SOUTH WEST COASTAL MONITORING

making space for sand



Making Space for Sand – Church Cove Beach Report

Topographic and LiDAR Data Analysis

SWCM	TBR11	10/04/2024

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Taken by: Miranda Soskin

Summary

This report utilises Light Detection and Ranging (LiDAR), topography and aerial imagery data collected by the South West Coastal Monitoring (SWCM) Programme to analyse beach and dune volume at Church Cove. The aim is to highlight coastal change at Church Cove using SWCM data since 2007, focusing on beach and dune areas categorised into four zones: Beach, Mobile, Fixed, and Developed. Church Cove is a south-west facing cove beach >300 m long and 200 m wide. The beach is backed by a dune system, and golf course. A church and graveyard are situated in the western corner of the cove. A small stream flows through the middle of the beach, and the sides of the cove consist of hard rock cliff. Topographic data collected bi-annually along fixed cross-shore profile lines are presented to indicate change to the intertidal beach area over time. LiDAR data from each available flight is compared to create difference models of the intertidal area, compare volumetric data over time and to show change in Mean Seal Level (MSL) and dune toe contours over time.

There has been a total of 26 topographic surveys at Church Cove since 2007; 4 full coverage surveys, 21 interim surveys and 1 post-storm survey. Analysis of topographic data suggests the survey unit has remained stable since 2007, despite being heavily impacted from both the 2013/2014 and 2020 winter period. A seasonal signal can be seen with lower beach levels in spring and higher in the autumn.

Beach volume extracted from 6 LiDAR flights since 2007 have seen the Mobile Zone accreting gradually between 2008 and 2022 and the Beach Zone remaining stable despite large volume fluctuations. Both the Mobile and Beach Zone saw a decrease in volume during the 2014 LiDAR survey followed by a recovery of material. Dune toe contours have advanced seaward by up to 15 m along much of the dune.

Overall, Church Cove has been significantly impacted by the 2013/2014 and 2020 winter period but has shown signs of recovery in subsequent years.

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1.0 Introduction

The aim of this report is to highlight beach and dune change at Church Cove using data collected as part of the South West Coastal Monitoring (SWCM) Programme since 2007. Four zones have been identified to define the beach/dune area and are defined as:

- **Beach Zone** – The wet beach area has been defined using Mean Low Water Spring (MLWS) and Mean High Water Spring (MHWS) contours extracted from all LiDAR data captured by SWCM. The Beach Zone will therefore encompass the area between the MHWS and MLWS contours, with volumes for this area extracted from each LiDAR surface.
- **Mobile Zone** – This area is defined as the active dune face and embryo dune[1] from MHWS +1 m to the back of the mobile area, often distinguished by vegetation depth or urban development. The Mobile Zone has been defined using aerial imagery from 2007 to 2021 and historic OS maps and has been verified through site visits.
- **Fixed Zone** – This area is defined by permanent dune vegetation that may also include scrub or invasive species, effectively denoting vegetation atop sandy soil.
- **Developed Zone** – This is defined as urban development areas (i.e., car parks, unnatural grassy areas, roads, houses etc.) which have been built atop previously present dune systems.

1.1 Study Site

Church Cove is a southwest facing pocket beach backed by a small dune system mostly constrained by a golf course and is confined by small rocky headlands to the northwest and southeast (Fig.1). The beach has a cross-shore distance of ~270 m and longshore distance of ~170 m with an average spring tidal range of 4.7 m.

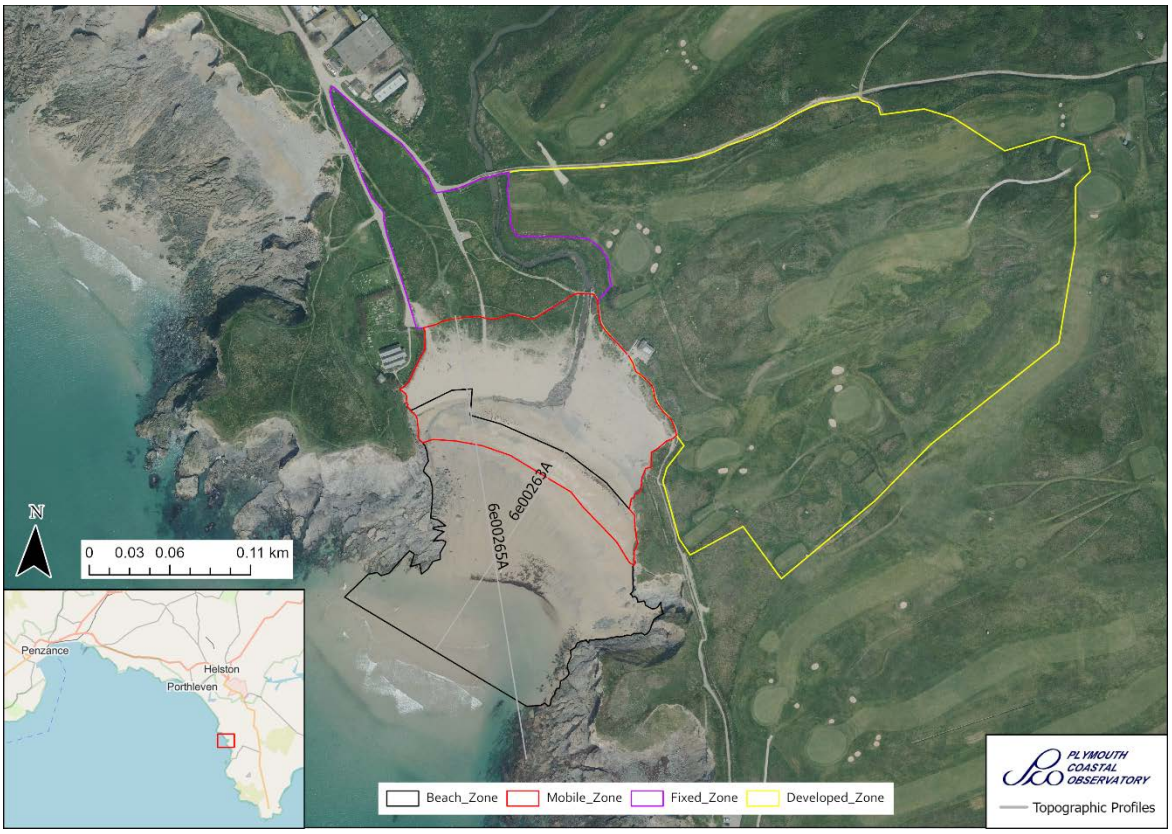


Figure 1 - Location Map of Church Cove Beach and Dune System, indicating the four defined zones outlined in section 1.0. Interim topographic profiles are also overlain to show their location, as detailed in section 2.1

[1] An embryo dune, or yellow dune, is the earliest stage of dune growth, usually found along the seaward extent of a dune system or newly formed dune.

2.0 Methods

Data utilised in this report was collected by SWCM between 2007 and 2023. Information on topographic and LiDAR data collection and specifications can be found on the Website for the National Network of Coastal Monitoring Programmes.

2.1 Topographic Data

SWCM have undertaken routine topographic beach surveys at 34 of the 40 MS4S sites since 2006. All surveys are conducted from the MLWS contour to the backshore. On average, each surveyed beach receives two interim surveys a year and one full coverage survey every 5 years:

- Interim - Conducted twice a year in the spring (conducted between January and April), and autumn (conducted between September and December). An interim survey consists of collecting data points at 5m intervals along pre-defined profiles; these are outlined in Figure 1.
- Full coverage – Conducted once per phase (6 years), or annually at more vulnerable sites (conducted between May and September). Full coverage surveys include a full profile survey at 50 m intervals and continuous spot height data collected across a 5 m grid covering the whole beach.

Analysis of the Cross-Sectional Area (CSA) change is conducted for each individual profile between each separate survey. Changes in CSA are measured relative to the fixed master profile which is defined by a pre-determined stable landward position and the MLWS level in reference to Ordnance Datum.

2.1.1 Topographic Data Analysis

Topographic data is presented as the following, where applicable:

Trend Analysis Plot - The combined profile trend in CSA is presented for each survey unit (example shown in Fig.2). The sum of all interim profile CSA is combined for each survey conducted to date to provide a survey unit with a single 'beach area' value, known hence-forth as the Combined Profile Area (CPA). CPA is compared using linear trend analysis over a temporal scale (Fig.2).

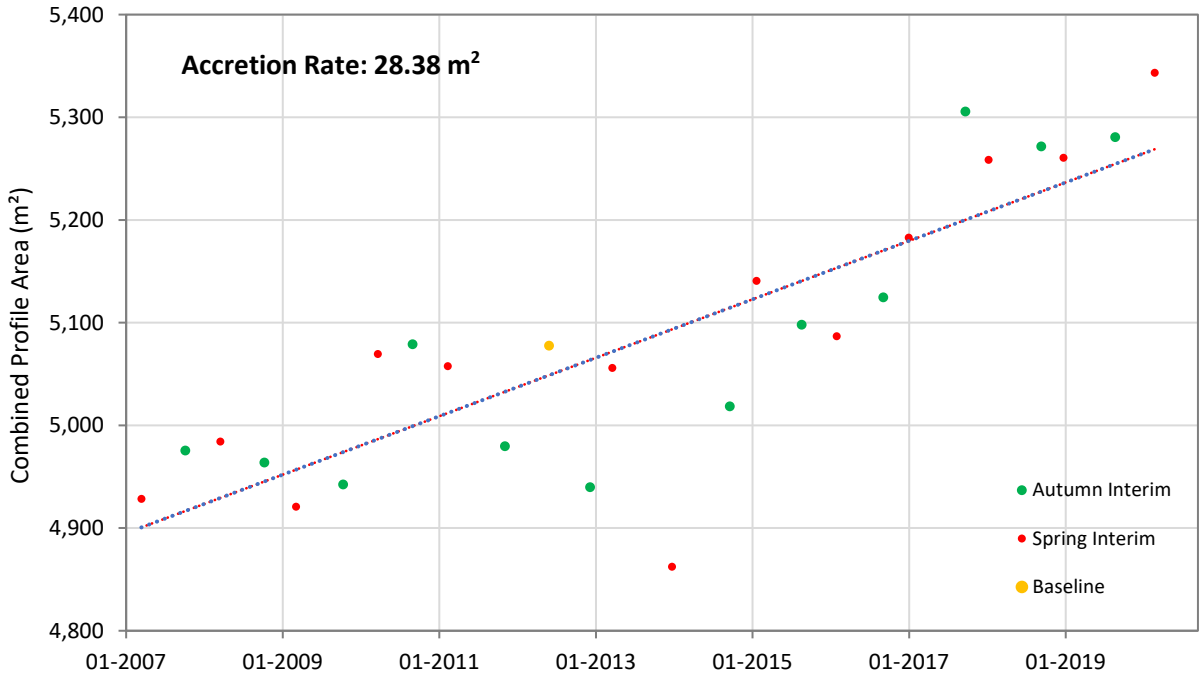


Figure 2 - Example of trend analysis for CPA for each survey with a linear trend rate highlighted at 28.4 m^2 y^{-1} equating to the increase of 0.56% of the average CPA per year.

If a profile has been omitted from a particular survey, for reasons of obstruction or similar, the average CSA of that profile from all available surveys is taken to ensure a consistent 'beach area'; if fewer than 75% of surveys have been conducted for a particular profile, the profile is omitted.

