COASTAL GEOMORPHOLOGICAL CHANGE IN NORTHEAST ENGLAND: THE ROLE OF REGIONAL-SCALE MONITORING

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SUMMARY

Regional scale monitoring is important to ensure that coastal management decisions by local maritime authorities are based upon accurate and up-to-date information on coastal geomorphological change. This helps inform ongoing management and maintenance of beaches and structural defences, as well as planning the type and timing of major capital investments in new or improved defences, or their removal for purposes of adaptation to coastal change or inter-tidal habitat creation. Data from this type of monitoring also provide understanding useful for other purposes such as exercising appropriate development control on coastal land and assessing the potential geomorphological impacts arising from the landfall of marine infrastructure, such as pipelines and cables. This paper presents the background to, and over a decade of results from, the Cell 1 Regional Coastal Monitoring Programme, which covers the coastline between St. Abb's Head in Scotland and Flamborough Head in Yorkshire.

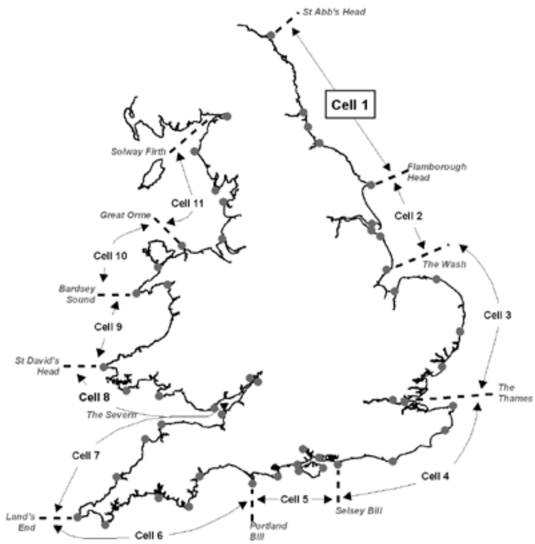

Figure 1. Coastal sediment cells in England and Wales.

INTRODUCTION

The Cell 1 Regional Coastal Monitoring Programme (Cell 1 monitoring) covers approximately 300 km of the northeast UK coast, from St. Abb's Head (just across the border into Scotland) to Flamborough Head in the East Riding of Yorkshire, covering Northumberland, Tyne & Wear, County Durham, Hartlepool, Redcar & Cleveland and Yorkshire. This coast is often referred to as 'Coastal Sediment Cell 1' (Figure 1), after the esteemed work that was undertaken on mapping of littoral cells in England and Wales (Motyka and Brampton, 1993).

Within Cell 1, the coastal landforms vary considerably (Figure 2). They variously comprise: low-lying tidal flats with fringing saltmarshes; wide, sweeping sandy beaches backed by coastal dunes; hard rock cliffs that are mantled with glacial till of varying thicknesses; and softer rock cliffs prone to extensive landslides. There are also many different forms of coastal defence (Figure 3), including offshore breakwaters, revetments, sea walls, harbour piers, and quay walls, as well as different management activities such as beach recharge and sediment recycling, dune management, and adaptation to coastal change (e.g. abandonment and re-wilding, roll-back of coastal footpaths, etc.). Some areas in Northumberland, and through much of County Durham, have been significantly affected by historic tipping of colliery spoil, leading to 'artificial' spoil beaches and cliffs.

Cell 1 monitoring commenced in its present form in September 2008 and is managed by Scarborough Borough Council on behalf of the North East Coastal Group. Prior to 2008, coastal monitoring was undertaken on a consistent basis across Northumberland and North Tyneside as part of the (then) Northumbrian Coastal Authorities Group's monitoring programme which commenced in 2002, whilst several authorities elsewhere within Cell 1 undertook their own local monitoring programmes.

Figure 2. Coastal landforms within Cell 1:
a, coastal saltmarsh (Northumberland); **b**, coastal sand dunes (Northumberland); **c**, colliery spoil beaches (County Durham); **d**, landsliding soft cliffs (North Yorkshire); **e**, limestone sea cliffs (Berwickshire); **f**, chalk sea cliffs (East Yorkshire).

The present programme is funded by the Environment Agency, working in partnership with the eight maritime local authorities in the region (Northumberland County Council, North Tyneside Council, South Tyneside Council, Sunderland City Council, Durham County Council, Hartlepool Borough Council, Redcar & Cleveland Borough Council and Scarborough Borough Council), as well as other relevant bodies such as the Northumberland Area of Outstanding Natural Beauty Partnership, Durham Heritage Trust, North York Moors National Park, Natural England, the National Trust and local Port & Harbour Authorities.

The main elements of the Cell 1 monitoring are (Figure 4):

- beach profile surveys;
- beach topographic surveys;
- cliff-top recession surveys;
- real-time telemetered wave and tidal level data collection;
- bathymetric and sea bed characterisation surveys;
- vertical and oblique aerial photography;
- Light Detection and Range (LiDAR) surveys;
- ecological habitat mapping; and
- walk-over visual inspection surveys of built and natural assets

Figure 3. Coastal defences within Cell 1:
a, Scarborough Spa coastal slope stabilisation, North Yorkshire; **b**, Seahouses main pier, Northumberland (image courtesy Balfour Beatty); **c**, Littlehaven Promenade & seawall, South Tyneside; **d**, Trow Quarry, South Tyneside; **e**, Sandsend Road, North Yorkshire; **f**, Runswick Bay, North Yorkshire; **g**, Whitby Harbour Piers, North Yorkshire (image courtesy Balfour Beatty).

Figure 4. Survey types forming the Cell 1 monitoring:
a, beach profile survey using hand-held GPS (image courtesy Academy Geomatics); **b**, beach topographic survey using quad-bike mounted GPS (image courtesy Academy Geomatics); **c**, vertical and oblique aerial photography; **d**, multi-beam echo sounder bathymetric survey; **e**, wave buoy (image courtesy Fugro); **f**, walkover inspections.

The beach profile, beach topographic and cliff-top recession surveys are undertaken using Global Position Systems (GPS) 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. In selected areas, targeted laserscan surveys are undertaken to reveal rock falls, instabilities or the formation of fissures, overhangs and caves in areas where such activity threatens cliff top assets such as coastal highways or access roads. In addition, to these 'direct response' morphological data, the programme includes collection of broader aerial photography and LiDAR data, alongside background environmental forcing data on waves and tides and more specific bathymetric and sediment data relating to the nearshore areas.

