ROYAL HASKONING

Halcrow

Cell One Coastal Monitoring (2008-11)
Aerial Photographic Survey 2010: Areas of Change

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Final Report

August 2010

Contents

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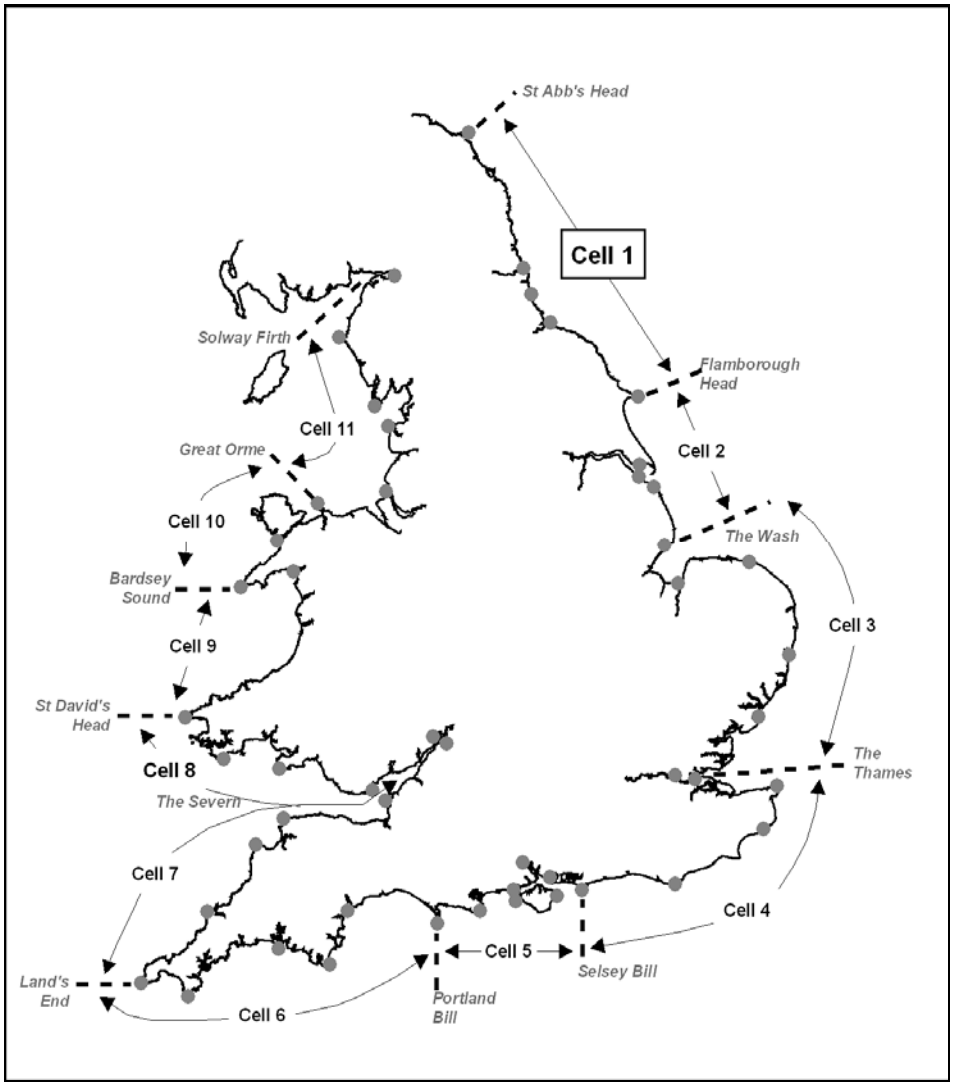
Glossary of Terms

Term	Definition
Beach nourishment	Artificial process of replenishing a beach with material from another source.
Berm crest	Ridge of sand or gravel deposited by wave action on the shore just above the normal high water mark.
Breaker zone	Area in the sea where the waves break.
Coastal squeeze	The reduction in habitat area which can arise if the natural landward migration of a habitat under sea level rise is prevented by the fixing of the high water mark, e.g. a sea wall.
Downdrift	Direction of alongshore movement of beach materials.
Ebb-tide	The falling tide, part of the tidal cycle between high water and the next low water.
Fetch	Length of water over which a given wind has blown that determines the size of the waves produced.
Flood-tide	Rising tide, part of the tidal cycle between low water and the next high water.
Foreshore	Zone between the high water and low water marks, also known as the inter-tidal zone.
Geomorphology	The branch of physical geography/geology which deals with the form of the Earth, the general configuration of its surface, the distribution of the land, water, etc.
Groyne	Shore protection structure built perpendicular to the shore; designed to trap sediment.
Mean High Water (MHW)	The average of all high waters observed over a sufficiently long period.
Mean Low Water (MLW)	The average of all low waters observed over a sufficiently long period.
Mean Sea Level (MSL)	Average height of the sea surface over a 19-year period.
Offshore zone	Extends from the low water mark to a water depth of about 15 m and is permanently covered with water.
Storm surge	A rise in the sea surface on an open coast, resulting from a storm.
Swell	Waves that have travelled out of the area in which they were generated.
Tidal prism	The volume of water within the estuary between the level of high and low tide, typically taken for mean spring tides.
Tide	Periodic rising and falling of large bodies of water resulting from the gravitational attraction of the moon and sun acting on the rotating earth.
Topography	Configuration of a surface including its relief and the position of its natural and man-made features.
Transgression	The landward movement of the shoreline in response to a rise in relative sea level.
Updrift	Direction opposite to the predominant movement of longshore transport.
Wave direction	Direction from which a wave approaches.
Wave refraction	Process by which the direction of approach of a wave changes as it moves into shallow water.

Preamble

The Cell 1 Regional Coastal Monitoring Programme covers approximately 300km of the north east 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 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.



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 data collection, analysis and reporting is being undertaken as a partnership between 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
- walk-over surveys

The present report covers the **Aerial Photography Survey 2010** and provides details of this 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, and aerial photography.

1 Introduction

1.1 Scope of work

Coastal Sediment Cell 1 runs from St Abbs Head, north of Berwick-upon-Tweed, to Flamborough Head in the East Riding of Yorkshire. This report forms a component of the Cell 1 coastal monitoring programme being undertaken by Halcrow and Royal Haskoning for a consortium of local authorities coordinated by Scarborough Borough Council.

The purpose of this report is to review aerial survey data collected in Spring 2010 for the whole of Cell 1, and to document notable changes based on a visual comparison with orthorectified aerial photographs collected in the past.

In addition to this report, GIS data providing a map of all cliff behaviour units (CBUs) in Cell 1 has been produced. Each CBU is classified by cliff type using the methodology developed for Defra1 and used in the National Coastal Erosion Risk Management (NCERM) project currently being developed by Halcrow for the Environment Agency.

1.2 Specification of the 2010 aerial survey

The aerial survey undertaken in spring 2010 comprised the following datasets:

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

All data were delivered in 0.25km^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, vertical imagery and LiDAR surveys were not synchronous, but were instead captured as close together as possible.

1.3 Data assessed

The coastline of Cell 1 has been the subject of a number of aerial surveys in the past 10 to 15 years. However, until the current cell-wide monitoring programme was developed, coastal monitoring was the responsibility of different coastal groups, resulting in surveys being uncoordinated and data being stored in different formats. Consequently, the assessment of change along different sections of Cell 1 has been based on different dates for photography:

- For Berwick-upon-Tweed to Staithes the assessment compares 2010 GIS-based imagery with 1999 data in Cities Revealed Viewer (.crv) format;
- From Staithes to Speeton in the south of Filey Bay, the assessment compares 2010 and 2003 GIS-based imagery; and
- For the small section of coast between Speeton and Flamborough Head, the assessment again compares 2010 GIS-based imagery with 1999 data in Cities Revealed Viewer (.crv) format.

Data held in CRV format are not compatible with ArcView GIS, and therefore cannot be directly overlain or compared with the 2010 data. It is possible to export data from CRV format to an ArcView compatible TIFF, but the process is time consuming, and was not required for the qualitative visual comparisons undertaken. However, should the amount of coastal change between different epochs of photography need to be quantified in the

[1] Lee EM and Clark A 2002 Investigation and Management of Soft Rock Cliffs. Thomas Telford.

future, data in CRV format will need to be exported to TIFF format to allow direct comparison with the 2010 data in GIS. The 1999 CRV format survey also covers the coast from Staithes to Speeton so it would be possible to identify selected hotspots from the qualitative regional study and then undertake more detailed analysis for the three sets of images.

The details of the specific datasets being assessed in this document are summarised in Table 1. All assessments undertaken are based on vertical orthorectified imagery, and no comparison has been made between oblique images. There is currently no data on the accuracy of the orthorectified imagery (i.e. fit between position of features in the photography and the corresponding small scale Ordnance Survey mapping). The root mean square error (RMSE) of the 2010 data was specified at ±10cm. A visual comparison of 25cm resolution data from 1999 and the newly acquired 10cm resolution from 2010 is shown in Figure 1.

Table 1. Details of vertical aerial imagery used in this assessment

Year Flown	Format	Resolution	Coverage	GIS compatibility
1999	Orthorectified images (.CRV)	25 cm	Whole of Cell 1	Yes, if exported from Cities Revealed Viewer
2003 (June to August)	Orthorectified images (.SID)	12.5 cm	Just SBC frontage	Yes
2008	Orthorectified images (.SID)	12.5 cm	NECAG frontage	Yes
2010 (May to June)	Orthorectified images (.ECW)	10 cm	Whole of Cell 1	Yes

Figure 1. Qualitative comparison of vertical imagery from 1999 and 2010, highlighting landslide reactivation at Cayton Bay.

1.4 Methodology

The newly-acquired 2010 aerial photography was compared with previous surveys from 1999, 2003 and 2008. An example of change between 1999 and 2010 at Cayton Bay is shown in Figure 1, which shows reactivation of the Cayton Bay landslide, headscarp recession and destruction of a number of properties. Areas of change were validated against data collected during past Cell 1 cliff and asset inspection surveys, to identify areas of change requiring further detailed investigation.

Those areas which have undergone a clear change in morphology or level of activity are noted and the changes described in a purely qualitative manner. Most observed changes are minor and localised. Many areas show a reduced vegetation cover in 2010 compared previous imagery. This may be due to antecedent weather conditions and not related to cliff or dune activity, and so care has been taken to ensure documented changes are related to coastal instability or erosion. The assessment runs from north to south. Geographical locations mentioned in the text are based on comparison to 1:50,000 Ordnance Survey data.

1.5 GIS deliverables

In addition to the results of the 2010 survey and this report, the deliverable also includes a bespoke GIS database for each local authority. The GIS allows the user to view the 2010 and 1999 aerial photography and cliff behaviour unit classifications together with an Ordnance Survey basemap in order to gain a detailed insight of specific stretches of coast. The GIS is provided in ArcReader format, which is free software that can be used by any individual or organisation and does not need a licence. Guidance on use of the software is provided on the accompanying DVD.

