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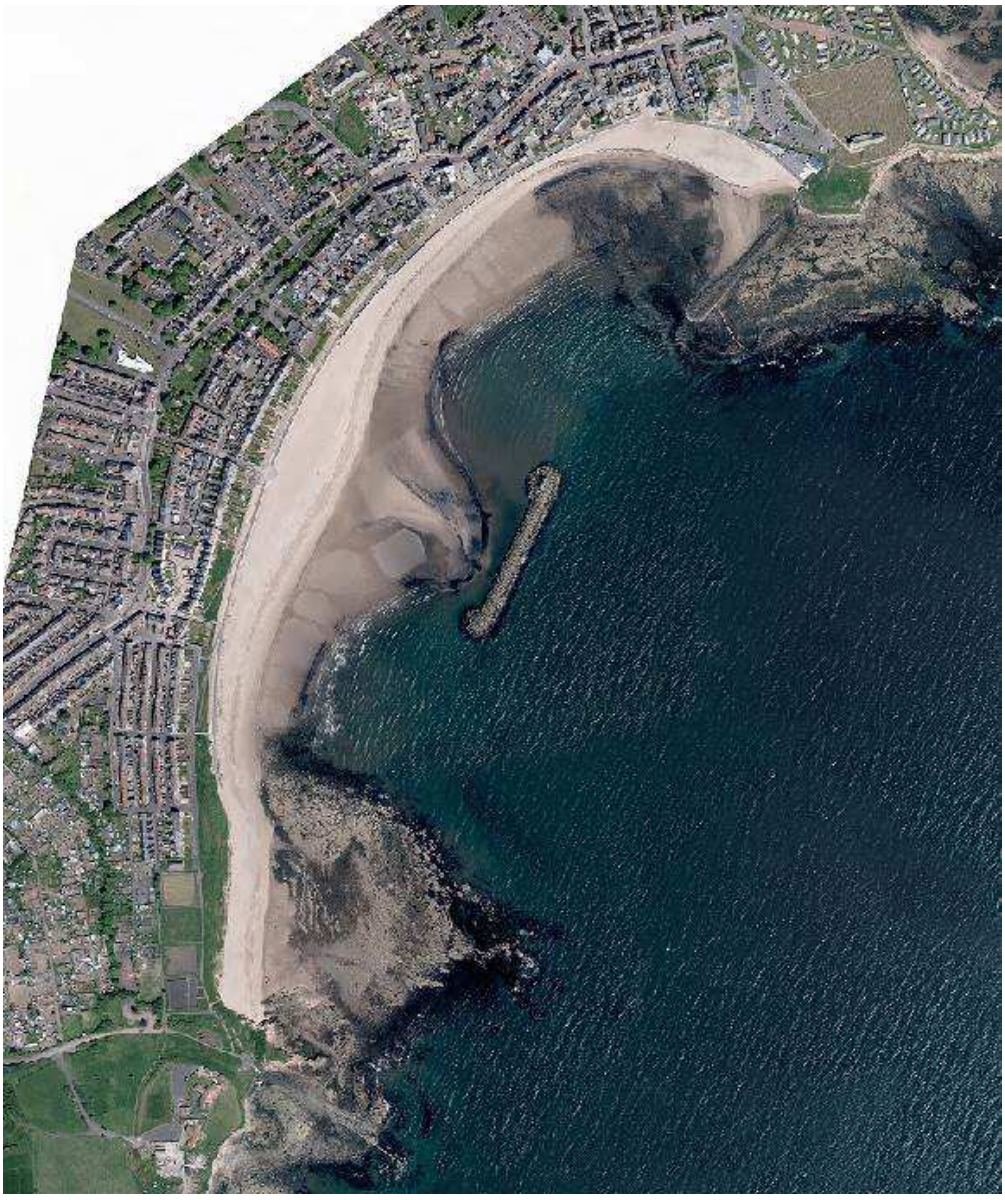

Cell 1 Regional Coastal Monitoring Programme
Aerial Photography and LiDAR Surveys 2017

A great place to live, work & play

February 2018

Scarborough Borough Council

Cell 1 Regional Coastal Monitoring Programme
Aerial Photography and LiDAR Surveys 2017

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Contents

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[1] Scarborough Borough Council is acting as client on behalf of all Local Authorities within 'Coastal Cell 1'.

Preamble

The Cell 1 Regional Coastal Monitoring Programme covers approximately 300km of the northeast coastline, from the Scottish Border (just south of St. Abb's Head) to Flamborough Head in East Yorkshire. This coastline is often referred to as 'Coastal Sediment Cell 1' in England and Wales (Figure 0-1). Within this frontage the coastal landforms vary considerably, comprising low-lying tidal flats with fringing salt marshes, hard rock cliffs that are mantled with glacial till to varying thicknesses, softer rock cliffs, and extensive landslide complexes.

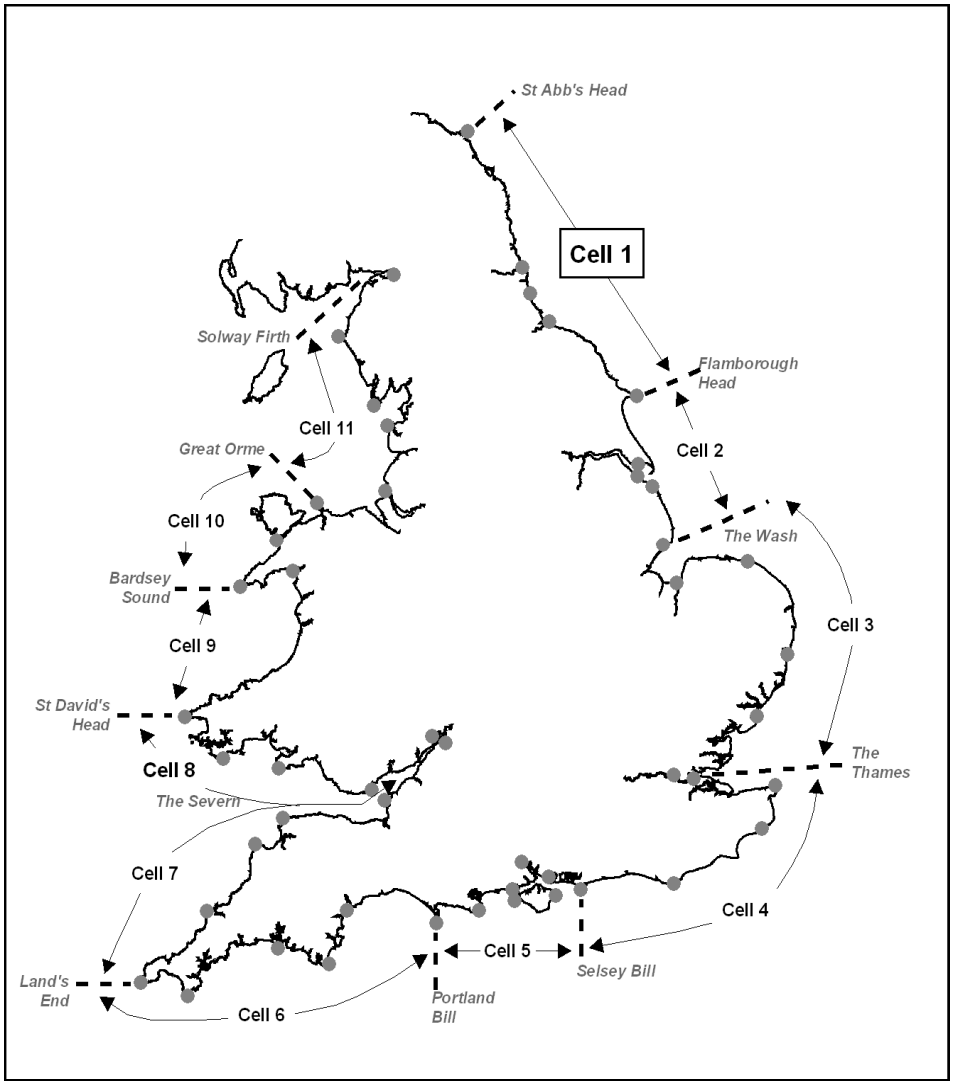


Figure 0-1 - Sediment Cells in England and Wales

The programme commenced in its present guise in September 2008 and is managed by Scarborough Borough Council on behalf of the North East Coastal Group. It is funded by the Environment Agency, working in partnership with the following organisations.

The main elements of the Cell 1 Regional Coastal Monitoring Programme involve:

- beach profile surveys
- topographic surveys
- cliff top recession surveys
- real-time wave data collection
- bathymetric and sea bed characterisation surveys
- aerial photography
- LiDAR survey
- walk-over inspection surveys

Royal HaskoningDHV has been appointed to provide Analytical Services in relation to the Cell 1 Regional Coastal Monitoring Programme 2016 - 2021.

The present report covers the **Aerial Photography and LiDAR Surveys 2017** and provides details of these surveys and a comparison with past aerial surveys.

In addition, separate reports are produced for other elements of the programme as and when specific components are undertaken, such as beach profile, topographic and cliff top surveys, wave data collection, bathymetric and sea bed characterisation surveys, and walk-over inspection surveys.

1. Introduction

1.1 Scope of work

Coastal Sediment Cell 1 extends from St. Abbs Head, north of the Scottish Border, to Flamborough Head in East Yorkshire. The purpose of this report is to review aerial photography and LiDAR (Light Detection and Ranging) survey data collected in 2017 for Cell 1, and to document notable changes based on a visual comparison with selected orthorectified aerial photographs collected in the past

1.2 Previous Surveys

The coastline of Cell 1 has been the subject of a number of aerial photography surveys in the past 15^{+} years, as summarised below:

- St. Abb's Head to Flamborough Head, 1999
- Staithes to Speeton (Scarborough Borough Council's frontage), 2003
- St. Abb's Head to River Tyne, 2008
- St. Abb's Head to Flamborough Head, 2010
- St. Abb's Head to Flamborough Head, autumn 2012 to spring 2013
- St. Abb's Head to Flamborough Head, 2015

Note: Those surveys prior to 2010 were taken as part of forerunner programmes to the present Cell 1 Regional Coastal Monitoring, and those since 2010 have been undertaken as part of the ongoing Cell 1 Regional Coastal Monitoring programme. Prior to 2010, the photographs are of varying format (e.g. some were scanned from prints) and accuracy (e.g. manual geo-referencing rather than ortho-rectification) whilst from 2010 onwards the Cell 1 Regional Coastal Monitoring programme has ensured a greater consistency of format and accuracy in the outputs.