Specifically for the bathymetric surveys, a long running memorandum of agreement (MoA) exits between the national framework of regional coastal monitoring programmes (a framework led by the Channel Coastal Observatory (CCO) and of which the Cell 1 monitoring is part) and the UK's Marine & Coastguard Agency (MCA). The aim of this MoA is to detail the arrangements for the regional programmes, individually or collectively, and the MCA to work in partnership, where funding has already been agreed for survey areas. This is in order to optimise public expenditure by sharing the costs of procurement of swath bathymetry surveys for areas of mutual interest, and to make data freely available via the CCO data management centre and the UK Hydrographic Office (UKHO) Data Archive Centre. The Cell 1 monitoring has, through this collaboration with the MCA, now captured detailed multi-beam nearshore bathymetric data for the full length of its coastline.

The overall aim of the Cell 1 monitoring is to provide a comprehensive integrated suite of information, complimented by expert observational information provided by the walk-over visual inspections on the ground. Key aspects of the programme are the need for sound quality assurance of data and the ongoing collation, storage and use of this major resource. All data and routine interpretative reports for the programme are available on the project website. This paper outlines the rationale for the programme and presents general findings to date, including demonstrations of how the data are already being used to help inform coastal management decisions in the region through four case studies.

Regional Coastal Monitoring

Coasts can be highly dynamic environments. In order to assess and appropriately manage the risks from coastal erosion and sea flooding, maritime Local Authorities and the Environment Agency, together with other organisations with related responsibilities, have recognised the need for regional-scale coastal monitoring programmes to improve the long-term and broad-scale understanding of coastal processes and shoreline change across coastal cells (Bradbury *et al.*, 2001, 2004; Cooper *et al*, 2009, 2019). This provides the necessary core data to inform coastal management decisions, including future coastal adaptation in response to sea level rise resulting from global climate change.

These data are also used to reduce uncertainty in design assessments for capital coastal defence schemes, fine-tune existing operational and maintenance regimes, and enable post-project evaluation of specific schemes to be interpreted within a broader context. These data can also support the set-up, calibration and verification of numerical models that are used in initiatives such as Tidal Flood Forecasting Systems and physical coastal processes assessment, thereby improving confidence in their outputs.

The particular advantages of a region-wide understanding are:

- Delivery of continuous improvement in shoreline management – By continually building the knowledge and understanding of how the coast behaves and evolves, the philosophy of Defra's Shoreline Management Plan (SMP) Guidance (i.e. not just to repeat 'business as usual', but to enhance the coastal processes understanding and its role in SMP production) will be delivered.
- Selection of the most suitable SMP policies or Coastal Strategy options – By providing improved coastal data more quantitative information on mechanisms and rates of coastal change will mean that uncertainties are reduced and consequently policies or options will be selected that have greater sustainability in the longer-term.
- Improved phasing of schemes – Improved understanding of the behaviour of the coastal systems will mean that schemes can be constructed at more appropriate time, avoiding implementation earlier than they need be, under an overly precautionary approach, or later than they should have been, under an otherwise purely reactive approach that often involves interim emergency works.
- Improved scheme design – Reduced uncertainties and improved measured data from the nearshore zone will mean that defences will be better designed to particular marine parameters, such as more appropriate crest levels to reduce overtopping risk, or foundation levels to reduce undermining risk from beach level fluctuations.
- Enhanced operational management and maintenance regimes – The context provided by the regional coastal monitoring data to local activities will provide opportunities in terms of operational management and maintenance regimes that are more tailored to local issues, such as seasonal beach level changes, and also the implications of wider scale changes, such as longer-term trends of erosion or accretion.

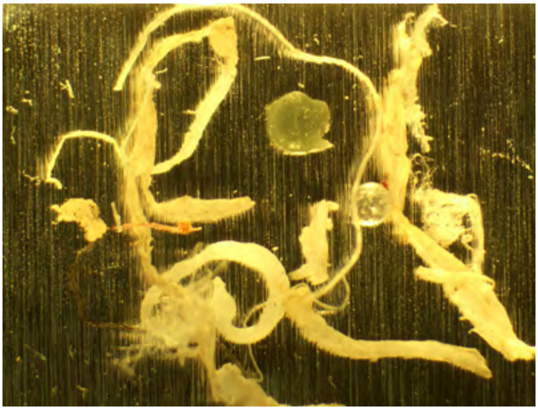

Figure 5. Microplastic fibres, fragments and beads. Image courtesy SOCOTEC.

Figure 6. Eroding refuse amongst colliery spoil cliffs at Lynemouth Bay in Northumberland.

Aims and Objectives

The aim of the Cell 1 monitoring is to provide better understanding on the coastal processes and the locations, rates and mechanisms of shoreline morphological change at key locations between St. Abb's Head and Flamborough Head. Recognising that 'one size does not fit all', rather than simply mirroring programmes from some other coastal regions of the UK, the programme has specifically been designed to gain further insight into areas of risk and uncertainty that were identified in the two SMPs which between them cover the entire Cell 1 frontage; the Northumberland & North Tyneside SMP2 (Royal Haskoning, 2009) and the River Tyne to Flamborough Head SMP2 (Royal Haskoning, 2007).

The design of the Cell 1 monitoring therefore reflects the nature and magnitude of uncertainties in the coastal erosion and sea flooding risks in the northeast region. The selection of appropriate monitoring techniques and suitable data collection frequencies during its design took into consideration the following:

- anticipated extent and mechanisms of change in cliff top position, based on understanding of underlying solid geology and overlying drift geology;
- behaviour of dunes and beaches, based on seasonal and longer-term historic observations;
- magnitude and variation in coastal forcing conditions, such as waves, tides and surges, and exposure of the shore to those;
- composition of shoreline and nearshore sediments and their dynamism;
- extent of development in areas of coastal change, recognising that much of the northeast coast is rural but that there are some key urban and industrial areas;
- the anticipated behaviour of the coastal cell under future sea level rise resulting from global climate change; and
- the availability of complementary data from other sources (e.g. Environment Agency, Port Authorities, CEFAS Wavenet).

The programme also provides a framework within which region-wide bespoke studies can be procured and undertaken to investigate emerging issues. In the northeast region, three specific recent studies of emerging topical interest have been:

- The Cell 1 Sediment Transport Study (Royal HaskoningDHV, 2013, 2014) used techniques of Historical Trends Analysis, Sediment Tracing, and Sediment Transport Modelling to characterise the key sediment transport linkages across Cell 1. One of the most notable findings was the effects of historic tipping of colliery spoil (and its more recent cessation) at key locations in Northumberland and County Durham (Cooper *et al.* 2017).
- The Cell 1 Microplastics Study analysed sea bed sediment samples collected as part of the bathymetric and sea bed characterisation surveys for the quantity and type of microplastics (Figure 5) in the marine environment (See *et al.* 2020).
- The Cell 1 Coastal Landfills Study (Royal HaskoningDHV, 2019) assessed the risks from coastal change to identified historic landfill sites within the region (Figure 6), leading to development of a capital scheme to manage eroding refuse at Lynemouth Bay in Northumberland.

