SOUTH WEST COASTAL MONITORING

making space for sand



Making Space for Sand – Rock Dunes Beach Report

LiDAR Data Analysis

SWCM | TBR34 | 05/12/2023

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Taken by: APEM Ltd

Summary

This report utilises Light Detection and Ranging (LiDAR) and aerial imagery data collected by the South West Coastal Monitoring (SWCM) Programme to analyse beach and dune volume at Rock Dunes. The aim is to highlight coastal change at Rock Dunes using SWCM data since 2007, focusing on beach and dune areas categorised into four zones: Beach, Mobile, Fixed, and Developed. Rock is in the mouth of the Camel Estuary and is a westerly facing sandy beach. 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.

Mobile Zone volume showed a steady increase between 2008 and 2016 (Fig.12). From 2017, the Mobile Zone begins to erode quickly with material transported up-river, as illustrated in Figure 2. The overall erosion rate for the Mobile Zone was 12,665 m^3 y^{-1} from 2008 to 2022 (Fig.12). Beach Zone volume suggests a similar impact to the Mobile Zone. Beach Zone volume remains stable between 2008 and 2017 before also experiencing a significant loss in volume, eroding by 20% at a rate of 67,500 m^3 y^{-1} (Fig.13). The loss of material from the Mobile and Dune Zone, suggests a relocation of material within the estuary. The Dune Toe contours at Rock Dunes have shown significant changes, experiencing a dune retreat of ~185 m on the northern side of the beach, whilst round the corner of the southern beach the Dune Toe has advanced by ~35 m.

Overall, Rock Dunes beach has lost significant amounts of material on the northern side of the beach, whilst further up river material has been building up. Since 2016 the unit has been significantly losing material.

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1.0 Introduction

The aim of this report is to highlight beach and dune change at Rock Dunes 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

Rock Dunes is in the mouth of the Camel Estuary and is a westerly facing sandy beach which protrudes seawards, forming an almost headland type feature. Therefore, this beach is rather unique as it faces north-west through to south-west, within the river mouth. The beach is backed by a dune system, also acting as a headland, trapping material flowing in and out of the estuary.

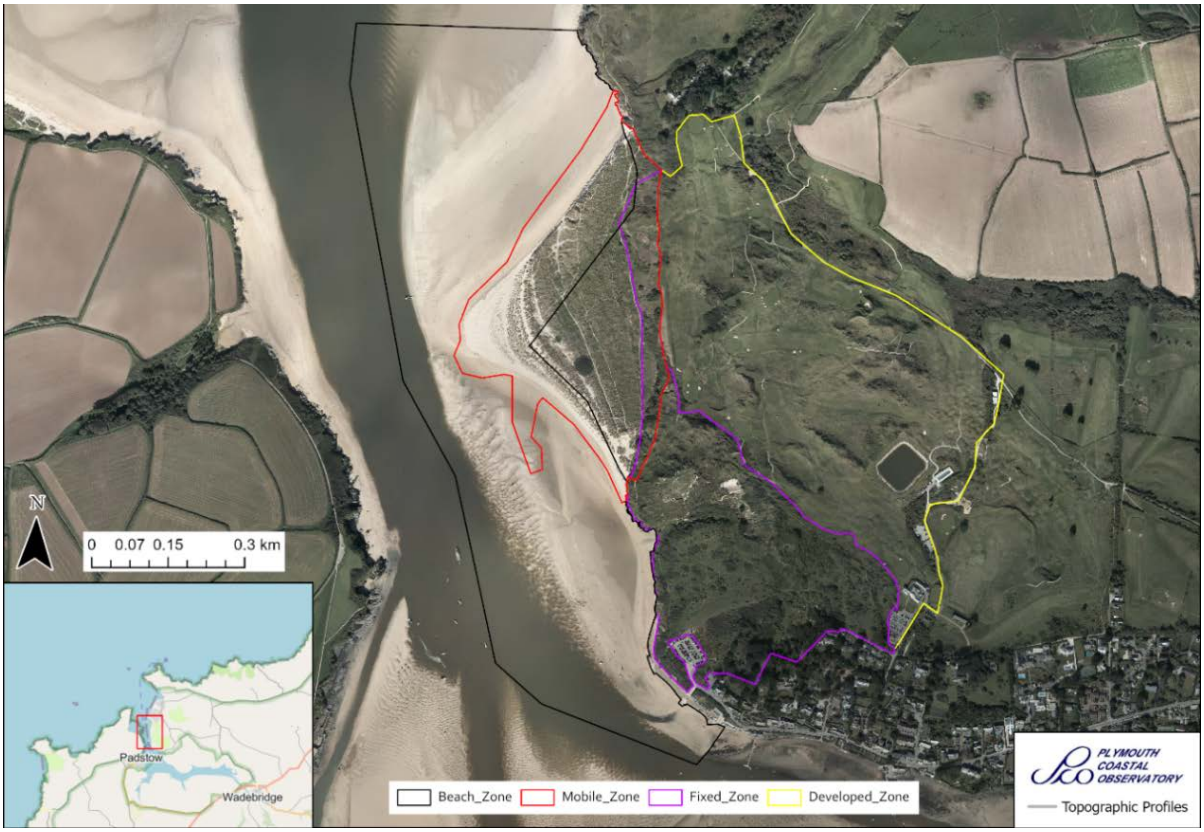


Figure 1 - Location Map of Rock Dunes Beach and Dune System, indicating the four defined zones outlined in section 1.0.

[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 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.

2.1.1 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]).

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 Accuracy Statement

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.

3.0 Results

3.1 LiDAR Data Analysis

There has been a total of 9 LiDAR flights captured at Rock Dunes since 2007 through the SWCM Programme.

3.1.1 Difference Models

Difference models between each epoch of LiDAR data 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.

Please note that the difference models below (figures 2 - 11) display the analysis for the whole system, encompassing Hawker's Cove, Rock and Daymer Bay. Analysis specific to Hawker's Cove and Daymer Bay are available in reports TBR33 and TBR35 respectively.

Figure 2 shows the difference in elevation between the first filtered LiDAR data from February 2008 compared with the most recent, captured in October 2022. Rock dunes have observed extensive amounts of erosion across the north of the unit, decreasing in volume by >3 m, across the whole dune system. Conversely, the southern extent of Rock Dunes has seen a build-up of >3 m. Similarly, large areas of accretion can also be seen on Hawker's Cove, building up on the back of the beach.

