SOUTH WEST COASTAL MONITORING

making space for sand



Making Space for Sand – Harlyn Beach Report

Topographic and LiDAR Data Analysis

SWCM TBR31 12/01/2024

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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 Harlyn. The aim is to highlight coastal change at Harlyn using SWCM data since 2007, focusing on beach and dune areas categorised into four zones: Beach, Mobile, Fixed, and Developed. Harlyn is a north facing beach, sheltered from the dominant swell of the North Atlantic. It is a medium sized beach, reaching up to 600 m in width, and has a small river flowing out from the east of the unit. It has a semi-diurnal tide type and an average spring tidal range of 6.5 m. The majority of the beach is backed by hard rock cliffs, however the entrance to the beach, in the east, is backed by a small dune system and a car park.

Since 2007, there have been 36 topographic surveys conducted at Harlyn; 4 full coverage surveys, 31 interim surveys and 1 post-storm survey. The analysis reveals that the beach area has been accreting between 2007 to 2024. The highest combined area was recorded in the 2011 spring interim, followed by a gradual decline until beach recovery was observed in autumn 2016. Subsequently, there has been a larger variation in combined profile area, with the latest survey showing an above-average area. When comparing profile cross-sectional areas to the entire time series, stability is largely observed since 2007, with seasonal variation.

Beach volume was extracted from 6 LiDAR flights since 2007. The Mobile Zone has shown no long-term change between 2008 and 2022, however it did experience a considerable loss of material following the 2013/14 winter storms. Since the 2014 survey, Harlyn's Mobile Zone has recovered, recording the highest volume in 2022. The Beach Zone in contrast has seen a gradual accretion of volume between 2008 and 2022, showing limited change following the 2013/14 winter storms.

Overall Harlyn beach has shown distinct trends; increasing until 2011, gradually decreasing until 2021, then experiencing a trend for accretion in recent years.

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1.0 Introduction

The aim of this report is to highlight beach and dune change at Harlyn Beach 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

Harlyn is a north facing beach, sheltered from the dominant swell of the North Atlantic. It is a medium sized beach, reaching up to 600 m in width and has a small river flowing out from the east of the unit. It has a semi-diurnal tide type and an average spring tidal range of 6.5 m. The majority of the beach is backed by hard rock cliffs, however the entrance to the beach, in the east, is backed by a small dune system and a car park. The four beach and dune zones are represented in Figure 1.



Figure 1 - Location Map of Harlyn 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 2024. 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).

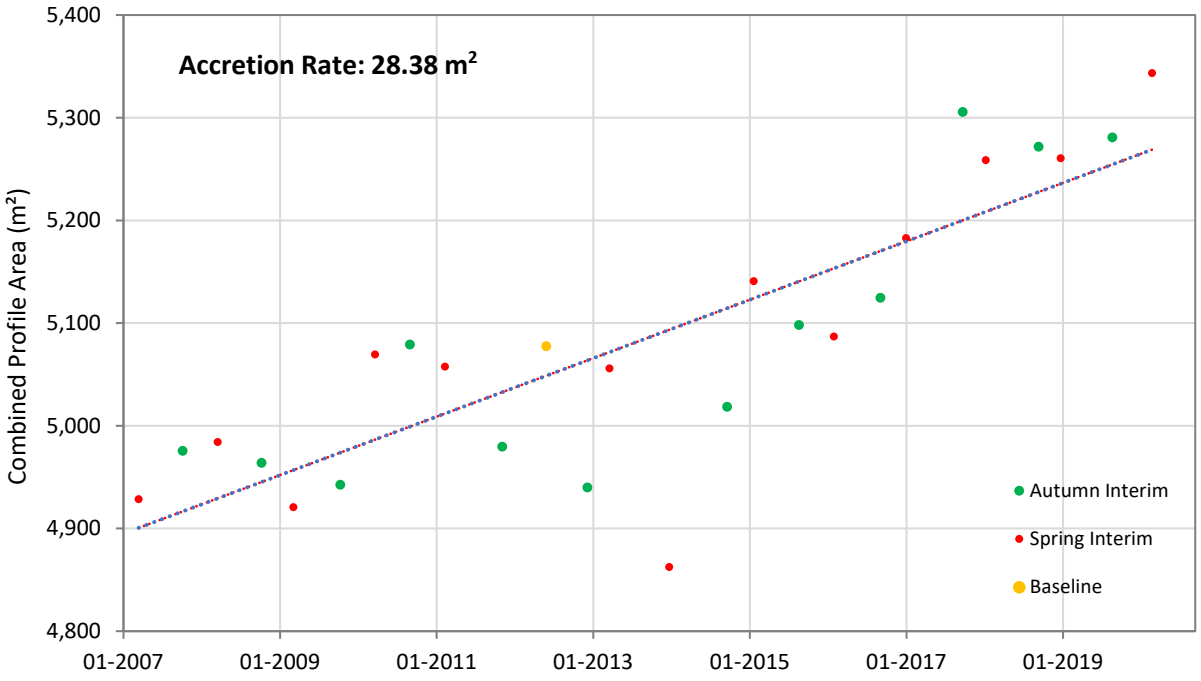


Figure 2 - Example of trend analysis for CPA for each survey with a linear trend rate highlighted at 28.4 m^2 y^{-1} equating to the increase of 0.56% of the average CPA per year.

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 (2006-2022) 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.

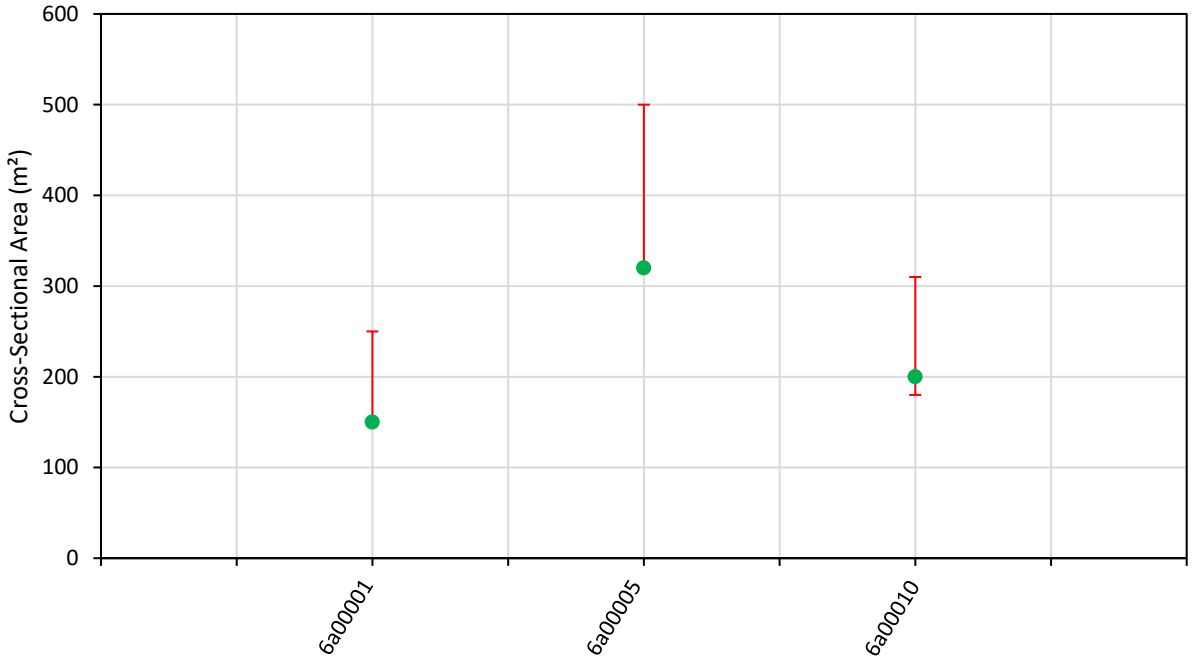


Figure 3 - Example plot showing the most recent CSA value recorded for three separate profile lines (green dots). The error bars represent the range of CSA recorded by each profile throughout the topographic dataset.