Monitoring Outputs

The monitoring outputs from beach profile surveys, beach topographic surveys and wave and tide recording have revealed that most of the beaches within the region experience seasonal changes in morphology, with lower, flatter beach profiles in winter compared to summer. Typically, this is triggered by winter storms, which remove sediment form the upper beach, causing lowering at the toe of structures or erosion at the toe of dunes, and deposit it on the lower beach or in the shallow nearshore zone. Although there is generally not a strong longshore transport of beach sediment, once drawn down to the lower beach profile fine sediment can become transported in suspension in the water column by the prevailing net southerly tidal currents or, for slightly coarser sediment, along nearshore bars such as at Whitby in North Yorkshire, before being moved back onshore during calmer periods. During summer months, the beaches typically rebuild naturally. This understanding of seasonal changes has been useful in some in areas in avoiding unnecessary and potentially damaging 'knee-jerk' reactions of intervention, sometimes driven by political expediency, upon observations of winter lowering or erosion.

It is also noticeable that in areas of Northumberland and County Durham where colliery spoil tipping has historically occurred, the backing sea cliffs, coastal slopes or sand dunes have become relict features, disconnected from marine processes by the prograding shore. However, after cessation of tipping when the regional coal mines closed (the most recent closure being in 2005) the spoil beaches and spoil cliffs have eroded, by up to 5 m per year in places. Although marine erosion of the natural features landward of the spoil has not yet commenced, it will occur once the legacy of the fronting spoil has fully eroded.

In general, cliff-top recession occurs at relatively low rates along many frontages, but, where apparent changes have occurred, they are generally triggered by periods of prolonged and/or intense rainfall coincident with high tides or stormy seas, or from freeze-thaw cycles in the groundwater within fissures of the cliff. These mechanisms can lead to local rock falls in the harder cliffs and fairly large-scale landslips in the softer cliffs (or small headscarp slippages in areas where layers of till overlay more resistant bedrock). An example of a landslip at Cresswell in Northumberland is shown in Figure 7, where the event has caused recession landward to the edge of the coastal highway. Similarly, ongoing coastal slippages along the cliffs leading to Cowbar within Redcar & Cleveland (Figure 8), has resulted in abandonment of the original access road and its relocation inland.

The captured aerial photography is also useful in understanding ongoing morphological changes. Whilst the larger estuaries of the Rivers Tweed, Tyne, Wear, Tees and Esk have breakwater and pier control structures at their mouths, many of the small river channels and becks which drain into the North Sea within Cell 1 are unconstrained at their mouths and can adopt differing courses dependent upon preceding physical conditions such as rainfall (affecting river spate) or sea storms (affecting beach changes). In some locations the changing course of these channels across the foreshore can increase, or conversely reduce, exposure to erosion processes along the toe of adjacent dunes or lead to undermining of nearby coastal structures. An example is shown in Figure 9, where the course of small beck has change alignment along a beach at Meggies Burn in Northumberland.

Figure 7. Landslip in superficial (drift) geological deposits at Cresswell in Northumberland.

Figure 8. Coastal erosion in superficial (drift) geological deposits at Cowbar in Redcar & Cleveland.

Figure 9. Changing course of a small beck across the foreshore at Meggies Burn in Northumberland, between 2017 (left) and 2019/20 (right).

Figure 10. Opening of a 'sink hole' in the cliff top at Whitburn Coastal Park in South Tyneside, between 2017 (left) and 2019/20 (right).

In some areas, the cliffs are experiencing cave formation at their bases and when these caves penetrate deep into the rock structure, it can lead to wash-out of softer material behind and the formation of 'sink holes' in the cliff top land. Figure 10 shows an example from Whitburn Coastal Park in South Tyneside, where a sink hole opened between 2017 and 2019/20.

CASE STUDIES

The data from the Cell 1 monitoring have practical uses in helping inform contemporary and planned future coastal risk management decisions, exemplified by the following case studies:

- Holy Island, Northumberland - The use of topographic surveys, aerial photography and LiDAR data to help inform landscape-scale changes in sedimentation rates and associated inter-tidal habitat development within a National Nature Reserve;
- Lynemouth Bay, Northumberland – The use of beach profile surveys and LiDAR data to quantify rates of ongoing coastal change for purposes of managing the risks from eroding coastal landfill;
- Meggies Burn, Northumberland – The use of aerial photography to observe the patterns of change in alignment of the outflow channel of a small burn and the connectivity with erosion or stability of adjacent dunes and effects on nearby coastal defence structures; and
- Marsden Bay, South Tyneside – The use of aerial photography and laserscan surveys of the cliffs to assess the risks to the existing cliff top public footpath and coastal highway from rock falls and cliff instability.

Holy Island

The Holy Island of Lindisfarne is an island which lies approximately 1.5 km off the coast of Northumberland. Prior to construction of the causeway in the mid-20th century, access to Holy Island from the mainland was across the intertidal area between the two. The causeway, which is at similar elevations to the adjacent inter-tidal flats, was constructed between 1954 and 1966 across the shortest distance between the mainland and the island.

At the request of Natural England (then English Nature), monitoring of morphological changes either side of the causeway has been undertaken as part of the Cell 1 Regional Monitoring Programme since 2004. This was instigated in response to concerns by the organisation that the causeway was causing increased rates of sedimentation, leading to greater colonisation of the muddy sandflats with saltmarsh species, especially the common cordgrass *Sporobolus anglicus* (note that after a taxonomic revision in 2014, *Spartina anglica* was re-classified as *Sporobolus anglicus*, but is still often referred to by its original name in wider parlance).

The availability of wide expansive inter-tidal muddy sandflats is seen as one of the principal features of the Lindisfarne National Nature Reserve (NNR) since

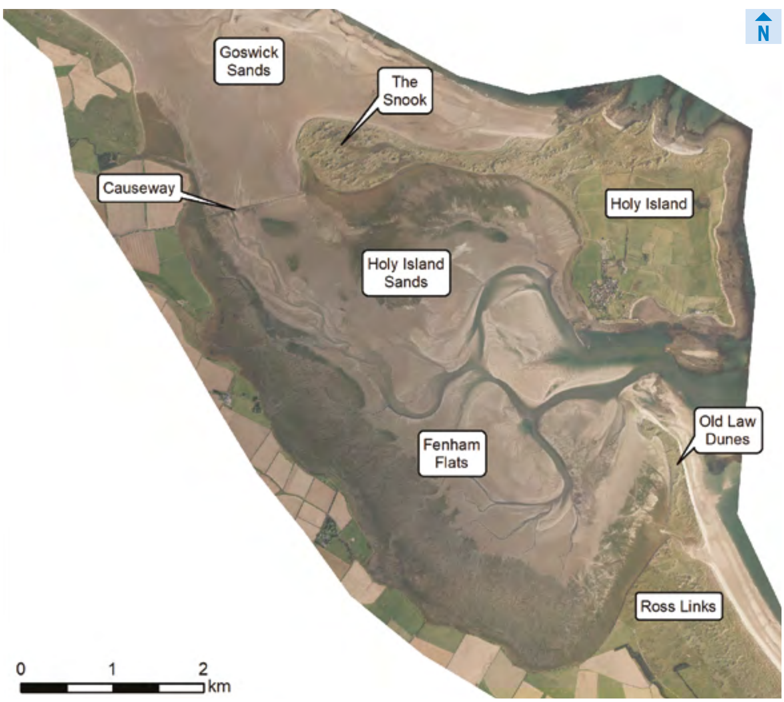

Figure 11. Geomorphological features of Lindisfarne National Nature Reserve (2020).

