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Dynamic Coast - National Coastal Change Assessment: National Overview

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National Coastal Change Assessment
Steering Committee

Executive Summary

Research Questions

- What is the extent and location of eroding and potentially erodible coastline in Scotland?
- What is the extent and rate of coastal change in Scotland over time?
- Where are the vulnerable areas of Scottish coast?
- What social, economic and cultural heritage assets lie within these vulnerable areas of Scottish coast?

Main Results

- The soft coastline (coasts with the potential to erode) makes up 19% (3,802 km) of the Scottish coast. However, between a half and a third of all coastal buildings, roads, rail and water network lie in these erodible sections.
- Since the 1970s, 865 km of the soft coastline has moved position: 11% (423 km) has advanced (accreted); 12% (442 km) has retreated (eroded); and the remaining 77% (2,936 km) has remained approximately stable.
- Compared with the historic period (1890 to 1970 and adjusted for time period), the proportion of advancing coast has fallen by 22%, since the 1970s. The proportion of retreating coast has increased by 39%. Larger shifts in the balance of erosion and accretion are found particularly on the east coast and Solway Firth.
- Where coastal changes occur, they are faster than before. Nationally, average erosion rates since the 1970s have doubled from before to 1.0 m/yr whilst accretion rates have almost doubled to 1.5 m/yr.
- The observed changes since the 1970s are consistent with our expectations of climate change.
- If recent erosion rates were to continue in the future, by 2050 at least 50 residential and non-residential buildings, 1.6 km of railway, 5.2 km of road and 2.4 km of clean water network as well as significant areas of runways, cultural and natural heritage sites are expected to be affected by coastal erosion. These numbers are likely to be underestimates.
- If erosion rates increase in the future, as expected with climate change, the NCCA and National Flood Risk Assessment are likely to underestimate the extent of assets at risk from future coastal erosion and associated coastal flooding. Large numbers of assets are sited close to potentially erodible coasts (including 30,000 buildings, 1,300 km of roads and 100 km of railway lines).
- Given the observed changes and future expectations under climate change, a window of opportunity now exists to plan, mitigate and adapt in advance to avoid widespread harm and cost. This requires cross sector and integrated adaptation and mitigation planning.

Background

Climate Change (Scotland) Act 2009 requires development of an Adaptation Programme to address risks identified in the UK's Climate Change Risk Assessment (UK-CCRA).

No organisation has an overview of recent coastal changes or the implications these have on society's adjacent assets.

Some Local Authorities have a clear understanding of their coastline but a lack of a national overview hinders strategic assessments and implementation of national and regional policies by Scottish Government and its public bodies.

The NCCA addresses a gap in the national understanding of the resilience and vulnerability of Scotland's coastal assets.

It has the potential to inform strategic planning via Shoreline Management Plans, Flood Risk Management Planning, Strategic and Local Plans, National and Regional Marine Planning.

Research Undertaken

- The NCCA used 2,300 maps and data to analyse all 21,000 km of the Scottish shoreline to a level of detail never achieved before. It mapped the position and type of the soft coastline in 1890, 1970 and today, assessing the likelihood of its present and future erosion.
- Areas of erosion were projected to 2050, to provide indicative figures of the natural and built assets at increased risk if past changes and rates continue.
- The NCCA took no account of future management (improving resilience) or accelerating erosion due to climate change (increasing risk). Managing these assumptions, NCCA mapped the proximity of assets along the whole coastline to better understand coastal erosion resilience and potential exposure to hazard.
- Several web-maps allow public access to the underlying data and evidence base (dynamiccoast.com).
- NCCA source data is available to public sector organisations to support delivery of statutory duties, particularly flood risk management and climate change adaptation planning. It allows a step-change to occur in public sector adaptation planning.

Scottish Government Riaghaltas na h-Alba gov.scot
Scottish Natural Heritage Dualchas Nàdair na h-Alba All of nature for all of Scotland Nàdar air fad airson Alba air fad
University of Glasgow
SEPA
Historic Environment Scotland Àrainneachd Eachdraidheil Alba
Adaptation Scotland supporting climate change resilience
Fife Council
National Library of Scotland Leabharlann Nàiseanta na h-Alba
Ordnance Survey
SCAPE

Disclaimer

The evidence presented within the National Coastal Change Assessment (NCCA) must not be used for property level of scale investigations. Given the precision of the underlying data (including house location and roads etc.) the NCCA cannot be used to infer precise extents or timings of future erosion.

The likelihood of erosion occurring is difficult to predict given the probabilistic nature of storm events and their impact. The average erosion rates used in NCCA contain very slow periods of limited change followed by large adjustments during storms. Together with other local uncertainties, not captured by the national level data used in NCCA, detailed local assessments are unreliable unless supported by supplementary detailed investigations.

The NCCA has used broad patterns to infer indicative regional and national level assessments to inform policy and guide follow-up investigations. Use of these data beyond national or regional levels is not advised and the Scottish Government cannot be held responsible for misuse of the data.

The National Coastal Change Assessment Reports

The National Coastal Change Assessment (NCCA) has taken two and a half years and has produced a significant amount of new information. Whilst the mapped data are available via the webmaps (dynamiccoast.com), the following list details the reports which can be read in isolation or together.

1 - National Overview: an overview of the project, its results, implications and recommendations.

2 - Summary: a succinct summary of the NCCA.

3 - Erosion Policy Context: the existing and draft policies in Scotland that either refer to or affect coastal erosion, largely based on the responses contributed by the project partners of the NCCA.

4 - Methodology: describes the methodologies used within the NCCA, including 3D analysis.

5 - Data Audit: summarises the datasets used within the NCCA and outlines their copyright status.

6 - Defence Asset Database: reviews the current requirement for a national coastal defence asset database.

7 - Cell Reports: The NCCA results for each of the 11 coastal cells are presented and discussed (10 reports in total summarising changes within 142 sites around the Scottish coast).

8 - Whole Coast Assessment: a summary of the proximity of society's assets along the entire Scottish coastline. It details how many buildings, roads, railways and designated sites are located at various distances from the coast.

9 - Vulnerability Assessment: an indicative national assessment considering the assets that are increased risk of future coastal erosion if recent rates of change (since the 1970s) continue to 2050.

10 - Recommendations: summarises the recommendations arising from the NCCA.

Contents

National Overview

Dynamic Coast – Scotland's National Coastal Change Assessment

1.0 Introduction

Before this assessment, the Scottish Government, its public bodies and Local Authorities had no national overview of the risks or resilience to coastal erosion. The National Coastal Change Assessment (NCCA) addresses this gap as the first national evidence base to have established the changes to our soft coast over the periods the 1890s to the 1970s, and the 1970s to the modern shoreline. Over two thousand maps of Scotland's soft coast have been compared and, in association with the Ordnance Survey (OS), the NCCA has also updated and revised their modern mapping. Government, public bodies, Local Authorities, and the public can now see how the coast has changed over the last 130 years via publically available web-maps.