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.

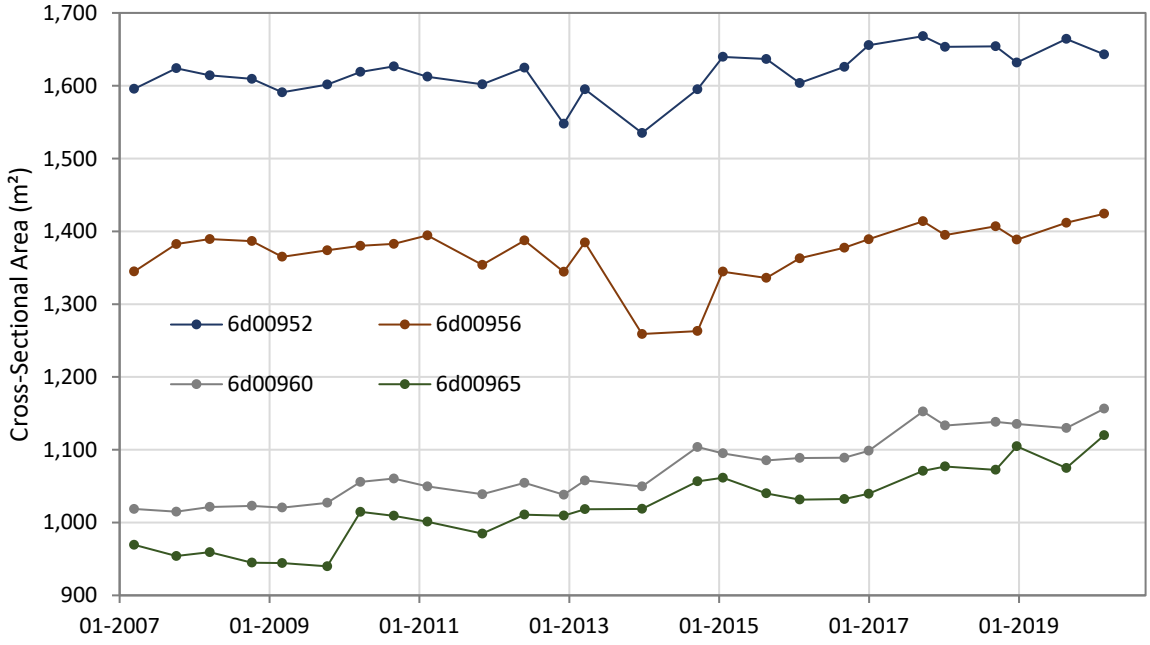


Figure 4 - Example of a cross-sectional area plot showing each of the interim profiles recorded for every survey since the 2007 baseline.

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 36 topographic surveys at Harlyn since 2007, 4 of which are full coverage surveys, 31 are interim surveys and 1 is a post-storm survey. Exact dates of each survey for Harlyn are available to view on our survey record. Analysis of the CPA indicates the survey unit has been accreting at 3.3 m^2 y^{-1} equating to 0.1% of the average beach area per year (Fig.5). The highest recorded combined area was during the 2011 spring interim (closely followed by the most recent 2024 spring interim), however the beach subsequently gradually dropped until autumn 2016 when beach recovery can be seen. Since then, larger variations can be seen in combined profile area, with the latest survey measuring an above average area.

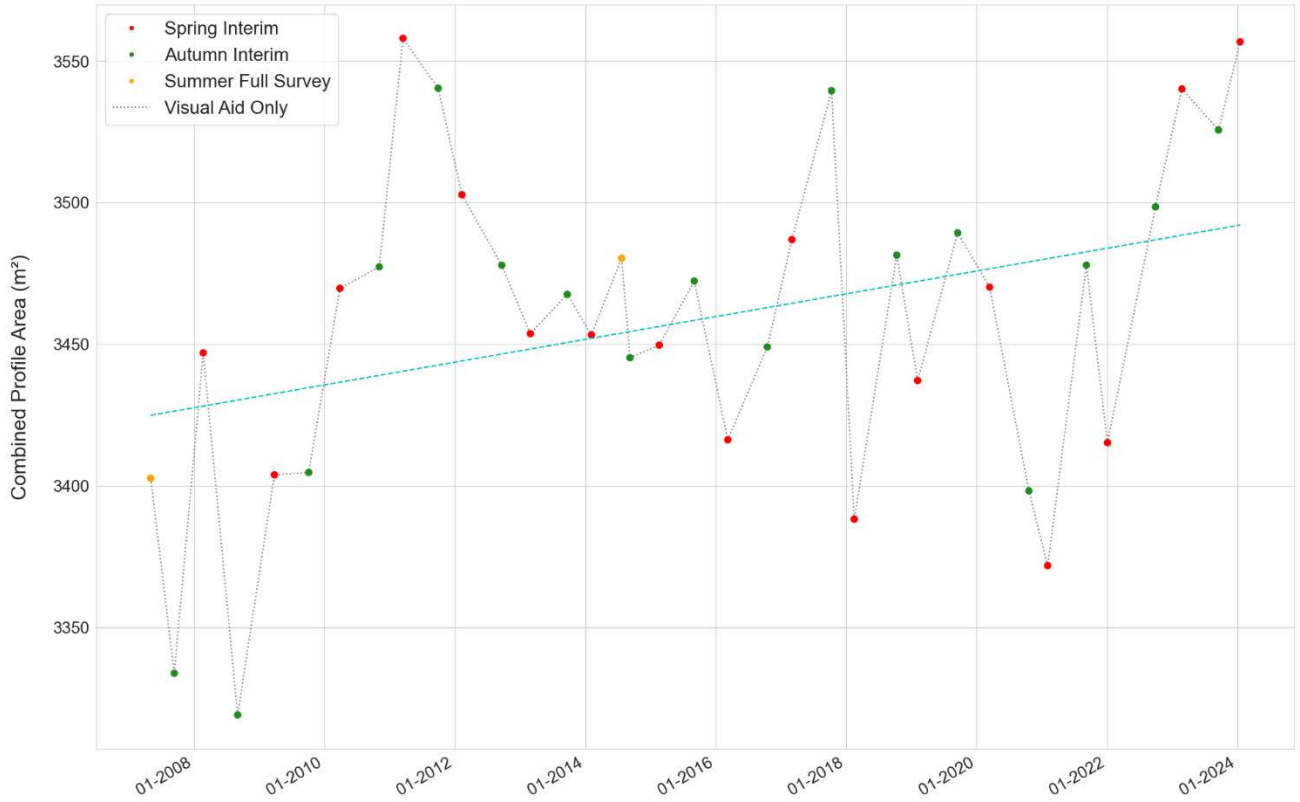


Figure 5 - The Combined Profile Area (CPA) for Harlyn, including every spring (red), summer (yellow) and autumn (green) survey completed between 2007 and 2024.

When compared to the entire dataset (Fig.6), during the 2024 spring interim most of Harlyn's profiles were very healthy, with the exception of profile 7b00072 which demonstrates a below average area to date.

When comparing profile cross-sectional areas of the entire time series (Fig.7), all profiles have displayed stability since 2007 with seasonal variation apparent, particularly on profile 7b00084.