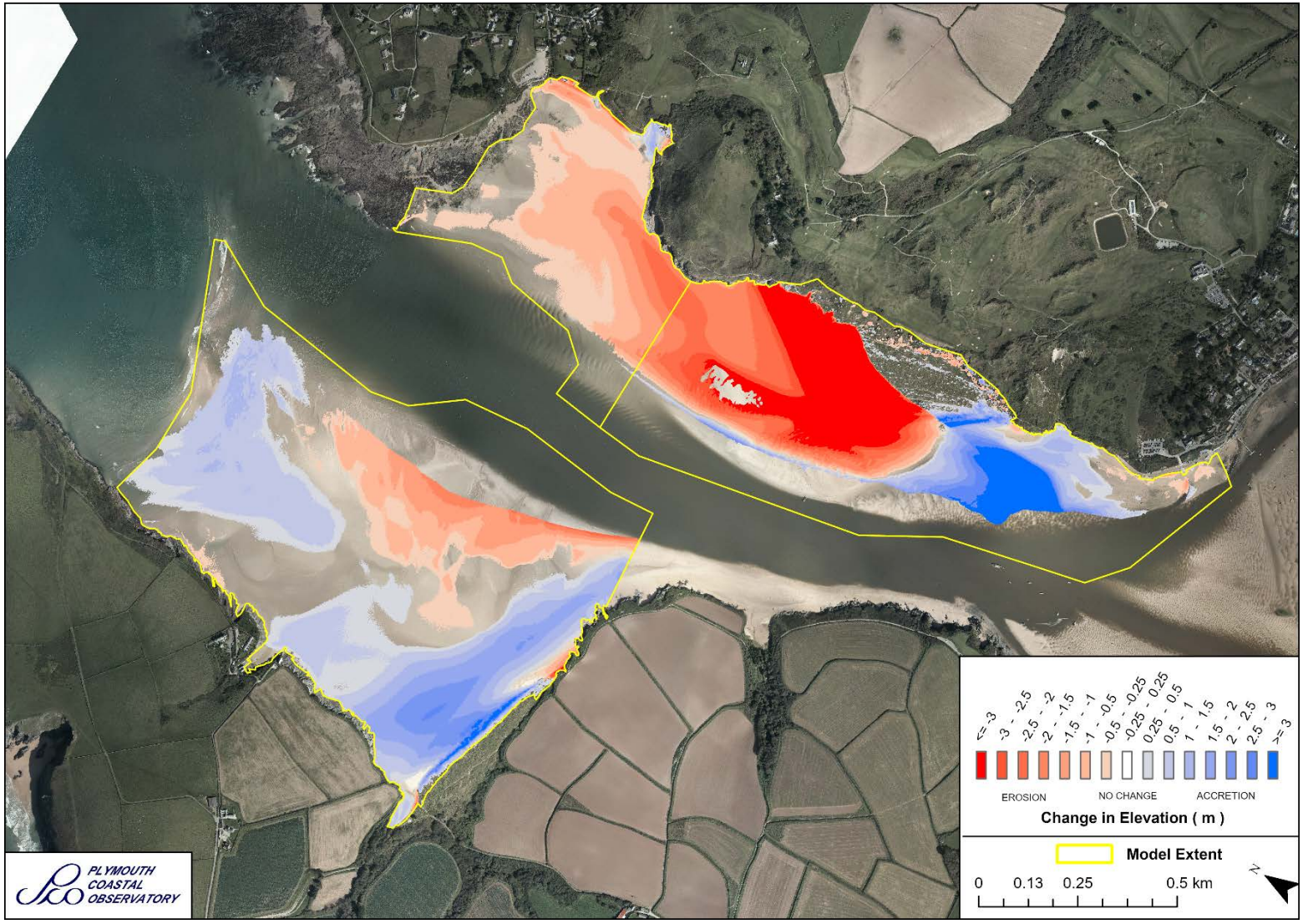


Figure 2 – Difference model indicating the changes in elevation observed between the February 2008 and October 2022 filtered LiDAR datasets within the yellow model extent.

Figure 3 shows differences in elevation between filtered LiDAR data from February 2008 compared with March 2009. Accretion is continuing to the south of Rock Dunes along the beach and dune face, suggesting material is building outwards into the river. Towards the north, some erosion can be observed along the mean sea level mark, creating a depression on the beach.

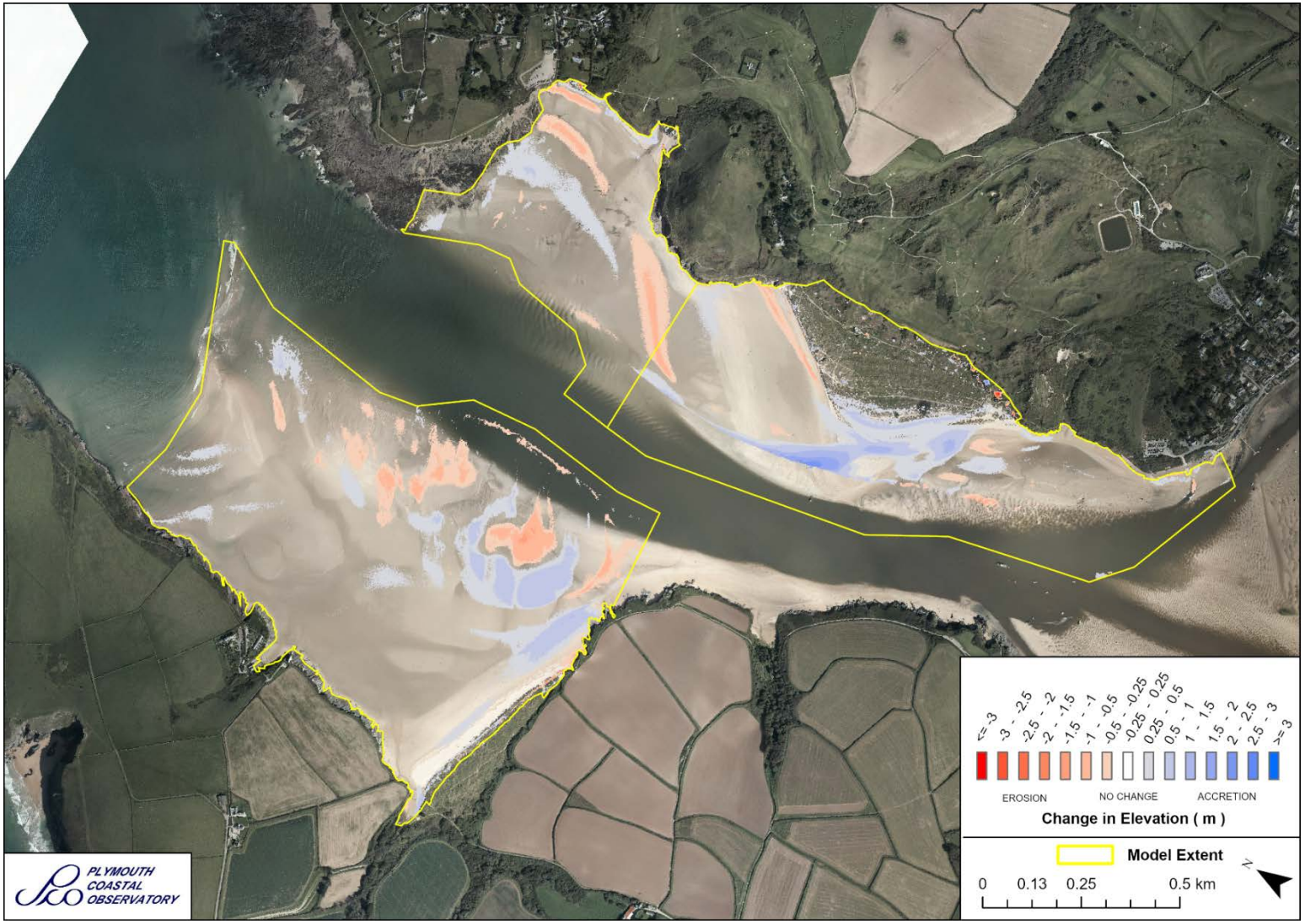


Figure 3 - Difference model indicating the changes in elevation observed between the February 2008 and March 2009 filtered LiDAR datasets within the yellow model extent.