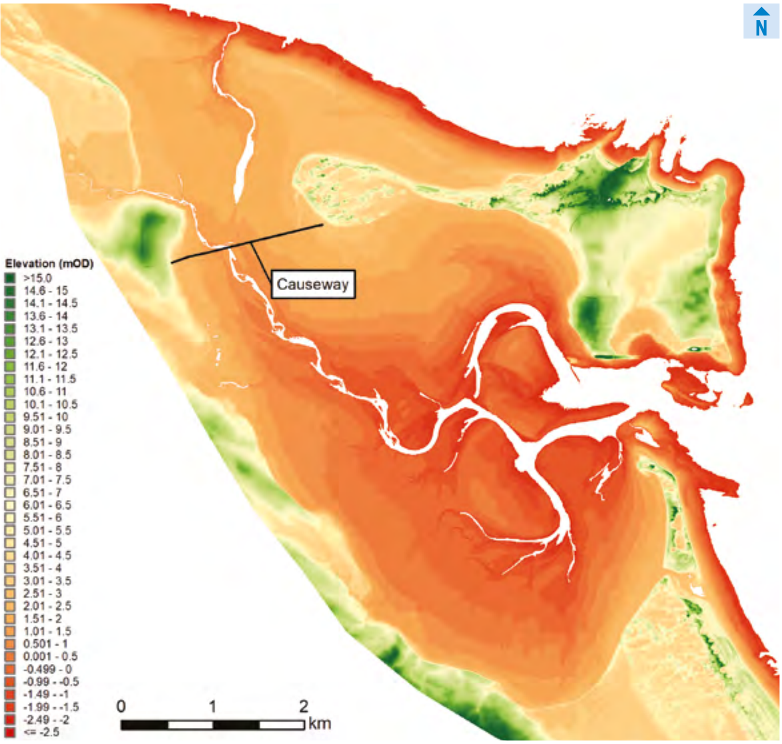

Figure 12. Bathymetry and topography of Lindisfarne National Nature Reserve (2020).

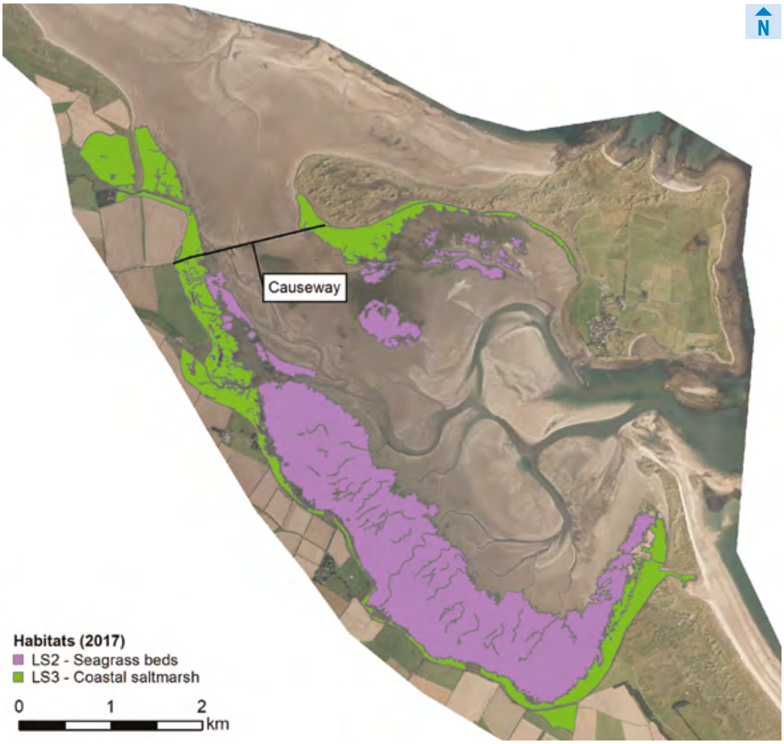

Figure 13. Ecological habitat mapping of Lindisfarne National Nature Reserve (2017).

it attracts over-wintering wader bird species in vast numbers. Attempts to manage the spread of the invasive *Sporobolus anglicus* have included hand-pulling and digging in the early 1970s, chemical control between 1977 and 1994 and most recently roto-burying between 1995 and 2002. Since 2002 there has been no management of *Sporobolus anglicus*.

Coastal processes at, and near to, the causeway are part of a wider dynamic geomorphological system that comprises (Figure 11):

- Goswick Sands – a barrier beach (north of the causeway) extending towards Holy Island which has naturally extended in length and prograded further offshore since 1860;
- Stable or accreting sand dunes on Holy Island at The Snook;
- Accreting inter-tidal muddy sandflats and fringing coastal saltmarsh of Holy Island Sands and Fenham Flats (south of the causeway); and
- Wide sandy beaches of Ross Back Sands, with backing sand dunes at Ross Links and Old Law which have been accreting and prograding seawards since the 17th century (Robertson, 1955).

Figure 11 is an aerial photographic image of Lindisfarne NNR taken in 2020 as part of the Cell 1 programme, whilst the corresponding LiDAR image in Figure 12 shows the bathymetry and topography of the area. The mapped coastal saltmarsh and seagrass *(Zostera)* habitats from the terrestrial ecological mapping element of the Cell 1 programme are shown in Figure 13 based on the 2017 aerial photography (the 2020 ecological mapping was not available at the time of writing).

By comparing the area of saltmarsh that was mapped in 2017 against the 1940s aerial photography it was observed that there had been an expansion in saltmarsh area over the intervening decades. However, monitoring the topography of the tidal flats either side of the causeway between 2004 and 2020 showed that there was no trend in sedimentation that can specifically be attributed to the causeway. Comparison of LiDAR data from 2010 and 2020 (Figure 14) showed that the deposition rates across Lindisfarne NNR were relatively consistent and there was no tendency for higher sedimentation rates in the vicinity of the causeway.