Profile charts for Harlyn can be found in Appendix 1; these display the cross-sections of each profile for the initial full coverage survey conducted in 2007 along with the two most recent interim surveys. All four profiles have shown accretion since the 2007 survey, except for profile 7b00072 which has seen beach level lowering across the lower half of the profile.

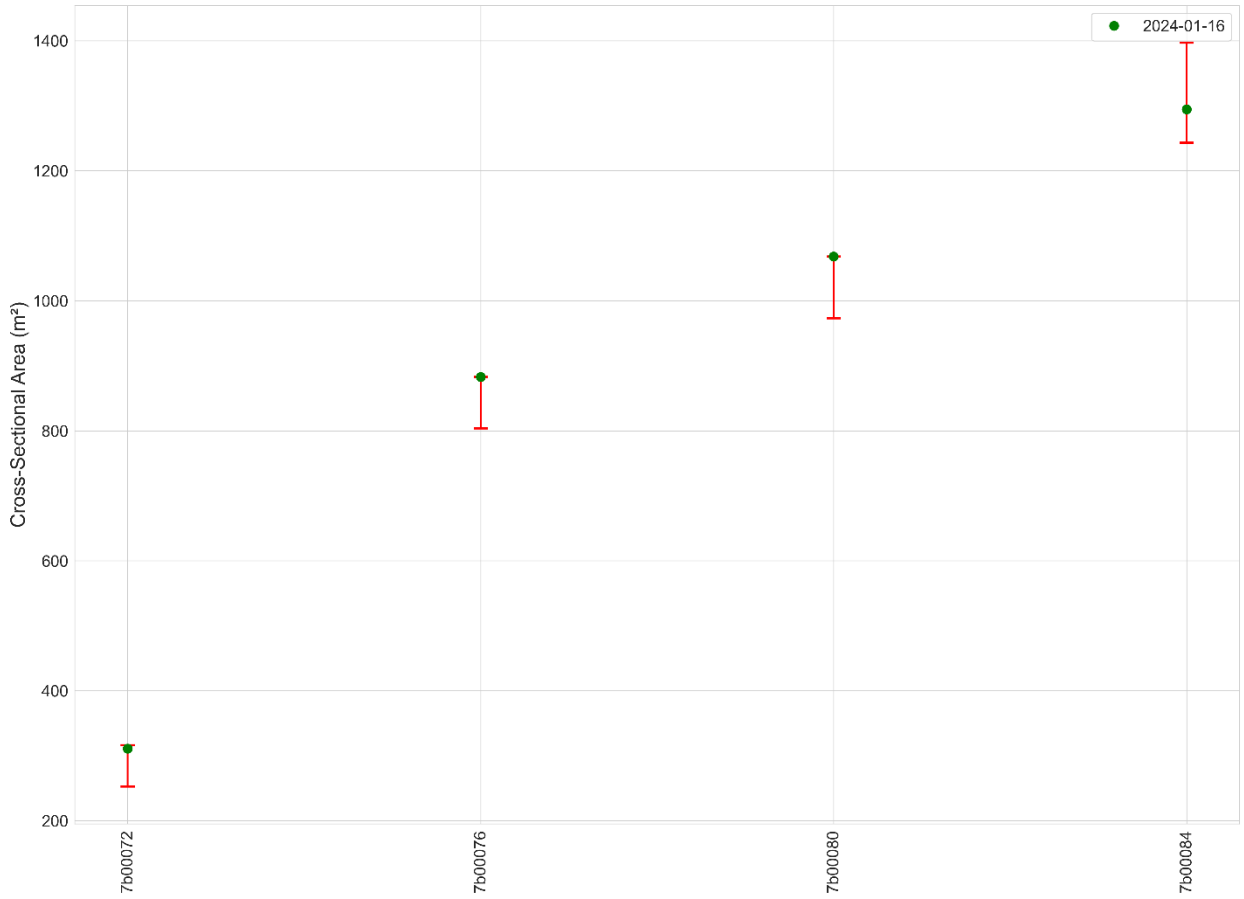


Figure 6 - Cross-sectional area of each interim profile, comparing the current area of the profile (green dot), with the maximum and minimum values (red error bar) recorded between 2007 and 2024.

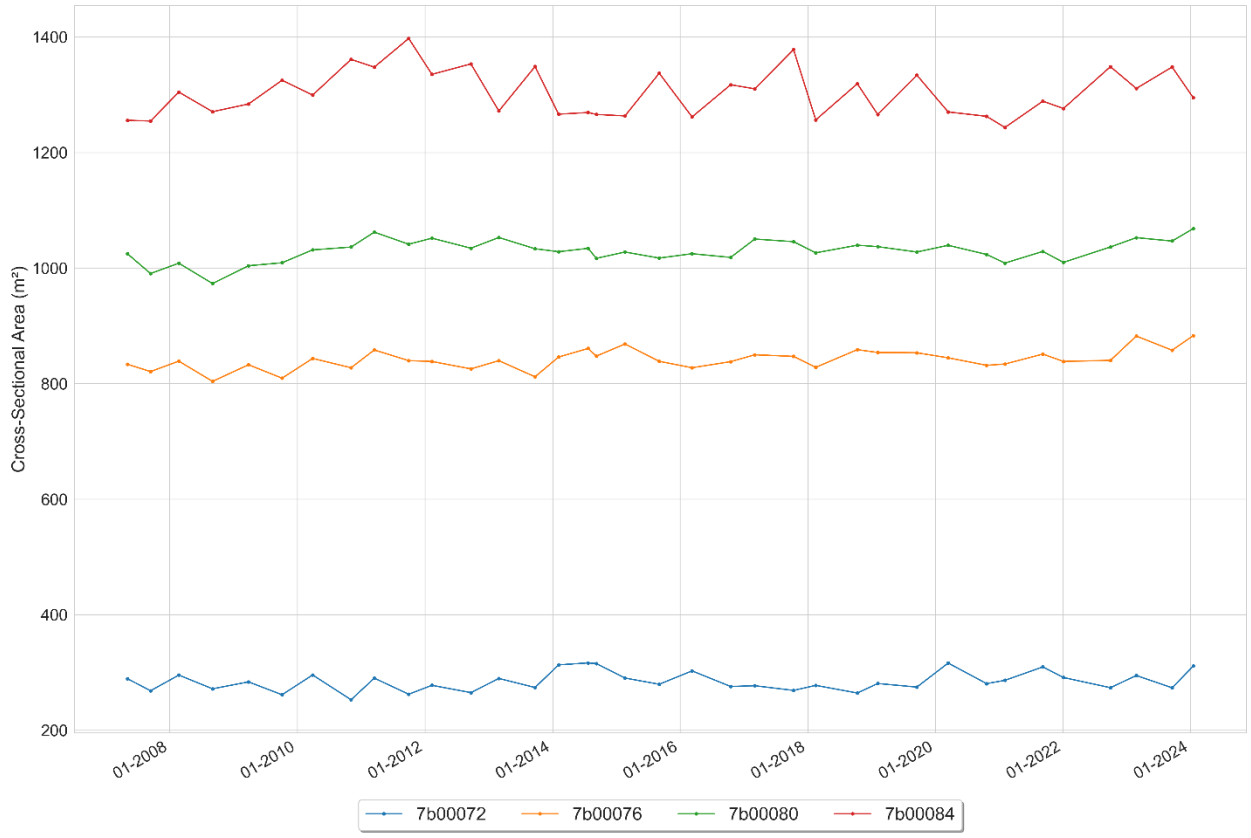


Figure 7 - Cross-sectional area of each interim profile, comparing the values recorded during each interim and baseline survey between 2007 and 2024.