Profile Extremes Analysis - This plot displays the range of CSA values recorded throughout the duration of data collection (2006-2024) for each individual interim profile; the most recent survey is represented as a green dot. An example is given in figure 3. This plot provides the reader with information on how the CSA for each interim profile from the most recent survey corresponds to the entire dataset range.

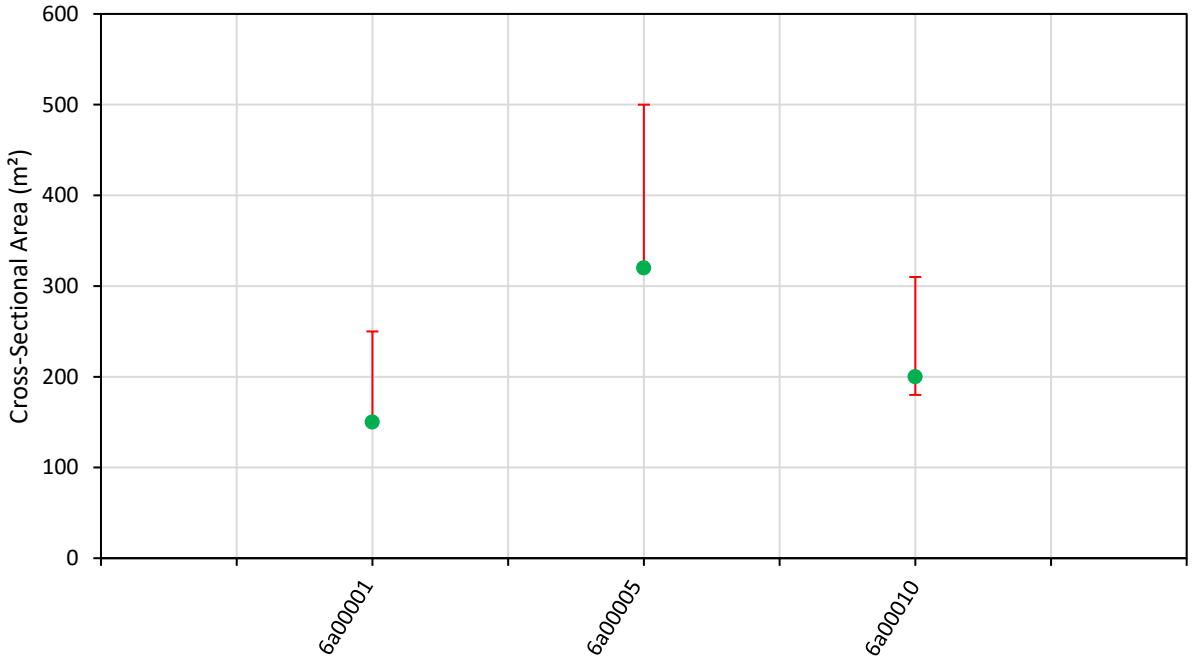


Figure 3 - Example plot showing the most recent CSA value recorded for three separate profile lines (green dots). The error bars represent the range of CSA recorded by each profile throughout the topographic dataset.

CSA Time Series Plot - CSA measurements for each interim profile are displayed on a separate plot representing values from each interim and full coverage survey conducted to date (example shown in Fig.4). This provides the reader with information on each interim profile's CSA evolution through time.

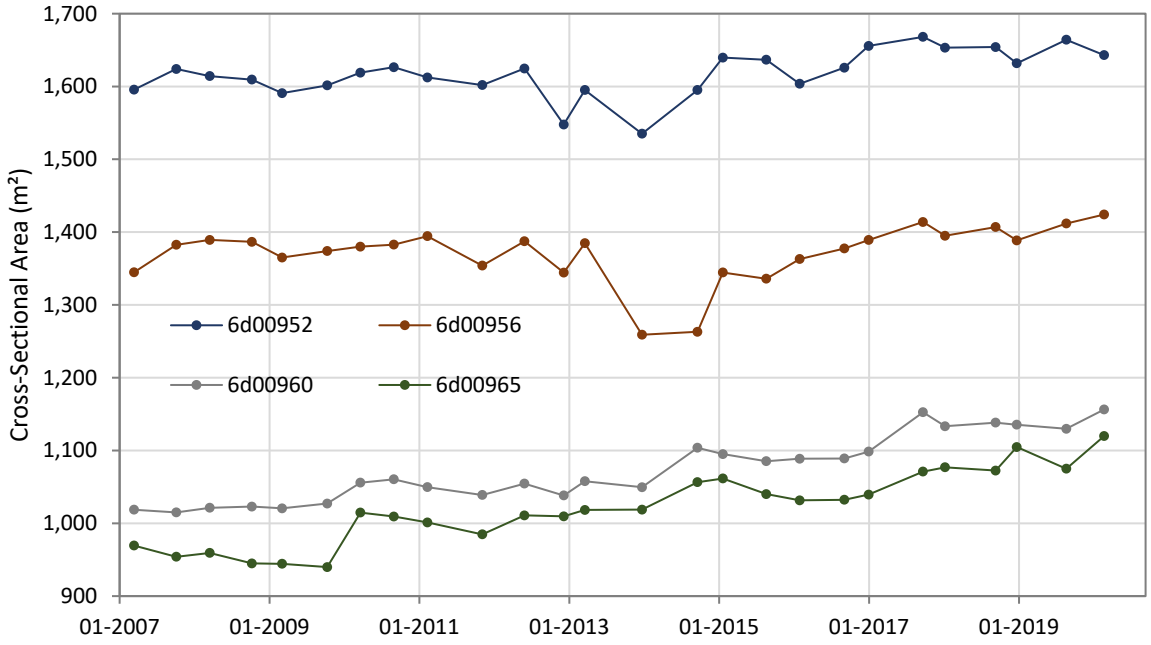


Figure 4 - Example of a cross-sectional area plot showing each of the interim profiles recorded for every survey since the 2007 baseline.

Individual Profile Charts - Each interim profile is portrayed as a cross-sectional profile comparing the most recent spring interim (blue), the previous spring interim (green) and the original full coverage survey (red). Profiles are displayed against the master profile (dotted red line) and are presented in the Appendices.

The 2013/2014 Storms – The winter period between September 2013 and April 2014 was, for many beaches in Cornwall, the most destructive period since SWCM records began in 2007. An abnormal number of significant storms, occurring in quick succession, heavily impacted many beaches, causing the loss of sediment from the intertidal area and dune face. This period is extensively discussed throughout this report and will hereinafter be referred to as the 2013/2014 winter period.

2.2 LiDAR Data

Airborne Light Detection and Ranging (LiDAR) data have been captured as part of the SWCM since 2007. Products include a point clouds, from which filtered and unfiltered 1 m^2 gridded surface models are derived:

- Unfiltered (Digital Elevation Model) representing the earth's surface including natural and artificial features such as trees and buildings.
- Filtered (Digital Terrain Model) representing the bare earth surface, with trees, buildings, cars etc. removed.

LiDAR is captured between September and March to minimise vegetation capture. Data is captured between MLWS and up to approximately 500 m inland. This report utilises "filtered" LiDAR data.

2.2.1 LiDAR Data Analysis

LiDAR data analysis is presented as the following:

Difference Modelling – Separate LiDAR surfaces are compared to produce a difference model of change based on gridded spot height elevations. The raw spot height data is processed into a gridded digital terrain model (DTM) and successive models are subtracted from one another to produce a difference model for the survey unit. Change in elevation is shown for values +/- 0.25 m and is represented by a colour scale bar.

Volume Extraction - Net sediment volume (m^3) is extracted for each LiDAR surface from the Beach Zone above MLWS and Mobile Zone above MHWS for trend comparison over time.

Contour Analysis – Contours are mapped from four LiDAR epochs spanning from 2007 to 2023, representing Mean Sea Level (MSL) and dune toe (calculated using the Stockdon equation by UoP, 2023[2]).

2.3 Accuracy Statement

Topographic Data – All survey points recorded along profiles have a measurement accuracy of +/- 0.03 m RMSE[3] in the horizontal and +/-0.03 m RMSE in the vertical.

LiDAR Data – Each LiDAR point cloud dataset has an average point density of 1.5 points per square metre. The digital terrain surfaces provide a minimum accuracy in elevation data of +/- 0.10 m RMSE with a minimum horizontal standard deviation as < 0.05 m. Please note that while every endeavour has been made to capture LiDAR as far seaward as MLWS, tidal and weather restrictions may in some instances have precluded this and coverage may be slightly reduced.

[2] Please refer to the following for Dune Toe elevation calculation: UoP, 2023. MS4S: Contemporary Dune Evolution and Future Predictions, Report, University of Plymouth, 33 pp.

[3] RMSE – Root-Mean-Square Error

3.0 Results

3.1 Topographic Data Analysis

There has been a total of 25 topographic surveys at Church Cove since 2007, 4 of which are baseline surveys and 21 are interim surveys. Exact dates of each survey for Par Sands are available to view on our survey record. Analysis of the CPA suggests the beach has remained stable between 2007 and 2023 despite moderate fluctuations in area including the second lowest value (1388 m^2) recorded in spring of 2014 following the 2013/14 storms (Fig.5). The beach displays strong seasonal variation, with spring surveys recording a more eroded beach state following the high energy conditions of the winter and spring and autumn surveys indicating a more accreted beach state following more constructive conditions during the summer and autumn.

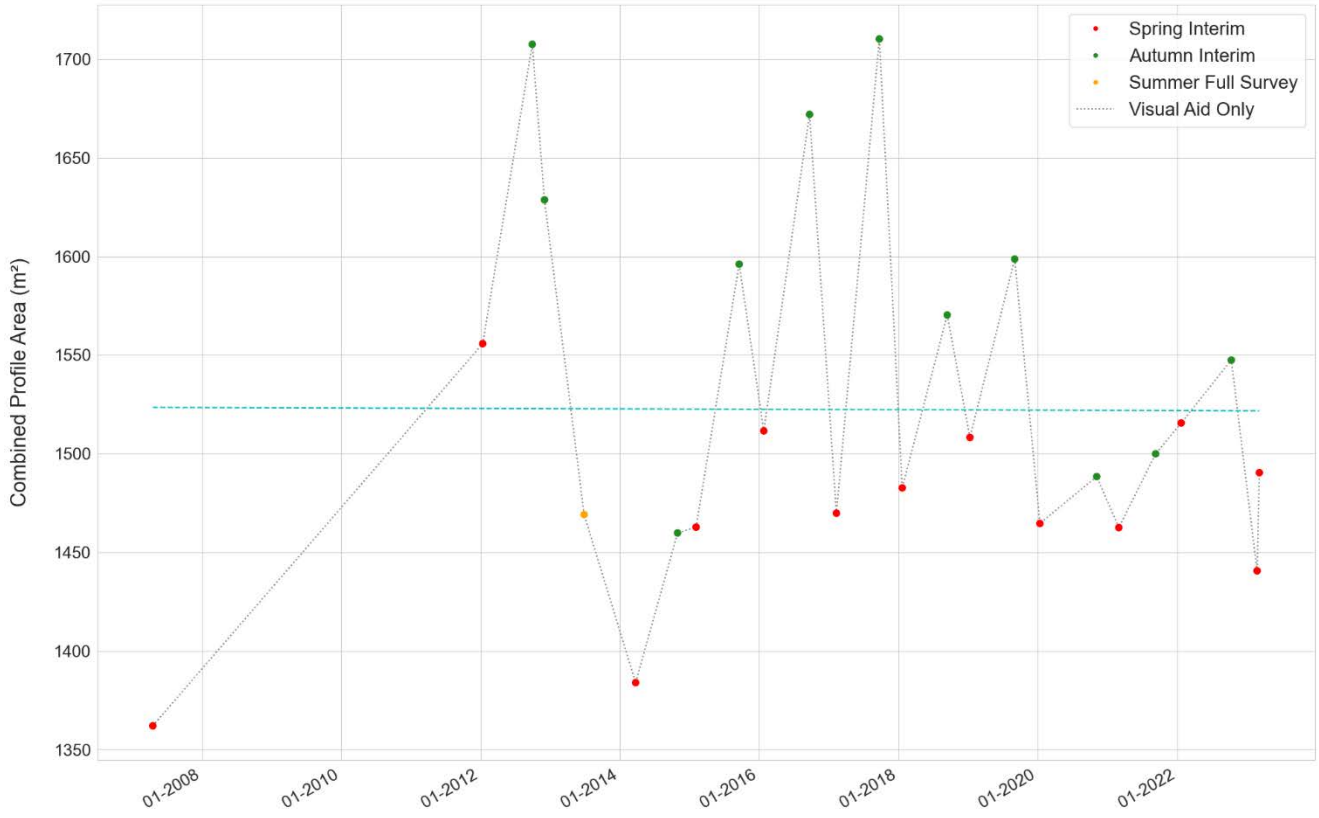


Figure 5 - The Combined Profile Area (CPA) for Church Cove, including every spring (red), summer (yellow) and autumn (green) survey completed between 2007 and 2023.