1.6 Regional overview

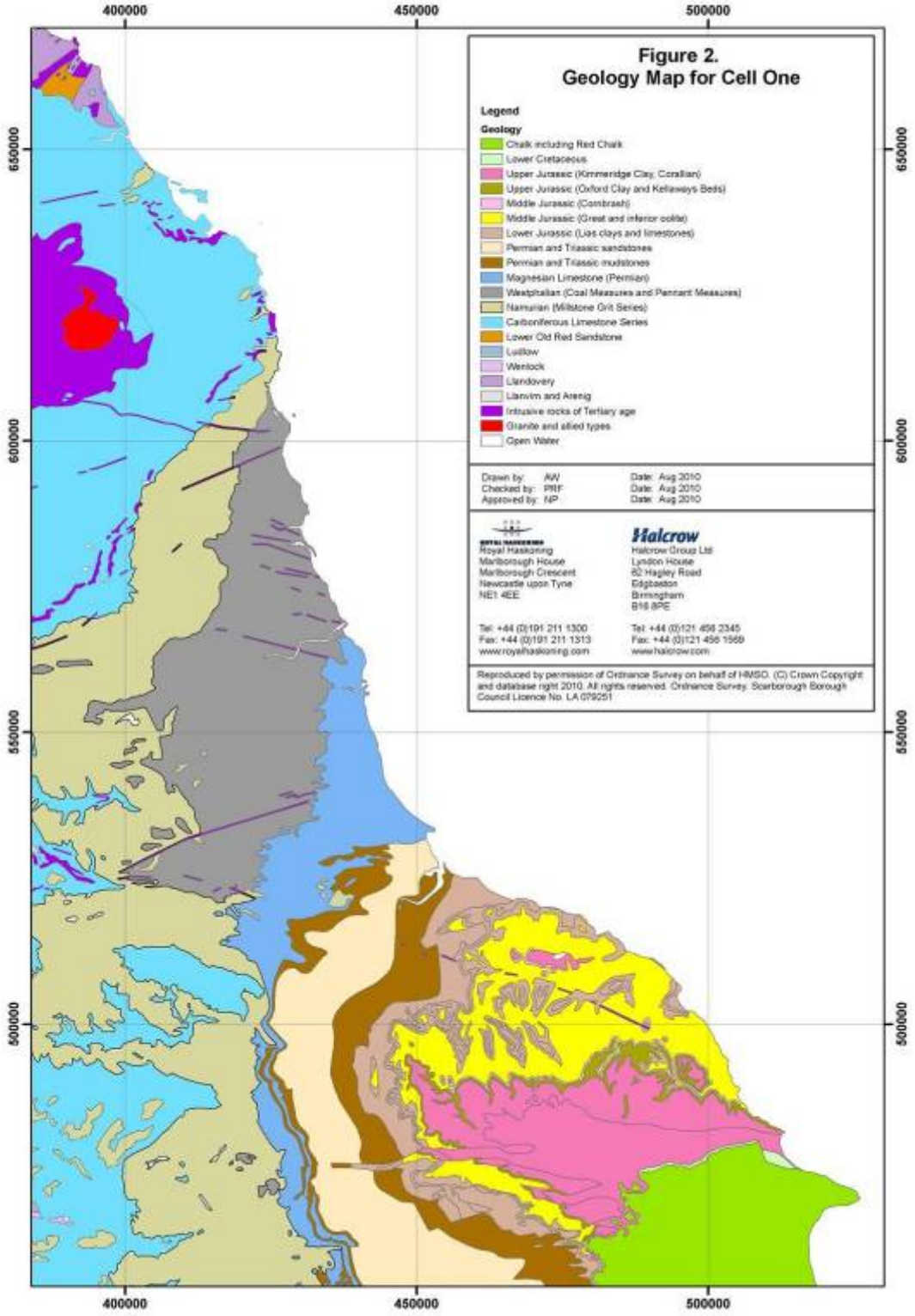
Coastal Sediment Cell 1 has a coastline of approximately 300km on the NE coast of England. Its aspect is generally northeast facing, but there is considerable local variation due to the underlying solid and drift geology which play a significant control on the coastal geomorphology (Figure 2). The bedrock 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 Alnmouth to Hartley and the North Tyneside coast from Hartley to Tynemouth is 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 cliffline. 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 monitoring 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 Cliff behaviour units

2.7 Methodology

Cliff behaviour units (CBU) provide a framework for understanding and management of cliff recession developed by Lee and Clark (2002) for Defra. A CBU spans the nearshore to the cliff top and is coupled to adjacent units with coastal sediment cells. CBUs are cascading sediment supply systems, with input from the cliff top, through put via the cliff face and output via the cliff toe. The classification scheme for CBUs recognises the variation in throughput and storage of sediment within the cliff system (Figure 3):

- **Simple cliffs** (topples and falls) comprise a single sequence of sediment inputs and outputs with limited intervening storage. Rates of cliff recession and sediment supply to the beach are therefore considered to be constant through time. Examples include the Silurian shale cliffs of St Abbs Head, the Jurassic cliffs of Bempton and pasts of Flamborough Head.
- **Simple landslides** (rotational landslides or mudslides) comprise a single sequence of sediment inputs and outputs with variable amounts of intervening storage within the failed mass. Rates of cliff recession and sediment supply to the beach are therefore considered to be episodic through time. Examples include the till cliffs of Sandsend and Hunmanby Gap
- **Composite systems** comprise a partly coupled sequence of different simple cliff sub-systems whereby the output from the upper system may fail directly to foreshore and not form an input to the lower cliff system. Examples are where near-vertical limestone simple cliffs are overlain by glacial sediment which fails through simple landslides. Failure of the till capping can be independent of recession of the underlying cliff and therefore these systems have annual and episodic components. Examples are common where a thick layer of glacial sediment overlies a simple cliff such as at Flamborough Head
- **Complex cliffs** comprise a series of interlinked sub-systems each with unique inputs and outputs. Complex cliffs are rare on the NE coast.
- **Dormant cliffs** (dormant, reactivated or slop-over-wall) comprise sequences of pre-existing landslide sequences which are currently stabilised by engineering, but which may be reactivated by climate change or failure of coastal defences. Dormant cliffs are also formed where fronting beaches or dunes have developed to protect the cliff. This process can be natural, such as at Bamburgh, where the once coastal castle is now fronted by an extensive beach and dune system, or in response to human activity, such as a Blast Beach, Horden, where colliery spoil deposits have afforded cliff protection.

This classification scheme also underpins the National Coastal Erosion Risk Management (NCERM) project currently being developed by Halcrow for the Environment Agency (Moore et al. 2010 [2]). NCERM seeks to model the implications of climate change to different CBUs so that coastal evolution can be better understood (Table 2).

[2] Moore R, Rogers J, Woodget A and Baptiste A (2010) Climate change impact on cliff instability and erosion. EA conference on Flood and Coastal Risk Management, 28th June to 1st July 2010.

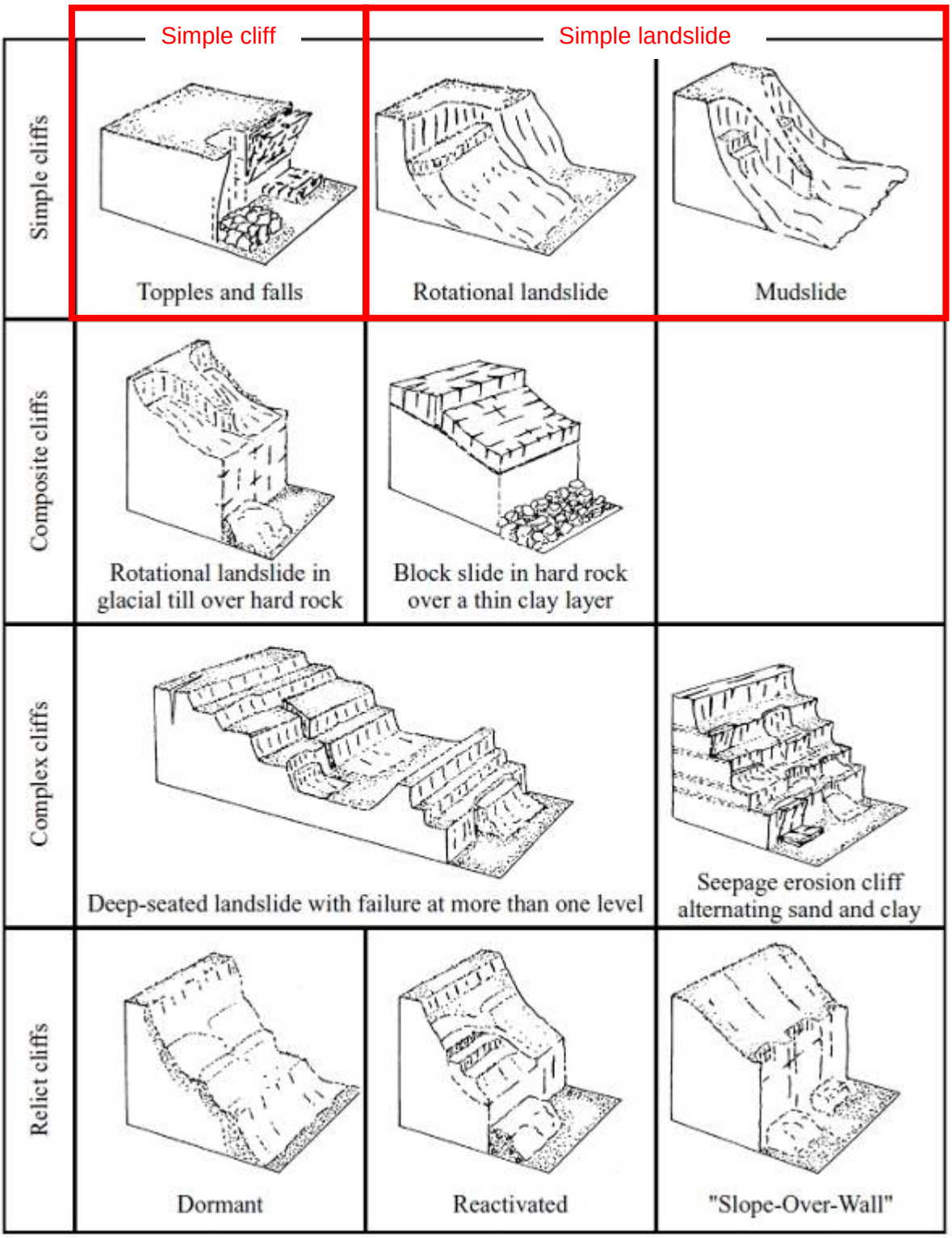


Figure 3. The key cliff behaviour unit (CBU) types

Table 2. Cliff behaviour unit recession mechanisms

Cliff Type	Periodicity of major recession events (years)	Response to increased toe erosion	Response to elevated groundwater	Northeast coast examples	Picture
1. Simple cliff	$1 - 10^1$	very rapid	moderate	St Abbs Head	
2. Simple landslide	$10^1 - 10^2$	rapid	rapid	Sandsend, Whitby; Hunmanby Gap, Filey Bay	

Cliff Type	Periodicity of major recession events (years)	Response to increased toe erosion	Response to elevated groundwater	Northeast coast examples	Picture
3. Composite	10^2 - 10^3	slow/moderate	moderate	Flamborough Head; Bempton Cliffs	
4. Complex	10^2 - 10^3	moderate	moderate to rapid	Cayton Bay and Tennants' Cliff; Flat Cliff, Filey	
5. Dormant	Variable	moderate to rapid	moderate to rapid	Scarborough South and North Bays; Blast Beach, Horden	

CBUs have previously been mapped and classified for the frontages managed by Scarborough Borough Council, East Riding of Yorkshire Council and Redcar and Cleveland Borough Council. The coastline to the north of Redcar and Cleveland generally has cliffs of more simple types, together with extensive areas of sand dunes, and CBUs have not previously been mapped along this frontage.