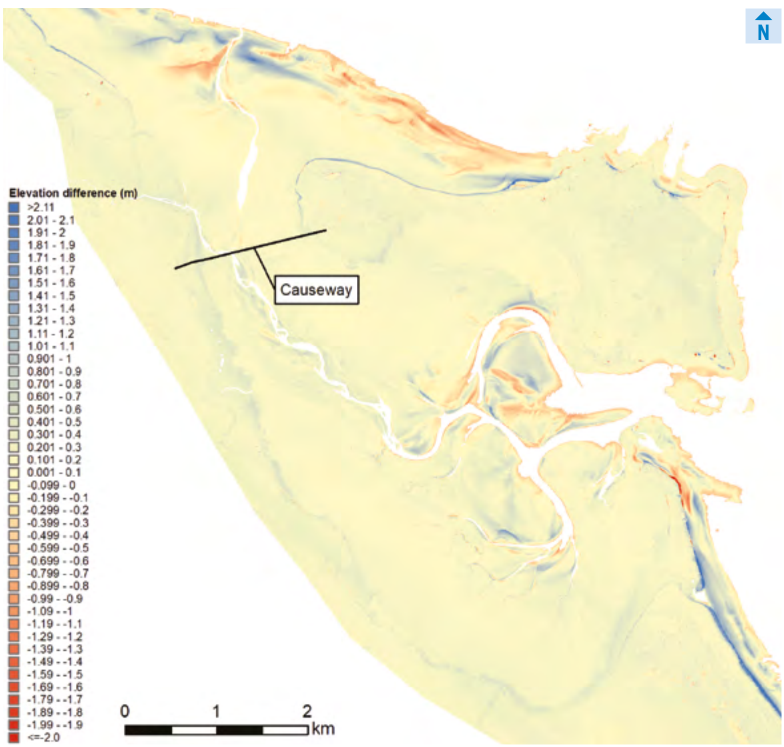

Figure 14. Difference in elevation between 2010 and 2020 LiDAR surveys demonstrating no notable increase in deposition in the vicinity of the causeway.

The evidence from the Cell 1 monitoring demonstrates that deposition across the NNR is driven by landscape-scale geomorphological change, strongly influenced by the prograding barrier beach at Goswick Sands and the prograding dunes at Ross Links and Old Law. These prograding features have reduced the tidal energy and wave exposure on backing inter-tidal flats, leading to deposition of sediments carried in suspension in the water column. As sedimentation occurs, currently at a rate that outpaces sea level rise, so the tidal flat elevations become more conducive to colonisation by saltmarsh vegetation, initially the pioneering *Sporobolus anglicus* and then a succession of other species. This natural process, coupled with cessation of management control of the *Sporobolus anglicus* in 2002, has led to the increase in saltmarsh habitat in Lindisfarne NNR over recent decades.

Lynemouth Bay

Lynemouth Bay extends between Snab Point in the north and Beacon Point in the south, and is intercepted by the narrow, unconstrained channel of the River Lyne (Figure 15). The beaches in Lynemouth Bay experienced extensive tipping of colliery spoil from 1934 to 2005, resulting in an artificially advanced shoreface, which led to subsequent land-claim and development of the Lynemouth Power Station and coal stocking yard.

At its peak in 1968, over 1.5 million tonnes of spoil were recorded as being tipped in one year, and in each year between 1965 and 1983 around 1 million tonnes were tipped. In total, it is likely that over 30 million tonnes of colliery waste were tipped at Lynemouth over seven decades. As a result of this disposal, the natural sea cliffs and coastal slopes to the north of the bay and the coastal sand dunes to

Profile	Location	First Survey	Latest Survey (at the time of writing)	Landward recession of MHWS over period stated		Comments
				Total recession (m)	Average annual rate (m/year)	
1aCMBC03	Northern end of Lynemouth Bay, near Snab Point	02/05/2002	28/11/2019	2	0.1	Stable cliffs
1aCMBC03A	Northumberland County Council land	01/10/2007	21/04/2020	29	2.3	Profiles CMBC03A and CMBC03B were added to the programme in October 2007
1aCMBC03B	Coal Authority land	01/10/2007	21/04/2020	58	4.6	
1aWDC01	Power Station Revetment	03/05/2002	22/04/2016	67	4.8	No longer surveyed as the fronting spoil beach has eroded back to the revetment
1aWDC02	Lyne Sands	03/05/2002	28/11/2019	54	3.1	Recession based on seaward berm
1aWDC03	Southern end of Lynemouth Bay	03/05/2002	28/11/2019	55	3.1	

Table 1. Beach profile surveys and erosion rates in Lynemouth Bay.

the south became detached from marine processes. They are currently stable, relict features, but the colliery spoil cliffs or colliery spoil beaches in front of them are actively eroding landwards since cessation of tipping activity in 2005.

Monitoring of coastal change in Lynemouth Bay has been undertaken as part of the Cell 1 monitoring (or its predecessor programme across Northumberland) since 2002, with aerial photography and beach profile surveys. Various profiles have been added or removed over time and the location of these profiles is shown in Figure 15. Annual average erosion rates, based upon the most up to date data, are shown in Table 1.

In four areas of the bay, various plastics, rubbers, construction rubble and assorted other refuse wastes have historically been tipped within the colliery spoil. With the ongoing erosion of the surrounding colliery spoil, these materials are becoming washed-out into the wider environment causing unwanted pollution. Waste management works are proposed at Lynemouth Bay in 2021/22 as a capital scheme to excavate and physically treat these materials, and take the unwanted polluting elements off-site for appropriate disposal, with on-site recovery of the treated colliery spoil for backfilling the excavations.

To investigate recent changes in the shoreline position and help inform the design of this capital scheme, LiDAR data for the years 2000 and 2019 have been analysed. The 2000 data were available from the Environment Agency at 2 m horizontal resolution, with the 2019 data being captured by the Cell 1 monitoring at 1 m horizontal resolution.

These data have been used to develop Digital Ground Models (DGMs) in a Geographical Information System (GIS) for each year. Output plots clearly show significant changes in coastal position over this 19-year period. Figure 16 describes the shoreline in 2000 and 2019 in the vicinity of Areas 1 and 2 of the capital scheme, where most of the plastics and refuse is proposed to be removed. The tipped colliery spoil cliffs have eroded to encroach upon areas containing the plastics and other refuse material, which is the mechanism causing its release into the wider environment.

To further support development and post-project evaluation of the imminent capital scheme within Lynemouth Bay, the scope of the Cell 1 monitoring has been enhanced from December 2020 to now also include a topographic survey (from the toe of the cliffs/slopes down to low water) and a cliff-top survey along the line of the colliery spoil cliffs.

Figure 15. Beach profile survey locations in Lynemouth Bay.