When comparing to the entire dataset (Fig.6), both profiles at Church Cove recorded below average area during the 2023 spring interim. Both profiles also indicate relatively high variance, with up to a 22% change in area recorded for both between 2007 and 2023 (Fig.6).

When comparing profile cross-sectional areas to the entire time series (Fig.7), both profiles follow a similar trend of accretion and erosion, indicating gradual recovery following the 2013/14 winter season (Fig.7).

Profile Charts for Church Cove can be found in Appendix 1, these display the cross-sections of each profile for the initial baseline survey conducted in 2007 along with the two most recent interim surveys. Both profiles have seen accretion across the entire beach face since 2007, with 6e00265A indicating a 0.5 m increase in elevation of the fore dune.

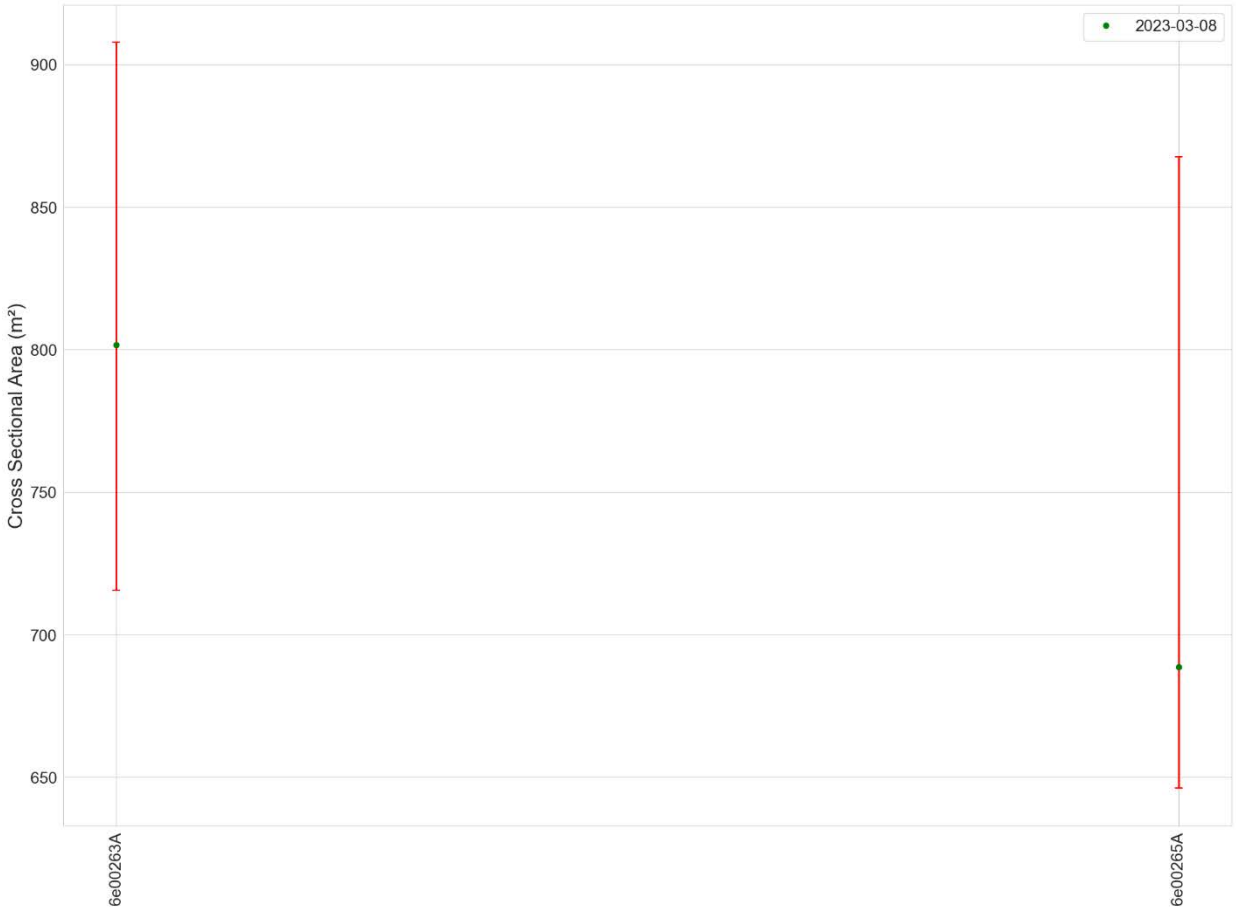


Figure 6 - Cross-sectional area of each interim profile, comparing the current area of the profile (green dot), with the maximum and minimum values (red error bar) recorded between 2007 and 2023.

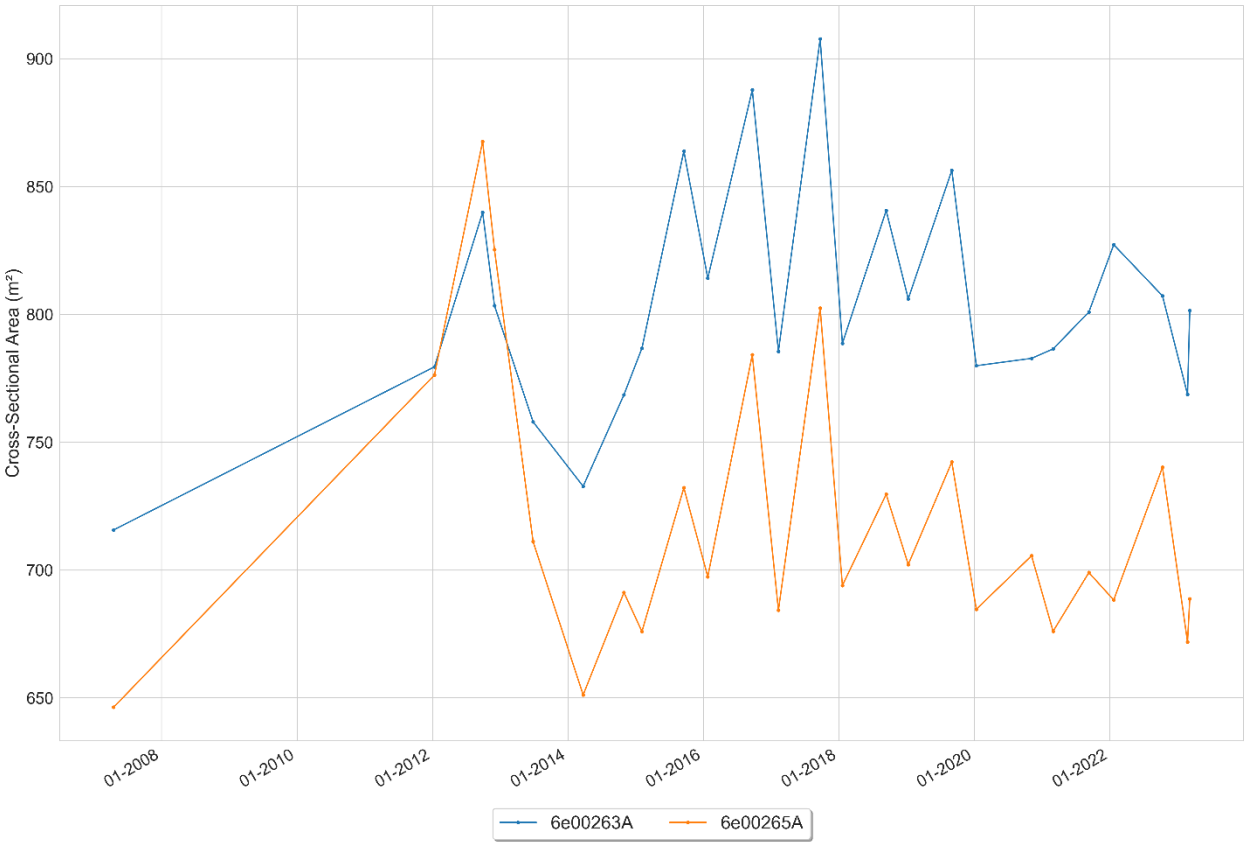


Figure 7 - Cross-sectional area of each interim profile, comparing the values recorded during each interim and baseline survey between 2007 and 2023.

3.2 LiDAR Data Analysis

There has been a total of 5 LiDAR flights captured at Church Cove since 2007.

3.2.1 Difference Models

Difference models depicting each epoch of LiDAR are presented here. Accretion and erosion values observed behind the dune system can be attributable to noise in the filtered LiDAR data or man-made changes in elevation and should be dismissed as such.

Figure 8 shows the difference in elevation between the first filtered LiDAR data from September 2007 compared to the most recent, captured in February 2023. The figure is dominated by accretion across much of the upper beach as well as considerable accretion at the dune toe and fore dune area. There is significant erosion and accretion to the southeast of the beach along the cliff face.