3.2 LiDAR Data Analysis

There has been a total of 6 LiDAR flights captured at Harlyn 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 February 2008 compared to the most recent, captured in October 2022. A lot of movement has been observed over this epoch, seeing accretion on the upper beach to the southeast, whilst the dune system has seen erosion of up to 2.5 m. The intertidal zone has mostly observed accretion up to 1.5 m, largely to the east, whereas the seaward extent has eroded along the whole unit.

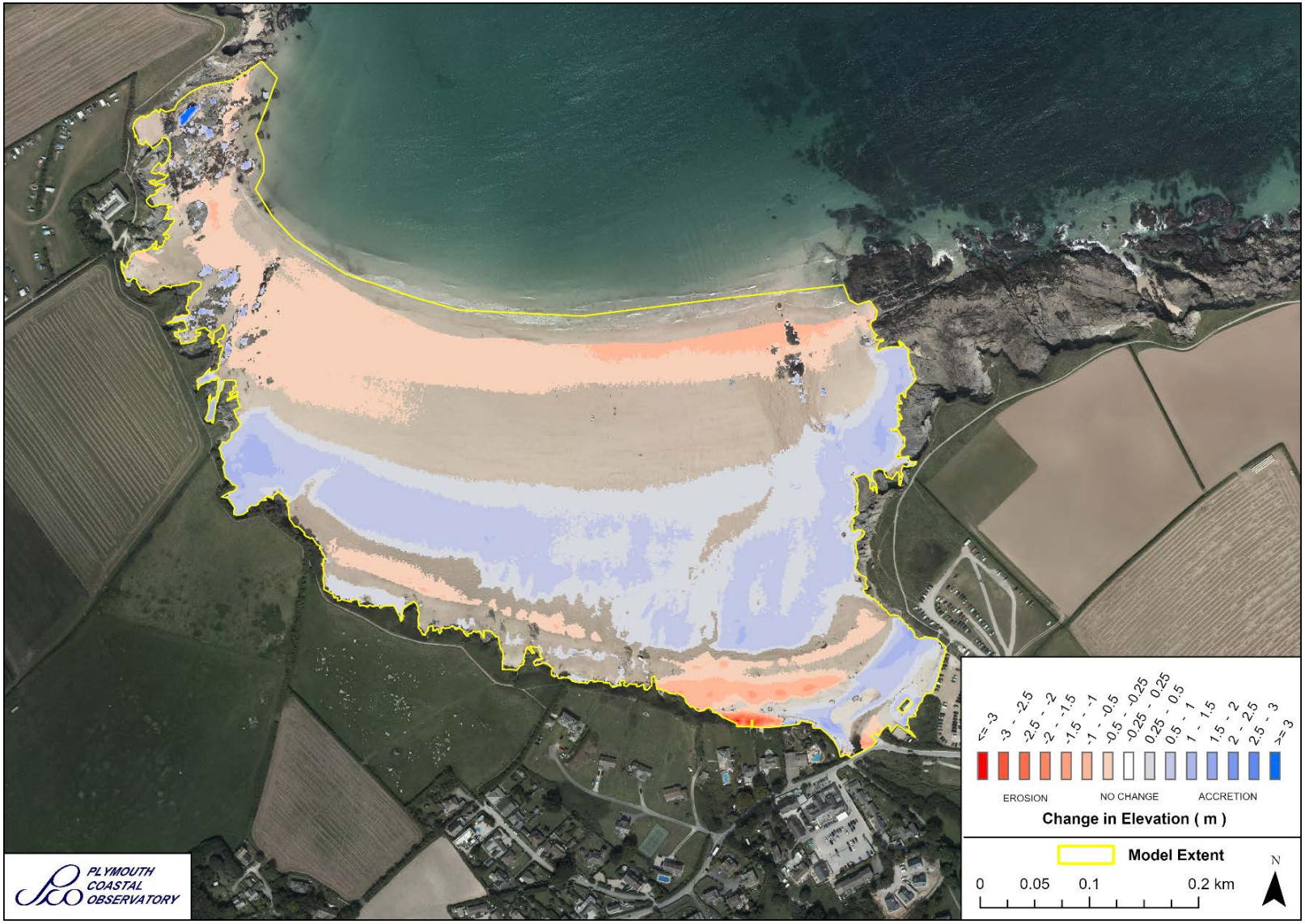


Figure 8 – Difference model indicating the changes in elevation observed between the February 2008 and October 2022 filtered LiDAR datasets within the yellow model extent.

Figure 9 shows differences in elevation between filtered LiDAR data from February 2008 compared to March 2009. There is minimal change observed at the low tide terrace, whereas the upper beach and dune system experience low level accretion; the beach face sees up to 1.5 m of erosion.

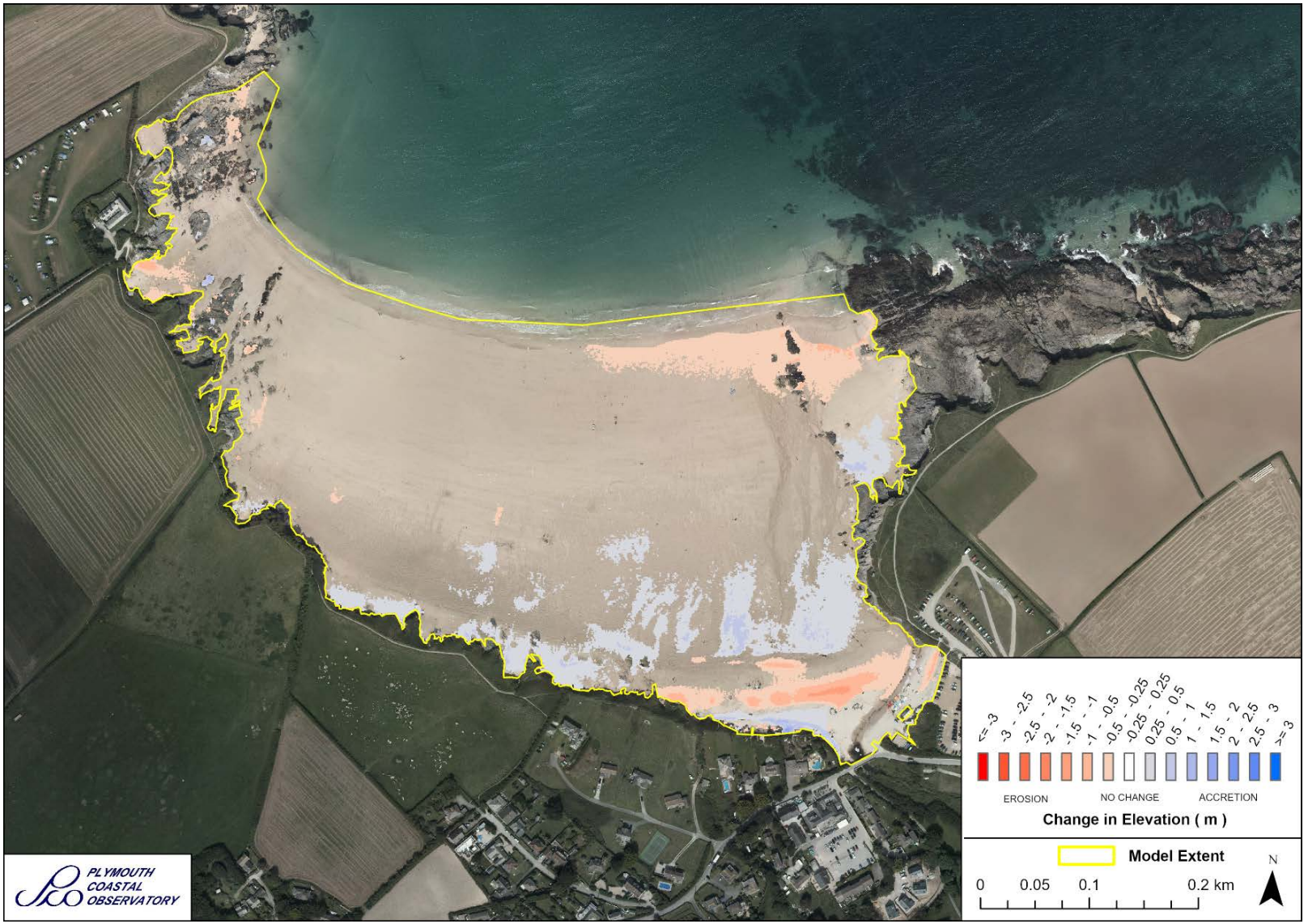


Figure 9 - Difference model indicating the changes in elevation observed between the February 2008 and March 2009 filtered LiDAR datasets within the yellow model extent.

