Cell 1 Regional Coastal Monitoring Programme
Analytical Report 5: 'Full Measures' Survey 2012

Redcar and Cleveland Borough Council
Final Report

March 2013

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Abbreviations and Acronyms

Acronym / Abbreviation	Definition
AONB	Area of Outstanding Natural Beauty
DGM	Digital Ground Model
HAT	Highest Astronomical Tide
LAT	Lowest Astronomical Tide
MHWN	Mean High Water Neap
MHWS	Mean High Water Spring
MLWS	Mean Low Water Neap
MLWS	Mean Low Water Spring
m	metres
ODN	Ordnance Datum Newlyn

Water Levels Used in Interpretation of Changes

Water Level Parameter	Water Level (m AOD) Hartlepool Headland to Saltburn Scar	Skinningrove	Hummersea Scar to Sandsend Ness	Sandsend Ness to Saltwick Nab
HAT	3.25	3.18	3.15	3.10
MHWS	2.65	2.68	2.65	2.60
MLWS	-1.95	-2.13	-2.15	-2.20
Water Level Parameter	**Water Level (m AOD) Saltwick Nab to Hundale Point**	**Hundale Point to White Nab**	**White Nab to Filey Brigg**	**Filey Brigg to Flamborough Head**
HAT	3.10	3.05	3.05	3.10
MHWS	2.60	2.45	2.45	2.50
MLWS	-2.20	-2.35	-2.35	-2.30

Source: *River Tyne to Flamborough Head Shoreline Management Plan 2*.
Royal Haskoning, February 2007.

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 intertidal 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 sediment to varying thicknesses, softer rock cliffs and extensive landslide complexes.

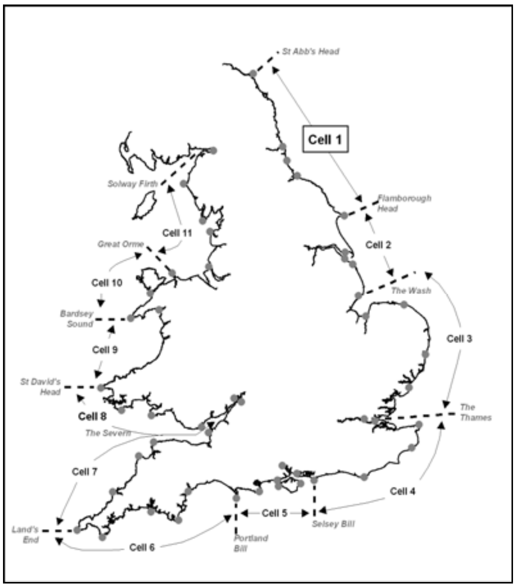


Figure 1 Sediment Cells in England and Wales

The work commenced with a three-year monitoring programme in September 2008 that was managed by Scarborough Borough Council on behalf of the North East Coastal Group. This initial phase has been followed by a five-year programme of work, which started in October 2011. The work is funded by the Environment Agency, working in partnership with the following organisations:

- Northumberland County Council
- Northumberland Coast Area of Outstanding Natural Beauty
- North Tyneside Council
- South Tyneside Council
- Sunderland City Council
- Durham County Council
- Redcar & Cleveland Borough Council
- Hartlepool Borough Council
- Whitby · Scarborough · Filey Borough of Scarborough — A great place to live, work & play
- East Riding of Yorkshire Council
- Environment Agency
- Natural England
- The National Trust

The original three year programme of work was undertaken as a partnership between Royal Haskoning, Halcrow and Academy Geomatics. For the current five year programme of work the data collection associated with beach profiles, topographic surveys and cliff top surveys is being undertaken by Academy Geomatics. The analysis and reporting for the programme is being undertaken by Halcrow.

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 beach profile surveys, topographic surveys and cliff top recession surveys are undertaken as a 'Full Measures' survey in autumn/early winter every year. Some of these surveys are then repeated the following spring as part of a 'Partial Measures' survey.

Each year, an Analytical Report is produced for each individual authority, providing a detailed analysis and interpretation of the 'Full Measures' surveys.

This is followed by a brief Update Report for each individual authority, providing ongoing findings from the 'Partial Measures' surveys.

Annually, a Cell 1 Overview Report is also produced. This provides a region-wide summary of the main findings relating to trends and interactions along the entire Cell 1 frontage.

To date the following reports have been produced:

Table 1 Analytical, Update and Overview Reports Produced to Date

Year		Full Measures		Partial Measures		Cell 1 Overview Report
		Survey	Analytical Report	Survey	Update Report	
1	2008/09	Sep-Dec 08	May 09	Mar-May 09		-
2	2009/10	Sep-Dec 09	Mar 10	Feb-Mar 10	Jul 10	-
3	2010/11	Aug-Nov 10	Feb 11	Feb-Apr 11	Aug 11	Sep 11
4	2011/12	Sep-Oct 11	Oct 12	Mar-May 12	Feb 13	
5	2012/13	Sep 2012 (*)	Mar 13			

* The present report is **Analytical Report 5** and provides an analysis of the 2012 Full Measures survey for Redcar and Cleveland Borough Council's frontage.

In addition, separate reports are produced for other elements of the programme as and when specific components are undertaken, such as wave data collection, bathymetric and sea bed sediment data collection, aerial photography, and walk-over visual inspections.

For purposes of analysis, the Cell 1 frontage has been split into the sub-sections listed in the Table 2.

Table 2 Sub-divisions of the Cell 1 Coastline

Authority	Zone
Northumberland County Council	Spittal A
	Spittal B
	Goswick Sands
	Holy Island
	Bamburgh
	Beadnell Village
	Beadnell Bay
	Embelton Bay
	Boulmer
	Alnmouth Bay
	High Hauxley and Druridge Bay
	Lynemouth Bay
	Newbiggin Bay
	Cambois Bay
	Blyth South Beach
North Tyneside Council	Whitley Sands
	Cullercoats Bay
	Tynemouth Long Sands
	King Edward's Bay
South Tyneside Council	Littehaven Beach
	Herd Sands
	Trow Quarry (incl. Frenchman's Bay)
	Marsden Bay
Sunderland Council	Whitburn Bay
	Harbour and Docks
	Hendon to Ryhope (incl. Halliwell Banks)
Durham County Council	Featherbed Rocks
	Seaham
	Blast Beach
	Hawthorn Hive
	Blackhall Colliery
Hartlepool Borough Council	North Sands
	Headland
	Middleton
	Hartlepool Bay
Redcar & Cleveland Borough Council	Coatham Sands
	Redcar Sands
	Marske Sands
	Saltburn Sands
	Cattersty Sands (Skinningrove)
Scarborough Borough Council	Staithes
	Runswick Bay
	Sandsend Beach, Upgang Beach and Whitby Sands
	Robin Hood's Bay
	Scarborough North Bay
	Scarborough South Bay
	Cayton Bay
	Filey Bay

1. Introduction

1.1 Study Area

Redcar & Cleveland Borough Council's frontage extends from the South Gare breakwater at the mouth of the River Tees to Cowbar Nab, Staithes. For the purposes of this report, report and for consistency with previous reporting, it has been sub-divided into six areas, namely:

- Coatham Sands
- Redcar Sands
- Marske Sands
- Saltburn Sands
- Cattersty Sands (Skinningrove)
- Staithes

The Staithes frontage straddles the boundary of jurisdiction of Redcar & Cleveland Council and Scarborough Borough Council and therefore reporting has been duplicated in both reports.

1.2 Methodology

Along Redcar & Cleveland Borough Council's frontage, the following surveying is undertaken:

- Full Measures survey annually (since 2008) each autumn/early winter comprising:
    - Beach profile surveys along nine transect lines
    - Topographic survey along Coatham Sands
    - Topographic survey along Redcar Sands
    - Topographic survey along Marske Sands
    - Topographic survey along Saltburn Sands
    - Topographic survey along Cattersty Sands
- Partial Measures survey annually each spring (since 2009) comprising:
    - Beach profile surveys along nine transect lines
    - Topographic survey along Redcar Sands
    - Topographic survey along Saltburn Sands
    - Topographic survey along Cattersty Sands
- Cliff top survey annually at:
    - Staithes

The Full Measures survey was undertaken along this frontage in September 2011, when weather conditions were fine and dry and the sea state was calm.

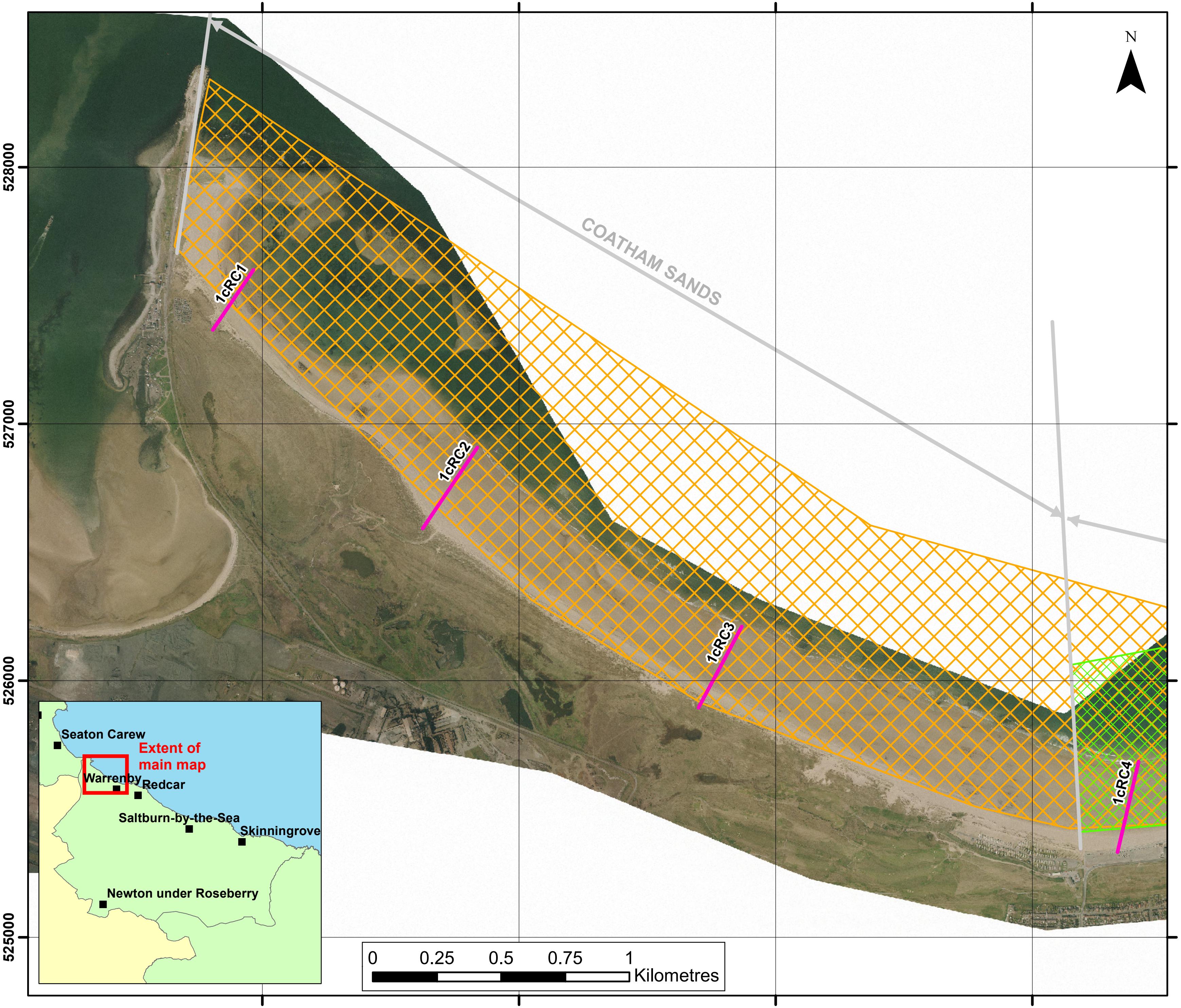
All data have been captured in a manner commensurate with the principles of the Environment Agency's *National Standard Contract and Specification for Surveying Services* and stored in a file format compatible with the software systems being used for the data analysis, namely SANDS and ArcGIS. This data collection approach and file format is comparable to that being used on other regional coastal monitoring programmes, such as in the South East and South West of England.

Upon receipt of the data from the survey team, they are quality assured and then uploaded onto the programme's website for storage and availability to others and also input to SANDS and GIS for subsequent analysis.

The Analytical Report is then produced following a standard structure for each authority. This involves:

- description of the changes observed since the previous survey and an interpretation of the drivers of these changes (Section 2);
- documentation of any problems encountered during surveying or uncertainties inherent in the analysis (Section 3);
- recommendations for 'fine-tuning' the programme to enhance its outputs (Section 4); and
- providing key conclusions and highlighting any areas of concern (Section 5).

Data from the present survey are presented in a processed form in the Appendices.



KEY

Topographic Profiles
- Annual
- 6 monthly

Topographic Surveys
- 6 monthly
- yearly
- 5 yearly

Cliff Top Monitoring Pegs
- 50m centres
- 100m centres
- 300m centres

(Indicative survey extents shown)

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Figure 2 - Map 1
Survey Locations
Coatham Sands
Redcar & Cleveland Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

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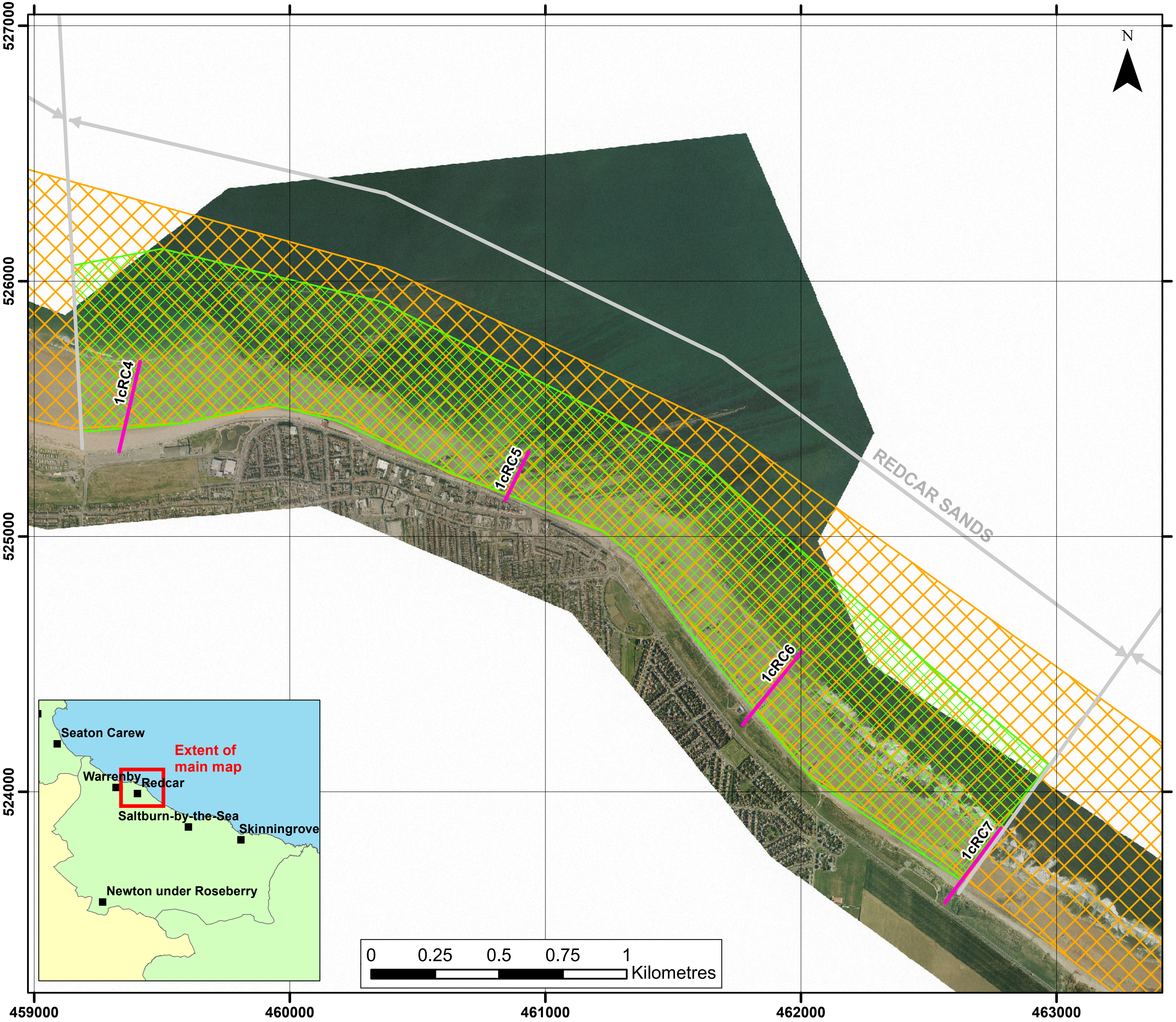

KEY

Topographic Profiles
- Annual
- 6 monthly

Topographic Surveys
- 6 monthly
- yearly
- 5 yearly

Cliff Top Monitoring Pegs
- 50m centres
- 100m centres
- 300m centres

(Indicative survey extents shown)

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Figure 2 - Map 2
Survey Locations
Redcar Sands
Redcar & Cleveland Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

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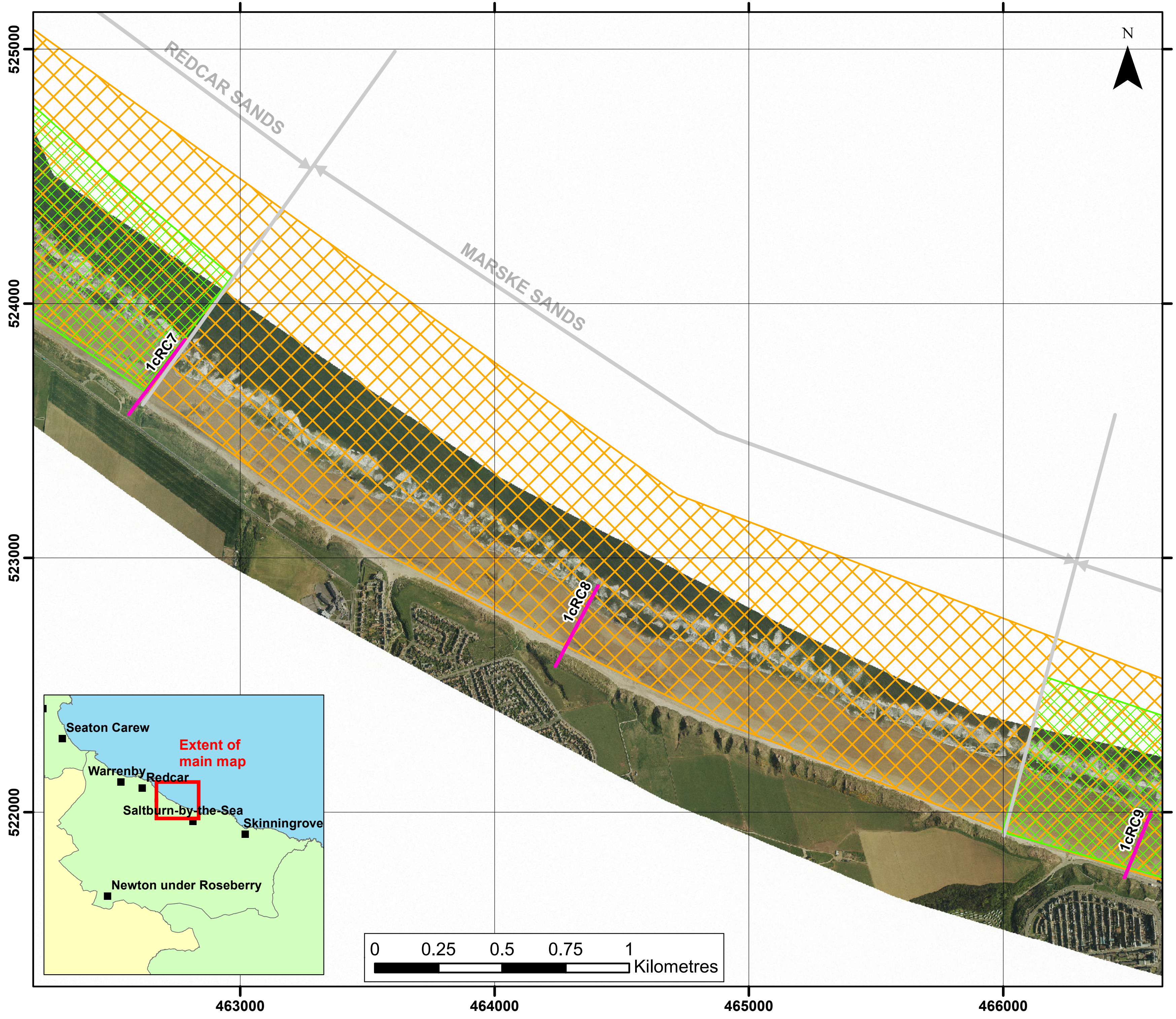

KEY

Topographic Profiles
- Annual
- 6 monthly

Topographic Surveys
- 6 monthly
- yearly
- 5 yearly

Cliff Top Monitoring Pegs
- 50m centres
- 100m centres
- 300m centres

(Indicative survey extents shown)

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Figure 2 - Map 3
Survey Locations
Marske Sands
Redcar & Cleveland Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

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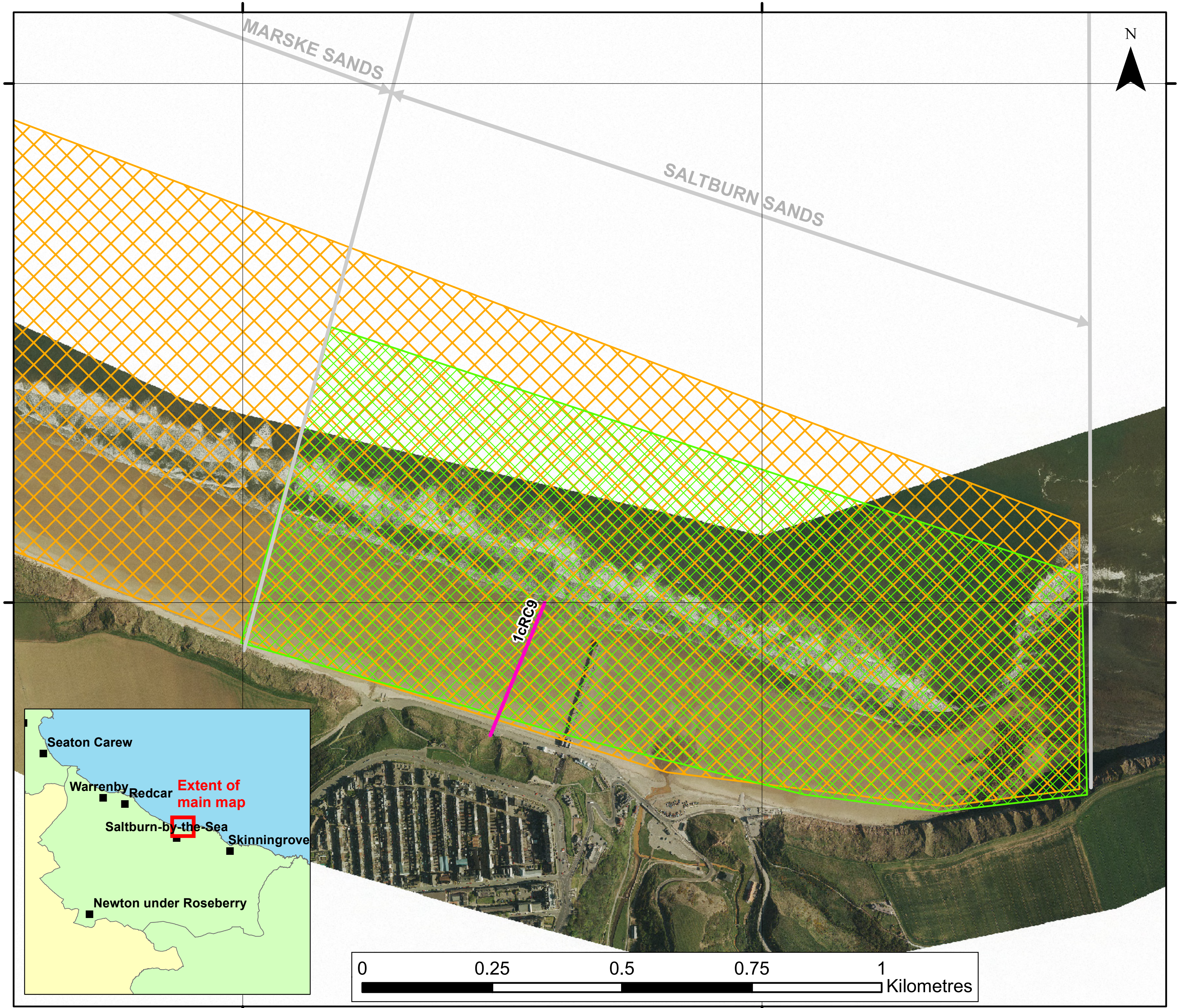

KEY

Topographic Profiles
- Annual
- 6 monthly

Topographic Surveys
- 6 monthly
- yearly
- 5 yearly

Cliff Top Monitoring Pegs
- 50m centres
- 100m centres
- 300m centres

(Indicative survey extents shown)

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Figure 2- Map 4
Survey Locations
Saltburn Sands
Redcar & Cleveland Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

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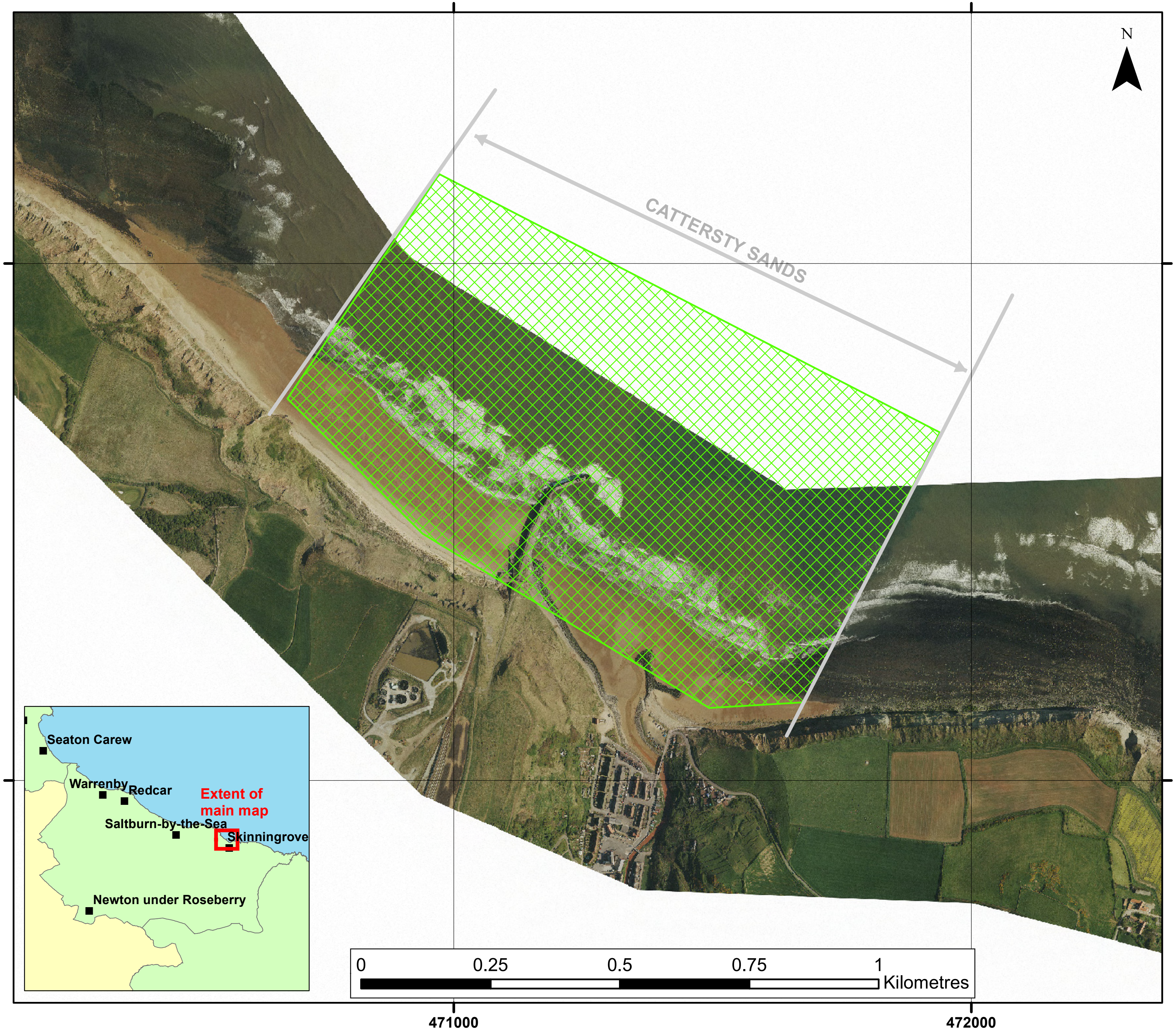

KEY

Topographic Profiles
- Annual
- 6 monthly

Topographic Surveys
- 6 monthly
- yearly
- 5 yearly

Cliff Top Monitoring Pegs
- 50m centres
- 100m centres
- 300m centres

(Indicative survey extents shown)

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Figure 2 - Map 5 Survey Locations Cattersty Sands Redcar & Cleveland Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