1.1 Aims

The aim of the NCCA is to undertake a historical mapping analysis to compare the past and current positions of Scotland's shoreline. The past changes are projected forward to identify indicative areas at greater risk of future erosion. The NCCA incorporates research into the inherent erodibility of the coastal zone, to further improve our understanding of risk and resilience. An assessment has been carried out of the entire coast to identify the proximity of society's assets and to provide greater context for vulnerability assessments. This vulnerability assessment seeks to establish the overlap between the areas of anticipated erosion and the assets, along with the flood-prone areas, that may be influenced by coastal erosion. It considers for the first time the actual erosion rates and flood risk. The document below provides a national overview for the NCCA as well as general summaries and trends. Detailed regional trends are covered within cell-by-cell reports (NCCA Report 8 includes Coastal Cells 1 to 11). The indicative vulnerability assessment is contained in NCCA Report 11. All NCCA reports can be accessed via the online web-maps (dynamiccoast.com).

1.2 Background

The extent of coastal erosion in Scotland is increasingly recognised as an information gap that hinders policy. Scotland has thus far been under-prepared in that our approach to coastal erosion has been piecemeal and often reactive to damaging events. Coastal erosion (and its linked capacity to exacerbate coastal flooding) has not been systematically addressed. In response, the Scottish Government has sought to fund research that allows an assessment of our inherent resilience against, and vulnerability to, coastal change, today and into the future.

The NCCA research has identified historical coastal change to inform a range of resilience and vulnerability assessments along Scotland's coastline. In addition to, and in support of, an earlier CREW project (how coastal erosion could be incorporated into coastal flood management), the NCCA seeks to identify those shorelines where potential erosion may influence flood risk.

Such an approach aims to support the improved policy framework provided by the Scottish Climate Change Adaptation Programme, Flood Risk Management policies, National / Regional Marine Plans and Strategic and Local Development Planning. NCCA Reports 3 and 4 provide further information on the policy context and the policies pertinent to coastal erosion. It is hoped that the NCCA will provide the evidence base and impetus to coordinate and integrate approaches to better manage erosion and flood risk, as called for within the Adaptation Sub Committee of the Committee on Climate Change (Sept 2016, link). This will enable Scotland to be more resilient to coastal erosion and related coastal flooding risk, and more informed about the impacts of climate change and erosion at the coast.

The NCCA has been developed by the University of Glasgow (J. D. Hansom and J. M. Fitton) and the Scottish Government (A. F. Rennie) in partnership with Scottish Natural Heritage (SNH), Scottish Environment Protection Agency (SEPA) and Historic Environment Scotland (HES) and commissioned on behalf of the Scottish Government by the Centre of Expertise for Waters (CREW) (crew.ac.uk). A steering group set up to help guide the direction of the research included the following: The Scottish Government, Scottish Natural Heritage, Historic Environment Scotland, Scottish Environment Protection Agency, Adaptation Scotland, Ordnance Survey and Fife Council.

1.3 Glossary

Table 1.1 below provides a glossary of terms used in this report.

Table 1.1: A glossary to the terms used within this report

Term	Definition
Accretion	The build-up of sediment resulting in the seaward movement of the coastline / Mean High Water Springs
Advance	The seaward movement of the Mean High Water Springs line, however the cause of this movement is not inferred. See accretion, which is associated with natural coastal processes.
Artificial coast	A coastline with man-made structures along the upper beach that inhibit erosion and movement of Mean High Water Springs landward
Adaptation	The adjustment in economic, social or natural systems in response to actual or expected climatic change, to limit harmful consequences and exploit beneficial opportunities
Asset	An item, such as a building or protected area, that is deemed to have an economic, social, or cultural value (or combination of)
Digital Terrain Model	A three-dimensional representation of the terrain (earth's) surface. As such it excludes buildings and vegetation. It is used interchangeably with Digital Elevation Model
Digital Surface Model	A three-dimensional representation of the surface, including buildings and vegetation (if present)
Erosion	The removal of sediment resulting in the landward movement of the coastline / Mean High Water Springs
Erosional bight	An area of erosion adjacent to the end of coastal defences, that commonly occurs as the sediment supply deficit (exacerbated by defences) is made up within the next available section of beach
Gardens of Designed Landscape	Sites listed within the Inventory of gardens and designed Landscapes, in support of the Ancient Monuments and Archaeological Areas Act 1979.

Term	Definition
Geological Conservation Review Site	The Geological Conservation Review is a UK-wide review, undertaken by the Joint Nature Conservation Committee, which selected the very best and most representative geological and geomorphological features of Britain. For geological sites these underpin the Site of Special Scientific Interest network
Downdrift/updrift	Where a tide or wave-driven longshore current occurs, sediment is moved from updrift toward the downdrift section of coast
Hard and mixed coast	A coastline composed of physically resilient rocks often with superficial sediments, which is unlikely to retreat. Erosion rates may be millimetres per year and adjacent assets are unlikely to be affected by erosion
High Water Mark of Ordinary Spring Tides (HWMOST)	The HWMOST became Mean High Water Springs in later Ordnance Survey maps; this is a terminology modification and the definitions remain unchanged.
Mean High Water Springs (MHWS)	The height of MHWS is the average throughout the year of two successive high waters during those periods of 24 hours when the range of the tide is at its greatest. The values of MHWS vary from year to year with a cycle of approximately 18.6 years. (National Tidal and Sea Level Facility)
LiDAR	LIDAR (Light Detection and Ranging) is a remote sensing method that uses lasers to measure distances thereby creating detailed three-dimensional maps
Negative gradient	Low-lying inland coastal areas, which are separated from the shore by a barrier, which if removed would allow tidal flooding
Potentially Vulnerable Area	Areas where a significant flood risk exists now or is likely to occur in the future. They are based on terrestrial sub-catchments and should be viewed alongside flood risk
Properties in Care	Properties which are listed in the care of Scottish Ministers, under the Historic Environment Scotland Act 2014
Retreat	The landward movement of the Mean High Water Springs line, however the cause of this movement is not inferred. See erosion, which is associated with natural coastal processes.
Sediment budget	Sediment budget is a concept that applies to sandy and muddy shores and it refers to the balance between sediment added to and removed from the coastal system; in this respect, the coastal sediment budget is like a bank account. When more material is added than is removed, there is a surplus of sediment and the shore builds seaward. On the other hand, when more material is removed than is added, there is a deficit in sediment supply and the shore retreats landward.

Term	Definition
Sediment supply	Sediment budget is a concept that applies to sandy and muddy shores and it refers to the balance between sediment added to and removed from the coastal system; in this respect, the coastal sediment budget is like a bank account. When more material is added than is removed, there is a surplus of sediment and the shore builds seaward. On the other hand, when more material is removed than is added, there is a deficit in sediment supply and the shore retreats landward.
Scheduled Monuments	Nationally important sites, listed in support of the Ancient Monuments and Archaeological Areas Act 1979.
Soft coast	A coastline composed of unconsolidated sediments, which is not inherently resilient to erosion, but relies on the balance of natural processes to maintain its shape in response to storms and every day processes
Special Area of Conservation	A site designated under the Habitats Directive. These sites, together with Special Protection Areas, are collectively known as Natura sites and are internationally important for threatened habitats and species
Special Protection Area	A site designated under the Birds Directive. These sites, together with Special Areas of Conservation, are collectively known as Natura sites and are internationally important for threatened habitats and species
Site of Special Scientific Interest	Areas of land and water (to the seaward limits of local authority areas) considered by Scottish Natural Heritage to represent the best of our natural heritage - its diversity of plants, animals and habitats, rocks and landforms, or a combination of such natural features.

