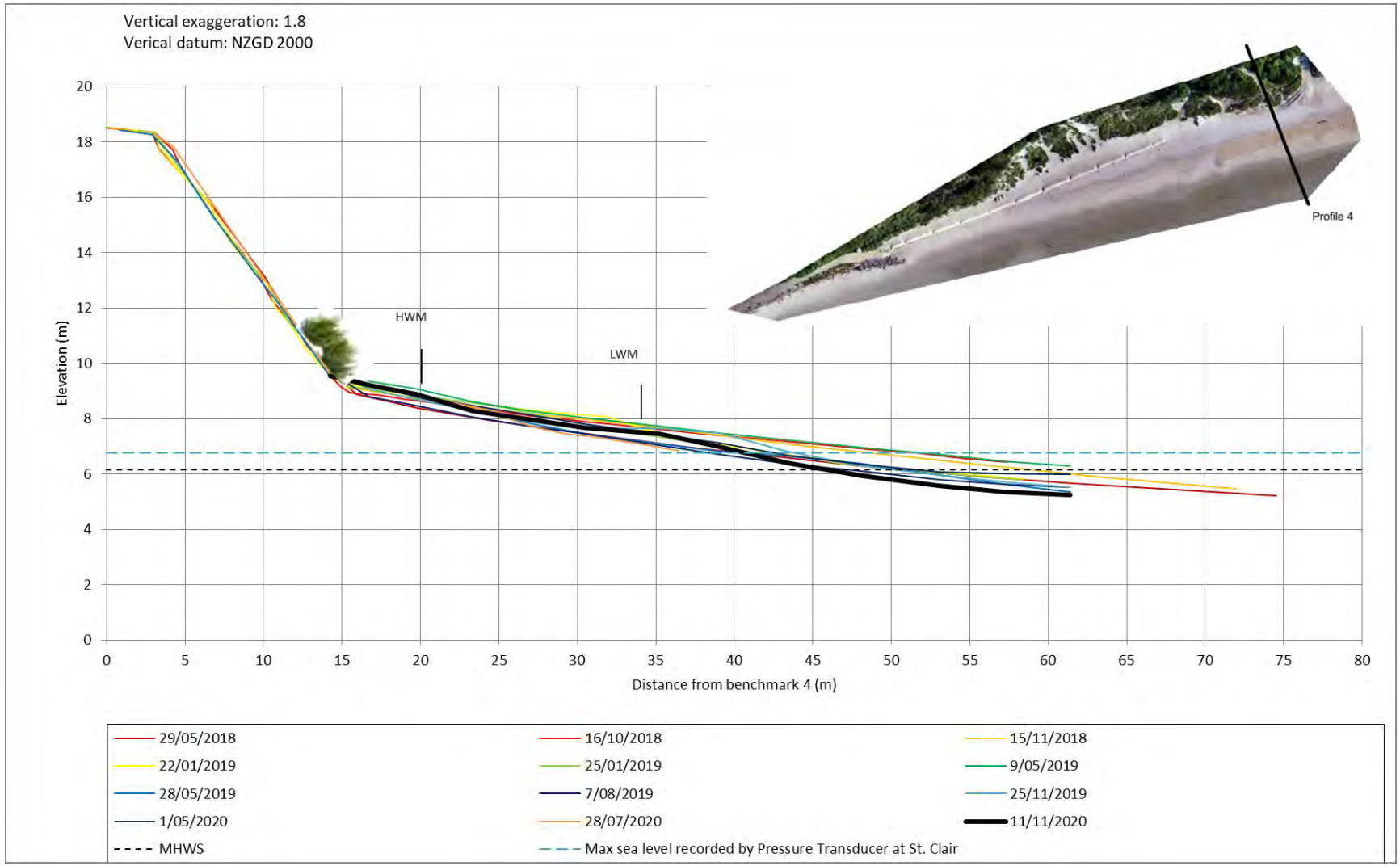

Figure 4.8: Profile 4

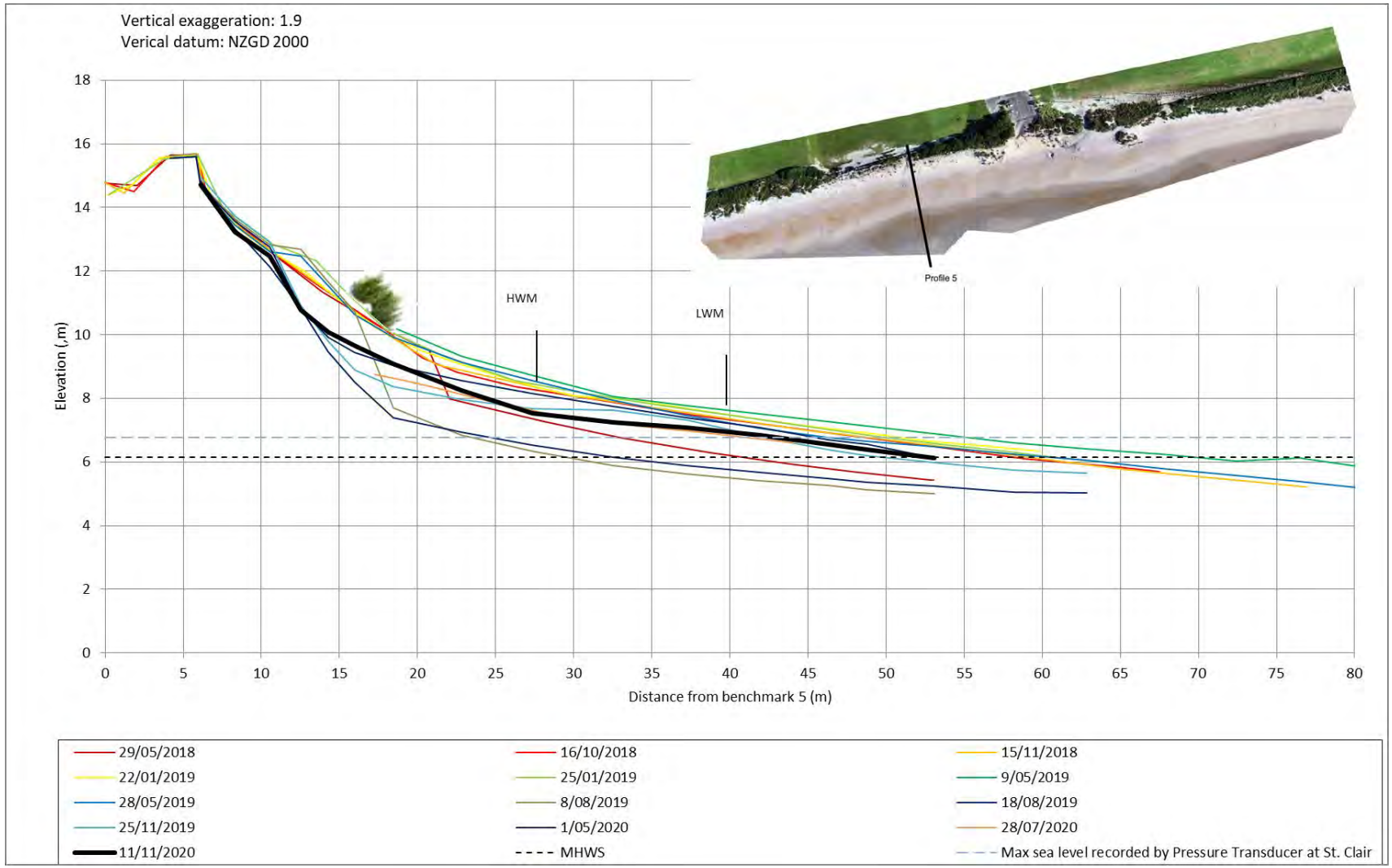

Figure 4.9: Profile 5

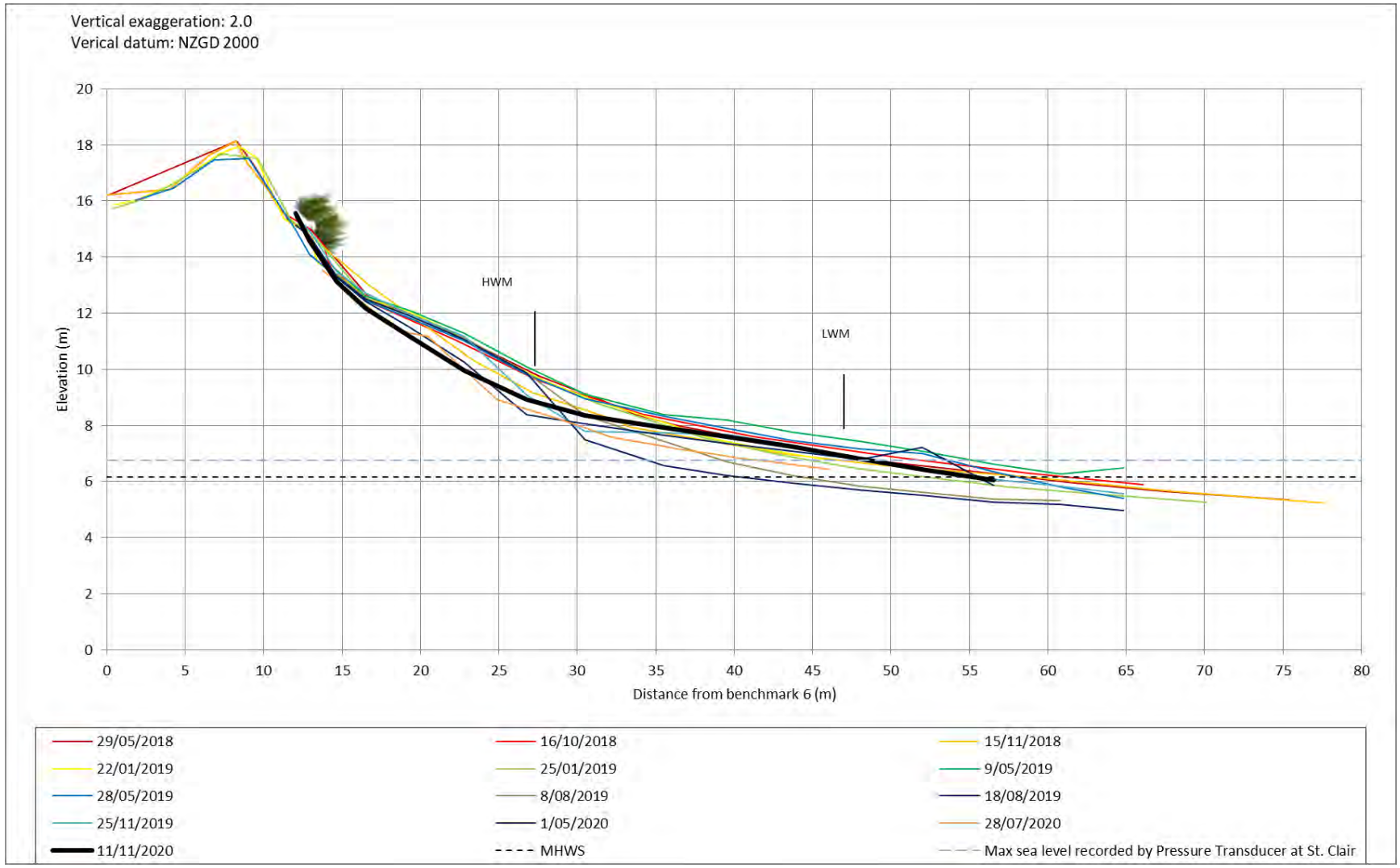

Figure 4.10: Profile 6

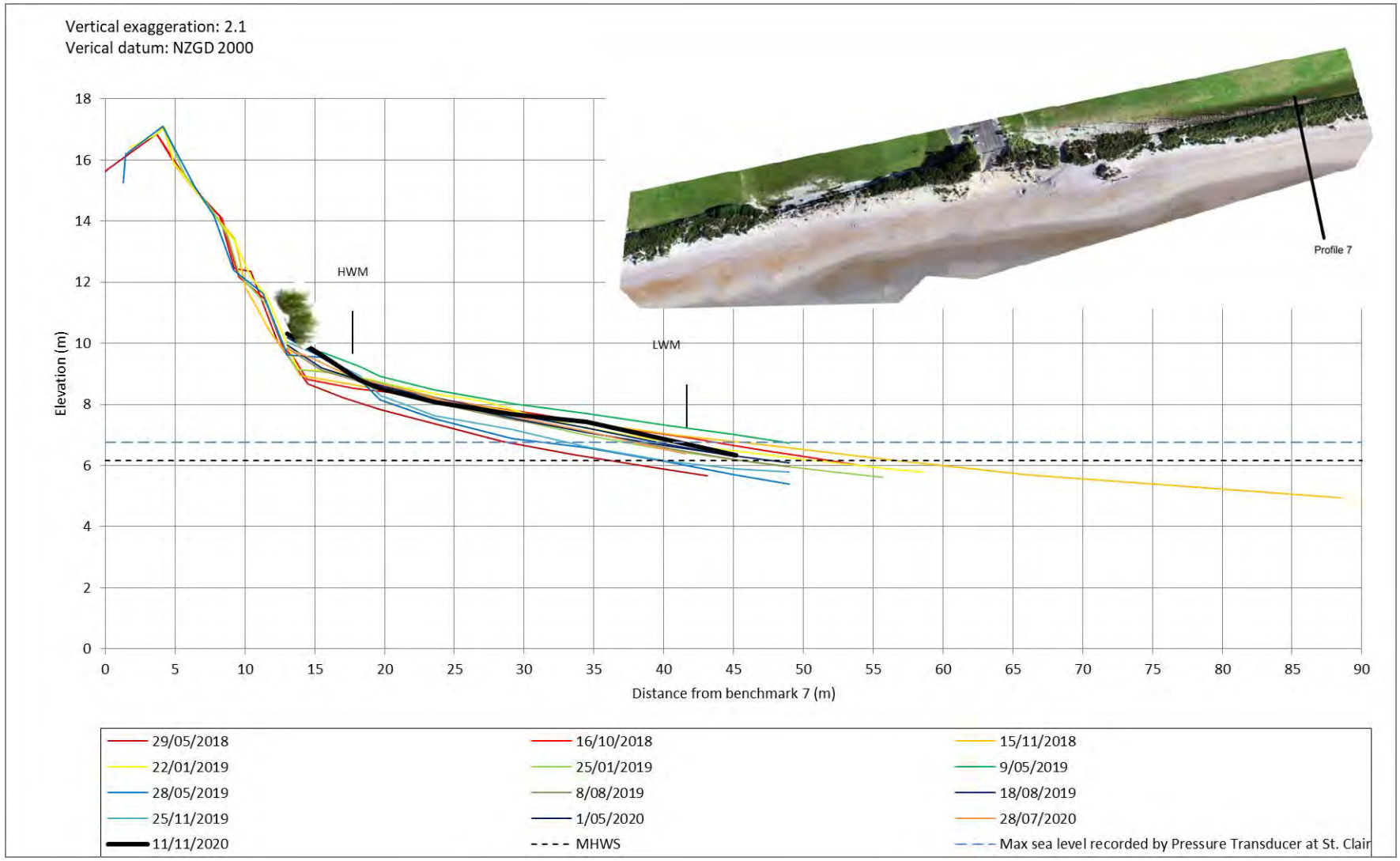

Figure 4.11: Profile 7

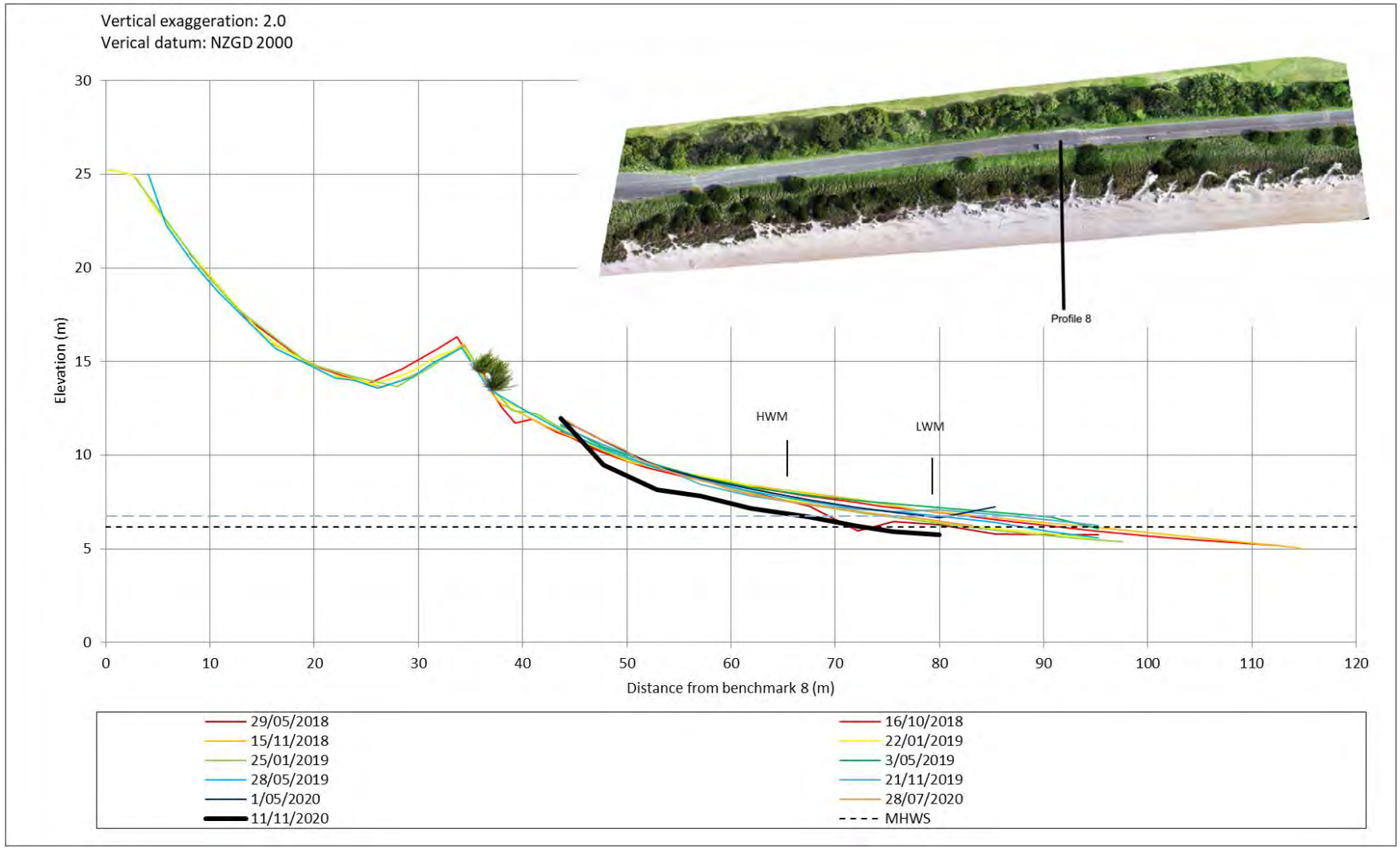

Figure 4.12: Profile 8

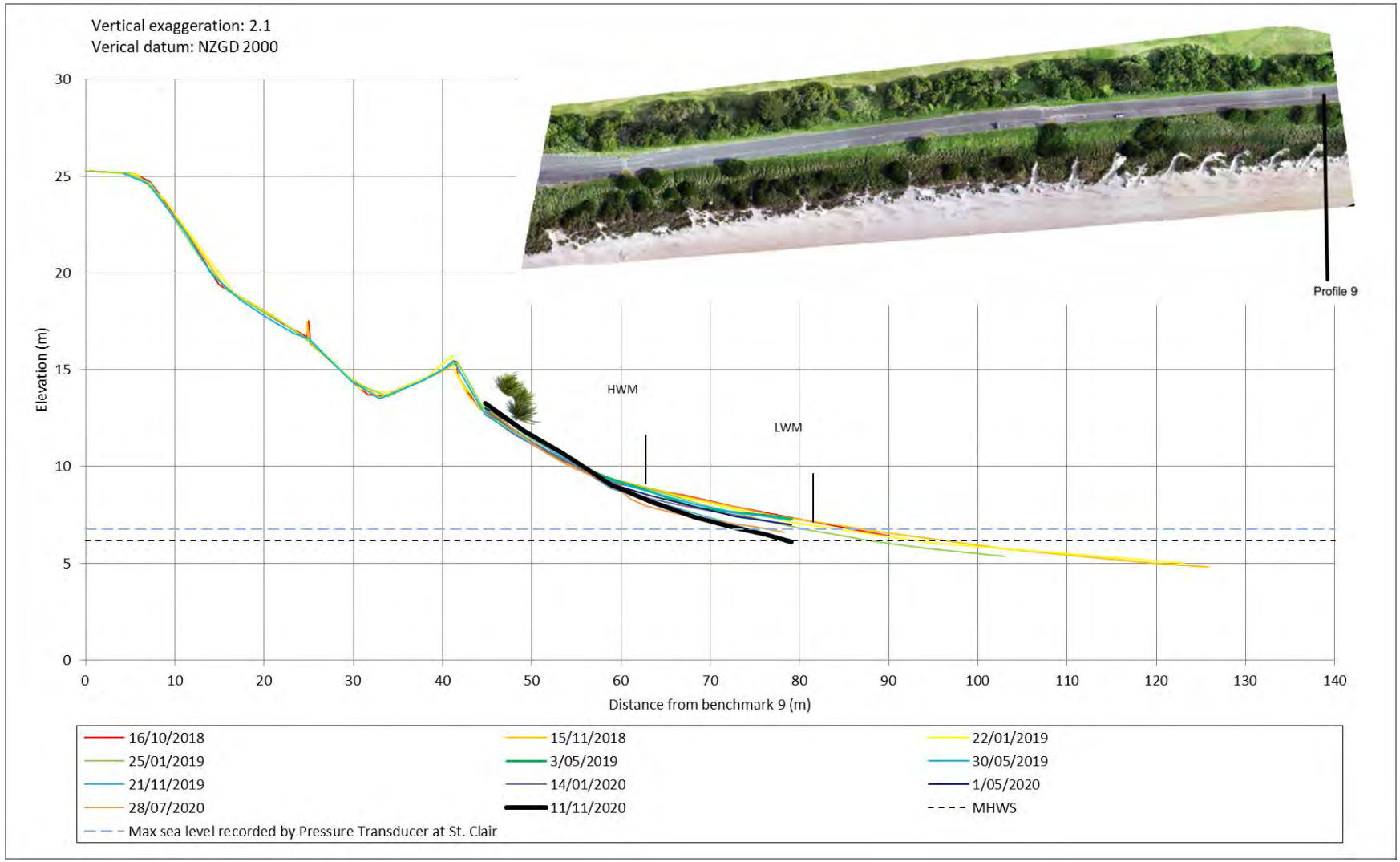

Figure 4.13: Profile 9

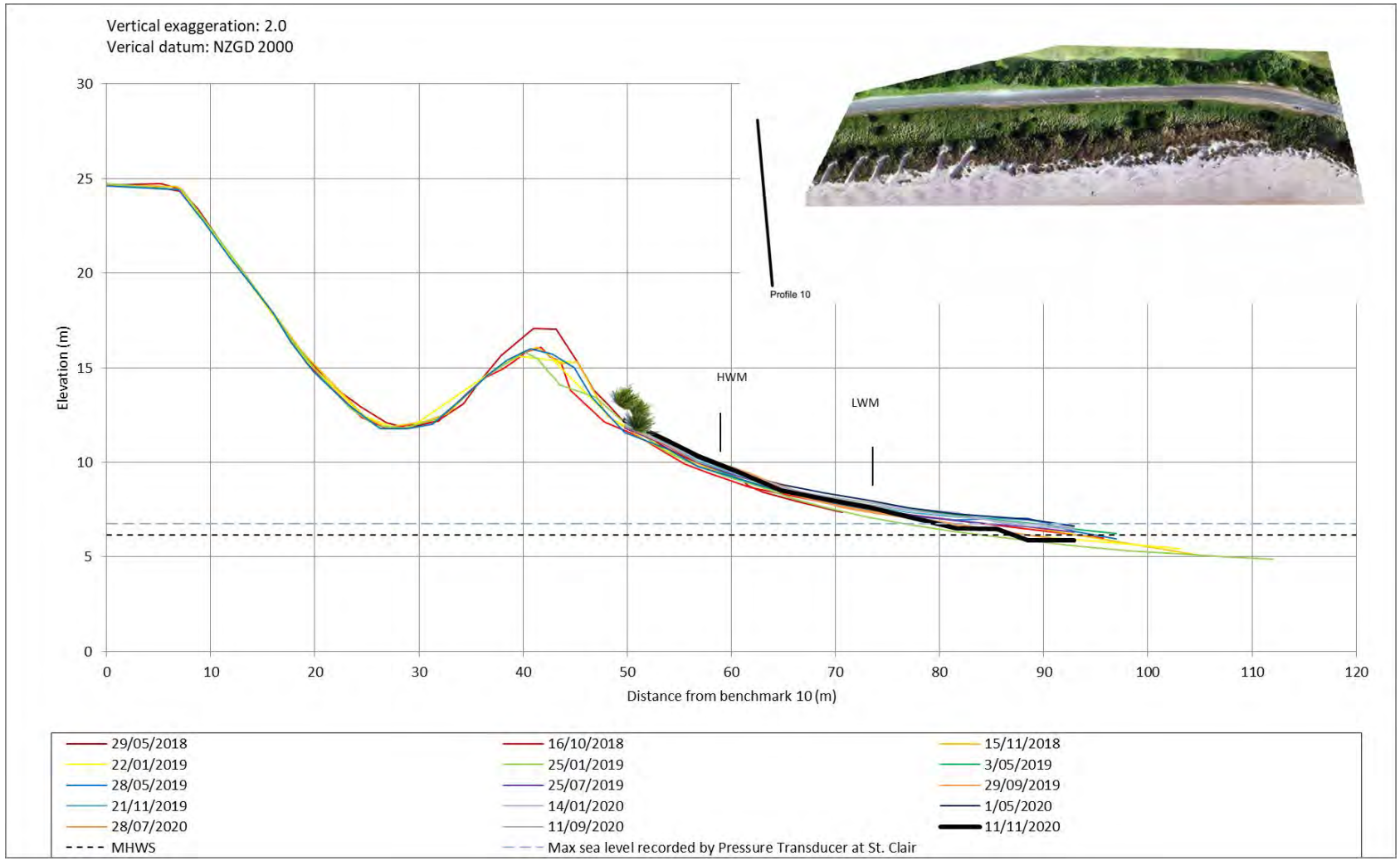

Figure 4.14: Profile 10

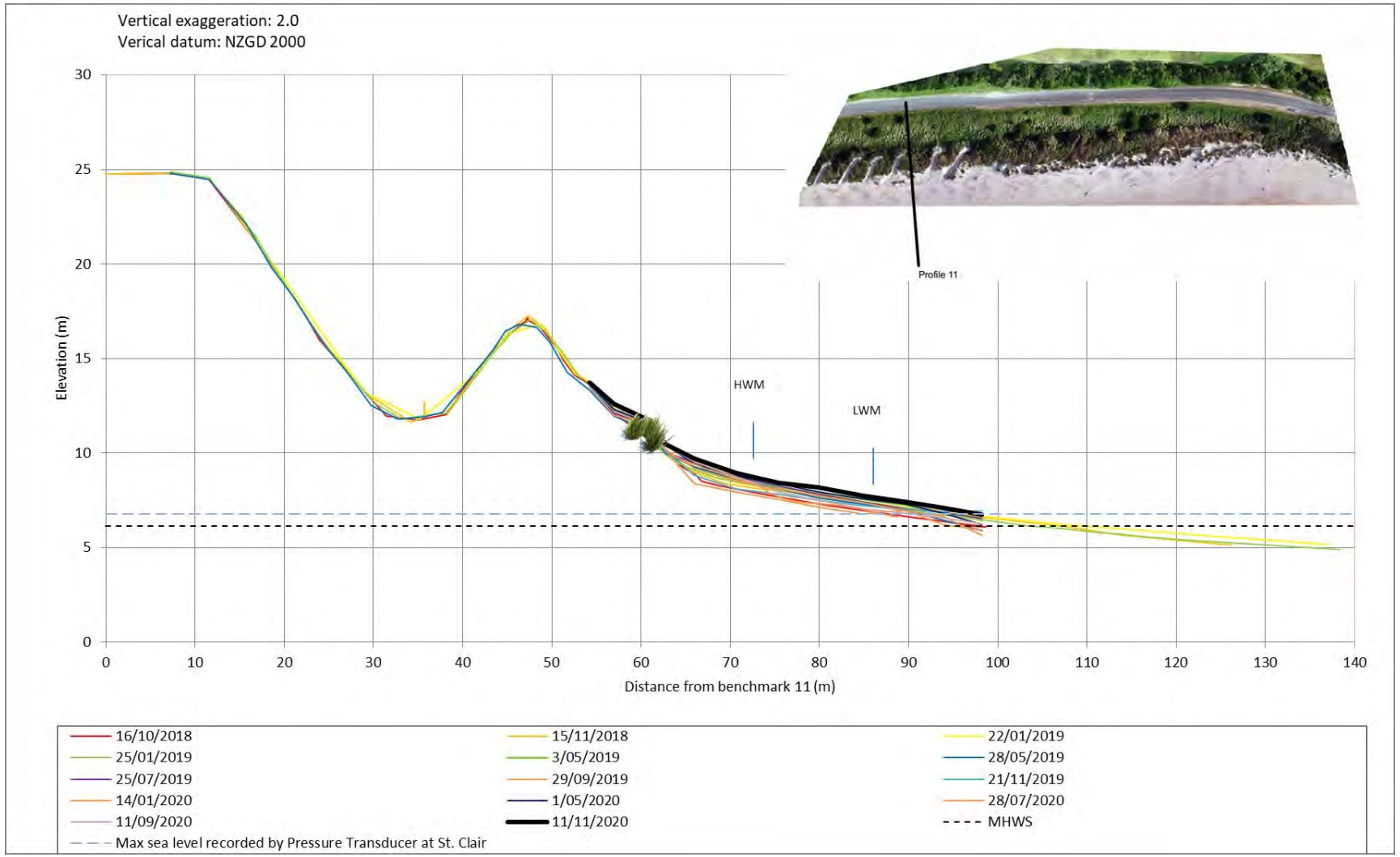

Figure 4.15: Profile 11

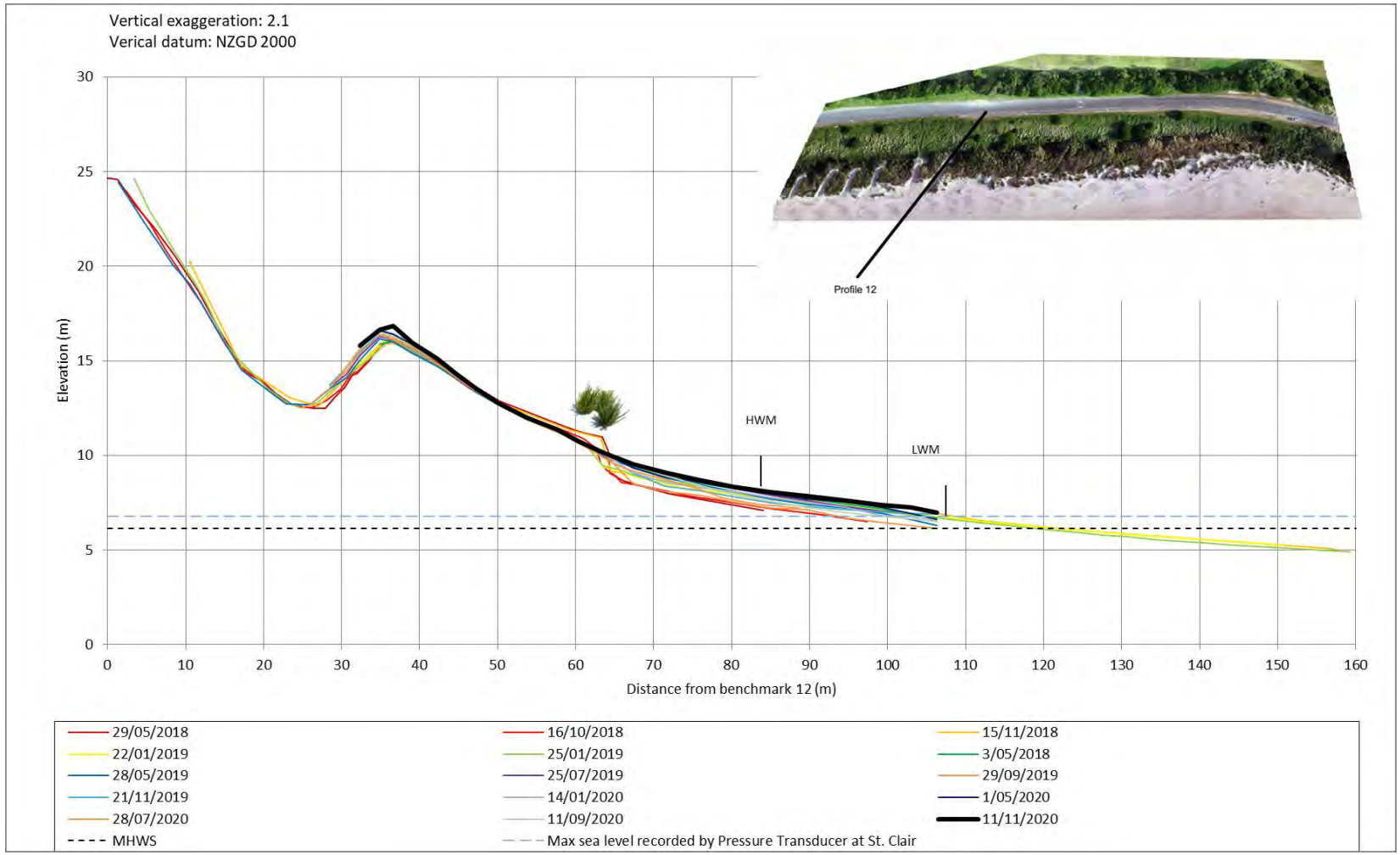

Figure 4.16: Profile 12

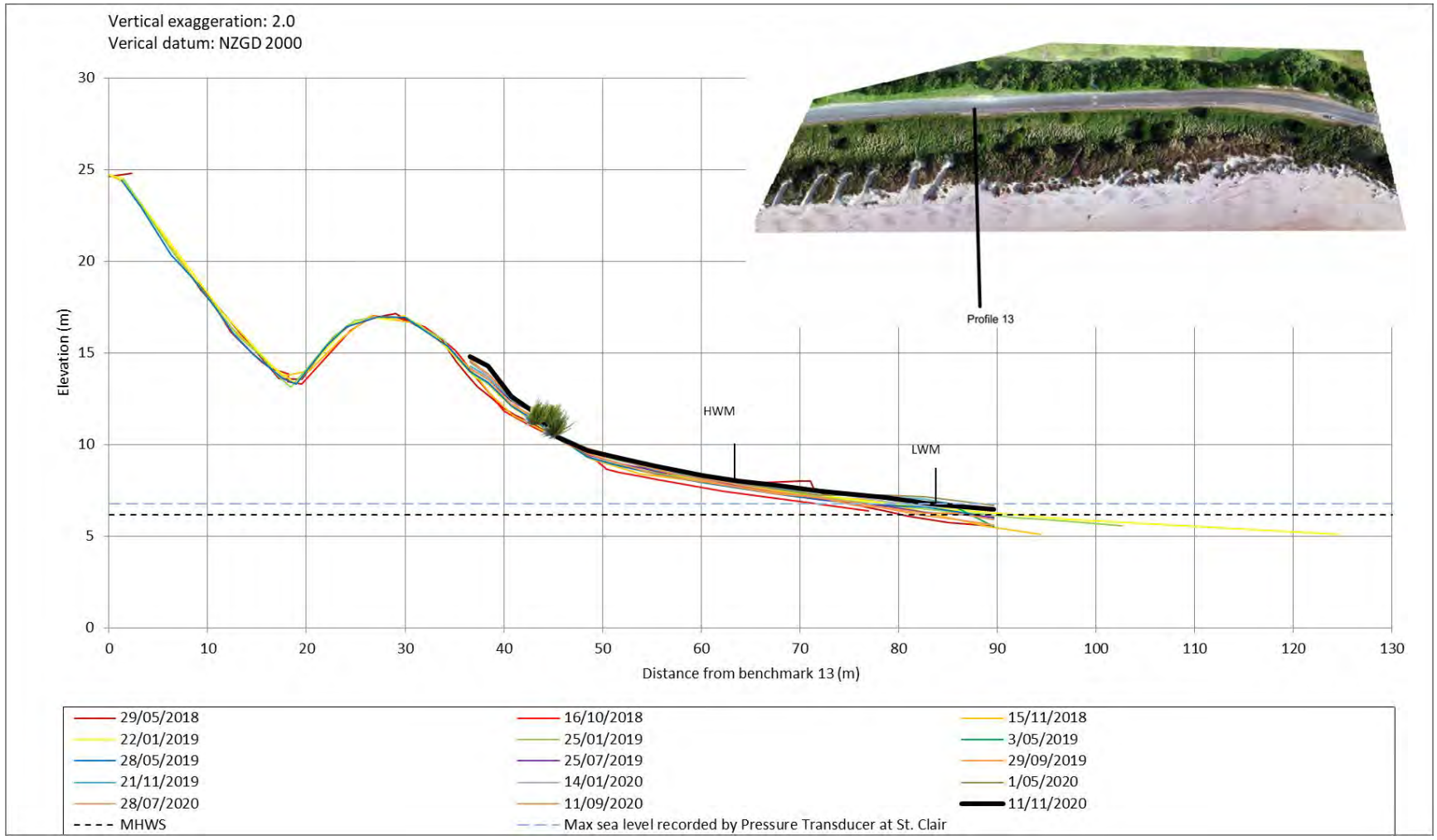

Figure 4.17: Profile 13

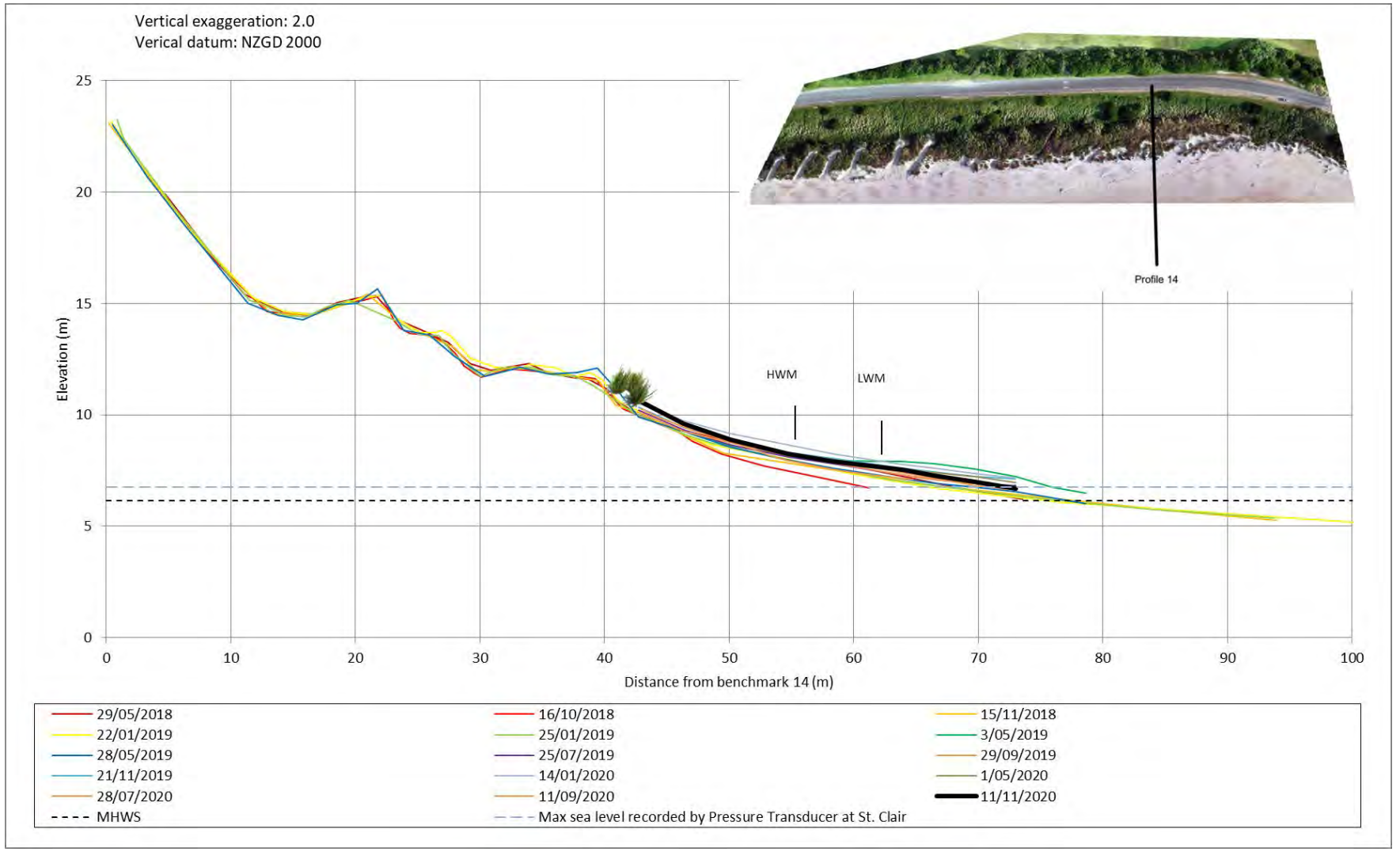

Figure 4.18: Profile 14

5. UAV – PHOTOGRAMMETRY SURVEY

5.1 Methods

Details of the methods used in the UAV – photogrammetry surveys were described in the first beach and dune monitoring report (Adam et al. 2018). The pattern of sand loss or gain during 2018 was presented in that report. Since mid-winter 2019 report, beach changes are quantified using four additional parameters (in Equations 2 – 5):

$$Average\ elevation\ sand\ loss\ = \frac{Volume\ of\ sand\ loss\ zone}{Area\ of\ sand\ loss\ zone} \quad (2)$$

$$Average\ elevation\ sand\ gain\ = \frac{Volume\ of\ sand\ gain\ zone}{Area\ of\ sand\ gain\ zone} \quad (3)$$

$$Overall\ beach\ volume\ change = Volume\ of\ sand\ loss\ zone - Volume\ of\ sand\ gain\ zone \quad (4)$$

$$Overall\ beach\ elevation\ change\ = \frac{Overall\ beach\ volume\ change}{Calcuation\ area} \quad (5)$$