Note: LiDAR surveys of the Cell 1 frontage accompany the aerial photography surveys since 2010, but not prior to this date.

1.3 Previous Analyses

Changes in the Cell 1 coastline between the baseline survey and the 2010 survey were documented in the Cell 1 report *Aerial Photographic Survey 2010: Areas of Change* (dated August 2010). The 2010 aerial photography was also used to inform the *Northumberland and North Tyneside Rocky Foreshore Coastal Squeeze Study* (dated 2010).

Changes observed in the Cell 1 coastline were then updated to 2012/13 in the Cell 1 report *2012/13 Aerial Survey Analysis* (dated December 2013). The 2012/13 aerial photography was also used to inform two bespoke Cell-wide analyses:

1. highlighting the presence of possible archaeological features (see *2012/13 Aerial Survey Archaeological Assessment Report*, dated January 2014); and

2. mapping the presence of BAP habitats (see *Mapping of BAP Habitats from Aerial Imagery*, dated December 2015).

For the 2015 survey a somewhat different approach was adopted to the analysis and reporting of coastal changes. Scarborough Borough Council commissioned an extensive trawl through available archives of historic aerial photography, enabling images from various years in the 1940s and covering the whole Cell 1 frontage to be purchased. These were then digitized and geo-referenced and used as a baseline for comparing

against the 2015 survey. The Cell 1 report *Analysis of 1940s and 2015 Aerial Photography & Detailed Assessment of Filey Bay to Cayton Bay* (dated March 2016) provides the results of this detailed analysis. As the report title suggests, a more detailed examination of changes within both Cayton Bay and Filey Bay was also undertaken, specifically to inform an ongoing Coastal Strategy in these areas, additionally using historic aerial photography data from both 1968 and 1996 for that frontage.

1.4 Aerial Photography and LiDAR Survey 2017

The survey undertaken in 2017 delivered the following datasets:

- Orthorectified digital vertical aerial at 10cm pixel resolution and an accuracy of at least ±10cm;
- Oblique imagery of the coastal frontage; and
- LiDAR elevation model at 1m resolution. Data were supplied as both 'first return' (with vegetation and buildings) and 'bare earth' elevation models.

All data were delivered in 1 km^2 tiles in GIS-ready format. The specification of the survey dictated that all data were to be captured at mean low water of spring tides to maximise coverage of the intertidal zone. The surveys were also to be undertaken on cloud free days to ensure clarity of imagery. For operational flexibility, the aerial photography and LiDAR surveys were not synchronous, but were instead captured as close together as possible. The aerial photography was undertaken by Cyient and the LiDAR data was collected by the Environment Agency.

In general, the quality of the aerial imagery appears better than that recorded in 2015, as shown in Figures 1-1 and 1-2.

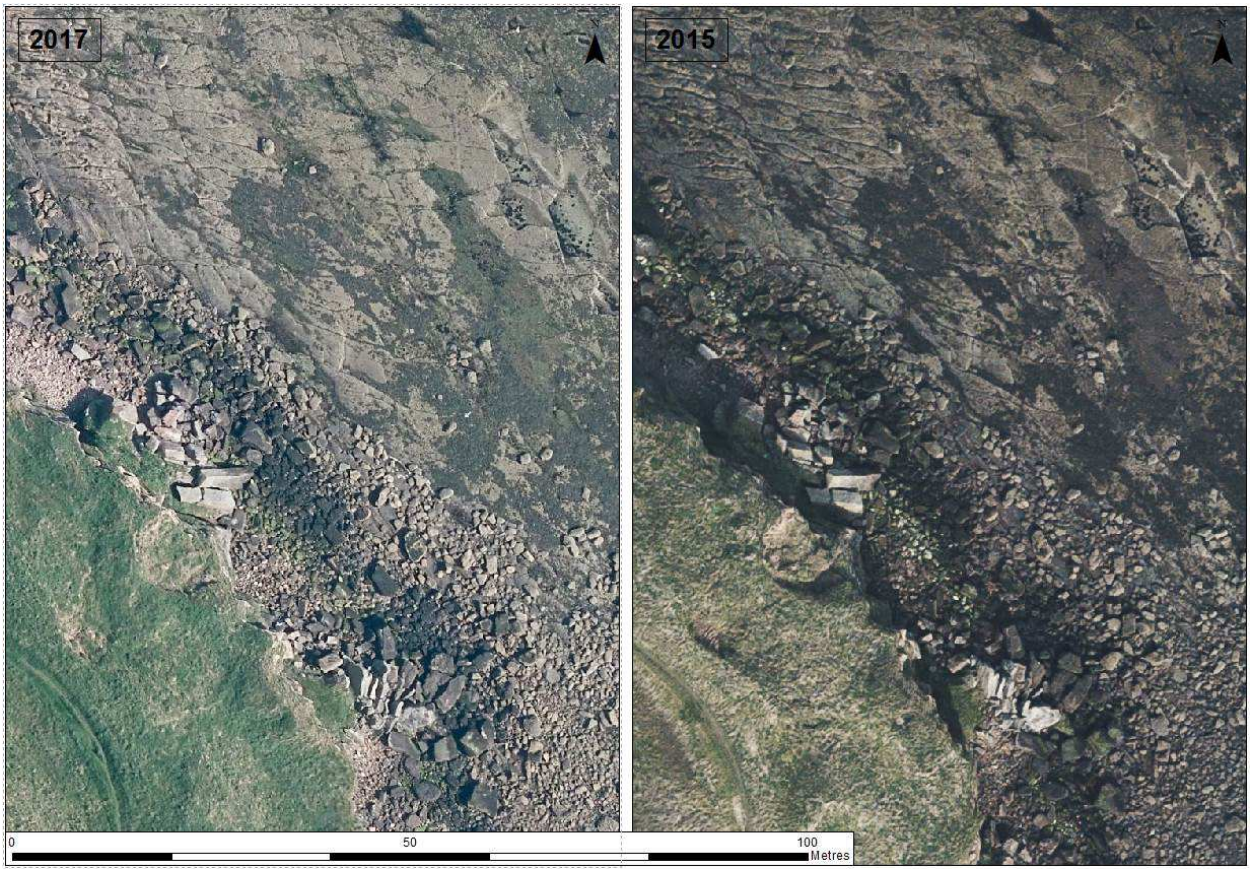


Figure 1-1 – Comparison of image quality at rocky foreshore from 2017 (left) and 2015 (right)

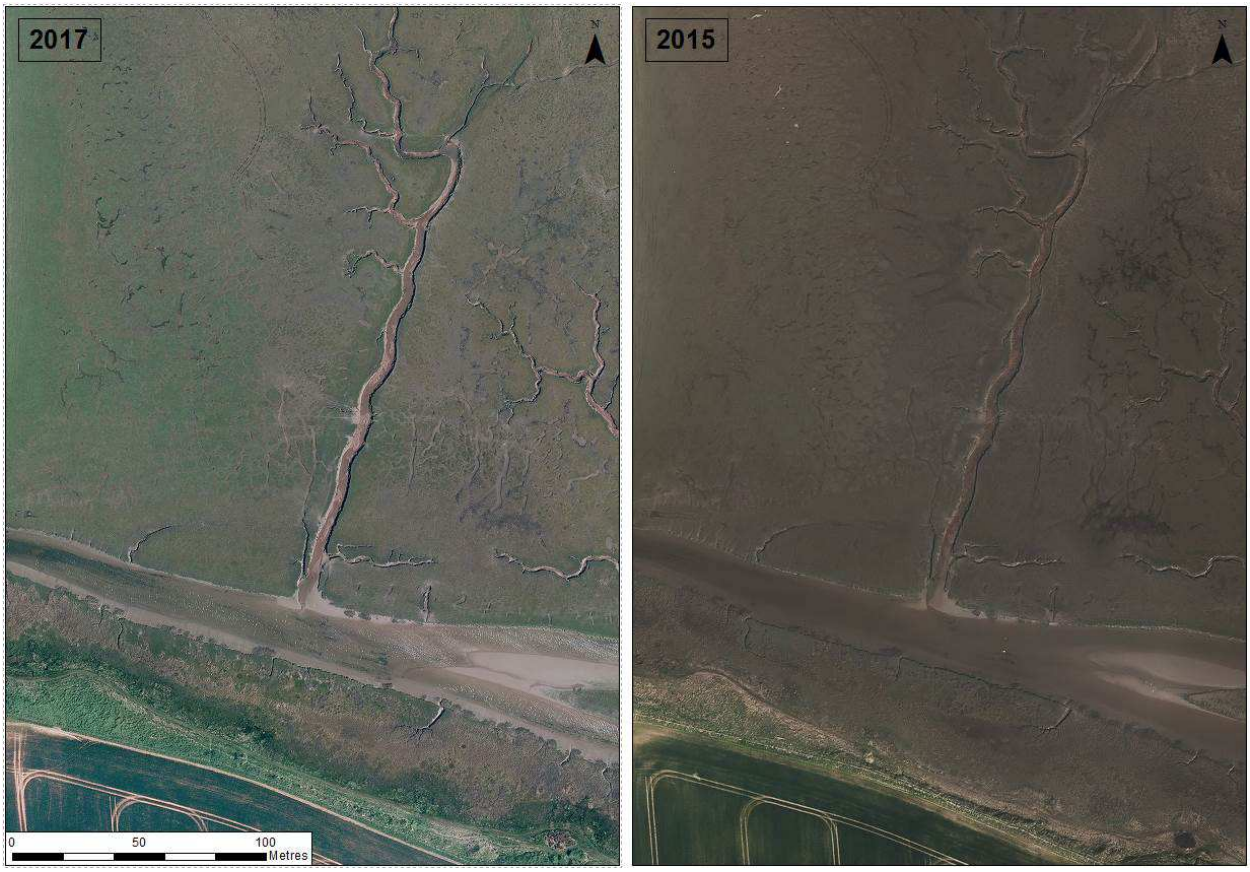


Figure 1-2 – Comparison of image quality at a saltmarsh creek from 2017 (left) and 2015 (right)

The newly-acquired 2017 aerial photography was compared directly against the previous survey from 2015 in ArcReader GIS to identify areas ('hotspots') of coastal change over the short term. In particular, changes in cliff top and dune crest position between surveys were identified and, where measurable change has occurred, quantified.