1.4 Methods

To estimate coastal change on a national scale, the NCCA used national data sets (NCCA Report 6) and mapping products that were available digitally. A full version of the methodology used can be found in NCCA Report 5. However, the methodologies used to complete the aims of the NCCA are briefly described below:

- To prioritise and analyse the coastal change outputs, a classification of the coastal type (either soft, hard and mixed, or artificial coast) was required. This was generated using expert knowledge from Hansom, Fitton, and Rennie and aerial photography. The areas of soft coast were then prioritised for analysis as these the locations where change is possible.
- Following on from this, the historic high water mark (MHWS) from the 1898-1904 coastline was manually digitised and verified from georectified OS 6 Inch Maps. This data is termed the '1890s coastline'.
- The historic high water mark (MHWS) from OS 1:10, 000 maps 1956 to 1995 (most of the data is from the 1970s) was digitally extracted and manually verified. This data is termed the '1970s coastline'.
- The modern high water mark (MHWS) was digitally extracted and manually verified from OS MasterMap. Where possible this was replaced by MHWS lines derived from digital terrain models created from LiDAR and aerial photography. This data is termed the 'modern coastline' and includes data from 2003 to 2016.

- The coastlines were compared to identify the amount and rate of change. The change analysis produced two datasets, the first compared the coastal change between the 1890s and 1970s datasets. The second analysed changed between the 1970s and modern datasets.
- The coastal change rates were then extrapolated into the future and the assets that are potentially impacted by future erosion were identified.

2.0 Results

2.1 Characteristics of Scotland's coastline

Hard rocky coast and other areas of mixed sediments that are largely resilient to coastal erosion dominate Scotland's coastline. Using NCCA data, together they make up a coastal length of 15,613 km or 78% of the shoreline by length. The 'mixed' description reflects that where superficial consolidated sediments (overburden) lies on top of bedrock it will have limited erosion potential. The soft coast makes up 19% of the shoreline by length, extending to 3,802 km; artificial coast makes up the remaining 3%, extending over 591 km (Figure 2.1). The distribution of these categories varies around the coast with the east coast having a larger proportion of soft and artificial sections of coast and the north and west coasts reflecting a long, rock-dominated and often fjordlike coastline (Figure 2.1 and Figure 2.2)

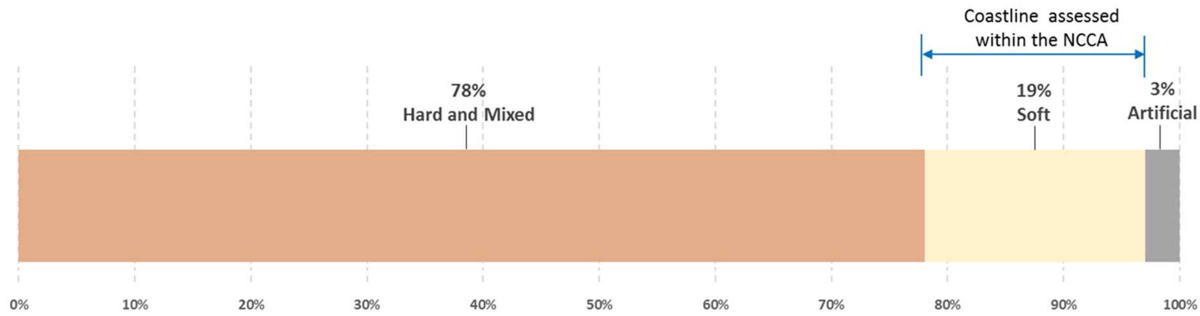

Figure 2.1: Proportion of Hard & Mixed (78% - 15,613 km), Soft (19% - 3,802 km) and Artificial (3% - 591 km) coastline in Scotland (Source: NCCA).

Table 2.1 Length of Scottish coastline by coastal cell. Removed from the analysis were sections of MHWS where the tidal limit extends a distance (ca. greater than 200 m) upstream in inlets where fluvial rather than coastal processes dominate.

		Total Length		Hard and Mixed		Soft		Artificial	
		km	%	km	%	km	%	km	%
Cell 1	Forth	452	2%	184	41%	105	23%	163	36%
Cell 2	Tay & East Coast	546	3%	278	51%	188	34%	80	15%
Cell 3	Moray Firth	1,024	5%	332	32%	603	59%	89	9%
Cell 4	North Coast	560	3%	416	74%	137	24%	7	1%
Cell 5	West Coast	7,414	37%	6,243	84%	1,143	15%	28	0%
Cell 6	Clyde	1,405	7%	884	63%	376	27%	145	10%
Cell 7	Solway	546	3%	247	45%	291	53%	8	2%
Cells 8 & 9	Western Isles	4,414	22%	4,015	91%	376	9%	23	1%
Cell 10	Orkney	1,024	5%	623	61%	372	36%	28	3%
Cell 11	Shetland	2,621	13%	2,391	91%	212	8%	18	1%
		20,006	100%	15,613	78%	3,802	19%	591	3%

A useful method to examine coastal characteristics and functioning is the coastal cell, first delimited in Scotland by Ramsay and Brampton (2000). Use of coastal cells as a coastal management tool is based on a recognition that the processes that shape and alter the coast are unrelated to administrative boundaries but are related to changes and interruptions to sediment availability by natural boundaries (headlands). Changes in erosion, accretion and sediment supply in one coastal cell are regarded to be largely unrelated to, and unaffected by, conditions in adjacent coastal cells, and the cell can be seen as self-contained in terms of sediment movement. For example, at many sites sediment largely moves in one direction and may pass around a headland (the major cell boundaries) only in very small volumes. Within a cell, any engineering structures that interrupt alongshore sediment delivery on the updrift side of a coast may impact on the downdrift coast. Within estuaries, sediment may circulate freely between both banks and so the inner portions of major firths and estuaries are defined as sub-cells (Ramsey and Brampton, 2000). Whilst the cell system is ideal from a scientific perspective, it remains that Local Authorities jurisdiction may straddle a cell boundary.