Figure 4 shows differences in elevation between filtered LiDAR data from March 2009 compared with March 2011. This 2-year epoch has seen very similar sediment movement to Figure 3. Erosion is continuing at Daymer Bay, and accretion is continuing at Rock Dunes, indicating a north to south sediment transport movement. Similar to previous analysis, material is building outwards towards the river.

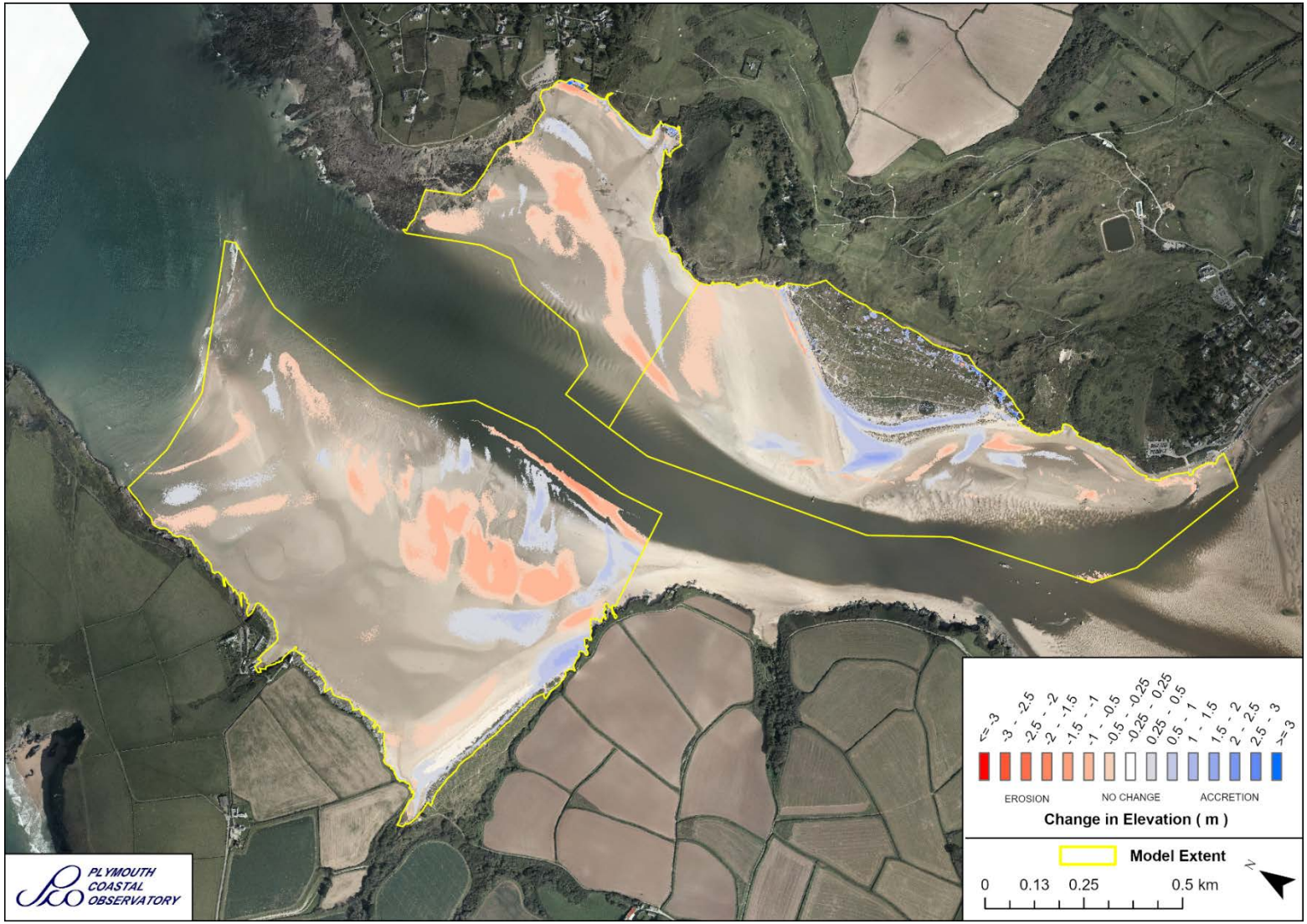


Figure 4 – Difference model indicating the changes in elevation observed between the March 2009 and March 2011 filtered LiDAR datasets within the yellow model extent.

Figure 5 shows differences in elevation between filtered LiDAR data from March 2011 compared with April 2012. Accretion is continuing at Rock Dunes along the dune face. It is now clear from the aerial imagery that the dune face has retreated landwards. The low-tide terrace has remained stable, whilst Hawker's Cove has seen a build-up of material along the dune face.