Figure 10 shows differences in elevation between filtered LiDAR data from March 2009 compared to March 2011. Again, the low tide terrace sees minimal change, whereas some small pockets of accretion can be seen on the dune system. Changes are however, dominated by ~2.5 m of erosion on the beach face and a build-up of material (up to 1.5 m) can be seen around the high-water line.

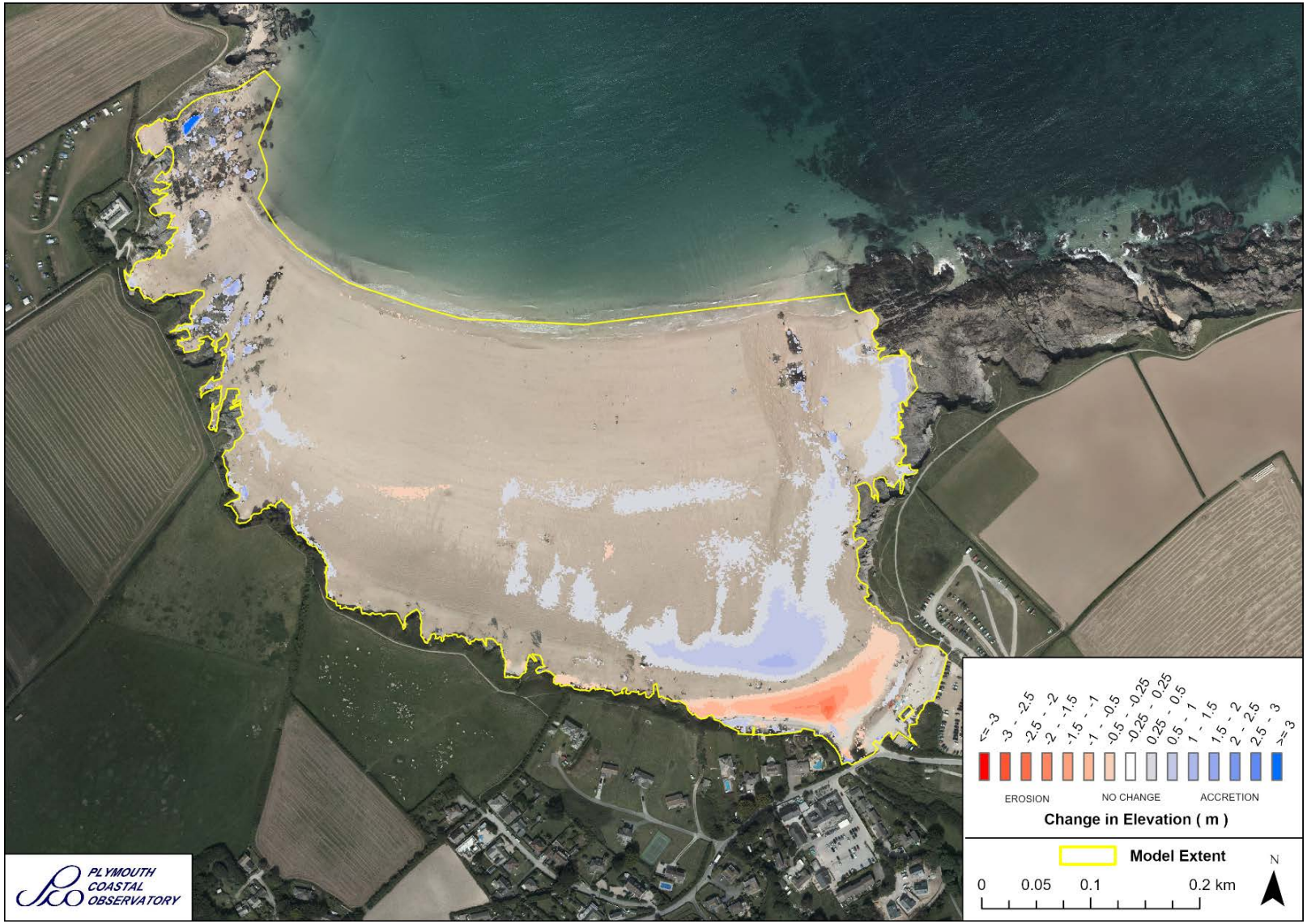


Figure 10 – Difference model indicating the changes in elevation observed between the March 2009 and March 2011 filtered LiDAR datasets within the yellow model extent.

Figure 11 shows differences in elevation between filtered LiDAR data from March 2011 compared to March 2014. High level erosion can be observed along the dune system continuing to the beach face, eroding by up to 3 m. Similarly, the middle of the beach saw up to 1 m of erosion. Material has moved seaward forming an intertidal bar up to 1.5 m high.