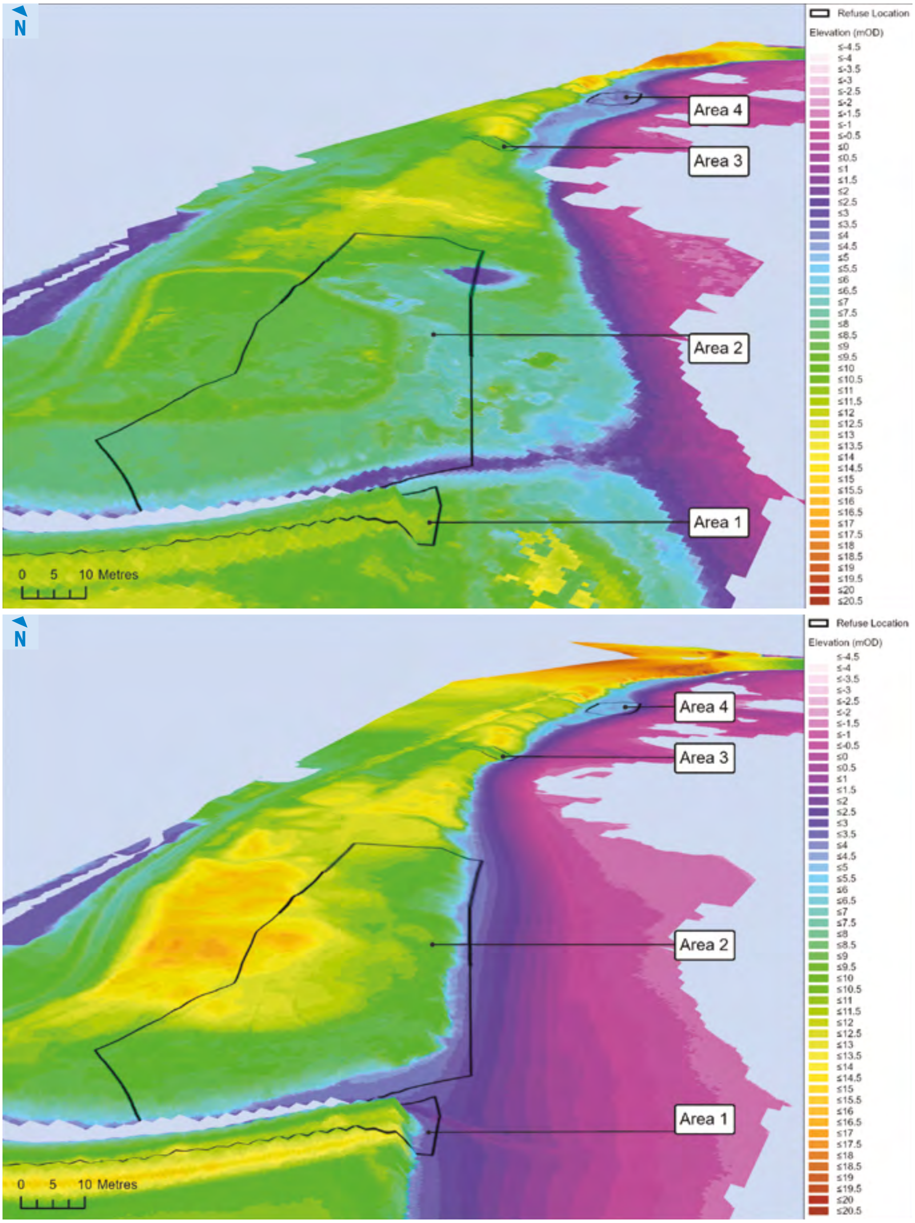

Figure 16. Shoreline position in the vicinity of Areas 1, 2, 3 and 4 in 2000 (top) and 2019 (bottom).

Meggies Burn

Blyth South Beach is located in southeast Northumberland and extends approximately 4.2 km from the River Blyth estuary in the north to Seaton Sluice Harbour in the south. The northern 1.5 km of beach is backed by hard defences (seawall and promenade), whilst the southern 2.7 km is formed of a sand dune system. The long sandy beach, dunes and (where present) promenade are of significant amenity and recreational value. The dunes have ecological value, designated as part of the Blyth to Seaton Sluice Dunes Local Nature Reserve and are located immediately adjacent to the Northumberland Shore Site of Special Scientific Interest (SSSI). A combined footpath and cycle way, which passes through the dune, is heavily used by walkers, cyclists and dog-walkers.

Surface water from the low-lying agricultural fields landward of the dunes is drained into the culverted

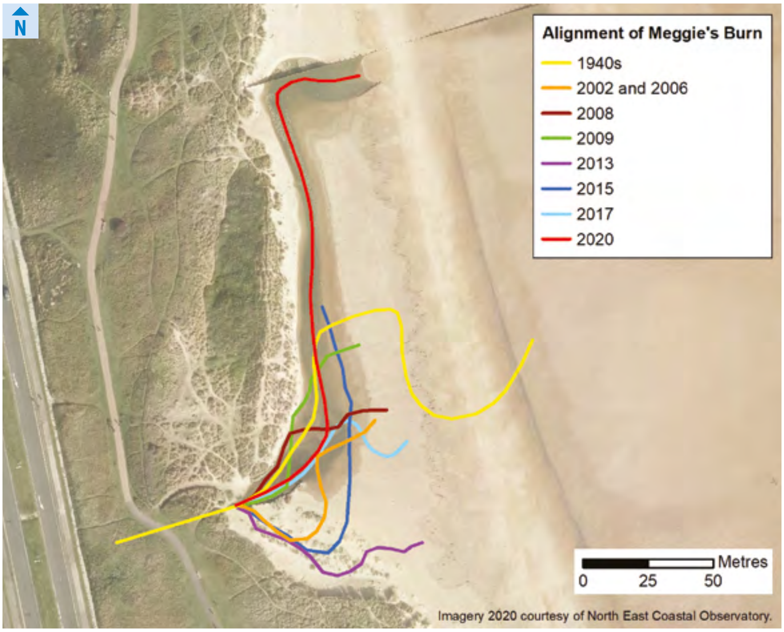

Figure 17. Thalweg of the channel of Meggies Burn from the 1940s to 2020.

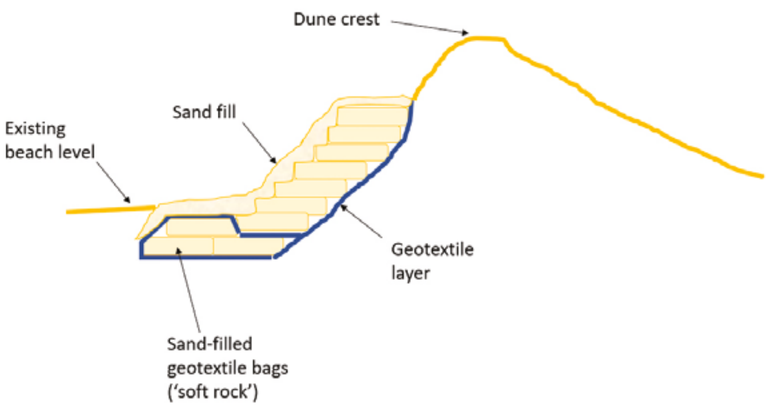

Figure 18. Dune stabilisation scheme at Meggies Burn, 2016.