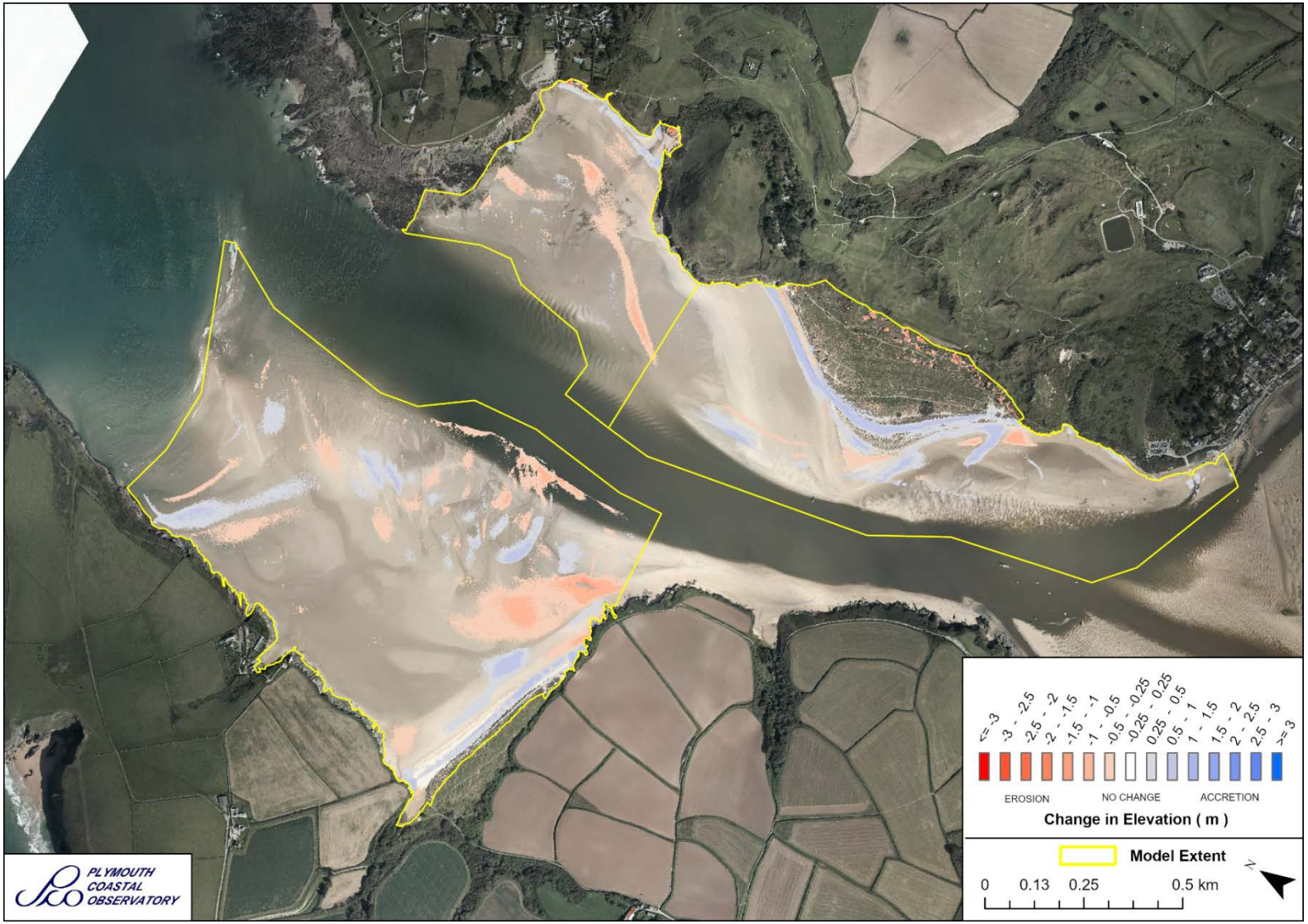


Figure 5 - Difference model indicating the changes in elevation observed between the March 2011 and April 2012 filtered LiDAR datasets within the yellow model extent.

Figure 6 shows differences in elevation between filtered LiDAR data from April 2012 compared with March 2014. The impact of the 2013/14 winter storms has caused high levels of erosion at Rock Dunes in the north, but significant accretion in the south, suggesting the material has moved from north to south. Material is continuing to build out seawards into the river. Hawker's Cove has seen erosion along the river edge as well as pockets of erosion on the dune face.

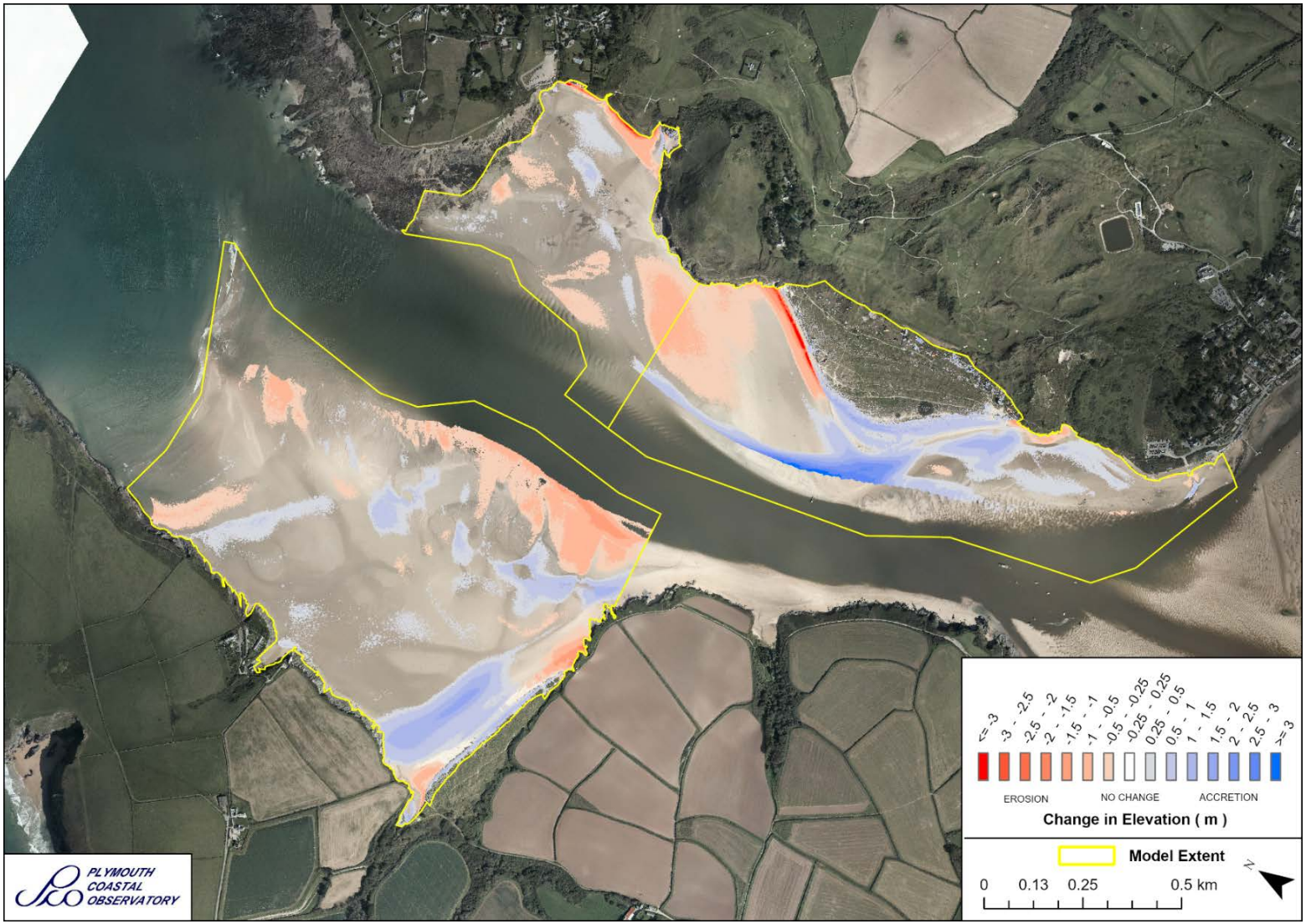


Figure 6 - Difference model indicating the changes in elevation observed between the April 2012 and April 2014 filtered LiDAR datasets within the yellow model extent.

Figure 7 shows differences in elevation between filtered LiDAR data from March 2014 compared with March 2016. Widespread erosion can be observed to the north of the unit, seeing >3 m of erosion on the dune face/crest. Again, material is building up at the end of the dune system, seeing >3 m change in elevation at the seaward extent, building out into the river.