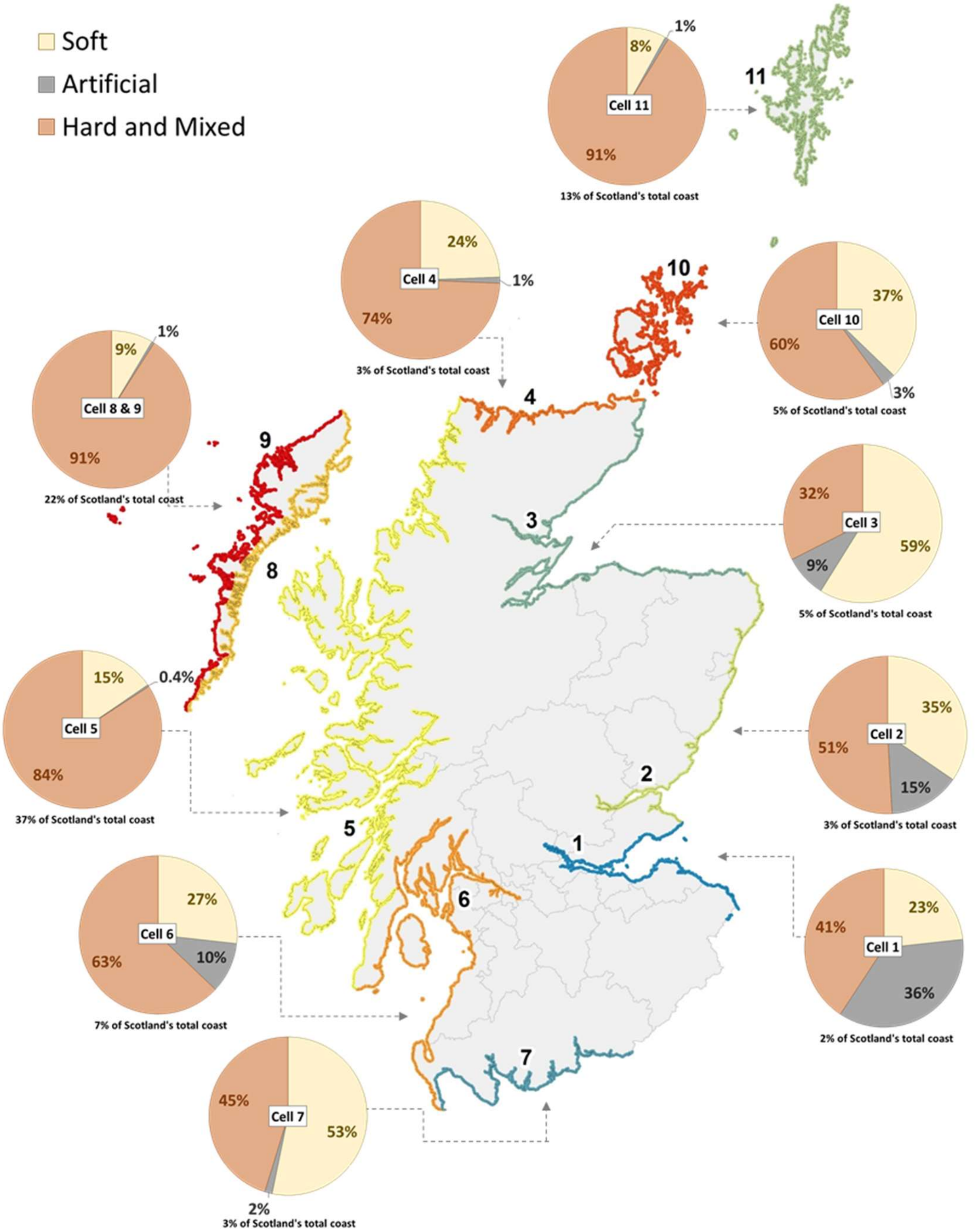

Figure 2.2: Distribution of Hard & Mixed, Soft and Artificial coastlines in Scotland, by coastal cell (Source: NCCA).

Table 2.2: National Statistics for Scotland's coastline

Statement	Source / Scale
Scotland has at least 11% by length of Europe's coastline (based on EUrosion (2004))	EUrosion (2004) appraised the erosional status of Europe's coastline estimating that, at 1:100,000 scale, Europe's coastline is 100,925 km long, with Scotland's shoreline being 11,220 km (or 11% of Europe's coast). This excludes the inner parts of the main firths. SNH (1999) estimated a coastal length of 11,800 km. EUrosion (2004) http://www.eurosion.org/reports-online/reports.html Baxter *et al* (1999) Scotland's living coastline. SNH. London.
Scotland's coastline is 21,305 km long (based on the most detailed national mapping 2015).	The NCCA has established the total length of the Mean High Water Spring tideline in Scotland is **21,305 km**, based on the Ordnance Survey's MasterMap dataset (captured at 1:1250, 1:2500 and 1:10 000 scales in urban, rural and mountain/moorland areas respectively).
Scotland has 3,802 km of 'soft' erodible coast, or 19% of the total coast (based on the most detailed national mapping 2015 & NCCA).	The soft or potentially erodible coast identified within the National Coastal Change Assessment is based on geological datasets and aerial imagery at a more detailed level than EUrosion (2004) and is depicted on the updated OS MasterMap MHWS line. Two other categories include Artificial and Hard / Mixed coasts.
Scotland has 591 km of artificial coast, or 3% of the total coast (based on the most detailed national mapping**).**	Artificial coast (protected by human structures with no beach frontage) was identified within the National Coastal Change Assessment, based on an analysis of geological datasets and aerial imagery, and is depicted on the OS MasterMap MHWS line.
Majority of defences were built before the 1970s.	The artificial coast measured 541km in the 1970s and 590km in the modern mapping. More than 90% of defences were installed before the 1970s maps but the lack of comprehensive modern air photography to corroborate means the modern extents are an underestimate.
Scotland has 15,613 km of hard / mixed coast or 73% of the total coast. (based on the most detailed national mapping)	Hard/mixed coast (rocky/limited erodible overburden) was identified within the National Coastal Change Assessment, based on an analysis of geological datasets and aerial imagery, and is depicted on the OS MasterMap MHWS line.
865 km of soft shoreline has changed more than 10 m since the 1970s.	865.3 km of soft shoreline has moved more than 10m or at a rate exceeding 0.5m/yr since the 1970s. 423.2km (11%) has advanced, 442.1 km (12%) has retreated and 2,936.5 km has remained stable (77%).
£1.2bn of residential properties benefit from the protective function of coastal sediment accretion (9,888 properties)	Fitton, J.M. (2015) A National Coastal Erosion Risk Assessment for Scotland. Unpublished PhD Thesis, University of Glasgow.

Using the coastal cell-based approach, much of the east coast is characterised by long expanses of soft coast backed by low-lying land that has supported urban and industrial development. Together with extensive transport infrastructure the east coast is asset rich. The north and west coasts, as well as the western and northern isles are dominated by rocky coastlines, and although soft coasts are present, for example on the western seaboards of the Uists and in Orkney, the level of development is more limited and built assets more infrequent. An exception to this general pattern in the west is the Firth of Clyde where extensive lengths of previously soft coast have been defended to protect the asset-rich hinterlands supporting industrial and housing development and the Solway where Scotland's greatest extent of saltmarsh occurs. Table 2.2 summarises some key statistics for Scotland's coastline.

2.2 Coastal Change Results

2.2.1 National Results

The soft coastline (coasts with the potential to erode) makes up 19% (3,802 km) of the Scottish coast (Figure 2.1). However, between a half and a quarter of the coastal buildings, roads, rail and water network lie in these erodible sections (see NCCA report 9: Whole Coast Assessment, section 2.3.1).