In addition, the time-series changes of beach volume and beach elevation from the first UAV survey on 3rd May 2018 to latest survey on 11th November 2020 are presented.

5.2 Results

The beach and dune elevation changes in each area are presented as i) DSMs; ii) beach change maps (net change in elevation between DSMs); iii) the percentage of accretion/erosion areas; and iv) volumetric sand accretion/erosion and average elevation change. Table 5 summarises these figures.

Figures 5.37 and 5.38 present the time-series graphs of volumetric sand change and average elevation change in each area, respectively.

Table 4: List of figures showing the DSM, beach change map, accretion/erosion area, volumetric sand accretion/erosion and average elevation change.

	Area 1	Area 2	Area 3	Area 4
DSM	5.1 - 5.3	5.10 – 5.12	5.19 – 5.20	5.26 – 2.29
Beach change map	5.4 – 5.6	5.13 – 5.15	5.21 – 5.22	5.30 – 5.33
Percentage of accretion/erosion area	5.7	5.16	5.23	5.34
Volumetric sand accretion/erosion	5.8	5.17	5.24	5.35
Average elevation change	5.9	5.18	5.25	5.36

Appendix 2 lists the GCP layout and coordinates. Appendix 3 presents the key quality parameters generated in the Pix4D reports.

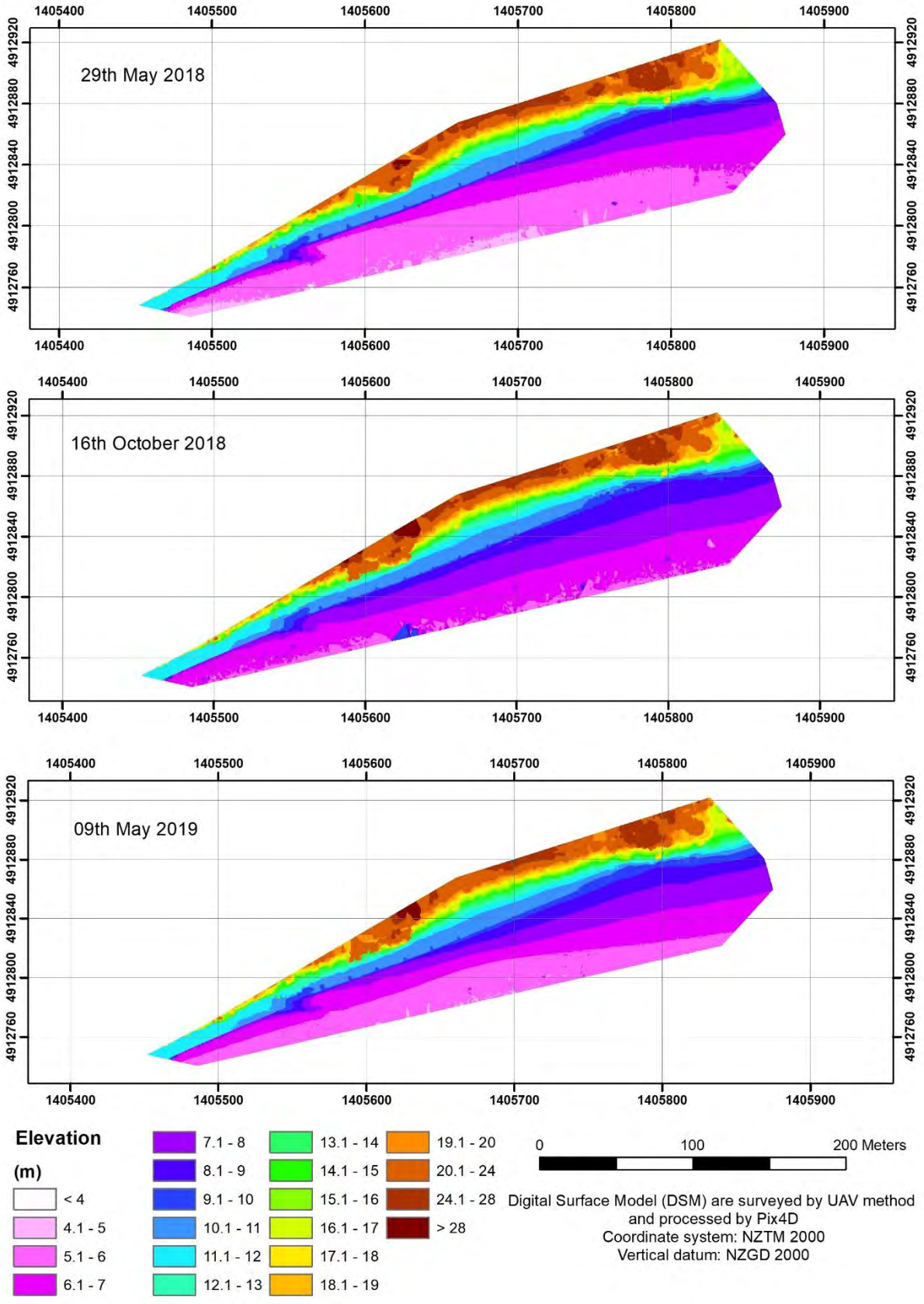

Figure 5.1: Area 1: Digital Surface Models (DSMs) on 29th May 2018, 16th August 2018 and 9th May 2019.

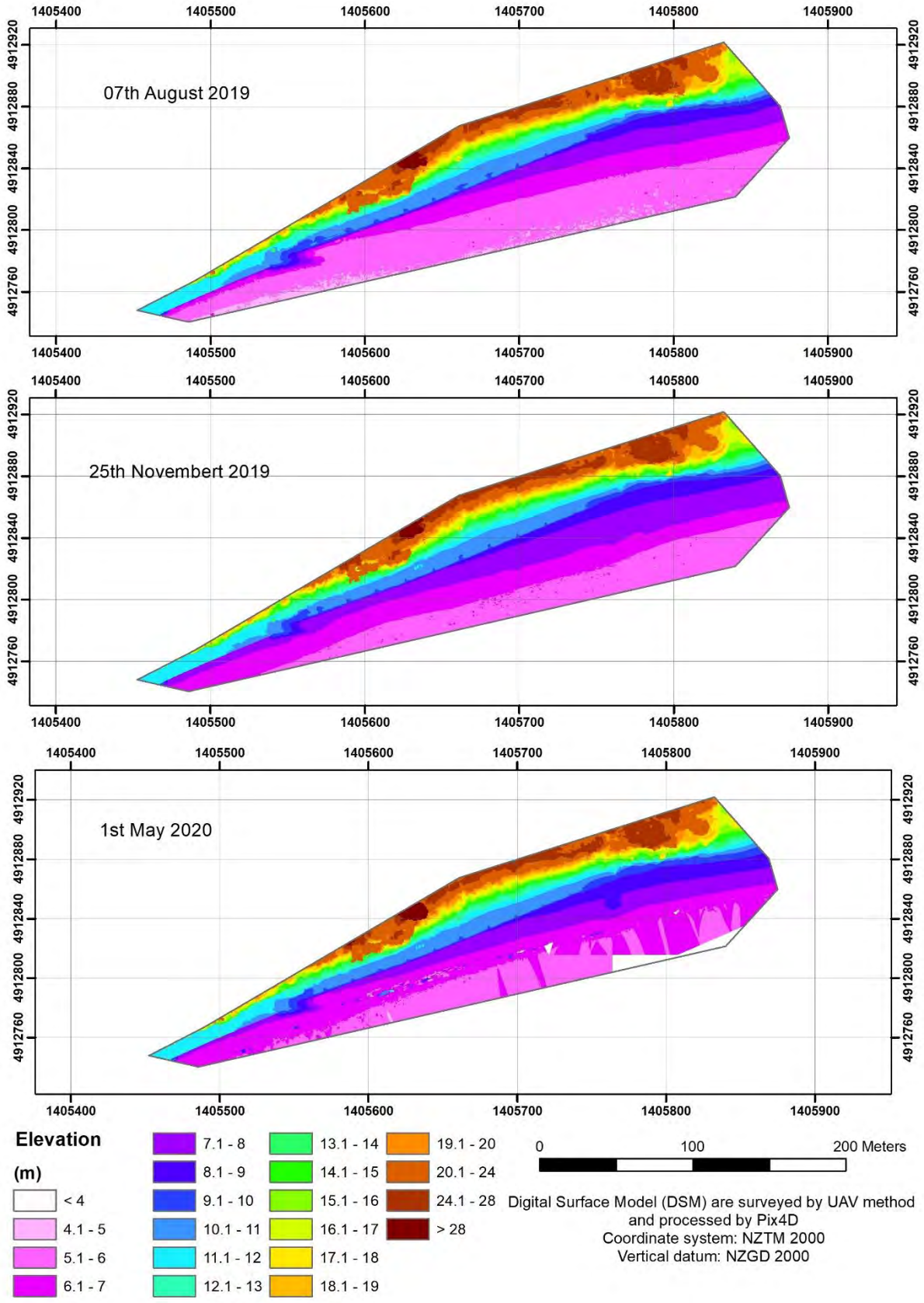

Figure 5.2: Area 1: Digital Surface Models (DSMs) on 7th August 2019, 25th November 2019, and 1st May 2020