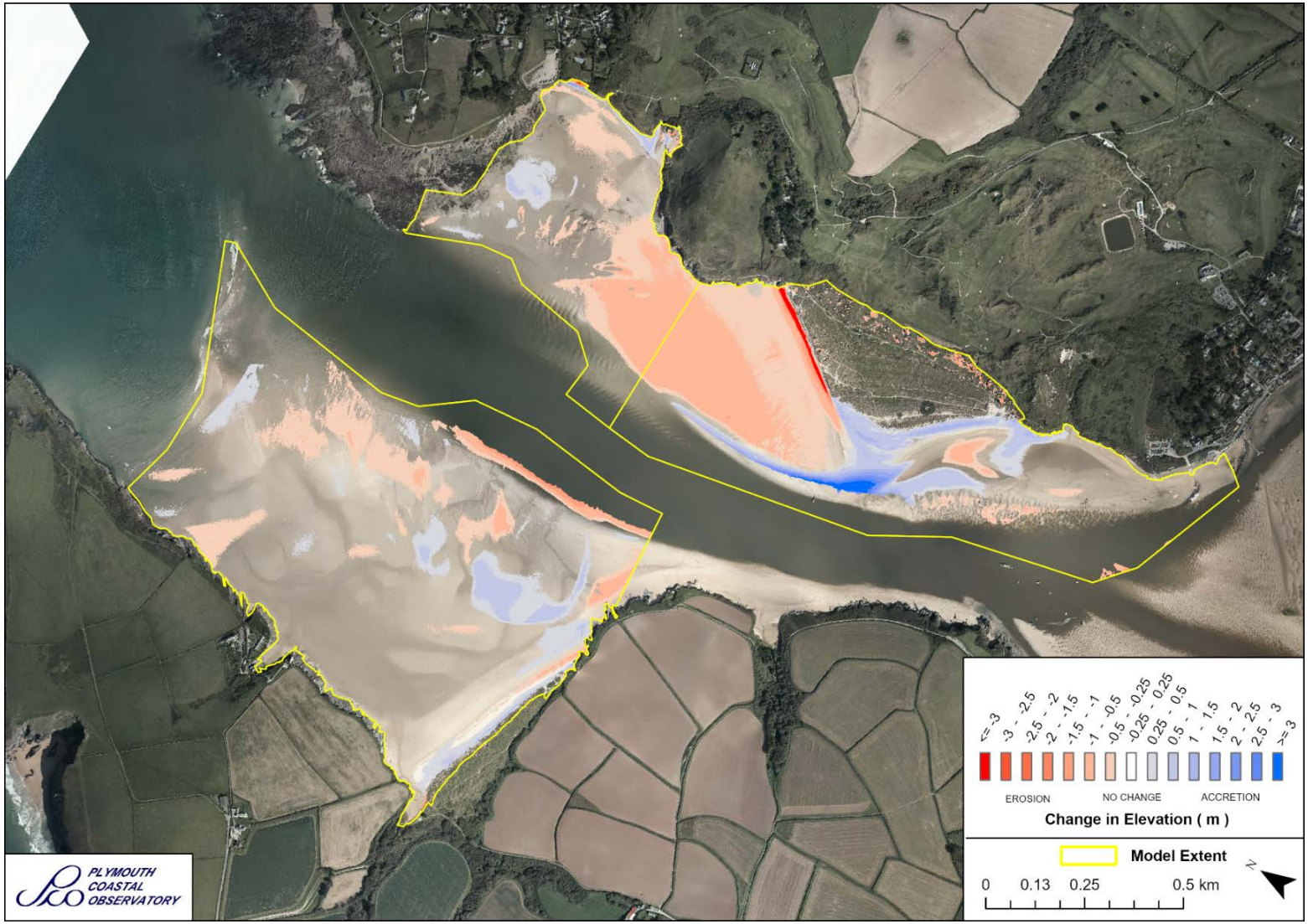


Figure 7 - Difference model indicating the changes in elevation observed between the March 2014 and April 2016 filtered LiDAR datasets within the yellow model extent.

Figure 8 shows differences in elevation between filtered LiDAR data from March 2016 compared with March 2017. The northern end of Rock Dunes has lost large amounts of material, particularly on the dune crest (>3 m change in elevation), whilst the southern end of the beach is building outwards into the river, indicating a southward transport of material.

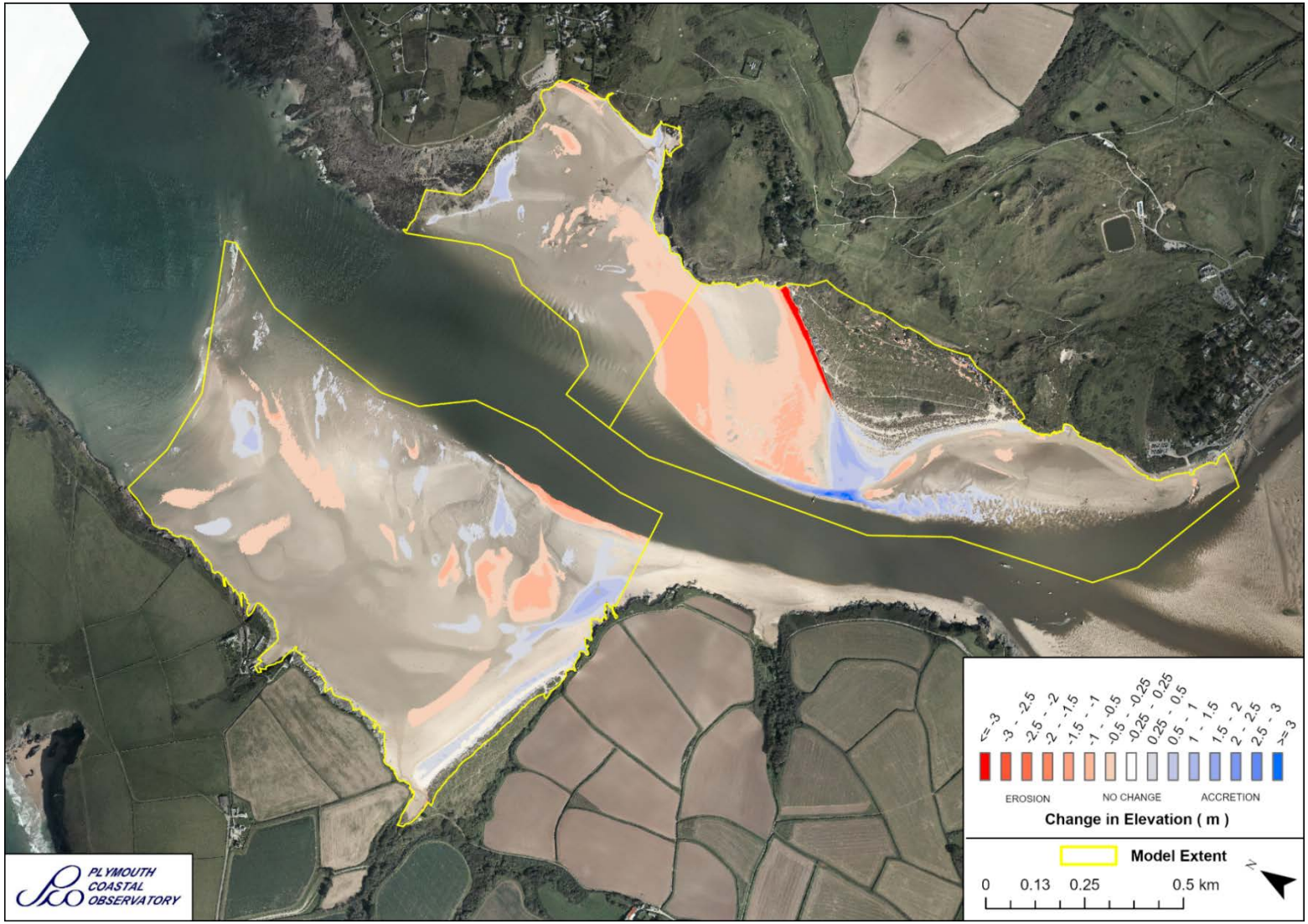


Figure 8 - Difference model indicating the changes in elevation observed between the March 2016 and April 2017 filtered LiDAR datasets within the yellow model extent.