The historical period extended from 1899 to 1976, during which time 17% (622 km) of the soft coast eroded, 29% (1,067 km) accreted and the remaining 55% remained stable (2,036km) (Figure 2.3).

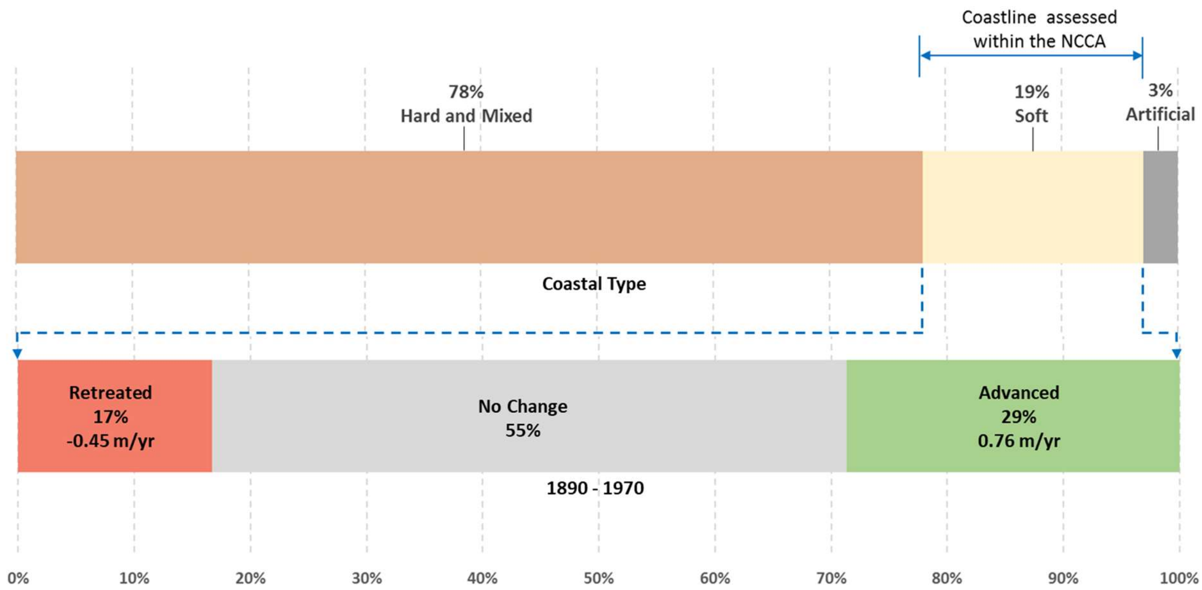

Figure 2.3 Historical coastal change results (not adjusted for time period)

Since the 1970s, 865 km of the soft coastline has moved position: 11% (423 km) has accreted; 12% (442 km) has eroded; and the remaining 77% (2,936 km) has remained approximately stable (Figure 2.4). The average survey date for the historical maps is 1899, with 1976 for the 1970s maps and 2013 for the modern maps. This means that approximately **half the time** has been available over the modern period (37 years) to allow change to occur, compared with 77 years over the historical period. Standardising the data to account for this shows that since the 1970s there has been a 39% increase in the amount of erosion which has occurred and a 22% fall in the amount of accretion, compared with the comparable period before the 1970s (Figure 2.4). In addition, there has been an overall doubling in average erosion rates to 1.0 m/yr over the modern period (from 0.5 m/yr before 1970).

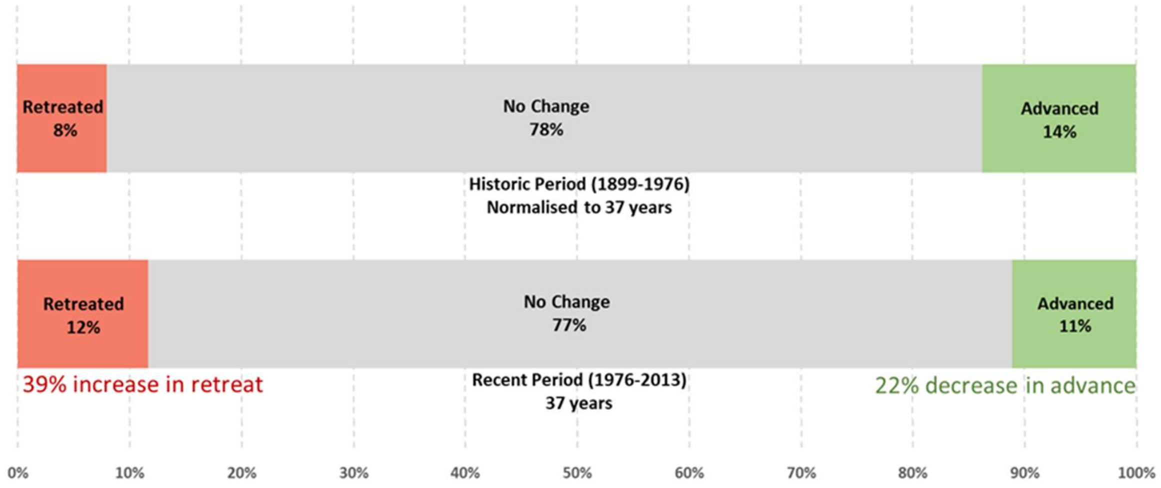

Figure 2.4: The proportion of soft coast that has advanced, retreated, or not changed in the historical (1890-1970) and modern (1970-Modern) time periods (historical data normalised to 37yrs).

2.2.2 National Interpretation

The normalised data suggests that a trend of increasing erosion extent and declining accretion extent has occurred between the historical and recent periods that may provide the basis for extrapolation over the next 37 years, assuming a continuation of these trends (Figure 2.5). Although it is not possible to identify where any additional erosion will be located by 2050, given the regional bias in increases in erosion extent (Table 2.3), it is likely to be located on the east coast. The recent rates of erosion have also been used to project any known significant erosion inland to inform the Vulnerability Assessment.

Figure 2.5: Extrapolation of the possible future changes based on a continuation of the trends over the historic and recent change (normalised for time period).

2.2.3 Regional Results

In addition to the national trends identified above, there are clear differences due to the level of natural protection influencing the soft coast erosion and accretion trends within each coastal cell (Figure 2.6). This is because some of the soft sections of coast are within cells dominated by rocky enclosed coasts, whereas others lie within more open cells dominated by extensive lengths of exposed soft coast.