Meggies Burn. The outfall of the burn is located just to the south of the end of the promenade towards the northern end of Blyth South Beach. The alignment of the unconstrained channel of the burn, as it leaves the outfall pipe and crosses the inter-tidal shore, has historically been variable.

Changes in alignment of the burn's channel between 2002 and 2020 have been well documented by aerial photography from the Cell 1 monitoring (Figure 17). In some years, the channel adopted a more central alignment (such as 2008 and 2017), whilst in other years it developed a more southerly alignment (such as 2013), and the remainder a more northerly alignment (such as 2009 and 2020). In 2002, 2006 and 2015 a more southerly alignment was initially adopted after leaving the outfall, closely hugging the dune toe to the south of the burn, before turning to adopt a more central or northerly discharge across the foreshore.

Between 2013 and 2015, the burn had persistently adopted a more southerly alignment. This caused erosion of the dune toe to the south and localised slumping in the dune face, which prompted local concerns about the erosion potentially affecting the footpath if it was left unattended. In response to this, a small scheme was implemented in 2016 involving the placement of 1,300 geotextile bags filled with a total of 1,300 m^3 of sand won locally from dredging the entrance to Seaton Sluice Harbour. The bags were topped with a minimum 300 mm covering of sand to restore the dune profile (Figure 18). Around this time, rock armourstones were also placed along the southern flank of the channel, to prevent the flow reaching the toe of the newly 'repaired' dunes.

In late 2019, the channel of the burn had moved north along the toe of the dunes to reach the last timber groyne, causing a large scour hole to be created in the beach as the channel meandered beneath it. The scour developed following a period of very heavy rainfall over a few days which caused the burn to be in spate. When coupled with high equinox tides, the channel flow diverted north until it reached the groyne. The sand level was higher on the north side of the groyne, so the force of water from the burn washed away the sand underneath the groyne causing the scour hole to form. The hole was cordoned off and then infilled with adjacent beach sand using mechanical plant. After the spate abated, and the newly formed channel bed dried, it left exposed former anti-tank defences that were installed along Blyth South during World War II, but which had subsequently become buried by beach sand and had not previously been observed for at least a decade.

Marsden Bay

As well as collecting coastal data routinely across the Cell 1 frontage, the monitoring also provides a mechanism by which additional bespoke local surveys and studies of various types and frequencies can be undertaken. One example of this is the Marsden Bay Risk Management and Emergency Response Plan, which was completed in 2019.

Due to long-standing concerns about coastal erosion in Marsden Bay, and in particular the risk posed to the cliff top public footpath and adjacent coastal highway, South Tyneside Council requested that repeat laserscan surveys be undertaken to inform a risk assessment and subsequent emergency response plan. This work built upon a baseline of laserscan monitoring that was undertaken at monthly intervals by the University of Northumbria between February 2015 and March 2017. The Cell 1 monitoring commenced its laserscan surveys in Marsden Bay in June/July 2019 and is repeating these at 6-monthly intervals, with specific post-rock fall surveys as and when needed.

There have been a number of notable rock falls along the South Tyneside frontage in recent years, particularly at Frenchman's Bay and Lizard Point in 2010 and in Marsden Bay adjacent to the (now demolished) Lifeguard Station by the Redwell Steps. The history of rock falls in these cliffs has left a series of rock stacks, arches and caves along the frontage and this is representative of the characteristic behaviour of cliffs of this type.

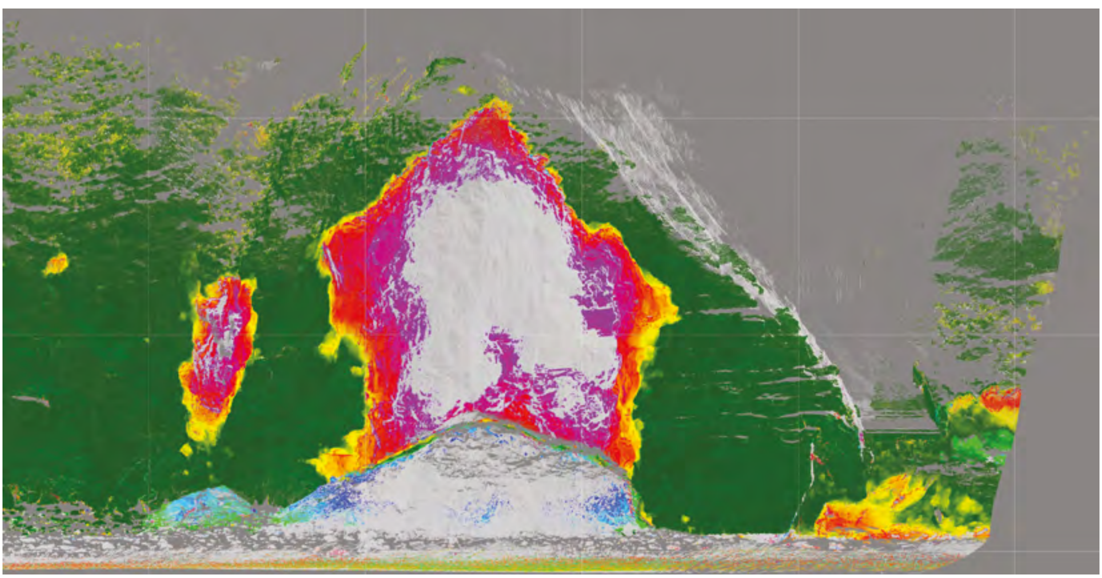

Figure 19. Normal perspective of rockfalls from laserscan imagery. Image courtesy Academy Geomatics.

The risk management approach has been to use both laserscan surveys and the Cell 1 monitoring 2-yearly walkover inspections to identify locations where caves are undercutting the cliff toe, and ensure that the cliff-top path is set back beyond the inland extent of cave penetration with a suitable buffer to safeguard the public. Where the coast road is affected by caves, a local diversion is planned in the short term, with a more permanent re-modelling of the road layout as a potential intervention in the longer-term. Suitable warning signs have been erected and the cliff-top path and existing low-level fencing have been realigned where necessary, between The Grotto and the southern end of the bay.

A further laserscan survey of this cliff area was undertaken in early February 2021, following a local rock fall which occurred on 30 January 2021. Figure 19 shows an output plot from this laserscan, showing the cliff face viewed from a normal perspective (i.e., as if standing on the beach facing the cliff). The yellow, red and purple shading show areas of material loss from the cliff face, in order of increasing magnitude, whilst the grey area in the cliff face shows where the surface change was greater than 2 m in depth. Similarly, the grey area on the beach at the toe of the cliff shows where the ground level increased by over 2 m in height due to the deposit of material from the cliff face as debris. Areas of green show little change (light green) or no change (dark green) in surface elevation compared to pre-rock fall conditions.