Figure 9 shows differences in elevation between filtered LiDAR data from March 2017 compared with April 2019. Rock Dunes has experienced the full brunt of erosion, losing >3 m in elevation on the dune crest and face. As this section of the coast is dramatically retreating, the southern end of Rock Dunes is building outwards into the river, suggesting a continued transport of material to the south. A mixture of erosion and accretion can be seen on Hawker's Cove with the western half of the beach experiencing accretion.

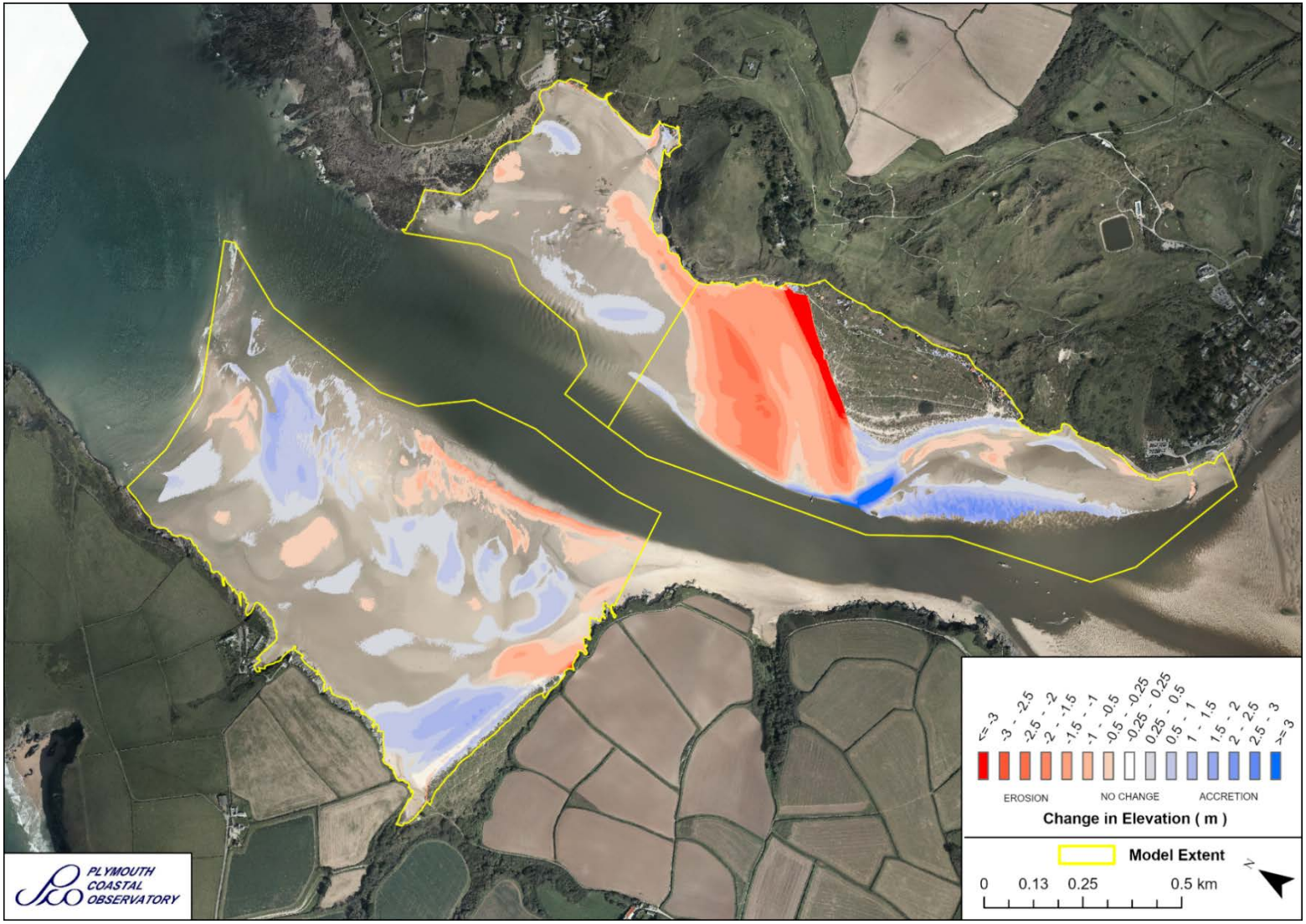


Figure 9 - Difference model indicating the changes in elevation observed between the March 2017 and April 2019 filtered LiDAR datasets within the yellow model extent.

Figure 10 shows differences in elevation between filtered LiDAR data from April 2019 compared with November 2020. Rock Dunes shows significant erosion, with a loss on the dune system of >3 m. This model indicates that at least some of the material lost at Rock Dunes has been building up on the beach behind, extending out to the south of the unit and into the river.