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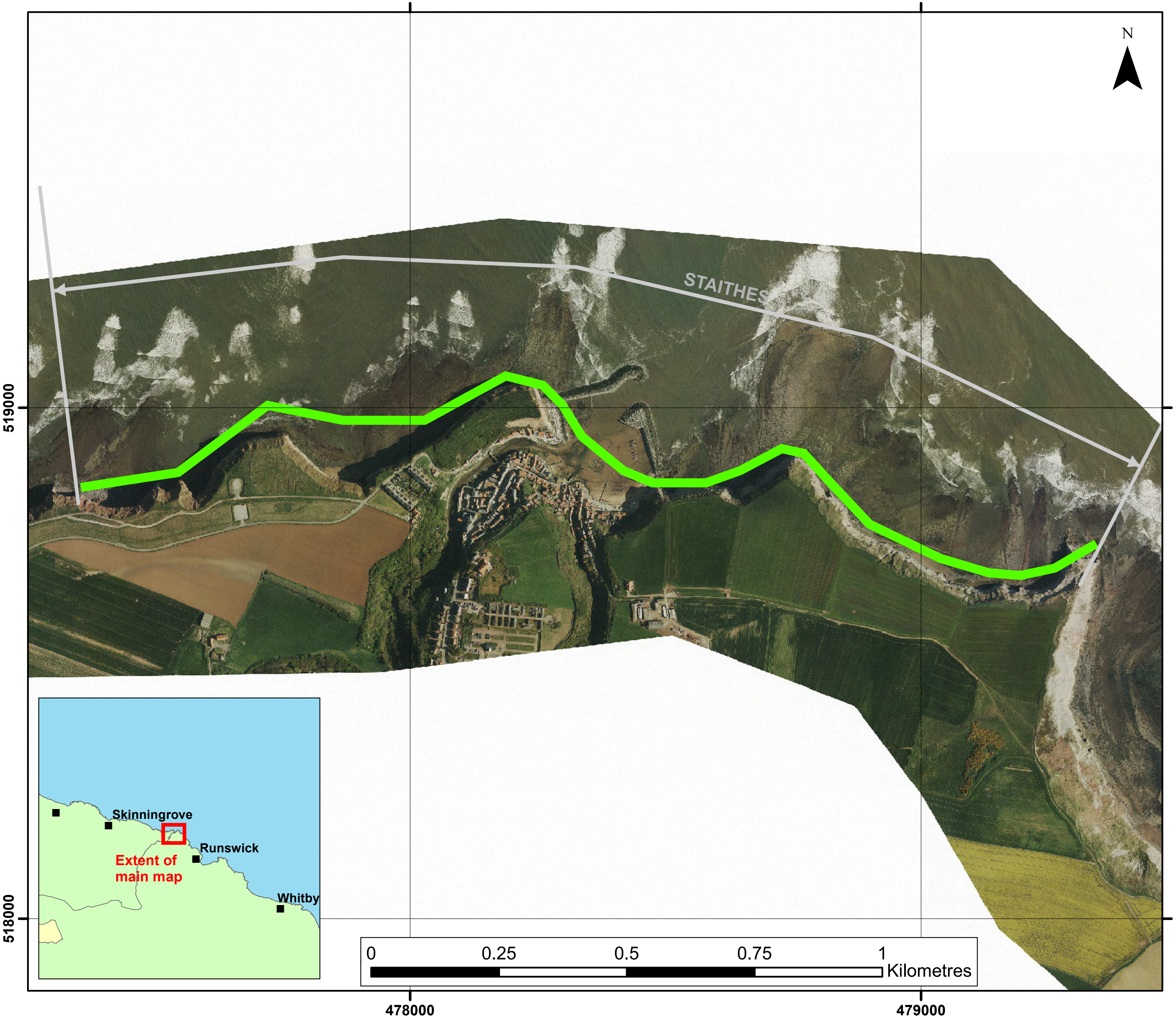

KEY

Topographic Profiles
- Annual
- 6 monthly

Topographic Surveys
- 6 monthly
- yearly
- 5 yearly

Cliff Top Monitoring Pegs
- 50m centres
- 100m centres
- 300m centres

(Indicative survey extents shown)

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Figure 2 - Map 6
Survey Locations
Staithes
Redcar & Cleveland
Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

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2. Analysis of Survey Data

2.1 Coatham Sands

Survey Date	Description of Changes Since Last Survey	Interpretation
20th Oct 2012	**Beach Profiles:** Coatham Sands is covered by four beach profile lines during the Full Measures survey (RC1 to RC4; Appendix A). Profile **1cRC1** is located approximately 300m south of the South Gare breakwater, immediately in the lee of the German Charlies slag banks. The upper profile is dominated by dune ridges, which have remained stable since the 2009 surveys. In the October 2012 profile the toe of the dunes has been eroded by 0.8m since March 2012. The beach below the HAT line has accreted by around 0.4m since March 2012. In the bottom third of the profile there has been little overall change. Overall the profile shows accretion since the last survey. Although between HAT and MHWS a berm At Profile **1cRC2** the beach and dunes are high compared to the profiles recorded since 2008. The seaward face of the dunes above HAT appears to have accreted by around 0.4m since March 2012. Between HAT and MHWS there was little overall change in the beach. Below MHWS the beach has eroded by around 0.2m, although two slight ridges have formed in the lower beach. Profile **1cRC3** was higher in October 2012 for much of its length than the other recorded profiles. The dunes, above the HAT level had accreted by 0.5m since March 2012. Beyond HAT the beach is very similar to the level of the beach recorded in March 2012, with the recorded changes being within a range of ±0.2m. Profile **1cRC4** is the beginning of the defended section. At the level of HAT the beach has accreted by 0.4m since March 2012. From the MHWS level to 170m chainage the beach has changed very little over the summer months. From 170m chainage to the end of the profile close to the MLWS level the beach has accreted by 0.3m.	The toe of the dunes in profile RC1 has eroded by a significant amount (0.8m since March 2012). The remainder of the profiles either show little change or accretion of around 0.4m on the beaches over the summer. The beach gradients have also changed very little. The topographic change plot shows in the northern quarter of the frontage the recorded changes were more patchy and severe. In the southern part of the frontage the changes were more muted. **Longer term trends**: The 2011 and 2012 Full Measures topographic change plots show that erosion has occurred close to the beach. The prominontory in the northern third of the frontage has continued to erode. In both 2011 and 2012 the southern two-thirds of the bay have been subject to limited change that was associated with development of a series of shore parallel ridge and runnel systems. **Autumn 2008 to Autumn 2012 trends** There are two areas that both display distinct patterns of behaviour. In the north of the bay, near the

Survey Date	Description of Changes Since Last Survey	Interpretation
	Topographic Survey: Coatham Sands is covered by an annual topographic survey extending from the South Gare Breakwater, although the survey is contiguous with the Redcar Sands topographic survey (which is surveyed 6-monthly). Data have been used to create a DGM (Appendix B – Map 1a) using a Geographic Information System (GIS) package. This shows that the beach contours recorded in Winter 2012 were relatively consistent across the frontage, with a gently shelving beach slope and shore parallel contours. The beach is narrower and steeper in the north, close to the breakwater. The GIS has also been used to calculate the differences between the current topographic (Winter 2012) survey and the earlier topographic survey (Winter 2011), as shown in Appendix B – Map 1b, to identify areas of erosion and accretion. The changes in elevation between Winter 2011 and Winter 2012 have been small, within ±0.2m across most of the frontage. There is some evidence of shore parallel bands of accretion and erosion in the centre of the bay. The most extreme changes have occurred in the northern-most quarter of the frontage, close to the shore between South Gare breakwater and the dunes, where up to 1m has been lost. The remaining three quarters of the frontage have seen minimal accretion or erosion, where the largest changes observed are accretion of 0.4m and erosion of 0.5m over the summer of 2012. **Long Term Topographic Trends Autumn 2008 to Autumn 2012:** The long term difference plot (Appendix B – Map 1c) shows that there are two distinct areas of behaviour on this frontage, the northern quarter and the southern three-quarters. The northern quarter close to the South Gare Breakwater has had erosion of up to 0.75m on the upper beach close to the shore and over 1m of accretion down the beach which is in a crescent, or bay formation. The majority of the beach has been subject to modest accretion of around 0.25m to 0.5m. There is one area of erosion of up to 0.75m on the mid and lower foreshore in the south of the bay.	breakwater there is a distinct area of erosion close to an area of accretion, which are north in a crescent shape showing that the bay form is stable although there may be accretion or erosion. The accretion observed in this location is the single largest, consistent change over the previous four years on this frontage. The remainder of the bay has been subject to accretion overall with one patch of erosion in the mid and lower beach in the southern part of the frontage.

2.2 Redcar Sands

Survey Date	Description of Changes Since Last Survey	Interpretation
20th Oct 2012	**Beach Profiles:** Redcar Sands is covered by three beach profile lines during the Full Measures survey (RC5 to RC7; Appendix A), with RC7 being approximately on the boundary with the Marske Sands area. Profiles RC5 and RC6 have changed significantly following construction of new coastal defences.  The new defence at Profile RC6.	A new defence has been built, which affects the landward section of profiles RC5 and RC6. Profile RC5 had accreted while RC6 remained stable. RC7 was stable for most of the profile but eroded at the lower end. Two mounds of material accreted on the beach at RC5. At RC 6 and RC7 the beach gradient remained the same between spring and autumn. The topographic change plots support the pattern of localised accretion and stability shown in the beach profiles. There was accretion overall although the north-east facing part of the frontage had a patchy distribution of accretion and erosion. **Longer term trends**: The construction of a new defence means that this 2012 Full Measures Report will act as a new baseline for the behaviour of the beach in front of the defence. The overall observed pattern is of stability with some accretion in parts of the bay (such as on the rocks offshore of Redcar). **Autumn 2008 to Autumn 2012 trends** The plot of long term elevation net difference between Winter 2008 and Autumn 2012 shows that the changes observed are of a similar magnitude to those observed over the six month survey periods. This suggests that net long term change is limited and that the pattern of change indicated reflects seasonal

Survey Date	Description of Changes Since Last Survey	Interpretation
	At profile **1cRC5** the new defence has been included in the profile in March and October 2012. At the toe of the sea wall between 15m and 25m the beach has eroded by 0.2m. From 25m to 75m chainage a mound of material had accreted on the beach in October, whereas in March the beach level was so low that a rocky shore platform was exposed. This change in the beach was due to the accretion of 0.4m of material. From 75m to 125m chainage the beach has accreted another mound of material due to the 0.2m of accretion since March 2012. Further down the beach, beyond 125m chainage the rocky shore platform of the lower beach is exposed. At profile **1cRC6** the defence is shown for the first time in October 2012. The changes above MHWS will be due to the new defence. Below MHWS most of the beach had eroded or accreted by 0.2m. At the lowest part of the profile beyond 200m chainage the beach had eroded by up to 0.4m since March 2012. Profile **1cRC7** experienced no changes on the section above MHWS. Below MHWS the beach was stable, with accretion and erosion of less than ±0.2m until 215m chainage. Below 215m chainage the beach had eroded by 0.5m since March 2012, exposing the rocky shore platform of the lower beach	movement of beach sediment.
	Topographic Survey: Redcar Sands is covered by a six-monthly topographic survey. Data have been used to create a DGM (Appendix B – Map 2a) using a Geographic Information System (GIS) package. The plot shows shore-parallel contours for most of the frontage with the exception of the beach in front of Redcar. At Redcar the contours show a bay form between the two rock outcrops of Redcar Rocks and West Scar. The most landward part of the contour embayment is close to Redcar Esplanade, so the centre of the bay is steep. This is the area where a major coastal defence scheme was being constructed during the topographic survey. Beyond this 600m length, the contours are regularly-spaced intervals showing a straight slope. The GIS has also been used to calculate the differences between the current topographic survey (Autumn 2012) and the most recent (Spring 2012) topographic survey, as shown in Appendix B – Map 2b, to identify areas of erosion and accretion. Between the last survey in Spring 2012 and the current Autumn 2012 the north facing part of the frontage had seen subject to slight accretion. The north-east facing part of the frontage had patchy accretion and erosion with almost equal areas of accretion and erosion. The erosion was slight 0.2m and most prevalent in the middle of the foreshore. Over a metre of accretion was recorded on the rocks just offshore of Redcar.	

Survey Date	Description of Changes Since Last Survey	Interpretation
	Long Term Topographic Trends Autumn 2008 to Autumn 2012: The plot of changes between Autumn 2008 and Autumn 2012 (Appendix B Map 2c) shows a variable distribution of net erosion and accretion. In the northern third of the frontage there has been modest accretion of around 0.5m. In the central third of the frontage between Redcar Rocks and West Scar there is erosion and accretion of roughly equal area. Erosion of up to 1m occurred on the two parts of the bay where the rocks meet the shoreline. On the seaward part of the beach at the extent of the survey accretion of around 1m was recorded. In the centre of the bay accretion of around 0.5m was recorded. The southern third of the frontage is dominated by accretion of up to 0.75m, with only limited erosion at the back of the beach.	

2.3 Marske Sands

Survey Date	Description of Changes Since Last Survey	Interpretation
20th Oct 2012	**Beach Profiles:** Marske Sands is covered by two beach profile lines during the Full Measures survey (RC7 to RC8; Appendix A), with RC7 being approximately on the boundary with the Redcar Sands area. Profile **1cRC7** is located along The Stray and has been discussed in Section 2.2. Overall, profile **1cRC8** has stayed stable since 2008. From the HAT level at 70m chainage to 210m chainage the beach has changed very little. Between 210m and 265m chainage the beach has accreted by 0.5m since March 2012. Beyond 265m chainage the beach has eroded by 0.3m. **Topographic Survey:** Marske Sands is covered by an annual topographic survey, although the survey is contiguous with the Redcar Sands and Saltburn Sands topographic surveys (both of which are surveyed six-monthly). Data have been used to create a DGM (Appendix B – Map 3a) using a Geographic Information System (GIS) package. This shows that the beach contours are relatively consistent across the frontage and exhibit a gently sloping beach with shore parallel contours at regular intervals. The GIS has also been used to calculate the differences between the Autumn 2011 and Autumn 2012 topographic survey, as shown in Appendix B – Map 3b, to identify areas of erosion and accretion. Since the previous topographic survey in Autumn 2012, there has been a general redistribution of sediment with changes of ±0.1m across much of the frontage. Patches of around 0.6-0.8m of erosion seaward of Scanbeck Howle were the largest recorded change. Isolated areas of accretion of around 0.7 were also observed in the north of the plot. The upper beach close to the shore has been subject to up to erosion in a thin strip running along much of the frontage. **Long Term Topographic Trends Autumn 2008 to Autumn 2012:** The changes observed over the four years shown in Appendix B – Map 3c show predominant accretion of up to 0.75m in the mid beach. There was a strip of erosion of 0.5m to 0.75m on the upper beach at	The beach profiles for Marske Sands were stable overall with minimal change along much of the profile. At the lowest extent of the profiles there was more variability. The plot of the changes in topography between Winter 2011 and Winter 2012 shows that there has been patchy redistribution of the sediment within the bay. The magnitude of change observed tended to be within a range of ±0.1m, so the bay has been stable overall. There is a weak shore parallel trend to the changes, which are likely to be due to the evolution of a ridge runnel system in the wider bay. **Longer term trends**: When comparing the 2011 and 2012 topographic plots the shore-parallel bands of accretion and erosion are still present, but the severity of the changes is more muted in 2012 than it was in 2011. **Autumn 2008 to Autumn 2012 trends** The erosion of the upper beach close to the shoreline is shown on both plots. The long term plot shows that the upper beach level has apparently dropped by 0.75m over the previous four years. The lowering of the beach level in front of the cliff may be a precursor for recession of this frontage. The accretion of the middle of the foreshore is also

Survey Date	Description of Changes Since Last Survey	Interpretation
	the shore. There are areas of up to 0.5m erosion on the lower beach but they are isolated patches.	apparent on both plots and dominates the four year plot showing that it is likely that the beach has accreted overall.

2.4 Saltburn Sands

Survey Date	Description of Changes Since Last Survey	Interpretation
20th Oct 2012	**Beach Profiles:** Saltburn Sands is covered by one beach profile during the Full Measures survey (RC9; Appendix A). Profile **1cRC9** experienced no changes on the defended section above HAT. From 20m to 40m chainage the beach had eroded by 0.2m since March 2012. Beyond 40m chainage the beach had accreted by up to 0.2m. The gradient of the beach had remained very similar between March and October 2012. **Topographic Survey:** Saltburn Sands is covered by a six-monthly topographic survey, although the survey is contiguous with the Marske Sands topographic survey which is surveyed annually. Data have been used to create a DGM (Appendix B – Map 4a) using a Geographic Information System (GIS) computer software package. This shows that the beach contours are shore parallel and gently shelving for the majority of the frontage. The contours are indented opposite a stream on the hinterland, which indicates the erosion of a channel across the beach. The GIS has also been used to calculate the differences over the 12 month period between Autumn 2011 and Autumn 2012 topographic survey, as shown in Appendix B – Map 4b, to identify areas of net erosion and accretion. During the 12 months covered by thee plot the whole of the frontage showed slight accretion of up to 0.5m. A significant area of erosion was at the mouth of Skelton Beck in the middle of the plot where the beach had eroded by up to 0.5m Erosion of up to 0.25m also occurred at the eastern extent of the surveys, at the low water line in the north and in a thin strip along the high water line. Comparison with the most recent Partial Measures survey in Spring in Appendix B – Maps 2b and 2c) shows that most of this change occurred over the Summer of 2012 and since Spring 2012 the foreshore has exhibited significant changes, most noticeably at the mouth of the stream. The beach has been subject to a reversal in erosive/accretion areas since the Winter 2011 to Spring 2012 difference plot In Between Winter 2011 and Spring 2012 the area is dominated by slight accretion with the exception of the mouth of the stream which shows erosion.	The beach has accreted over the summer as a result the October 2012 profile is higher than all of the previous surveys throughout much of its length. The Full Measures difference plots for 2012 show little change throughout much of the bay. The main difference is the erosion observed at the mouth of the stream over 2012. This is likely to be due to the scour at the mouth of the stream outweighing any accretionary process acting on the beach. This could be due to the fact that 2012 was an exceptionally wet year and as a result many of the streams in the area would have been at capacity. **Longer term trends**: A comparison between the 2011 and 2012 Full Measures Reports shows a reversal in trend from erosion overall with accretion at the mouth of the stream in 2011 to accretion overall with erosion at the mouth of the stream in 2012. It is possible that the sediment regime at Saltburn Sands is related to rainfall and how much sediment is bought in from the stream, but it is considered that the stream would only have local impact on the bay. **Autumn 2008 to Autumn 2012 trends** The frontage has accreted overall over the last four years. It has accreted more in the east than the west, possibly as sediment has accumulated against the small headland at the east of the bay. There are patches of erosion, most notably a strip at the back of

Survey Date	Description of Changes Since Last Survey	Interpretation
	In the Full Measures 2011 report the Spring 2011 to Winter 2011 plot showed overall erosion with accretion at the mouth of the stream. The main consistent change over the 2011 and 2012 was the continuing erosion of the upper beach along the high tide line. **Long Term Topographic Trends Autumn 2008 to Autumn 2012:** The plot of the change over the last four years (Appendix B – Map 4c) shows that the bay has experienced net accretion. Accretion varies along the bay, with only up to 0.25 in the west, increasing to 1m accretion in the east. Patches of net erosion are limited to the back of the beach, where up to 0.75m of erosion has occurred, and associated with the effect of a stream discharging on to the beach.	the beach. There is also a patch seaward of the mouth of the stream, where flood discharge has affected the beach morphology The continued erosion of the upper beach is likely to lead to recession of the shoreline as the protective effect of the beach diminishes.

2.5 Cattersty Sands

Survey Date	Description of Changes Since Last Survey	Interpretation
October 2012	**Topographic Survey:** Cattersty Sands is covered by a six-monthly topographic survey. Data have been used to create a DGM (Appendix B – Map 5a) using a Geographic Information System (GIS) package. The beach is steeper to the west of the breakwater than the east, but has a uniform gradient. East of the breakwater the beach includes the mouth of the stream and the harbour so the gradient is shallower. In the central part of the eastern section of the beach the contours indicate a stream cutting a channel, which is most deeply incised at its landward extent. The GIS has also been used to calculate the differences between Autumn 2011 and Autumn 2012 topographic survey DGM (as shown in Appendix B – Map 5b), to identify areas of net erosion and accretion. The difference plot shows patches of accretion close to the low water line and in the centre of the beach. The amount of accretion was commonly less than 0.5m although in some areas it was as much as 1m. The erosion of up to 1m covers the rest of the bay. There is no clear pattern in the distribution of erosion or accretion and they cover an almost equal area of the bay. In 2012 there is an obvious difference on each side of the jetty, as there was in previous years. During 2011 the differences on the beach varied around the mouth of Kilton Beck, but this is not apparent in 2012. **Long Term Topographic Trends Autumn 2008 to Autumn 2012:** The Autumn 2008 to Autumn 2012 plot (Appendix B – Map 5c) of elevation difference shows that Cattersty Sands has been subject to net accretion. The majority of the bay has accreted by around 0.75m over four years. However, erosion was prevalent at the mouth of the stream, where up to 1m of material was lost. There were strips of erosion on the west side of the jetty on the seaward and landward extents of the frontage. There were localised patches of erosion around the jetty and at the eastern extent of the survey.	The difference model shows Cattersty Sands to be a dynamic area, influenced by both coastal and fluvial processes. In the 2012 plot there is a difference in beach behaviour on either side of Kilton Beck. However, both sides of the breakwater have an almost equal distribution of accretion and erosion. Erosion was observed on the upper beach in the 2011 and 2012 Full Measures Reports. The erosion of the beach is likely to lead to management issues if it continues. **Longer term trends**: The change plots from the Full Measures Survey 2011 and 2012 show that the erosion on the beach has occurred in broadly the same parts of the shore. The hotspots have been to the centre of the jetty on the eastern side and at the bottom of the jetty on the western side. The beach continued to erode in the middle of the beach at the northern extent. The mouth of the stream was also a location of erosion over the last two years. Accretion occurred over both 2011 and 2012 on the mid beach to the east of the stream. **Autumn 2008 to Autumn 2012 trends** The difference plot from the previous four years shows that the frontage has accreted overall. The areas of erosion include the stream and patches near the jetty. Continued erosion of the stream may lead to problems due to scour on the landward side of the defences.

2.6 Staithes

<table>
<tr><th>Survey Date</th><th>Description of Changes Since Last Survey</th><th>Interpretation</th></tr>
<tr><td>September 2012</td><td>Cliff-top Survey:

Twenty ground control points have been established at Staithes for biannual cliff top monitoring. The separation between any two points is around 100 m. Data collection involves a distance offset measurement from the ground control point to the cliff edge along a fixed bearing.

Between March 2012 and September 2012 fifteen of the twenty posts showed change within a range of ±0.1m, which is not considered significant. Four posts showed growth of the cliff, which is likely to be error in the measurement. Post number 7 showed the largest negative change of all of the posts, with a value of -0.1m of erosion.

Calculation of erosion rates based on the recorded change between 2008 and 2012 indicates that half (10 posts) of the frontage has recorded a change rate within a range of ±0.1m/yr, which is considered to be within the error of the measurement. Eight of the remaining pots have positive rates, which is due to error. Two posts show erosion, Post 4 (on the open coast near Cowbar Lane) has a rate of -0.2m/yr and Post 13 (near the eastern breakwater) has a rate of -0.6m/yr. This pattern was very similar to that observed in the 2012 Partial Measures Report.

Appendix C provides results from the September 2010 survey, showing the distance from the ground control point to the edge of the cliff top along the defined bearing and changes in position since the November 2008 baseline survey.

A second study of cliff failure for Cowbar Nab is being carried out by Durham University (Appendix D). A laser scanner is used to monitor the surface of the cliff and measure the amount of retreat experienced on the face. The area covered by the Durham study is between Points 7 and 10 of the cliff top survey. The average annual rate for Points 7 to 10 varies between -0.1 to +0.3m/yr based on the change between 2008 and 2012.

A first annual report was published in February 2012 and is available in Appendix D. The method of the study was to measure the survey area from the cliff surface in the laser scan (9,125.2 m2). The total number of measured rockfalls during this period was 9,968, with a total volume of 318.99 m^3. This equates to a spatially averaged erosion rate of 1.99 x 10-3 myr^{-1} over this 15-month period. The maximum monthly erosion rate was 3.7x 10^{-3} myr^{-1} (Feb, 2012), and the minimum 0.01 x 10^{-3} myr^{-1}</td><td>The majority of the Staithes frontage has remained stable over the summer of 2012. There was concern raised due to numerous cliff falls on the eastern part of the bay, close to Point 13. However, that survey location recorded minimal change (0.03m) as the cliff failure did not affect that survey line.

Longer term trends: Table C1 shows that survey location 13 has shown the greatest total erosion with a loss of 2.3m (±0.1m) between the November 2008 baseline and September 2012, resulting in a long term average recession rate of 0.6m/yr. The other survey location showing recession is Point 4, which has a rate of 0.2m/yr.

The higher rates for these points are likely to be due to one or two large failures of the cliff, rather than progressive recession. When the large loss is put into the recession rate calculation and averaged over five years it gives a comparatively high rate. The record of cliff recession should be collected over a longer term in order to provide more accurate rates.

The Durham University report averages the loss of material across the whole face and is noticeably higher than the erosion rate provided by the coastal monitoring. This may mean that the cliff is steepening and that the erosion of the cliff top will catch-up with a period of large falls affecting the top of the cliff. Further years of high resolution of the face by Durham will give much more confidence in the</td></tr>
</table>

Survey Date	Description of Changes Since Last Survey	Interpretation
	(May, 2011) (see Appendix D). The Durham University study is a high resolution precise pattern of change on the cliff face, which is not directly comparable with the six-monthly record of cliff top recession. In coming years the Durham study will have recorded data for a longer period, meaning that there will be more confidence in the averages.	erosion rates and capture any large failures which affect the cliff top.

3. Problems Encountered and Uncertainty in Analysis

There were no major problems encountered during the surveys.

Individual Surveys

There were no noted errors in the October 2012 dataset. The construction of the coastal defence through part of the frontage means that the behaviour and volumes of the beaches pre and post construction can be compared but that any changes in behaviour can not be attributed to natural processes.

Cliff Top Surveys

The cliff top surveys at Staithes are assumed to have a limit of accuracy of ± 0.1m due to the techniques used. At a number of locations apparent cliff advance has been calculated, which is unlikely, excepting a toppling mechanism of failure. It is more likely that this is due to a different point being identified as the edge of the cliff, especially with different seasonal vegetation covers. More accurate data on cliff recession at Staithes will be derived from analysis of aerial photos collected, or planned for collection, in 2010, 2012 and 2014.

4. Recommendations for 'Fine-tuning' the Monitoring Programme

The aim of cliff monitoring data is to gain a reliable record of the frequency and magnitude of cliff top failures. Data are collected every six months, but previous surveys have had a low accuracy, meaning that survey error is typically greater than any measured short term change. It is possible that a more reliable pattern of change will be determined over the longer term. However, in the short term, more reliable assessments of cliff recession will be derived from analysis of time-series remote sensing data. A high quality baseline survey, comprising LiDAR and aerial photography, was collected in 2010, a repeat survey was completed in Sept/Oct 2012 and a second repeat survey is planned for 2014. These data will be analysed to give more accurate information on the behaviour of the cliffs in a separate report.

5. Conclusions and Areas of Concern

- At Coatham Sands the beach profiles show erosion at isolated parts of the beach but overall the beach has remained stable or accreted a modest amount. The topographic change plot shows that the greatest changes are in the north of the frontage near South Gare Breakwater. In the south of the frontage the majority of the beach changes are within ±0.2m in 2012. This is a similar pattern to the one observed in the long term plot of change.

- Redcar Sands has had accretion and stability overall. The change in the beach dues to the construction of the new defence will not be clear for a number of years. The changes in the beach should continue to be monitored to understand how the new defence will affect the beach.

- Marske Sands has been stable over 2012. The beach profiles and topographic change plots show that the beach overall has changed very little. The long term difference plots show a strip of erosion on the landward extent of the survey which could be a precursor to recession of this frontage.

- The Saltburn Sands beach profiles show that the beach has accreted over the summer and is in high compared to previous surveys. The topographic change plots of Saltburn Sands show redistribution of sediment. At the mouth of Skelton Beck erosion has occurred, which is likely to be due to the high rainfall experienced over 2012. The long term difference plots show a strip of erosion on the landward extent of the survey which could be a precursor to recession of this frontage, although it is unlikely to be as severe as on the Marske Sands frontage.

- The Cattersty Sands difference model shows that it is a dynamic area, influenced by both marine and fluvial processes. In the 2012 plot there is an almost equal distribution of accretion and erosion. The four year change plot shows accretion overall but there are isolated areas of erosion close to the shore in the north and near the river mouth in the south.

- The measurements of the Staithes cliff top shows stability overall. However, the monitoring has only been being carried out for three years so a trend is unlikely to be clear from such a limited data set. One point has eroded by 2.3m since November 2008, which is the maximum erosion observed for this frontage. An additional study, being carried out by Durham University will capture with high accuracy the changes on the cliff face. In future years this will aid in the calculation of accurate erosion rates. It is currently in its first year and has recorded a spatuially averaged rate of recession of around 2mm/yr.