Where notable change occurred, aerial photography was 'draped' over a DGM created using the LiDAR data from 2015 and 2017 within ArcGIS to calculate locations and rates of change between successive surveys. This was performed at Port Mulgrave and Filey Flat Cliffs, the two areas of most notable change in the cliffs.

Although the aerial photography covers the entirety of Coastal Sediment Cell 1, namely from St. Abb's Head to Flamborough Head, the analysis focuses on the coastline between the Scottish Border and Speeton, covering the responsibilities of Northumberland County Council, North Tyneside Council, South Tyneside Council, Sunderland City Council, Durham County Council, Hartlepool Borough Council, Redcar & Cleveland Borough Council and Scarborough Borough Council.

This analysis of short term 'hotspots' of coastal change between 2015 and 2017 complements the analysis of longer term (1940s to 2015) coastal change that was previously undertaken with the 2015 dataset.

1.5 Regional overview

Coastal Sediment Cell 1 has a coastline of approximately 300km on the northeast coast of England. Its aspect is generally northeast facing, but there is considerable local variation due to the underlying solid and drift geology which play a significant control on the coastal geomorphology. The bedrock that crops out along the coast forms an almost complete sequence of Carboniferous to Upper Cretaceous rocks. The presence and thickness of glacial sediments varies, but they are generally thicker towards the south.

The north of Northumberland, from Berwick northwards, extending across the border to St Abbs Head, is characterised by hard shales of Silurian age which form simple cliffs of moderate height and sections of glacial sediments which form simple landslides. The central and southern Northumberland coast from Berwick-upon-Tweed to Hartley and the North Tyneside coast from Hartley to Tynemouth are characterised by a low elevation coastline dominated by sand dunes with occasional low elevation simple cliffs of Carboniferous limestone or gritstone, or higher cliffs formed of intrusive volcanic rocks associated the Whin Sill.

South of the River Tyne to Saltburn, the coastline is well-developed and has extensive defences and harbour structures with some unprotected low cliffs cut in glacial sediments which form small simple landslides, outcrops of hard Magnesian limestone which form simple cliffs, and occasional dune frontages. This coast, together with much of the southern Northumberland coast, was formerly characterised by extensive coal mining activity with spoil being tipped directly onto the beach, contributing to the coastal sediment system. In recent years, following the decline in this industry, considerable effort has been made to remediate beaches, and today only localised evidence of colliery spoil remains, e.g. at Blast Beach, Horden, where extensive spoil protects a relict cliff. This has resulted in a net loss of sediment from the coastal system and is thought to have triggered localised increases in erosion rates. Furthermore, monitoring has shown very high initial rates of erosion of the residual spoil, but with rates decreasing as the shore profile is more strongly influenced by the natural geomorphology. As spoil is removed so the dormant cliffs will be exposed. There is little historical evidence upon which to base prediction of future recession rates. This ongoing aerial surveying as part of the Cell 1 Regional Coastal Monitoring programme will be essential in providing this future understanding.

From Saltburn to Flamborough, the coastline is dominated by high, often near vertical, cliffs cut in Jurassic limestones and mudstones and Cretaceous chalk, with a variable thickness cover of glacial sediments, forming simple or composite cliffs. As a result of faulting in bedrock, and the pattern of glaciation, at many locations along this section of coast glacial sediment crops out at or near sea-level. This results in many simple landslides, such as those seen in Robin Hood’s Bay, Sandsend, around Scarborough (e.g. the well-documented landslides at Holbeck Hall and Cayton Bay) and in Filey Bay.

2. Changes detected

2.1 Introduction

This section documents the results of the comparison between the newly-collected 2017 aerial photography and the previous 2015 survey to identify short term 'hotspots' of coastal change.

The assessment runs from north to south, and the SMP2 Policy Unit (PU) or SMP2 Management Area (MA) references have been specified to help locate areas of change given below. Geographical locations mentioned in the text are based on 1:25,000 Ordnance Survey maps.

2.2 Areas of Change – Cell 1a Scottish Border to River Tyne (2015 - 2017)

- **Marshall Meadows Bay**, Berwick-upon-Tweed (PU1.1): An area of cliff which appeared bare of vegetation in 2015, indicating either a small slippage or provision of a local access ramp to the beach, appears to have become partially remediated by 2017.
- **Sharpers' Head**, Berwick-upon-Tweed (PU1.2): The coastal slopes fronting the caravan park just to the west of the headland have suffered small slippages in a number of locations, although this is not affecting the siting of the caravans on the cliff top at present.
- **Sandstell Point**, Berwick-upon-Tweed (PU2.4): The sand spit at the mouth of the Tweed estuary has long been known to be dynamic in form and position, and changes continue between 2015 and 2017. The crest of the spit appears more seaward and the channel at the mouth of the estuary, between the end of the spit and the Berwick Breakwater, appears narrower (Figure 2-1).

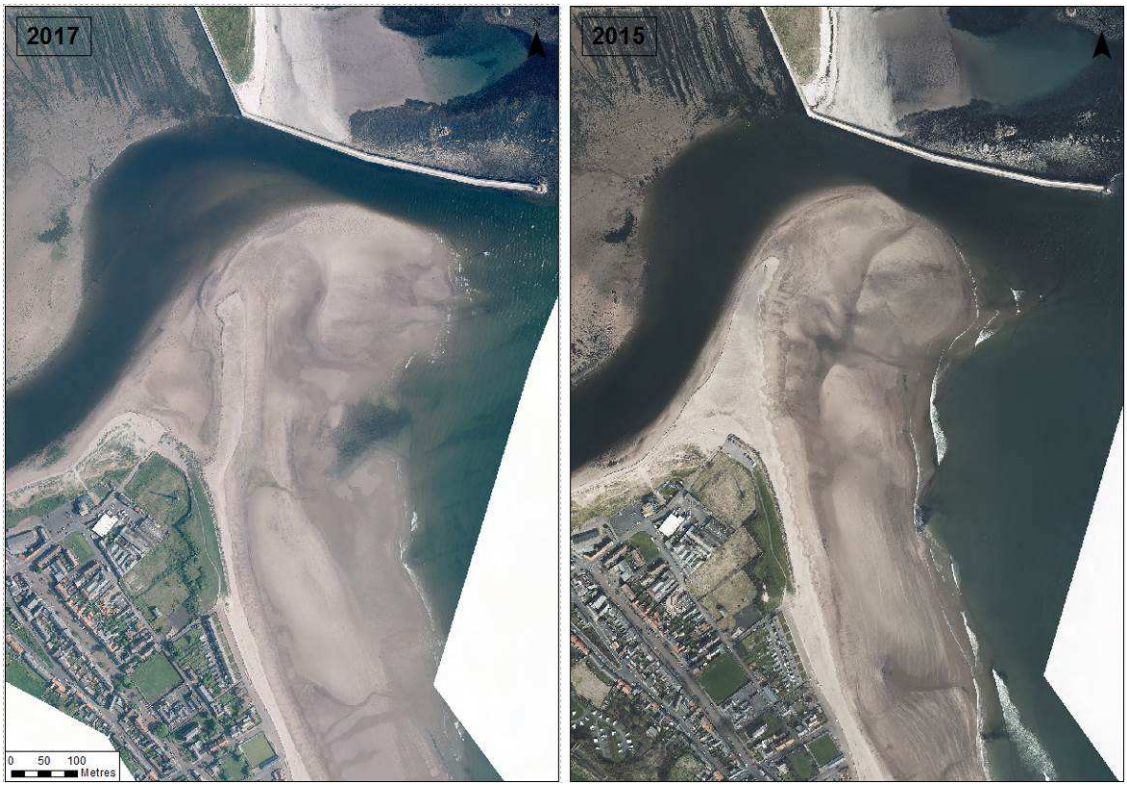


Figure 2-1 – Changes at Sandstell Spit 2017 (left) and 2015 (right)

- **Goswick Sands**, Berwick-upon-Tweed (PU4.1): There appears to have been sand accretion which has partially buried the concrete anti-tank blocks that are now used as coast protection measures in front of a 'scalloped' section of the dunes.
- **Holy Island** (PU4.8 & PU5.1): Restoration works at Lindisfarne Castle have resulted in temporary scaffolding around the historic building. Around the northern side of the island, there appears to be plentiful embryonic dune vegetation growth within the sandy bays that stretch between rocky headlands.
- **Ross Back Sands**, Belford (PU4.4): There is a continued growth of sand to the seaward face of the dune spit that extends from western end of Ross Back Sands.
- **Seahouses** (PU6.3): Although the tidal state may not have been directly comparable between surveys, there does appear to be more mud deposited in Seahouses inner harbour in 2017 compared to 2015. Also, a rock breakwater has been placed along the ledge of the rocky shore platform within the harbour to dissipate wave energy entering the harbour mouth (Figure 2-2). This covers a length of approximately 110m.