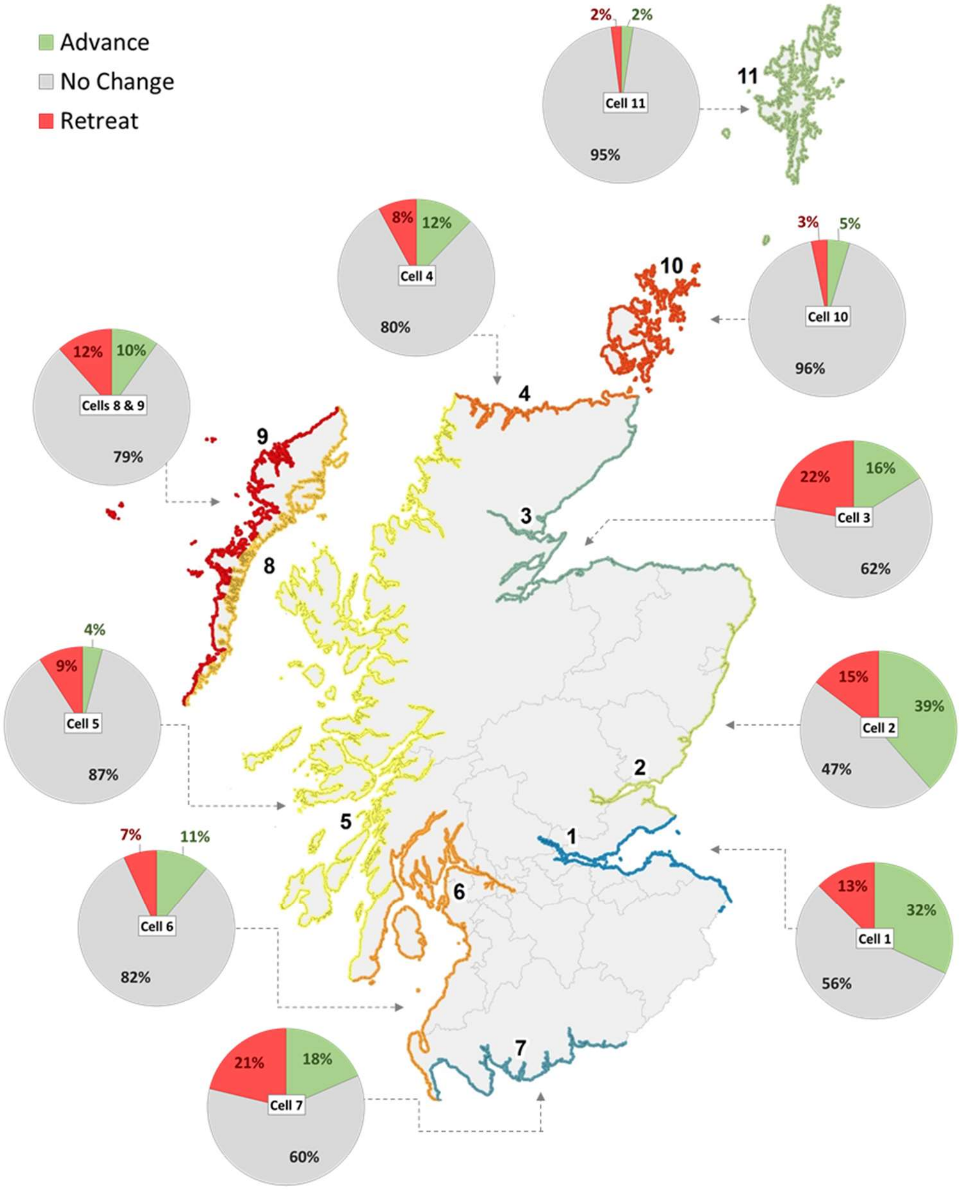

Figure 2.6: The proportion of advance, retreat and no change along the soft coast within the 1970-Modern data within each coastal cell. Note the larger proportion of accretion and erosion within the east coast cells and Solway Firth (Cells 1-3 & 7).

The more exposed mainland east coast cells (1,2,3) and Solway Firth (7) have greater proportions of soft coast erosion and accretion (i.e. significant change) and lower proportions of stability (see the grey sections of Figure 2.6). On the rock-dominated cells (for example cells 8, 9, 10, 11), soft coast stability is far higher and the extent of erosion and accretion lower. Whilst the natural level of protection offered to the soft sections of coast by the surrounding rocky coast has not changed through time, the proportion of soft coast experiencing erosion and accretion has. Again, accounting for the time periods the standardised data on a cells basis shows a more detailed picture (see Table 2.3), where erosion is becoming more common within the Firth of Forth, Firth of Tay and East coast, Moray Firth, West coast, Solway Firth, Orkney and Shetland Isles (i.e. Cells 1-3, 5, 7, 10 and 11). Erosion is becoming less common on the North coast, Clyde and Western Isles (Cells 4, 6 & 8/9). Accretion is becoming more common within the Firth of Forth, Firth of Tay and east coast, North coast, Solway Firth and Western Isles (Cells 1, 2, 4, 7-9). Accretion is becoming less common within the Moray Firth, West coast, Clyde, Orkney and Shetland.

Table 2.3 Traffic light portrayal of changes in the erosion and accretion extent since 1970s in comparison with the historical period (normalised for time period). Relative direction and magnitude of change is shown by arrows and intensity of colour: red (erosion) and green (accretion). Also note the detailed bar chart is shown in Figure 2.8.

Cell		Change between 1890-1970 (normalised) and 1970-Modern			
		Retreat		Advance	
1 -	Firth of Forth	Large Increase	▲	Increase	▲
2 -	Tay & East coast	Large Increase	▲	Increase	▲
3 -	Moray Firth	Large Increase	▲	Small Decrease	▼
4 -	North coast	Small Decrease	▼	Small Increase	▲
5 -	West coast	Small Increase	▲	Decrease	▼
6 -	Clyde	Small Decrease	▼	Small Decrease	▼
7 -	Solway Firth	Increase	▲	Small Increase	▲
8 & 9 -	Western Isles	Small Decrease	▼	Small Increase	▲
10 -	Orkney	Increase	▲	Decrease	▼
11 -	Shetland	Large Increase	▲	Decrease	▼

Again, when the spatial distribution of these changes is considered Figure 2.6 the greatest changes in erosion and accretion are located principally on the east coast Cells (Cell1 erosion extent has doubled and Cell 2 & 3 extent has tripled, and Solway. Whilst there are also increases in accretion in these Cells, they are smaller than the erosional loss (see Figure 2.8). Within the enclosed cells (Cells 4-11) where the level of protection offered from the surrounding rocky shore is higher, the changes to accretion and erosion has been muted.

2.2.4 Regional interpretation

The changing dominance of erosion and accretion (outlined above) is interpreted here as a switch toward erosion. This erosion trend is more evident on the large extent of soft coast in the east where a greater proportion of historical development (i.e. assets located close to the coast) has occurred requiring the construction of coastal defences. In contrast, the enclosed soft sections of coast within the rock-protected cells, have less mobility, less erosion and accretion extents and less shifts in the erosion/accretion balance over time. This supports the assertion that if the impact of climate change is manifest in greater coastal erosion, then this is more likely to have an east coast bias that is unlikely to be offset by accretion. Whilst the increased accretion may be thought to ameliorate additional erosion, often the accretion is located within more remote and undeveloped sections of the inner firth. Unfortunately, the reverse is not always the case, in that erosion extends across all sections of the developed and undeveloped shores.