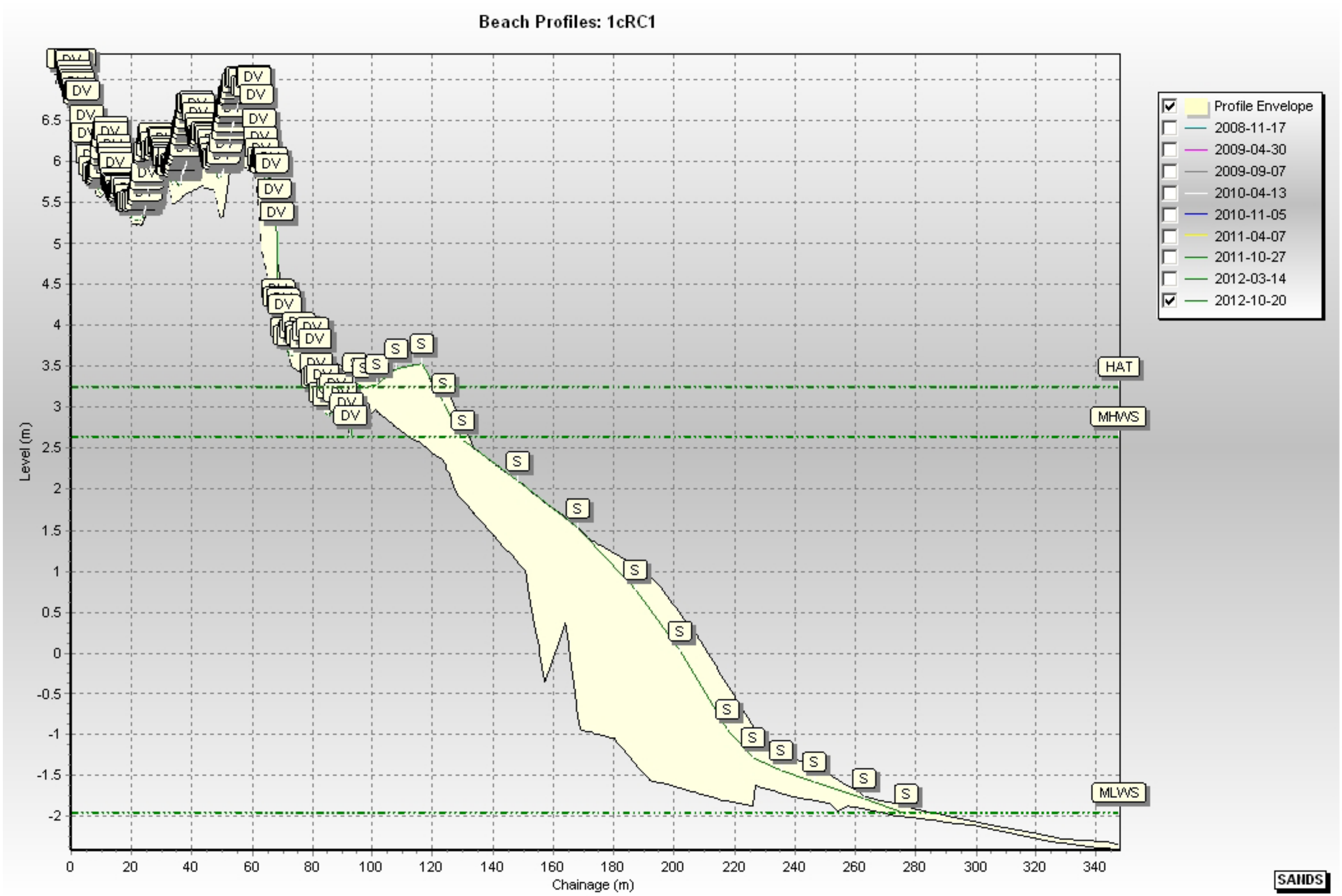
Appendices

Appendix A

Beach Profiles

The following sediment feature codes are used on some profile plots:

Code	Description
S	Sand
M	Mud
G	Gravel
GS	Gravel & Sand
MS	Mud & Sand
B	Boulders
R	Rock
SD	Sea Defence
SM	Saltmarsh
W	Water Body
GM	Gravel & Mud
GR	Grass
D	Dune (non-vegetated)
DV	Dune (vegetated)
F	Forested
X	Mixture
FB	Obstruction
CT	Cliff Top
CE	Cliff Edge
CF	Cliff Face
SH	Shell
ZZ	Unknown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Level (m)
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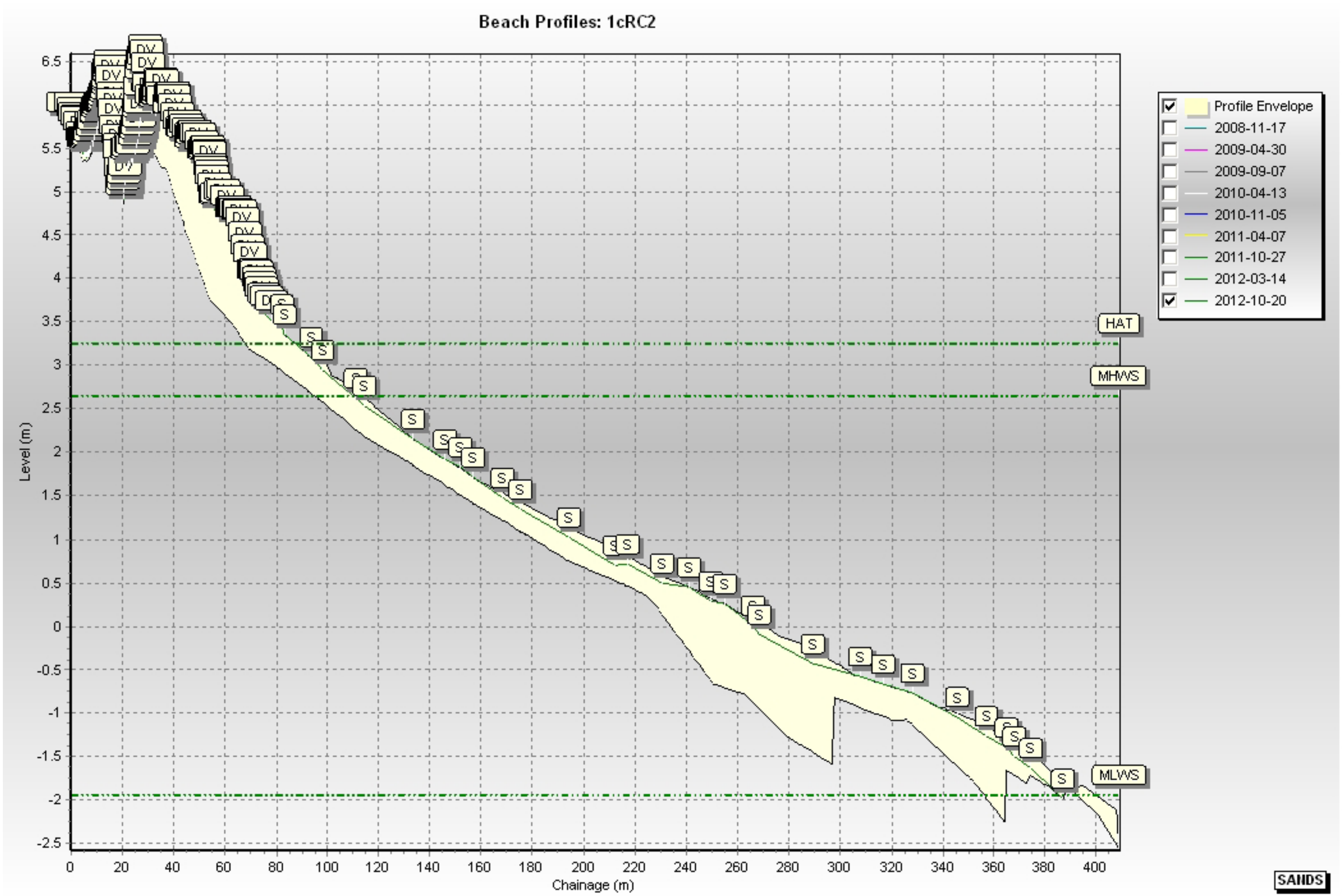
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
Chainage (m)
Profile Envelope
2008-11-17
2009-04-30
2009-09-07
2010-04-13
2010-11-05
2011-04-07
2011-10-27
2012-03-14
2012-10-20
HAT
MHWS
MLWS
DV
S
SANDS



Beach Profiles: 1cRC2
Level (m)
Chainage (m)
Profile Envelope
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2009-04-30
2009-09-07
2010-04-13
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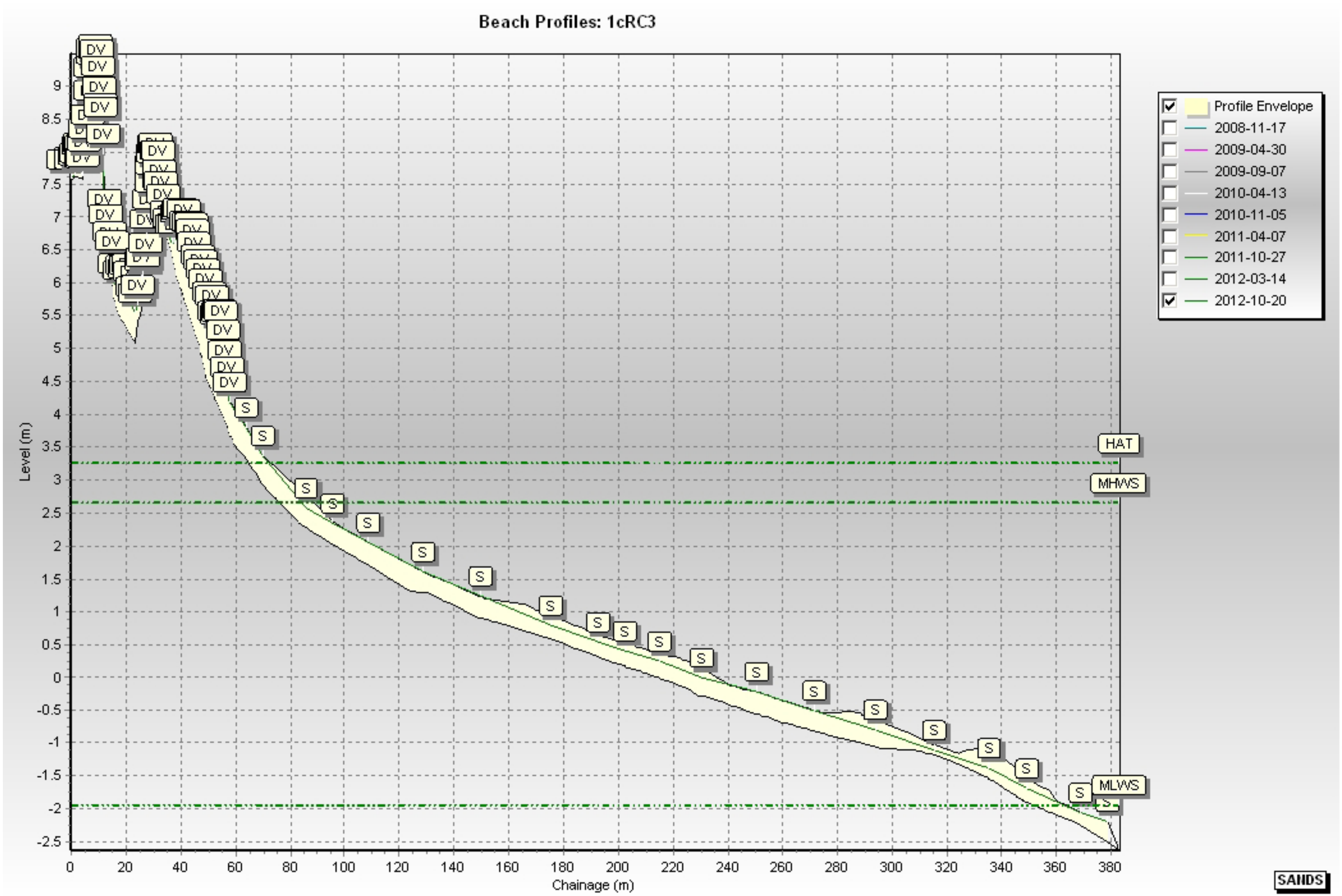
HAT
MHWS
MLWS
SANDS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Chainage (m)
Profile Envelope
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2009-04-30
2009-09-07
2010-04-13
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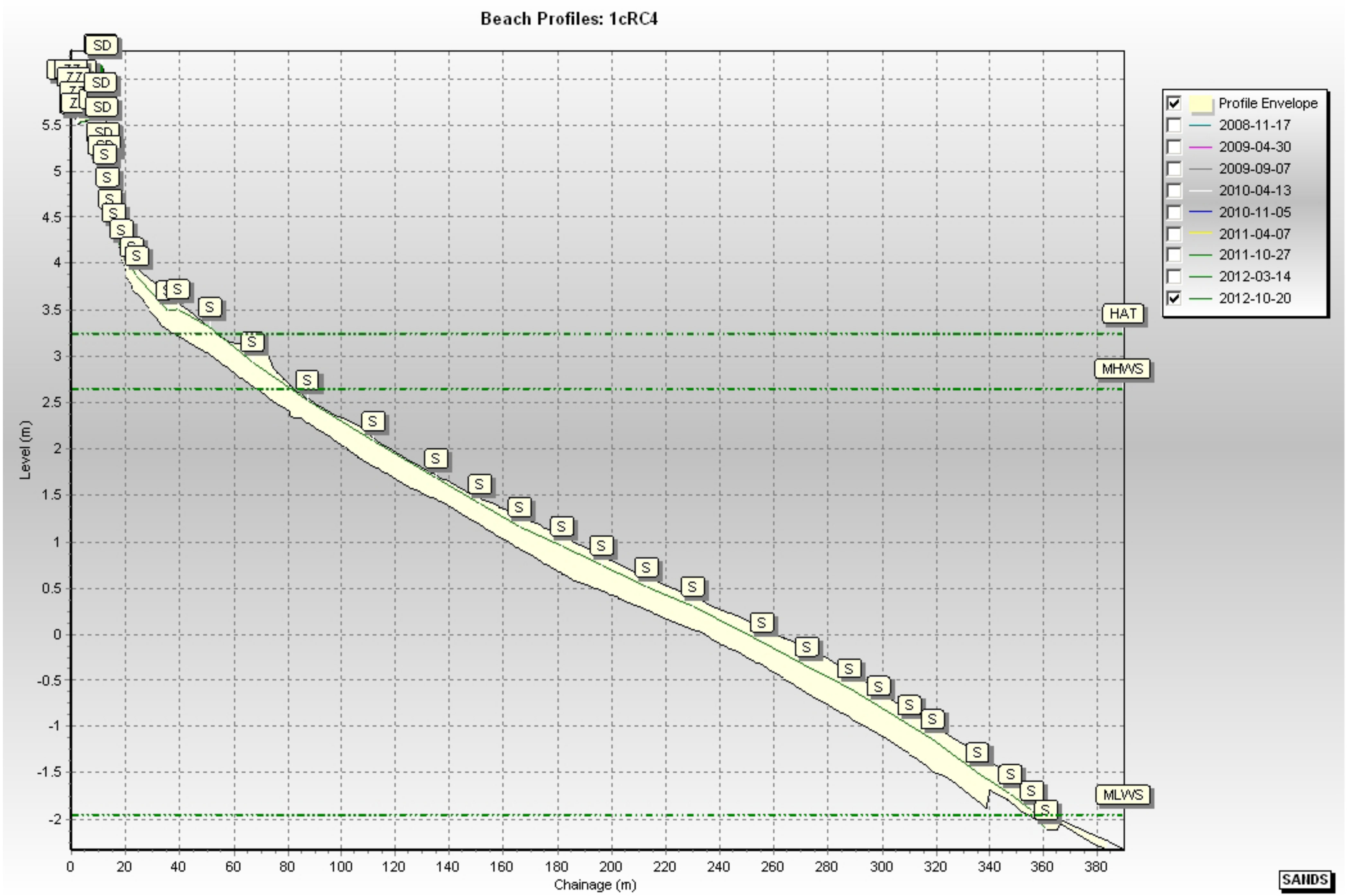
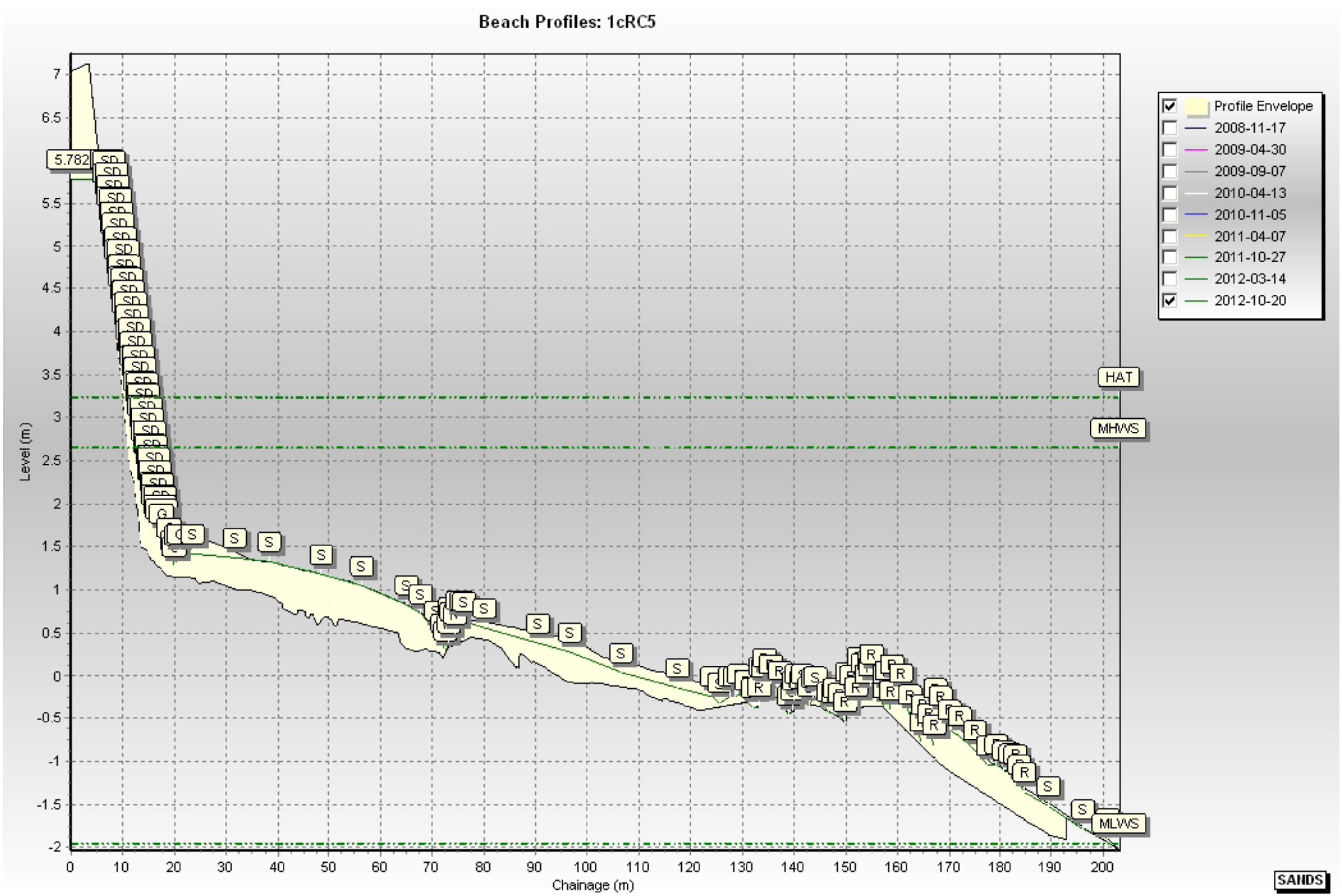
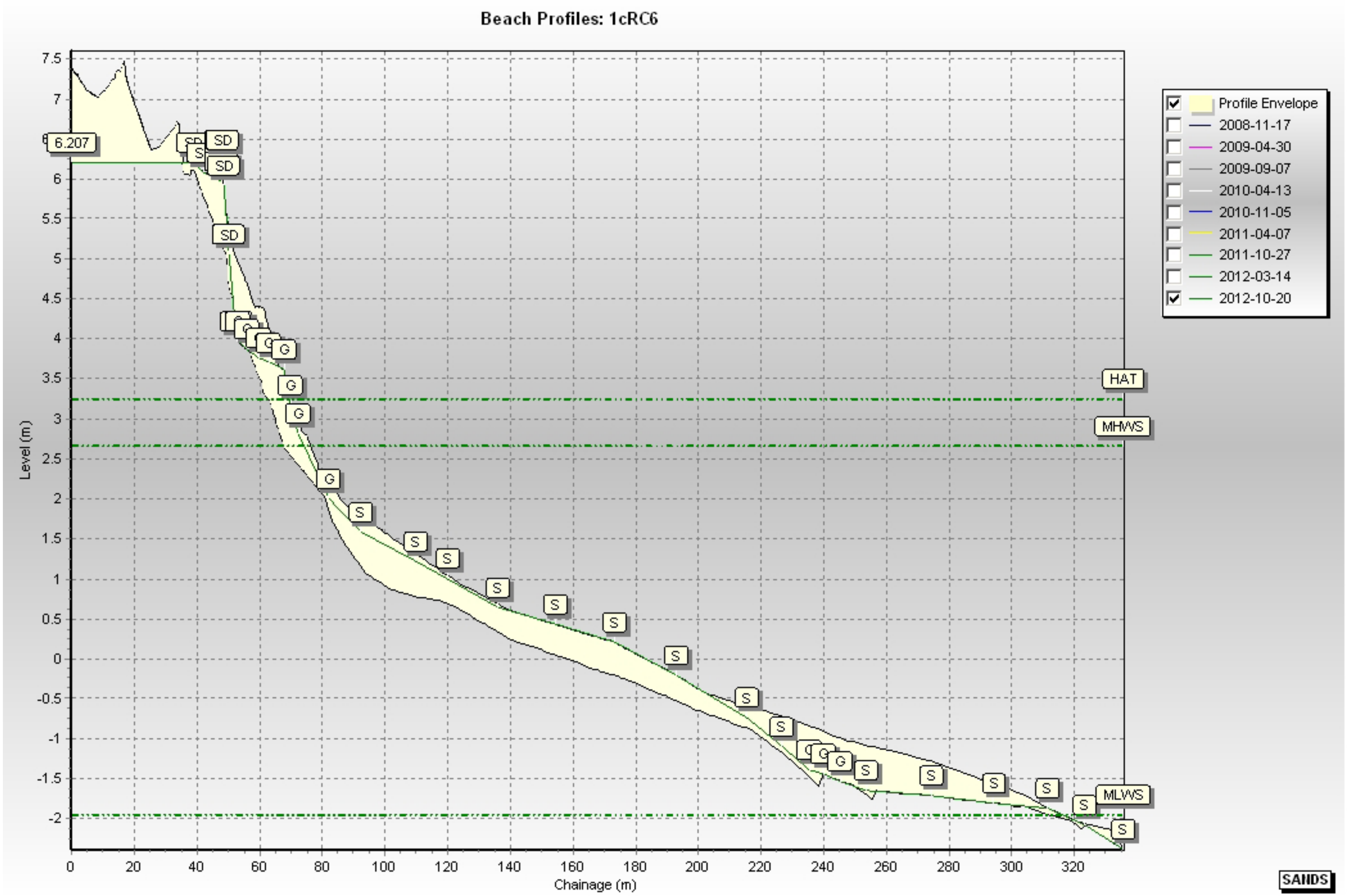
2012-03-14
2012-10-20
HAT
MHWS
MLWS
SANDS



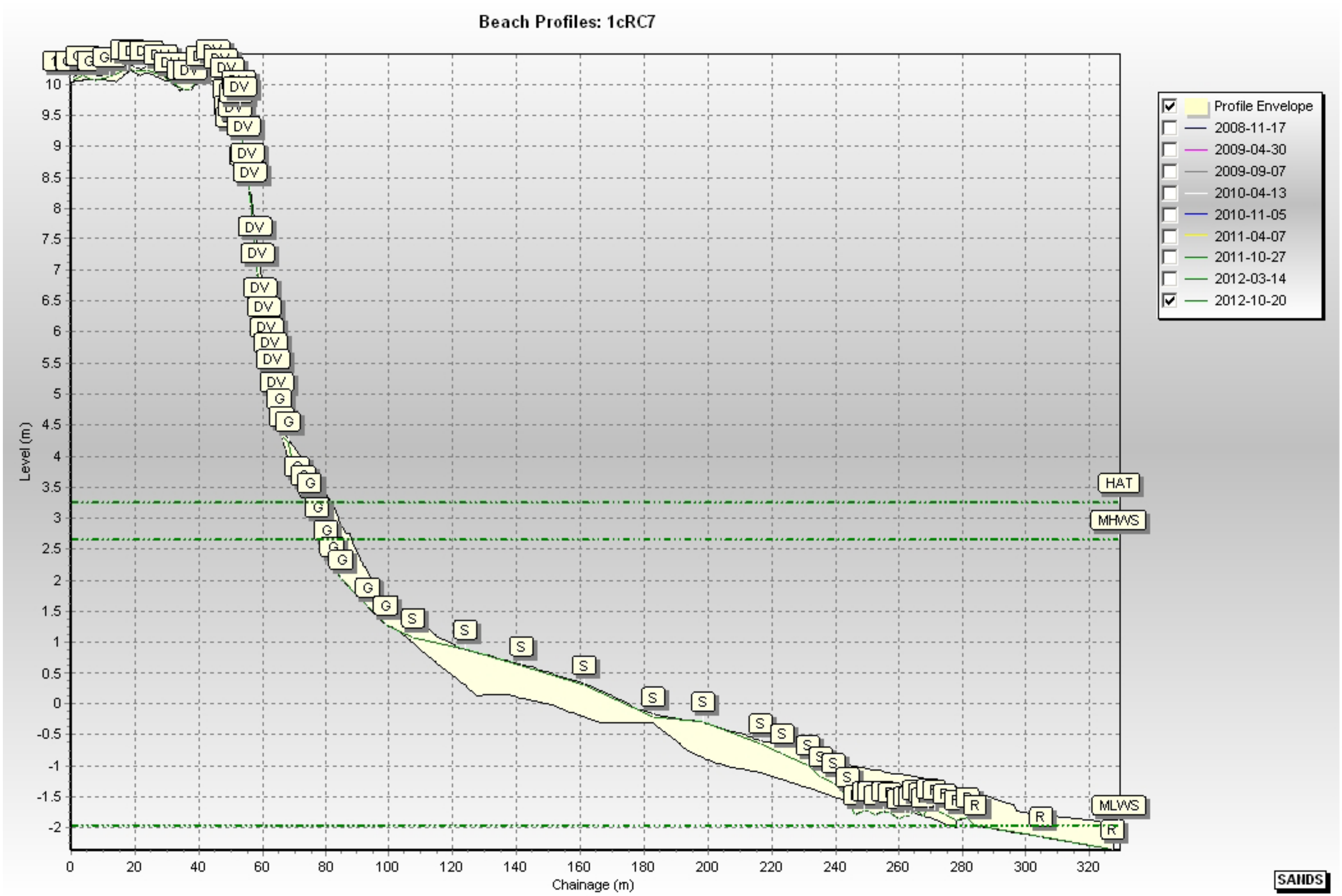
Beach Profiles: 1cRC4
Level (m)
Chainage (m)
Profile Envelope
2008-11-17
2009-04-30
2009-09-07
2010-04-13
2010-11-05
2011-04-07
2011-10-27
2012-03-14
2012-10-20
HAT
MHWS
MLWS
SANDS



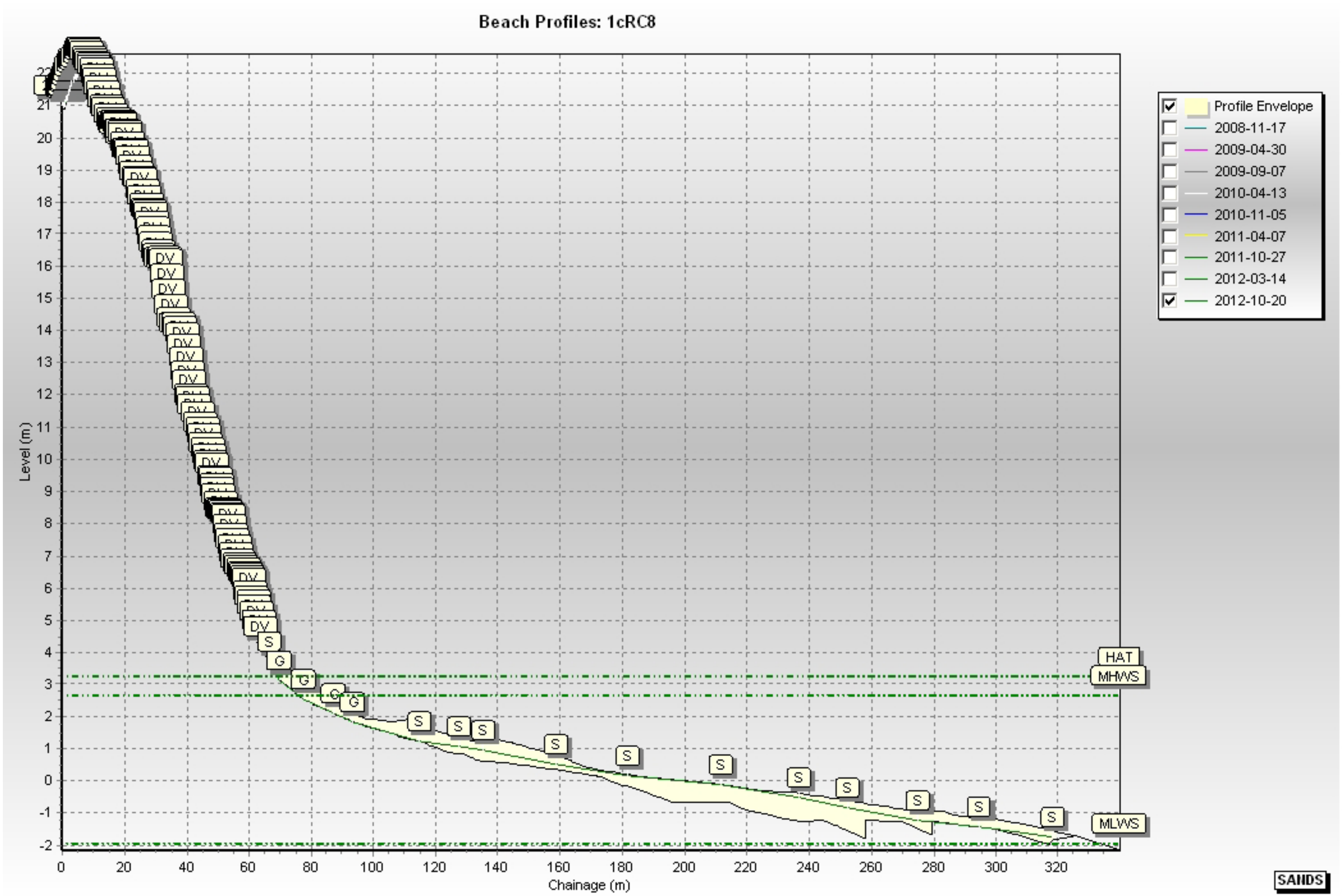
Beach Profiles: 1cRC5
Level (m)
Chainage (m)
Profile Envelope
2008-11-17
2009-04-30
2009-09-07
2010-04-13
2010-11-05
2011-04-07
2011-10-27
2012-03-14
2012-10-20
HAT
MHWS
MLWS
5.782
SANDS



Beach Profiles: 1cRC6
Level (m)
Chainage (m)
6.207
SD
S
SD
SD
G
S
HAT
MHWS
MLWS
Profile Envelope
2008-11-17
2009-04-30
2009-09-07
2010-04-13
2010-11-05
2011-04-07
2011-10-27
2012-03-14
2012-10-20
SANDS