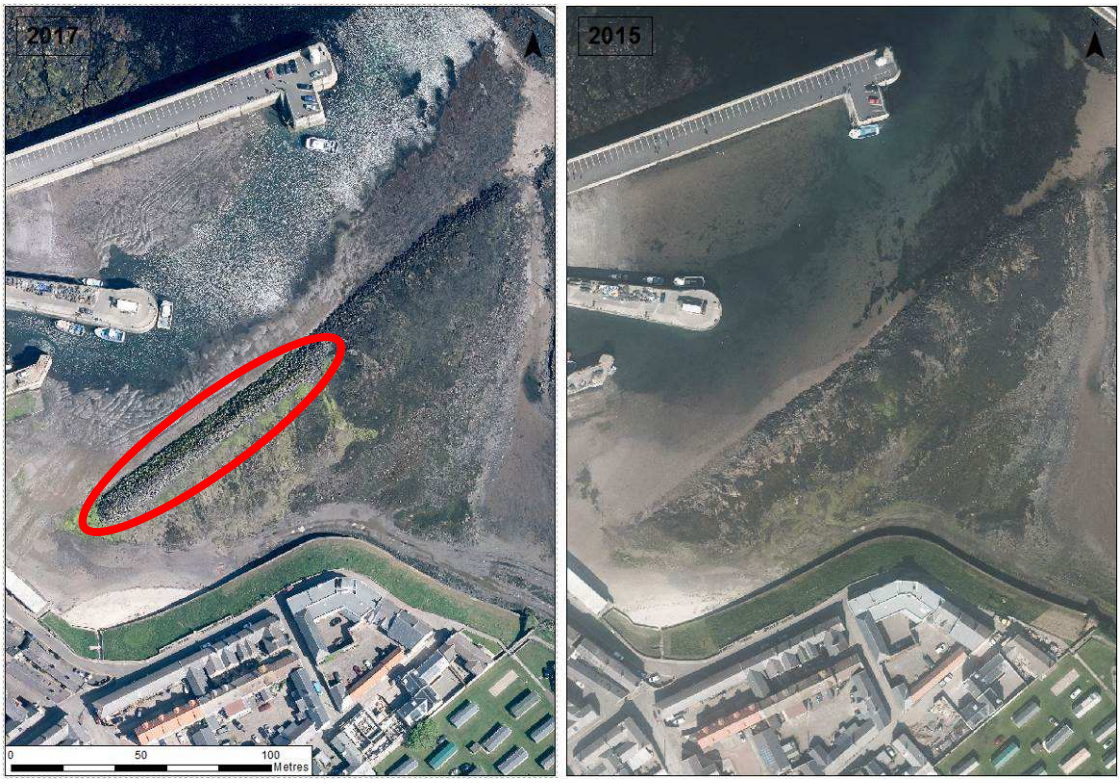


Figure 2-2 – Rock breakwater installed at Seahouses Harbour in 2017 (left) compared to pre-work in 2015 (right)

- **Beadnell North** (PU8.1): The failing Reno mattresses used to form a revetment where the road is less than 10 m from the coastal margin remain clearly visible in the 2017 aerial photography.
- **Beadnell Bay** (PU8.4): Towards the centre of Beadnell Bay, in the vicinity of the burn to both its north and south, there is embryonic dune growth in front of the toe of the main front dune crest.
- **Low Newton** (PU9.2): There are some very small slippages in the cliffs running from Low Newton towards Newton Point.

- **Embleton Bay** (PU9.2): The rock scars which outcrop on the foreshore and shallow nearshore zone show a smaller plan area in 2017, indicating that sand accretion has occurred within the bay since 2015.
- **Boulmer** (PU11.1): A short rock revetment has been placed at the toe of the cliffs of the northern-most property in Boulmer village, and the previous short sections of rock revetment fronting the main village have been completed as a continuous defence structure.
- **Alnmouth Bay** (PU13.1): The dunes appear to have become slightly wider and better vegetated throughout the bay. It is notable that the channel of the River Aln was diverted slightly further offshore in 2017 compared to 2015 where it ran slightly closer to the dunes, and it is likely that the dune accretion is associated with this natural change in position of the unconstrained channel.
- **Church Hill** (PU13.8): The short length of retaining wall shown to be collapsed in 2015, remained in this condition in 2017.
- **Birling Links** (PU14.1): The concrete anti-tank blocks used to protect the dunes south of Birling Carrs have become more exposed in 2017, indicating sand lowering on the foreshore. In 2015, they were visible over a length of around 140 m and in 2017 they are exposed over approximately 400 m of frontage.
- **Warkworth Harbour** (PU15.2): The sand build-up seaward of the dilapidated timber jetty has continued, keeping the main channel flowing flush against the quays at Amble.
- **Hauxley** (PU17.3): The concrete outfall from Hauxley Nature Reserve to the beach remains *in situ*, but a new 'daylight' channel has been constructed, making the old outfall structure redundant.
- **Druridge Bay** (PU17.4): Towards the southern end of Druridge Bay, the beach levels dropped between the 2015 and 2017 surveys, exposing both rock outcrops on the inter-tidal zone and also the concrete anti-tank blocks which were previous buried.
- **Cresswell** (PU17.5): The landslip in the cliffs just to the north of Cresswell that occurred prior to the 2015 survey has not worsened to 2017, but remains impacting the carriageway.

Figure 2-3 – Landslip at Cresswell impacting the road carriageway in 2017

- **Snab Rocks** (PU18.2): The private defences at the property immediately south of Snab Rocks, which were extended a few years ago (and visible in the 2015 aerial photography), now have a property being constructed behind the extended length.
- **Lynemouth** (PU19.1): Some of the colliery spoil beach to the south of the Power Station has become quite noticeably eroded.

Figure 2-4 – Erosion of colliery spoil south of Lynemouth

- **Newbiggin Moor** (PU20.1): Two of the caravans at the caravan park which were closest to the edge of the cliff top have been removed between 2015 and 2017. Elsewhere along this frontage, erosion has cut the cliff top right back to the footpath on the northern face of Newbiggin Point.
- **Newbiggin Bay** (PU20.3): Beach levels in 2017 were higher than at the time of the 2015 survey, resulting in much of the rock placed at the toe of the seawall at the southern end of Newbiggin bay being buried or partially buried by beach sand. It also appears that the tombolo in the lee of the offshore breakwater in the centre of Newbiggin Bay has continue to grow in volume.
- **Sandy Bay** (PU21.3): The cliffs at the southern end of the caravan park continue to be active and show ongoing signs of small scale, but persistent, erosion
- **Cambois** (PU21.5): It appears that a terrace/platform has been constructed seaward of Cambois House, close to the cliff top. This is an area where the cliffs have historically been unstable and erosion could commence at any time.
- **Meggies Burn** (PU23.2): The burn had adopted a southerly alignment in 2015, prompting erosion counter-measures to the toe of the dunes to the south. However, by the time of the 2017 survey, the burn was flowing north-easterly to discharge at sea.
- **Whitley Bay Miniature Golf Course** (PU25.2): The undefended cliffs fronting the golf course continued to experience slumping between 2015 and 2017.

- **Whitley Bay** (PU25.3): Construction works were underway at the time of the 2017 aerial survey, associated with promenade and seawall works as part of the Whitley Bay Coastal Masterplan.

2.3 Areas of Change – Cell 1b River Tyne to Chourdon Point, Seaham (2015 - 2017)

- **Littlehaven** (MA02): Construction works were underway at the time of the 2017 aerial survey, associated with a new toilet block at the rear of the car park behind the promenade and seawall.

- **Man Haven** (MA04): A sink hole in the cliff top has been partially infilled and fenced-off for reasons of public safety between 2015 and 2017.

- **Lizard Point** (MA04): There appear to have been further rock falls at Lizard Point, vindicating the decision by the National Trust to close the car park and return the area to a natural grassland state.

- **Old Harbour Quarry** (MA05): The sink hole at Whitburn Coastal Park has marginally increased in size between 2015 and 2017, now measuring 20 m across at its widest point.

- **Whitburn Rifle Ranges** (MA06): At one location a headwall of a drain has collapsed at the crest of the cliff and been replaced with some infill to support the drain and fencing. The concrete debris from the headwall is strewn across the foreshore.

- **Roker Pier** (MA07): Construction works were underway at the time of the 2017 aerial survey on the Rocker Pier.

- **Pincushion** (MA09): The cliffs between Pincushion Rocks and Ryhope Dene have undergone slippage in several distinct areas and remain broadly active in a similar manner south towards Featherbed Rocks.

2.4 Areas of Change – Cell 1c Chourdon Point, Seaham to Saltburn (2015 - 2017)

- **Crimdon** (MA11): Some fencing seems to have been placed in front of the dunes in attempt to trap wind-blown sand.

- **Hartlepool North Sands** (MA11): Considerable shingle accumulated at the upper beach between the pier and Parton Rocks between 2015 and 2017.

- **Hartlepool Headland** (MA11): Construction works were underway at the time of the 2017 aerial survey, on the Hartlepool Headland scheme. The placement of rock armour at the toe of the existing wall is apparent along approximately 1 km of frontage around the Headland.

- **Coatham Sands** (MA13): There have been reports that the December 2013 and January 2017 storms caused severe erosion of the dunes at Coatham Sands, especially in the vicinity of Majuba area near the public car park. In the immediate lee of the South Gare breakwater, the trend is one of accretion in the shelter of the structure, with a notable increase in the extent of dune vegetation (Figure 2-5). Some areas of 'scalloped' dune evident in the 2017 aerial photography was also present in the photography that was collected in 2015 and appears not to have worsened. Arguably in some areas (e.g. Figure 2-6) it may have marginally recovered, although remaining heavily scalloped. Some areas that have been described as 'breaching' or 'severely eroding' during the January 2017 storms, were clearly in such a state before the 2015 photography was collected and thus the damage to these dunes cannot be ascribed to the January 2017 storms (Figures 2-7 to 2-10), although it may have been caused by the December 2013 surge.