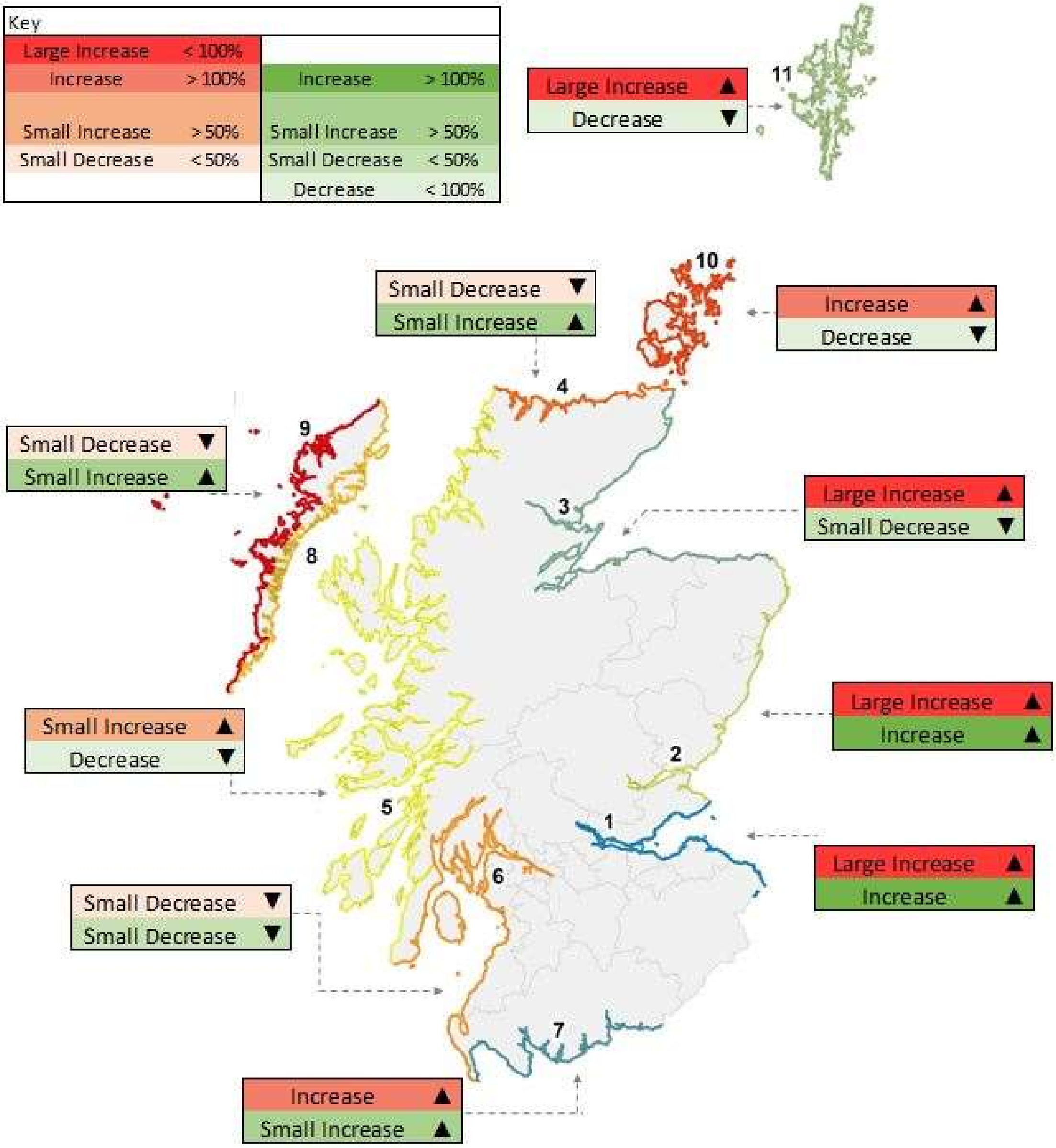

Figure 2.7: Map showing the distribution of changing extent of erosion and accretion between historical period (1890s-1970s) and recent period (1970s-Modern).

The reader is referred to the individual each cell reports for a detailed picture and statistics of changes within that cell (NCCA Report 7). The Cell Reports provide accounts for the changes at 142 sites around the coast, as shown in Figure 2.9 and Table 2.4.