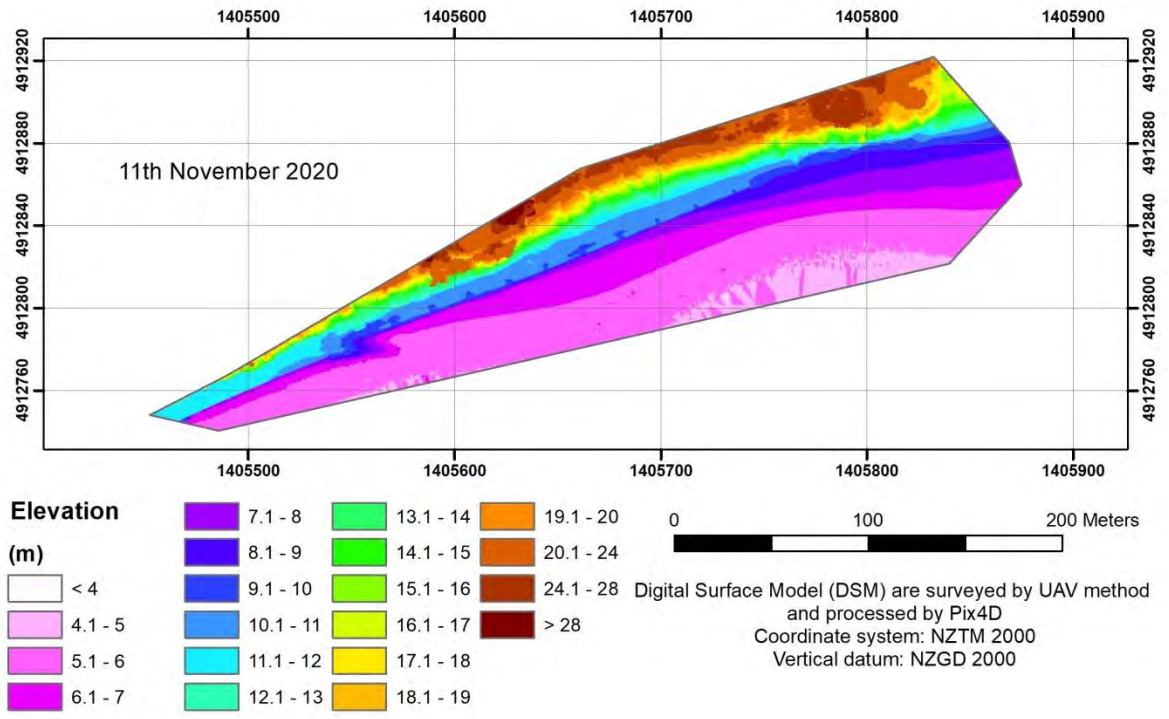

Figure 5.3: Area 1: Digital Surface Models (DSMs) on 11th November 2020

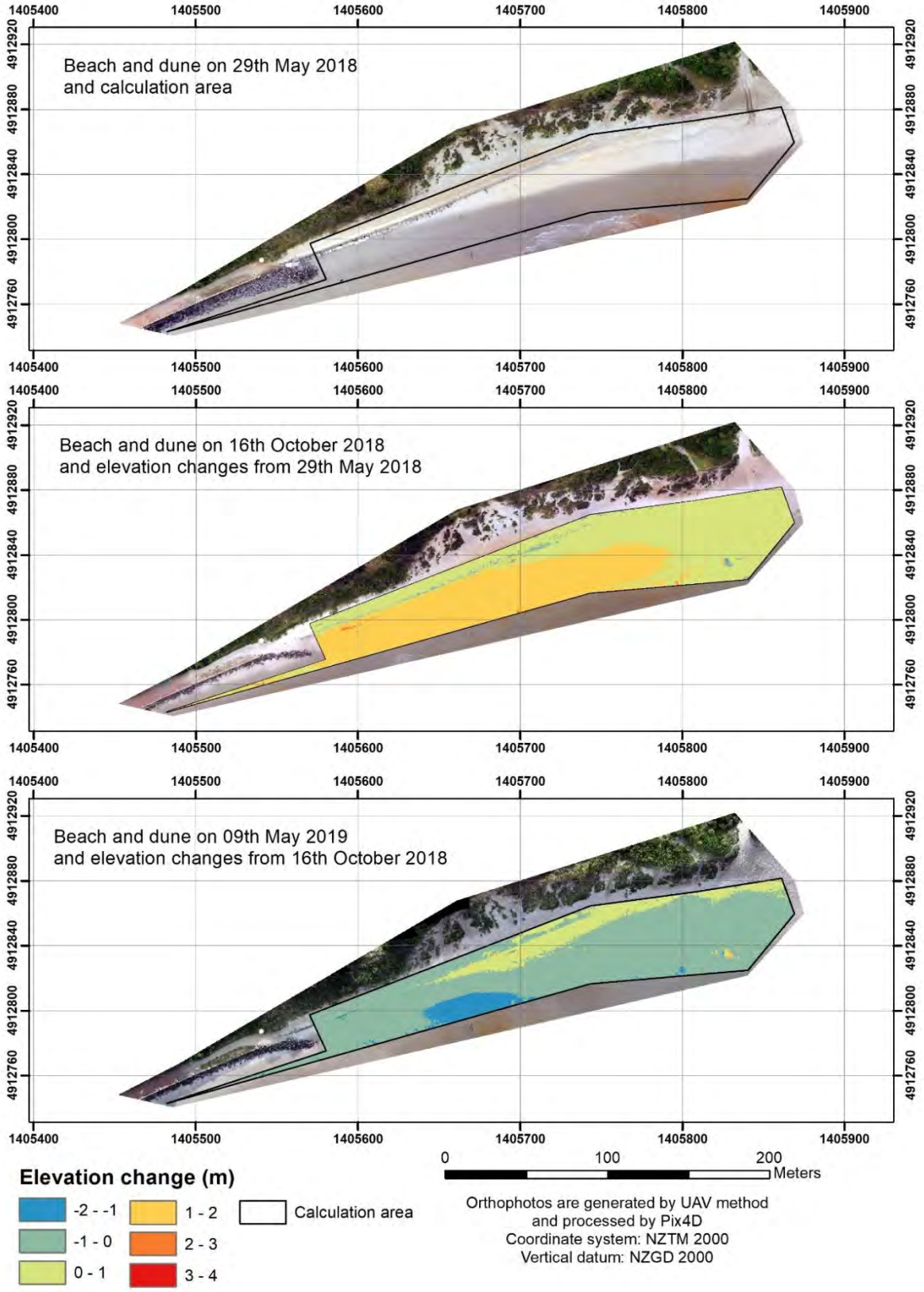

Figure 5.4: Area 1: Changes in beach elevation between surveys on the 29th May 2018 to 9th May 2019.

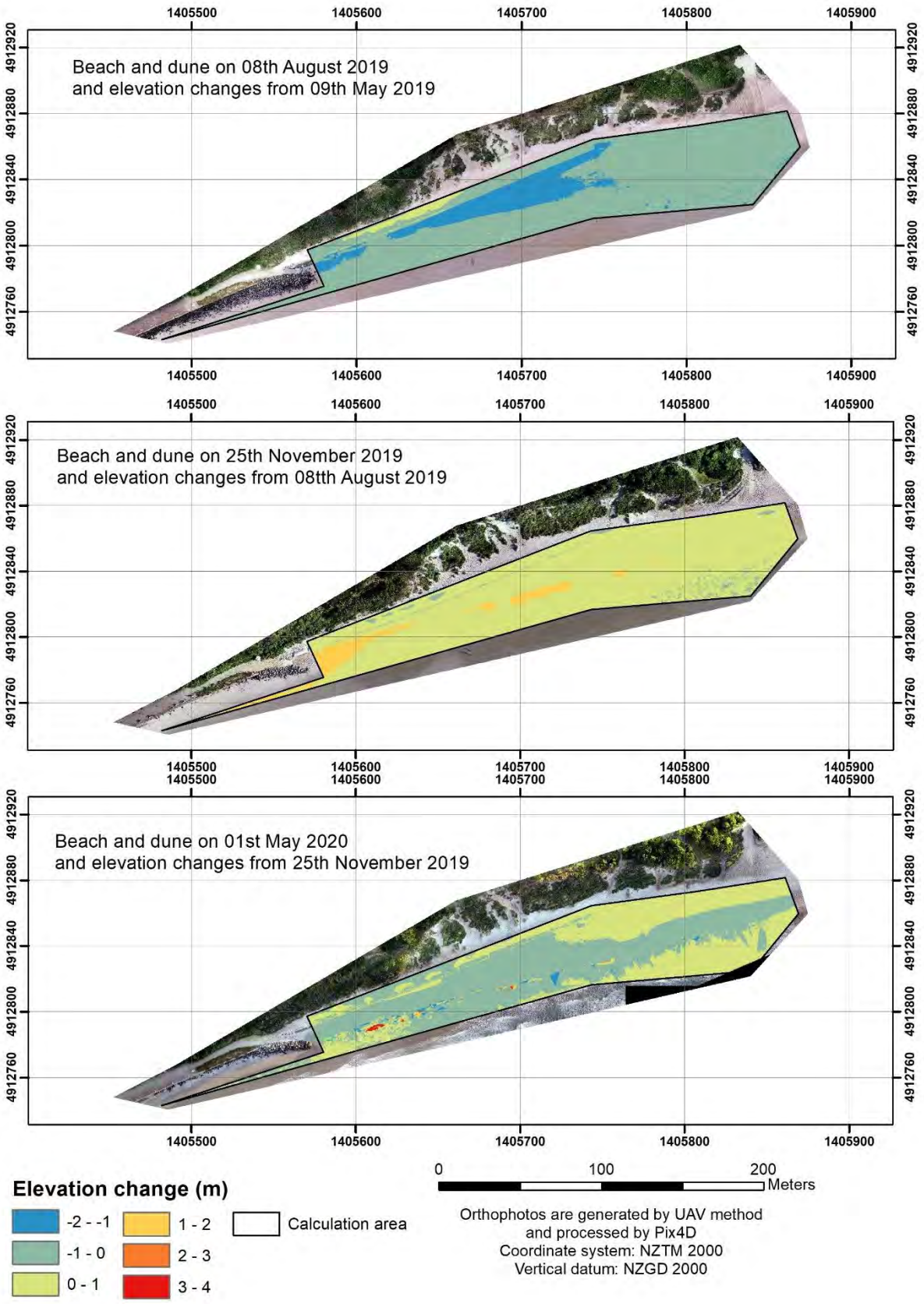

Figure 5.5. Area 1: Change in beach elevation between surveys on the 9th May 2019 to 1st May 2020.

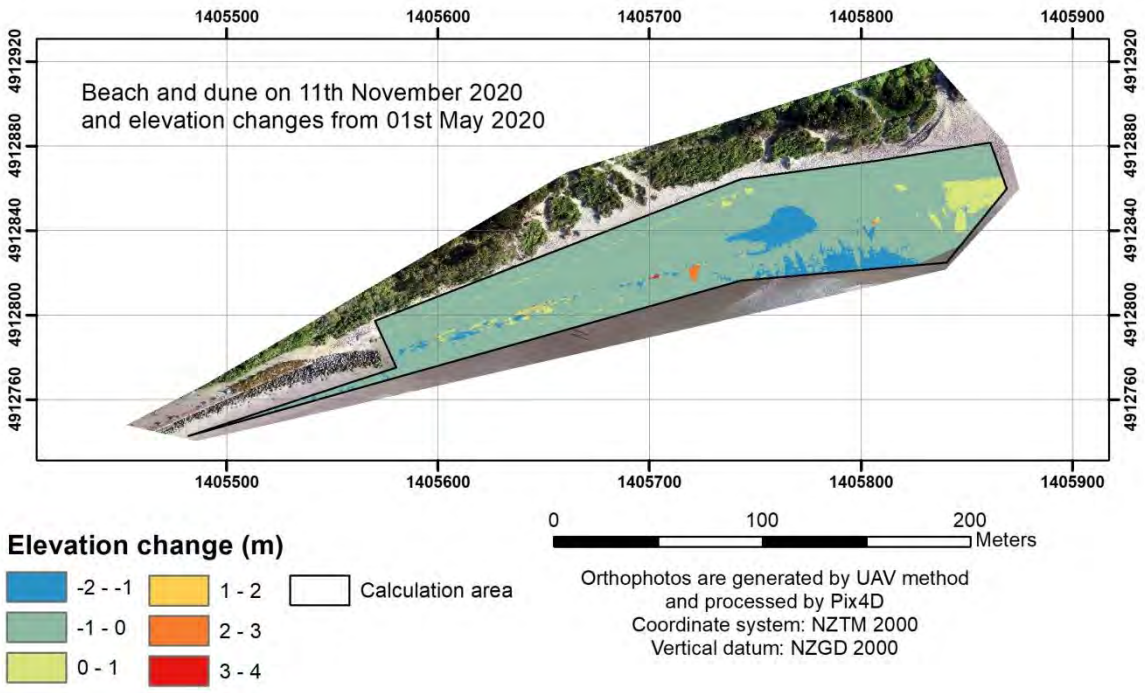

Figure 5.6. Area 1: Change in beach elevation between surveys on the 1st May 2020 to 11th November 2020.

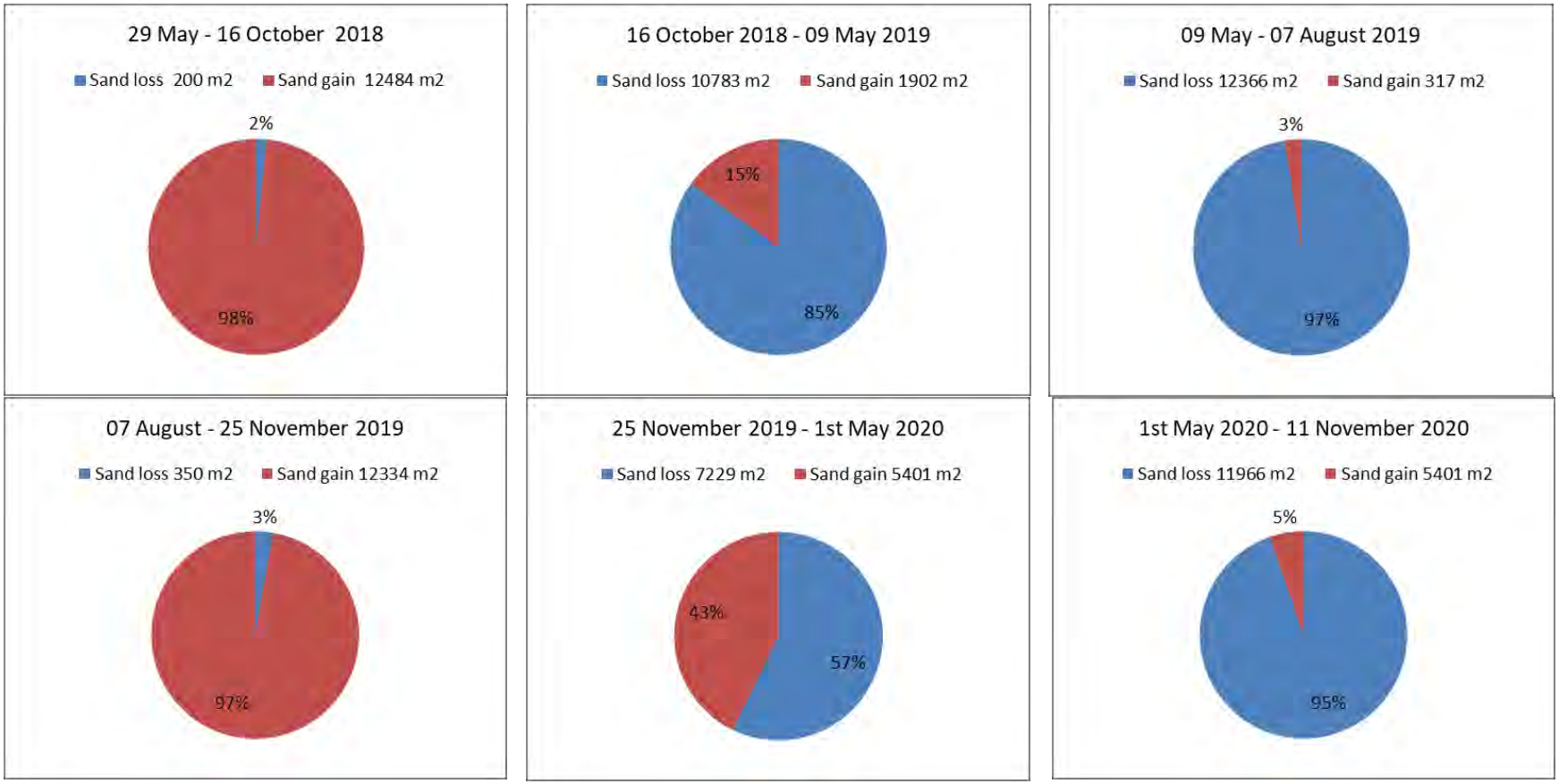

Figure 5.7: Area 1: Percentage net loss and net gain in Area 1 between surveys on the 29th May 2018 and the 11th November 2020.

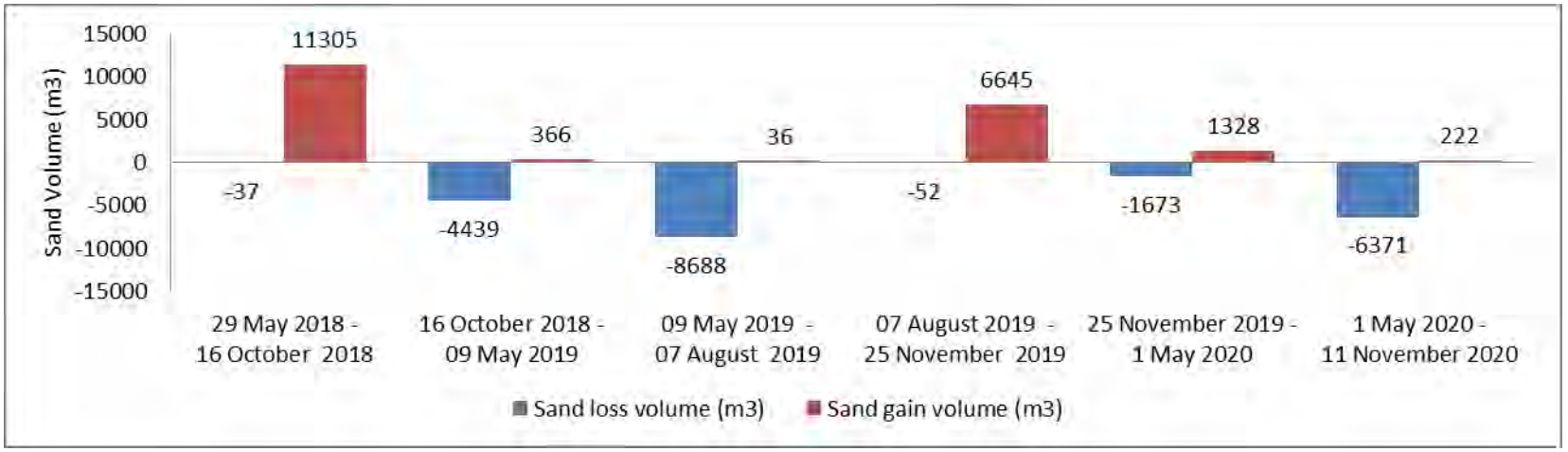

Figure 5.8: Area 1: Total sand volume changes between surveys on the 29th May 2018 and the 11th November 2020.

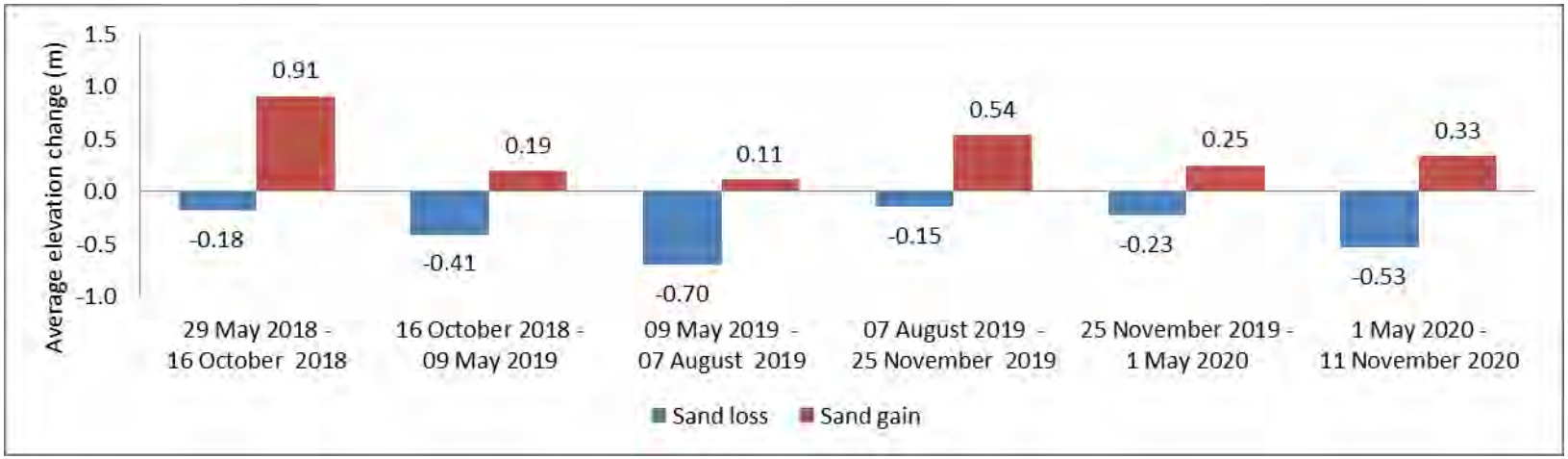

Figure 5.9: Area 1: Average elevation change between surveys on the 29th May 2018 and the 11th November 2020.

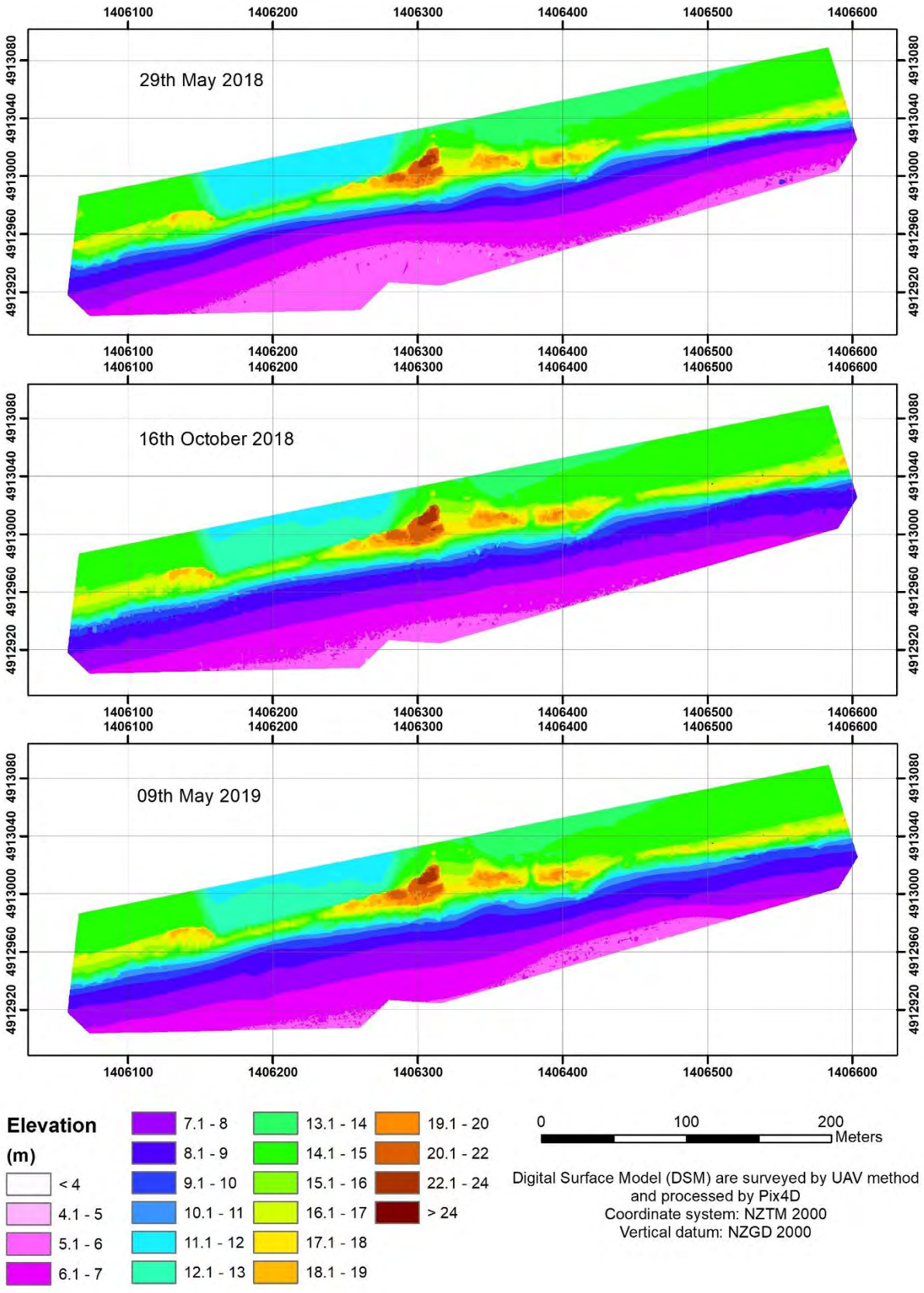

Figure 5.10: Area 2: Digital Surface Models (DSMs) on the 29th May 2018, 16th October 2018 and 09th May 2019.