Beach Profiles: 1cRC7
Level (m)
Chainage (m)
Profile Envelope
2008-11-17
2009-04-30
2009-09-07
2010-04-13
2010-11-05
2011-04-07
2011-10-27
2012-03-14
2012-10-20
HAT
MHWS
MLWS
SANDS



Beach Profiles: 1cRC8
Level (m)
Chainage (m)
Profile Envelope
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2009-04-30
2009-09-07
2010-04-13
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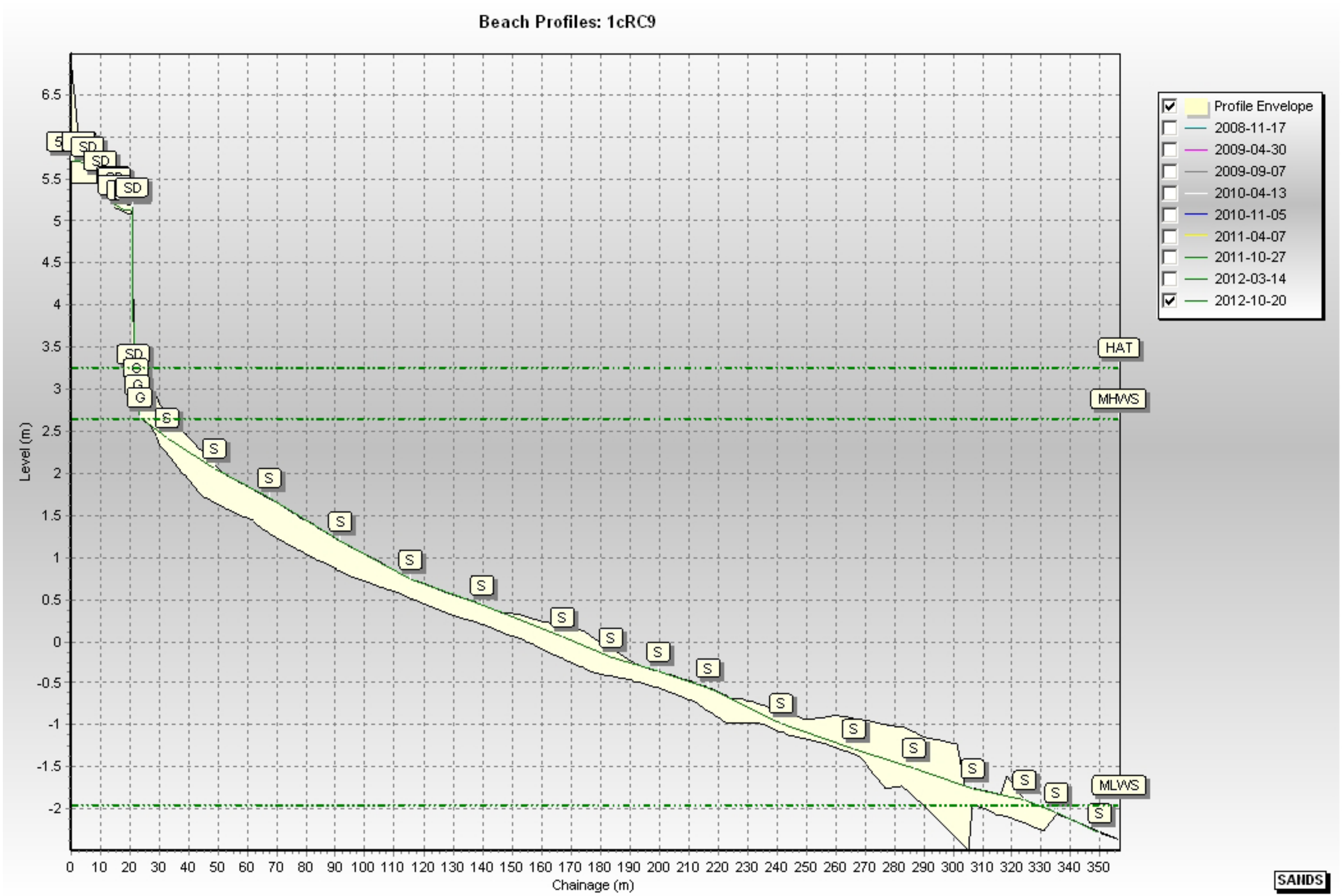
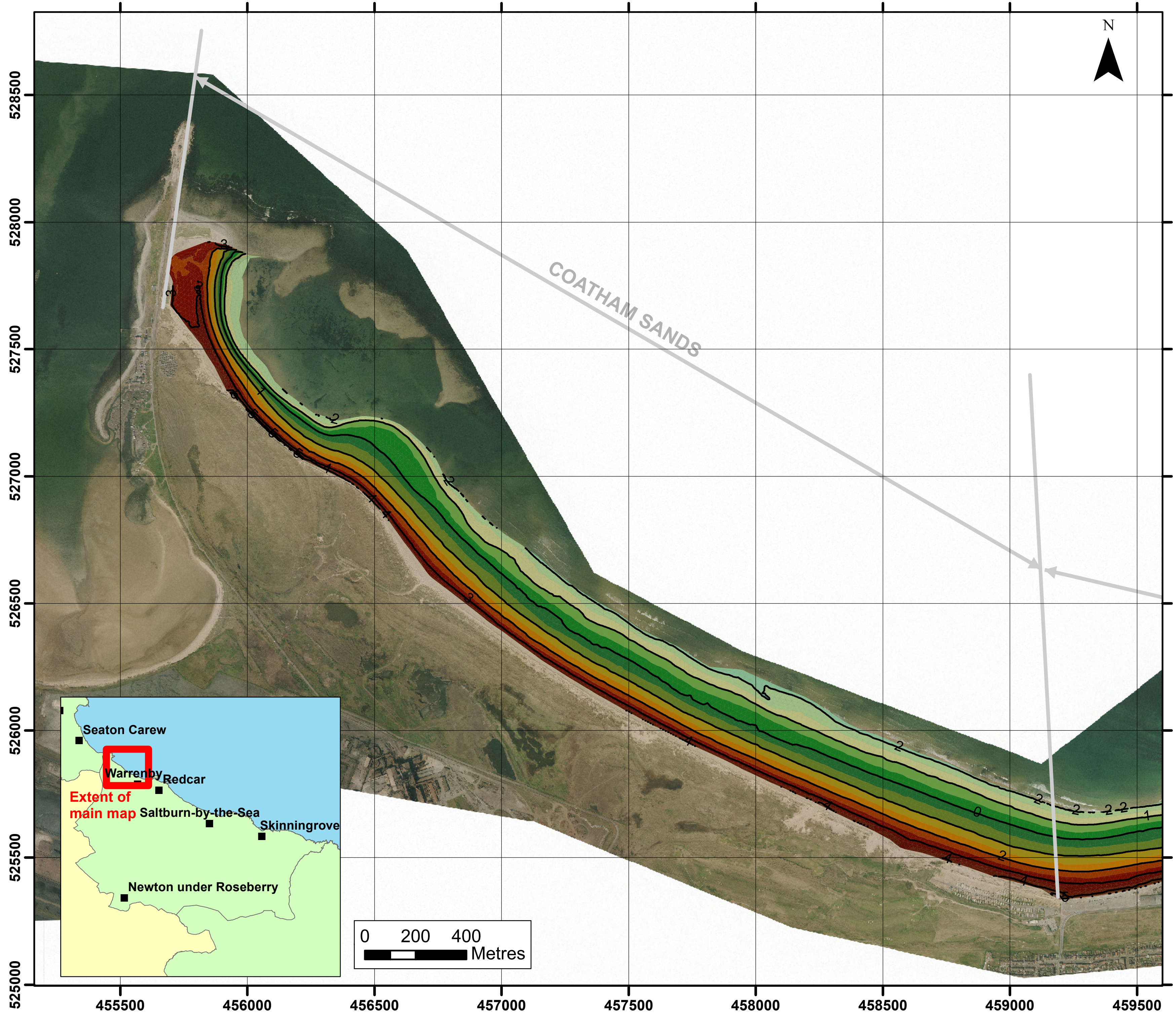
HAT
MHWS
MLWS
SANDS



Beach Profiles: 1cRC9
Profile Envelope
2008-11-17
2009-04-30
2009-09-07
2010-04-13
2010-11-05
2011-04-07
2011-10-27
2012-03-14
2012-10-20
HAT
MHWS
MLWS
Level (m)
Chainage (m)
SANDS

Appendix B

Topographic Survey



KEY Elevation (m OD)

- 7 - 7.5
- 6.5 - 7
- 6 - 6.5
- 5.5 - 6
- 5 - 5.5
- 4.5 - 5
- 4 - 4.5
- 3.5 - 4
- 3 - 3.5
- 2.5 - 3
- 2 - 2.5
- 1.5 - 2
- 1 - 1.5
- 0.5 - 1
- 0 - 0.5
- -0.5 - 0
- -1 - -0.5
- -1.5 - -1
- -2 - -1.5
- -2.5 - -2
- -3 - -2.5
- Contour 1m

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B - Map 1a
Topographic Survey
Coatham Sands
Redcar & Cleveland
Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

Halcrow
A CH2M HILL COMPANY

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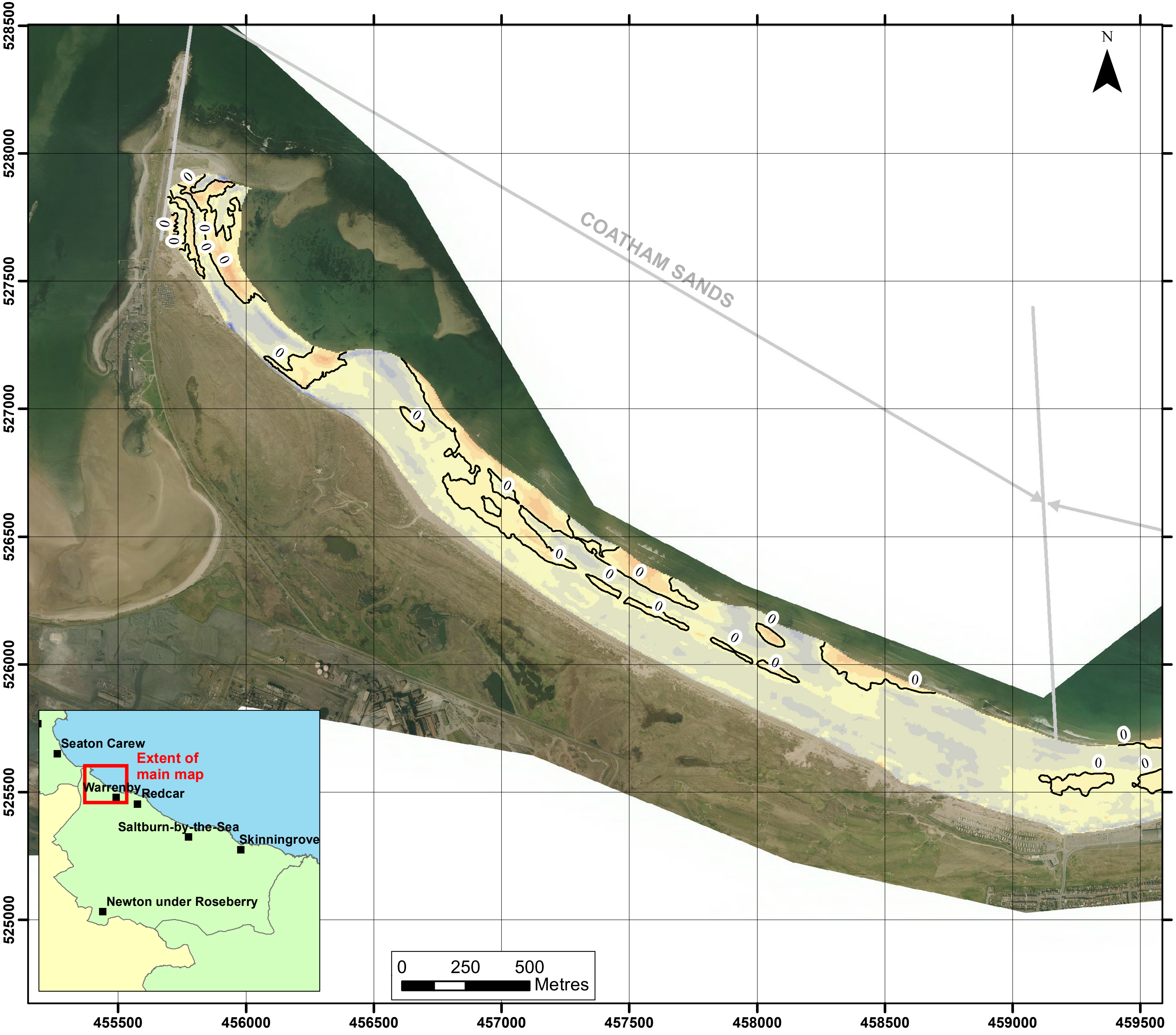
Fax: +44(0)121 456 1569
www.halcrow.com

Photography courtesy of North East Coastal Observatory
www.northeastcoastalobservatory.org.uk



KEY Winter 2011 and Winter 2012
Change in elevation (m OD)

- <-2
- -2 - -1.75
- -1.75 - -1.5
- -1.5- -1.25
- -1.25 - -1
- -1 - -0.75
- -0.75 - -0.5
- -0.5 - -0.25
- -0.25 - -0.1
- -0.1 - 0
- 0 - 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 1.75
- 1.75 - 2
- >2

Loss

Change < 0.1 m

Gain

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B - Map 1b
Short-term Elevation change Coatham Sands Redcar & Cleveland Borough Council

Analytical Report 5
Full Measures (Autumn)
Surveys 2011 to 2012

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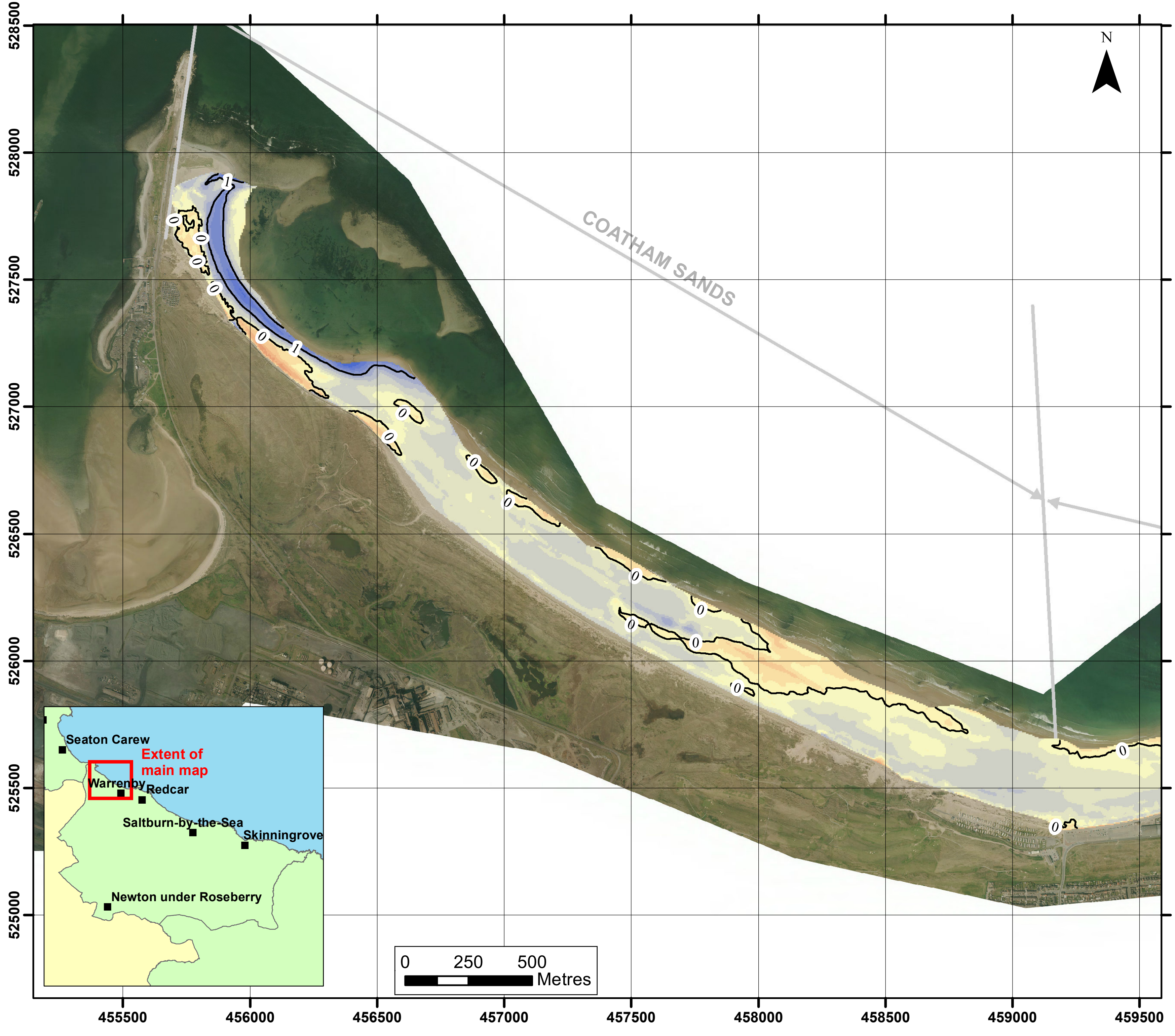

KEY Autumn 2008 and Autumn 2012
Change in elevation (m OD)

<-2	Loss
-2 - -1.75	
-1.75 - -1.5	
-1.5- -1.25	
-1.25 - -1	
-1 - -0.75	
-0.75 - -0.5	
-0.5 - -0.25	
-0.25 - -0.1	
-0.1 - 0	Change < 0.1 m
0 - 0.1	
0.1 - 0.25	Gain
0.25 - 0.5	
0.5 - 0.75	
0.75 - 1	
1 - 1.25	
1.25 - 1.5	
1.5 - 1.75	
1.75 - 2	
>2	

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B - Map 1c
Long-term Elevation change Coatham Sands Redcar & Cleveland Borough Council

Analytical Report 5
Full Measures (Autumn)
Surveys 2008 to 2012

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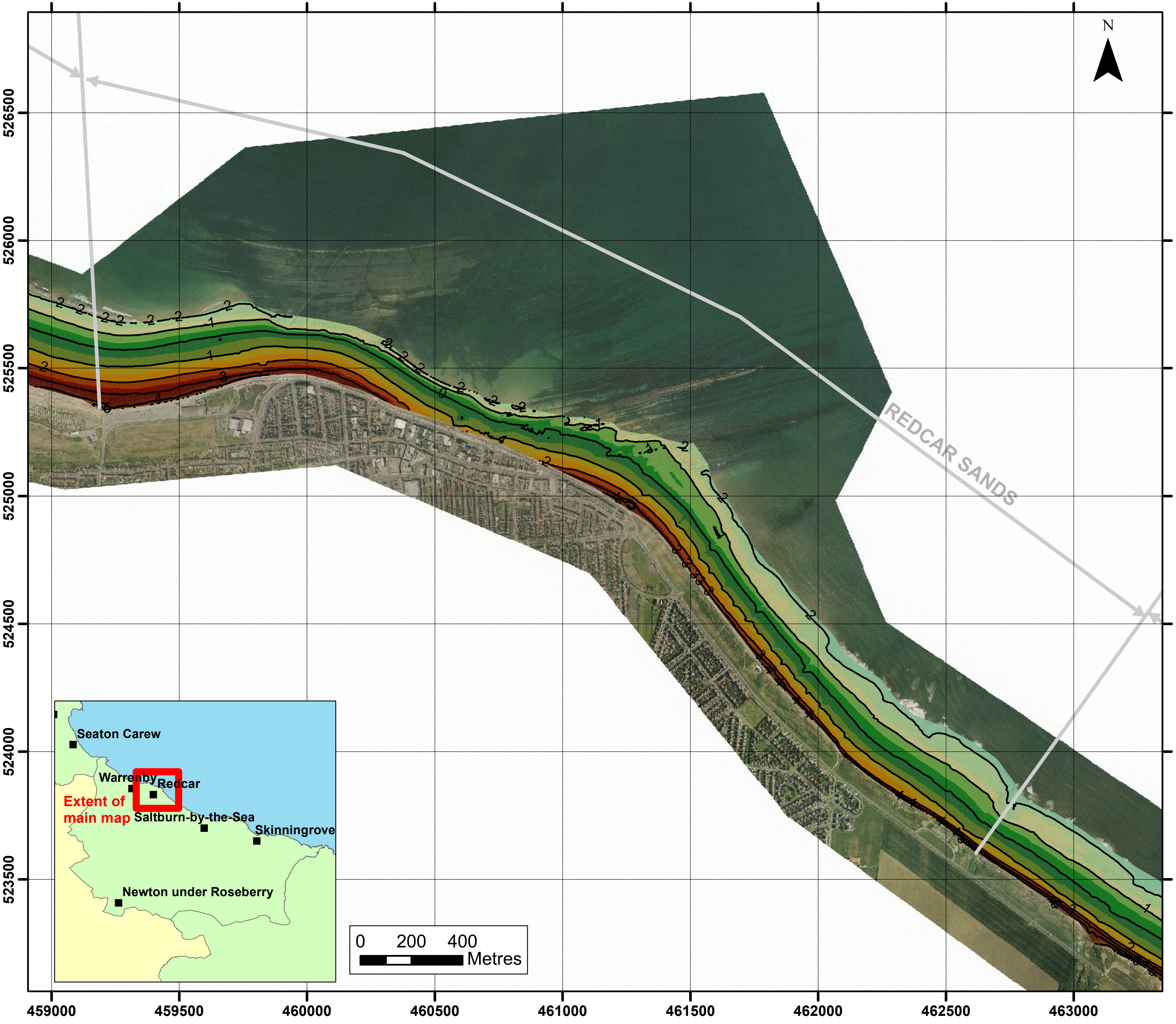

KEY Elevation (m OD)
7 - 7.5
6.5 - 7
6 - 6.5
5.5 - 6
5 - 5.5
4.5 - 5
4 - 4.5
3.5 - 4
3 - 3.5
2.5 - 3
2 - 2.5
1.5 - 2
1 - 1.5
0.5 - 1
0 - 0.5
-0.5 - 0
-1 - -0.5
-1.5 - -1
-2 - -1.5
-2.5 - -2
-3 - -2.5
Contour 1m

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B - Map 2a
Topographic Survey
Redcar Sands
Redcar & Cleveland
Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

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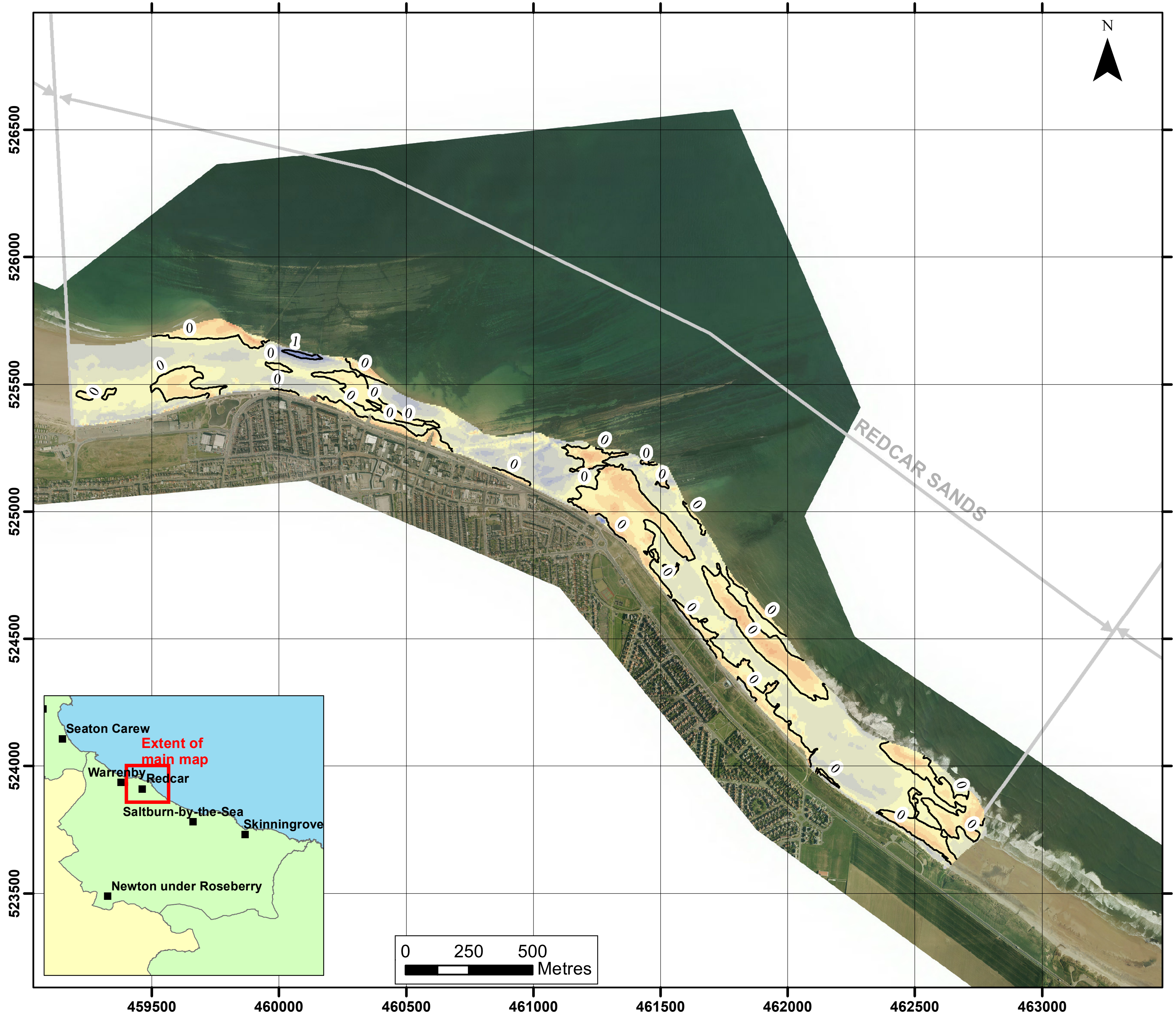

KEY Spring 2012 and Autumn 2012
Change in elevation (m OD)

<-2		Loss
-2 - -1.75		
-1.75 - -1.5		
-1.5- -1.25		
-1.25 - -1		
-1 - -0.75		
-0.75 - -0.5		
-0.5 - -0.25		
-0.25 - -0.1		
-0.1 - 0		Change < 0.1 m
0 - 0.1		
0.1 - 0.25		Gain
0.25 - 0.5		
0.5 - 0.75		
0.75 - 1		
1 - 1.25		
1.25 - 1.5		
1.5 - 1.75		
1.75 - 2		
>2		

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B- Map 2b
Short-term
Elevation change
Redcar Sands
Redcar & Cleveland
Borough Council

Analytical Report 5
Full Measures Surveys
Spring 2012 to Autumn 2012

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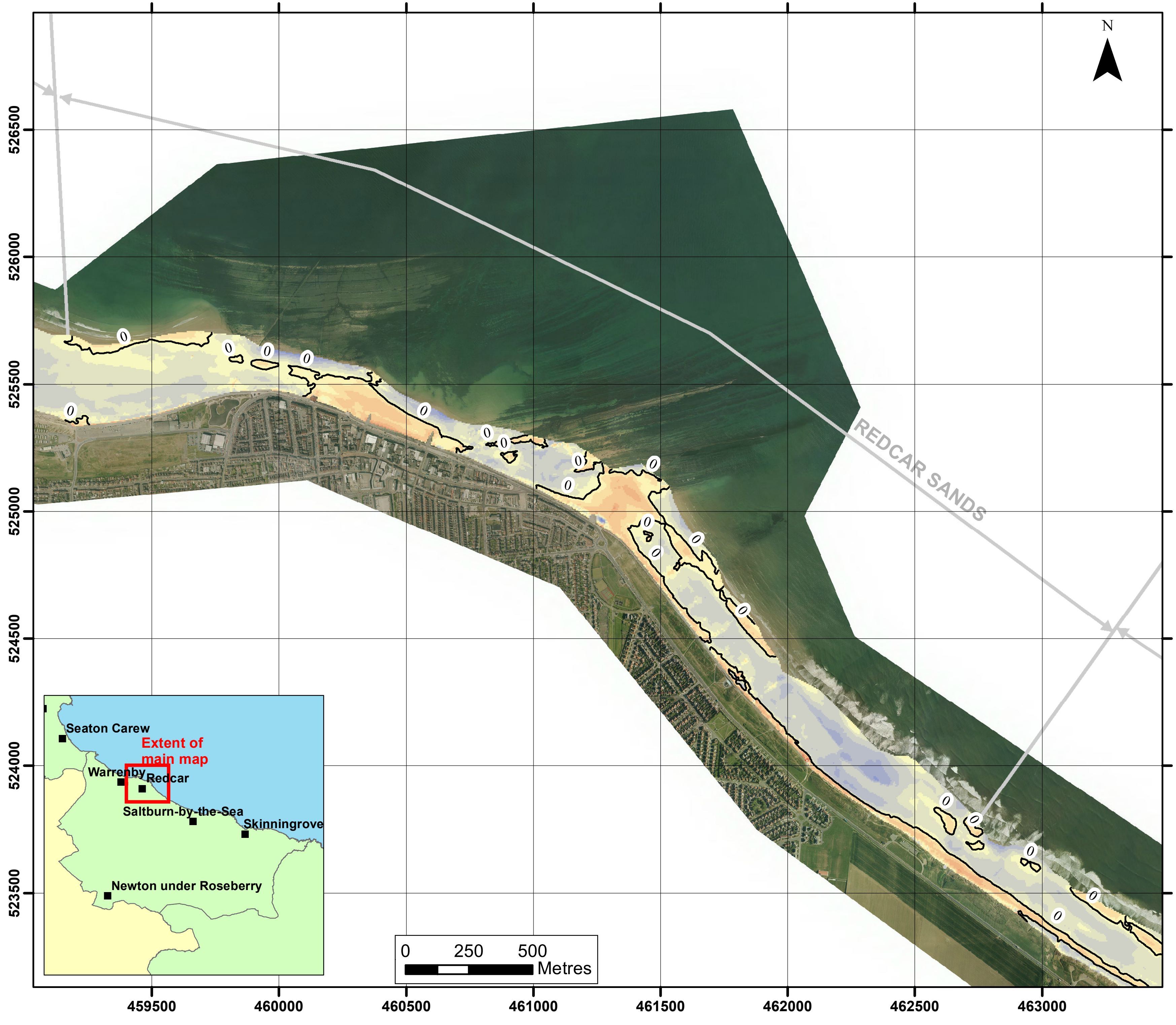