The rock fall event was video-recorded by a member of the public, gaining much social media and local media interest. The post-rock fall laserscan data was compared against an earlier laserscan survey of the cliffs along this frontage from November 2020 (Figure 20). This comparison revealed that two rock falls had occurred, very close to each other, with one being significantly larger than the other. The smaller rock fall moved approximately 18 m^3 of material from the cliff face to the cliff toe, cutting the cliff face back by

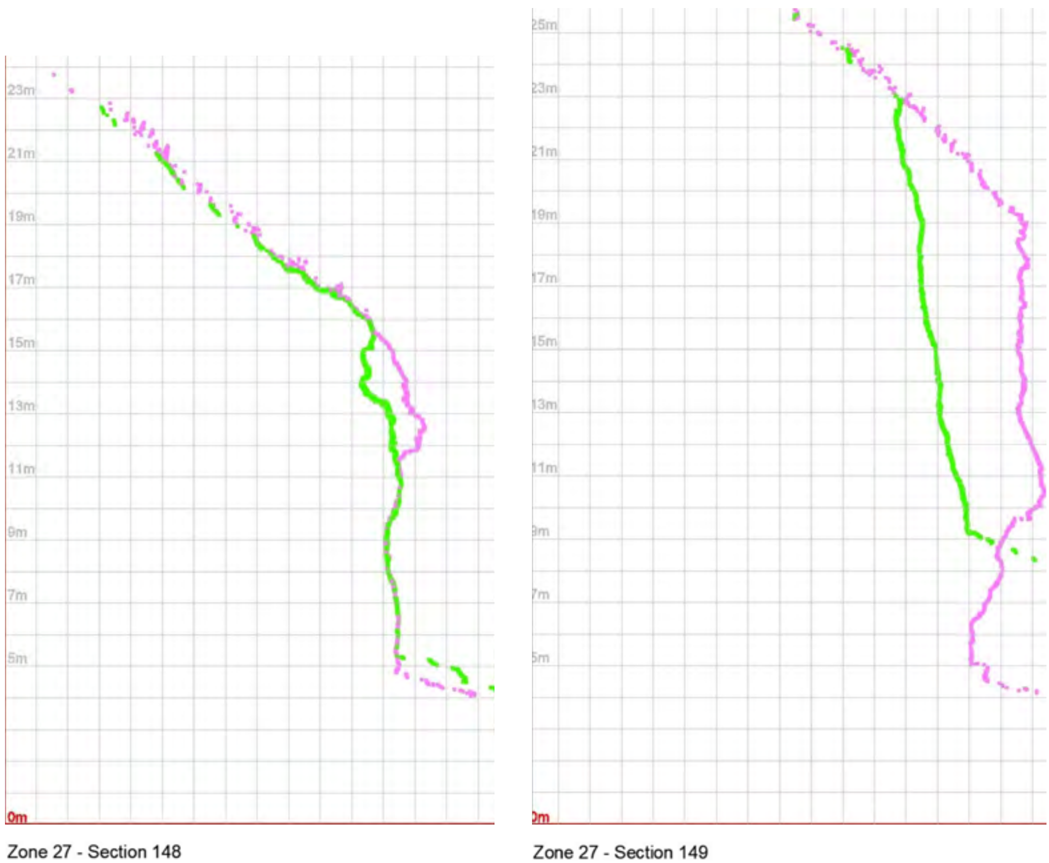

Figure 20. Small rockfall of overhanging cliff face (left) and larger rockfall of cliff face above caves at the cliff toe (right). The Pink line shows November 2020 survey, green line shows February 2021 survey. Images courtesy Academy Geomatics

up to 2.3 m at the point of deepest change. This rock fall was caused by the collapse of an overhanging section of rock mid-way up the cliff. During the larger rock fall around 311 m^3 of material dropped suddenly from the cliff face to the cliff toe, with the greatest depth of incision into the cliff face being 3.6 m. This rock fall occurred in an area where two small caves were observed in the November 2020 laserscan data, which have now become blocked by the toe debris. This rock fall involved the shearing of a larger section of cliff face from directly above the caves, with failure movement along a near-vertical plane.

CONCLUSIONS

The Cell 1 Regional Coastal Monitoring Programme has been running between 2008 and 2021. The main elements of this programme have comprised twice-yearly beach and cliff edge surveys, annual reviews of wave and tide data, and less frequent vertical and oblique aerial photography and LiDAR, bathymetric and sea bed sediment surveys and walk-over coastal inspections.

General findings have revealed the seasonal changes in beach profile morphology, and in particular the storm-related lowering that can occur on the upper beach. However, the response in calmer periods is for beach recovery, with no longer-term trends currently evident other than in areas of foreshore that have been affected by historical colliery spoil tipping which, since its cessation, have been experiencing net erosion, with rates approaching around 5 m per year in places.

Several areas of cliffs exhibit signs of activity, especially after adverse weather when rock falls or landslips can occur, depending on the geological type. In several areas of the Cell 1 frontage, understanding of the locations and rates of erosion is leading to adaptation to the ongoing change by relocating footpaths, access roads or coastal highways, removing car park infrastructure and re-wilding areas of cliff top. Other areas of cliff experience erosion at their base, leading to the long-term formation of caves and the subsequent opening of ‘sink holes’ in cliff top land or the long-term development of sea stacks.

Some of the most notable changes along the Cell 1 frontage are three-dimensional in nature and are best captured by the beach topographic surveys, aerial photography and LiDAR surveys. These focus around areas where channels of small rivers and burns outflow across the foreshore in an unconstrained manner, with their alignment influence by antecedent weather and marine conditions. At times, changes in channel alignment can lead to increased (or decreased) erosion pressure on dunes adjacent to the river mouth.

The walkover inspections surveys, although not covered in this paper, also lead to routine awareness of changes in condition of coastal defence structures or natural features that can be fed back to coastal managers for appropriate interventions or other risk management actions.

All data and interpretative reports derived from the Cell 1 monitoring are freely available on the project website: http://www.northeastcoastalobservatory.org.uk

In many parts of the frontage, the coastal monitoring data have proven invaluable in informing practical coastal risk management activities including:

- Selecting sustainable shoreline management plan policies or coastal strategy options;
- Developing outline and detailed design of effective schemes;
- Evaluating performance of implemented schemes;
- Planning and securing investments in capital and revenue expenditure; and
- Prioritising maintenance budgets in areas of most need.

As the programme has developed, in addition to the above, there has been an increased focus on the need for information to support discussion and engagement with stakeholders and communities, refining the understanding of SMP policy and management delivery, using new information to support ongoing adaptive shoreline management in many locations.

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