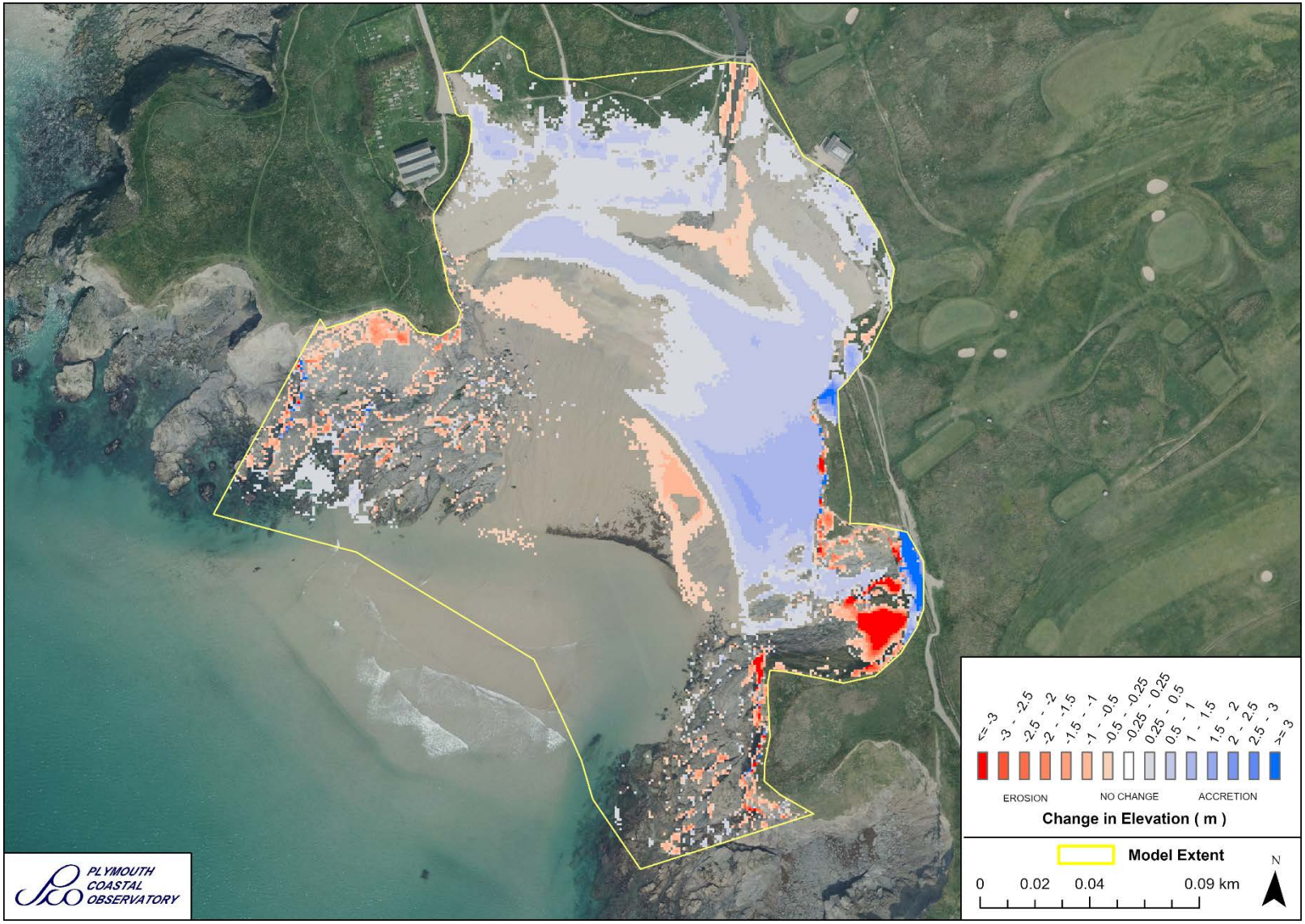


Figure 8 – Difference model indicating the changes in elevation observed between the September 2007 and February 2023 filtered LiDAR datasets within the yellow model extent.

Figure 9 shows differences in elevation between filtered LiDAR data from September 2007 compared to October 2010. Widespread accretion can be observed across the majority of the lower beach with an increase of up to 2 m in elevation in places, there is also subsequent erosion observed across the upper beach face with up to a 2 m loss in elevation, particularly to the west of the beach which has seen gains of up to 2 m in elevation.

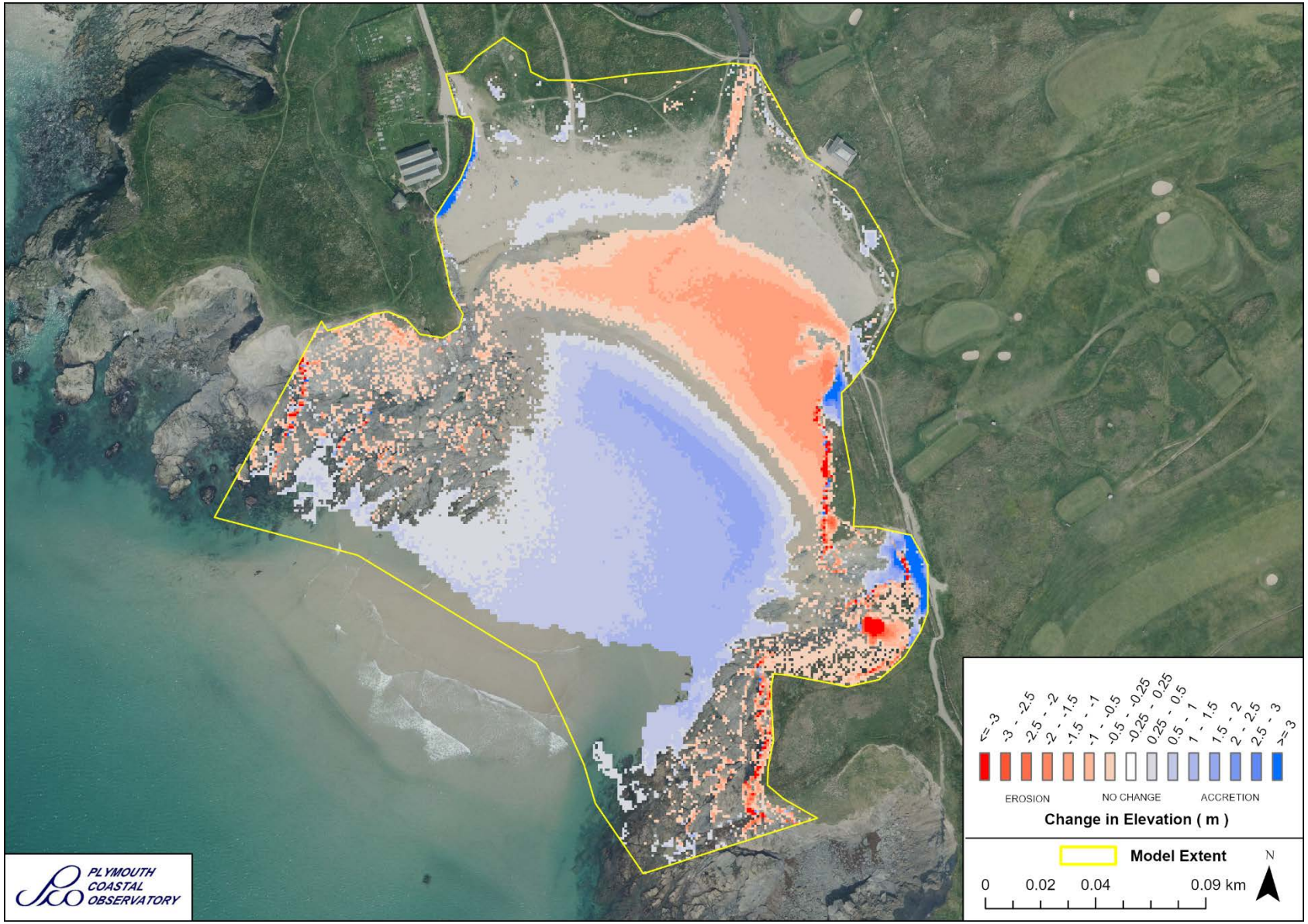


Figure 9 - Difference model indicating the changes in elevation observed between the September 2007 and October 2010 filtered LiDAR datasets within the yellow model extent.

Figure 10 shows differences in elevation between filtered LiDAR data from October 2010 compared to May 2014. Following the 2013/14 storm season, the lower beach and upper beach berm underwent erosion of up to 2 m in elevation which is primarily focused to the east of the beach. In contrast however, significant accretion is also observed across the beach face, again focused on the west of the beach, where elevation gain of up to 2.5 m is visible.

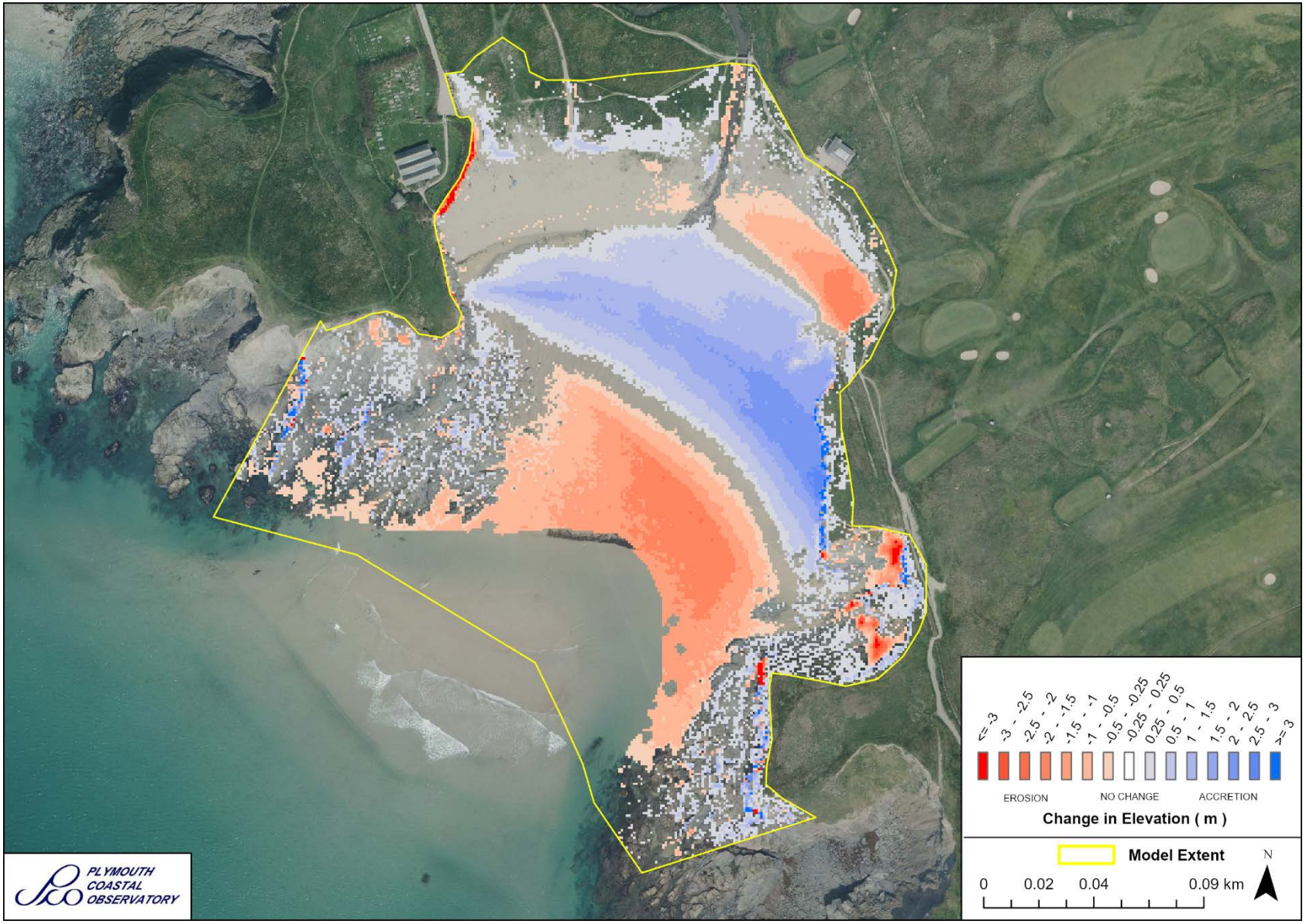


Figure 10 - Difference model indicating the changes in elevation observed between the October 2010 and May 2014 filtered LiDAR datasets within the yellow model extent.