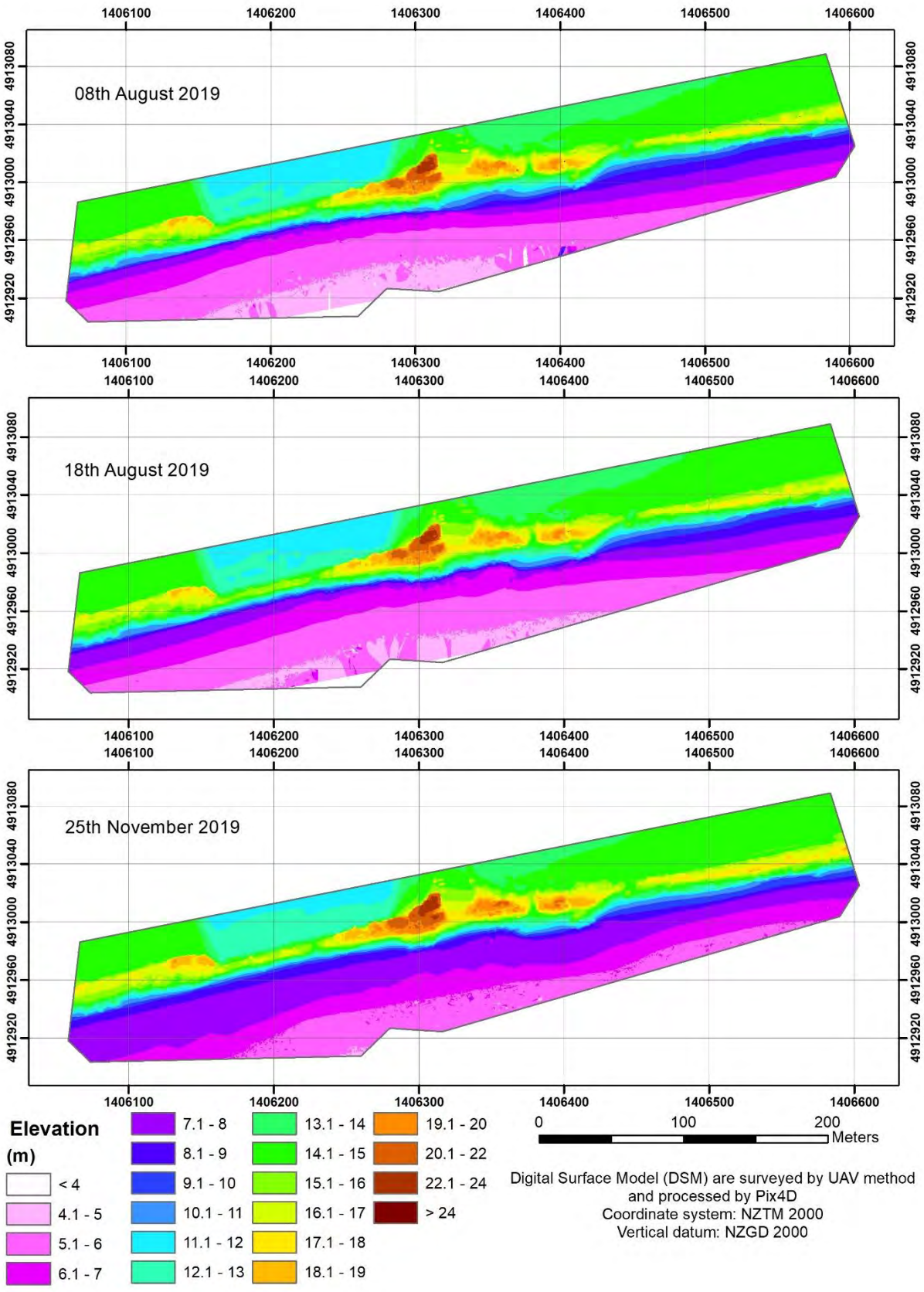

Figure 5.11: Area 2: Digital Surface Models (DSMs) on the 8th August 2019, 18th August 2019 and 25th November 2019.

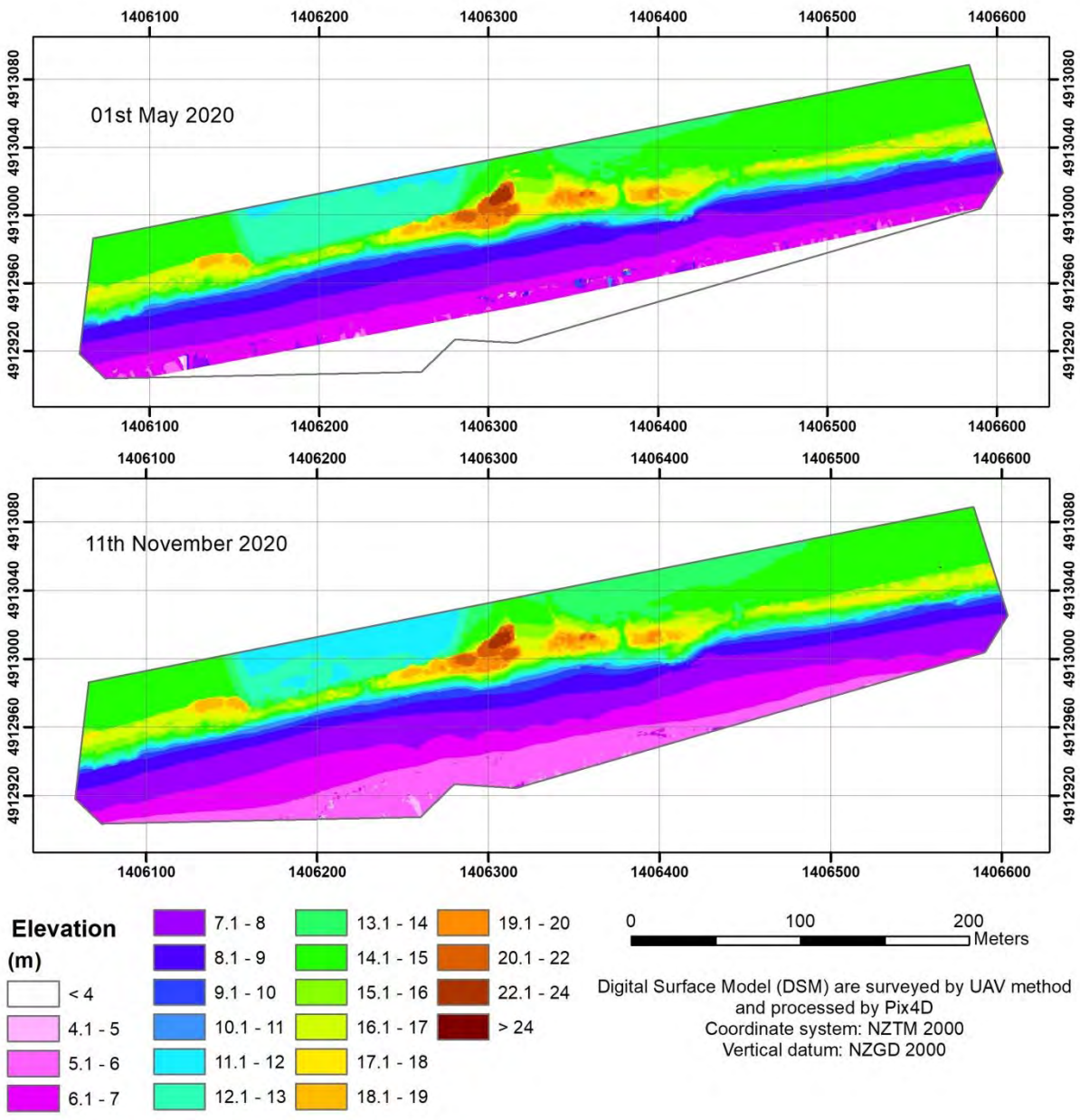

Figure 5.12: Area 2: Digital surface model (DSMs) on the 1st May 2020, the 11th November 2020

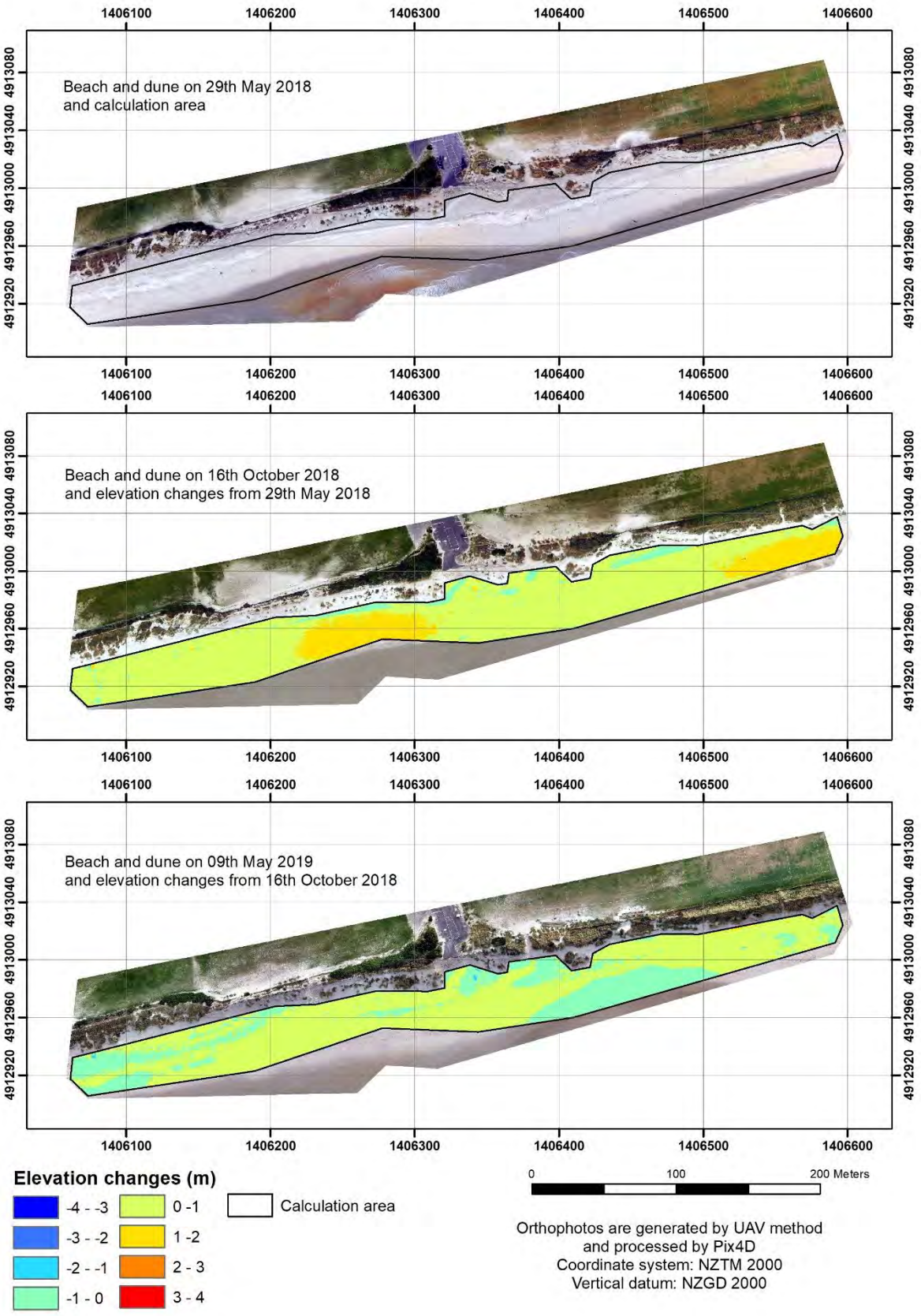

Figure 5.13: Area 2: Change in beach elevation between surveys on the 29th May 2018 and the 9th May 2019.

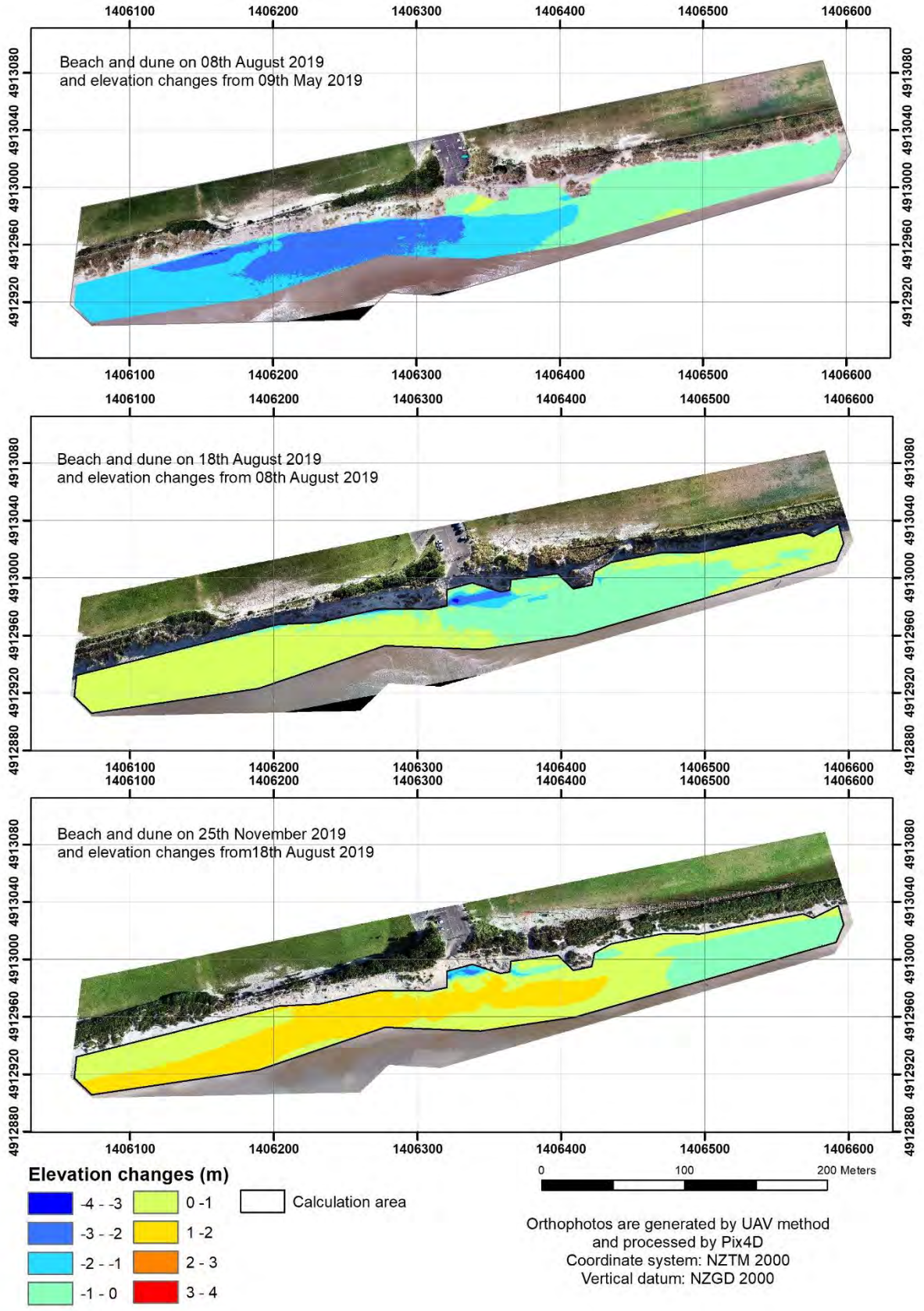

Figure 5.14: Area 2: Change in beach elevation between surveys on the 9th May 2019 and the 25th November 2019.

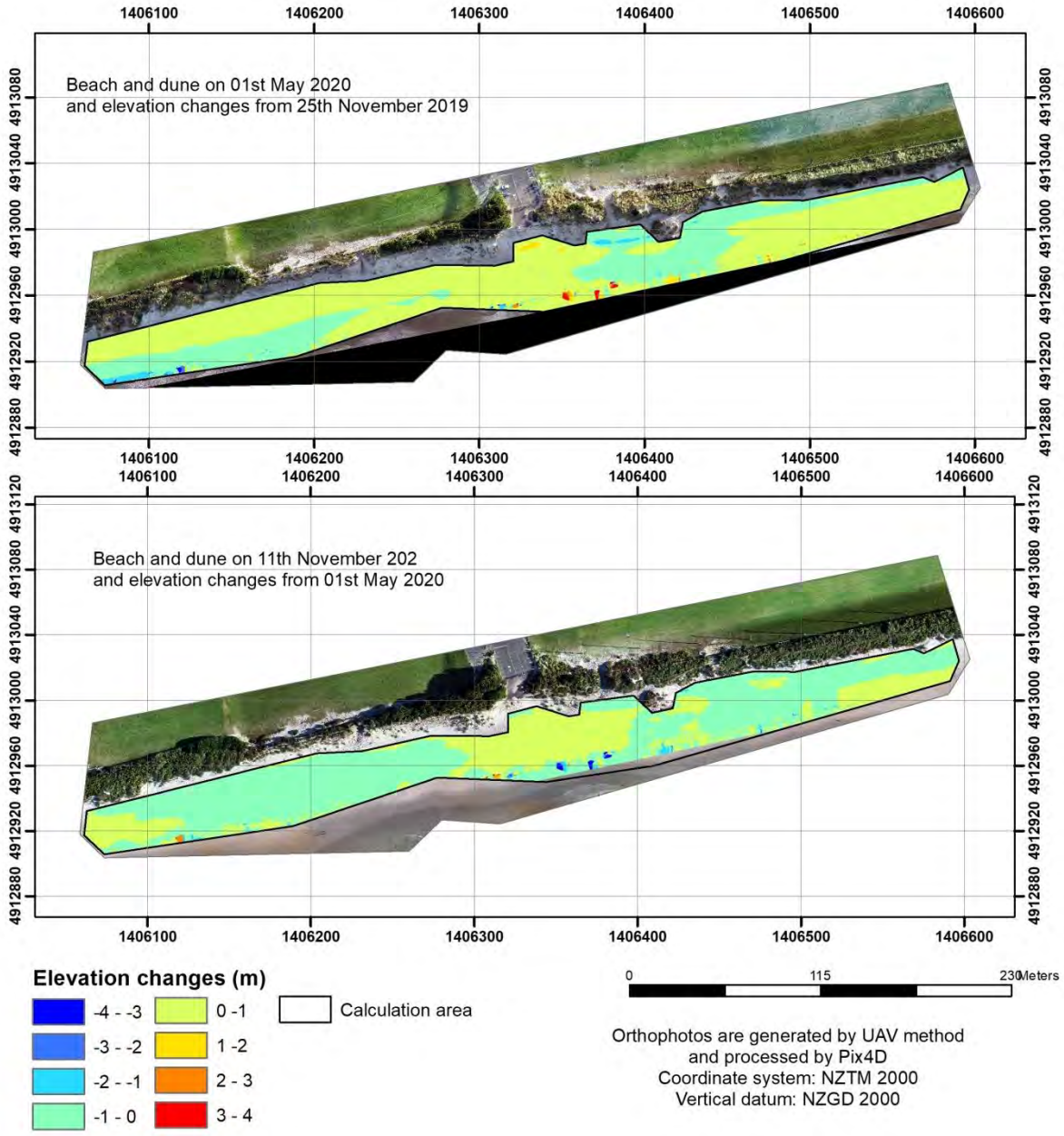

Figure 5.15: Area 2: Change in beach elevation between surveys on the 25th November 2019 and the 11th November 2020

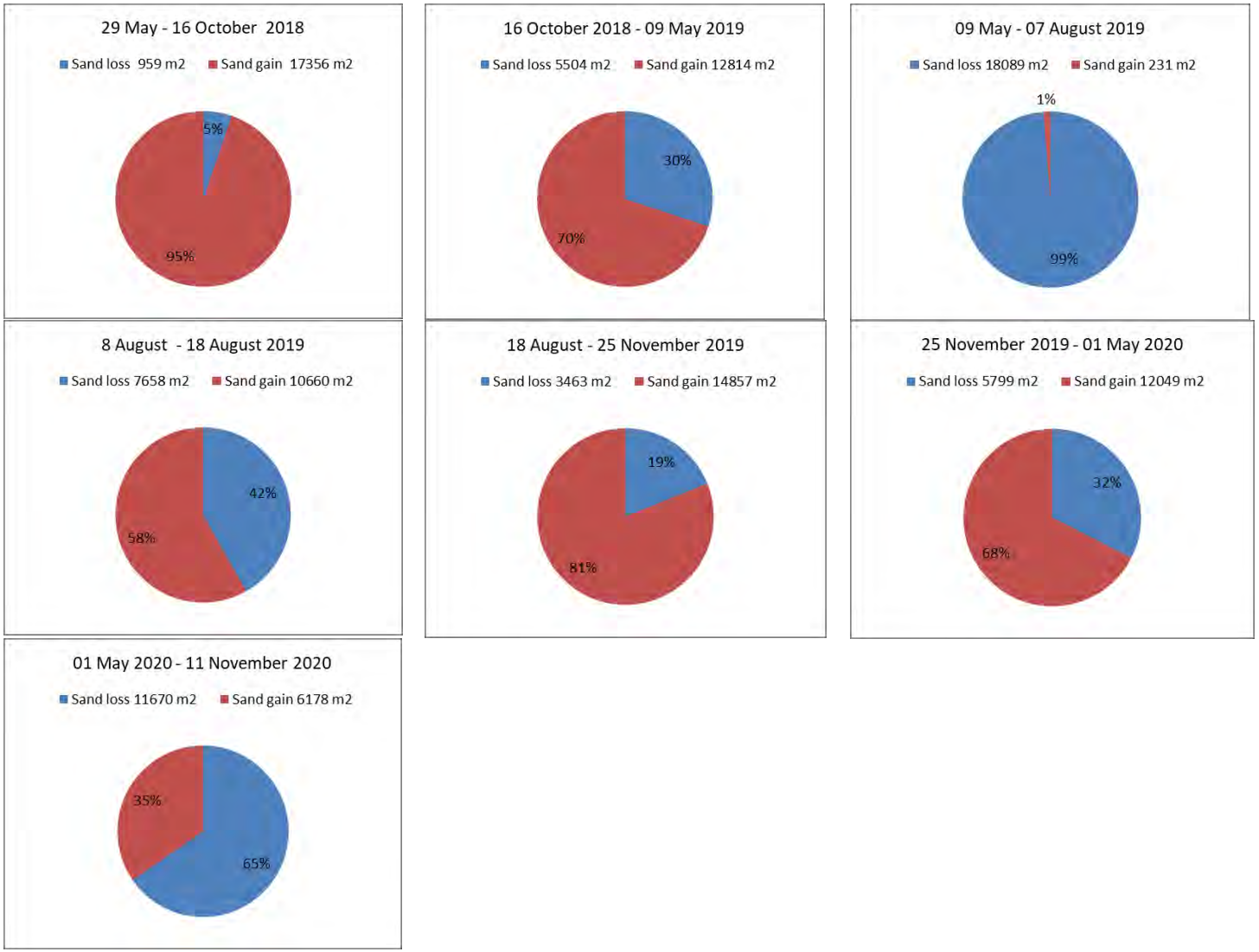

Figure 5.16: Area 2: Percentage net loss and net gain between surveys on the 29th May 2018 and 11th November 2020.

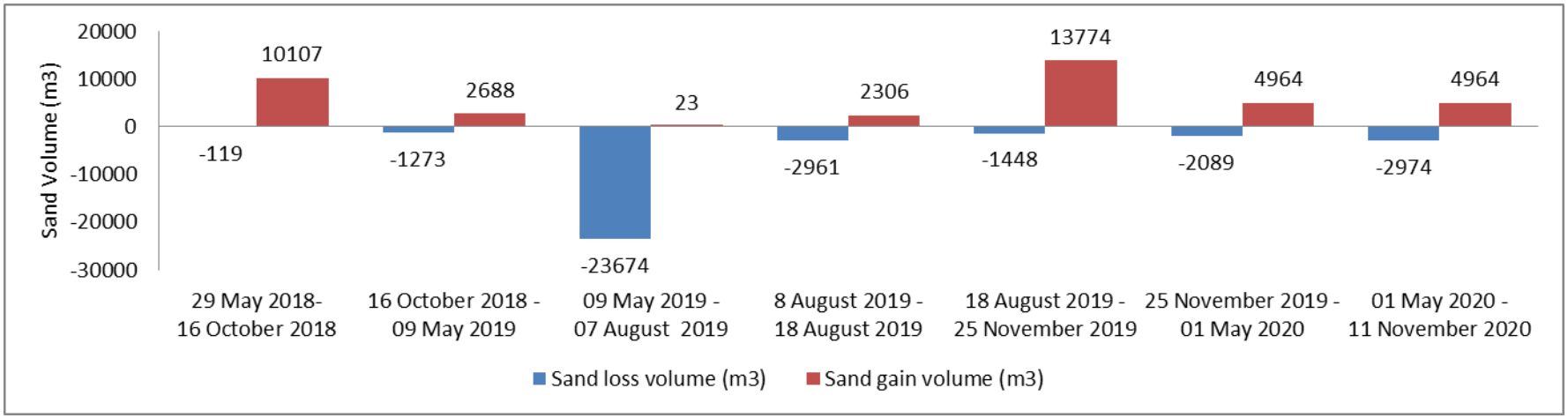

Figure 5.17: Area 2: Total sand volume changes between surveys on the 29th May 2018 and the 11th November 2020.

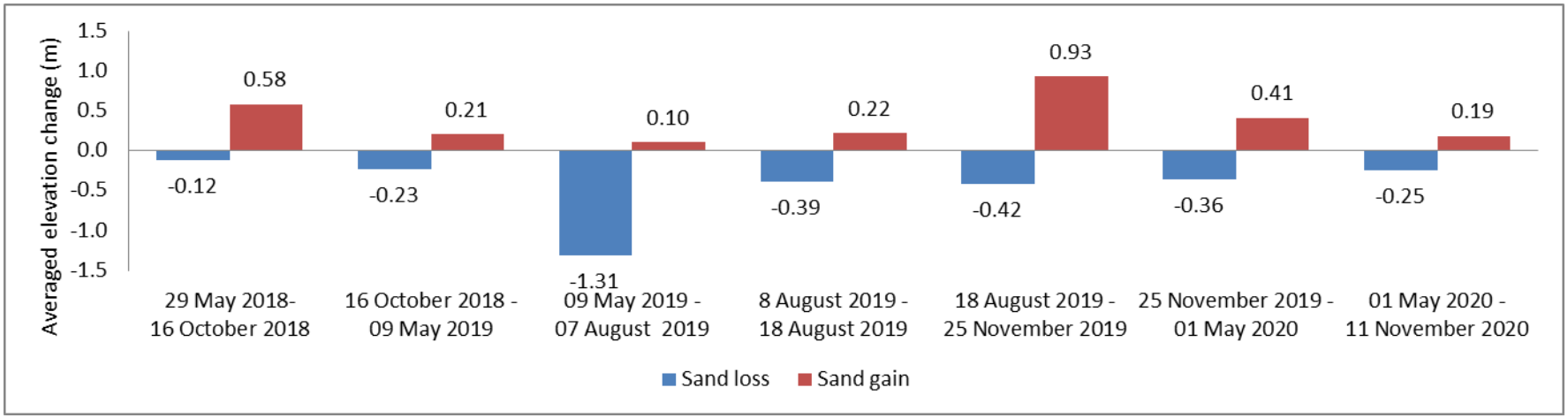

Figure 5.18: Area 2: Average elevation change between surveys on the 29th May 2018 and the 11th November 2020.