The tasks undertaken for this study has therefore been to:

- Validate all previously mapped and classified CBUs in the southern part of Cell 1 using the 2010 aerial imagery; and
- Undertake new mapping and classification of cliffs in the north of Cell 1 to create a complete dataset.

Non-cliffed frontages have not been mapped or classified at this stage. Therefore much of the northern section of Cell 1, which is dominated by dunes or a low elevation coastal hinterland, has not been mapped.

2.8 Results

The mapping exercise has resulted in 453 individual cliff units being mapped. Of these, 157 are simple landslides, 146 are composite cliffs, 83 are simple cliffs, 36 are complex cliffs, and 31 are dormant. The spatial distribution of CBUs is presented in Figures 4 to 8

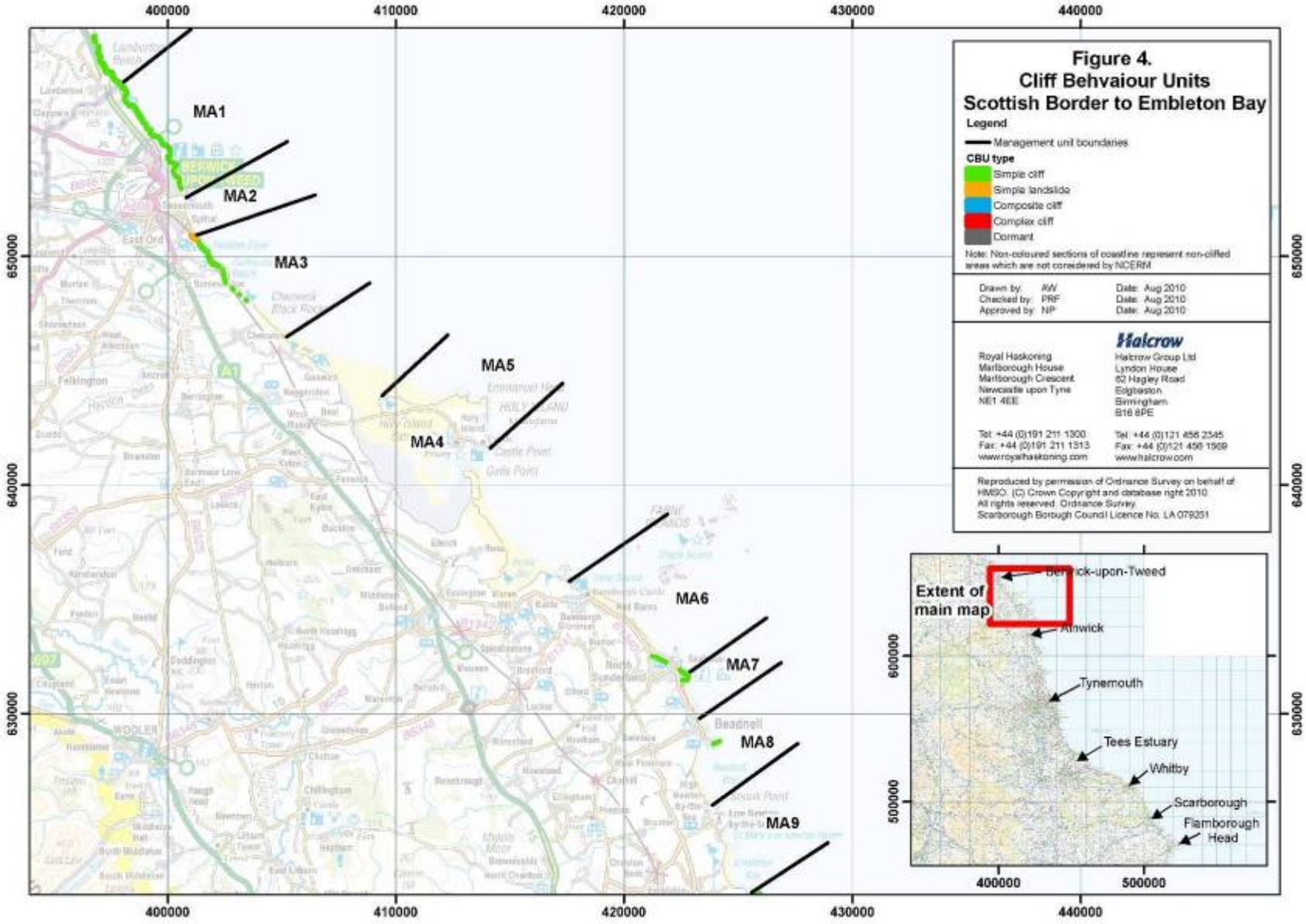

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Figure 4.
Cliff Behvaiour Units
Scottish Border to Embleton Bay
Legend
Management unit boundaries
CBU type
Simple cliff
Simple landslide
Composite cliff
Complex cliff
Cormant
Note: Non-coloured sections of coastline represent non-cliffed areas which are not considered by NCERM
Drawn by: AW Date: Aug 2010
Checked by: PRF Date: Aug 2010
Approved by: NP Date: Aug 2010
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Extent of main map
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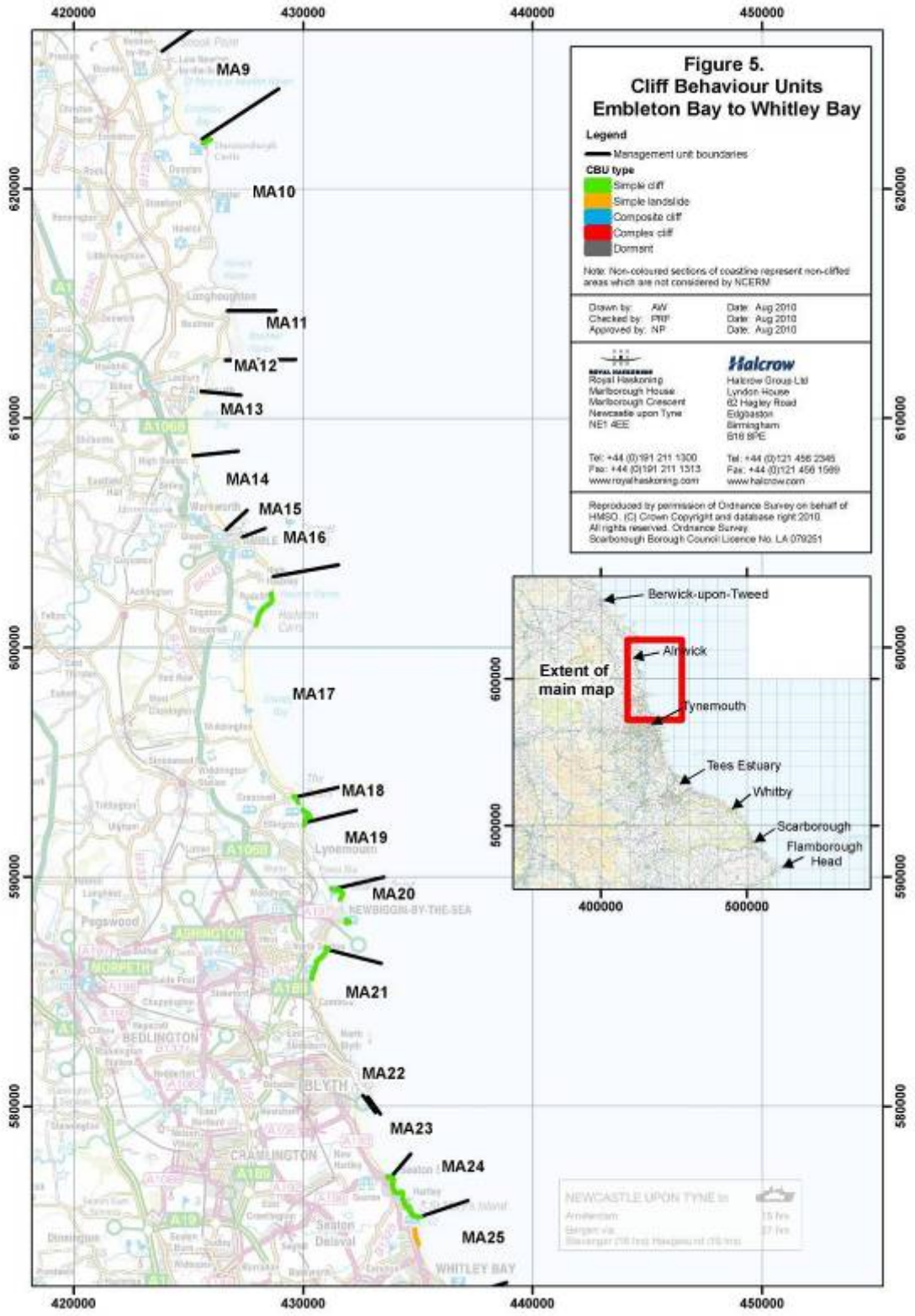
Figure 5.
Cliff Behaviour Units
Embleton Bay to Whitley Bay
Legend
Management unit boundaries
CBU type
Simple cliff
Simple landslide
Composite cliff
Complex cliff