KEY Autumn 2008 and Autumn 2012
Change in elevation (m OD)

<-2
-2 - -1.75
-1.75 - -1.5
-1.5- -1.25
-1.25 - -1
-1 - -0.75
-0.75 - -0.5
-0.5 - -0.25
-0.25 - -0.1
-0.1 - 0
0 - 0.1
0.1 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1
1 - 1.25
1.25 - 1.5
1.5 - 1.75
1.75 - 2
>2

Loss
Change < 0.1 m
Gain
Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B- Map 2c Long-term Elevation change Redcar Sands Redcar & Cleveland Borough Council

Analytical Report 5
Full Measures (Autumn)
Surveys 2008 to 2012

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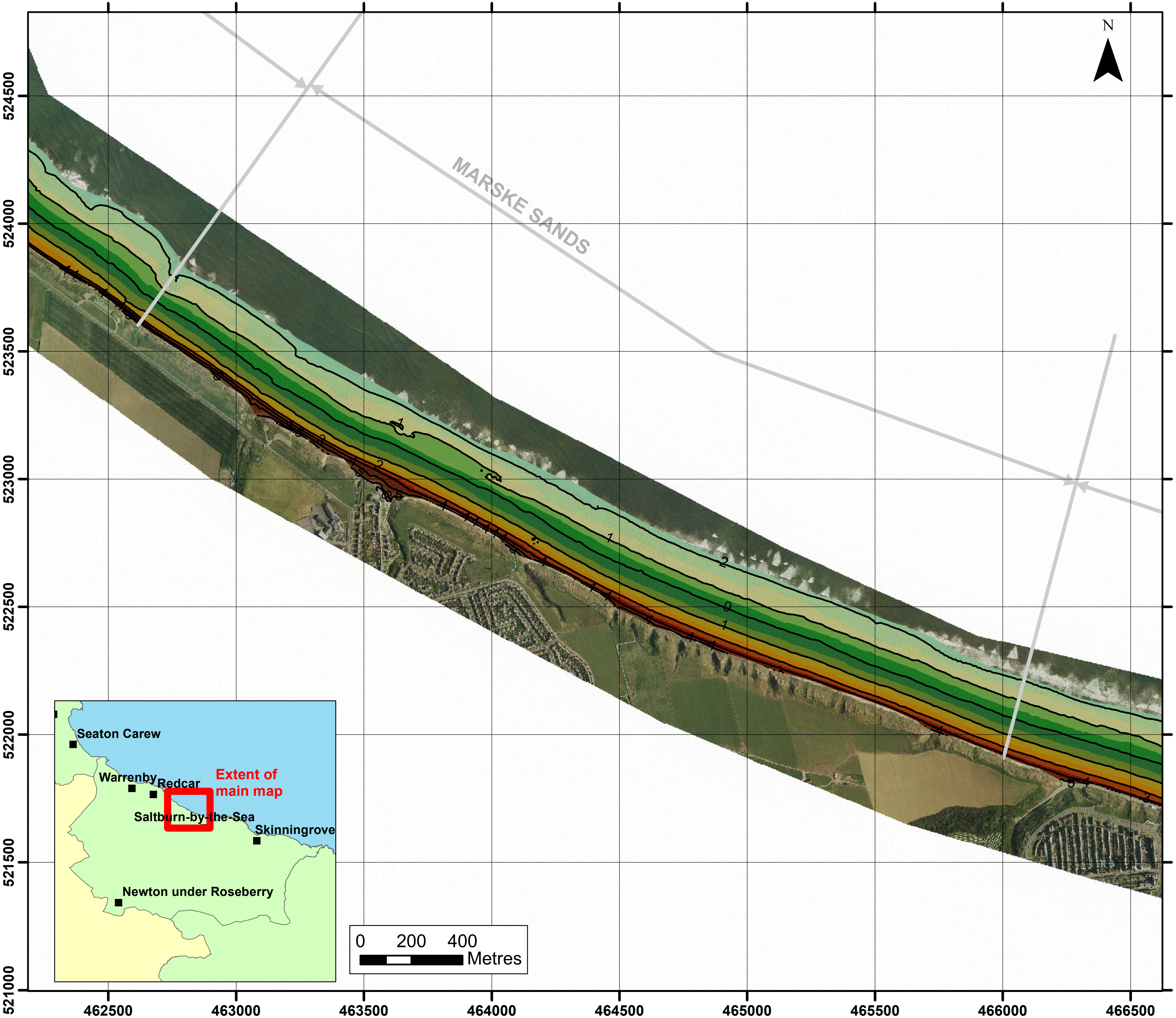

KEY Elevation (m OD)

- 7 - 7.5
- 6.5 - 7
- 6 - 6.5
- 5.5 - 6
- 5 - 5.5
- 4.5 - 5
- 4 - 4.5
- 3.5 - 4
- 3 - 3.5
- 2.5 - 3
- 2 - 2.5
- 1.5 - 2
- 1 - 1.5
- 0.5 - 1
- 0 - 0.5
- -0.5 - 0
- -1 - -0.5
- -1.5 - -1
- -2 - -1.5
- -2.5 - -2
- -3 - -2.5
- Contour 1m

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B - Map 3a
Topographic Survey
Marske Sands
Redcar & Cleveland Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

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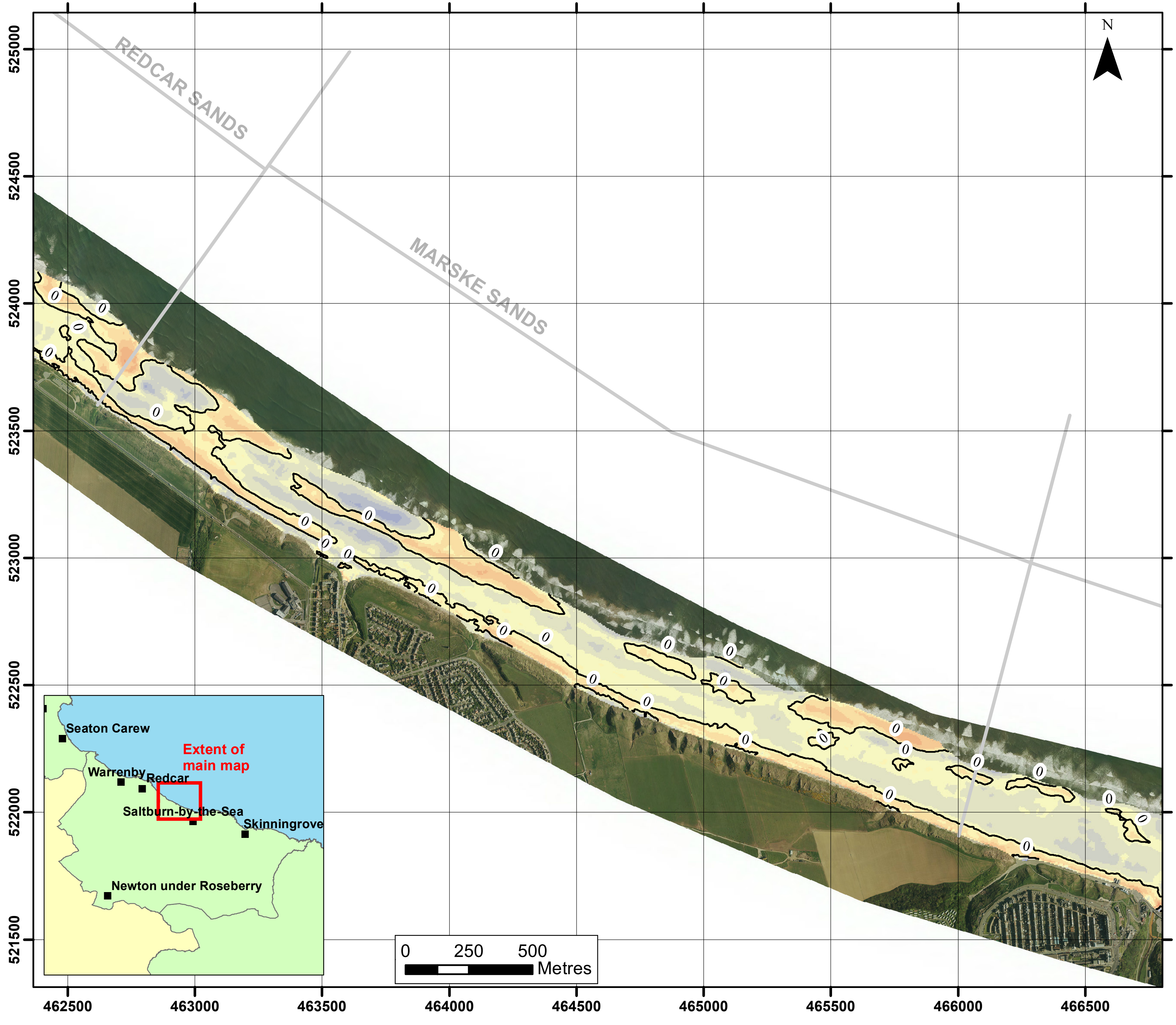

KEY Autumn 2011 and Autumn 2012
Change in elevation (m OD)

<-2	Loss
-2 - -1.75	
-1.75 - -1.5	
-1.5- -1.25	
-1.25 - -1	
-1 - -0.75	
-0.75 - -0.5	
-0.5 - -0.25	
-0.25 - -0.1	
-0.1 - 0	Change < 0.1 m
0 - 0.1	
0.1 - 0.25	Gain
0.25 - 0.5	
0.5 - 0.75	
0.75 - 1	
1 - 1.25	
1.25 - 1.5	
1.5 - 1.75	
1.75 - 2	
>2	

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B - Map 3b
Short-term Elevation change Marske Sands Redcar & Cleveland Borough Council

Analytical Report 5
Full Measures (Autumn) Surveys 2011 to 2012

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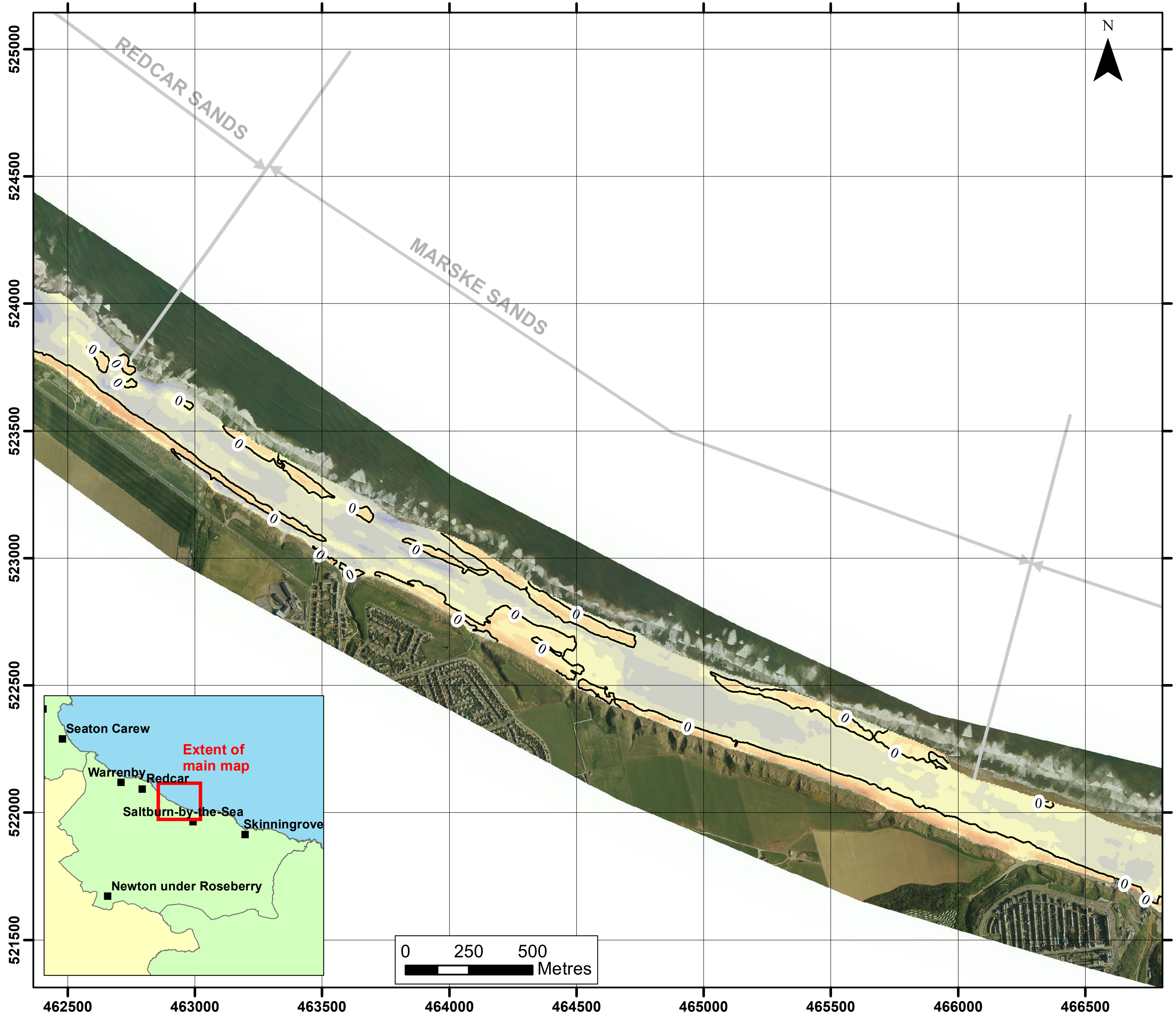

KEY Autumn 2008 and Autumn 2012
Change in elevation (m OD)

Range	
<-2	Loss
-2 - -1.75	
-1.75 - -1.5	
-1.5- -1.25	
-1.25 - -1	
-1 - -0.75	
-0.75 - -0.5	
-0.5 - -0.25	
-0.25 - -0.1	
-0.1 - 0	Change < 0.1 m
0 - 0.1	
0.1 - 0.25	Gain
0.25 - 0.5	
0.5 - 0.75	
0.75 - 1	
1 - 1.25	
1.25 - 1.5	
1.5 - 1.75	
1.75 - 2	
>2	

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B - Map 3c
Long-term Elevation change
Marske Sands
Redcar & Cleveland Borough Council

Analytical Report 5
Full Measures (Autumn) Surveys 2008 to 2012

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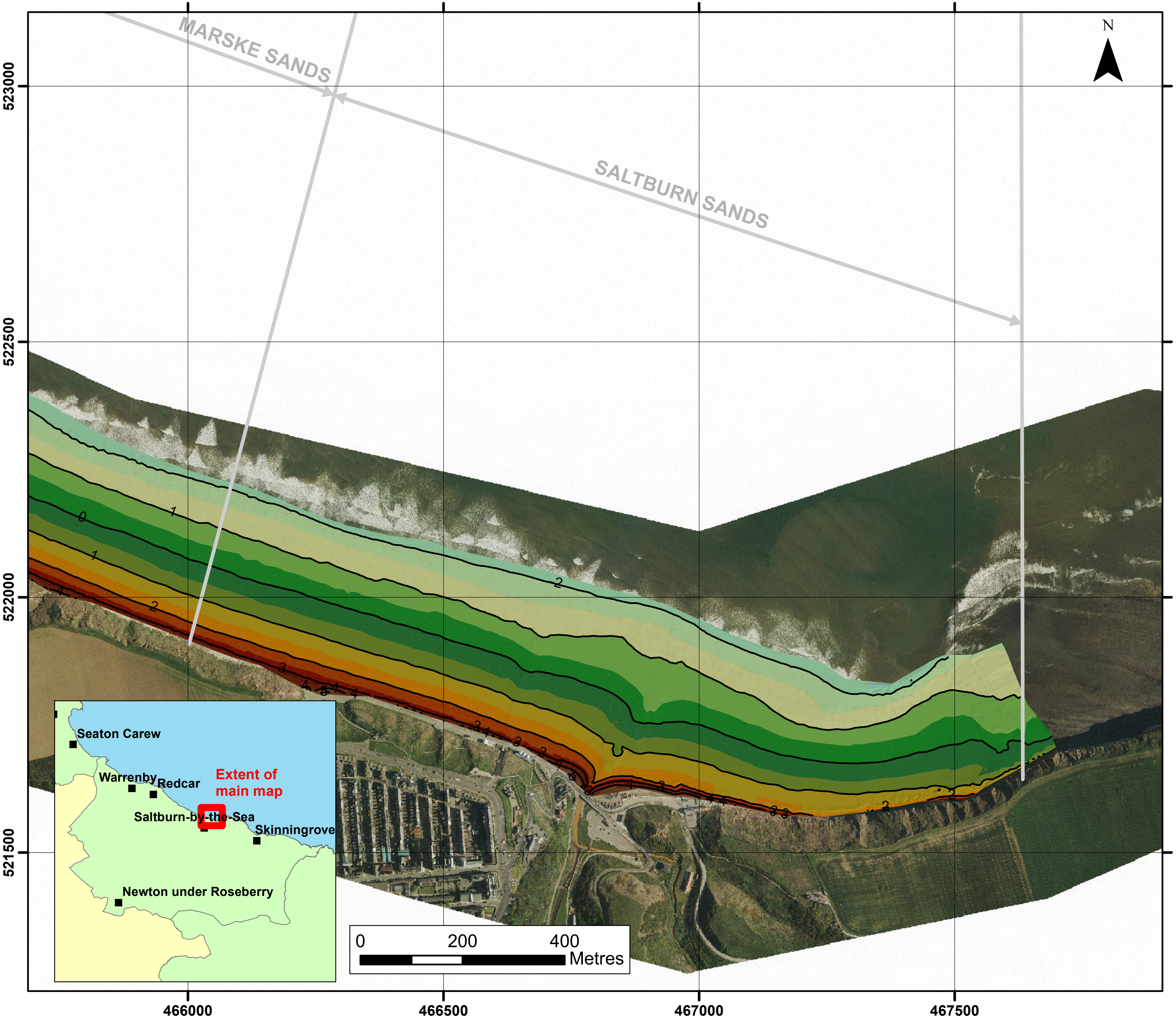

KEY **Elevation (m OD)**

- 7 - 7.5
- 6.5 - 7
- 6 - 6.5
- 5.5 - 6
- 5 - 5.5
- 4.5 - 5
- 4 - 4.5
- 3.5 - 4
- 3 - 3.5
- 2.5 - 3
- 2 - 2.5
- 1.5 - 2
- 1 - 1.5
- 0.5 - 1
- 0 - 0.5
- -0.5 - 0
- -1 - -0.5
- -1.5 - -1
- -2 - -1.5
- -2.5 - -2
- -3 - -2.5
- Contour 1m

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B - Map 4a
Topographic Survey
Saltburn Sands
Redcar & Cleveland Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

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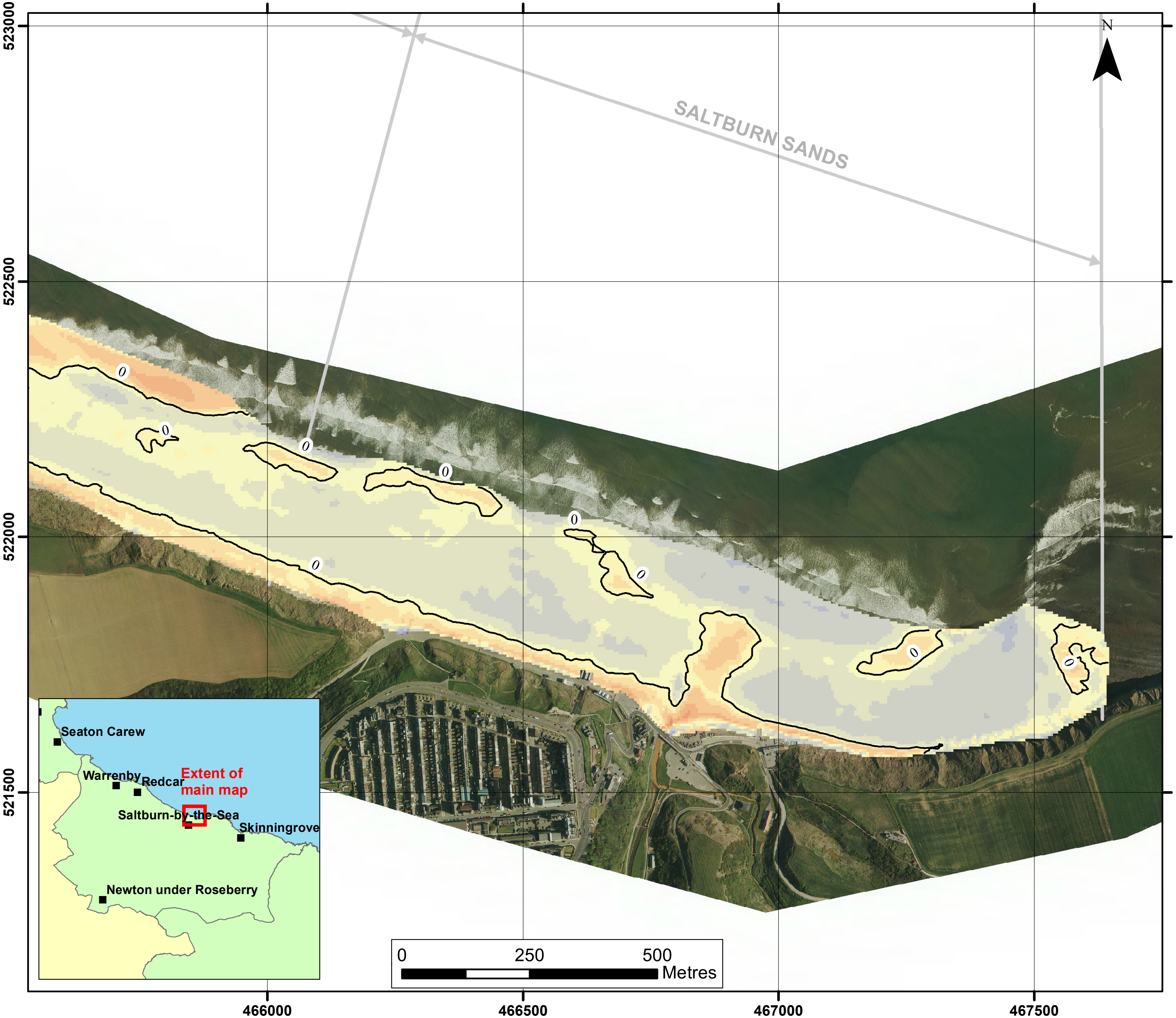

KEY Autumn 2011 and Autumn 2012
Change in elevation (m OD)

- <-2
- -2 - -1.75
- -1.75 - -1.5
- -1.5- -1.25
- -1.25 - -1
- -1 - -0.75
- -0.75 - -0.5
- -0.5 - -0.25
- -0.25 - -0.1
- -0.1 - 0
- 0 - 0.1
- 0.1 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5
- 1.5 - 1.75
- 1.75 - 2
- \>2

Loss

Change < 0.1 m

Gain

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B- Map 4b
Short-term
Elevation change
Saltburn Sands
Redcar & Cleveland
Borough Council

Analytical Report 5
Full Measures (Autumn)
Surveys 2011 to 2012

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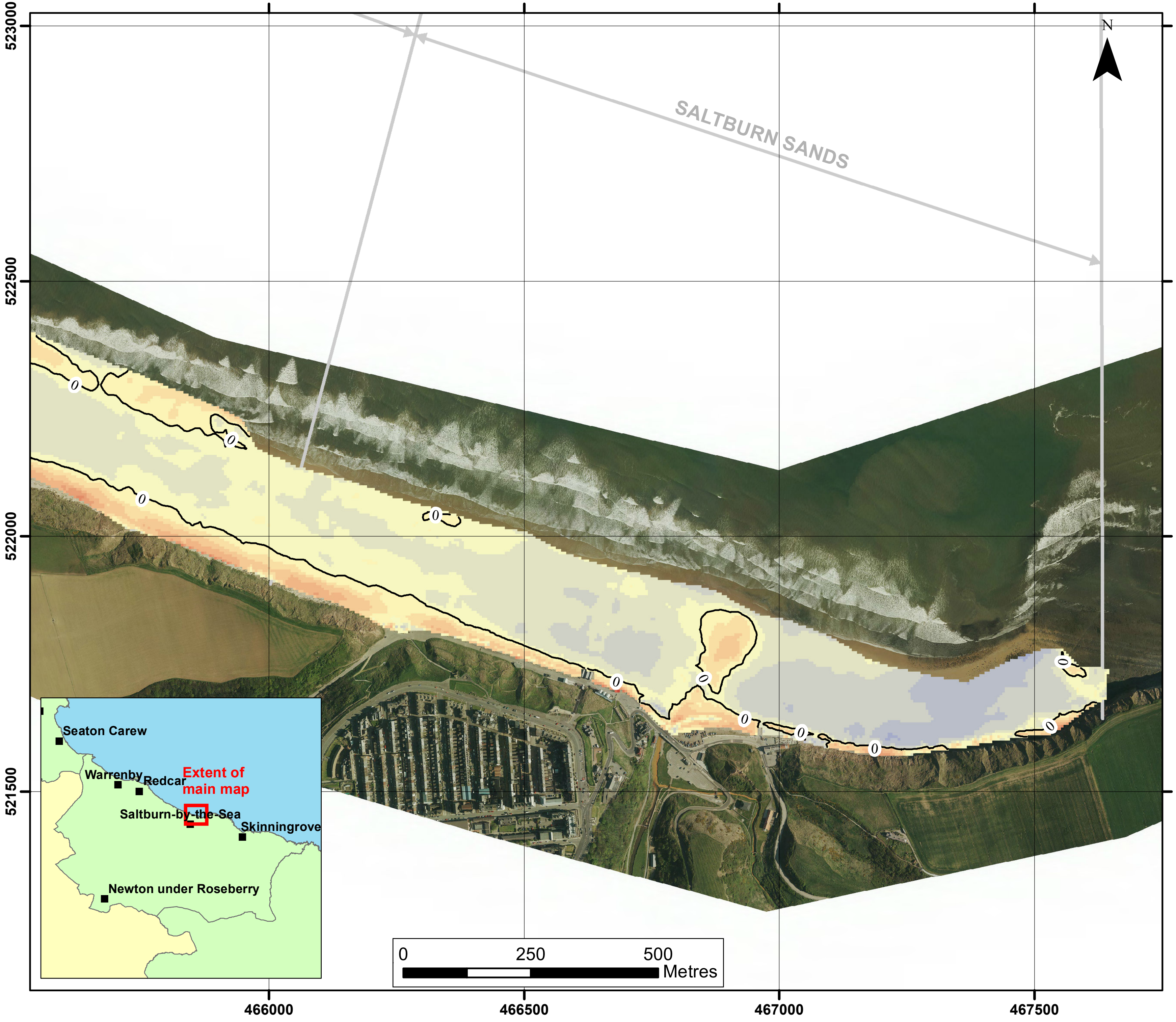

KEY Autumn 2008 and Autumn 2012
Change in elevation (m OD)

<-2	Loss
-2 - -1.75	
-1.75 - -1.5	
-1.5- -1.25	
-1.25 - -1	
-1 - -0.75	
-0.75 - -0.5	
-0.5 - -0.25	
-0.25 - -0.1	
-0.1 - 0	Change < 0.1 m
0 - 0.1	
0.1 - 0.25	Gain
0.25 - 0.5	
0.5 - 0.75	
0.75 - 1	
1 - 1.25	
1.25 - 1.5	
1.5 - 1.75	
1.75 - 2	
>2	

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B- Map 4c
Long-term Elevation change Saltburn Sands Redcar & Cleveland Borough Council

Analytical Report 5
Full Measures (Autumn)
Surveys 2008 to 2012

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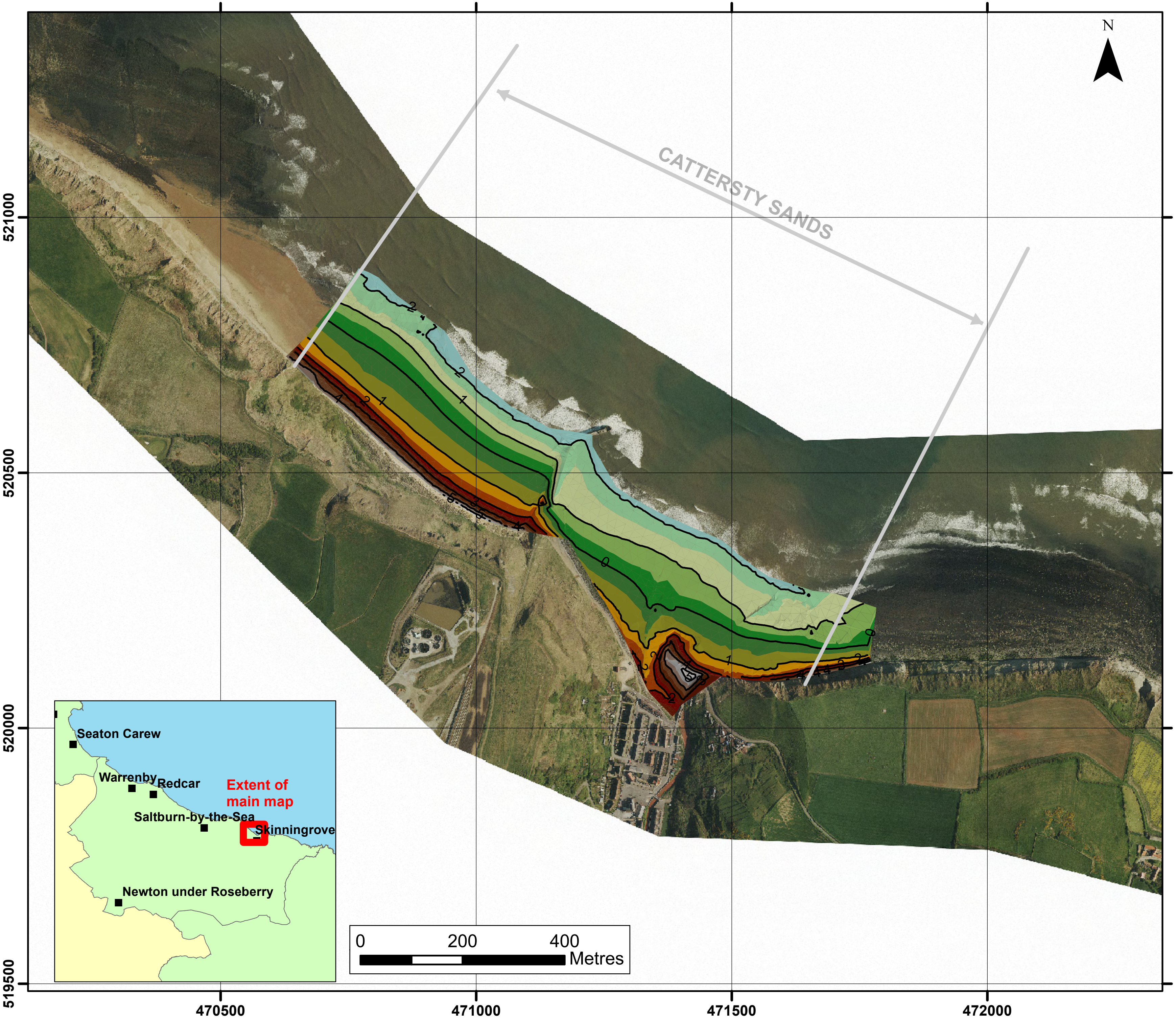