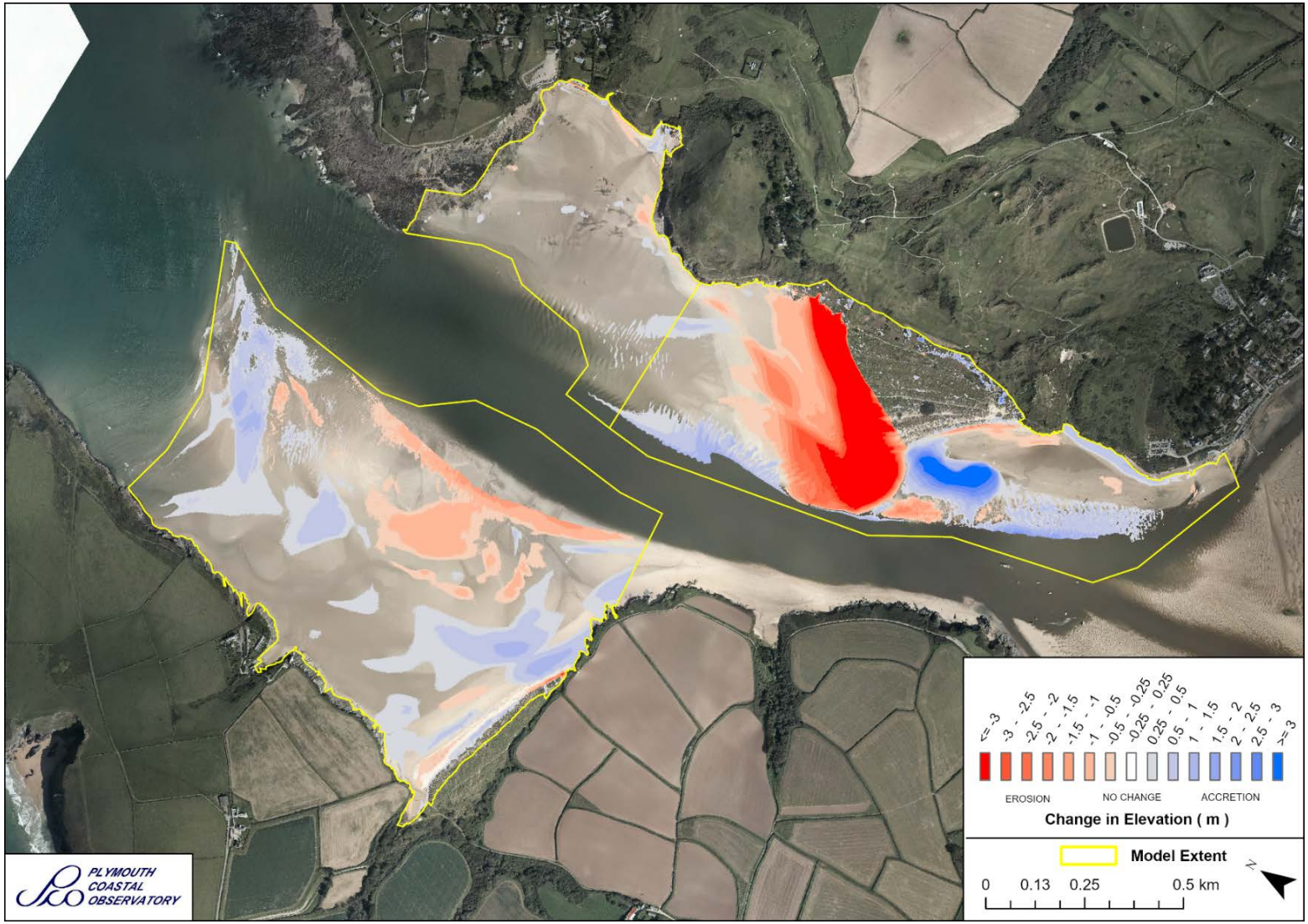


Figure 10 - Difference model indicating the changes in elevation observed between the April 2019 and November 2020 filtered LiDAR datasets within the yellow model extent.

Figure 11 shows differences in elevation between filtered LiDAR data from November 2020 compared with October 2022. Similar to the last epoch, a lot of significant change has occurred across the entire beach. Daymer Bay has remained relatively stable, however significant erosion can be seen at Rock Dunes, losing >3 m in elevation on the dune system, curving round to the southern beach behind it. Conversely, a large area of accretion has built-up to the south, behind the dune system. Across the river, Hawker's Cove has also seen a build-up of material along the dune face, whilst erosion takes place along the beach face.

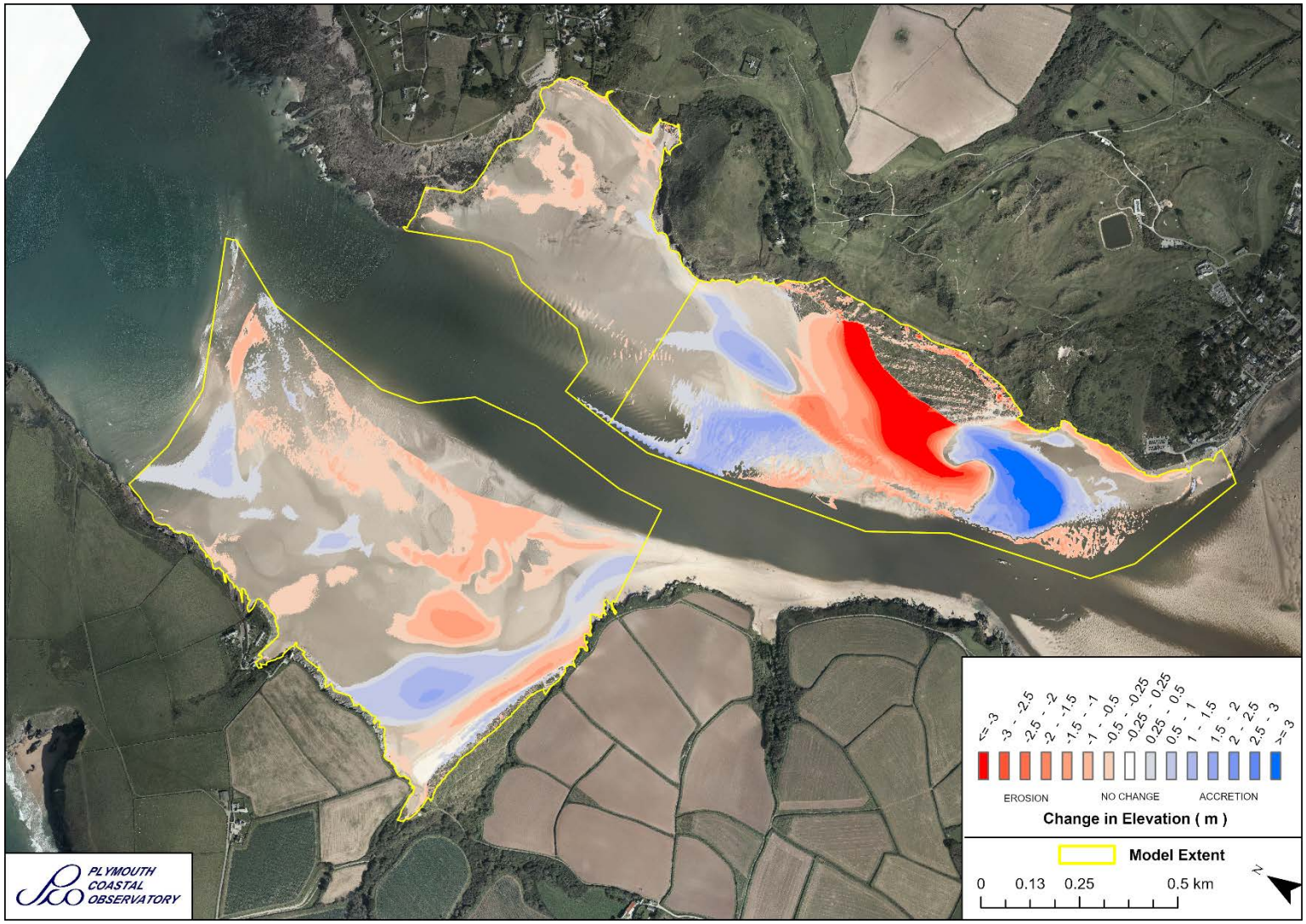


Figure 11 - Difference model indicating the changes in elevation observed between the November 2020 and October 2022 filtered LiDAR datasets within the yellow model extent.

3.1.2 Beach and Dune Volume Extraction

Surface volume extracted from each available LiDAR dataset from the Mobile Zone above the MHWS contour (2.35 m OD) are shown in Table 1. Mobile Zone volume underwent steady accretion between 2008 and 2016 (Fig.12). From 2017, the Mobile Zone begins to erode quickly with material transported up-river, as illustrated in Figure 2. The overall erosion rate for the Mobile Zone was 12,665 m^3 y^{-1} from 2008 to 2022.

Surface volume extracted from each LiDAR dataset from the Beach Zone above the MLWS contour (-3.00 OD) are shown in Table 1. It suggests a similar response to the Mobile Zone. Beach Zone volume remains stable between 2008 and 2017 before experiencing a significant loss in volume, eroding by 20%, a rate of 67,500 m^3 y^{-1} (Fig.13). The loss of material from the Mobile and Dune Zone, suggests a relocation of material within the estuary.