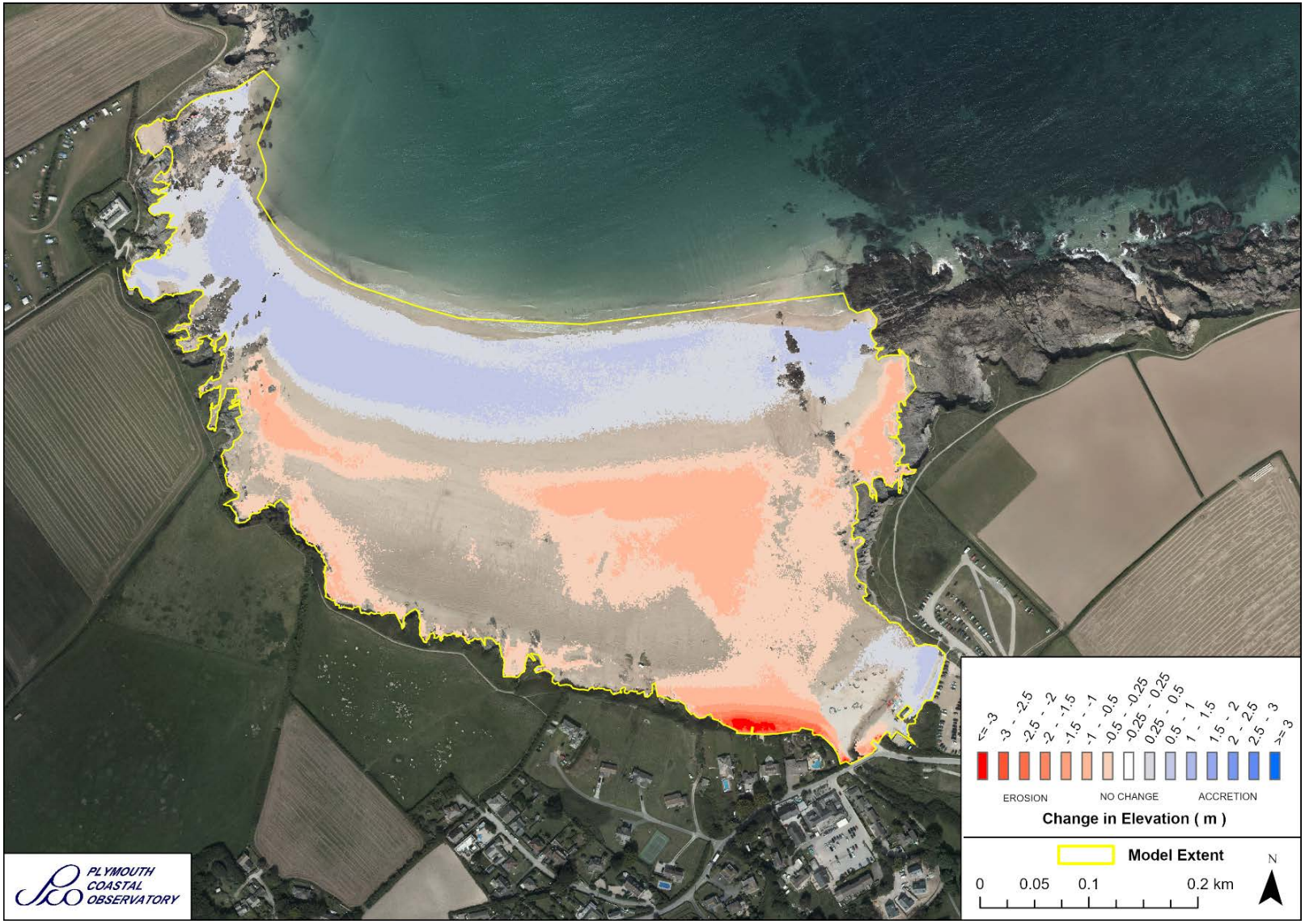


Figure 11 - Difference model indicating the changes in elevation observed between the March 2011 and March 2014 filtered LiDAR datasets within the yellow model extent.

Figure 12 shows differences in elevation between filtered LiDAR data from March 2014 compared to February 2019. This epoch indicates large areas of change, with accretion observed within the dune, dune face and a large section of the intertidal area, countered by erosion observed along the seaward extent and the removal of the bar shown in figure 11.

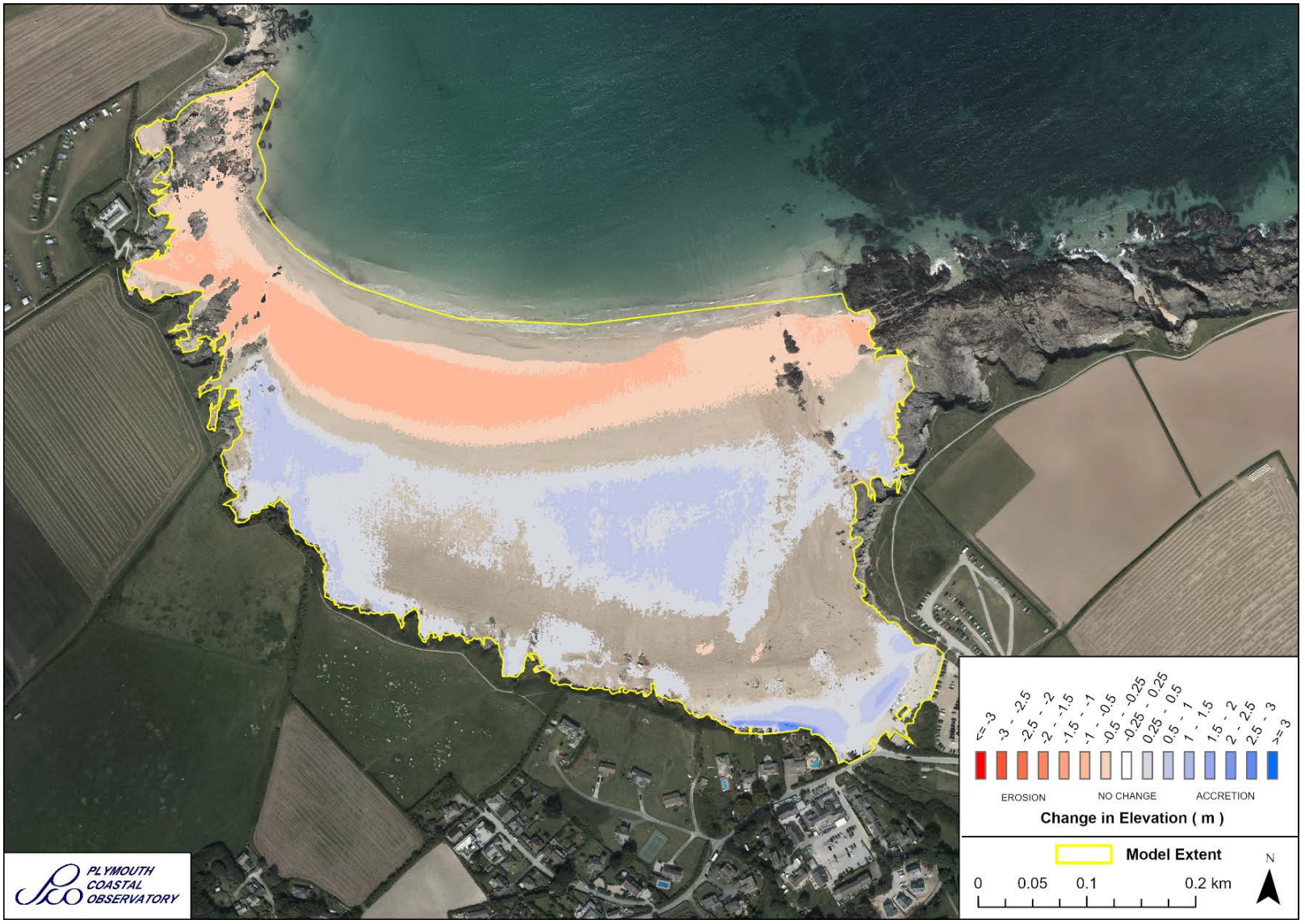


Figure 12 - Difference model indicating the changes in elevation observed between the March 2014 and February 2019 filtered LiDAR datasets within the yellow model extent.

Figure 13 shows differences in elevation between filtered LiDAR data from February 2019 compared to October 2022. Small pockets of erosion can be seen on the dune crest however the majority of the upper beach has seen accretion up to 2 m. Erosion of up to 1.5 m is indicated along the high-water mark along the width of the beach. An intertidal bar has formed in the nearshore followed by further erosion towards the seaward extent.