Dormant
Note: Non-coloured sections of coastline represent non-cliffed areas which are not considered by NCERM
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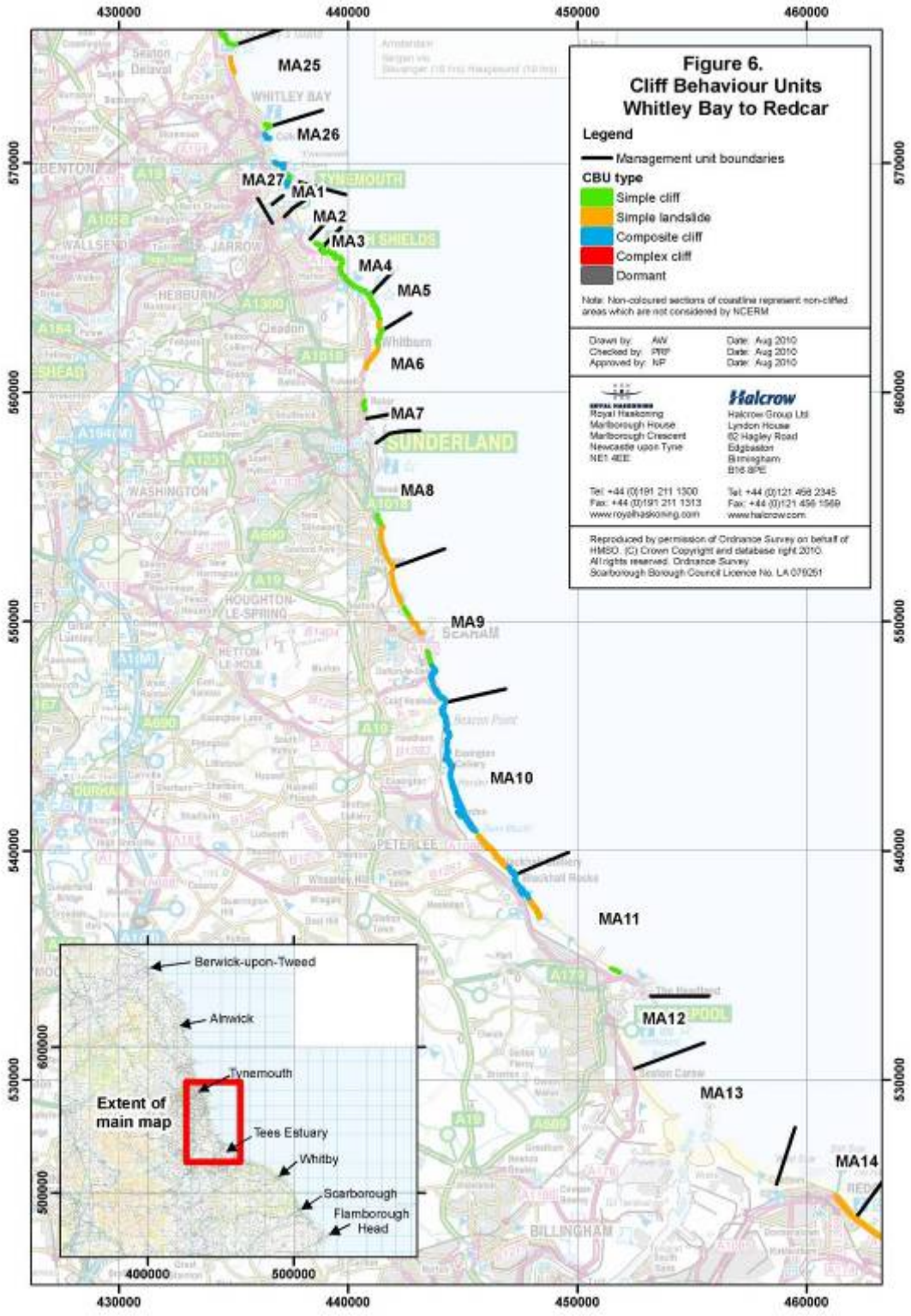
Figure 6.
Cliff Behaviour Units
Whitley Bay to Redcar
Legend
Management unit boundaries
CBU type
Simple cliff
Simple landslide
Composite cliff
Complex cliff
Dormant
Note: Non-coloured sections of coastline represent non-cliffed areas which are not considered by NCERM
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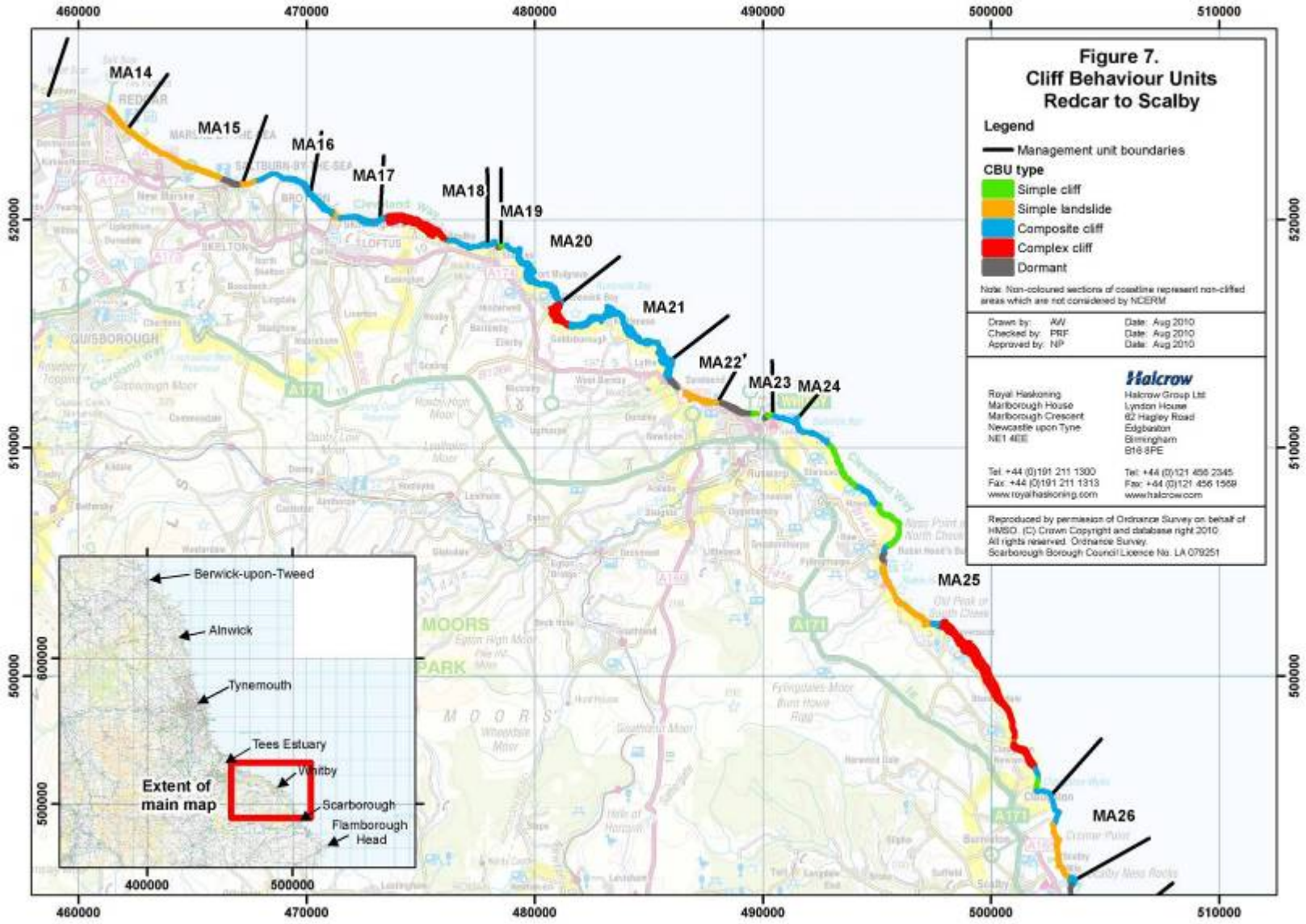
Figure 7.
Cliff Behaviour Units
Redcar to Scalby
Legend
Management unit boundaries
CBU type
Simple cliff
Simple landslide
Composite cliff
Complex cliff
Dormant
Note: Non-coloured sections of coastline represent non-cliffed areas which are not considered by NCERM
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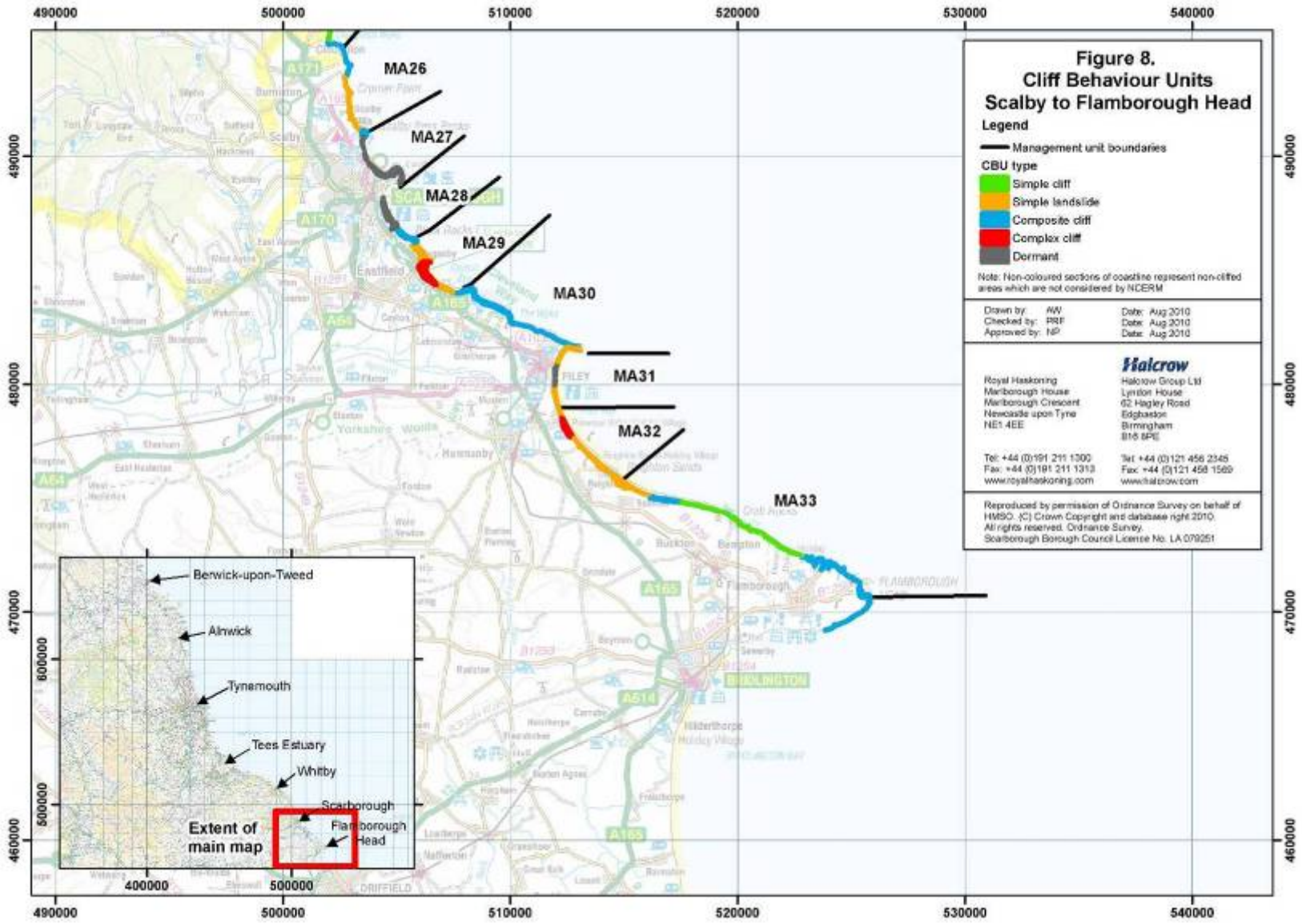
Figure 8.
Cliff Behaviour Units
Scalby to Flamborough Head
Legend
Management unit boundaries
CBU type
Simple cliff
Simple landslide
Composite cliff
Complex cliff
Dormant
Note: Non-coloured sections of coastline represent non-cliffed areas which are not considered by NCERM
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3 Changes detected

3.9 Introduction

This section documents the results of the qualitative comparison of historical aerial photography against the 2010 data. The SMP2 Policy Unit codes have been specified to help locate areas of change given below. Maps 9 to 13 highlight the locations of identified change.