KEY

Elevation (m OD)

- 5.5 - 6
- 5 - 5.5
- 4.5 - 5
- 4 - 4.5
- 3.5 - 4
- 3 - 3.5
- 2.5 - 3
- 2 - 2.5
- 1.5 - 2
- 1 - 1.5
- 0.5 - 1
- 0 - 0.5
- -0.5 - 0
- -1 - -0.5
- -1.5 - -1
- -2 - -1.5
- -2.5 - -2
- Contour 1m

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B- Map 5a
Topographic Survey
Cattersty Sands
Redcar&Cleveland
Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

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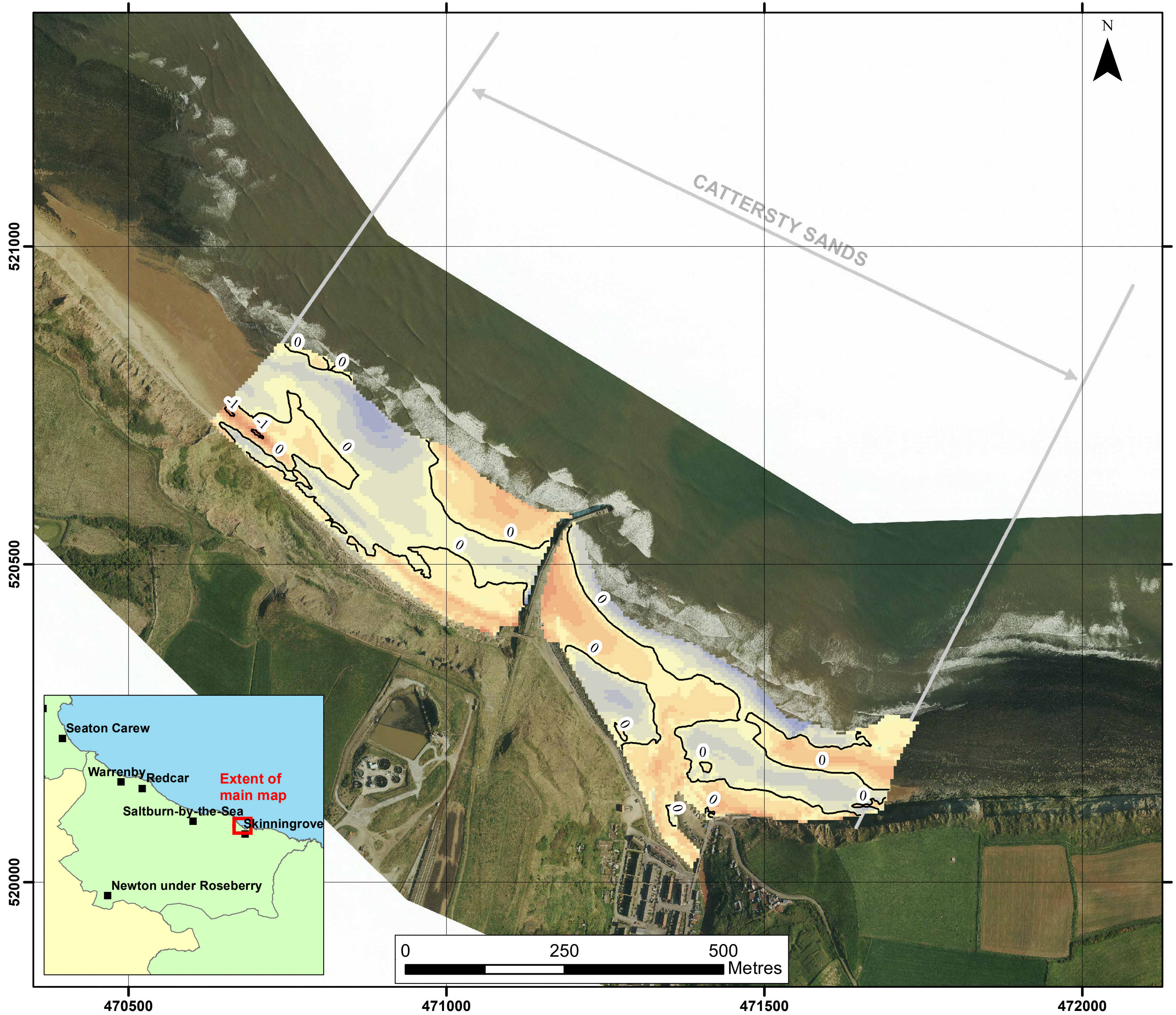

KEY Autumn 2011 and Autumn 2012
Change in elevation (m OD)

<-2	Loss
-2 - -1.75	
-1.75 - -1.5	
-1.5- -1.25	
-1.25 - -1	
-1 - -0.75	
-0.75 - -0.5	
-0.5 - -0.25	
-0.25 - -0.1	
-0.1 - 0	Change < 0.1 m
0 - 0.1	
0.1 - 0.25	Gain
0.25 - 0.5	
0.5 - 0.75	
0.75 - 1	
1 - 1.25	
1.25 - 1.5	
1.5 - 1.75	
1.75 - 2	
>2	

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B - Map 5b
Short-term Elevation change Cattersty Sands Redcar & Cleveland Borough Council

Analytical Report 5
Full Measures (Autumn) Surveys 2011 to 2012

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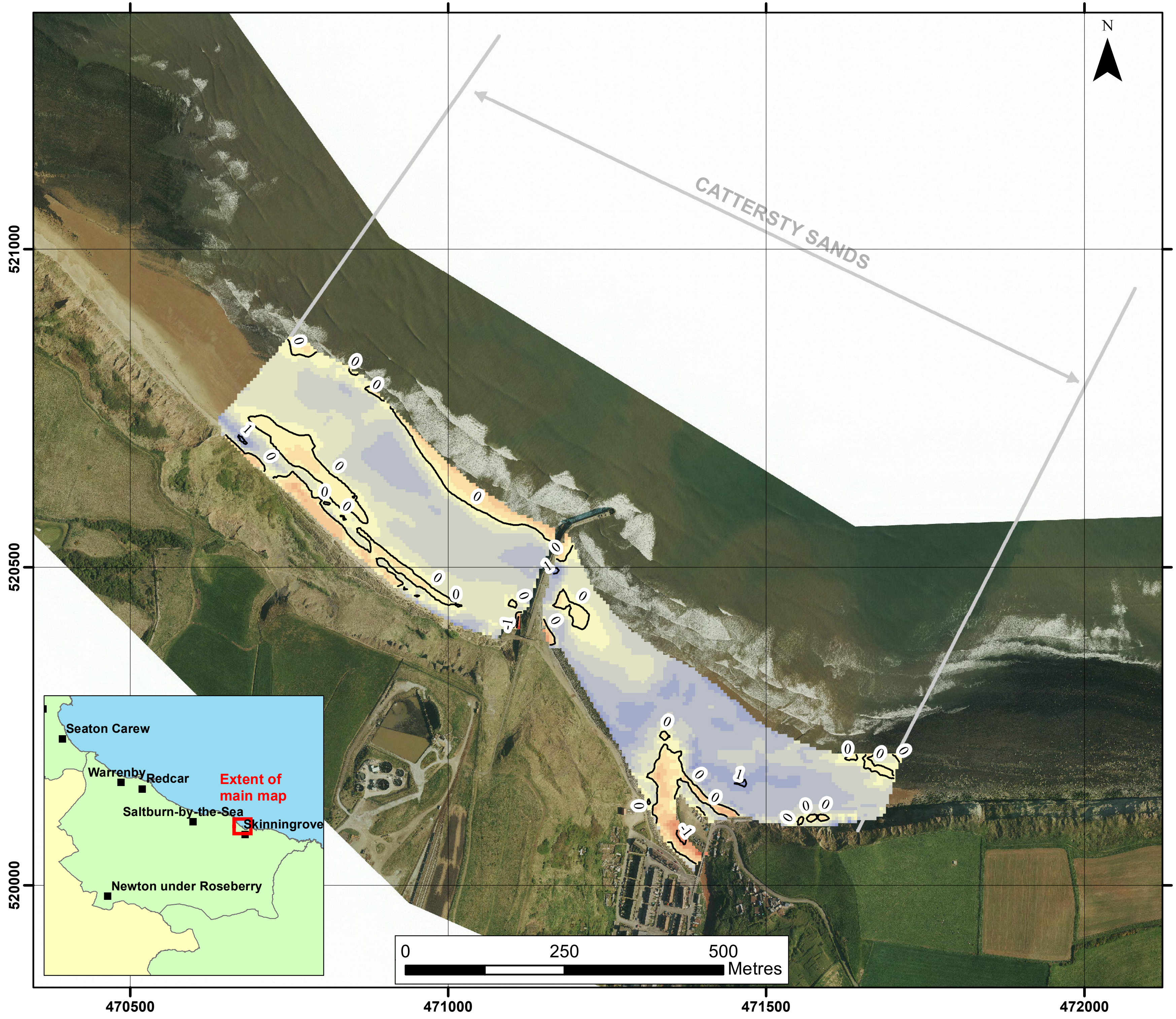

KEY Autumn 2008 and Autumn 2012
Change in elevation (m OD)

<-2	Loss
-2 - -1.75	
-1.75 - -1.5	
-1.5- -1.25	
-1.25 - -1	
-1 - -0.75	
-0.75 - -0.5	
-0.5 - -0.25	
-0.25 - -0.1	
-0.1 - 0	Change < 0.1 m
0 - 0.1	
0.1 - 0.25	Gain
0.25 - 0.5	
0.5 - 0.75	
0.75 - 1	
1 - 1.25	
1.25 - 1.5	
1.5 - 1.75	
1.75 - 2	
>2	

Contours of change

Client: North East Coastal Group
Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix B - Map 5c
Long-term Elevation change Cattersty Sands Redcar & Cleveland Borough Council

Analytical Report 5
Full Measures (Autumn)
Surveys 2008 to 2012

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Appendix C

Cliff Top Survey

Cliff Top Survey

Staithes

Twenty ground control points have been established within Staithes (Figure C1). The maximum separation between any two points is nominally 100m.

The cliff top surveys at Staithes are undertaken annually. Measurements are taken from a fixed ground control point along a fixed bearing to the edge of the cliff top.

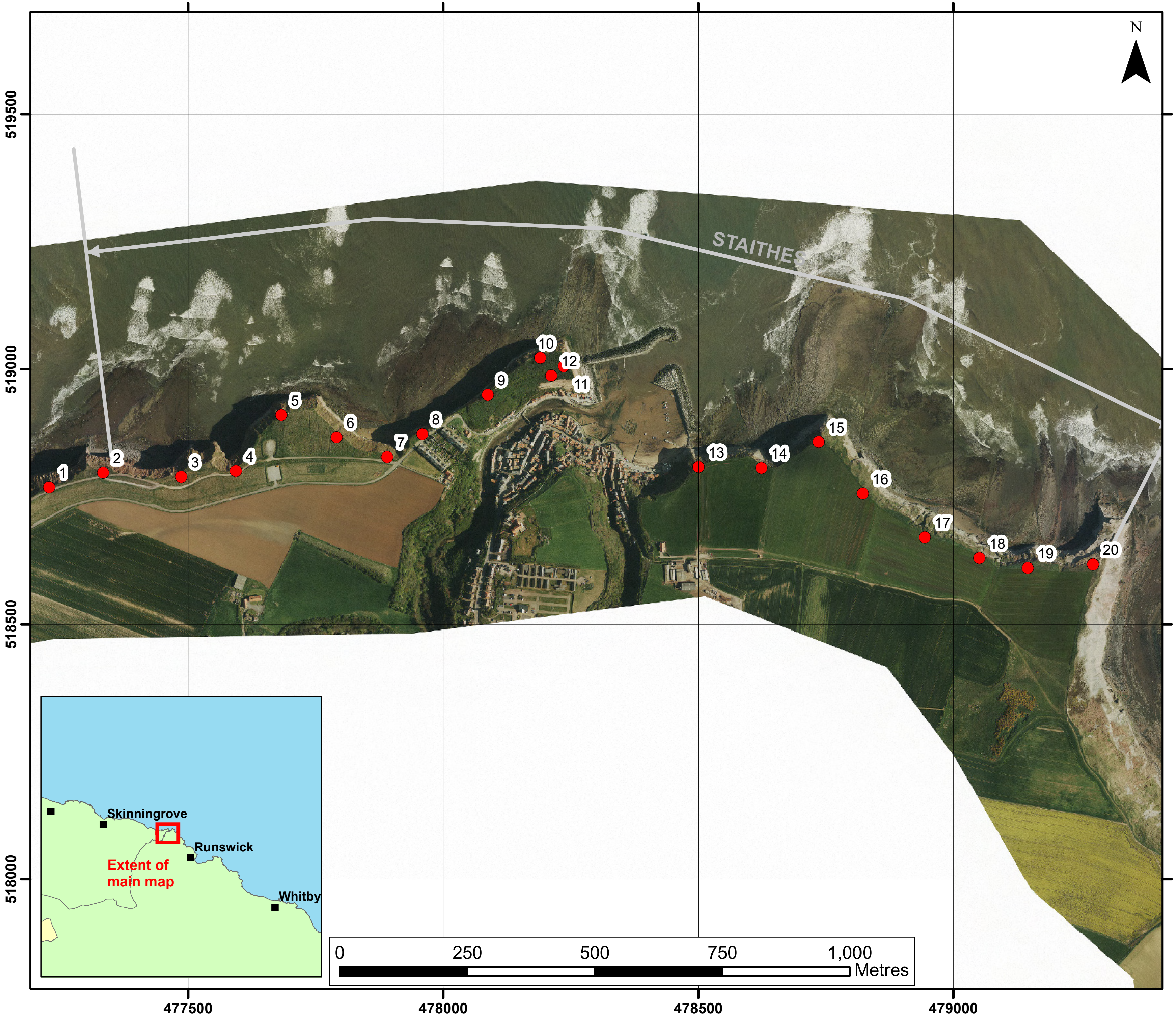
Table C1 provides baseline information about these ground control points and results from the 2008 (baseline) survey showing the position from the ground control point to the edge of the cliff top along the defined bearing. Future reports will show results from subsequent surveys and provide a means of assessing erosion since the baseline survey.

Table C1 – Cliff Top Surveys at Staithes

Ground Control Point Details				Distance to Cliff Top (m)			Total Erosion (m)		Erosion Rate (m/year)
Ref	Easting	Northing	Bearing (º)	Baseline Survey (Nov 2008)	Previous Survey (April 2011)	Present Survey (Oct 2011)	Baseline (Nov 2008) to Present (Oct 2011)	Previous (April 2011) to Present (Oct 2011)	Baseline (Nov 2008) to Present (Oct 2011)
1	477228	518769	320	1.9	1.7	1.6	-0.3	-0.1	-0.1
2	477334	518798	0	10.9	10.8	10.6	-0.3	-0.2	-0.1
3	477487	518789	350	7.1	8.5	8.2	1.1	-0.3	0.4
4	477594	518801	340	5.9	5.4	5.2	-0.7	-0.2	-0.2
5	477683	518911	350	8.4	9.7	9.4	1.0	-0.3	0.3
6	477792	518867	30	8.6	8.5	8.5	-0.1	0.0	0.0
7	477891	518828	60	7.7	7.7	7.5	-0.2	-0.2	-0.1
8	477959	518873	350	8.7	9.8	9.6	0.9	-0.2	0.3
9	478088	518950	350	7.6	8.4	8.0	0.4	-0.4	0.1
10	478191	519023	340	8.4	8.9	8.7	0.3	-0.2	0.1
11	478237	519007	60	6.9	6.8	6.7	-0.2	-0.1	-0.1

Ground Control Point Details				Distance to Cliff Top (m)			Total Erosion (m)		Erosion Rate (m/year)
Ref	Easting	Northing	Bearing (º)	Baseline Survey (Nov 2008)	Previous Survey (April 2011)	Present Survey (Oct 2011)	Baseline (Nov 2008) to Present (Oct 2011)	Previous (April 2011) to Present (Oct 2011)	Baseline (Nov 2008) to Present (Oct 2011)
12	478213	518988	150	6.1	6.5	6.5	0.4	0.0	0.1
13	478501	518809	15	11.4	9.4	9.2	-2.2	-0.2	-0.8
14	478624	518807	20	7.5	7.5	7.5	0.0	0.0	0.0
15	478737	518858	60	6.1	6.2	6.4	0.3	0.2	0.1
16	478823	518757	60	8	8.4	8.4	0.4	0.0	0.1
17	478944	518671	30	9.3	9.9	9.4	0.1	-0.5	0.0
18	479052	518630	20	9.2	9.4	9.3	0.1	-0.1	0.0
19	479147	518610	0	14.2	14.5	14.3	0.1	-0.2	0.0
20	479274	518618	20	11.4	11.5	11.2	-0.2	-0.3	-0.1

Note: It is assumed that the accuracy of cliff top monitoring using this technique is ±0.1m. Therefore observed changes have been altered by this amount prior to calculation of an erosion rate. Erosion rates are not calculated where the cliff line shows advance. This is likely to be the product of differing survey interpretation, and far less likely to be a toppling cliff edge.



KEY

Ground Control Points

Client: North East Coastal Group

Project: Cell 1 Regional Coastal Monitoring Programme 2011 to 2016

Appendix C - Map 1
Ground Control Points
Staithes
Redcar & Cleveland
Borough Council

Analytical Report 5
Full Measures Survey
Winter 2012

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Appendix D

Durham University Report on Staithes

Cowbar Coastal Cliff Monitoring, Staithes, N. Yorkshire

February 2012

Dr N Rosser

Dr S Waugh

University of Durham

Prepared for and on behalf of:

Redcar and Cleveland Borough Council

Steve Dunning

1. Table of Contents

2. List of Tables

3. List of Figures

3. Context

This report summarizes the installation and Year 1 results from an ongoing monitoring program at Cowbar Nab, Staithes, N. Yorkshire. The monitoring program is being undertaken for and on behalf of Redcar and Cleveland Borough Council.

The report includes detail on the design and specification of the instrumentation installed at the site, the underlying rationale for equipment choice and the methods used for data processing and analysis to aid the interpretation of results, and to permit comparison with other sites.

The latter part of the report describes the results collected to date, and generates erosion rates based upon this data. The report concludes with an interpretation of findings to date, and implications for the site.

4. Summary

The following tasks have been completed as part of this study in Year 1:

- Monthly high-resolution terrestrial laser scans of the cliff at Cowbar Nab have been undertaken since January 2011.
- The design and installation of 3-axis seismic monitoring station, and real-time data stream back to Durham has been completed (Section 8).
- The design and installation of cliff face environmental monitoring system to collect data on near-cliff weather conditions has been completed (Section 8).
- The design and installation of a laser-radar water-level gauge to measure sea surface elevation and cliff toe wave climate has been completed (Section 8).
- The design and installation of permanent terrestrial laser scanning system to observed changes to the cliff on a daily basis, has been completed (Section 11).

The following erosion rates have been calculated:

- The calculation of monthly erosion and long-term 15 month erosion rates has been completed, and compared to past rates measured at this site (Sections 10 & 12). A total of 318.99 m3 of rockfall in 9,968 discrete events has occurred during this period. Considerable month-on-month variability is observed, with May 2011 experiencing effectively no discernible change (Section 12).
- The net rate observed in the period January 2011 to March 2012 was 1.99 x 10-3 m yr-1 (Section 12).
- On average the observed rate is less than that previously observed at this site (358 m3 of rockfall from 4,494 m2 of cliff face, deriving 25 x 10 -3 myr-1 erosion).

The following conclusions have been drawn based upon this analysis:

- A preliminary analysis of Year 1 seismic monitoring data in respect of environmental conditions at site has been completed (Section 12). The seismic response of the cliff is in line with observations made elsewhere on this coast, and elsewhere worldwide. The set-up is now calibrated, and collecting continuous data on wave energy and impacts at the cliff toe. Future analysis will focus upon the correlation of this data with the rockfall and erosion output.
- There is no indication that the erosion of the cliff at Cowbar is accelerating or deviating away from behavior observed at this site previously. The concentration of erosion is currently focused away from the 'pinch points' at this site.

- No loss of cliff line was observed during this period, although critically this indicates cliff steepening, which will in time result in failure of the cliff top in future. Continued monitoring will help identify where and when this may occur.
- There is no evidence in the monitoring data of the development of a deeper-seated failure which would threaten the road and / or houses.

5. Site description & previous assessments of erosion rates

A series of previous studies have identified that the cliffs at Cowbar Nab are actively eroding, and with time may threaten the infrastructure and dwellings at the cliff top. This monitoring project has been developed to provide the best possible data on the rates and controls on erosion at Cowbar, to support future decision making.

The cliffs are near-vertical, interbedded shales, sandstones, limestones and mudstones, capped with a c. 5 m depth of glacial till.

The rates of erosion at this site have been measured by various authors. Agar (1960) using basic cliff top survey techniques, identified a rate of 4 feet per century (1.2 cm p.a.) and 13 feet per century (3.9 cm p.a.) for headlands, in general. More recently Lim (2006) studied the cliff line directly below Cowbar Cottages. The area of rock armour represents roughly the centre of the studied section, which had a length of about 140 m and a surface area of 3,922 m^2. The monitoring period extended over a period from October 2003 to April 2005 (19 months), during which a laser scan of the site was collected at as close to monthly intervals as the tidal conditions permitted and analysed to determine the volume changes through time. The total recorded volume of detachments in the monitoring period was about 576 m^3 according to Table 6.1 of Lim (2006).

Caution should be taken here is directly comparing the volumes derived by Lim (2006) and this study, given different cliff area (survey extent) under consideration, and the different definition of the survey (see section 6 below). Based upon this the total recession during the 19 months of monitoring was 15.5 cm, which represents a rate of approximately 9.8 cm yr^{-1}. Note that this rate is dominated by the effects of the single large rock fall event in a highly fractured area of rock mass above an engineered area where a drainage pipe protrudes from the cliff face.

Most recently, in a study for the Cowbar Residents Association, Rosser et al (2006), used historic photography and maps to estimate the long-term retreat rates at 3 cross-cliff profiles (P1 – P3) at Cowbar Nab (Table 1). Critically, this study identified the significant errors associated with using mapping data for retreat rate estimation at sites such as this, such that retreat rates did not exceed the error associated with the method adopted.

Table 1 Retreat rates estimated from historic datasets in the study, relative to the 2000 cliff line. NB: Negative values indicate that the cliff line is *apparently* moving to seaward.

Dataset	Retreat rate p1 (cm yr^{-1})	Retreat rate p2 (cm yr^{-1})	Retreat rate p3 (cm yr^{-1})	Ave. retreat rate (cm yr^{-1})
1895	-10.7	3.0	-3.2	-3.6
1919	-10.5	2.6	-2.5	-3.5
1930	-14.3	2.5	-1.9	-4.6
1946	-15.9	-7.3	1.1	-7.4
2000	0.0	0.0	0.0	0.0

6. Monitoring system overview, design & timescale

The approach taken to monitoring the seaward facing cliff at Cowbar Nab is based upon 9 years of research on erosion on this stretch of coastline. The monitoring comprises the use of high-resolution 3D laser scanning to capture erosion, microseismic monitoring of ground motions as a result of wave impacts, and environmental monitoring at the cliff face, to document the occurrence of erosion and rockfall, and to permit in future the analysis of specific drivers of erosion.

Monitoring design

The monitoring system is based around 2 data types:

1. Periodic 3D monitoring of erosion of the cliff face
2. Continuous monitoring of the environmental conditions at site

Periodic monitoring is achieved using monthly terrestrial laser scans, captured from the foreshore at low tides. A full methodology for the data collection and processing is provided in Sections 7 - 10.

Monthly monitoring is supplemented by daily laser scans captured using a permanently installed remote control laser scanner housed in a secure box on the cliff top on the opposite side of the Bay to the Nab, providing an almost uninterrupted view of the Nab cliff face. This scanner provides high-frequency but lower resolution data, which allows us to identify the day on which specific events occurred.

Continuous monitoring of environmental conditions is achieved using a combination of a cliff top weather station and web-cam, and a 3-axis broadband seismometer, and a laser radar water height gauge. The seismometer is able to characterize a wide bandwidth of microseismic accelerations due to wind, offshore- and nearshore-waves, in addition to anthropogenic noise. Recent research has shown this approach to be the more robust approach of characterizing energy delivery to coast, negating the need to model offshore data to the nearshore and coastline.

Timescale of installation

Periodic laser scans commenced at the outset of the project, and have continued as planned at near-monthly intervals since. Data is processed on a monthly basis, to provide an oversight on activity at the site and highlight any significant changes in behaviour.

The seismometer was custom built for this installation by Guralp Systems. The seismometer was ordered at the outset of the project, and was installed on site in June 2011. The seismometer suffered a firmware failure in August 2011. The instrument was replaced by a loaned sensor from the NERC SEIS-UK equipment pool to maintain data collection whilst the original instrument was repaired.

The weather station, laser radar and camera system were installed in August, 2011 by professional rope access contractors.

The permanent laser scanner was designed and developed specifically for this project, which required a series of laboratories test, software development and modification, and field-testing. The final field installation was conducted in September 2011.

7. Monitoring installation

3-axis seismometer

A 3-axis seismometer (Guralp CMG3-ESP) with data-logger, server and modem has been installed on the cliff top adjacent to the cottages on the Nab. The seismometer is housed in a custom constructed seismic well, to specification defined by the NERC supported SEIS-UK facility. A 1 m x 0.6 m x 1.5 m breeze-block lined well, with a 0.1 m deep granite slab base provides isolation from seismic noise, whilst ensuring a high degree of seismic connectivity with the cliff rock mass.

The CMG3-ESP was chosen due to its broad frequency response, which ranges from 100 Hz to 120 seconds, allowing infragravity waves to be captured. Recent research indicates that infragravity waves are key to wave energy delivery to rock coasts, to which this instrument is uniquely tuned (e.g. Norman, 2012).

The CMG3-ESP logs at 100 Hz recording ground displacements in N-S, E-W and vertical components. Data is streamed in real-time via a GPRS modem to SEIS-UK (University of Leicester), who run the UKs seismic research facility. Power for the system is provided from the adjacent lamppost, which also holds a GPS antenna for time synchronization, and a GPRS antenna for communication.

Servers at SEIS-UK process the data in real-time, whilst providing real-time status checks, via the following URL:

http://143.210.23.110/

Processed data (median signal powers of 5 set frequency bands, as defined by Norman (2012); total displacement; all at 15 minute intervals) is streamed to the data archive server in Durham, where it is merged with other monitoring data collected at site.

The methods and use of this data is more fully described in this paper and thesis:

- *Lim, M., Rosser, N.J., Petley, D.N., Keen, M. 2011. Quantifying the controls and influence of tide and wave impacts on coastal rock cliff erosion Journal of Coastal Research, Volume 27, issue 1, year 2011, pp. 46 - 56*
- *Norman, E.C. (2012) Microseismic monitoring of the controls on rocky coastal cliff erosion. Unpublished PhD Thesis, University of Durham.*

Figure 1 View into the seismic well, showing the Guralp seismometer encased within a foam box to minimize the effects of air circulation on the instrument. The data logger and model is contained with the black Peli-case. 12 v power and communications are provided via a buried conduit to the lamp-post adjacent to the site, which is seen entering the well at the top of this photo.

Figure 2 View of the sealed seismometer installation, flush with the ground, and set back from the edge of the cliff by 5 m.

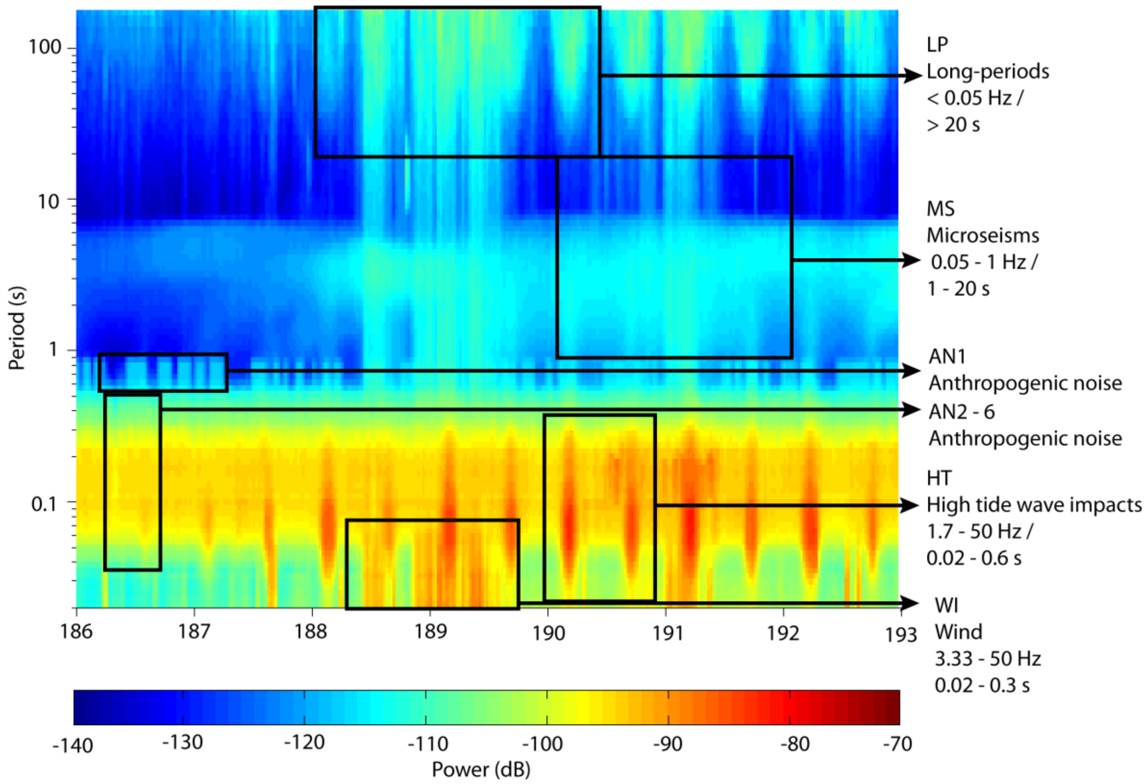

Figure 3 An example spectrogram from the dataset and the different bands of ground motion frequencies observed. Frequency power is presented in decibels (dB) calculated as 10 $\log_{10}((ms^{-1})^2/Hz)$. Each of the black boxes highlights an example of the typical temporal and power characteristics of each frequency band.