Figure 2-5 – Vegetation growth on dunes in the lee of South Gare Breakwater

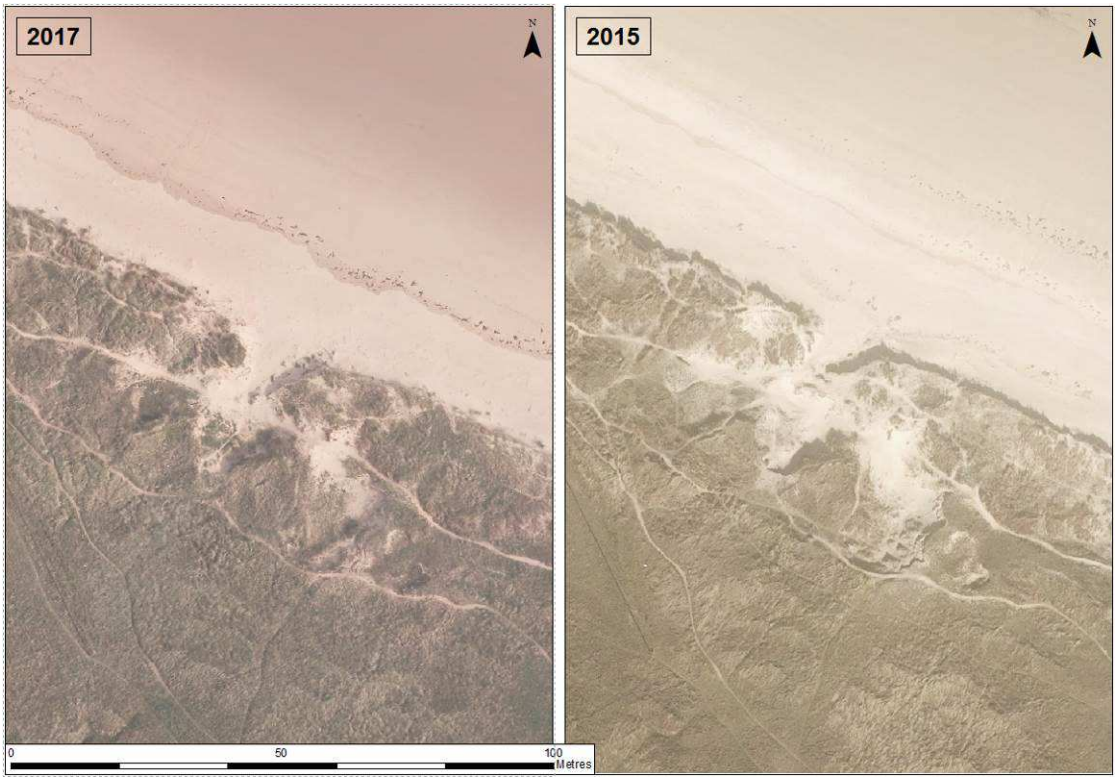


Figure 2-6 – 'Scalloping' of dunes along Coatham Sands

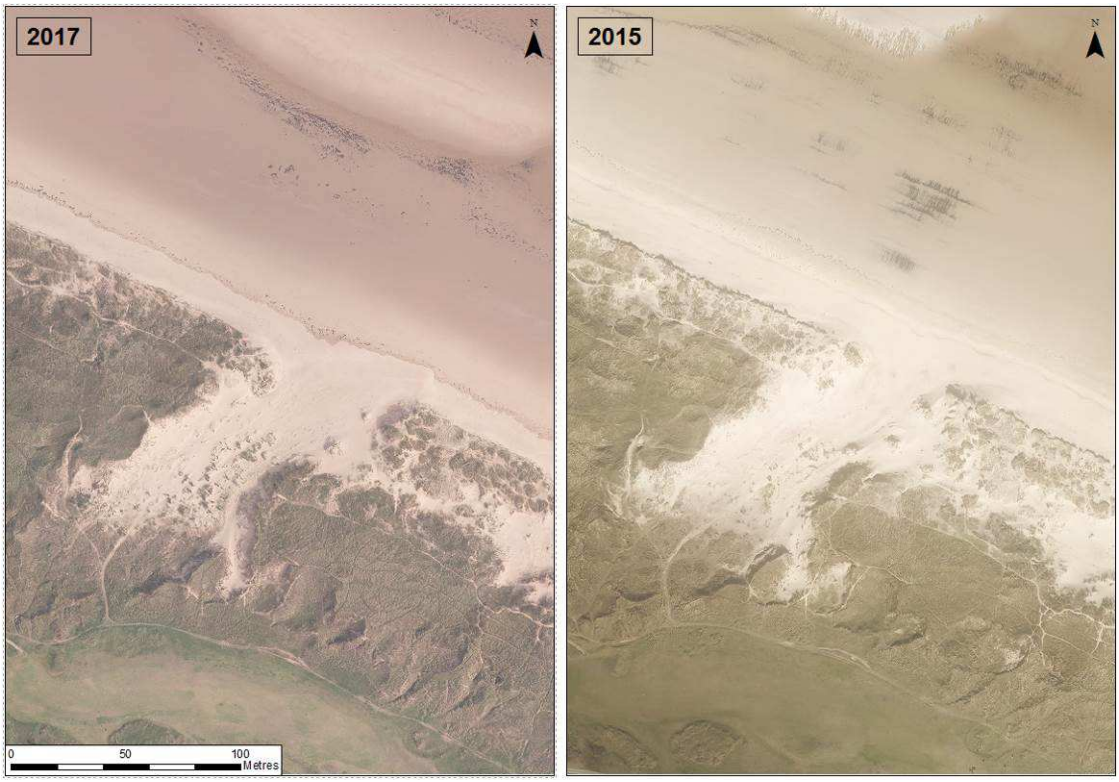


Figure 2-7 – Damage to dunes along Coatham Sands pre-dates January 2017 storms

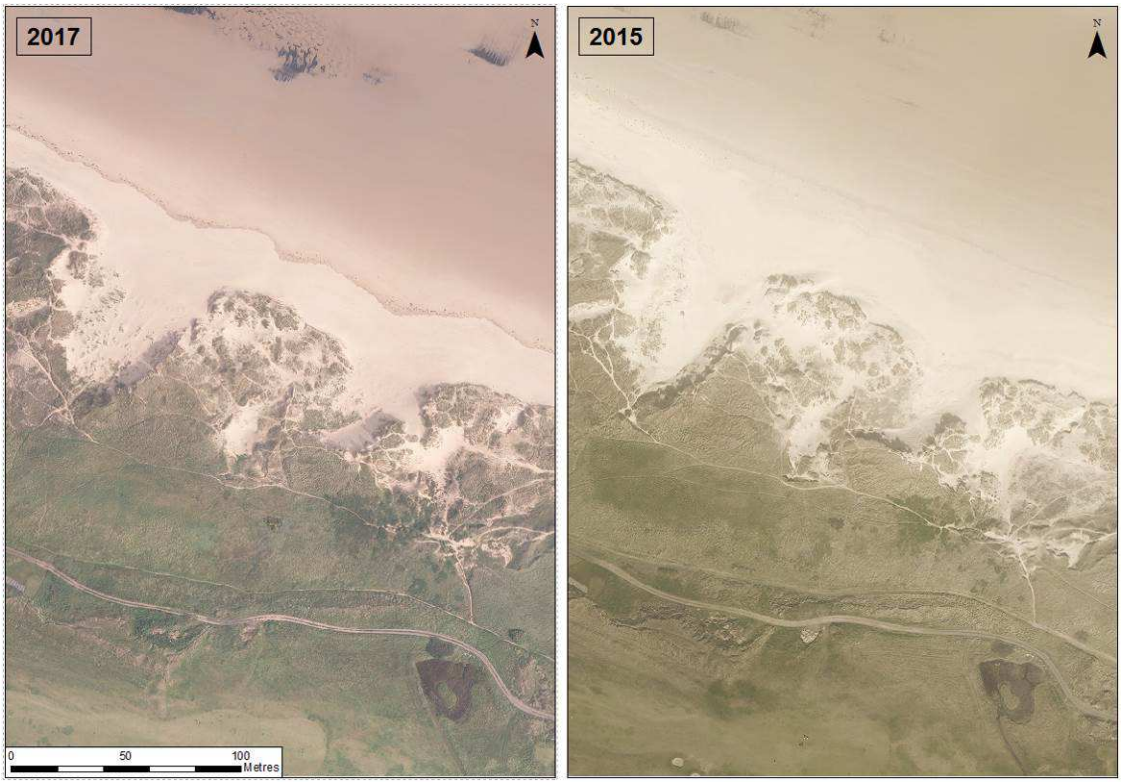


Figure 2-8 – Damage to dunes along Coatham Sands pre-dates January 2017 storms

Figure 2-9 – Dune condition fronting western section of caravan park along Majuba section of Coatham Sands pre-dates January 2017 storms

Figure 2-10 – Dune condition fronting eastern section of caravan park along Majuba section of Coatham Sands pre-dates January 2017 storms

2.5 Areas of Change – Cell 1d Saltburn to Staithes (2015 - 2017)

- **Skinningrove** (MA17): The coast protection scheme at Skinningrove involved the placement of rock armourstone along the seaward face and roundhead of the Jetty, along with refurbishment works to the Jetty itself. The repair of one failed section of the Jetty is visible in Figure 2-11. Some minor modifications were also made to the existing rock armour on the leeward side of the breakwater at its root.

Figure 2-11 – Rock armourstone and conrete repairs at Skinningrove Jetty

- **Skinningrove** (MA17): The coast protection scheme also involved modification to the fishtail groyne, immediately to the east of Skinningrove Beck. In the lee of the groyne, a classic embayed shingle berm had developed, but since the modifications to the structure, making it more of a conventional breakwater at the mouth of a beck, the shingle has eroded and it appears that only a thin section of beach now protects the boat slipway which crosses the breakwater (Figure 2-12). Future development of the beach at this location should be careful monitored.