3.10 Areas of Change – Cell 1a Scottish Border to River Tyne (1999-2010)

Sharper's Head, Berwick-upon-Tweed (PU1.2): Small areas of vegetation have disappeared within the cliffs near the caravan park since 1999 indicating on-going recent activity. This is consistent with the observations from recent asset inspections.

Saltpan Rocks, Berwick-upon Tweed (PU3.1): Small scale cliff top recession appears to be ongoing towards a road. This supports local ground inspection in that there appears to be recession of the backshore but with the capacity of the system to rebuild the general foreshore. The aerial photographs provide a longer term context within which to assess this underlying behaviour.

Ross Back Sands, Belford (PU4.4): The vegetation limit appears to have moved seaward indicating suggesting that the dunes have advanced, or that recent storm conditions have reduced. This is consistent with the observations from recent asset inspections.

Budle Point, Bamburgh (PU4.5): The dune front to the west appears to be receding while in front of Budle Point, it appears to be advancing. Recession of small sections of cliff just to the east of Budle Point is occurring, resulting in deepening of small bays. Any comment on position of the main channel through the extensive bar to the Bay. The indication from the ground inspections have been that the growth At Budle Point has influenced the position of the channel with knock-on impact on the coast.

Seahouses (PU6.1 to PU6.2): The removal of a number of blocks (possible coastal defences) from the storm beach along St Aidain's Dunes has occurred between 1999 and 2010. A small lake has also been created on the cliff top since 1999 behind the B1340 road.

Beadnell Bay (PU8.3): Vegetation density has increased on the blowouts of dunes fronting the caravan park, suggesting increased dune stability. Local erosion has been noted from ground inspection between 2008 and 2010.

Embleton Bay, Embleton PU9.3 to PU9.4): Small scale movement of the dunes fronts has occurred since 1999, with the dunes advancing in the north, towards Newton Haven, as recession to the south towards the golf course. Some changes in the general alignment of the estuary have also occurred since 1999.

Cushat Stiel, Craster (PU10.1): Small scale recession of the cliff top appears to have occurred just to the south of Cushat Stiel since 1999.

Howdiemont Sands, Longhoughton (PU10.3): Small scale and localised recession of the cliffs has occurred between 1999 and 2010.

Seaton Point Caravan Park, Longhoughton (PU12.1): Recession of the vegetation limit associated with the dune front has occurred along the east side of the caravan park since 1999, suggesting that the dunes are locally receding landward.

Alnmouth (PU13.2): The vegetation limit marking the dune front has advanced since 1999 between the golf course car park and the Aln estuary, suggesting the net seaward movement of the dunes between 1999 and 2010. Site monitoring suggests that this net trend masks a more complex spatial and temporal pattern of dune and estuary change.

Birling Carrs, Warkworth (PU14.1): Between 1999 and 2010 there has been recession of the dune vegetation limit in front of the golf course at Birling Carrs.

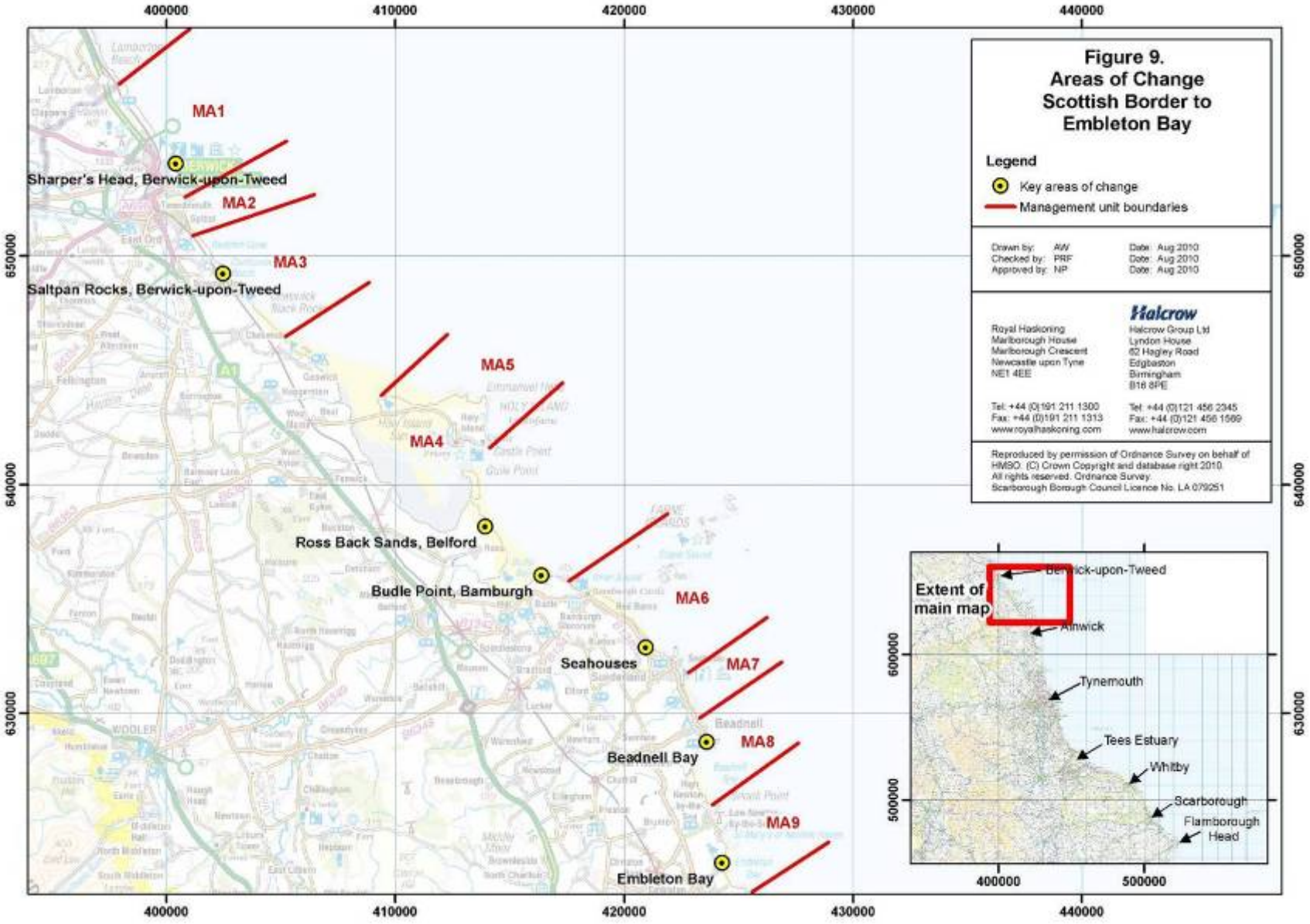
Figure 9.
Areas of Change
Scottish Border to
Embleton Bay
Legend
Key areas of change
Management unit boundaries
Drawn by: AW Date: Aug 2010
Checked by: PRF Date: Aug 2010
Approved by: NP Date: Aug 2010
Royal Haskoning
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NE1 4EE
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MA1
Sharper's Head, Berwick-upon-Tweed
MA2
MA3
Saltpan Rocks, Berwick-upon-Tweed
MA4
MA5
Ross Back Sands, Belford
Budle Point, Bamburgh
MA6
Seahouses
MA7
Beadnell Bay
MA8
MA9
Embleton Bay
Extent of main map
Berwick-upon-Tweed
Alnwick
Tynemouth
Tees Estuary
Whitby
Scarborough
Flamborough Head
400000
410000
420000
430000
440000
650000
640000
630000
600000
500000