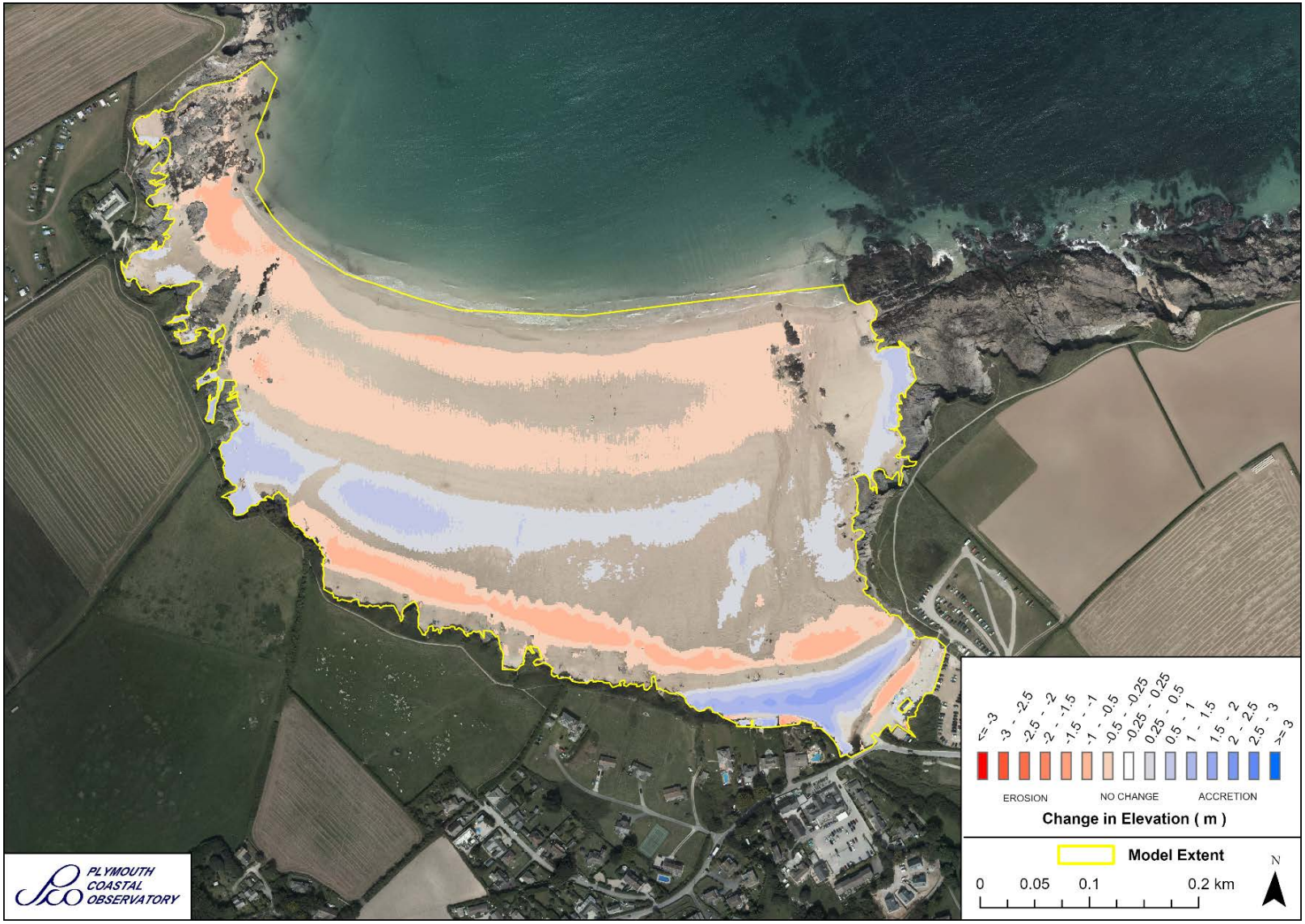


Figure 13 - Difference model indicating the changes in elevation observed between the February 2019 and October 2022 filtered LiDAR datasets within the yellow model extent.

3.2.2 Beach and Dune Volume Extraction

Surface volume extracted from each available LiDAR dataset from the Mobile Zone above the MHWS contour (3.50 m OD) are shown in Table 1. The Mobile Zone has shown no long-term change between 2008 and 2022, however it did experience a considerable loss of material following the 2013/14 winter storms, losing 33% between the 2011 and 2014 survey (Fig.14). Since the 2014 survey, Harlyn's Mobile Zone has recovered to pre-2013/14 levels (Fig.14), recording the highest volume in 2022 (18,146 m^3).

Surface volume extracted from each LiDAR dataset from the Beach Zone above the MLWS contour (-3.00 m OD) are also shown in Table 1. The Beach Zone has seen a gradual accretion of volume between 2008 and 2022 (Fig,15) accreting at 1,731 m^3 y^{-1} and showing limited change following the 2013/14 winter storms.

Table 1 – Surface volume values (m^3) extracted from all available filtered LiDAR datasets for the Mobile Zone above MHWS (3.50 m OD) and for the Beach Zone above MLWS (-3.00 m OD).

Date	Mobile Zone Volume (m^3)	Beach Zone Volume (m^3)
02/2008	17,463	625,596
03/2009	16,516	634,947
03/2011	13,819	656,103
04/2014	9,210	654,141
04/2019	12,992	659,731
10/2022	18,146	651,005

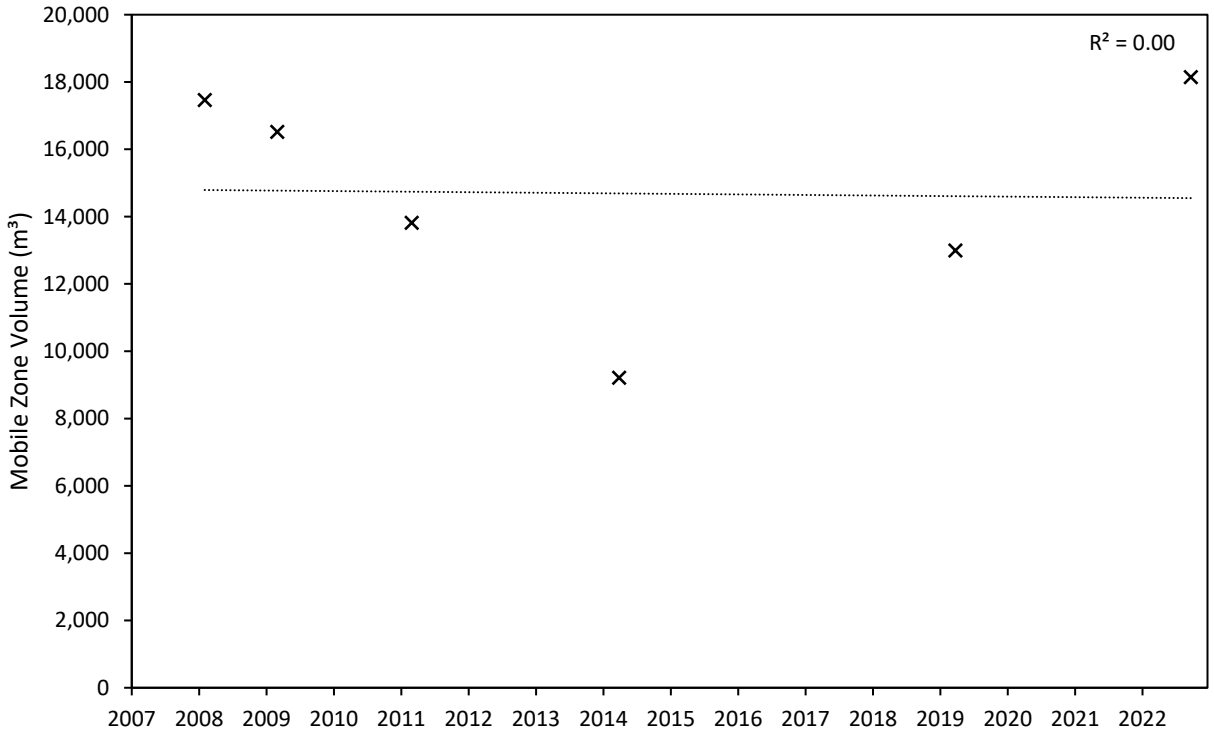


Figure 14 – Plot indicating beach volume (m^3) recorded in the Mobile Zone above MHWS (3.50 m OD) for each filtered LiDAR datasets between 2008 and 2022.