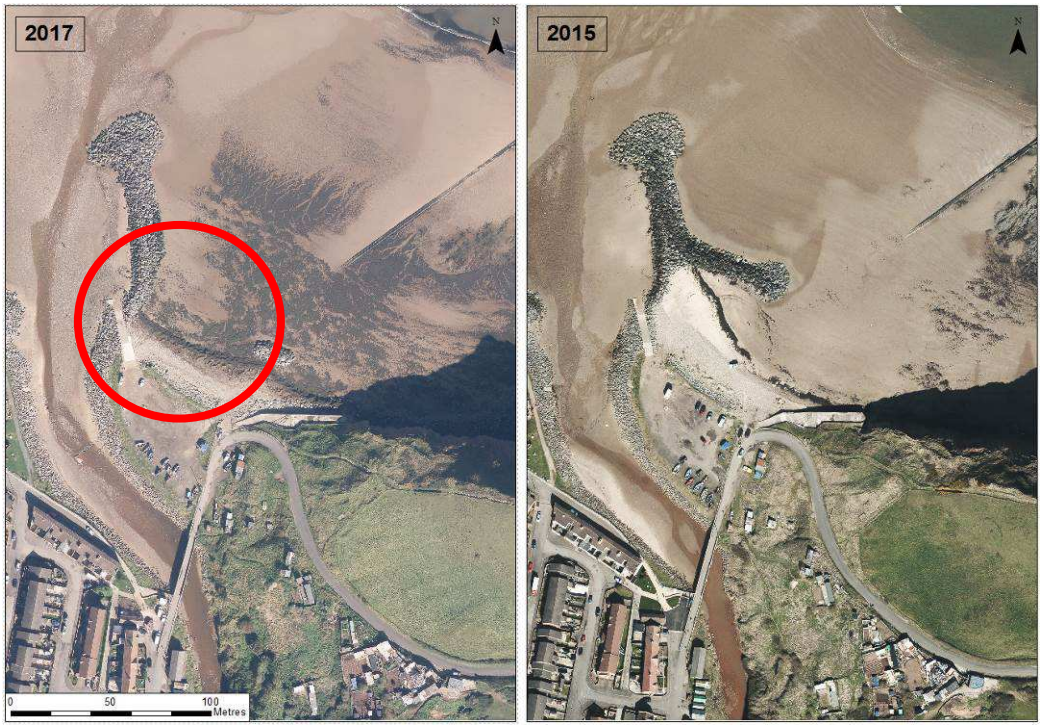


Figure 2-12 – Rock armourstone and conrete repairs at Skinningrove Jetty

- **Cowbar** (MA19): A short section of cliff near Cowbar Nab suffered a collapse between 2015 and 2017.

2.6 Areas of Change – Cell 1e Staithes to Speeton (2015 - 2017)

- **Port Mulgrave** (MA20): Two areas within Port Mulgrave suffered fairly large scale slippages between 2015 and 2017 (Figure 2-13). The first area was more central and appears to have experienced slippage mid way through the coastal slope across a width of approximately 100 m (Figure 2-14), whilst the second area was a chute type slippage located more to the southeast in the bay (Figure 2-15). The latter slippage appears to have been an extension of a previous slippage lower down the slope at this location.

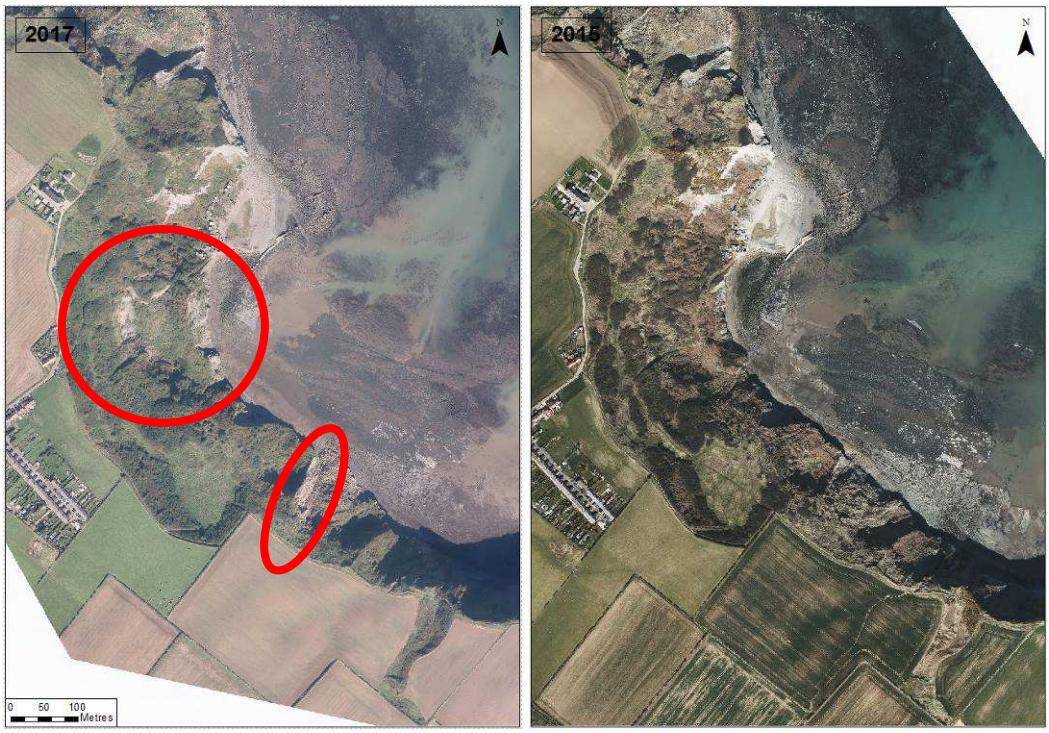


Figure 2-13 – Areas of landslip within Port Mulgrave

Figure 2-14 – Large landslip within Port Mulgrave

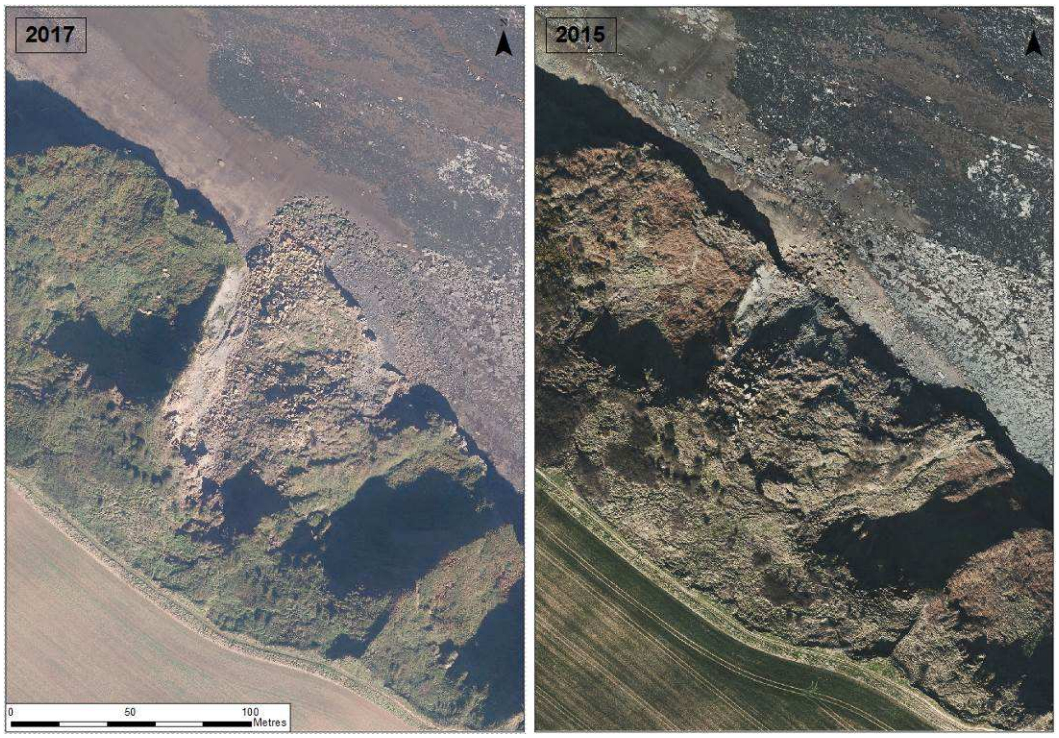


Figure 2-15 – Chute landslip within Port Mulgrave

- **Sandsend** (MA22): Along Sandsend Road a coast protection scheme was introduced in 2016, involving the construction of a stepped concrete revetment with upper Dycel concrete units (Figure 2-16), re-grading and drainage of the coastal slopes landward of the road (Figure 2-17), and infilling of the ravine at Rathwaite Gill (Figure 2-18), with an extended outfall structure.