Figure 3 shows an example of the output from the seismometer, here for a 1-week period, showing signal power across the instruments frequency response. A series of characteristics frequencies are identified:

Long-period frequency band (LP): There is a clear range of long-period signals < 0.05 Hz (> 20 s), which have a distinct pattern, differentiating these from the microseisms (MS) (1 – 0.05 Hz / 1 - 20 s) by a band of low powers (approximately -130 dB) at around 0.1 Hz / 10 s. Increases in LP power often occur with simultaneous increases in the microseism (MS) frequency range and high power high tide (HT) or wind (WI) frequencies (explained below).

The frequency of these LP signals and association with tides and incoming wind and wave characteristics suggests that the LP frequency band represents long-period ocean waves called infragravity waves. Infragravity waves lie within the period range of 0.05 – 0.003 Hz / 20 - 300 s and are generated as groups of swell waves from distant storms arrive at the coast resulting in 'surf beat' an increase and decrease of the mean sea level at the period of the groups (Munk, 1949; Tucker, 1950).

Microseism frequency band (MS): Microseisms are widely acknowledged to be generated by sea waves near the coast, and take two forms:

- Primary microseisms are microseismic waves that have the same periodicity as the incoming ocean waves (Haubrich et al., 1963);

- Double frequency (DF) microseisms are generated by the constructive superposition of waves of the same periodicity travelling in opposite directions (Longuet-Higgins, 1950).

Waves travelling from different directions can be generated either by storms of varying wind directions generating waves heading in multiple directions or by the meeting of landward waves with those reflected from the coast (Longuet-Higgins, 1950). The microseisms can be clearly distinguished in the spectrogram in the period range of 1 - 0.05 Hz / 1 - 20 s. The MS frequency band power corresponds well to the increased power at the high and low frequency bands (non-anthropogenic) e.g. LP, HT and WI frequencies, which are all associated with incoming waves and / or wind.

Anthropogenic frequency band (AN): Within the high-frequency range 1.1 - 25 Hz / 0.04 - 0.9 s there are six discrete frequency bands that have constant frequency power. This suggests that these features are generated by anthropogenic activity

- **AN1:** There is an intermittent short-period signal tightly constrained within the frequencies 1.1 - 2 Hz / 0.5 - 0.9 s. Both the frequency range and the power values have an 'on / off' nature, with powers at around -115 dB or -130 dB, rather than the gradual increase and decrease of the signals from natural sources. As a result, this frequency band is not considered further in the analysis.
- **AN2:** At 2 - 5 Hz / 0.2 - 0.5 s; the power typically ranges between -105 to -115 dB;
- **AN3:** Between 5 - 10 Hz / 0.1 - 0.2 s; the power is typically around -97 dB;
- **AN4**: In the region between 10 - 14.3 Hz / 0.07 - 0.1 s the average power is highest throughout this signal range (AN2 - 6) averaging -95 dB;
- **AN5:** Between 14.3 - 16.7 Hz / 0.06 – 0.07 s there is a band of power that mirror that of the 5 - 10 Hz / 0.1 - 0.2 s range;
- **AN6:** Between 16.7 – 25 Hz / 0.04 - 0.06 s the signal mirrors that of the 2 - 5 Hz / 0.2 - 0.5 s range.

There are two different types of high-frequency bands that are clearly driven by environmental conditions, rather than anthropogenic sources. These are high-power events that overlap with the high-frequency anthropogenic signals (AN1 - 6). Naturally generated high-frequency signals have increases in power that coincide with increased power in the microseism (MS) and long-period (LP) bands, suggesting that the signals are related:

High tide frequency band (HT): Regularly occurring high-power signals around -85 to -95 dB are monitored in the frequency range 1.7 - 50 Hz / 0.02 - 0.6 s. As shown later, these occur during some, but not every, high tide. Adams et al. (2005) observed a coastal cliff ground motion signal at 20 Hz / 0.05 s representing high-frequency ringing of the cliff mass in response to direct wave impacts against the toe. It is anticipated that the HT frequency band observed here represents the same phenomenon.

Wind frequency band (WI): Sporadic increases in power that have similar values to the high tide frequencies (HT), occur within the 3.3 - 50 Hz / 0.02 - 0.3 s frequency band. Young et al. (1996) identified that wind velocities of 3 ms^{-1} and stronger result in a significant increase of seismic energy delivery to the ground surface at frequencies of 15 - 60 Hz / 0.066 - 0.017 s, although found signal amplitude to be non-linear with wind velocity. Other studies (e.g.

Bungum et al., 1985; Given, 1990; Gurrola et al., 1990), observed wind seismic signals at lower frequencies, reaching as low as 1 Hz for winds above 3 ms^{-1} (Withers et al., 1996). Wind velocities above 3 ms^{-1} are frequent at the study site. The intermittent, high-power, high-frequency and stochastic nature of this frequency band, and commonly its coincidence with wave-generated frequencies, suggests that this frequency band represents the influence of wind upon the monitored cliff.

The data analysis of the seismic data focusses upon the analysis of these set frequency bands, subsampling this data to 15 minute intervals. Examples of the data are its relationship to the prevailing environmental conditions is provided below (Section 12).

Water level

A key component of the monitoring system is a high-frequency water level sensor, which monitors sea surface height (tides + set up + waves) at the cliff toe. This negates the need to model offshore wave buoy data across the near- and foreshore, which invokes inherent uncertainties.

Water level is measured using a high-frequency laser radar, mounted on a bracket at the top of the rock cliff, directly below the cottages, targeted at the cliff toe. This allows the water level to be monitored when in contact with the cliff toe. The laser records at a frequency of 100 hz, which is then averaged to 5 Hz to provide the mean water surface level. The laser has a range of 1,200 m, which at this range (32.5 m above sea level) overcomes problems associated with the limited reflection of near-infrared laser from the sea water surface. The system uses a Class 1 eye laser, at 905 µm, and so has no effect on wildlife or people.

The laser has a cabled connection to a PC housed in the seismic well on the cliff top, where software logs the data internally, and streams the data via a GPRS modem to Durham. The data is then archived and processed to 15-minute intervals, and merged into the rest of the monitoring data. An example of the data is provided in Figure 4, which shows the raw data stream (red - left axis) and a 1000 sample smoothed derivative (blue – right axis). The raw data minus the smoothed data gives wave heights, whereas purely the smoothed data gives mean sea surface water level.

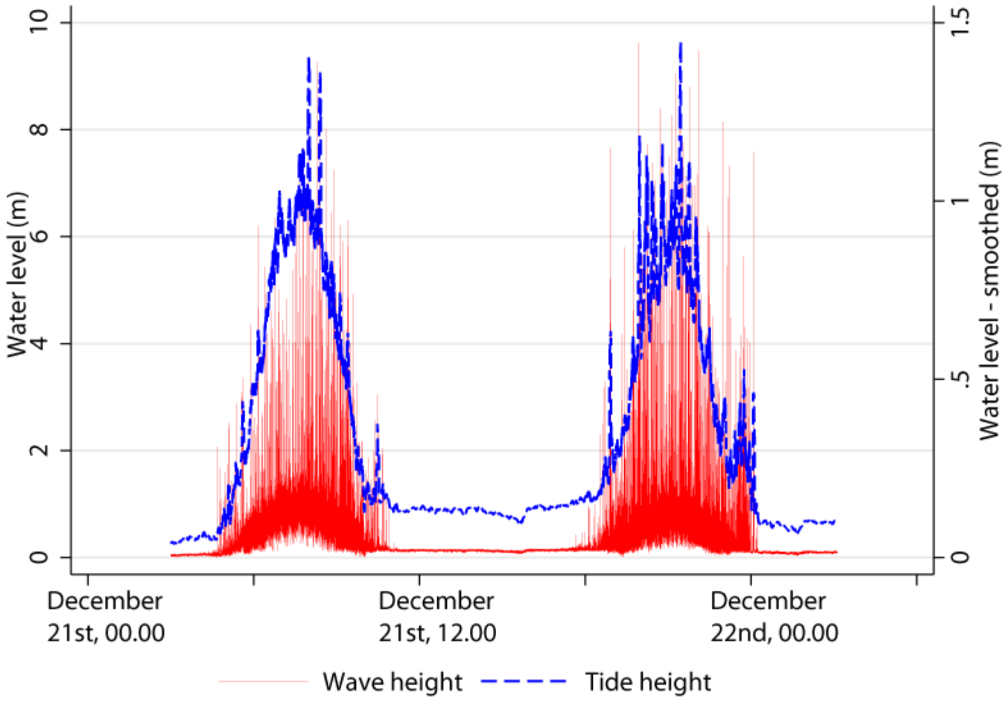

Figure 4 Water level obtained from laser radar, over a single day (21st December 2012)

Camera

To provide context to the monitoring data, a web-cam is positioned at the top of the rock cliff viewing the toe of the cliff and foreshore. The camera collects VGA photographs (1280 x 1600 pixels) at 5-minute intervals, and logs these to the PC in the seismic well. The camera also has UV illumination, although this is effective only over a short range, so is of limited utility in this context.

An example of the output from the camera is show in Figure 5.

Figure 5 View from the web-cam during low tide (left) and high tide (right)

Weather station

Cliff face environmental data is collection at site. Recent research has demonstrated that there is limited correlation between the occurrence of rockfalls from the cliff face and environmental conditions monitored at conventional weather stations further inland (e.g. Lim et al, 2011). More recently efforts have been made to explore the degree to which weather conditions on the cliff face differ to those inland, and then the degree to which these can explain rockfall occurrence (e.g. Norman, 2012).

An automatic weather station is mounted on a bracket at the top of the rock cliff, some 32 m above the toe of the cliff. The weather station has independent solar power, and connects wireless to an interface at the cliff top, which logs to the PC housed in the seismic well. This data is made available externally in real-time via an ftp:// server mounted on the PC, accessible via the GPRS modem, from which the data is archived in Durham and merged with the other monitoring data.

The weather station records the following variables:

- Barometric pressure
- Temperature
- Humidity
- Rainfall
- Wind speed
- Wind direction
- UV

Form these variables a series of secondary data is calculated, including:

- Dew-point
- Evapotranspiration
- Heat Index
- Solar Radiation
- Radiation dose
- Radiation index
- Temperature Humidity Sun Wind Index

Figure 6 Installation of the cliff face instrumentation, including weather station, laser radar and camera.

8. Monthly 3D laser survey

A full monthly survey of the cliff face of the Nab and the surrounding embayment is made from the foreshore using terrestrial laser scanning. The survey is collected using a Riegl VZ1000 terrestrial laser scanner. Specifications of this system are available at the following web-site:

http://www.riegl.com/uploads/tx_pxpriegldownloads/10_DataSheet_VZ1000_12-09-2011.pdf

The TLS system is calibrated annually by the manufacturer. Relevant certification can be provided on request.

Survey set-up

Two survey benchmarks have been established on the foreshore marked with standard survey nails, over which the TLS system is repositioned each month. In the first months survey the 3D position of the survey points was located using a Leica GPS System 1200, to within + / - 0.005 m (Figure 7 & 8). The coordinates of the control points are as follows:

Table 2 Control point surveys

ID	Lat (d.degrees)	Long (d.degrees)	Elevation OD (Nelwyn)
QP1	54.561062	54.560689	-0.23
QP2	-0.797309	-0.795425	-0.14

The manufacturer calibrates the dGPS system annually. Relevant certification can be provided on request.

Survey specification

Each survey is collected in a systematic manner, following methods established in previous work on this coast (see: Rosser et al, 2005).

A data set with a point spacing of 0.03 m across the cliff face of interest is collected, in addition to orthorectified full-color imagery, using the TLS system.

The first survey scan (January 2011) was georeferenced using a network of additional control points, positioned both with the TLS and the dGPS. This dataset is subsequently used to georeference all future scans using a registration work-flow based upon picking common points in successive scans, and then a multi-station adjustment which statistically matches scans, typically to within < 0.01 m across the survey scene.

The output of each survey is a point-cloud, geo-referenced into OSGB'02, and height corrected to the Newlyn Datum. Each survey contains around 5.6 m points, with attributes of RGB, reflectivity and signal amplitude, which are used for qualitative assessment of the cliff face (Figure 9 & 10).

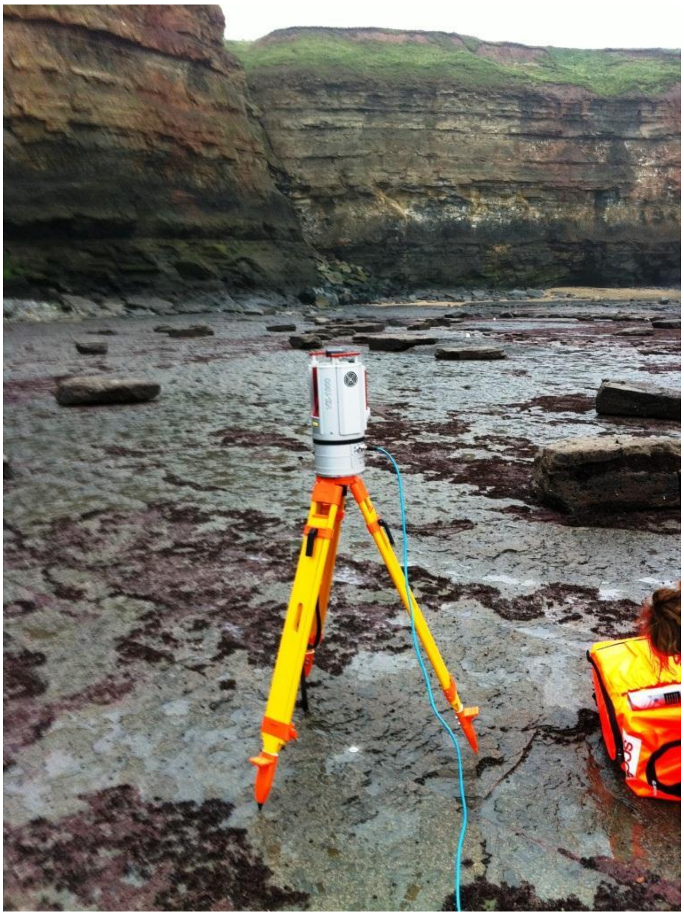

Figure 7 Reigl VZ-1000 at QP1 on the foreshore below Cowbar Nab.

Figure 8 Reigl VZ-1000 at QP1 on the foreshore below Cowbar Nab.

9. Calculation of erosion rates

Erosion rates are calculated by comparing successive scans, and each most recent scan with the first scan at the site, providing both a monthly and a rolling assessment of change. This data is also considered in the context of previously published results from this site.

Two methods are employed to calculate the erosion rate at Cowbar Nab using the TLS data:

1. Spatially averaged retreat rate
2. Rockfall magnitude - frequency retreat rate

Spatially averaged retreat rate

Two scans are aligned and co-registered, and then for each survey point the distance between it and the nearest point in the subsequent scan is calculated. This distance is commonly referred to as the Hausdorrf distance. The output from this process is a 3D point cloud, in which each point is attributed with a change distance. This data is then rasterised to a grid projected face-on to the cliff face, at 0.1 m resolution across the area of interest, allowing erosion to be mapped.

The scanner error threshold (0.03 m in this survey design) is then used to discretise the rockfalls from noise. Error assessments indicated a minimum reliably detectable rockfall size as 1.25×10^{-4} m^3 by change detection between sequential data sets with an absolute minimum detectable size of 1×10^{-6} m^3 (Lim et al., 2005). Zonal statistics are then used to isolate each rockfall, from which volume is calculated. The method does assume that single events captured within a single month are individual rockfall, with no superimposition.

The total volume of all rockfalls is calculated from the database, and then spatially averaged across the rockface surface, to obtain an average erosion rate for the site.

This method is fully described in the following papers:

- *Schürch, P., Densmore, A.L., Rosser, N.J., Lim, M. & McArdell, B. Detection of surface change in complex topography using terrestrial laser scanning: application to the Illgraben debris-flow channel. Earth Surface Processes and Landforms. 2011;36:1847-1859.*
- *Rosser, N.J., Petley, D.N., Lim, M., Dunning, S.A. & Allison, R.J. Terrestrial laser scanning for monitoring the process of hard rock coastal cliff erosion. Quarterly Journal of Engineering Geology and Hydrogeology. 2005;38:363-375.*

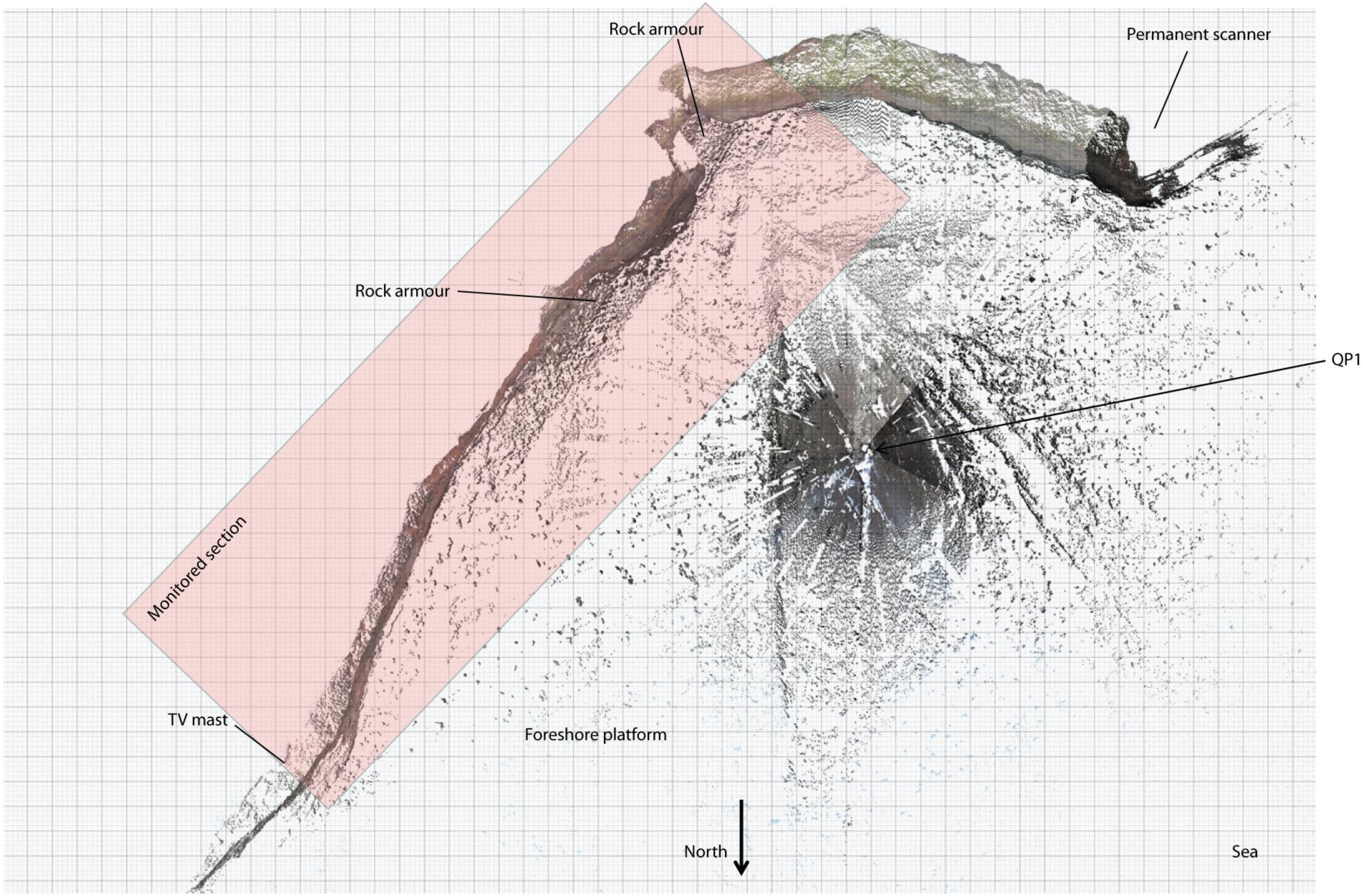

Figure 9 Orthophoto of the TLS data from QP1, from a bird's eye viewpoint. Major grid is 10 m intervals; minor grid is 2 m intervals. Points are coloured with RGB from the scanner. The monitored extent is highlighted in the red box.

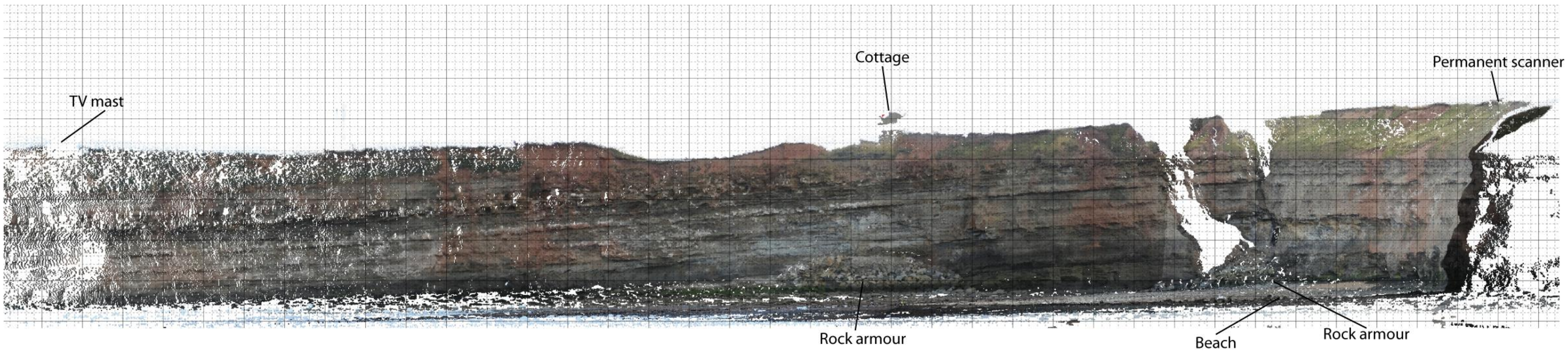

Figure 10 Orthophoto of the laser scan data collected from QP1. Major grid is 10 m intervals; minor grid is 2 m intervals. Points are coloured with RGB from the scanner

Rockfall magnitude - frequency retreat rate

The above method is widely utilized for deriving rock face erosion rates, and is arguably the accepted standard. However, this approach is limited by the possibility of the lack of inclusion of *all possible* event sizes in the erosion rate calculation. For example, over a short monitoring period such as a single year, it is quite likely that the largest possible event size at a given site is not captured within the monitoring period, which may have a significant influence on the long-term (decadal) retreat rate calculation.

To overcome this, we have developed an approach that uses widely observed magnitude frequency scaling relationships for rockfall (e.g. Malamud et al, 2004), to model erosion rates by accounting for the full range of possible event sizes at any given site.

The methods used in generating the rockfall inventory are discussed in detail by Lim et al. (2005) and summarized here. Frequency densities were calculated for rockfalls of differing magnitudes using the formula given by Malamud et al. (2004):

$$f(V_R) = \frac{\delta N_R}{\delta V_R} \quad (1)$$

where *f(VR)* is the frequency density of a rockfall of magnitude *VR*, *δNR* is the number of rockfalls with volumes that fall within the range of *δVR*, and *δVR* is the bin-width of the histogram. Parameter estimation is typically undertaken using least squares regression (LSR) on logarithmically transformed data (e.g. [Hovius et al., 1997], [Hovius et al., 2000] and [Korup, 2005]). It has been noted that the use of LSR may be inaccurate at the tails of power law distributed data (Goldstein et al., 2004). This is because the double logarithmic transformation of the data tends to distribute the error in the tail unevenly. It has therefore been suggested that a maximum likelihood estimator (MLE) is a more appropriate method in the modeling of power law distributions ([White et al., 2008] and [Rossi et al., 2010]). However, Goldstein et al. (2004) demonstrate that LSR is capable of producing models that are identical to MLE, provided the plot includes points from the mid-range of the data. As our inventories are considered to be complete through the mid-range of the data, LSR was considered the most appropriate parameter estimator.

In order to test the accuracy of the parameter estimation, the integral of Eq. (1) is derived:

$$\delta N_R = \int_{min}^{max} s V_R^{-\beta} \, dV_R \quad (3)$$

$$\delta N_R = \frac{sV_{R_{max}}^{1-\beta}}{1-\beta} - \frac{sV_{R_{min}}^{1-\beta}}{1-\beta}. \quad (4)$$

By setting the maximum and minimum values to fit the bin widths used to produce the histogram, it is possible to compare the actual number of failures within a given bin to those predicted by Eq. (4). Our parameterization is accurately describes the frequency distributions of rockfalls within the study area. Frequency densities were normalized by both time and area (events km^{-2} yr^{-1}).

Once the power law scaling parameters have been defined, it becomes possible to interpret the erosional flux (retreat rate) associated with a given event magnitude simply by multiplying the frequency density of the event by the magnitude. Applying this to the power law equation we get:

VRC=sVR⁻βVR (5)

$$V_{RC} = sV_R^{-\beta+1} \quad (6)$$

where *VRC* is the contributing volume in $m^3 km^{-2} yr^{-1}$ for an event of magnitude *VR*. Therefore, the total volumetric erosional flux (*VT*) of rock between a minimum and maximum magnitude can be calculated via:

$$V_T = \int_{min}^{max} sV_R^{-\beta+1}\, dV_R \quad (7)$$

$$V_T = \frac{sV_{R_{max}}^{2-\beta}}{2-\beta} - \frac{sV_{R_{min}}^{2-\beta}}{2-\beta} \quad (8)$$

A numerical consequence of Eq. (8) means as the value of *β* approaches 1, the volume of material contributed by larger events approaches unity with that contributed by smaller events. Once the value of *β* exceeds 1, the smaller events begin to contribute more material per km^2/yr than the larger events. Eq. (8) requires volumetric values for the minimum and maximum failure magnitudes. For long-term studies the maximum value can easily be identified from the inventory itself; at present at we make a judgment based upon experience of this coastline more widely.

The method, applied to the cliffs of N. Yorkshire, is fully described in the following paper:

- *Barlow, J., Lim, M., Rosser, N.J., Petley, D.N., Brain, M.J., Norman, E.C. & Geer, M. Modeling cliff erosion using negative power law scaling of rockfalls. Geomorphology. 2012;139-140:416–424.*

10. Permanent laser scanner

A fixed laser scanner has been developed and installed on the cliff top west of Cowbar Nab, providing a view onto the Nab cliff face. This is the only system of its kind in the UK. The scanner runs on an automated schedule run by a PC to capture the cliff face everyday at 2 am to maintain constant ambient light conditions (full darkness throughout the year), and to capture data at the least conspicuous time of day.

The scanner is a modified version of and MDL QuarryMan Pro (http://mdl.co.uk/en/15118.aspx), which has a reflectorless range of 1,200 m onto a 90% reflective white planar surface, with an encoder accuracy of 0.01^{o} in pan and tilt. From the location of the installation, the full length of the Nab from the inflection of the bay to the end of the Nab can be captured. We have developed custom controls software to control the scanner remotely, and to run scheduled sequences of scans each day.

The scanner is housed in a custom built steel box, mounted on a stable 0.5 m deep concrete foundation (Figures 11, 12, 13 & 14). The box contains deep cycle batteries to provide power back-up, a control PC with GPRS modem, and a series of relays which open and close the box window, and trigger the scanner. A motor driven window mechanism opens each night providing a secure installation for the scanner. Power is provided by a solar array located adjacent to the scanner on a pre-existing concrete slab.

Data is transmitted back to Durham via a GPRS modem each night, allowing for daily checks on system status, data quality and critically changes to the cliff face. All cabling and antennas have been buried > 0.5 m beneath the ground surface for protection and to reduce the potential impact of vandalism.

The scanner has been configured to capture the cliff face at 0.25 m point spacing, with a range precision of + / - 0.1 m (Figure 15). Although at a lower resolution than the VZ1000 data, the system provides very high temporal resolution, which is key to identifying the timing and hence controls on cliff change. The system uses an eye-safe laser (905 µm), firing at 250 points per second, and so has no effect on wildlife or people.

A significant portion of Year 1 has been in the design, installation and testing of this system. Ongoing work is focusing upon automating workflow for processing the daily scans to obtain rockfall geometry and changes in cliff reflectivity.

Note that the laser scanner was funded by a University of Durham research development grant.

Figure 11 Foreground: Permanent laser scanner installation, showing the view of Cowbar from the scanner housing in the background.

Figure 12 View inside the permanent scanner installation, showing the scanner nearest to the window mechanism, and the controls PC at the rear of the box

Figure 13 View of the automatic window (closed) on the scanner housing.