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	755,977	1,444,987
03/2009	771,366	1,490,659
03/2011	792,613	1,501,323
04/2012	803,777	1,524,268
04/2014	820,734	1,612,721
03/2016	813,256	1,612,397
03/2017	798,638	1,551,254
04/2019	748,081	1,452,105
11/2020	593,837	1,151,984
04/2022	454,863	1,181,026

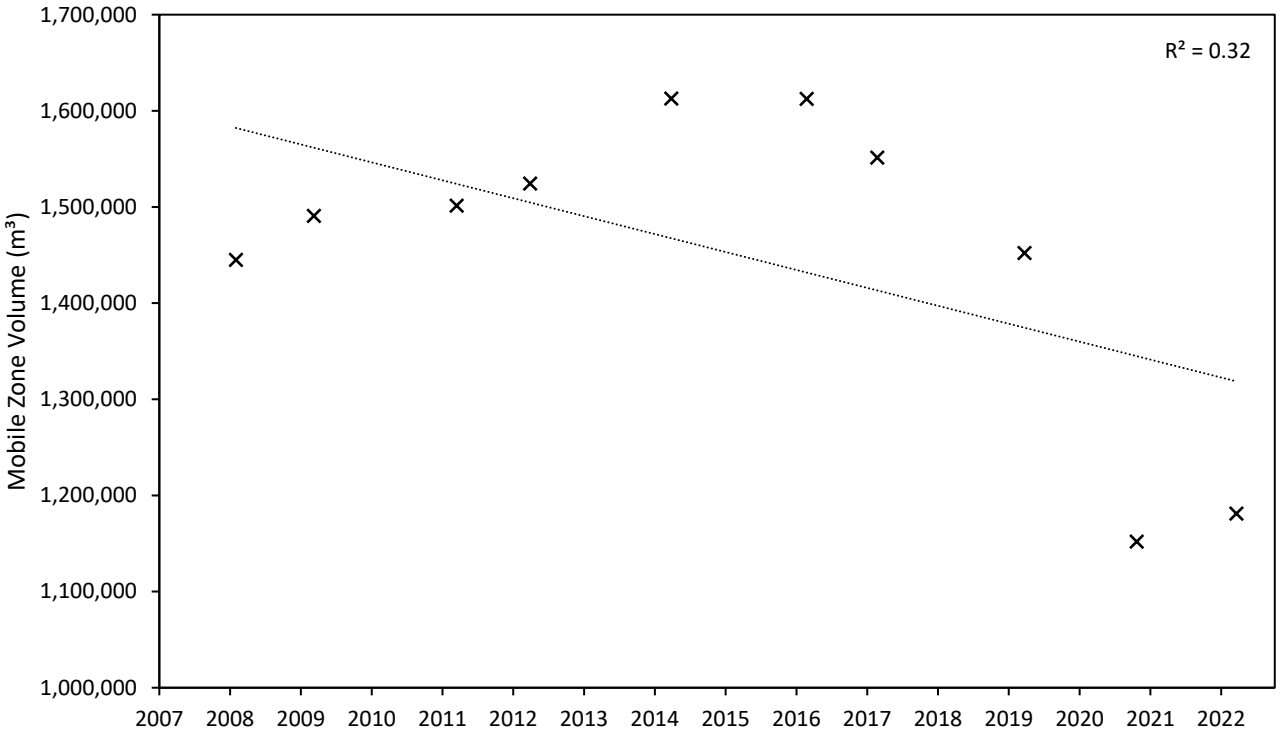


Figure 12 – Plot indicating beach volume (m^3) recorded in the Mobile Zone above MHWS (2.35 m OD) for each filtered LiDAR datasets between 2008 and 2022.

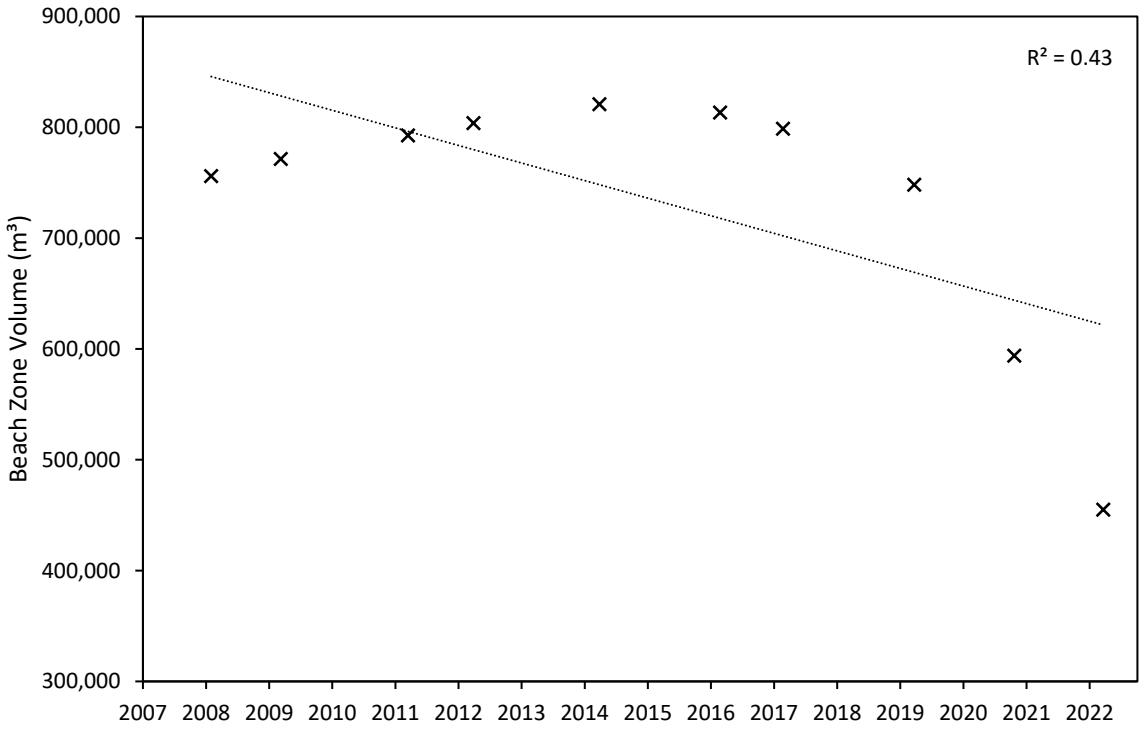


Figure 13 - Plot indicating beach volume (m^3) recorded in the Beach Zone above MLWS (-3.00 m OD) for each filtered LiDAR datasets between 2008 and 2022.

3.1.3 Contour Comparison

Figure 14 indicates the Mean Sea Level (MSL) and Dune Toe contours from the 2008, 2014, 2019 and 2022 LiDAR datasets. MSL contours, in the northern half of the unit, show a narrowing of the beach from 2008 to 2022 of approximately 226 m. The same is true of the Dune Toe contours, which have retreated by up to 185 m across the northern half of the dune system. However, to the south, the MSL contours show a widening of the beach of ~245 m and similarly, the Dune Toe contours have advanced by ~35 m.

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



Figure 15 – Aerial imagery from 1947.



Figure 16 – Aerial imagery from 2001.



Figure 17 – Aerial imagery from 2006.



Figure 18 – Aerial imagery from 2010.



Figure 19 – Aerial imagery from 2014.



Figure 20 – 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.