Figure 2-16 – Concrete revetment constructed at Sandsend Road

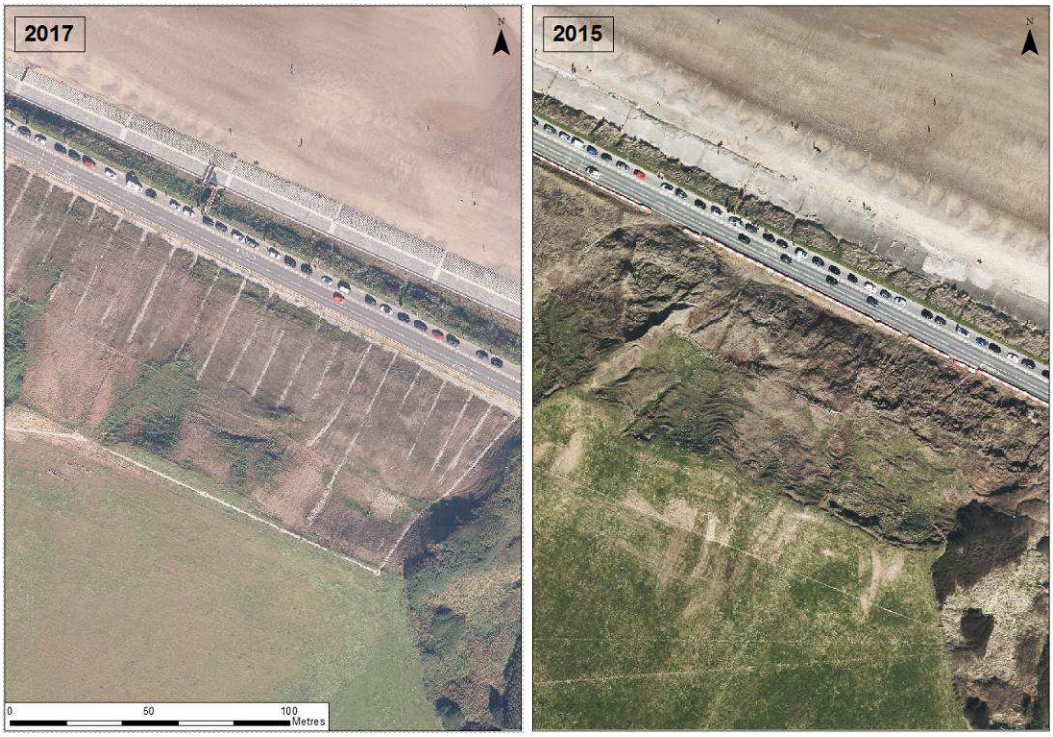


Figure 2-17 – Re-grading and drainage of the slopes landward of the road

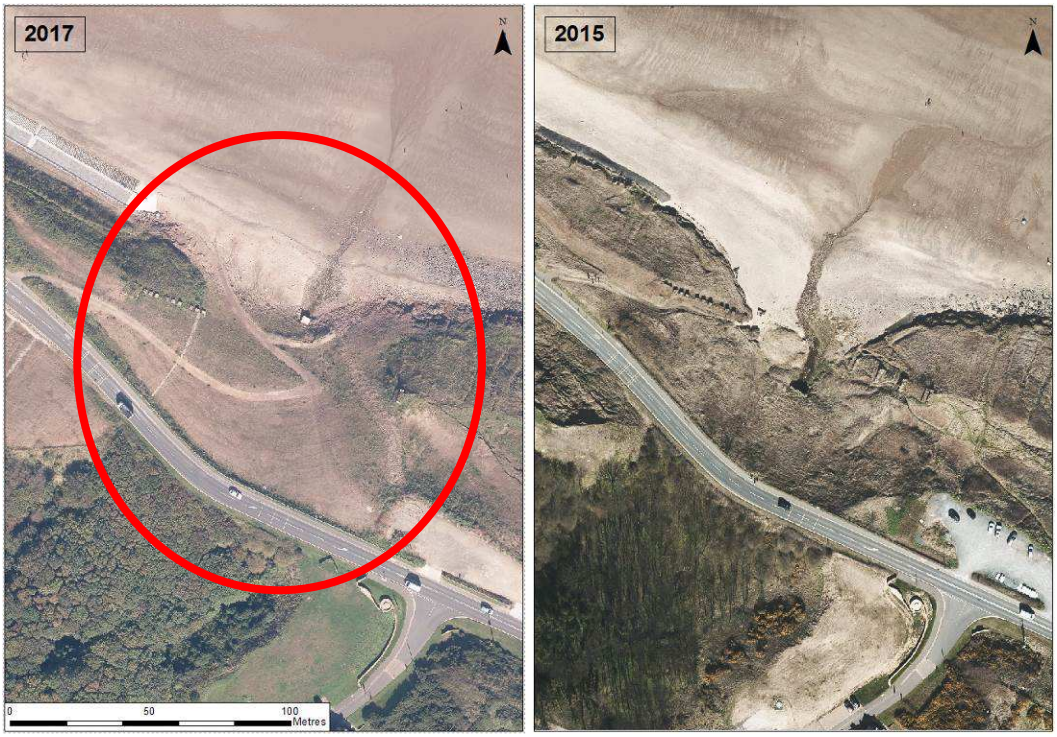


Figure 2-18 – Infilling of the ravine at Raithwaite Gill

- **Whitby West Cliff** (MA23): A series of shallow slips remain evident near the base of the cliffs, in the area where there is a gap in the rock revetment which fronts the seawall. However, these have not worsened between 2015 and 2017 (Figure 2-19).

Figure 2-19 – Shallow slippages at the toe of Whitby West Cliff

- **Scarborough South Bay** (MA28): Construction of new lifeboat station had been commenced at the time of the 2015 survey and was completed before the 2017 survey (Figure 2-20).

Figure 2-20 – RNLI Lifeboat Station at Scarborough South Bay

- **Cornelian Bay and Cayton Bay** (MA29): Whilst some areas appear to be recently or imminently active, there is no apparent movement between the 2015 and 2017 surveys.

- **Filey Brigg** (MA30) and **north of Filey Town** (MA31): As above, the apparently active or unstable sections of cliff do not appear to have altered since the 2015 survey. Remnants of past slippages and past rock falls remain evident in the slope face or cliff toe. The only exception is immediately south of Filey Town, where the seawall ends. At this location it is possible that the undefended cliffs to the immediate south remain active, although it should be noted that the 2015 survey is not particularly clear at this location (see Figure 2-21).

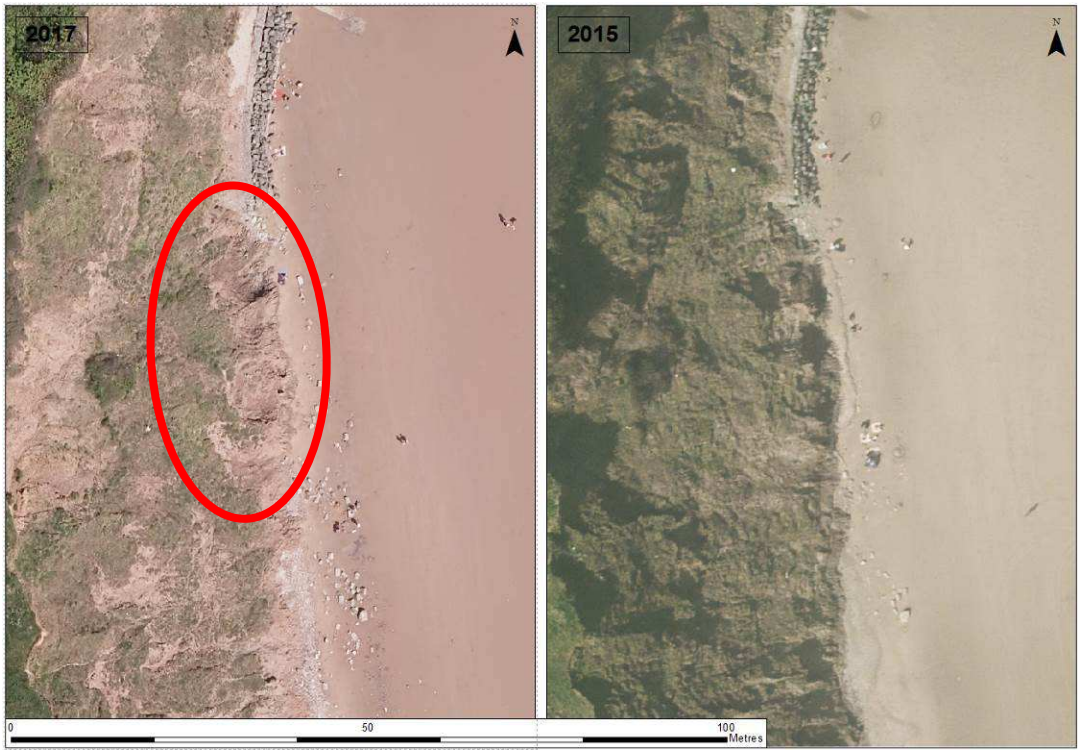


Figure 2-21 – Erosion south of Filey Seawall

- **Filey Bay** (MA32): A small number of isolated sections of Filey Bay, south of the town, appear to remain active, with occasional shallow slips in the cliffs. However, the most notable past slippages (medium scale and larger) do not appear to have worsened since the 2015 survey. At Flat Cliffs, however, there are measureable changes in cliff top position to the north of the access road into the hamlet from the Primrose Valley Holiday Park (Figure 2-22). This area is soon to benefit from urgent works to reduce the risk of future failures.

Figure 2-22 – Erosion at Flat Cliffs access road

- **General**: There are a small number of areas where occasional rock falls or small slippages near the cliff top have occurred. Other than the Cleveland Way footpath, which can be diverted inland when necessary, no assets are at risk from these occasional events.

3. LiDAR Analysis

In the two areas of greatest observed change, namely Port Mulgrave and Filey Flat Cliffs, LiDAR survey data was used to create a Digital Ground Model to further analyse the changes. Aerial photography was draped over the LiDAR-based DGM to enhance the analysis.

Figure 3-1 shows the changes in the two areas of landslip at Port Mulgrave between 2015 and 2017.