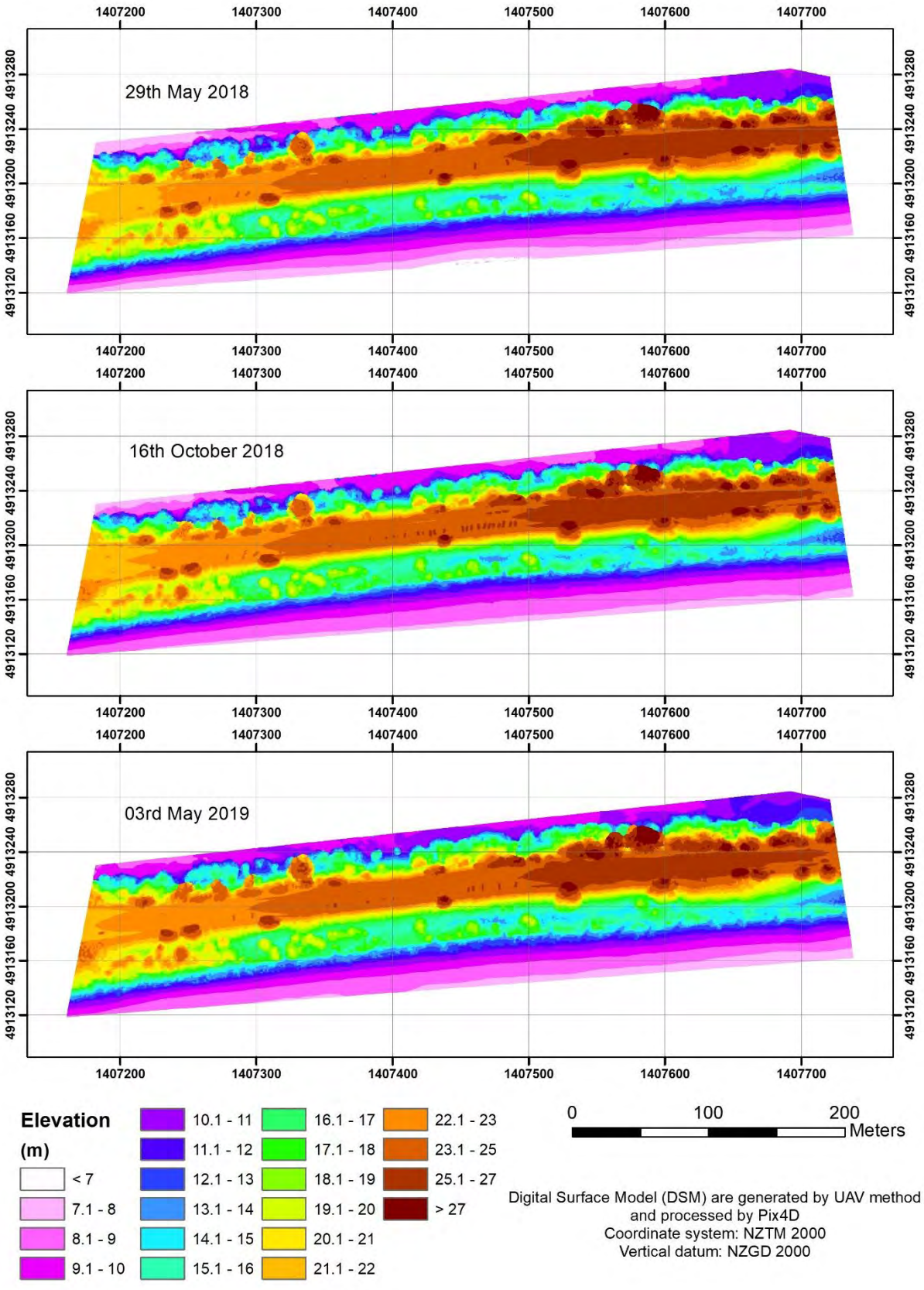

Figure 5.19: Area 3: Digital Surface Models (DSMs) of surveys on the 29th May 2018, 16th October 2018 and 03rd May 2019.

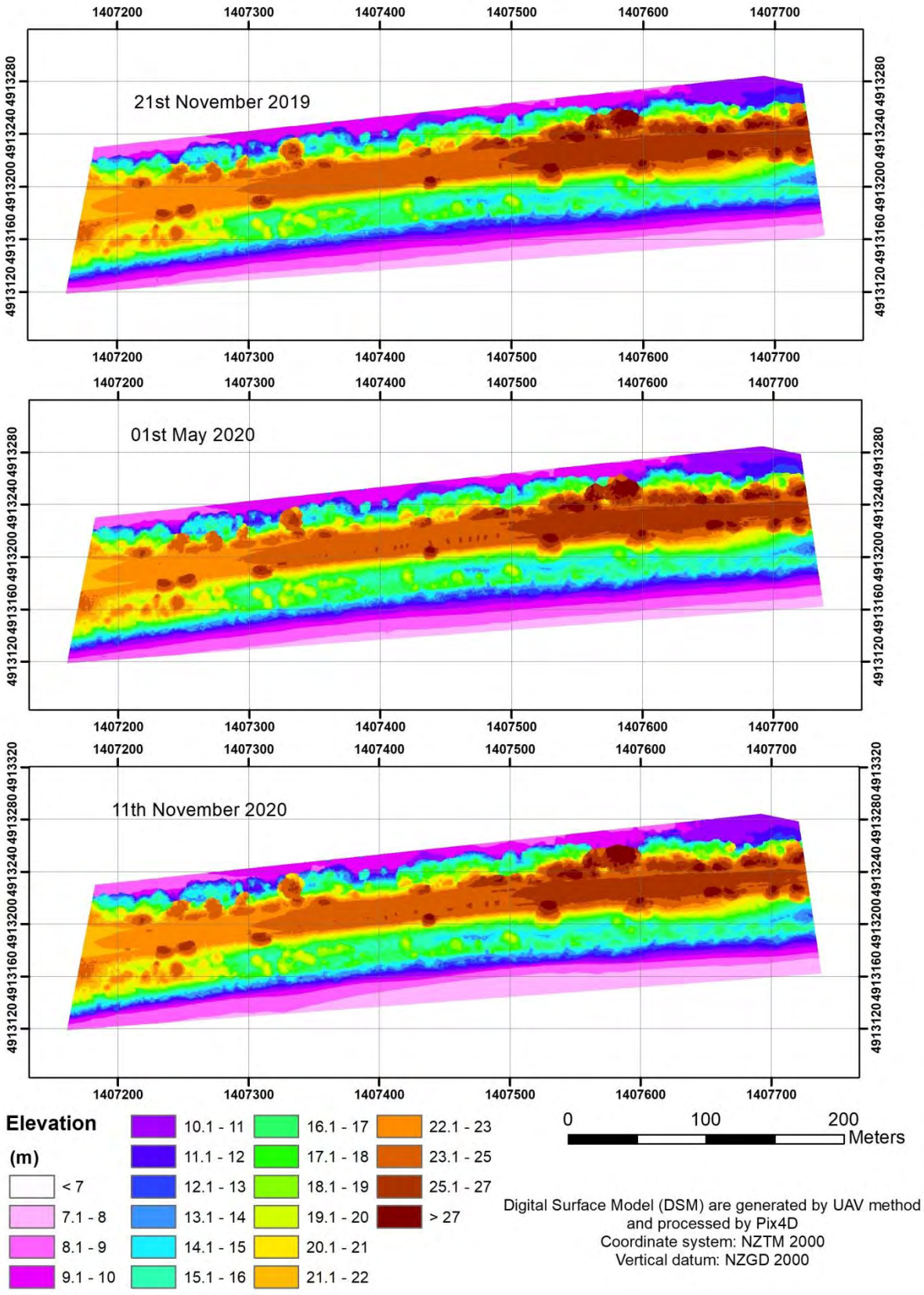

Figure 5.20: Area 3: Digital Surface Models (DSMs) of surveys on the 21st November 2019 and the 11th November 2020

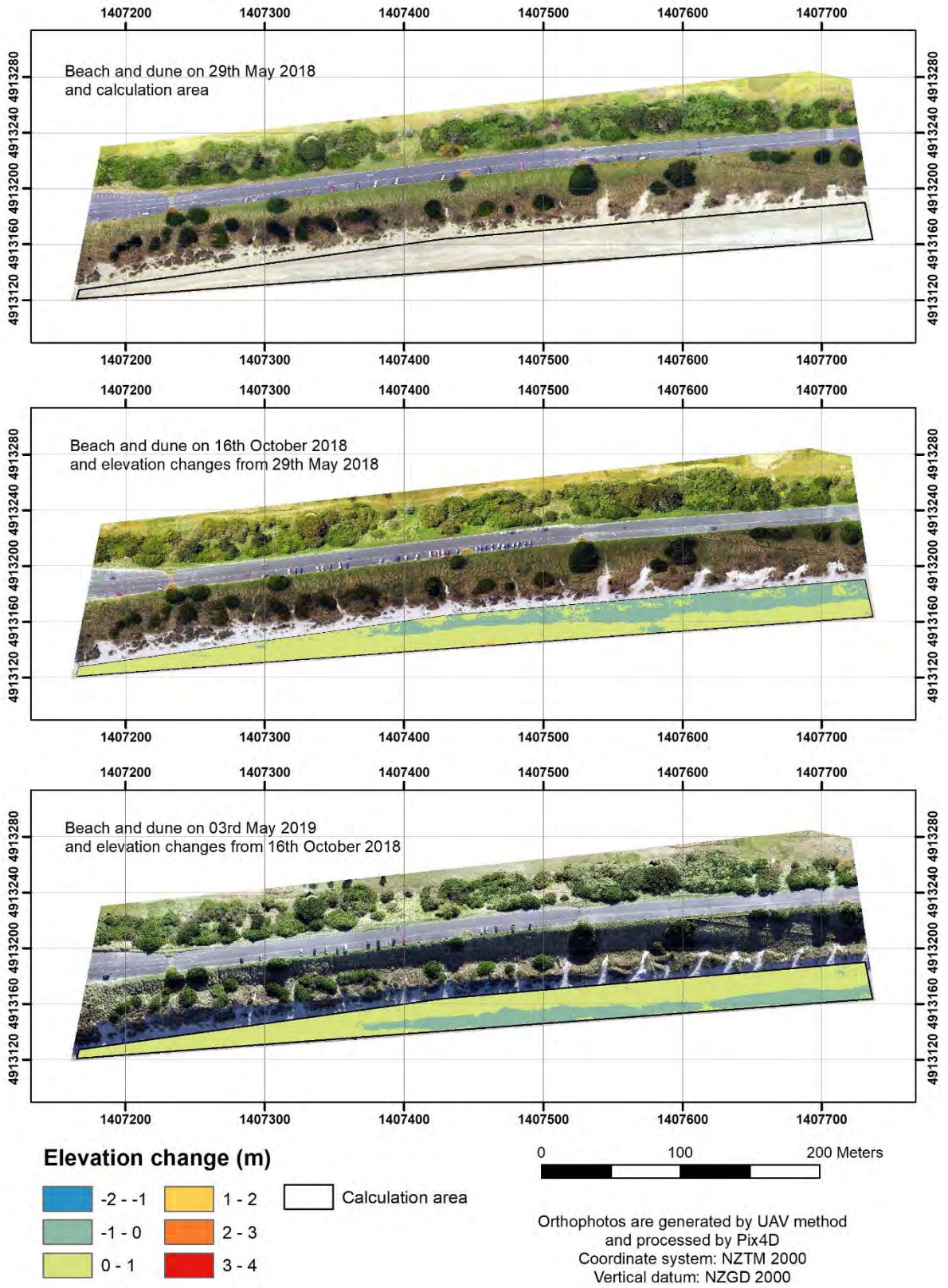

Figure 5.21: Area 3: Change in beach elevation between surveys on the 29th May 2018 and the 3rd May 2019.

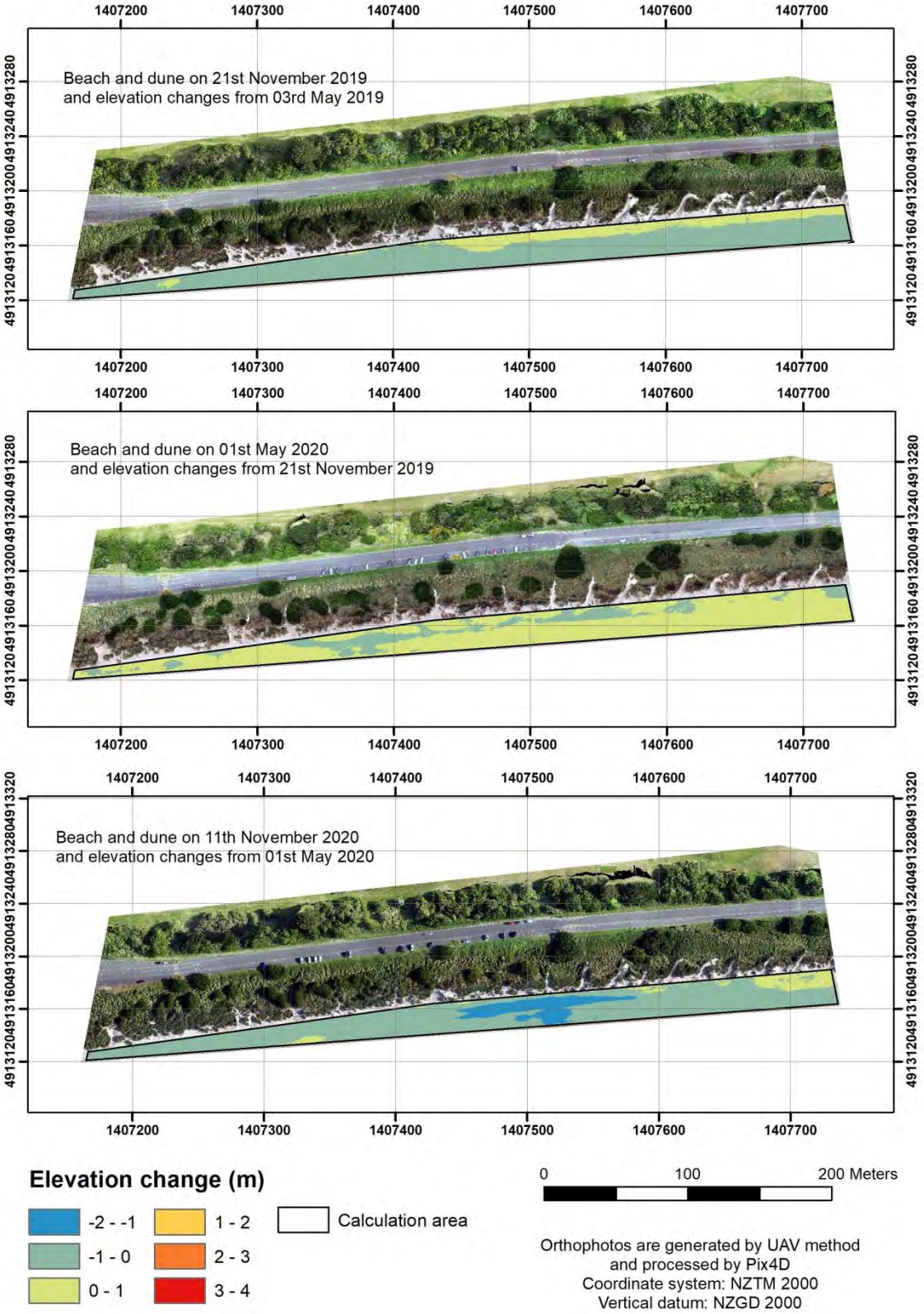

Figure 5.22: Area 3: Change in beach elevation between surveys on the 3rd May 2019 and the 11th November 2020.

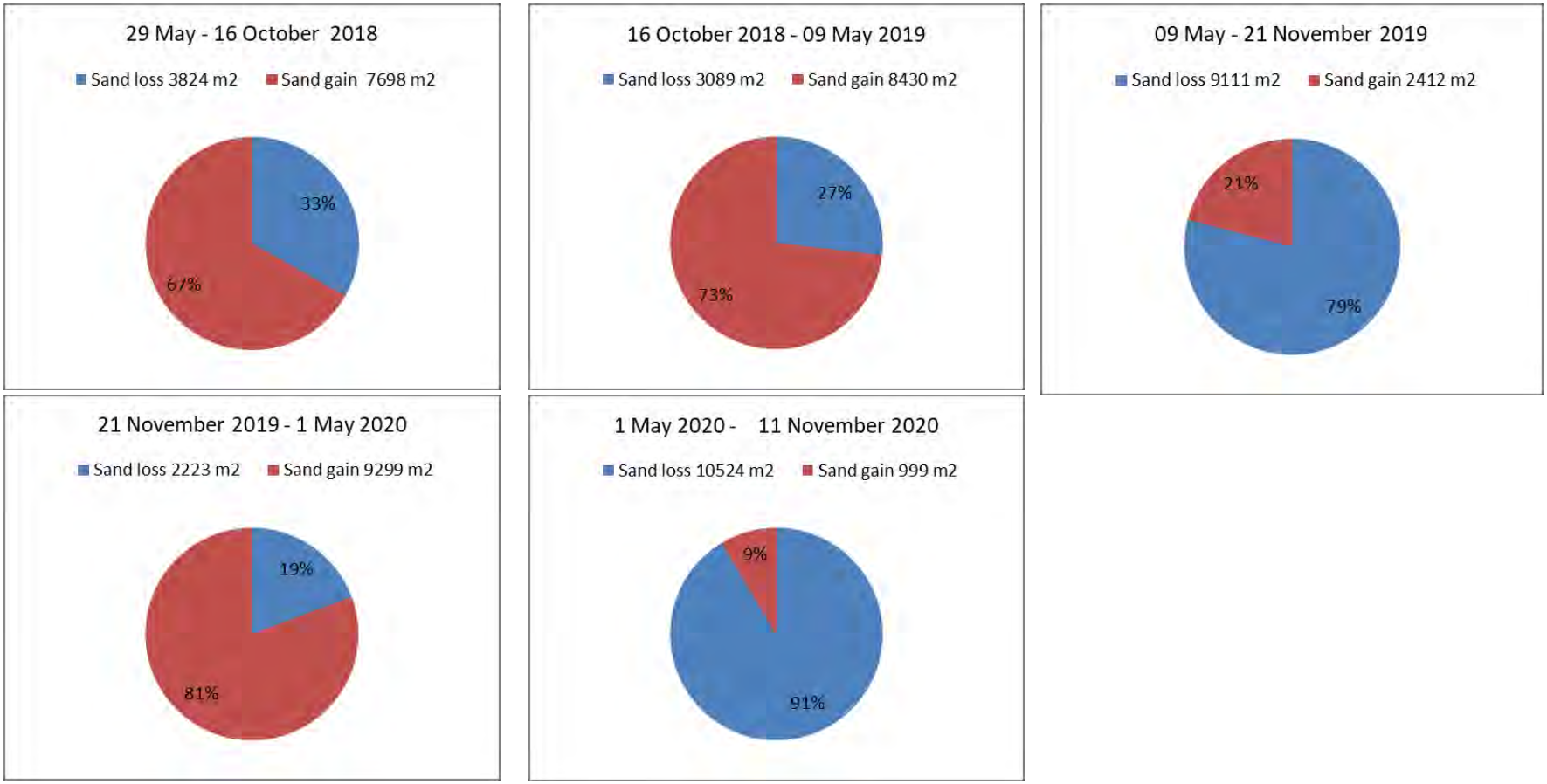

Figure 5.23: Area 3: Percentage net loss and net gain areas between surveys on the 29th May 2018 and the 11th November 2020.

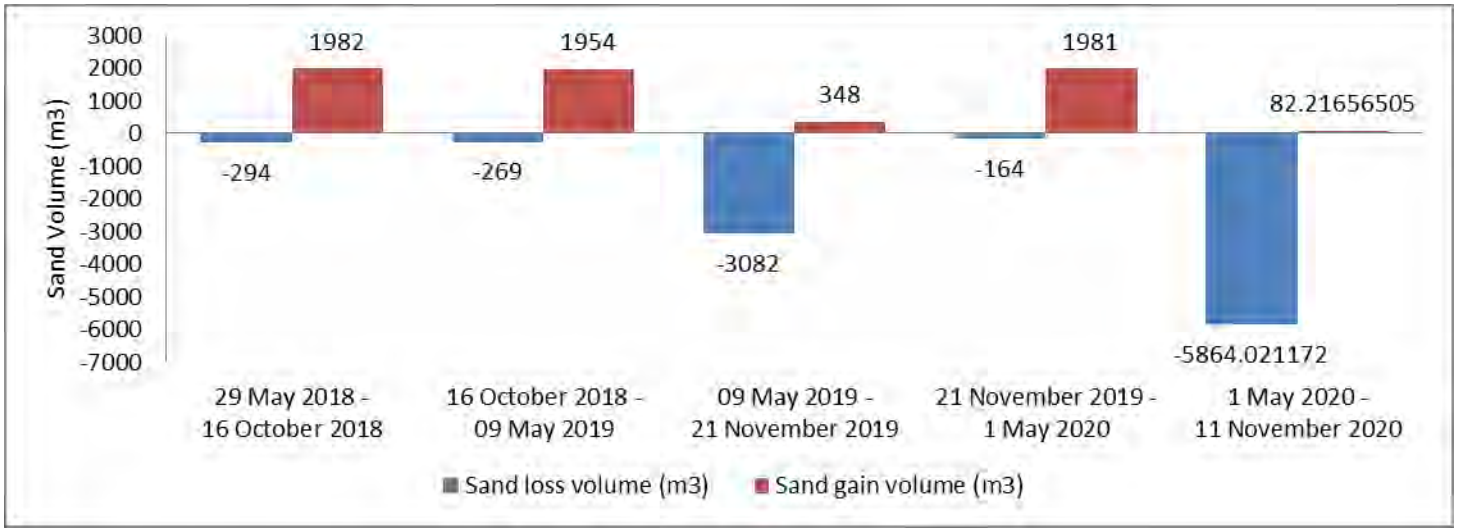

Figure 5.24: Area 3: Total sand volume changes between surveys on the 29th May 2018 and the 4th November 2020.

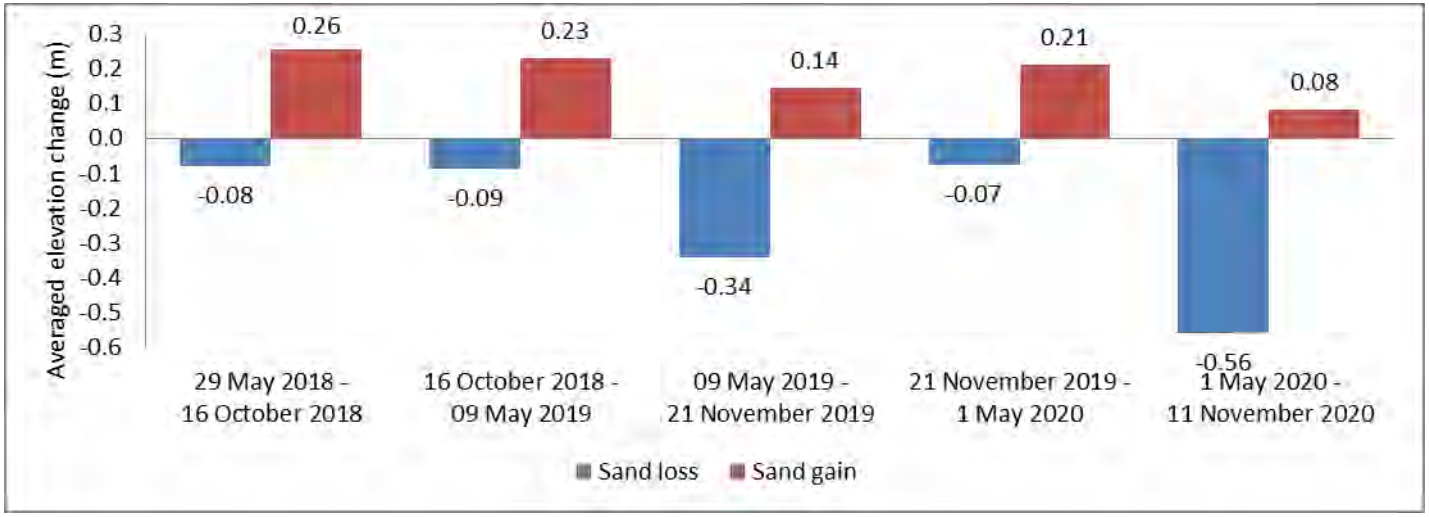

Figure 5.25: Area 3: Average elevation change between surveys on the 29th May 2018 and the 4th November 2019.