Figure 11 shows differences in elevation between filtered LiDAR data from May 2014 compared to February 2019. Widespread accretion can be observed across most of the beach, particularly across the upper beach face and lower beach seeing gains of up to 2 m in elevation. Minor erosion can be observed at the beach toe primarily to the east.

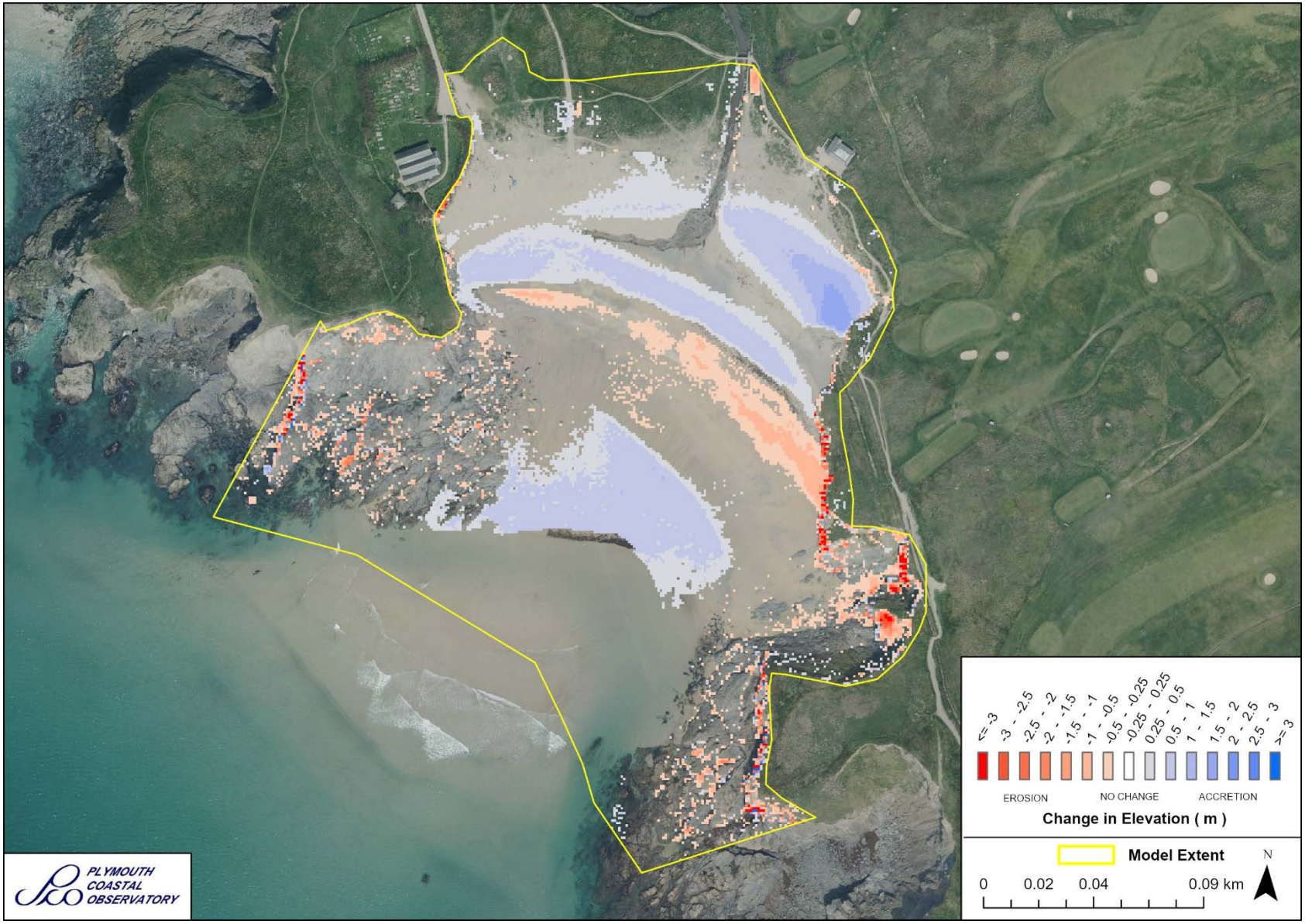


Figure 11 - Difference model indicating the changes in elevation observed between the May 2014 and February 2019 filtered LiDAR datasets within the yellow model extent.

Figure 12 shows differences in elevation between filtered LiDAR data from February 2019 compared to February 2023. Similarly to other beaches in the area, the beach is dominated with erosion between the two later datasets, with erosion of up to 2 m in elevation primarily observed along the course of the stream.

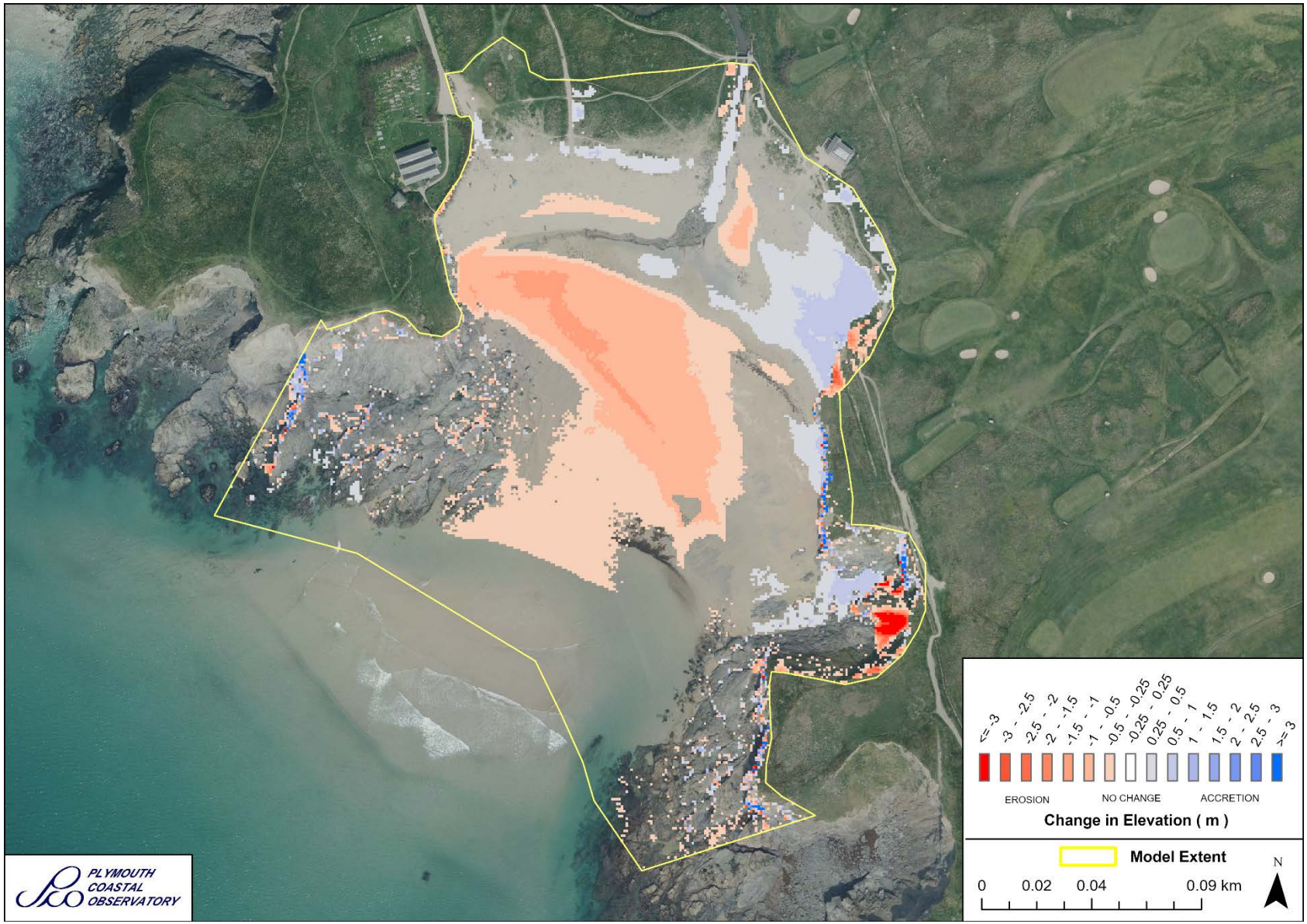


Figure 12 - Difference model indicating the changes in elevation observed between the February 2019 and February 2023 filtered LiDAR datasets within the yellow model extent.

3.2.2 Beach and Dune Volume Extraction

Surface volume extracted from each available LiDAR dataset from the Mobile Zone above the MHWS contour (2.40 m OD) are shown in Table 1 and Figure 13. LiDAR data from the Mobile Zone has shown a gradual accretion between 2007 and 2023, increasing in volume by 15% with the 2022 survey recording the highest value (Fig.13).

Surface volume extracted from each LiDAR dataset from the Beach Zone above the MLWS contour (-2.30 m OD) are shown in Table 1 and Figure 14. The Beach Zone has remained stable between 2007 and 2023 despite fluctuations in volume, the lowest recorded was during the 2007 survey, which saw a 32% increase in volume to the following 2010 survey (Fig.14).

Table 1 – Surface volume values (m^3) extracted from all available filtered LiDAR datasets for the Mobile Zone above MHWS (2.40 m OD) and for the Beach Zone above MLWS (-2.30 m OD).

Date	Mobile Zone Volume (m^3)	Beach Zone Volume (m^3)
07/2007	30,198	33,460
10/2010	27,201	44,158
05/2014	31,336	40,268
02/2019	34,672	42,322
02/2023	34,765	36,503

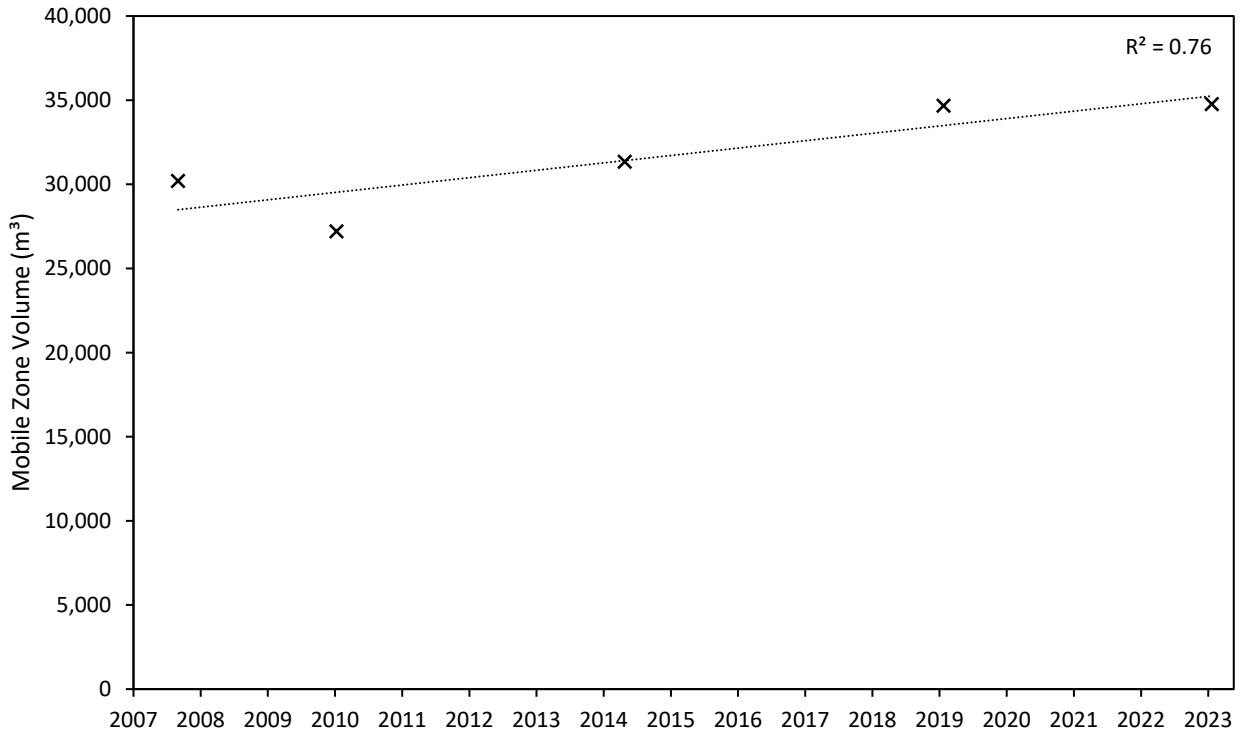


Figure 13 – Plot indicating beach volume (m^3) recorded in the Mobile Zone above MHWS (2.40 m OD) for each filtered LiDAR datasets between 2007 and 2023.