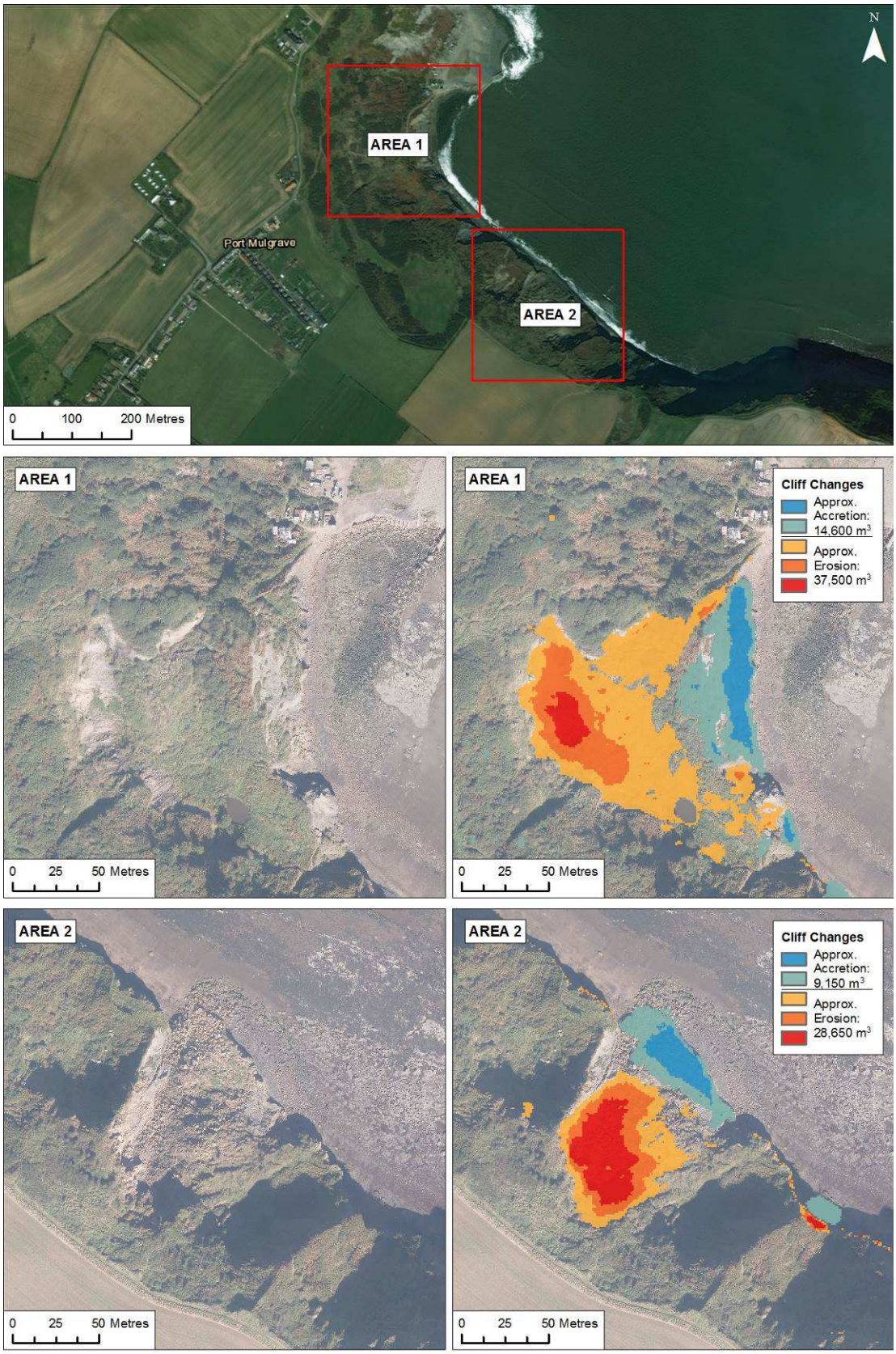
In Area 1 at Port Mulgrave, some 37,500 m^3 of material has been moved from the coastal slope during the landslip. Some 14,600 m^3 of this remains in the form of a talus at the toe of the cliffs, but the remaining 22,900 m^3 has been washed away by the tides.

In Area 2 the landslip was small, but still involved some 28,650 m^3 of material moved in the landslip. 9,150 m^3 of this remains in the talus, with 19,500 m^3 washed away.

Figure 3-2 shows the changes in the two areas of landslip at Filey Flat Cliffs between 2015 and 2017. These are both much smaller slips than those experienced at Port Mulgrave.

In Area 1 at Filey Flat Cliffs only 15 m^3 of material has been lost, from a plan area covering 15 m^2. At its greatest extent of change, the cliff top has eroded back by 1.6 m as a consequence.

In Area 2, the slippage is of greater concern because it is in an area that is closer to the access road. Here some only 40 m^3 of material has been lost during the slippage, covering a plan area of 25 m^2. The cliff top recession has been up to 2.6 m, at its greatest point.



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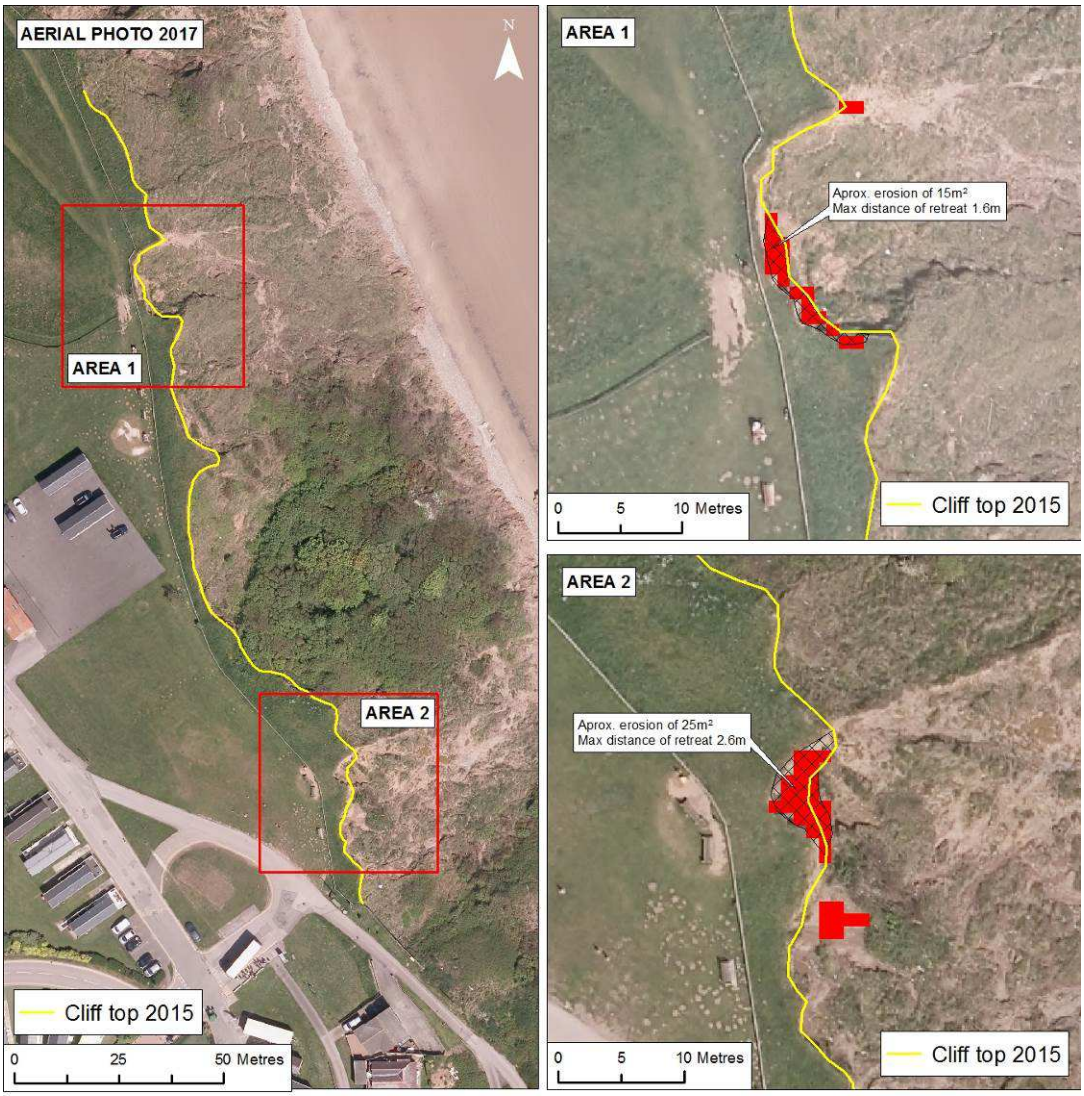
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Image/Data courtesy of North East Coastal Observatory.

Figure 3-1 – Analysis of Changes at Port Mulgrave



Image/Data courtesy of North East Coastal Observatory.

Figure 3-2 – Analysis of Changes at Filey Flat Cliffs

4. Summary

The review of the high quality orthorectified imagery acquired in 2017 has shown the data is of excellent quality and reveals a large amount of information on the form of the coast and the nature and location of activity in the present day.

Visual comparison with the 2015 survey highlights the following key findings:

- Several sections of cliff remain active, with occasional rock falls or slumps occurring. Generally, these present no risks to assets, which are either absent, set well back or adaptable to ongoing change (e.g. footpaths).
- A number of new construction works have been completed since the 2015 survey:
    - **Seahouses Harbour** – a rock breakwater constructed by the North Sunderland Harbour Commissioners;
    - **Boulmer Coast Protection Scheme** – implemented by Northumberland County Council;
    - **Hauxley** – Northumberland Wildlife Trust has created a new 'open' channel adjacent to an existing concrete outfall structure to control water levels within the Hauxley Nature Reserve;
    - **Whitley Bay Coastal Masterplan** – being delivered by North Tyneside Council;
    - **Roker Pier Refurbishment** – led by Sunderland City Council;
    - **Hartlepool Headland Coast Protection Scheme** – undertaken by Hartlepool Borough Council;
    - **Skinningrove Coast Protection Scheme** - delivered by Redcar & Cleveland Borough Council;
    - **Sandsend Road Coast Protection and Slope Stabilisation Scheme** – completed by North Yorkshire County Council; and
    - **Scarborough Lifeboat Station** – built by the RNLI.
- It is also apparent that some new developments have occurred (or are occurring) on the cliff top, with some in areas that are potentially vulnerable to erosion (e.g. Snab Point or Cambois House, both Northumberland).
- Some areas of the coastline remain dynamic, in particular at the mouths of estuaries or small burns such as the Tweed estuary, Aln estuary, Warkworth Harbour and Meggies Burn. In these locations, changes in the channel of the watercourses can have effects on the erosion or accretion of the adjacent coastlines or can cause increased loading pressure on structures such as quay walls.
- Beach changes have been observed through either lateral erosion of beach ridges (such as the colliery spoil beach at Lynemouth) or the covering or exposure of rocky foreshore, rock armourstone or concrete blocks used for coast protection.
- Several dune areas appeared to show embryonic dune vegetation growth in front of the toe of the main dune with no areas of notable blow-outs or erosion identified.
- The most notable areas of cliff erosion or instability are at Port Mulgrave and Flat Cliffs, where in both cases there are concerns about access. At Port Mulgrave, the National Trust has closed existing footpaths to prevent public access to the areas of landslip, whilst at Flat Cliffs urgent works are proposed in 2018 to help reduce the risk of further slippage and erosion of the cliffs adjacent to the sole access road to the hamlet. LiDAR data has been used to further analyses both of these areas of change.