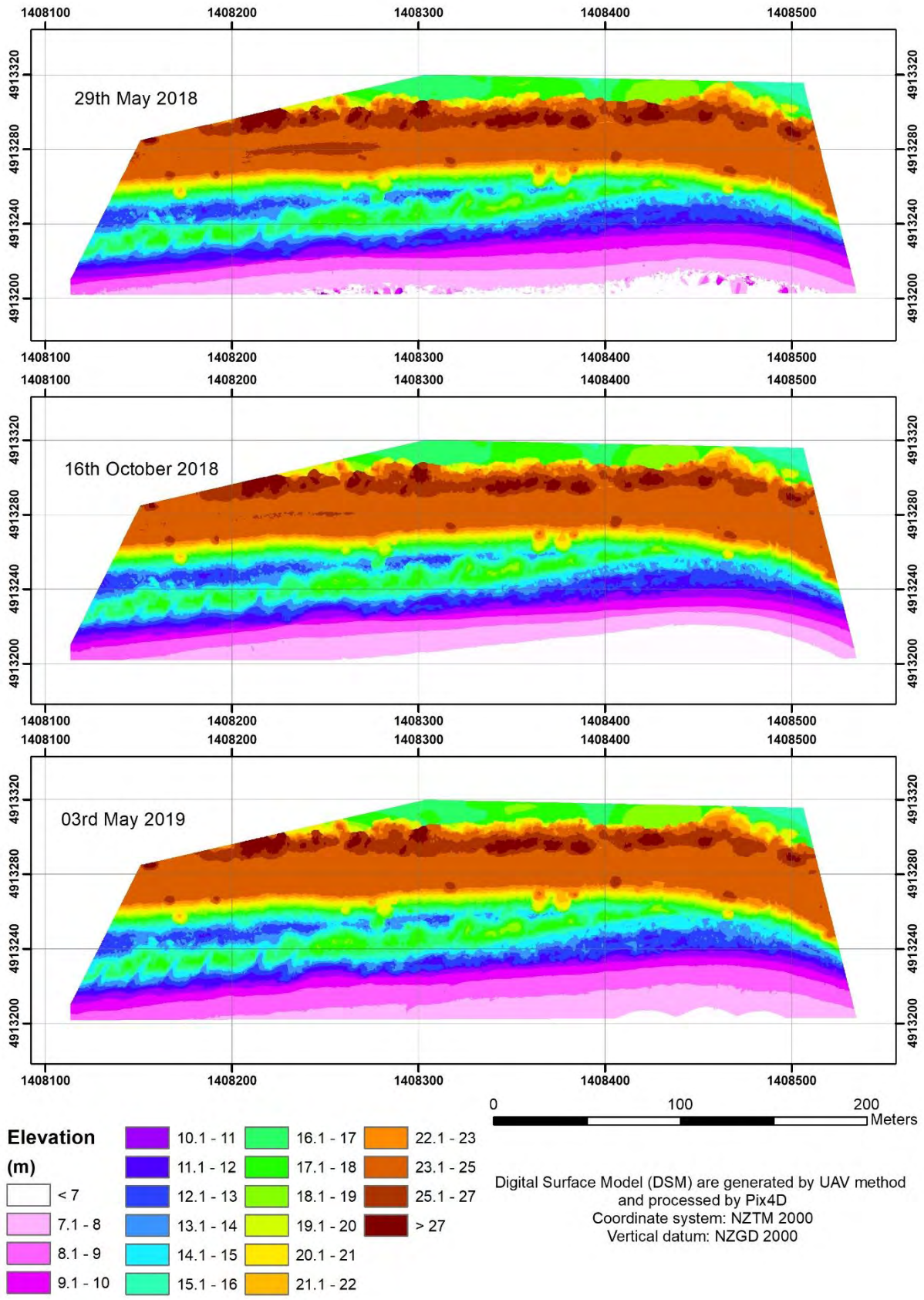

Figure 5.26: Area 4: Digital Surface Models (DSMs) on the 29th May 2018, 16th October 2018 and 3rd May 2019.

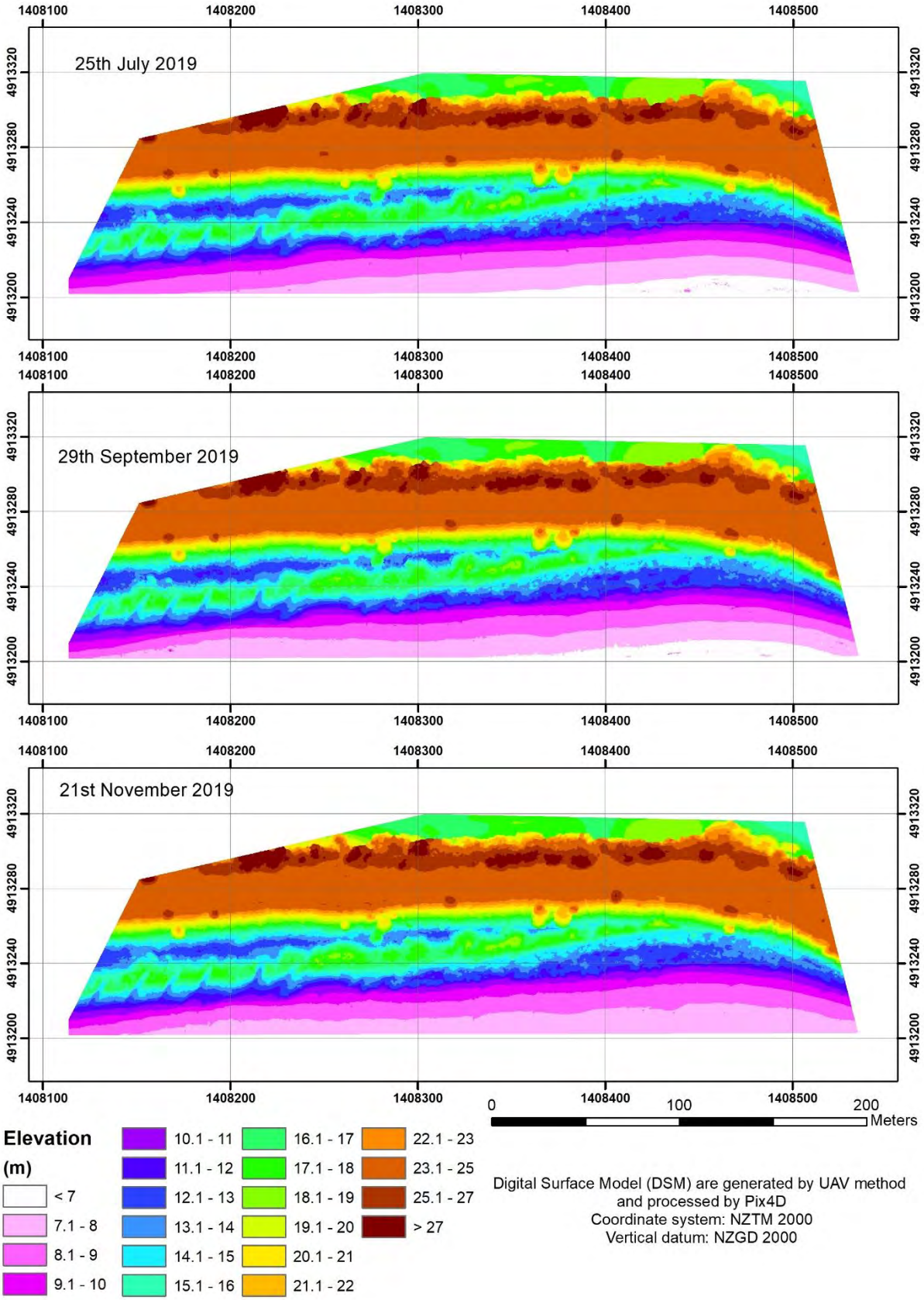

Figure 5.27: Area 4: Digital Surface Models (DSMs) on the 25th July 2019, 29th September 2019 and 21st November 2019.

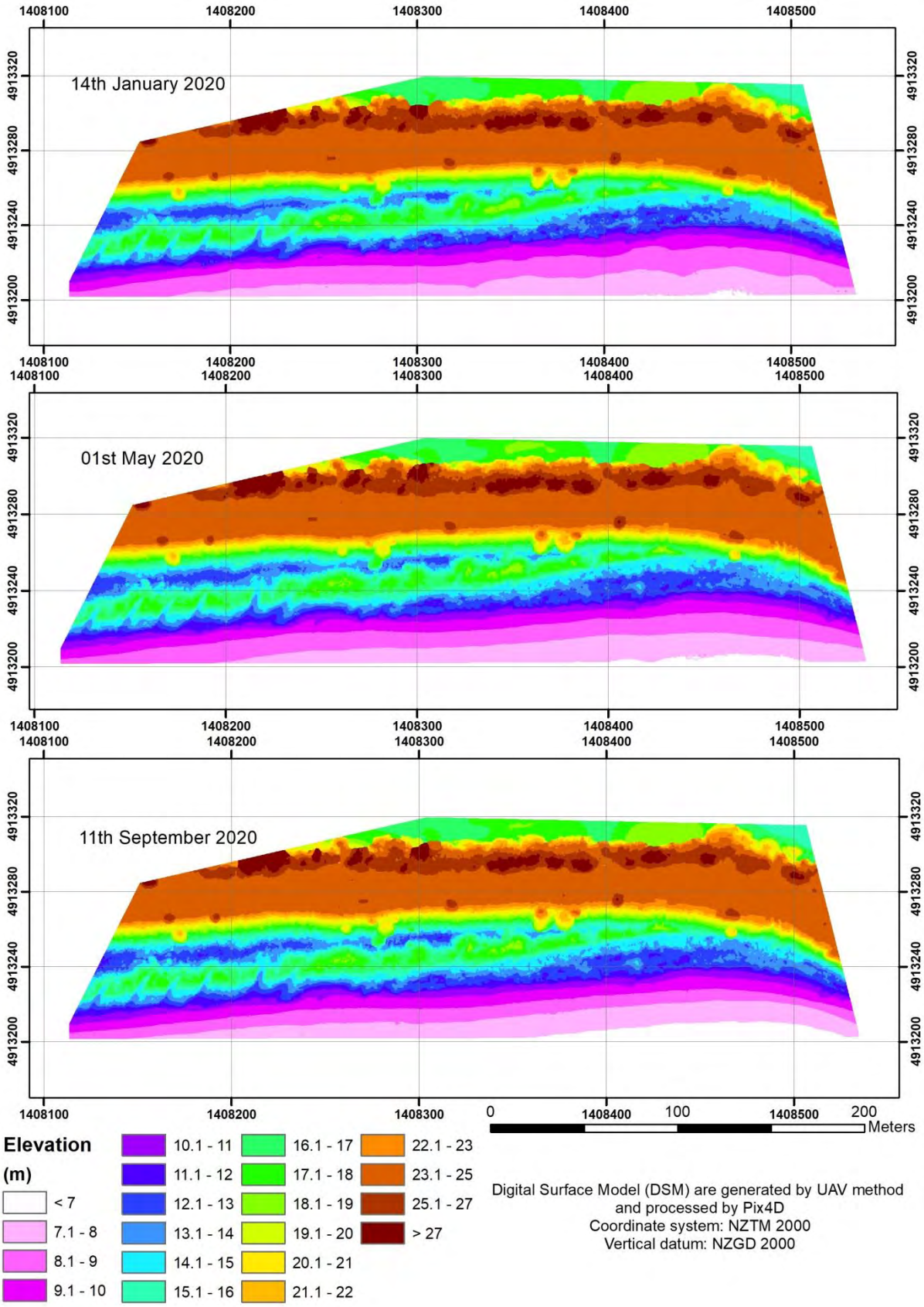

Figure 5.28: Area 4: Digital Surface Models (DSMs) on the 14th January 2020, 1st May 2020, 11th September 2020

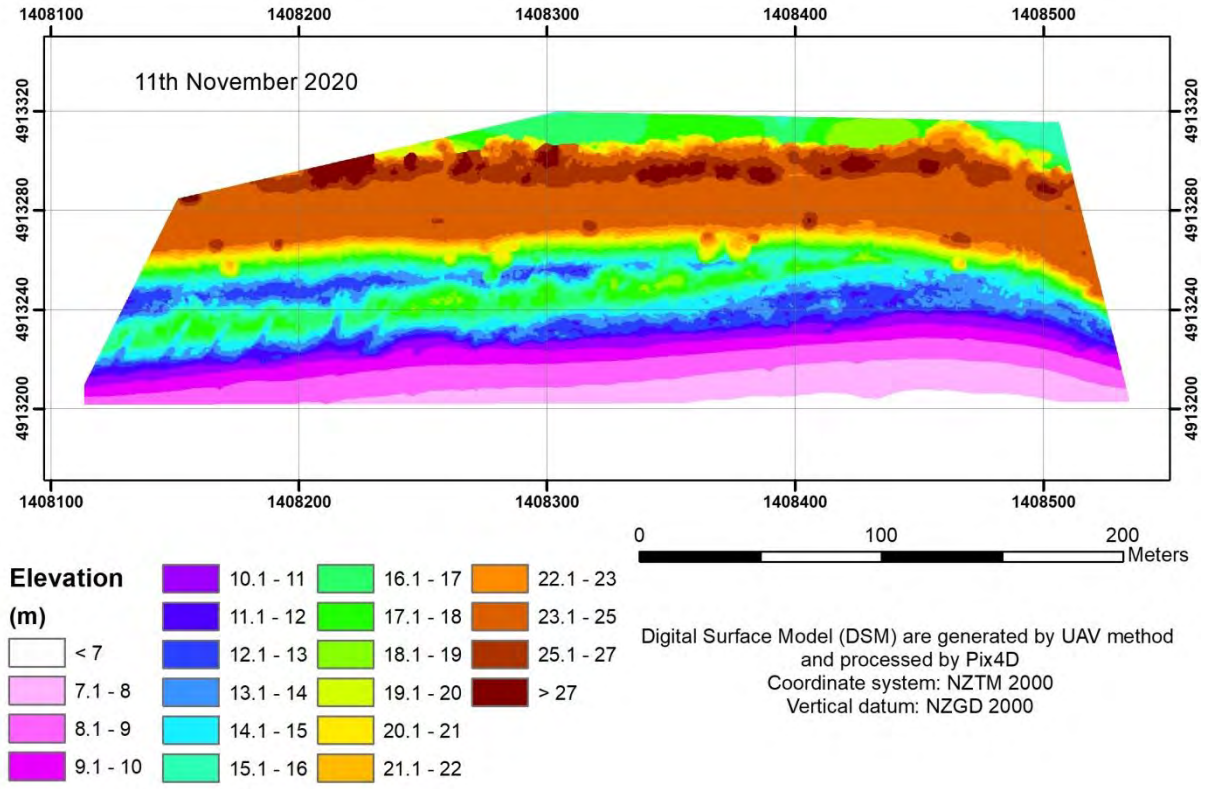

Figure 5.29: Area 4: Digital Surface Models (DSMs) on the 11th November 2020

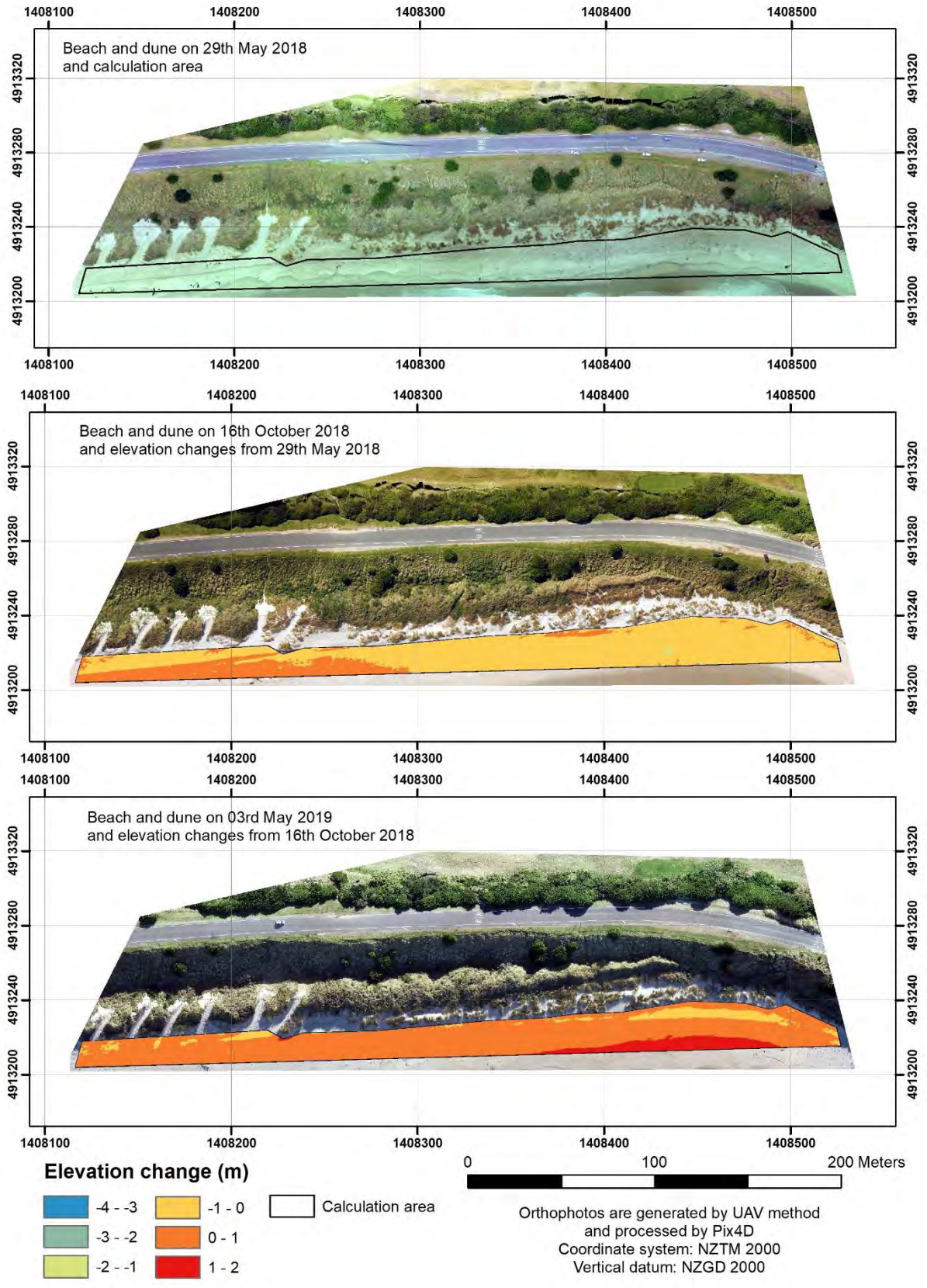

Figure 5.30: Area 4: Change in beach elevation between surveys on the 29th May 2018 and the 3rd May 2019

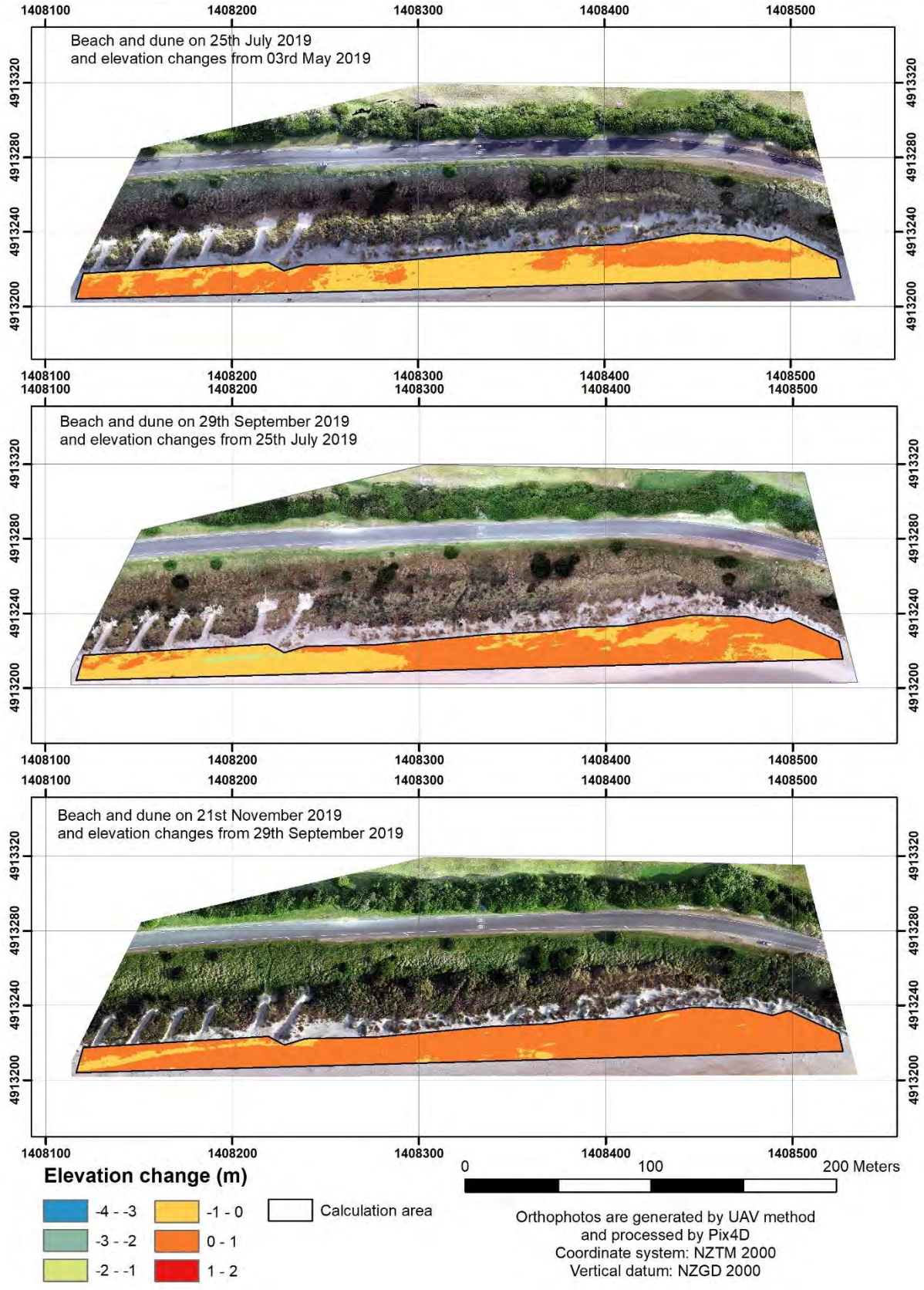

Figure 5.31: Area 4: Change in beach elevation between surveys on the 3rd May 2019 to the 21st November 2019

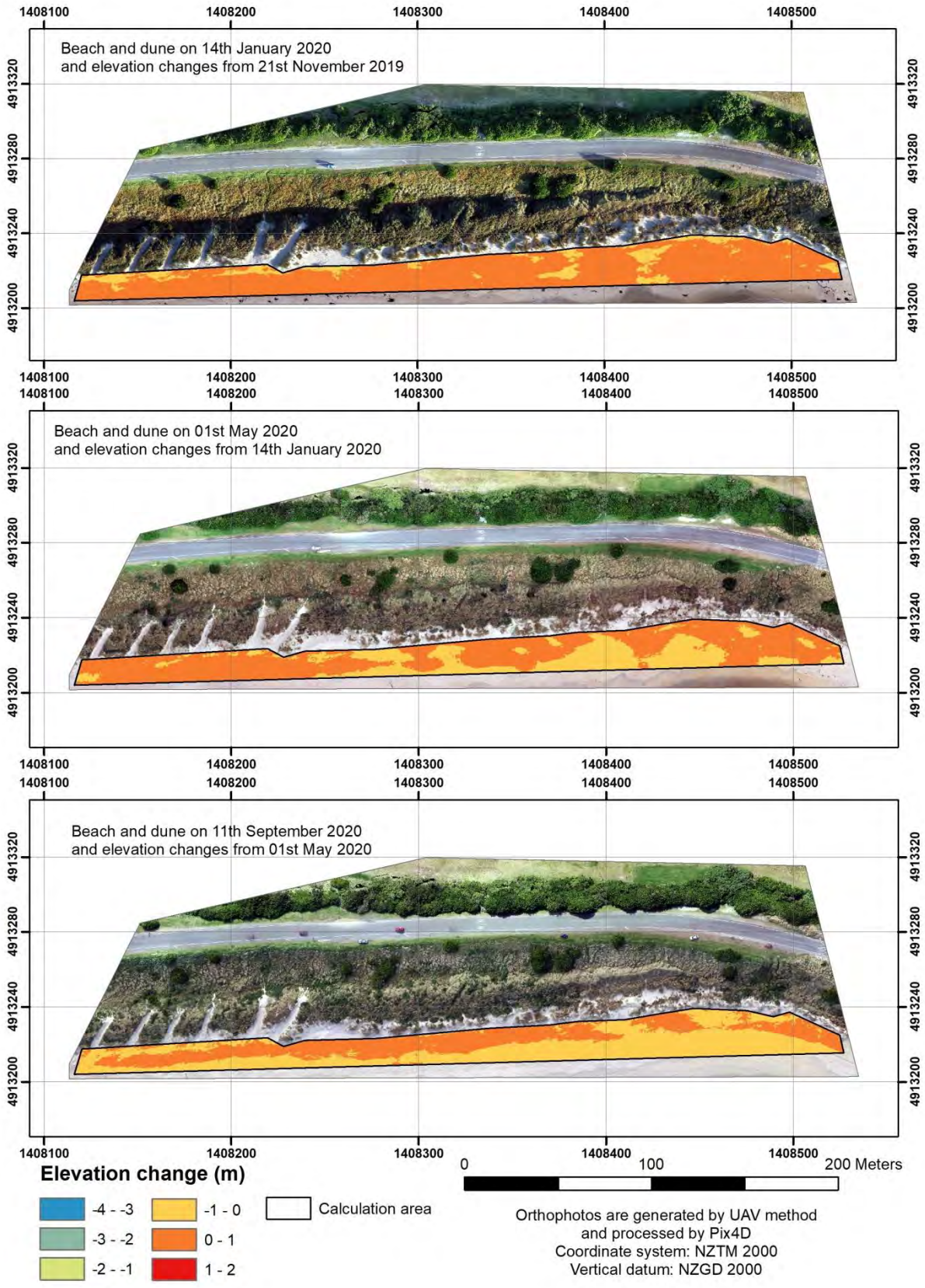

Figure 5.32: Area 4: Change in beach elevation between surveys on the 11st November 2019 to 11th September 2020.