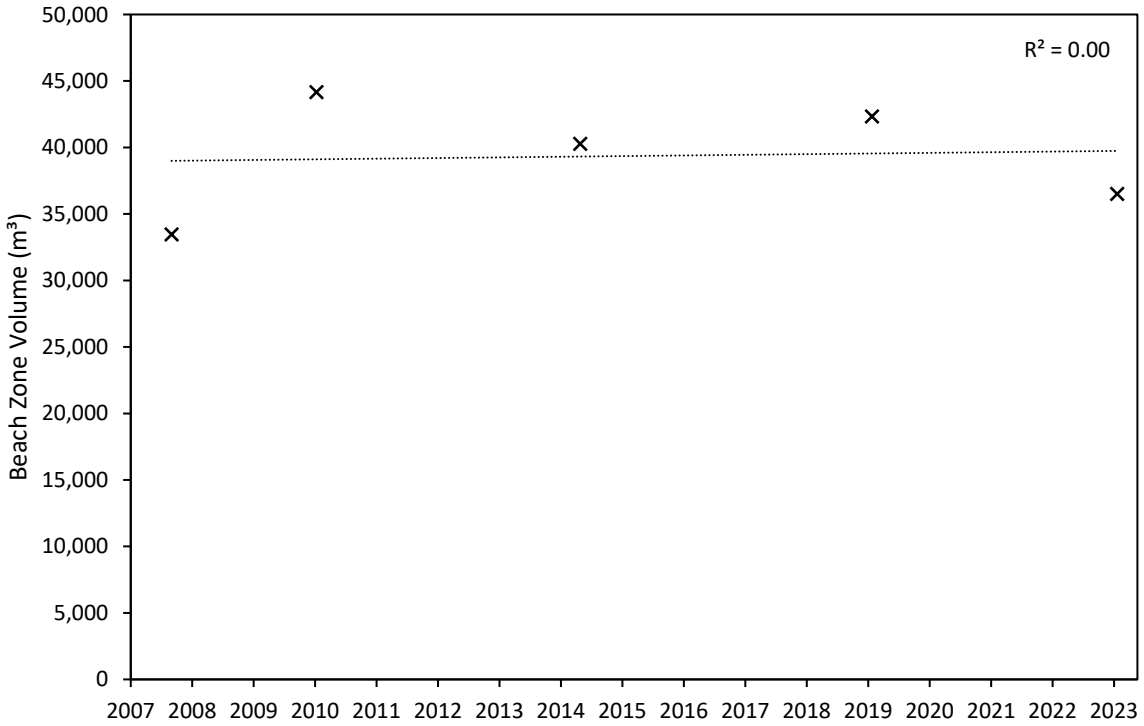


Figure 14 - Plot indicating beach volume (m^3) recorded in the Beach Zone above MLWS (-3.00 m OD) for each filtered LiDAR datasets between 2007 and 2023.

3.2.3 Contour Comparison

Figure 15 indicates the Mean Sea Level (MSL) and dune toe contours from the 2007, 2014, 2019 and 2023 LiDAR datasets. MSL contours indicate a varied response with the beach being at its widest during the 2014 survey despite the impact of the 2013/14 storms (Fig.15). The dune toe contour has advanced by up to 20 m along the majority of the dune front to the west and a platform has formed to the east of the beach (Fig.15), widening the upper beach with evidence of new dune vegetation detected in the aerial imagery to the east of the beach.

3.3 Historic Aerial Maps

Historic aerial photography captured in 1947 by the RAF, in 2001 by the Environment Agency (Figs. 16 and 17) and from 2007 onwards by the SWCM (Figs. 18-22) are presented here.

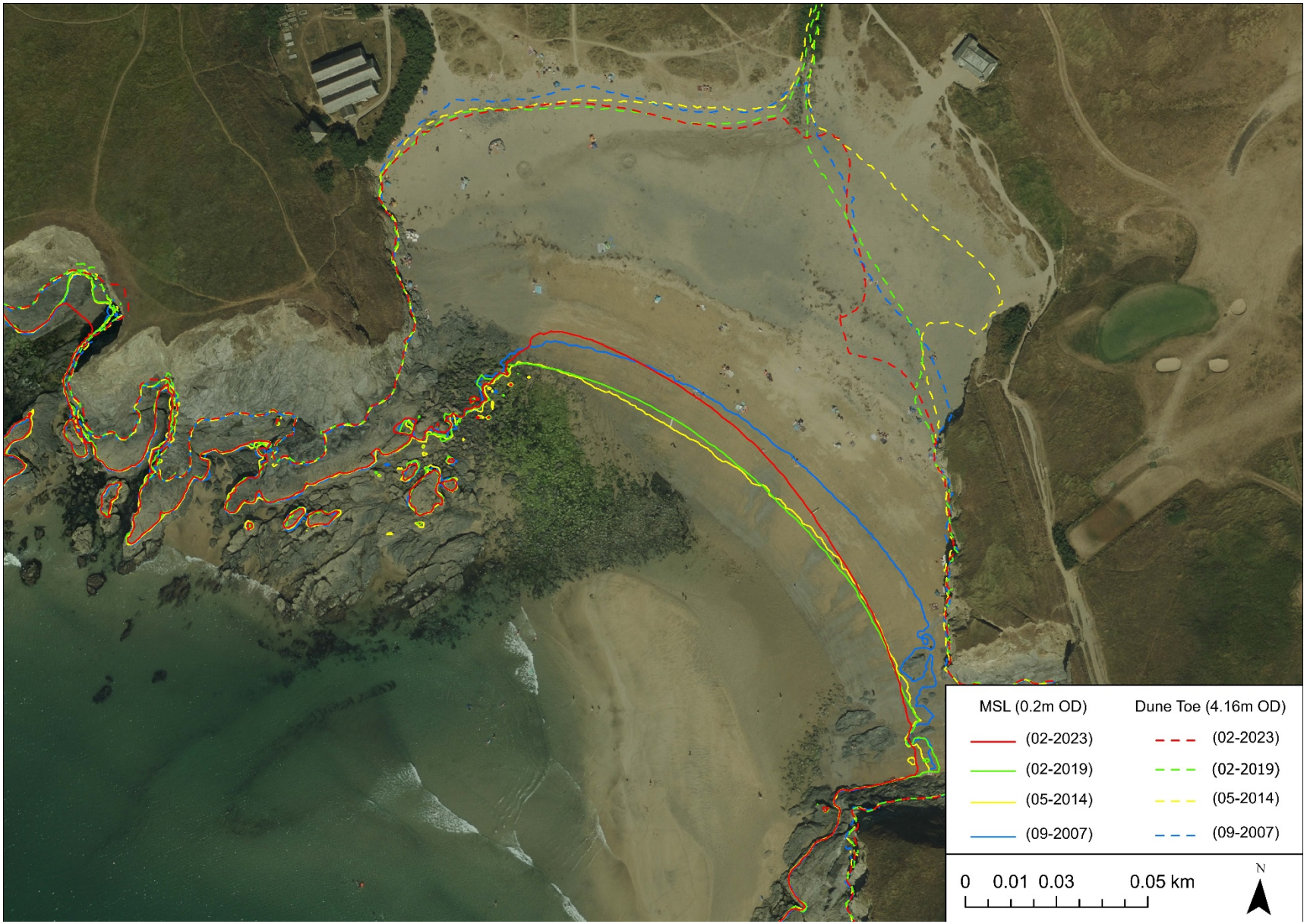


Figure 15 – Contour map indicating Mean Sea Level (solid line) and Dune Toe (dashed line) extracted from 2007, 2014, 2019 and 2023 LiDAR datasets.

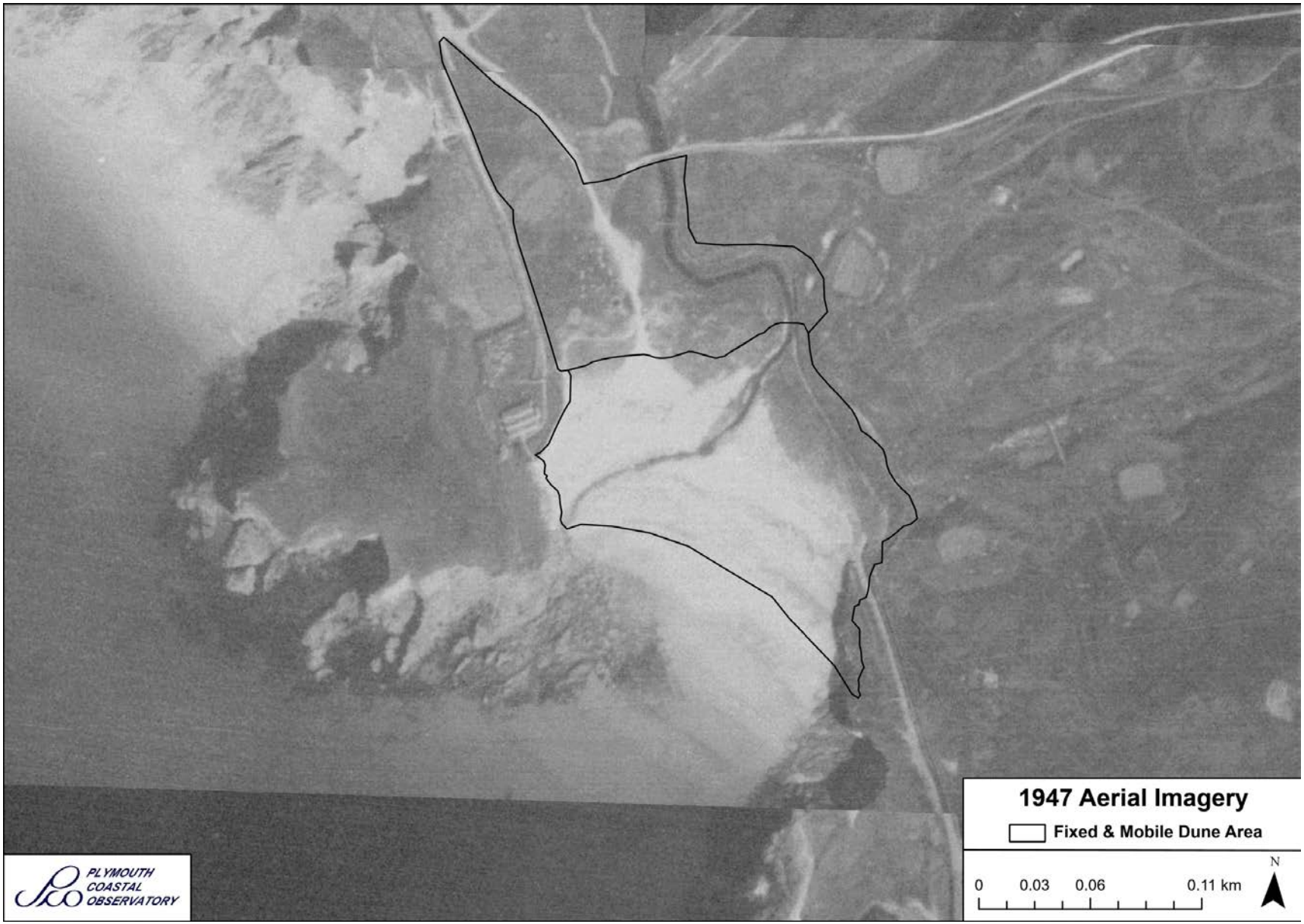


Figure 16 – Aerial imagery from 1947.