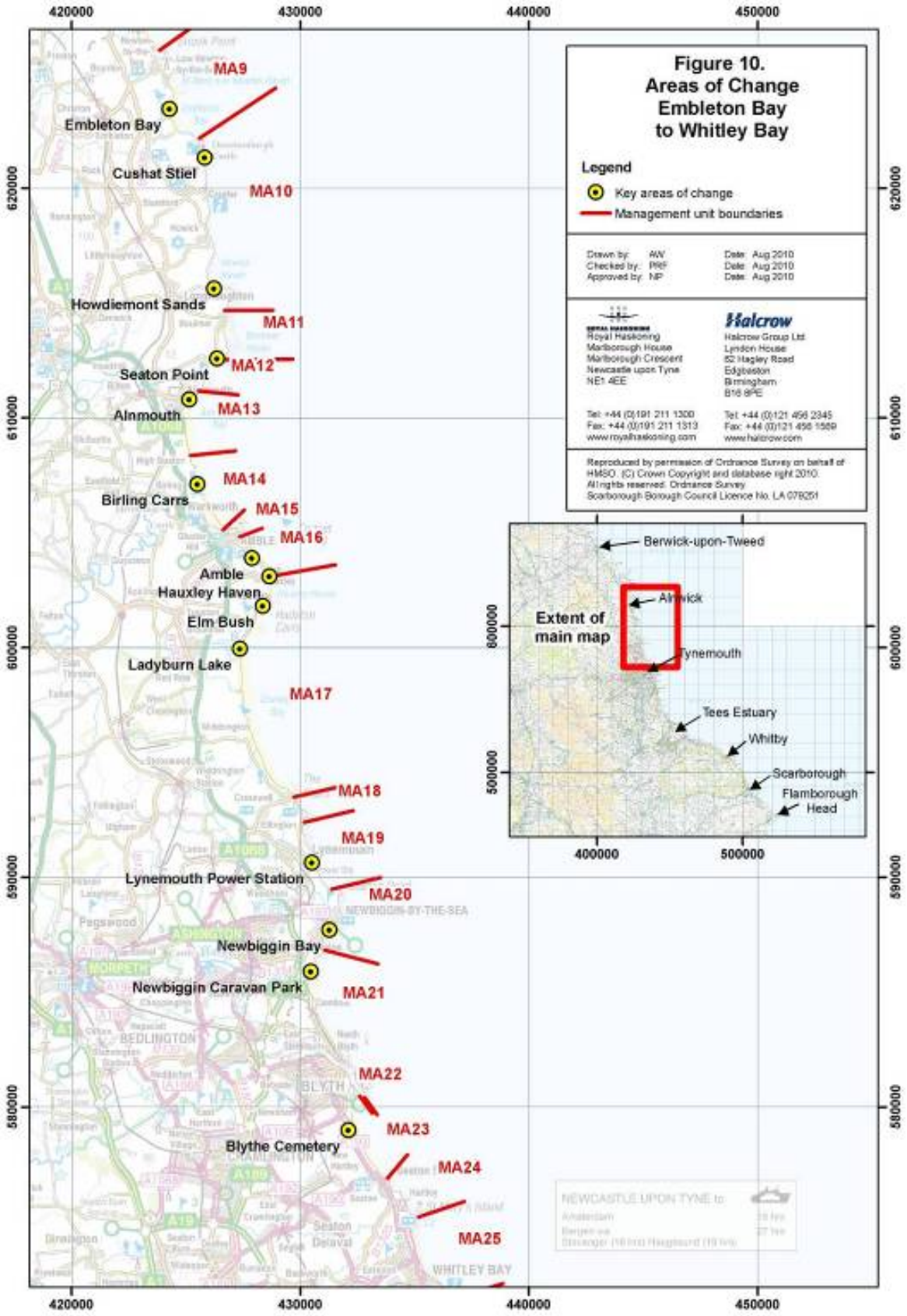
Figure 10.
Areas of Change
Embleton Bay
to Whitley Bay
Legend
Key areas of change
Management unit boundaries
Drawn by: AW Date: Aug 2010
Checked by: PRF Date: Aug 2010
Approved by: NP Date: Aug 2010
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Extent of main map
Berwick-upon-Tweed
Alnwick
Tynemouth
Tees Estuary
Whitby
Scarborough
Flamborough Head
MA9
Embleton Bay
Cushat Stiel
MA10
Howdiemont Sands
MA11
MA12
Seaton Point
MA13
Alnmouth
MA14
Birling Carrs
MA15
MA16
Amble
Hauxley Haven
Elm Bush
Ladyburn Lake
MA17
MA18
MA19
Lynemouth Power Station
MA20
Newbiggin Bay
Newbiggin Caravan Park
MA21
MA22
MA23
Blythe Cemetery
MA24
MA25
420000
430000
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450000
620000
610000
600000
590000
580000
500000
400000

Amble (PU16.3): There has been development of the caravan park including an increase in the extent of the road network, but no detectible change in the coastline.

Hauxley Haven, Amble (PU16.3 to PU17.1): Broad scale recession of the dune fronts to the north of Hauxley Haven appear to have occurred since 1999, as well as some small scale dune erosion in the vicinity of the car park.

Elm Bush, Amble (PU17.3): There appears to be an increase in coarse sediment on the beach in 2010 compared to 1999. Just north of Elm Bush, at the Bondi Carrs headland, site inspections have demonstrated continued erosion, but this was not clearly evident from the aerial photos.

Ladyburn Lake, Druridge Bay (PU17.3): The dune front in this area appears to have advanced seaward between 1999 and 2010.

Lynemouth Power Station (PU19.1): The slag bank which lies to the immediate north of the power station is open to the sea and shows evidence of significant erosion and landward recession between 1999 and 2010.

Newbiggin Bay (PU20.3 to 21.4): Since 1999 an offshore rock barrier has been built in the middle of the bay. This structure retains extensive beach recharge in the area.

Newbiggin Caravan Park (PU21.2): Between 1999 and 2010 there has been some minor headscarp recession just north of the Caravan Park. A pylon present in this location in 1999 seems to have been removed by 2010. Cliff top retreat is also evident over this timescale at the very south of the caravan site.

Near Blyth Cemetery (PU23.3): Just south of the cemetery, which sits on the cliff top, is an area of dunes which appear to have advanced seaward between 1999 and 2010. This example is given in Table 3.

Short Sands, King Edwards Bay, Tynemouth (PU26.6): The northern extent of the back of the bay appears to be lacking in vegetation cover in 2010. This suggests some recent dune activity

Location	Near Blyth Cemetery (PU23.3)
Observed changes	Area of sand dunes within small embayment have advanced seaward
1999 	**2010** 

Table 3. Example of change near Blyth Cemetery

Whitburn (PU5.1): Comparison of the 1999 and 2010 imagery indicates that a sinkhole has developed in this location about 20m back from the cliff top.

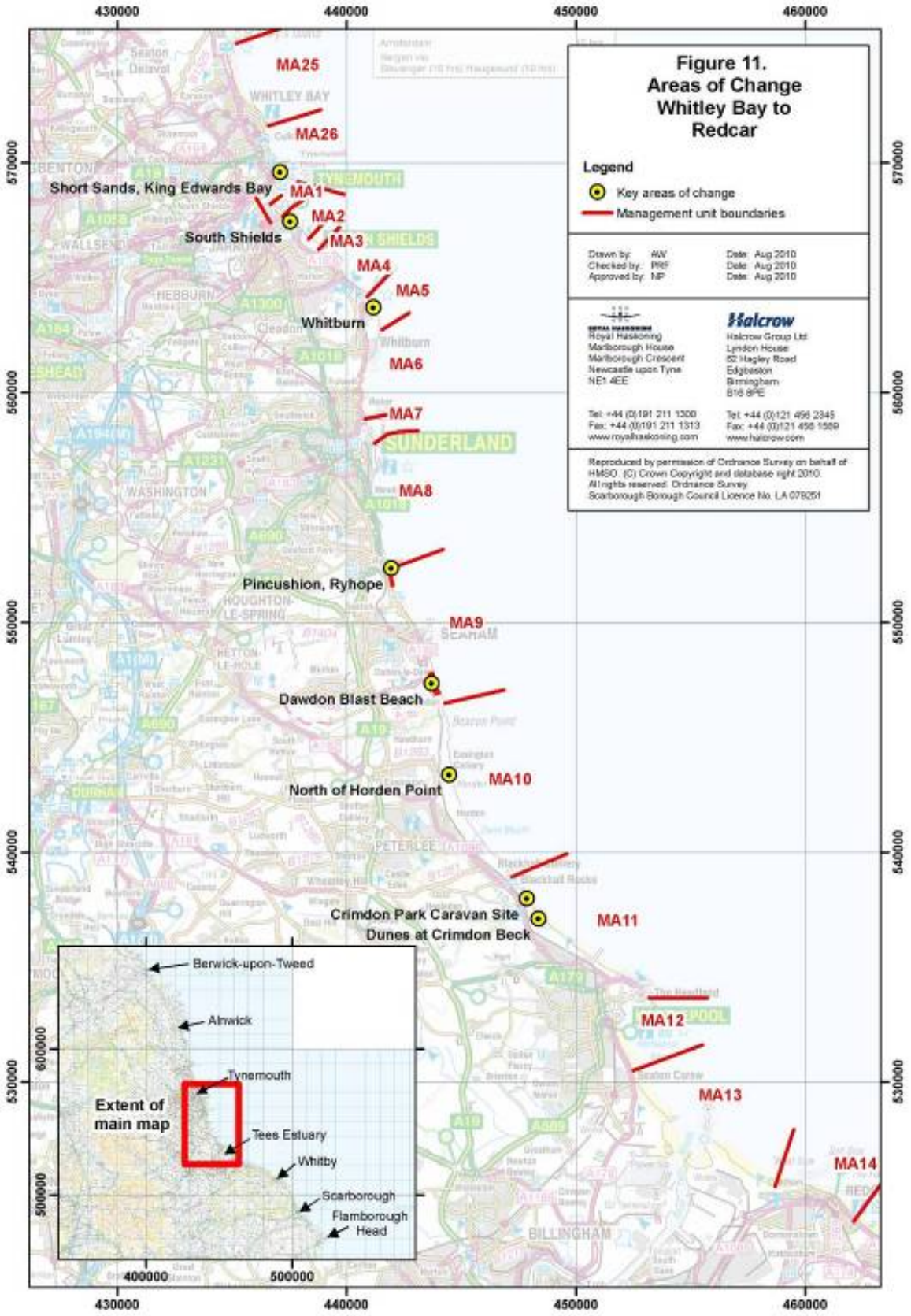
Figure 11.
Areas of Change
Whitley Bay to
Redcar
Legend
Key areas of change
Management unit boundaries
Drawn by: AW Date: Aug 2010
Checked by: PRF Date: Aug 2010
Approved by: NP Date: Aug 2010
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MA25
MA26
Short Sands, King Edwards Bay
MA1
MA2
South Shields
MA3
MA4
MA5
Whitburn
MA6
MA7
MA8
Pincushion, Ryhope
MA9
Dawdon Blast Beach
MA10
North of Horden Point
Crimdon Park Caravan Site
Dunes at Crimdon Beck
MA11
MA12
MA13
MA14
Berwick-upon-Tweed
Alnwick
Tynemouth
Extent of main map
Tees Estuary
Whitby
Scarborough
Flamborough Head
430000
440000
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Coastline at 'Pincushion' rock, Ryhope (PU8.4 to PU9.1): This section of coastline is experiencing ongoing development of active embayments. As a result, the bay head appears to be further landward in 2010 than it was in 1999.

Dawdon Blast Beach (PU9.7): This beach was used for coal waste tipping before the closure of the colliery in 1991. Since this time, erosion of the colliery spoil from the surface of the beach and redistribution in the coastal system by marine action has led to significant changes in beach geomorphology. The spoil has been eroded landward and the thickness of material reduced, particularly at the north end of the beach. This is clearly evident in the comparison of imagery from 1999 and 2010, as shown in Table 4.

3.11 Areas of Change – Cell 1b River Tyne to Chourdon Point, Seaham (1999-2010)

The SMP2 Policy Unit codes have been specified to help locate areas of change given below.

South Shields (PU2.1): The section of coastline immediately south of Tynemouth's South Pier is fronted by sand dunes in 1999. By 2010 the dune frontage has retreated landward. In some places this retreat is in excess of 50m.