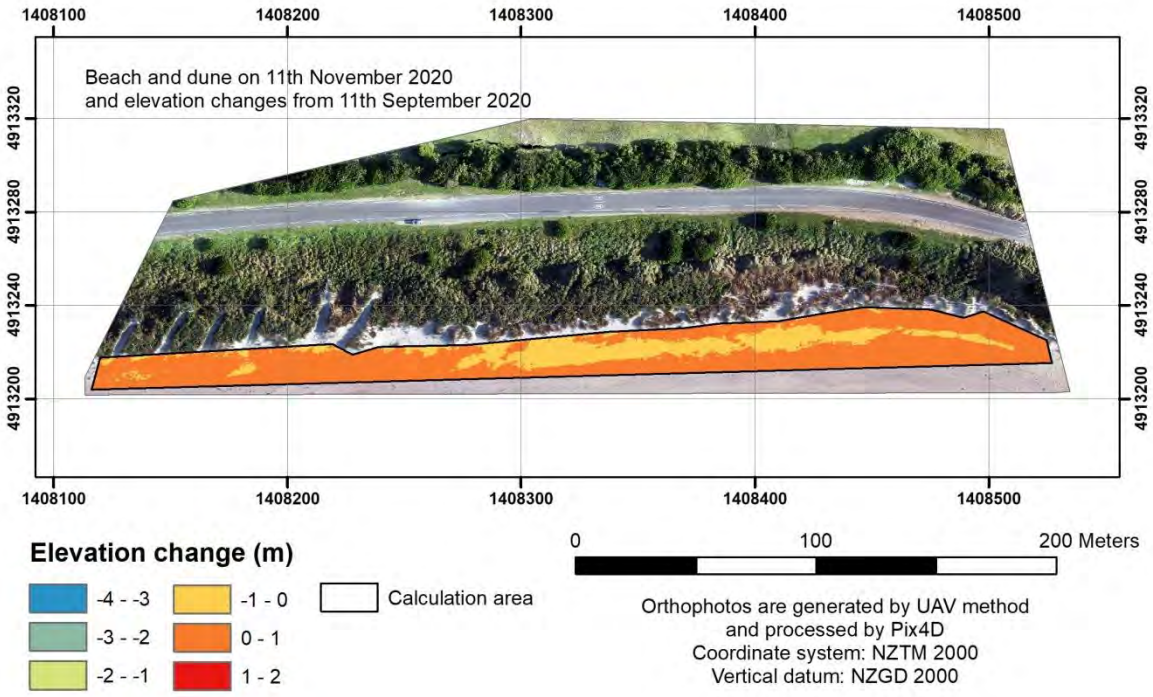

Figure 5.33: Area 4: Change in beach elevation between surveys on the 11st September 2020 to 11th November 2020

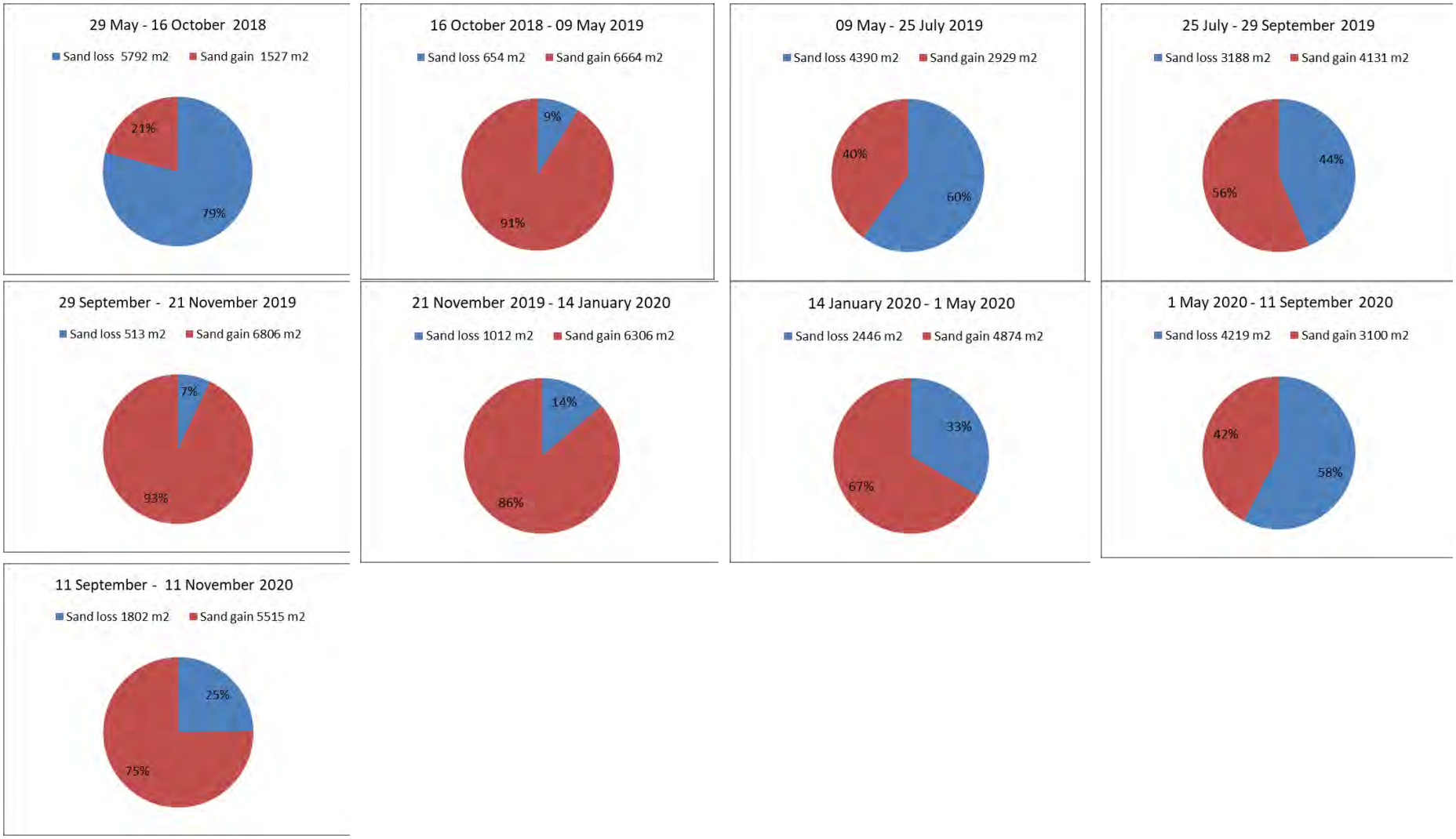

Figure 5.34: Area 4: Percentages of net loss and net gain areas between surveys on the 29th May 2018 and the 11th November 2020

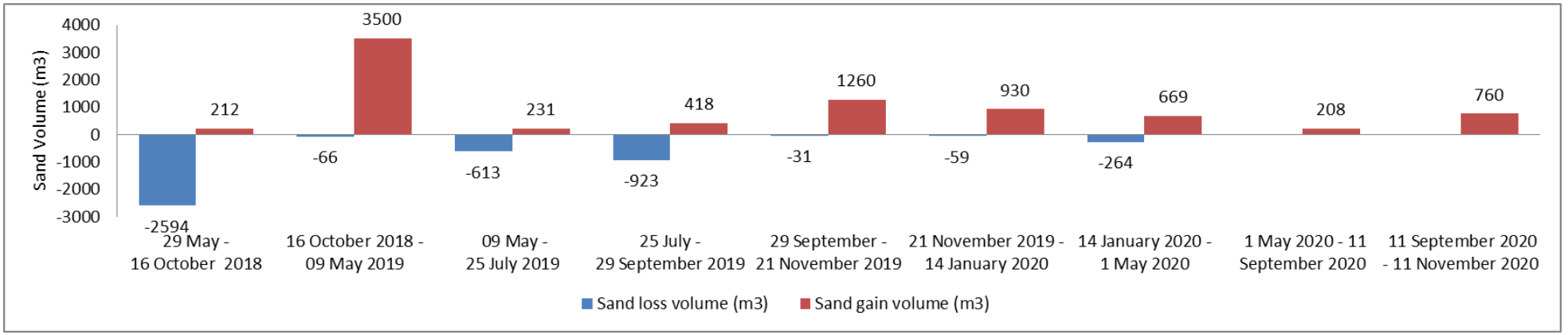

Figure 5.35: Area 4: Total sand volume changes between surveys on the 29th May 2018 and the 11th November 2020

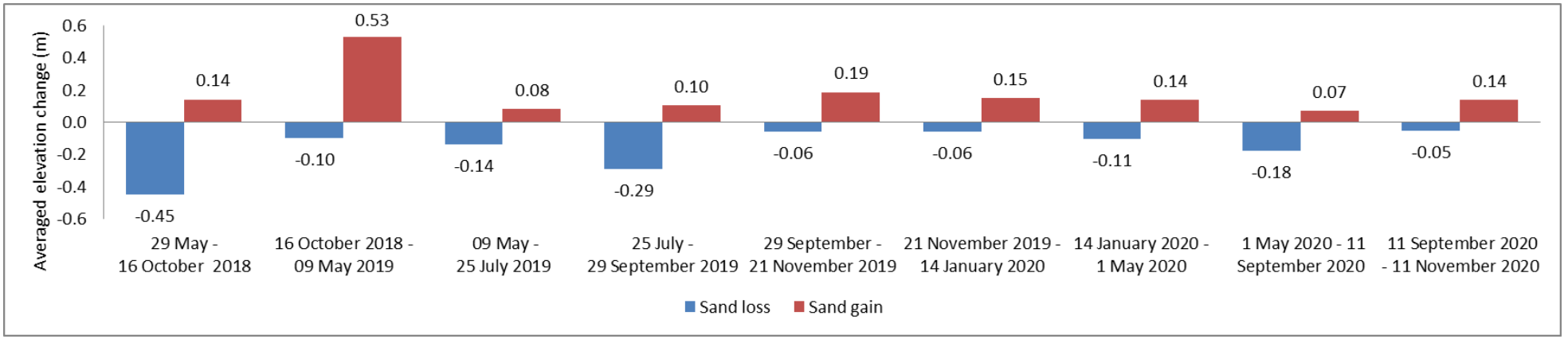

Figure 5.36: Area 4: Average elevation change between surveys on the 29th May 2018 and the 11th November 2020

Figure 5.37: Time-series of volumetric sand change in 4 survey areas between the 29th May 2018 and the 11th November 2020.

Figure 5.38: Time-series of beach elevation change in 4 survey areas between the 29th May 2018 and the 11th November 2020.

6. EFFECTIVENESS OF FOREDUNE NOTCHES

6.1. Elevation changes

Notch B and C (Figure 6.1a) were first constructed on the foredune at St Kilda on 29th April 2016. The foredune notches have resulted in substantial sand deposition on the foredune lee side (the swale). Figure 6.1b shows that elevation behind notch B and C increase up to 2.5m. In contract, topographic survey on section 17 (Figure 6.2) shows that there is little elevation changes behind the intact foredune.

6.2. Hydrodynamic changes

The hydrodynamic changes on the foredune before and after constructing the notches are examined. Computational fluid dynamics (CFD) simulations are conducted at two model morphology: before and after notch construction. The results show that the notches act as the conduit to steer the prevailing onshore oblique incident wind toward notch axis parallel, resulting in sand transport from the beach to the swale (Figure 6.3 – 6.4)

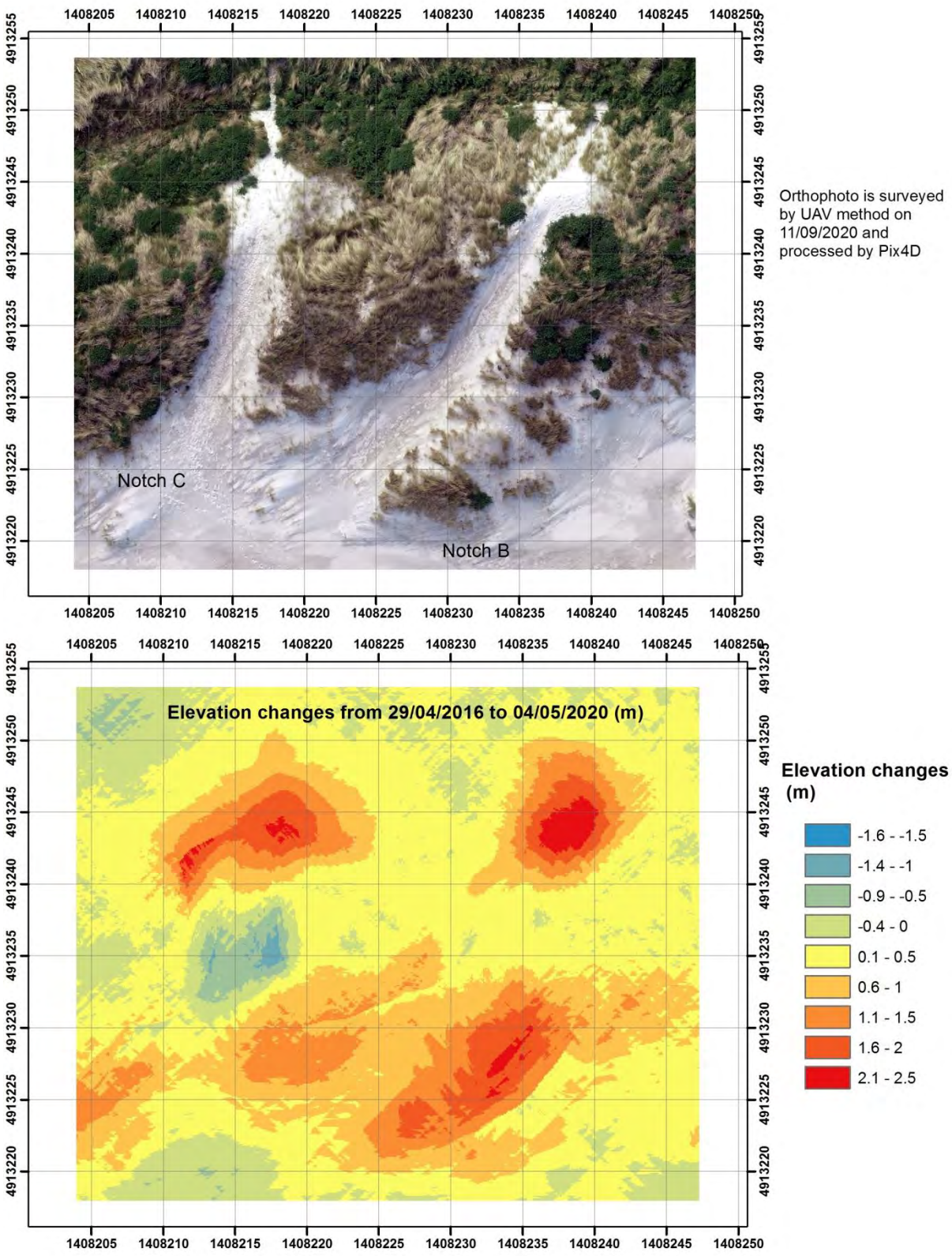

Figure 6.1: Elevation changes on Notch B and Notch C from the 29th April 2016 (when the notches were cut) to 4th May 2020.

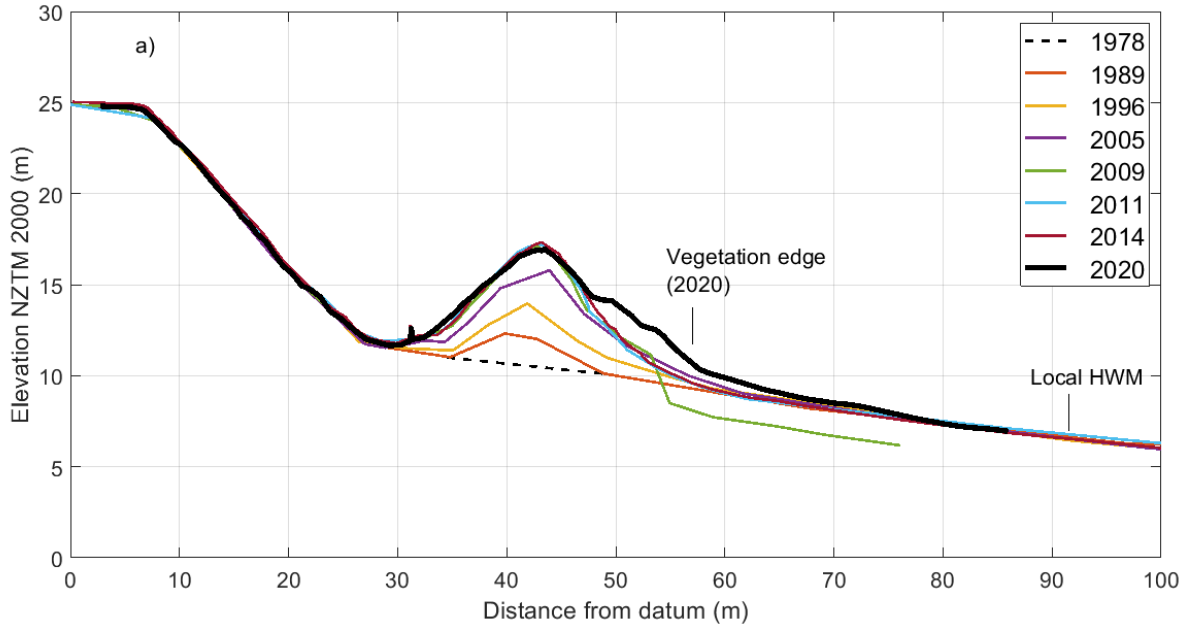

Figure 6.2: Elevation on transect section 17 at St Kilda.

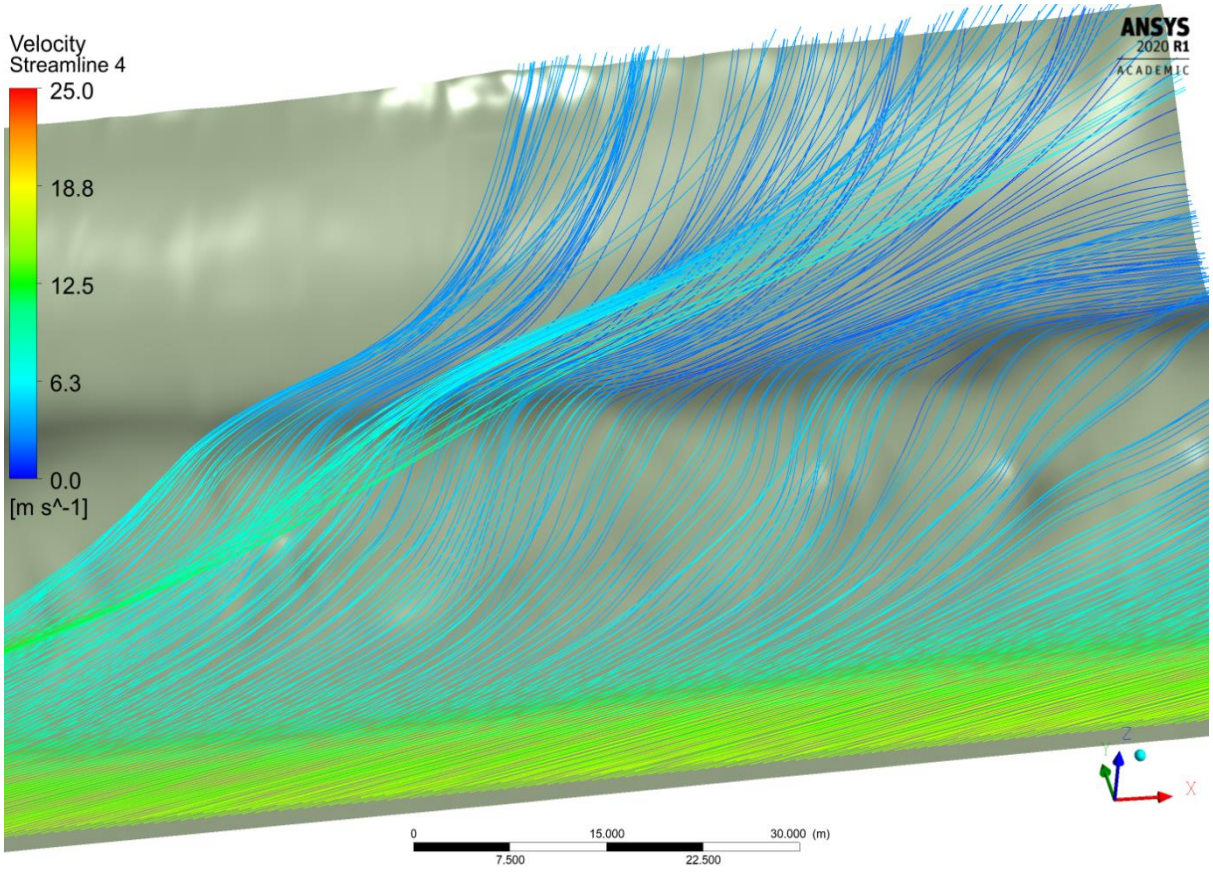

Figure 6.3: Computational fluid dynamics (CFD) simulations of onshore oblique incident wind approaching intact foredune at St. Kilda (before constructing the notches)

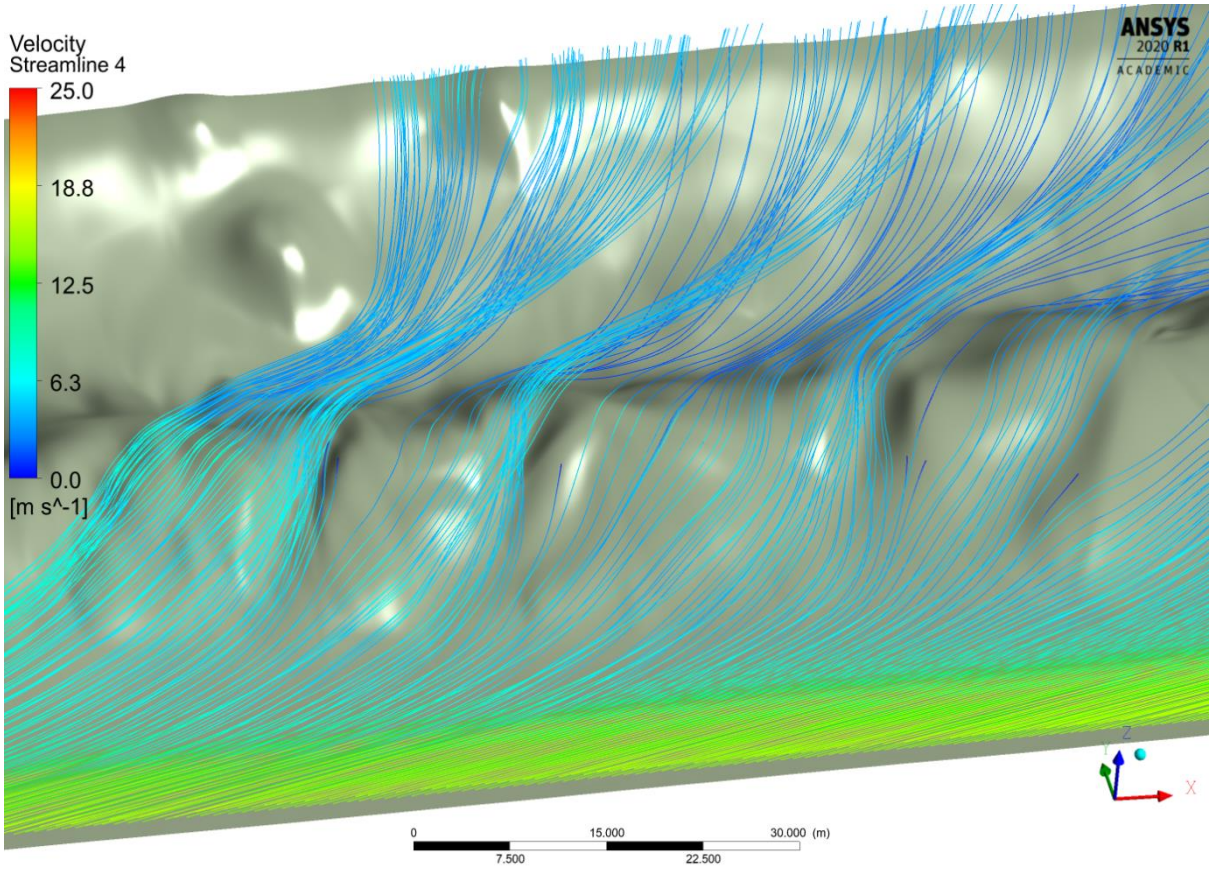

Figure 6.4: Computational fluid dynamics (CFD) simulations of onshore oblique incident wind approaching notched foredune at St Kilda (after constructing notches)

7. INTERPRETATION

7.1. Area 1

In 2020, a series of cold fronts crossed Dunedin between the 1st May and the 26th July 2020, resulting in some beach erosion in Area 1. The beach was lowered in front of the sea wall and geotextile tubes by an average of 1 m (Profiles 1-3 in Figure 4.5 – 4.7). From 1st May to 11th November 2020, beach erosion continued occurring and elevation decreased further up to 0.5m. However, no damage on the sea wall and geotextile tubes were found.

Overall in 2018 – 2020 periods, the beach in Area 1 appears to be vulnerable to erosion, especially during autumn - winter time. The geotextile tubes were broken after the autumn storm on early May 2019 (Figure 7.1). The beach generally is more stable during summer time.

Figure 7.1: Broken geotextile tube on early May 2019 after autumn storm. Photo: Tom Simons-Smith

7.2. Area 2

In 2020, the Area 2 beach experienced accretion of up to 1 m on the west side of Moana Rua Road between the 21st November 2019 and the 1st May 2020 (Profile 5 – Figure 4.9). However, beach erosion of up to 1 m occurred on the east side of Moana Rua Road (Profile 6 – Figure 4.10). Time-series data on Figure 5.37 & 5.38 show that the beach and dunes have been recovering from the significant erosion event on the 8th August 2019 (Figure 7.2). From 1st May 2020 to 11th November 2020, the beach erosion slightly occurred (less than 0.5m).

Winter storms lowered beach elevations on the west side of Moana Rua Road about 1 m between the 1st May and 26th July 2020 (Profile 5 – Figure 4.9; Figure 6.2). On the east side of the road (Profile 6), the beach experienced no significant change. However, at the east side end of Kettle Park (outside of surveyed areas), approximately 2 m beach scarp was found on the east side end of Kettle Park on 26th July 2020 (Figure 7.3 and Figure 7.4)

The foredune which was significantly eroded on 8th August 2019, has not been recovered fully at last survey (11th November 2020) (Profile 5 – Figure 4.9).

Overall in 2018 – 2020 periods, the beach and dune in Area 2 appear to be vulnerable to erosion. Similar to Area 1, erosion occurs mostly during the autumn – winter time and beach – dunes recover during summer time.

Figure 7.2: Rock and concrete were exposed in front of 4 m dune scarp on Profile 5 of Area 2, after winter storm on early August 2019.

Figure 7.3: Beach erosion of 1 m in Area 2 on the 26th July 2020.