Figure 17 – Aerial imagery from 2001.

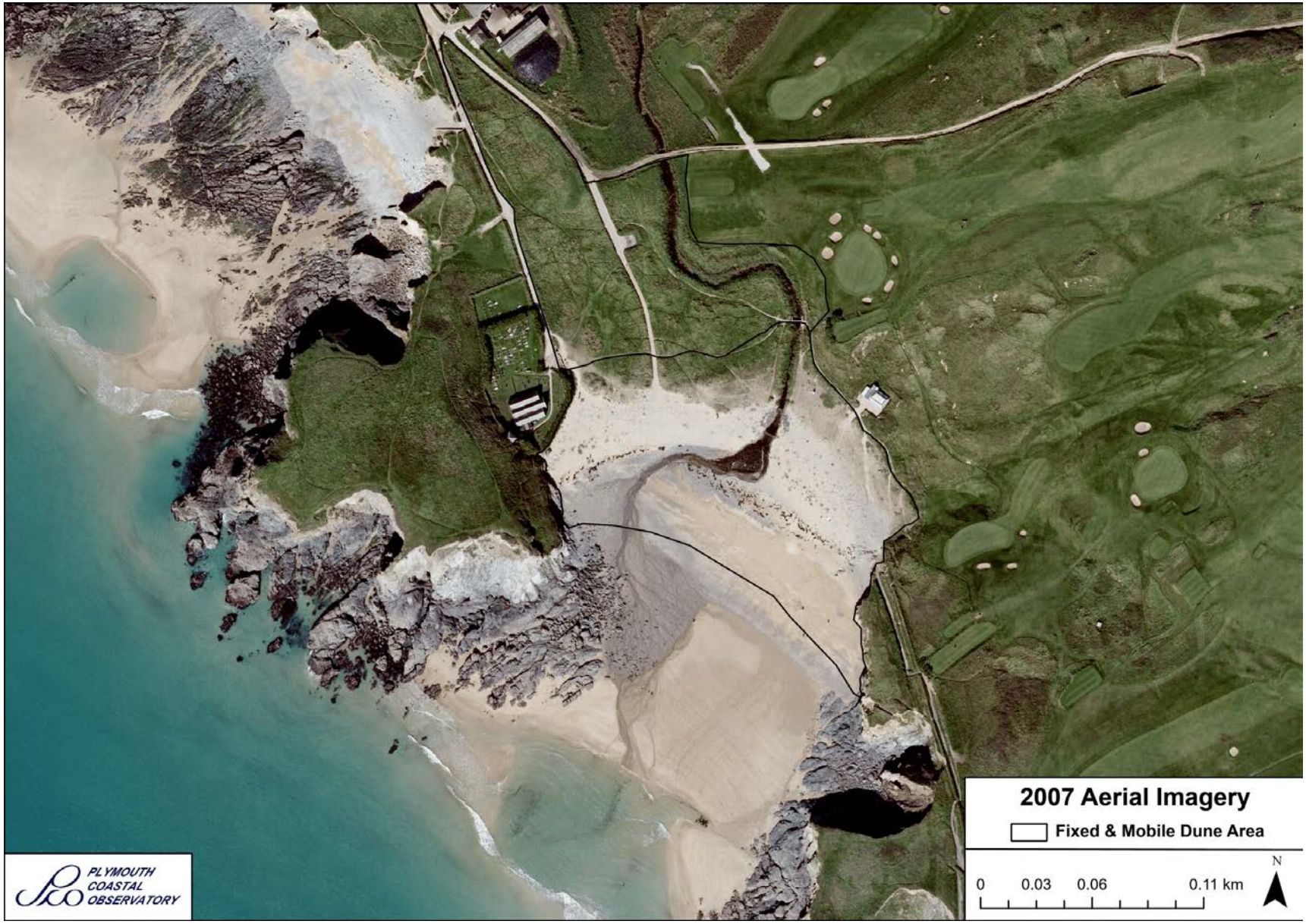


Figure 18 – Aerial imagery from 2007.

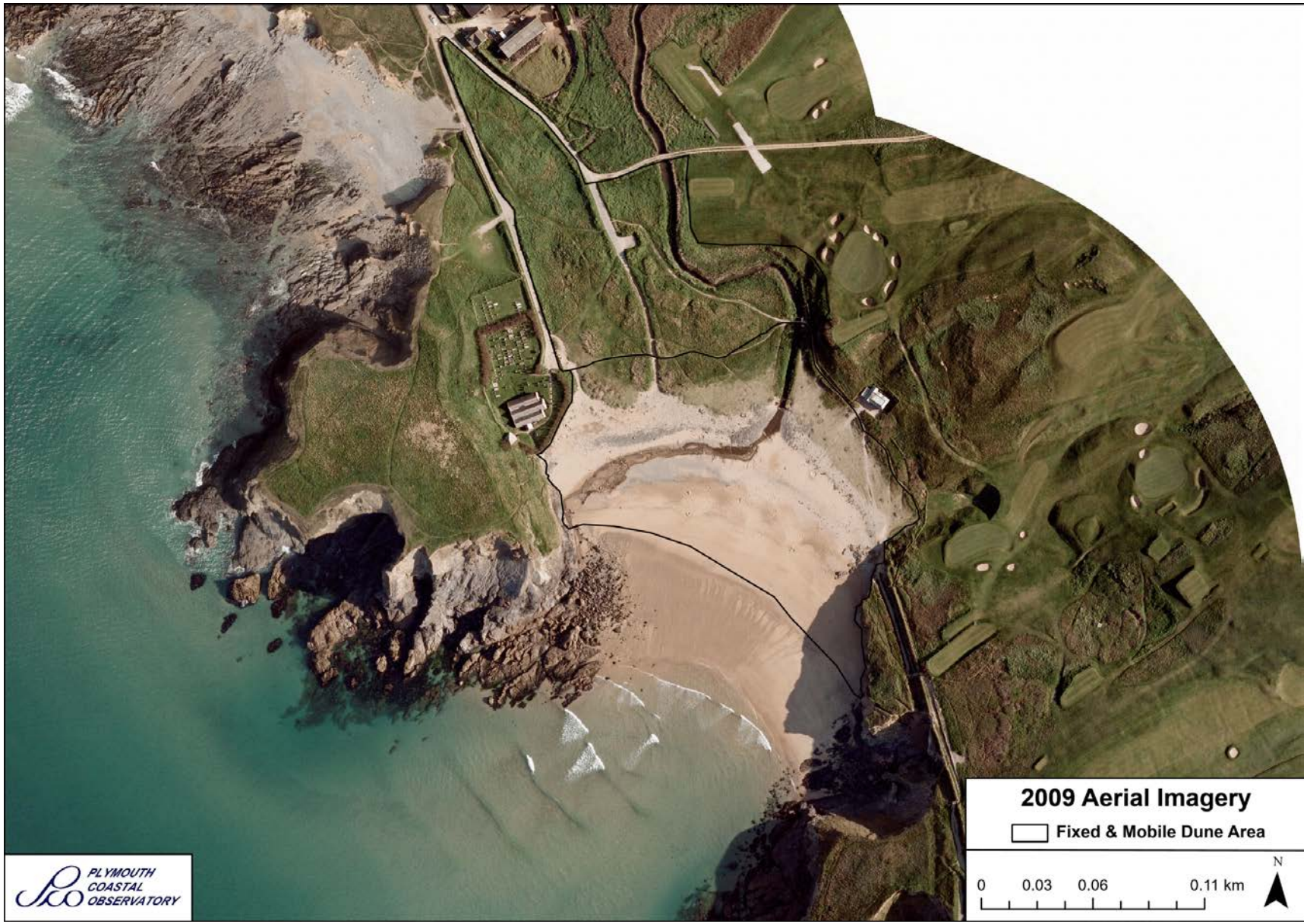


Figure 19 – Aerial imagery from 2009.

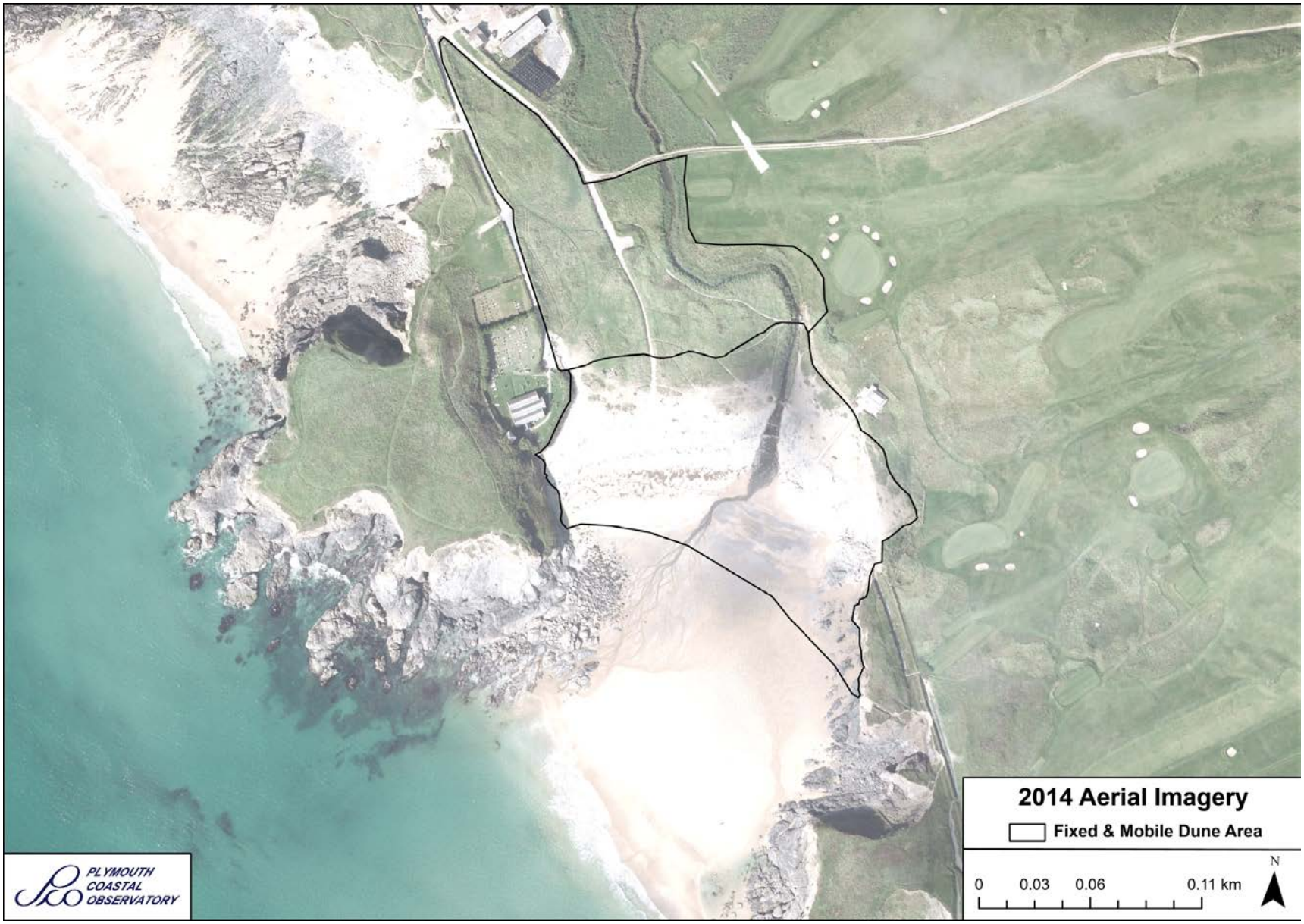


Figure 20 – Aerial imagery from 2014.