Figure 14 Fencing erected around the scanner housing

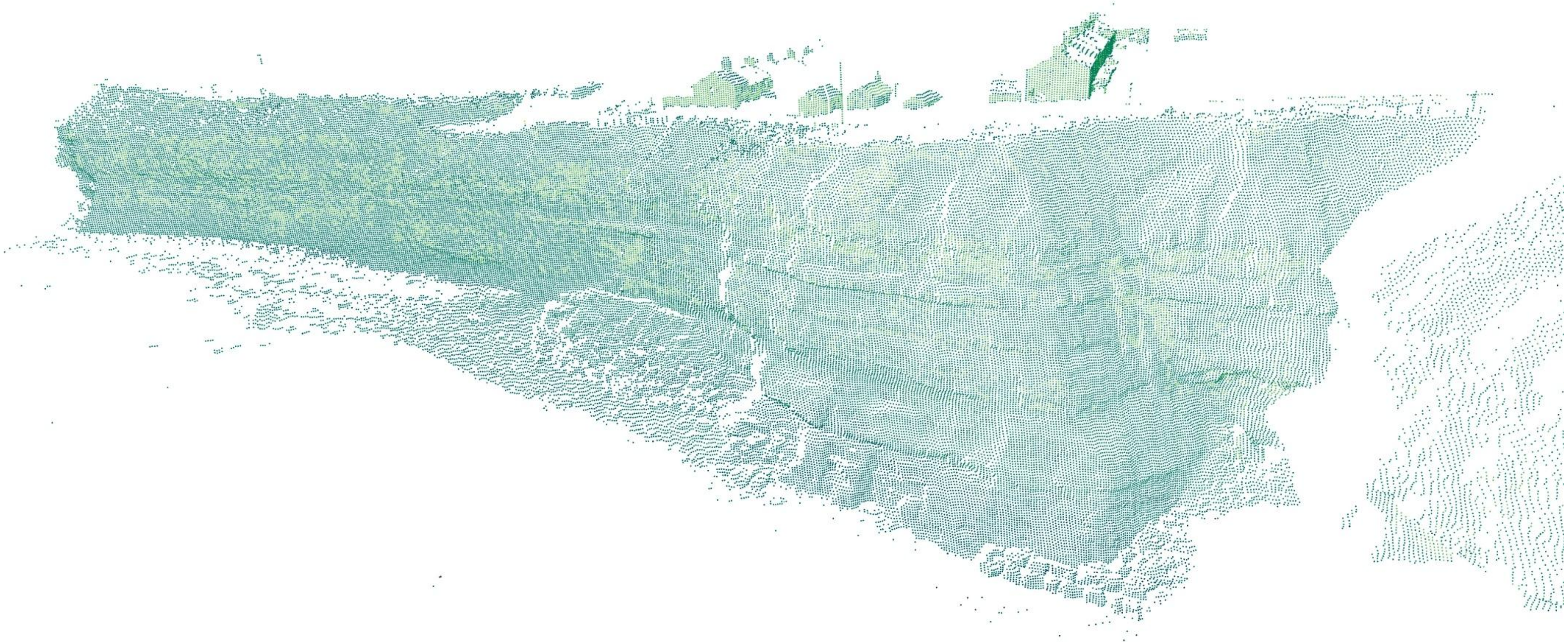

Figure 15 Laser scan data collected from the permanent TLS installation on the cliff top opposite to Cowbar Nab. Points are coloured by reflectivity.

11. Results – Year 1

Erosion rate calculation – Cowbar Nab, January 2011 – March, 2012

Table 3 summarizes the survey results from monitoring between January 2011 and March 2012. Months since the beginning of the monitoring program are named 1, 2, 3 . . . , with the corresponding date of the survey. The length of each survey epoch is calculated in days since the previous survey, and days since the first survey. For each month the total number of rockfalls is calculated, in the method discussed in Section 9, and the cumulative total volume of rockfalls measured during this period. Total change during the monitoring is shown in Figure 18.

Erosion rate is calculated in two ways. First the total rockfall volume is averaged across the survey area, and second by modeling rockfall magnitude frequency distribution (Section 10).

We measure the survey area from the cliff surface in the laser scan (9,125.2 m^2). The total number of measured rockfalls during this period was 9,968, with a total volume of 318.99 m^3. This equates to a spatially averaged erosion rate of **1.99 x 10^{-3} myr^{-1}**, over this 15-month period. The maximum monthly erosion rate was 3.7x 10^{-3} myr^{-1} (Feb, 2012), and the minimum 0.01 x 10^{-3} myr^{-1} (May, 2011).

Using the modelled erosion rate calculated by modelling the rockfall magnitude frequency distribution, we derive a mean erosion rate of **2.23 x 10^{-3} myr^{-1}**, with a maximum of 4.64 x 10^{-3} myr^{-1} and a minimum of 0.001 x 10^{-3} my^{-1}. In this assessment we assume a maximum event volume of 2,500 m^3, during a 100-year return period. See Barlow et al, 2011 for a discussion of this method.

We observe two notable rockfalls. The first larger rockfall from the monitoring is shown in Figure 16. Although large in extent, this rockfall is shallow in depth, whereby over 90% of its area, the rockfall depth does not exceed 0.05 m. The rockfall occurred in Dec 2011. It is likely that an initial failure at the apex resulted in the dislodgment of loss rock and superficial material from the cliff face below. The maximum depth of the failure at the apex was 1.23 m, reflecting a single sandstone block detachment, most probably triggered as a result of the upward propagation of failure from the cliff toe over a period of years.

The second large rockfall (Figure 17) shows a failure of the cliff toe, removing c. 15 m^3 of material. Future surveys should examine how this failure propagations upslope, and whether this leads to destabilization of the cliff face above. This rockfall occurred in January 2012. Critically, this section of the coast is a promontory that juts out from the cottages above, so any failure here is unlikely to influence critical infrastructure above.

We note also in Figure 16, clear evidence of the action of waves at the toe of the cliff, with the preferential removal of blocks in lower 6 m of the cliff face, that area which is regularly inundated by marine action. This process ultimately leads to undercutting of the cliff face, which is likely to failure via the propagation of smaller rockfalls moving up-cliff, rather than a deeper seated failure of the cliff rock mass. Continued monitoring will indicated which of these processes is likely to dominate at this site.

The area averaged erosion rate (Figure 19) shows a broadly seasonal pattern.

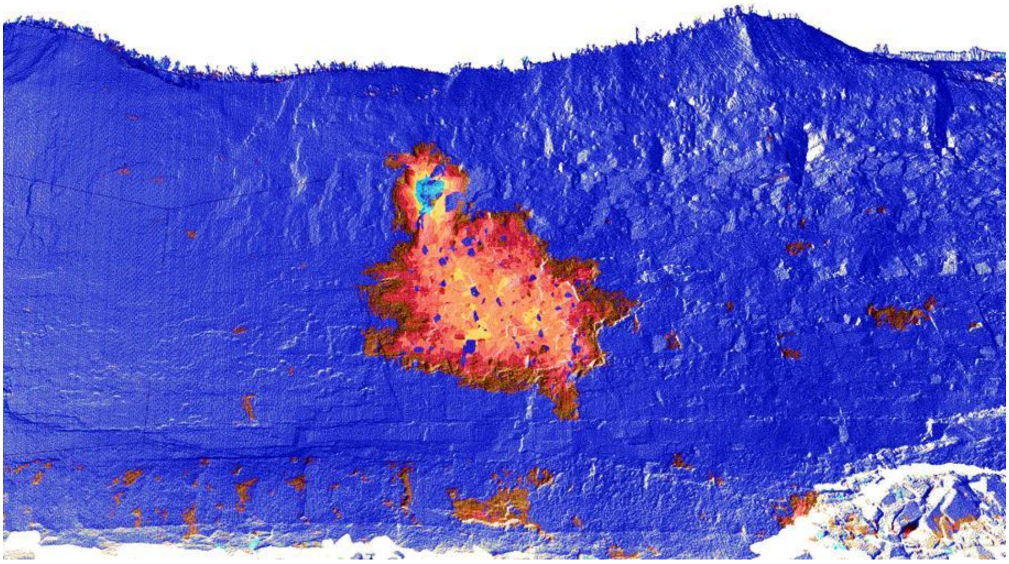

Figure 16 Rockfall from the cliff at Cowbar Nab, approximately 12.5 x 8 m, but < 0.05 m in depth across most of its extent. The deep loss of material is at the apex of the failure, reaching c. 1.23 m. The area shown in this image is approximately 52 m across, and 37.4 m in height. The limit of the rock armor is show on the right of the image.

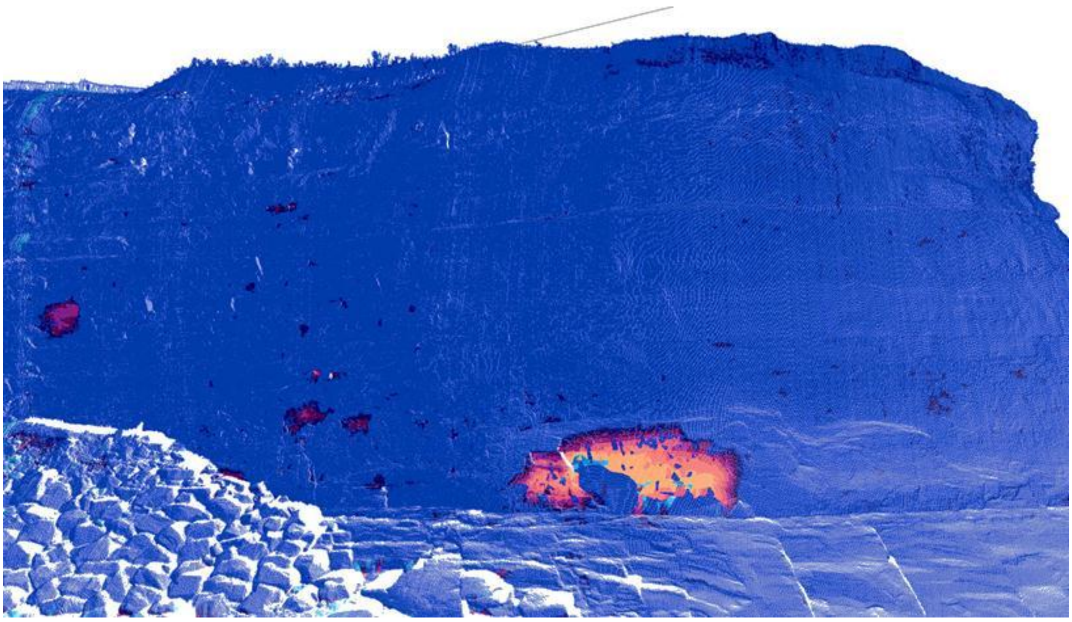

Figure 17 Rockfall at cliff toe, to the right of the rock armour. The size of the rockfall is approximately 8.5 m wide x 2.4 m high, and at its peak 1.1 m deep. The volume, assuming this to be a single event is 14.8 m^3.

Month	Month	Year	Survey date	Survey epoch length (days)	Running total of days	Number of rockfalls	Total volume of rockfalls (m^3)	Area average erosion rate (myr^{-1})	m/f modelled erosion rate (myr^{-1})
1	January	2011	14/01/2011	0	0	0	0	0.00	0.00
2	February	2011	18/02/2011	35	35	990	31.69	2.77	3.344
3	March	2011	21/03/2011	31	66	969	31.00	2.71	2.816
4	April	2011	28/04/2011	38	104	1036	33.15	2.90	1.716
5	May	2011	20/05/2011	22	126	4	0.13	0.01	0
6	June	2011	17/06/2011	28	154	21	0.68	0.06	0.022
7	July	2011	21/07/2011	34	188	660	21.11	1.85	0.484
8	August	2011	25/08/2011	35	223	560	17.93	1.57	2.684
9	September	2011	27/09/2011	33	256	972	31.11	2.72	4.554
10	October	2011	21/10/2011	24	280	802	25.66	2.24	4.642
11	November	2011	17/11/2011	27	307	708	22.65	1.98	3.85
12	December	2011	19/12/2011	32	339	207	6.62	0.58	0.176
13	January	2012	17/01/2012	29	368	609	19.48	1.70	1.76
14	February	2012	23/02/2012	37	405	1323	42.33	3.70	2.816
15	March	2012	26/03/2012	32	437	1108	35.45	3.10	2.86

Table 3 Erosion rate calculations from January 2011 to March 2012

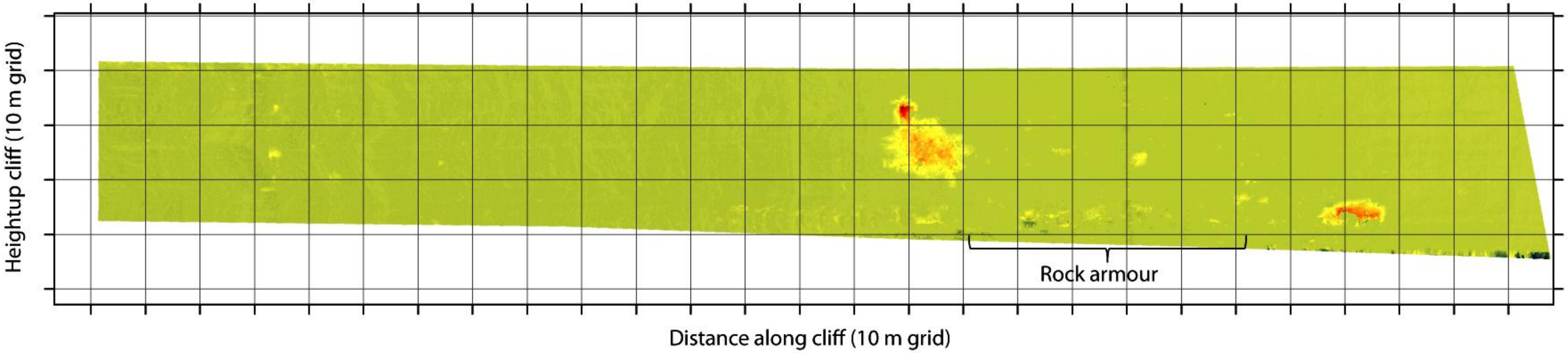

Figure 18 Total change from January 2011 – March 2012, viewed face-on to the cliff. Colour scale indicates: green 0.03 - -0.03 m; yellow 0.03 – 0.1 m; orange 0.1 – 0.25 m; and red 0.25 – 1.2 m. Grid is at 10 m intervals. The two large rockfalls shown in this image are illustrated in more detail in Figure 16 and 17.

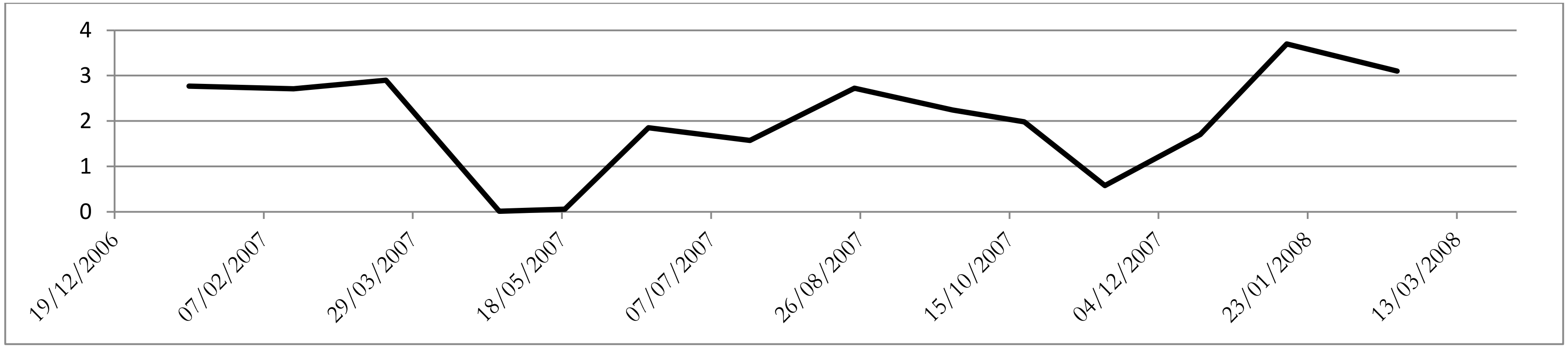

Figure 19 Area averaged erosion rate from January 2011 – March 2012, show in units of mm yr^{-1}.

Environmental conditions:

For Year 1 we have explored the correlation between the seismometer data and the prevailing environmental conditions at the site. We present 3 sub-sets of this data as illustration of how we intend to use this information in future.

First (Figure 20), we consider a single day with 2 tides. We plot marine conditions (wave heights – here modeled from the Tees Wave Buoy, sea level (monitored from the Whitby Tide Gauge), wind conditions captured by the cliff face installation, and the seismic data (ground motion velocity; 3-component power-spectrums.

In line with results from sites nearby, we observe a clear tidal signal in the seismic data, reflecting the increase in energy delivery as the water surface inundates the foreshore and then is in contact with the cliff face.

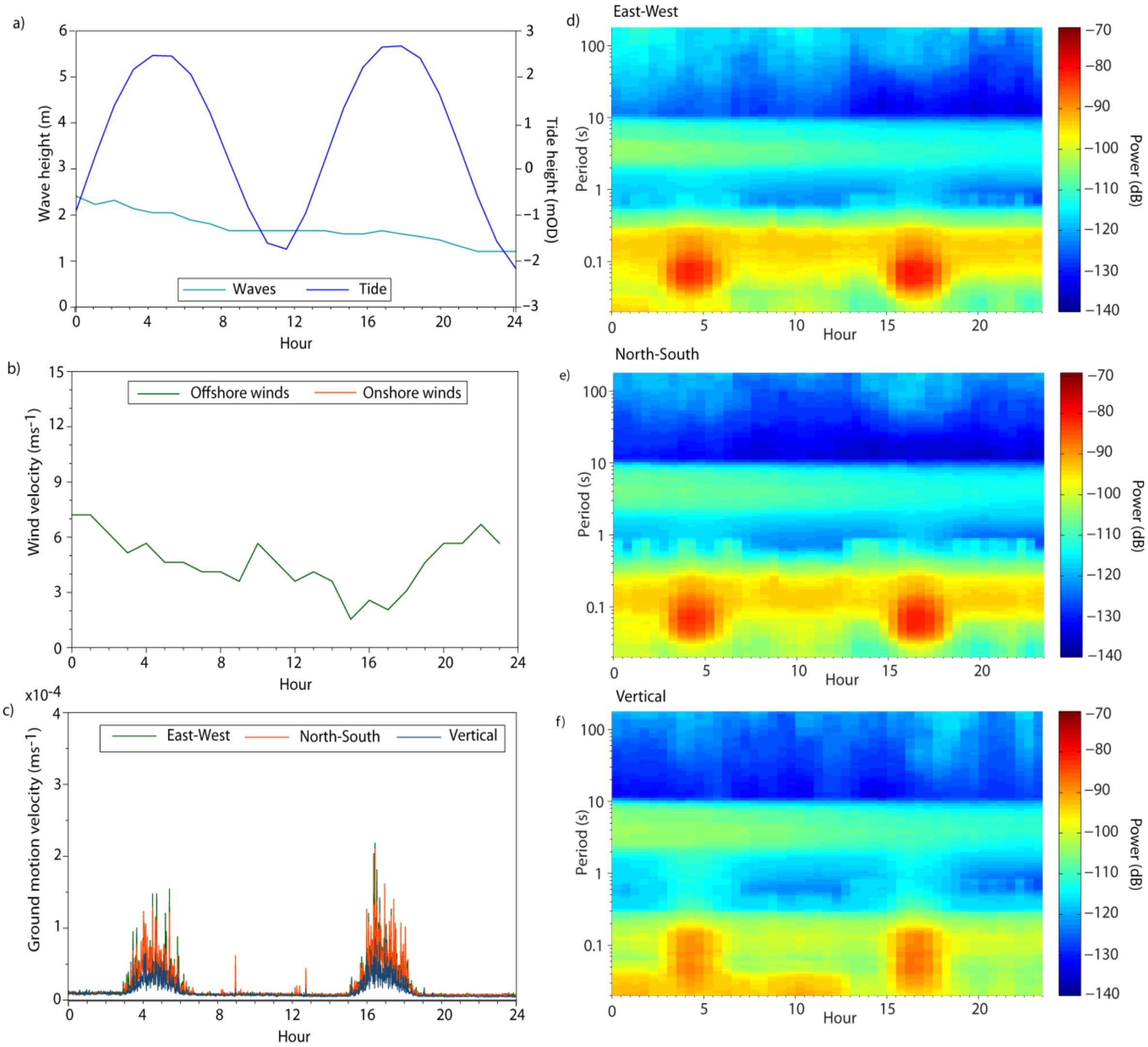

Figure 20 Spectrograms and environmental data for 04/12/11. a) Hourly max tide height modelled and hourly max wave heights obtained from the Tees wave buoy; b) Mean onshore and offshore wind speeds monitored hourly at Loftus; c) Ground motion velocity for all three components; d) East-west component spectrogram; e) North-south component spectrogram; f) Vertical component spectrogram.

Second, we consider a full tidal cycle, from Spring to Neap, which includes a period of on-shore, and offshore winds, and variable wave conditions as a result. We observe a considerable increase in wave energy delivery to the cliff during period of onshore winds during high tides, during which water depths permit long-period waves to propagate to the cliff toe, without significant energy loss in the near-shore or foreshore. It is during these periods that we expect the majority of the erosive work to be undertaken by the sea on the cliff face.

Future work during Year 2 will focus upon building a model based upon the numerical analysis of the environmental data with the cliff change data.

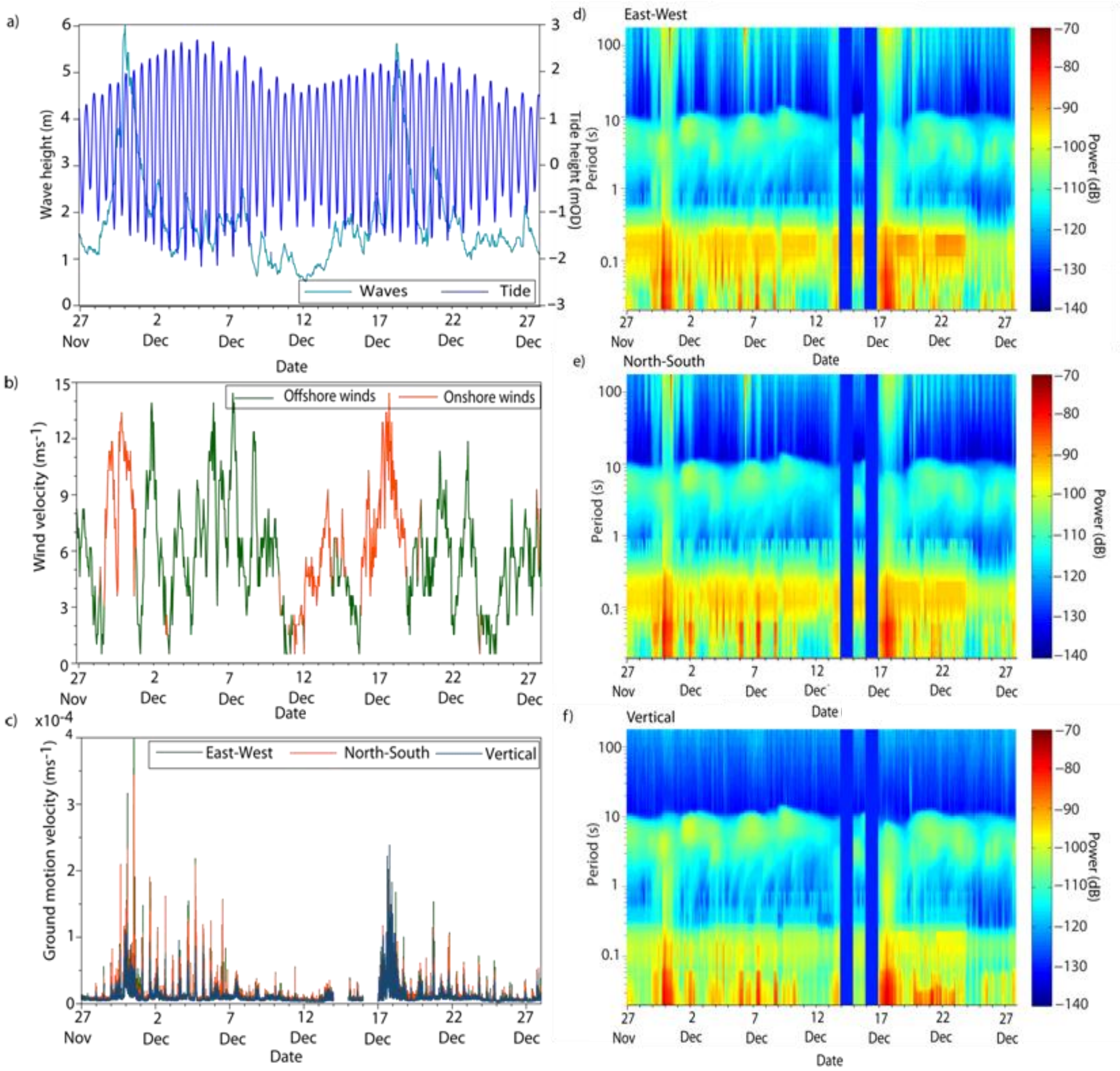

Figure 21 Spectrograms and environmental data for the winter month of December 2011 a) Hourly max tide height modelled for Boulby and hourly max wave heights obtained from the Tees wave buoy; b) Onshore and offshore wind speeds monitored hourly at Loftus; c) Ground motion velocity for all three components; d) East-west component spectrogram; e) North-south component spectrogram; f) Vertical component spectrogram. The 14th and 16th December contained noise across the spectrum as there were people working in the seismometer field on these days. The power values have been replaced with a null value, represented by the blue bands.

The 3rd period we consider is the full dataset collected to data (August 2011 to March 2012 (Figure 22). Two significant periods of data loss are illustrated by the blue areas in late September, and early January.

The spectrograms clearly show the seasonal variation in energy delivery in the 1 to 10 second period data, the long-period (> 100 s) and in the tidally modulated energy delivery at the cliff toe (< 0.1 s). Based upon previous work, it is likely that future analysis of this data in relation to the erosion signal will yield more significant correlations than using standard environmental variables alone.

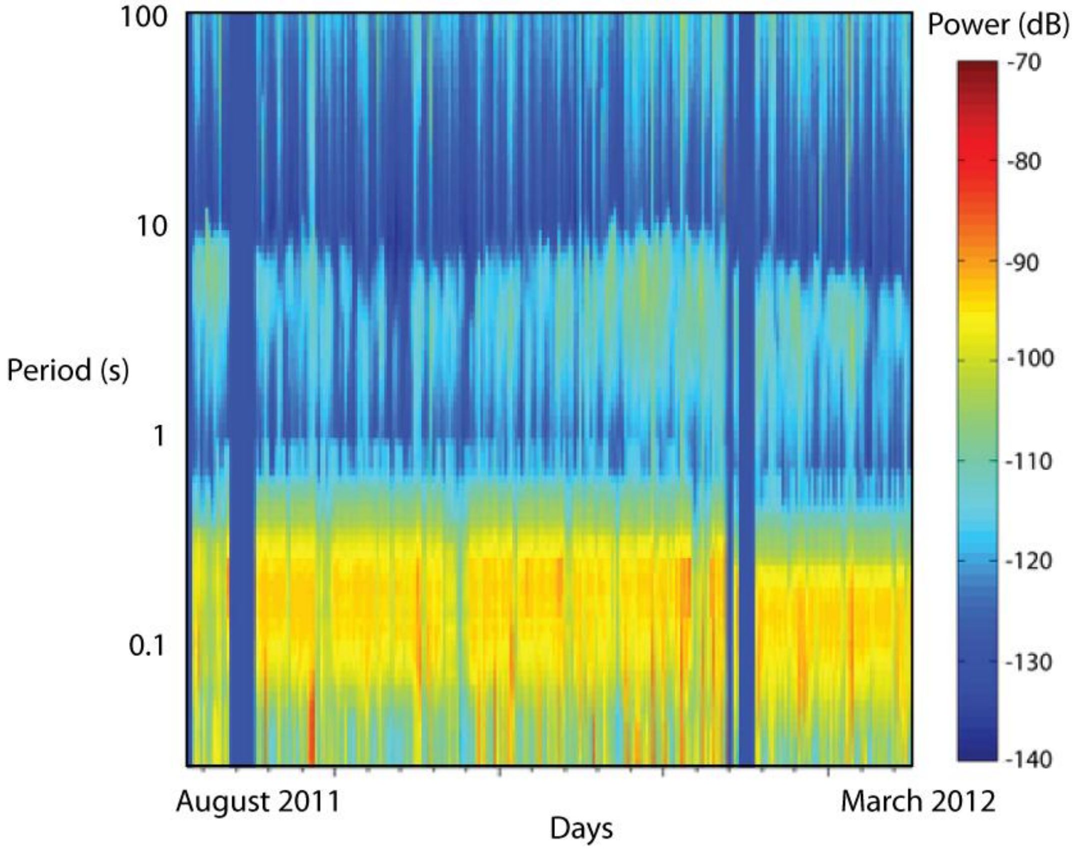

Figure 22 Full seismic data set from August 2011 – March 2012

12. Summary of results – Year 1

The following erosion rates have been calculated:

- The calculation of monthly erosion and long-term 15 month erosion rates has been completed, and compared to past rates measured at this site (Sections 10 & 12). A total of 318.99 m3 of rockfall in 9,968 discrete events has occurred during this period. Considerable month-on-month variability is observed, with May 2011 experiencing effectively no discernible change (Section 12).
- The net rate observed in the period January 2011 to March 2012 was 1.99 x 10-3 m yr-1 (Section 12).
- On average the observed rate is less than that previously observed at this site (358 m3 of rockfall from 4,494 m2 of cliff face, deriving 25 x 10 -3 myr-1 erosion).

The following conclusions have been drawn based upon this analysis:

- A preliminary analysis of Year 1 seismic monitoring data in respect of environmental conditions at site has been completed (Section 12). The seismic response of the cliff is in line with observations made elsewhere on this coast, and elsewhere worldwide. The set-up is now calibrated, and collecting continuous data on wave energy and impacts at the cliff toe. Future analysis will focus upon the correlation of this data with the rockfall and erosion output.
- There is no indication that the erosion of the cliff at Cowbar is accelerating or deviating away from behavior observed at this site previously. The concentration of erosion is currently focused away from the 'pinch points' at this site.
- No loss of cliff line was observed during this period, although critically this indicates cliff steepening, which will in time result in failure of the cliff top. Continued monitoring will help identify where and when this may occur.
- There is no evidence in the monitoring data of the development of a deeper-seated failure which would threaten the road and / or houses.

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