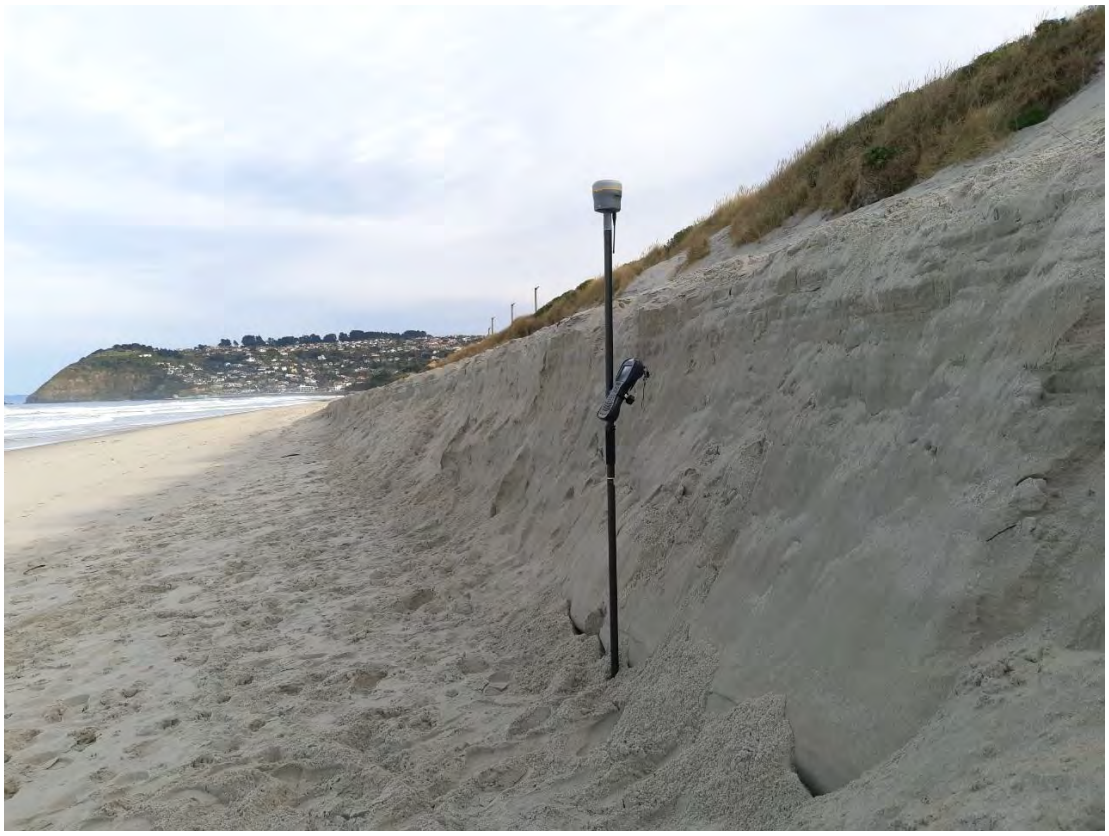

Figure 7.4: Upper beach erosion of approximately 2 m in Area 2 on the 26th July 2020.

7.3. Area 3

In 2020, the beach and dunes in Area 3 were relatively stable between the 21st November 2019 and the 1st May 2020. However beach erosion occurred from the 1st May 2020 to 11th November 2020. The beach at the bollard gates was lowered 1-2 m (Profile 8 in Figure 4.12, Figure 5.20). Averagely the beach elevation in Area 3 was lowered 0.5 m during this period (Figure 5.38).

Overall in 2018 – 2020 periods, the beach and dune in Area 4 were more stable than Area 1 and 2.

7.4. Area 4

There were no significant changes on the beach and dunes on 2020. Overall in 2018 – 2020, the beach and dunes were stable.

The elevation changes on the lee side of notched foredune in Area 4 (Figure 6.1) indicate that notching is an effective intervention to rollback the foredune. Without notching, the foredune is highly stable (Figure 6.2). More researches should be conducted to examine the patterns of wind flow and sand sedimentation on notched foredune at St Kilda.

7.5. Summary of all Areas

In 2020, beach accretion occurred in both areas between the 21st November 2019 and the 1st May 2020. A series of cold fronts occurred between 1st May and the 26th July 2020, which resulted in beach erosion of up to 1 m in Area 1, and up to 2 m in parts of Area 2. These events did not impact significantly on beach and dune elevations and volumes in Areas 3 and 4. From 1st May 2020 to 11th November 2020, erosion occurred in both Area 1, 2 and 3. Area 4 were stable.

Overall in 2018 – 2020 period, Area 1 and 2 appeared to be vulnerable for beach and dune erosion, especially during autumn – winter time. Area 3 and 4 were more stable.

8. CONCLUSIONS AND RECOMMENDATIONS

Areas 1 and 2 have been the most vulnerable to beach erosion since the commencement of the current monitoring programme. Winter storms in 2019 and 2020 have lowered the beach by 1 – 2 m over the end of 2020. However there is evidence that the beach and dune in these Areas have been recovered during summer time.

Areas 3 and 4 are more stable. The elevation changes in these areas occurred within a range of ± 0.5 m. However the more severe erosion (from 1 – 2m) might occurs at Area 3 as it was observed from 1st May 2020 to 11th November 2020.

The dunes eroded during significant events in 2019 in Area 2 have not been fully recovered at the last survey time (11th November 2020). However, no further dune erosion occurred.

Foredune notching is an effective intervention to rollback the foredune at St Kilda. Without notching, the foredune is highly stable. More researches should be conducted to examine the patterns of wind flow and sand sedimentation on notched foredune.

9. APPENDICES

Appendix 1: Coordinates of RTK-GPS surveys

Table A1: Coordinates of 14 benchmarks and reference points for RTK – GPS survey

Benchmarks	Northing (m)	Easting (m)	Elevation (m)
Benchmark 1	4,912,762.589	1,405,504.713	11.391
Benchmark 2	4,912,803.945	1,405,569.315	12.894
Benchmark 3	4,912,882.212	1,405,702.151	25.623
Benchmark 4	4,912,894.669	1,405,814.369	18.505
Benchmark 5	4,912,988.093	1,406,231.499	14.787
Benchmark 6	4,913,016.360	1,406,369.997	16.226
Benchmark 7	4,913,040.587	1,406,538.189	15.612
Benchmark 8	4,913,215.198	1,407,506.663	25.164
Benchmark 9	4,913,234.214	1,407,692.109	25.292
Benchmark 10	4,913,264.310	1,408,077.795	24.640
Benchmark 11	4,913,281.501	1,408,191.829	24.771
Benchmark 12	4,913,271.500	1,408,257.700	24.616
Benchmark 13	4,913,271.500	1,408,257.700	24.616
Benchmark 14	4,913,274.310	1,408,390.564	23.059
Reference Point A (for Area 1&2)	4912894.669	1405814.369	18.505
Reference Point B (for Area 3&4)	4913271.5	1408257.7	24.616

Coordinate system: NZTM2000; Vertical datum: NZGD2000 ellipsoidal heights

Appendix 2: GCP layout and coordinates of 04 Areas

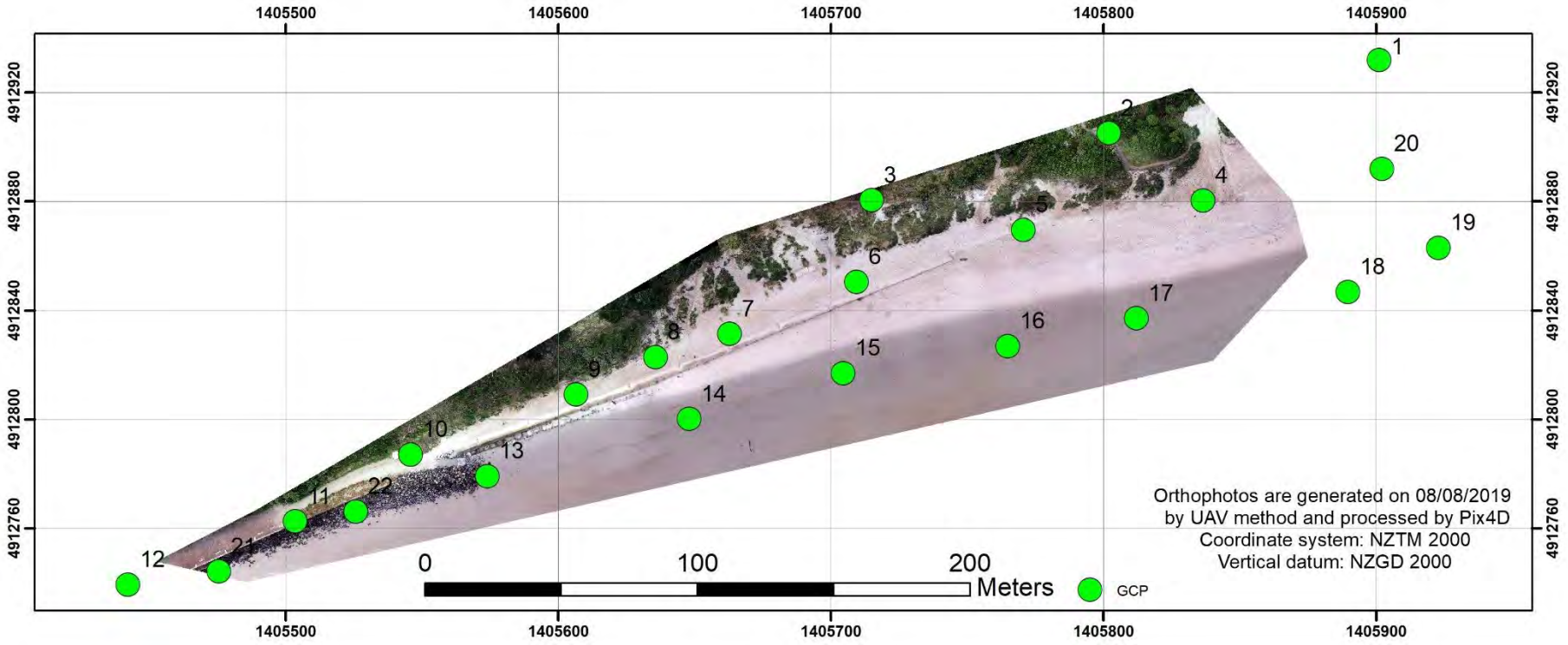

Figure A2.1: GCP layout in Area 01

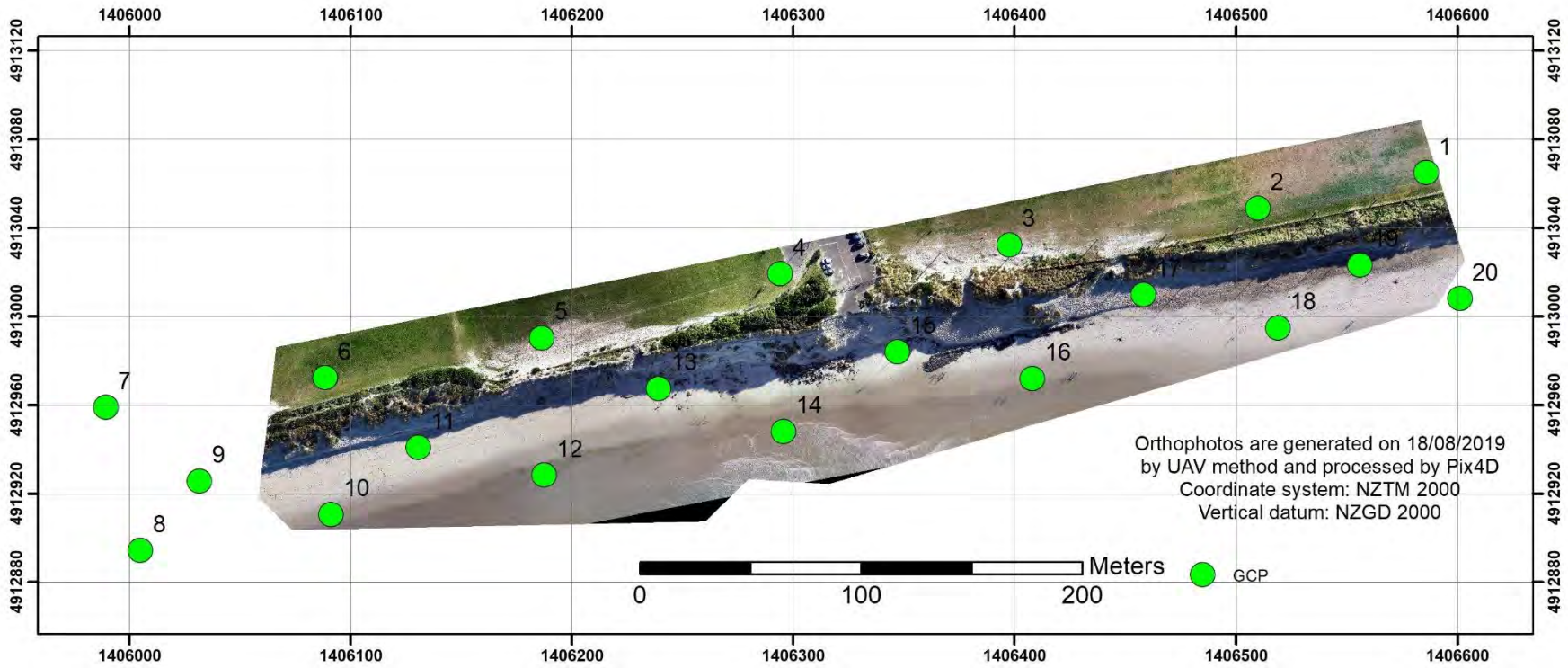

Figure A2.2: GCP layout in Area 02

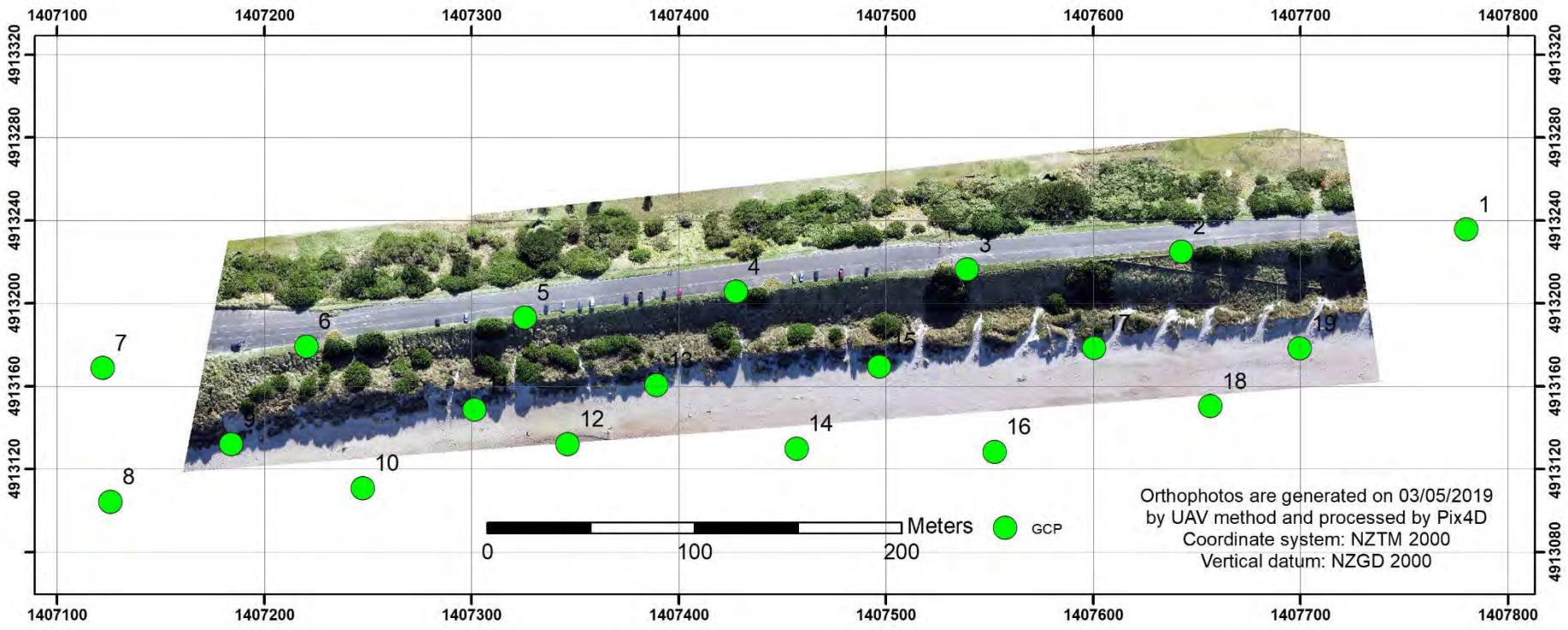

Figure A2.3: GCP layout in Area 03

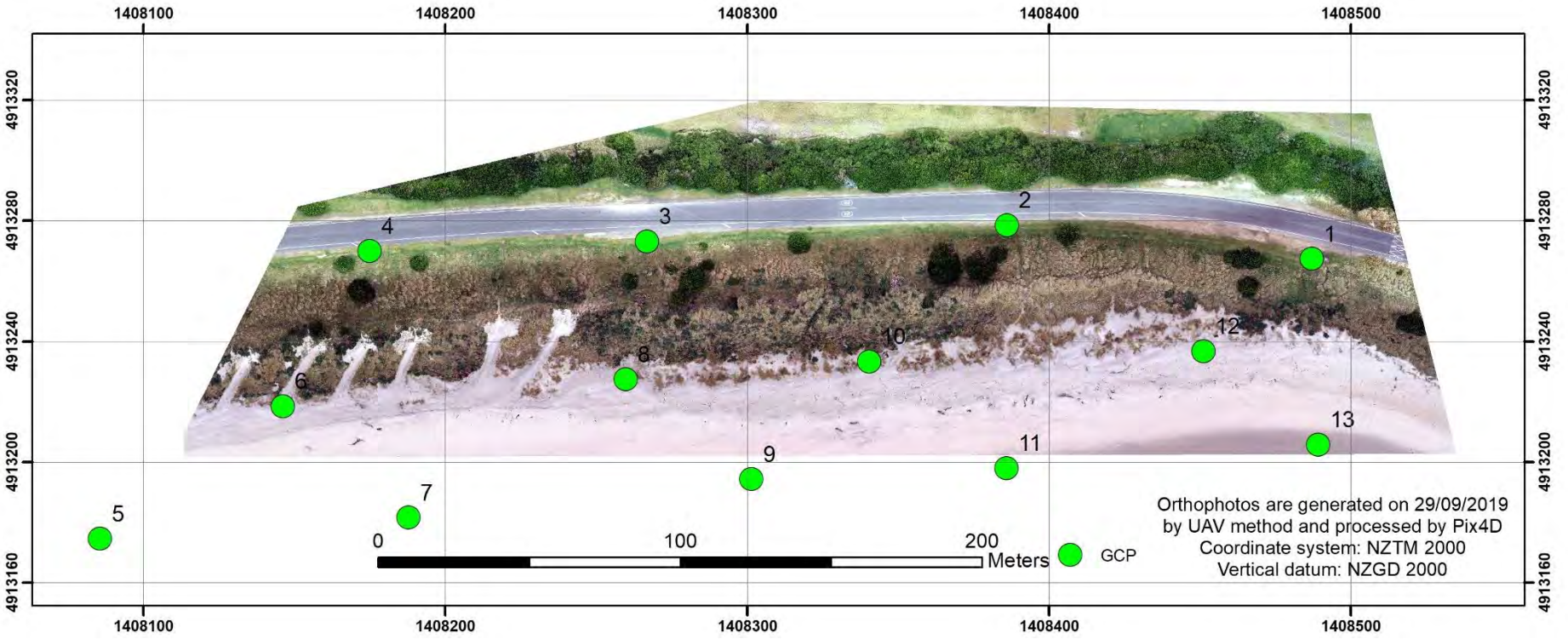

Figure A2.4: GCP layout in Area 04

Table A2.1. Coordinate of GCP in 04 areas

Area 1			Area 2			Area 3			Area 4		
GCP no.	Northing	Easting	GCP no.	Northing	Easting	GCP no.	Northing	Easting	GCP no.	Northing	Easting
1	4912931.945	1405901.07	1	4913065.144	1406586.207	1	4913235.703	1407780.028	1	4913267.415	1408487.023
2	4912905.106	1405801.959	2	4913049.081	1406509.989	2	4913225.13	1407642.492	2	4913278.615	1408386.026
3	4912880.547	1405714.932	3	4913032.461	1406397.832	3	4913216.435	1407539.129	3	4913273.228	1408266.814
4	4912880.447	1405836.601	4	4913019.427	1406294.238	4	4913205.736	1407427.668	4	4913270.028	1408175.027
5	4912869.629	1405770.586	5	4912990.523	1406186.435	5	4913193.225	1407325.622	5	4913174.693	1408085.724
6	4912850.568	1405709.491	6	4912972.539	1406088.555	6	4913179.331	1407220.302	6	4913218.622	1408146.259
7	4912831.491	1405662.821	7	4912959.152	1405989.394	7	4913168.904	1407121.997	7	4913181.726	1408187.85
8	4912822.969	1405635.672	8	4912894.448	1406005.074	8	4913104.392	1407125.71	8	4913227.508	1408259.818
9	4912809.254	1405606.567	9	4912925.883	1406031.812	9	4913132.121	1407183.903	9	4913194.435	1408301.436
10	4912787.195	1405545.878	10	4912910.781	1406091.184	10	4913110.932	1407247.394	10	4913233.413	1408340.433
11	4912762.668	1405503.608	11	4912941.057	1406130.562	11	4913148.78	1407301.443	11	4913198.106	1408385.887
12	4912739.498	1405442.247	12	4912928.534	1406187.539	12	4913132.168	1407346.231	12	4913236.873	1408451.182
13	4912779.32	1405573.966	13	4912967.65	1406239.271	13	4913160.53	1407389.342	13	4913205.874	1408489.116
14	4912800.298	1405648.084	14	4912948.282	1406295.618	14	4913129.965	1407456.849			
15	4912817.054	1405704.51	15	4912984.277	1406347.178	15	4913169.666	1407496.861			
16	4912826.997	1405764.861	16	4912972.216	1406408.165	16	4913128.469	1407552.375			
17	4912837.236	1405812.12	17	4913009.994	1406458.277	17	4913178.535	1407600.383			
18	4912846.879	1405889.607	18	4912995.01	1406519.038	18	4913150.452	1407656.483			
19	4912863.107	1405922.803	19	4913023.328	1406556.212	19	4913178.347	1407699.658			
20	4912892.059	1405902.071	20	4913008.214	1406601.343						
21	4912744.273	1405475.544									
22	4912766.284	1405525.909									

Appendix 3: Key Pix4D report parameters

Table A3: Key Pix4D report parameters

	UAV survey on the 29th May 2018				UAV survey on the 16th October 2018				UAV survey on the 03/09th May 2019			
	Area 1	Area 2	Area 3	Area 4	Area 1	Area 2	Area 3	Area 4	Area 1	Area 2	Area 3	Area 4
Average ground sampling distance (GSD) (cm)	1.98	2.13	2.51	2.45	2.02	2.36	2.54	2.49	1.27	1.46	1.61	1.91
Area covered (ha)	5.51	7.15	9.97	5.5	5.71	7.63	11.5	6.46	4.4	8.62	9.32	12.6
Median of key points per image	34582	23611	32525	31711	20739	19166	27490	32276	31689	26042	34337	33644
Number of images calibrated	122	216	303	209	176	185	406	309	205	318	311	311
Camera optimization (%)	3.32	0.26	3.27	2.27	1.91	0.66	3.23	3.19	0.31	0.7	1.9	0.7
Number of matches per calibrated image	6463.9	8344.2	7074.9	7256.2	4530.7	5377.2	11500.4	12011.6	15626.4	13335.5	10752.6	9903.6
Number of GCP	16	23	18	20	12	15	18	22	21	20	15	20
Mean RMS error (m)	0.035	0.036	0.044	0.039	0.046	0.045	0.054	0.048	0.018	0.019	0.045	0.041

	UAV survey on 25th July 2019	UAV survey on the 08th August 2019		UAV survey on 18th August 2019	UAV survey on 21-25th November 2019				UAV survey on 14th January 2020	UAV survey on 30th April – 1st May 2020			
	Area 4	Area 1	Area 2	Area 2	Area 1	Area 2	Area 3	Area 4	Area 4	Area 1	Area 2	Area 3	Area 4
Average ground sampling distance (GSD) (cm)	1.92	1.36	1.41	1.36	1.32	1.48	1.69	1.84	1.85	1.67	1.70	1.92	1.85
Area covered (ha)	10.6	5.2	7.5	7.35	6.26	11.4	9.7	12.6	14.2	9.16	10.5	9.19	15.2
Median of key points per image	11277	28743	16271.2	37845	32652	29226	35824	36058	45506	55258	56248	37060	23858
Number of images calibrated	229	205	315	256	269	300	268	240	297	199	280	209	293
Camera optimization (%)	0.74	0.2	1.38	0.39	0.41	3.35	0.17	0.11	0.28	0.17	1.07	0.09	0.51
Number of matches per calibrated image	40067	10100.5	16271.2	21566.2	14506.3	11311.2	10936.5	12783.8	12807	9547.16	21962	10515	7816
Number of GCP	20	21	19	20	20	6	16	20	20	20	19	16	19

Mean RMS error (m)	0.017	0.003	0.027	0.02	0.014	0.005	0.016	0.014	0.024	0.02	0.024	0.024	0.02

	UAV survey on 11th September 2020	UAV survey on 11th November 2020			
	Area 4	Area 1	Area 2	Area 3	Area 4
Average ground sampling distance (GSD) (cm)	1.86	1.64	1.69	1.96	1.86
Area covered (ha)	15.8	8.86	12.5	9.12	15.3
Median of key points per image	34386	40304	31598	41282	36353
Number of images calibrated	300	207	285	208	299
Camera optimization (%)	0.36	0.4	0.98	0.34	0.76
Number of matches per calibrated image	12656	9536	11366	15949	12970

Number of GCP	20	19	28	15	25
Mean RMS error (m)	0.022	0.025	0.022	0.031	0.029