Figure 21 – Aerial imagery from 2018.



Figure 22 – Aerial imagery from 2022.

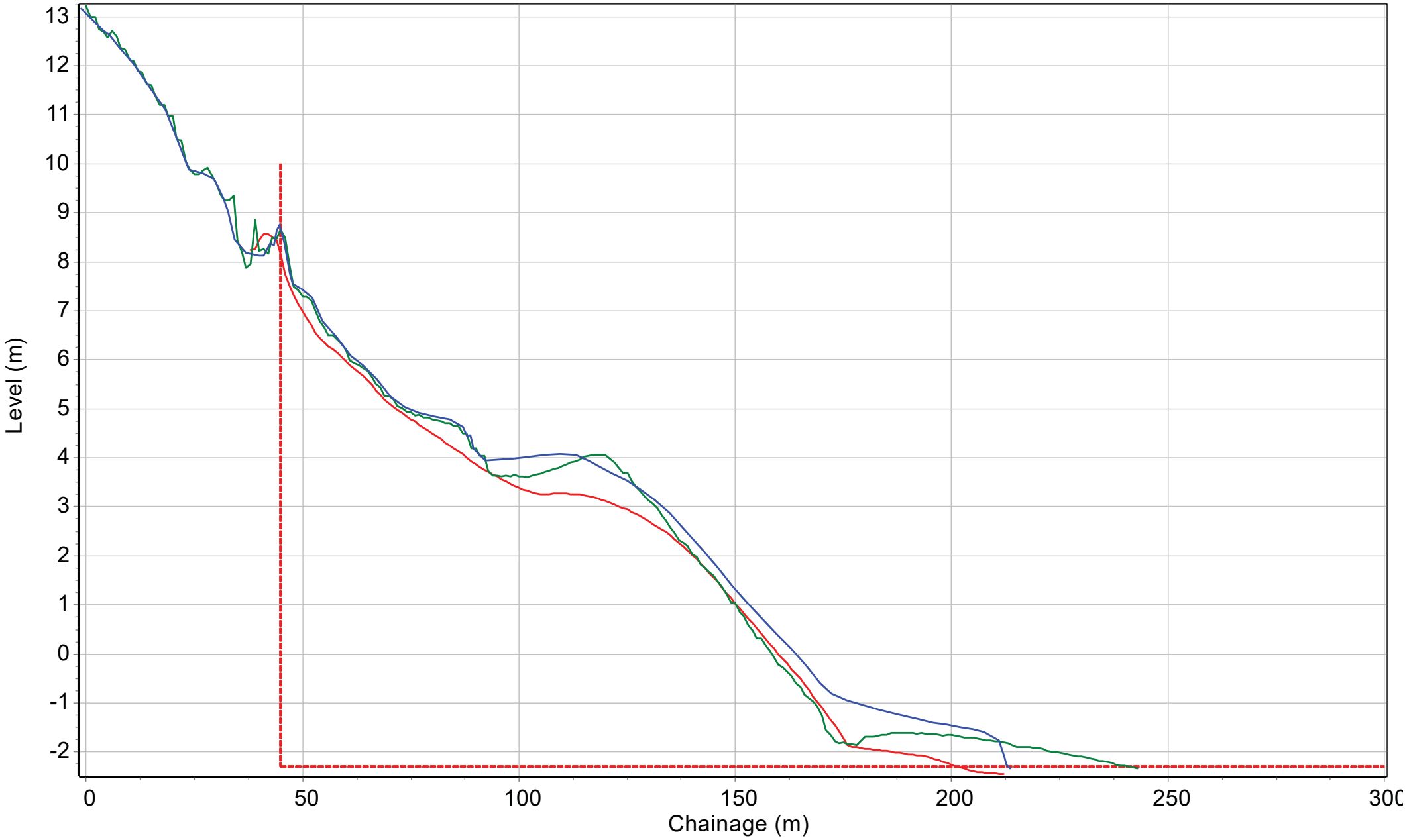
Glossary

1. Accretion: The net accumulation of deposited sediment, deposited by waves, tides or current.
2. Coastal Morphodynamics: The study of changes in coastal landforms and landscapes over time.
3. Contour Analysis: Mapping of contours from LiDAR datasets to represent Mean Sea Level (MSL) and Dune Toe elevations.
4. Cross-Sectional Area (CSA): The area of a two-dimensional cross-section of a cross-shore beach profile, running between Mean Low Water Spring and the back of the beach.
5. Developed Zone: Areas of urban development built atop previously present dune systems.
6. Difference Modelling: Comparison of separate LiDAR surfaces to produce a difference model of change based on gridded spot height elevations.
7. Digital Elevation Model (DEM) and Digital Terrain Model (DTM): DEM represents the Earth's surface with all features, while DTM represents the bare earth surface, excluding vegetation and structures.
8. Embryo Dune: The earliest stage of dune growth, typically found along the seaward extent of a dune system or newly formed dune.
9. Erosion: The process by which local sea level rise, strong wave action, and coastal flooding wear down or carry away rocks, soils, and sands along the coast.
10. Fixed Zone: Area defined by permanent dune vegetation, including scrub or invasive species, denoting vegetation atop sandy soil.
11. Intertidal Bar: A ridge or mound of sand, gravel, or other sediment deposited in the intertidal zone along a shoreline.
12. LiDAR: Light Detection and Ranging, a remote sensing method that uses light in the form of a pulsed laser to measure variable distances to the Earth.
13. Mean High Water Spring (MHWS): The height of mean high-water springs is the average throughout the year of two successive high waters during those periods of 24 hours when the range of the tide is at its greatest.
14. Mean Low Water Spring (MLWS): The height of the mean low-water springs is the average height obtained by the two successive low waters during the same period.
15. Mobile Zone: The area including the active dune face and embryo dune that is in motion due to wind action or other factors.
16. Root-Mean-Square Error (RMSE): A measure of the differences between values predicted by a model and the observed values.
17. Tidal Range: The vertical difference between high tide and low tide during a tidal cycle.

Appendices

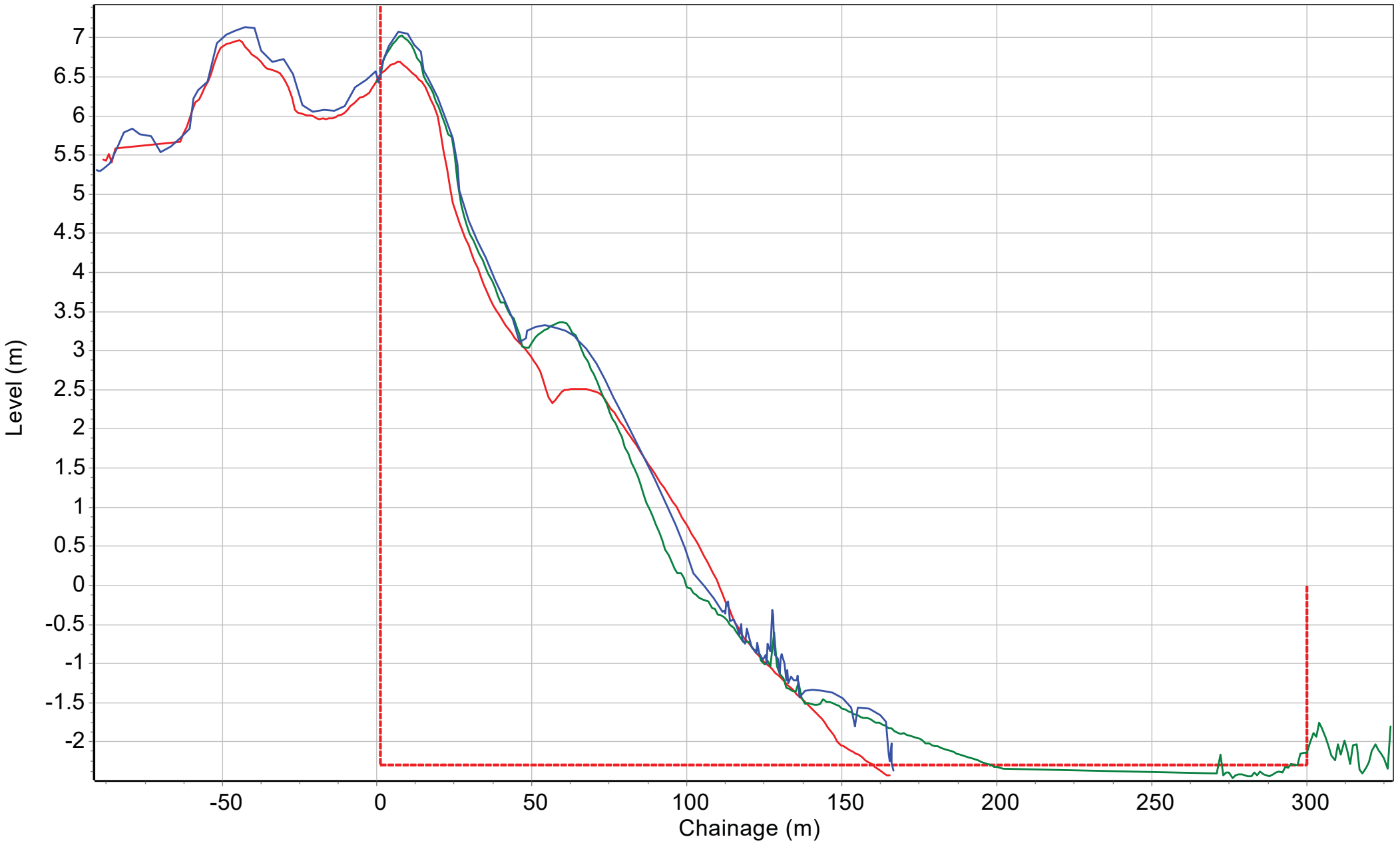
Appendix 1 – Profile charts extracted using SANDS software, indicating the most recent survey (blue), second most recent survey (green) and first survey, also known as the baseline (red).

Profiles: 6e00263A



SANDS

Profiles: 6e00265A



SANDS