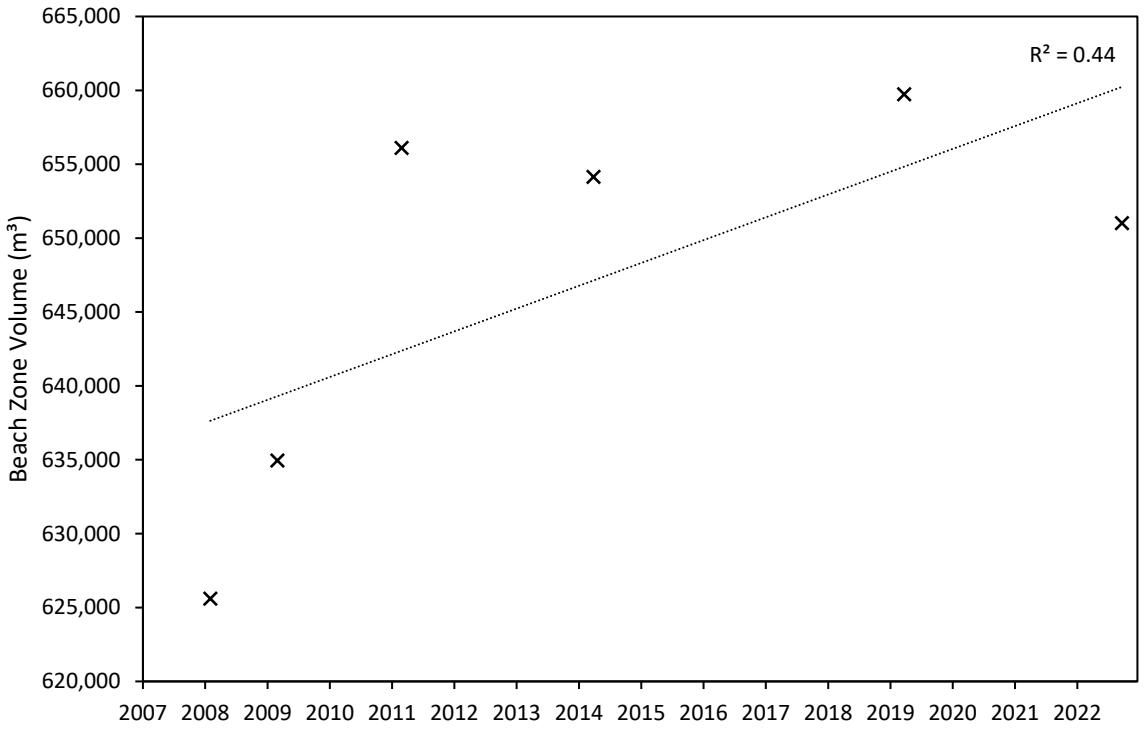


Figure 15 - Plot indicating beach volume (m^3) recorded in the Beach Zone above MLWS (-3.00 m OD) for each filtered LiDAR datasets between 2008 and 2022.

3.2.3 Contour Comparison

Figure 16 indicates the Mean Sea Level (MSL) and dune toe contours from the 2008, 2014, 2019 and 2022 LiDAR datasets. MSL contours indicate some widening of the beach to the east (approximately 20 m), from 2008 to 2022. However, after the 2014 storms the beach narrowed by up to 50 m. The same is true of the dune toe contours; after the 2014 storms, the dune system retreated ~21 m but has since seen some recovery in the 2022 dataset which has advanced by up to 19 m to the western extent of the beach entrance.

3.3 Historic Aerial Maps

Historic aerial photography captured in 1947 by the RAF, in 2001 by the Environment Agency and from 2007 onwards by the SWCM are presented here.



Figure 16 – Contour map indicating Mean Sea Level (solid line) and Dune Toe (dashed line) extracted from 2008, 2014, 2019 and 2022.



Figure 17 – Aerial imagery from 1947.

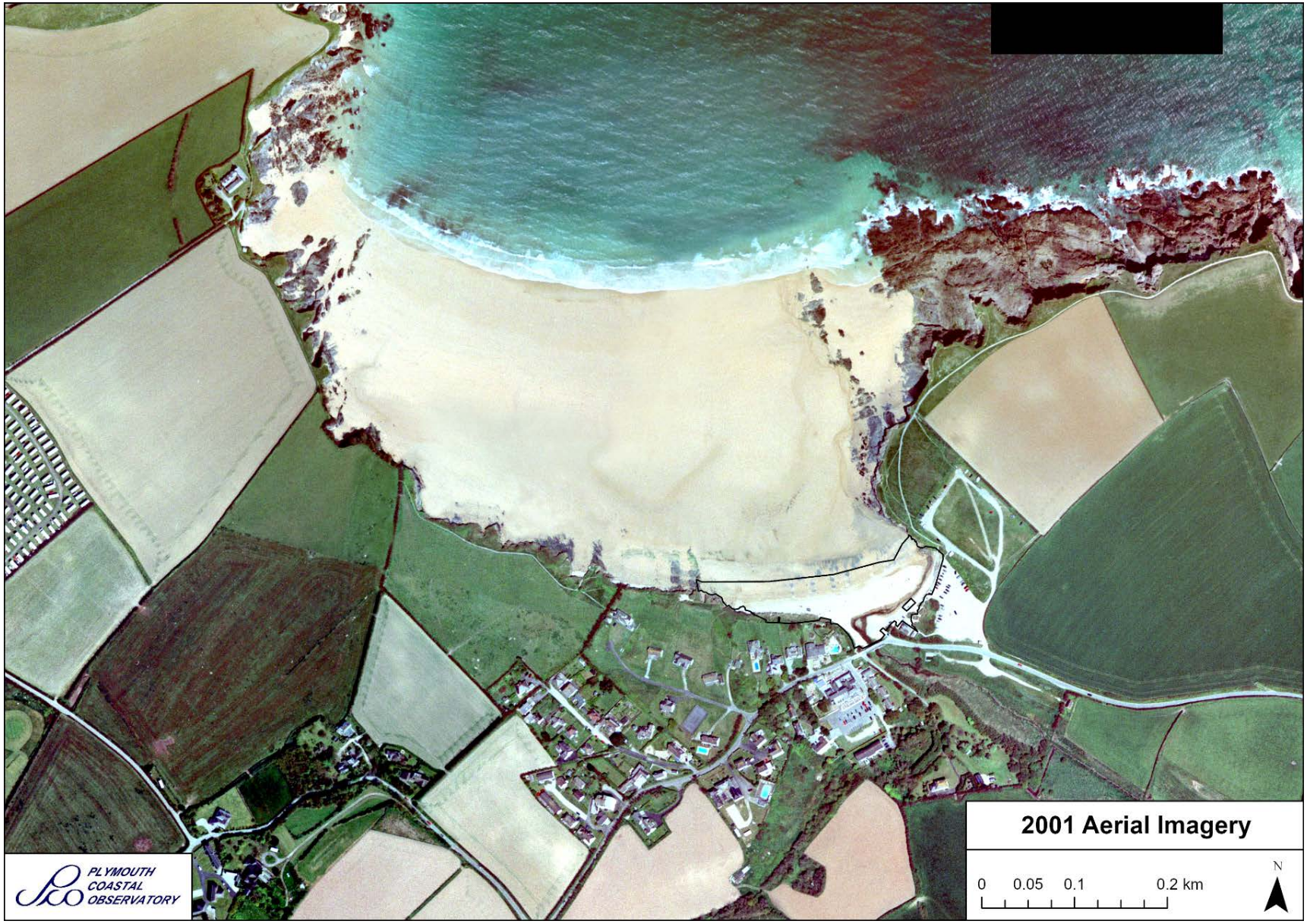


Figure 18 – Aerial imagery from 2001.



Figure 19 – Aerial imagery from 2006.



Figure 20 – Aerial imagery from 2010.



Figure 21 – Aerial imagery from 2017.

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 showing the cross-shore area of each interim profile from the most recent survey (blue), second most recent survey (green) and first survey, also known as the baseline (red) at Harlyn are presented below.