Location	Dawdon Blast Beach (PU9.7)
Observed changes	Erosion of colliery spoil from beach, particularly notable at the northern end of the beach
1999	**2010**
	

Table 4. Example of change at Dawdon Blast Beach

3.12 Areas of Change – Cell 1c Chourdon Point, Seaham to Saltburn (1999-2010)

The SMP2 Policy Unit codes have been specified to help locate areas of change given below.

North of Horden Point, near Easington Colliery (PU10.1): At this location there has been headscarp recession, cliff failure and the development of a talus cone on the beach between 1999 and 2010.

Caravan site at Crimdon Park (PU11.1): The 1999 and 2010 imagery indicates that there has been ongoing recession of the headscarp at this location, which is beginning to result in loss of land from the caravan site. This example is shown in Table 5.

Dunes near Crimdon Beck (PU11.1): The 2010 aerial photos show that the dunes just to the north of the Crimdon Beck outlet are more extensive and better vegetated than they were in the 1999 imagery. Site inspections have shown that this area has been subject to

erosion, with the loss of pill box, but the details are these changes were not clearly visible in the imagery.

Location	Crimdon Park Caravan Site
Observed changes	Headscarp recession due to mudsliding which is beginning to impinge on the Caravan Park
1999	**2010**
	

Table 5. Example of change at Crimdon Park Caravan Site

3.13 Areas of Change – Cell 1d Saltburn to Staithes (1999-2010)

This frontage is the responsibility of Redcar and Cleveland Borough Council and the cliff behaviour units have been mapped and described in past coastal inspection reports. To aid comparison, unique CBUs codes as well as SMP2 Policy Unit codes are provided.

Blue Nook, Boulby (E58/1a, PU18.1): A debris cone has formed from the lower part of the cliff at Blue Nook by 2010 which was not present in 1999.

Redhouse Nab to Cowbar Nab, Staithes (E59/4 to E59/1, PU18.1): Since 1999 there has been continued erosion of the soft till capping of the cliffs. The mudslide headscarps have retrogressed significantly since 2003, so that by 2010 the road along the cliff top is being lost and has consequently been redirected inland. At the western corner of Cowbar Nab, erosion is beginning to threaten the road access to properties on the Nab itself. This ongoing activity was also noted during the 2008 and 2010 coastal cliff walkover inspections. This example is shown in Table 6. This area is being monitored.

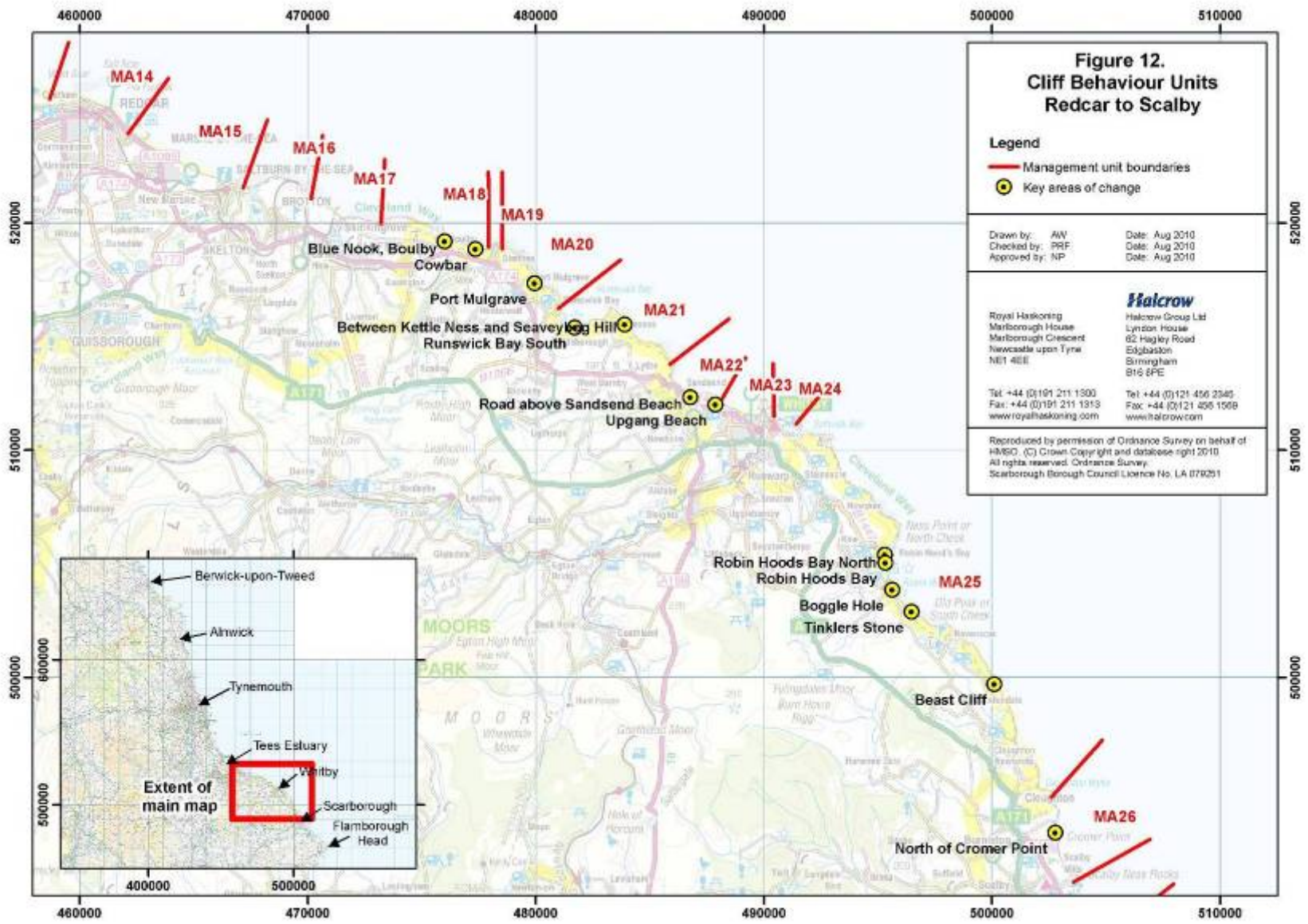
Figure 12.
Cliff Behaviour Units
Redcar to Scalby
Legend
Management unit boundaries
Key areas of change
Drawn by: AW
Checked by: PRF
Approved by: NP
Date: Aug 2010
Date: Aug 2010
Date: Aug 2010
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MA23
MA24
MA25
MA26
Blue Nook, Boulby
Cowbar
Port Mulgrave
Between Kettle Ness and Seaveyhog Hill
Runswick Bay South
Road above Sandsend Beach
Upgang Beach
Robin Hoods Bay North
Robin Hoods Bay
Boggle Hole
Tinklers Stone
Beast Cliff
North of Cromer Point
Berwick-upon-Tweed
Alnwick
Tynemouth
Tees Estuary
Whitby
Scarborough
Flamborough Head
Extent of main map
600000
500000
400000
500000

Location	Between Redhouse Nab and Cowbar Nab, near Staithes (PU18.1)
Observed changes	Mudsliding in upper till layer of the cliffs has caused significant headscarp recession and loss of the old Cowbar Lane

1999	**2010**
	

Table 6. Example of change between Redhouse Nab and Cowbar Nab

3.14 Areas of change – Cell 1d Staithes to Speeton (1999-2003-2008-2010)

This frontage is the responsibility of Scarborough Borough Council and the cliff behaviour units have been mapped and described in past coastal inspection reports. To aid comparison, the unique codes for each CBU are provided together as well as the SMP2 Policy Unit codes.

Port Mulgrave Bay (Mu6/5, PU20.3): An area of landslip visible on the 1999 and 2003 imagery shows extension by the 2010 imagery.

Runswick Bay South (Mu8/1, PU21.2): Continued development of mudslide embayments within this area have led to recession of the cliff line since 1999.

Between Kettle Ness and Seaveybog Hill (Mu8/6, PU21.3): Little change is observed between 1999 and 2003. Where the disused railway line nears the cliff top there appears to have been landslide activity and rockfalls since 2003, leading to cliff recession and development of a talus cone by 2010.

Above Sandsend Beach and coast road (Mu9/3, PU22.3): A comparison of the 2003 and the 2010 imagery shows increased cliff activity just upslope of the road and adjacent to the ravine by 2010. In 1999 the imagery appears to show remediation works being carried out in this area.

Upgang Beach and Whitby golf course (Mu10/2, PU22.4 to PU23.1): There has been ongoing mudslide activity since 1999 within the embayments fronting the golf course, leading to localised cliff recession.

Robin Hoods Bay (Mu16/1 and 16/2, PU25.2): The 2010 imagery shows increased activity to the north of the rock revetment. The cliffs are much less well vegetated than they were in 2003 and the headscarp has shown recession since 1999 which may be affecting gardens on the cliff top. Cliff toe erosion could not be detected.

Robin Hoods Bay (Mu16/2, PU25.2): Sometime between 1999 and 2003, a rock revetment was constructed at the cliff toe of this unit which reduced the levels of activity notably. Between 2003 and 2010 there is little evidence of change.

Robin Hoods Bay (Mu16/3, PU25.1): The undefended section of cliff between the southern end of the rock revetment and the seawall has shown increased activity since 1999. There has been extensive cliff recession of the cliff top at the western side of this section between 2003 and 2010.

South of Boggle Hole (Mu17/4, PU25.1): The cliff section immediately south of the ravine at Boggle Hole is less well vegetated in 2010 than it was in 2003. The cliff top has also shown recession since 1999 so that by 2010 it has retreated back to the footpath and field edge.

Tinklers Stone (Mu17/5 to 17/6, PU25.1): This area shows reduced vegetation cover and increased erosion since 2003. The cliff top has also shown recession back to the footpath and field edge between 1999 and 2010.

Beast Cliff (Mu18/3, PU25.1): The lower part of the complex Beast Cliff showed increased activity from 1999 to 2003 with well developed tension cracks by 2003. By 2010, these have developed into localised landslides.

North of Cromer Point (Mu19/8, PU26.1): Just north of Cromer Point a localised area of increased erosion has developed since 2003.

Castle Cliff, Scarborough (Mu21/2, PU27.2): Behind the road which winds around the headland the 2010 imagery shows evidence of localised rockfall activity which was not visible in 2003 or 1999. Table 7 shows this example.

Old Swimming Pool, promenade north of the Holbeck landslide (Mu22/6, PU28.4): In 1999 this unit featured the South Bay outdoor swimming pool. The 2003 imagery shows works being carried out on the cliffs and promenade here related to the infilling of the old swimming pool and removal of the associated buildings. By 2010 the slope has been re-vegetated and paved behind the promenade.

Cornelian Bay (Mu23/H2b, PU29.1): Comparison of the 1999, 2003 and 2010 images show that there has been ongoing increased activity at mudslide toes in Cornelian Bay. There is reduced vegetation cover and a backscarp has developed mid-slope.

Cornelian Bay South (Mu23/I, PU29.1): Between 1999 and 2010 there has been extensive recession of the headscarp of Cornelian Bay near the Knipe Point development. This was observed during the 2009 coastal cliff walkover survey. Furthermore there has been ongoing erosion of the headland at Knipe Point itself.

Knipe Point Bungalows (Mu24/A, PU29.2): There was little significant change in activity between 1999 and 2003. The 2008 and 2010 imagery shows evidence of the landslide that reactivated early 2008 at the northern end of Cayton Bay. Significant recession of the headscarp with associated loss of property and uplift of the landslide toe at beach level

can be seen in the 2010 image. This activity was noted during the 2008 and 2009 coastal cliff walkover inspections (Table 8).

Location	Castle Cliff, Scarborough (PU27.2)
Observed changes	Localised rockfall activity has occurred since 2003.
1999 	**2010** 

Table 7. Example of change at Castle Cliff, Scarborough

Cayton Bay (Mu24/C to 24/P, PU29.2): Mudsliding of till cliffs in the southern half of Cayton Bay has intensified between 2008 and 2010. This has resulted in ongoing recession of the cliff top, as noted during the 2008 and 2009 coastal cliff walkover inspections.

Lebberston Cliff (Mu25/V and W, PU30.1): Large mudslides at Lebberston Cliff appear to have ongoing activity since 1999 through to 2010, including ongoing headscarp recession.

Three Nabs, between Lebberston Cliff and Gristhorpe Cliff (Mu25/Y, PU30.1): The 2010 and 2008 aerial photos show localised recent activity at the headscarp, including cliff top recession which is directly impacting the Cleveland Way footpath in places. Such activity is less significant on the 1999 and 2003 images.

Newbiggin Cliff to Filey Brigg (Mu26/AJ to Mu27/B, PU30.2): The till capping of the cliffs along this stretch of coastline shows ongoing activity from 1999-2010 with numerous small, active mudslides. This was noted during the 2008 and 2009 coastal cliff walkover inspections.

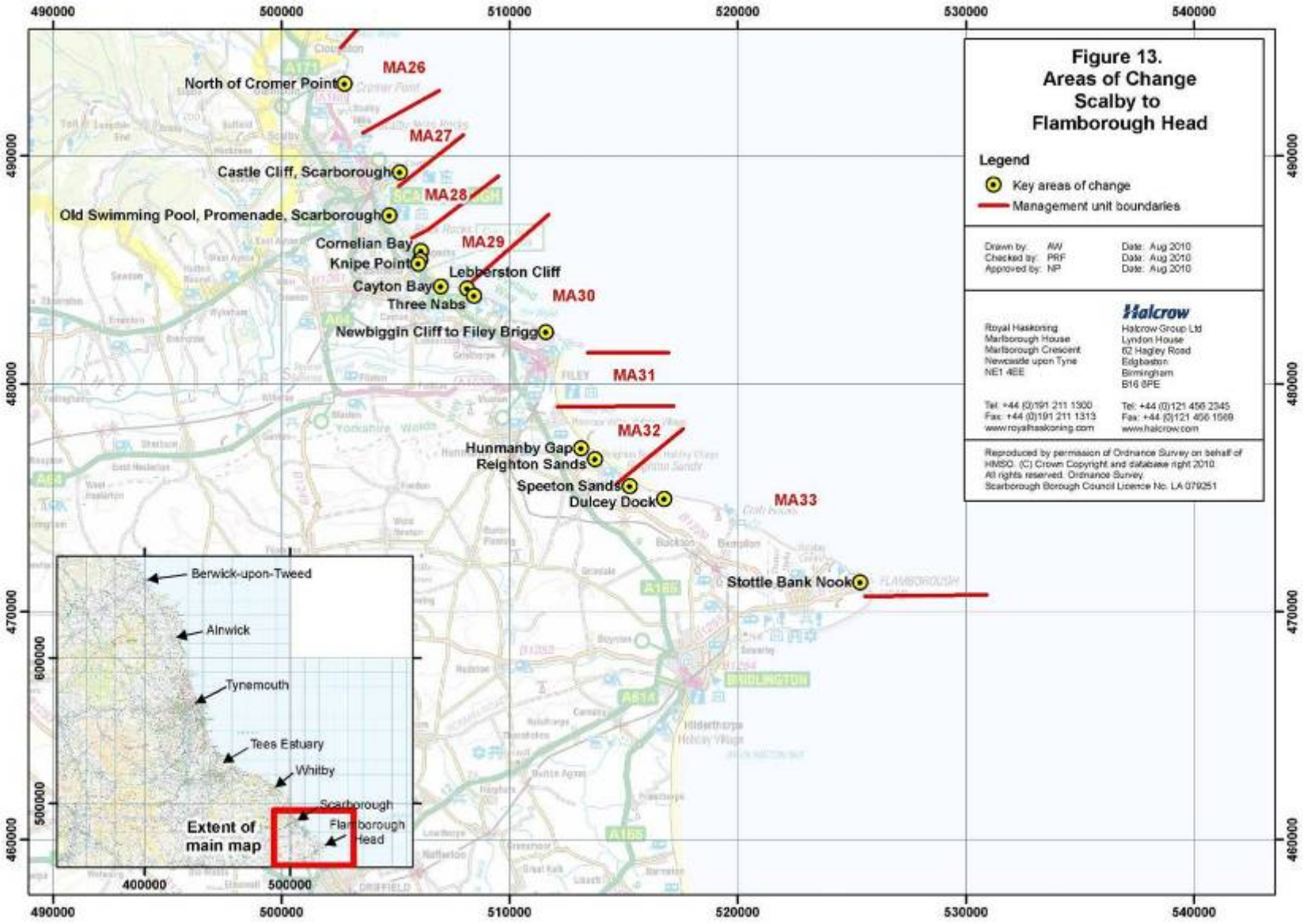
Figure 13.
Areas of Change
Scalby to
Flamborough Head
Legend
Key areas of change
Management unit boundaries
Drawn by: AW Date: Aug 2010
Checked by: PRF Date: Aug 2010
Approved by: NP Date: Aug 2010
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MA31
MA32
MA33
North of Cromer Point
Castle Cliff, Scarborough
Old Swimming Pool, Promenade, Scarborough
Cornelian Bay
Knipe Point
Lebberston Cliff
Cayton Bay
Three Nabs
Newbiggin Cliff to Filey Brigg
Hunmanby Gap
Reighton Sands
Speeton Sands
Dulcey Dock
Stottle Bank Nook
Berwick-upon-Tweed
Alnwick
Tynemouth
Tees Estuary
Whitby
Scarborough
Flamborough Head
Extent of main map
490000
500000
510000
520000
530000
540000
480000
470000
460000
600000
500000
400000

Location	Cornelian Bay south and Knipe Point headland (PU29.1 and 29.2)
Observed changes	Headscarp recession and erosion at the southern end of Cornelian Bay and the Knipe Point headland. Landslide reactivation on the south side of Knipe Point with associated loss of property and beach uplift at the unit toe.
1999 	
2010 	

Table 8. Example of change at Cornelian Bay south and Knipe Point

Hunmanby Gap (Mu29/BE2, PU32.2): There appears to have been a reduction in activity within Hunmanby Gap between 1999 and 2003. However, from 2003 to 2010 there is a notable increase in mudslide activity and cliff recession within Hunmanby Gap and along the ravine which runs inland.

Reighton Sands (Mu29/BQ, PU32.3): In 1999 and 2003, the aerial photos show a mudslide run out lobe present on the beach at the northern end of this unit. By 2008 and 2010 this lobe has been eroded by the sea and is no longer visible on the imagery.

Speeton Sands (Mu29/CE, PU33.1): The southern section of the unit appears to be more active in 2010 and 2008 than it was in 2003. There is a reduced cover of vegetation and

recession of the headscarp is evident. There was little notable change here between 1999 and 2003.

Dulcey Dock (Mu29/CJ, PU33.1): The chalk cliffs in the vicinity of Dulcey Dock are less well vegetated in 2010 than they were in 2003 and 2008, and show signs of recent rockfall activity. This activity was also noted during the 2010 coastal cliff walkover inspection. No significant change can be observed between 1999 and 2003.

3.15 Areas of Change – East Riding of Yorkshire Frontage (1999-2010)

Stottle Bank Nook (golf course) (E111/14, PU33.2): The 1999 and 2010 imagery indicates that headscarp recession through mudslide activity has occurred at this locality and is currently impacting on the route of the cliff top footpath.

<table>
<tr><td>Location</td><td colspan="2">Stottle Bank Nook (PU33.2)</td></tr>
<tr><td>Observed changes</td><td colspan="2">Mudsliding and consequent headscarp recession has made redirection of the cliff top footpath necessary</td></tr>
<tr><td colspan="2">1999
  </td><td>2010
  </td></tr>
</table>

Table 8. Example of change at Stottle Bank Nook

4 Summary and recommendations

4.16 Summary of observations

The review of the high quality orthorectified imagery acquired in 2010 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 past epochs of vertical photography from 2003 and 1999 has highlighted extensive evidence of change, including a general pattern of sand dune accretion in Northumberland and on-going cliff recession through rock falls and mudslides along the coast from Saltburn to Flamborough Head. Little change was detectable on sections of the coastline that are defended, or where cliffs are formed in more resistant rocks which erode at a low rate. This pattern of change confirms the observations made on site during recent cliff inspection surveys.

4.17 Recommendations

In order to make best use of the high quality 2010 data, it is suggested that a more detailed and quantitative comparison be made with past aerial survey data from 1999 and 2003. This work would provide rates of change for each cliff behaviour unit, which, together with the CBU classification, can be directly inputted to the NCERM model to make projections of future cliff recession rate (Figure 14).

In order to generate rates of change for cliff recession, the following tasks are required:

- Digitise cliff top in each epoch of imagery. This will require the 1999 data being exported from .CRV to .TIF format
- Measure changes in cliff top position between each epoch along a series of pre-defined shore normal transects
- Calculate root mean square error for each epoch of imagery to describe its accuracy with respect to the national grid
- Calculate amounts and rates of change, and associated errors, for each cliff behaviour unit.

This work need only be applied to cliffed frontages relevant to NCERM which are generally, but not exclusively, found on the coastline between Saltburn and Flamborough (see Figures 4 to 8). A risk-based approach can be utilised to focus work on the active cliffs which front key assets, such as towns and villages, major highways or environmentally designated areas.

Figure 14. Illustration of quantitative assessment of coastal change from a simple landslide in Filey Bay (purple line is 2003 cliff top, photo is from 2010). 9m recession since 2003 is equivalent to a recession rate of 1.3m/year.