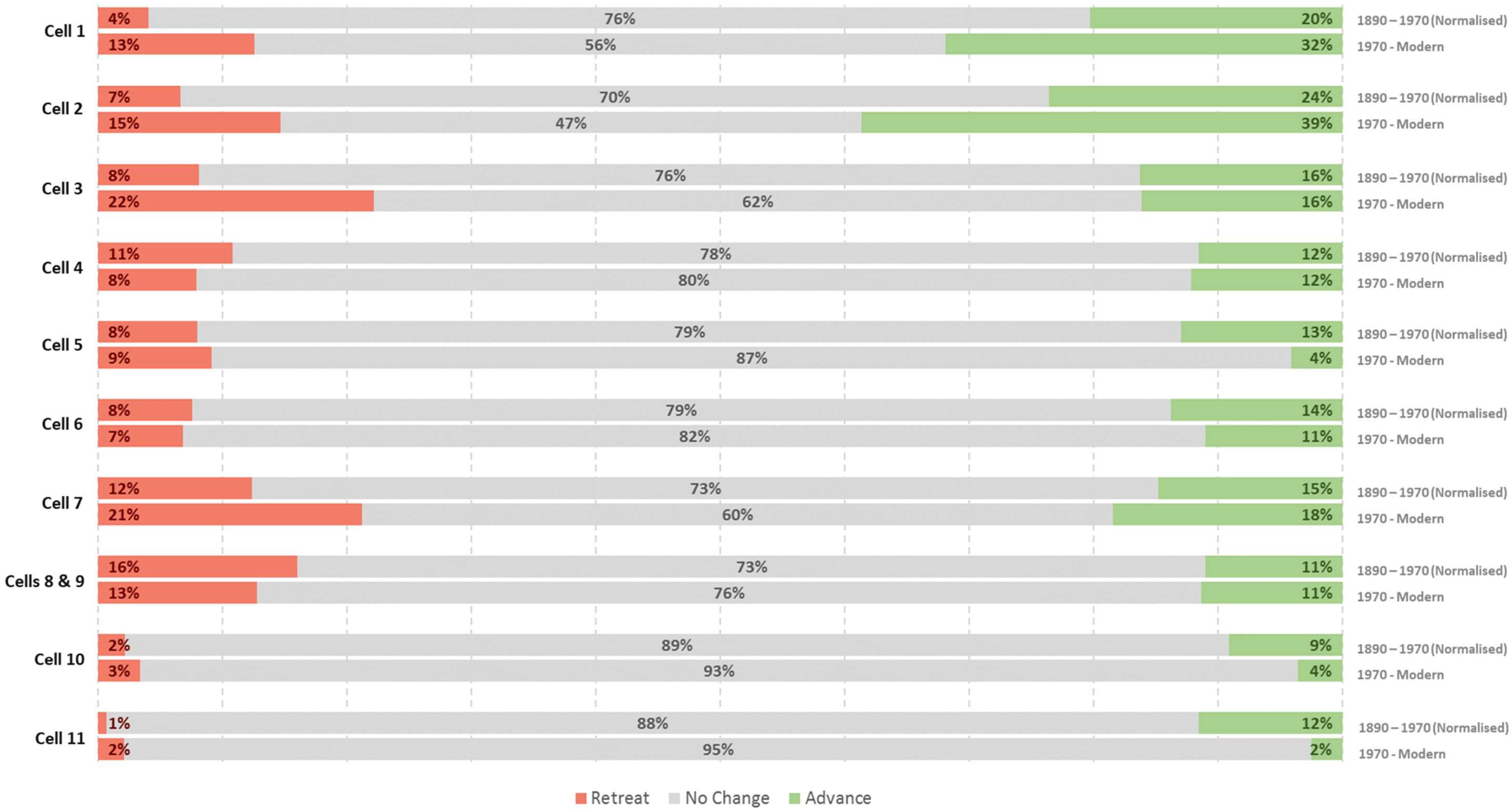

Figure 2.8: Proportion of normalised historical period (ca. 1890-1970) and recent (ca. 1970-Modern) advance, retreat, and no change within the soft coast of each cell. Note the proportion of erosion and accretion within the historical period has been reduced to normalise for a 37 year time period.

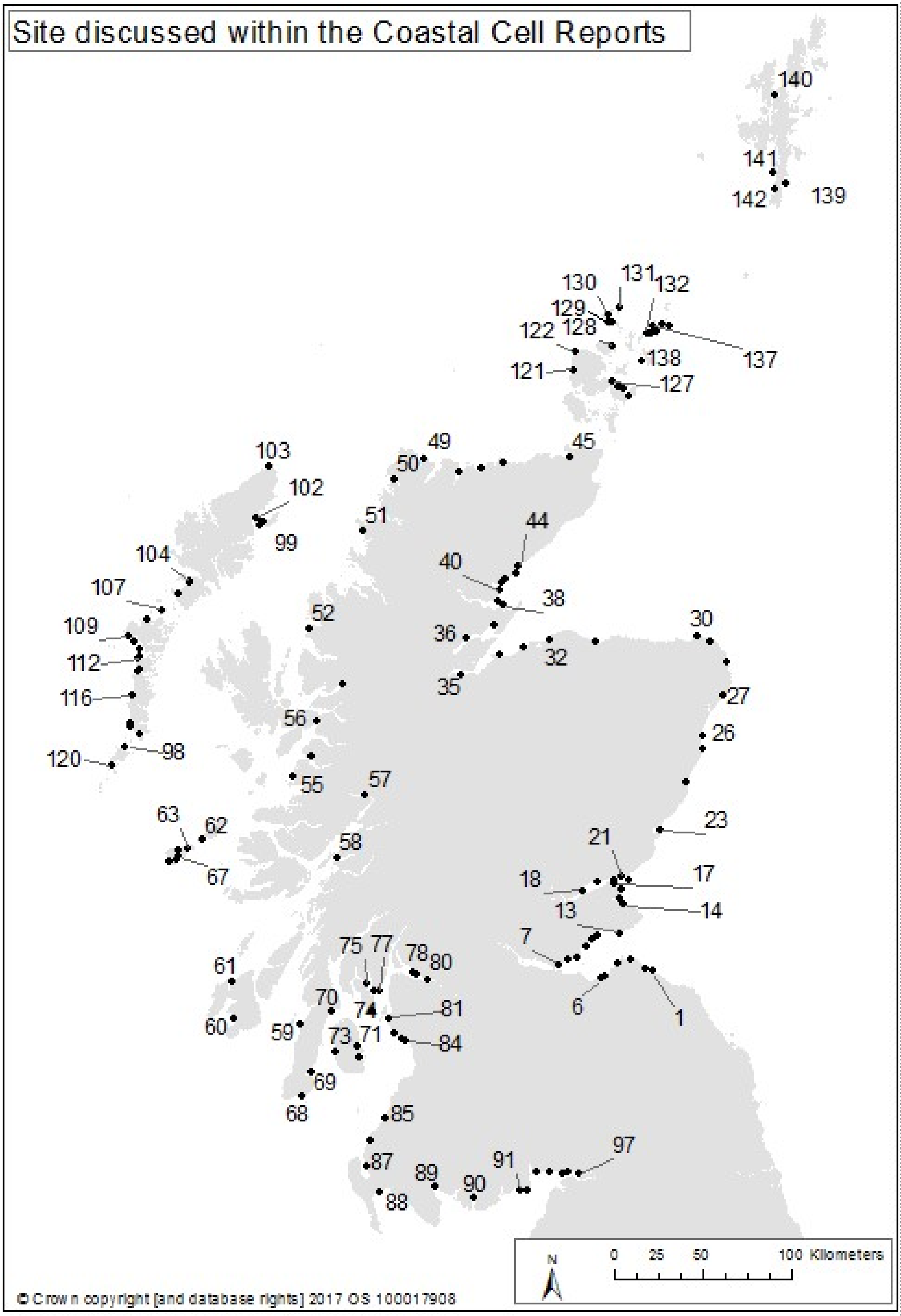

Figure 2.9: Location map of sites discussed within the Cell Reports. See Table 2.4 for more information. The Cell Reports. Sites are ordered by coastal cells which run anti-clockwise around the mainland coast before including islands.

Table 2.4: Sites discussed within the Cell Reports. See Figure 2.9 for map of sites. The Cell Reports. Sites are ordered by coastal cells which run anti-clockwise around the mainland coast before including islands.

#	Name	Coastal Cell	Local Authority
1	Dunbar	1a	East Lothian
2	John Muir Country Park at Dunbar	1a	East Lothian
3	North Berwick	1a	East Lothian
4	Gullane and Aberlady	1b	East Lothian
5	Port Seton	1b	East Lothian
6	Prestonpans	1b	East Lothian
7	Dalgety bay	1c	Fife
8	Aberdour to Burntisland	1d	Fife
9	Kinghorn	1d	Fife
10	Dysart	1d	Fife
11	West and East Wemyss	1d	Fife
12	Buckhaven	1d	Fife
13	Elie and Earlsferry	1d	Fife
14	St Andrews East Sands	2a	Fife
15	St Andrews West Sands	2a	Fife
16	Tentsmuir	2a	Fife
17	Tayport Caravan Site	2a	Fife
18	Carse of Gowrie	2a	Perth & Kinross
19	Dundee Airport	2a	Dundee City
20	Broughty Ferry	2a	Dundee City
21	Monifieth	2a	Angus
22	Barry Links and Buddon Ness	2a	Angus
23	Montrose	2b	Angus
24	Stonehaven	2c	Aberdeenshire
25	Nigg Bay (Aberdeeen)	2c	Aberdeen City
26	Aberdeen Bay	2d	Aberdeen City
27	Cruden Bay	2d	Aberdeenshire
28	St Fergus & Rattray head	2d	Aberdeenshire
29	Fraserburgh Bay	3a	Aberdeenshire
30	Rosehearty	3a	Aberdeenshire
31	Spey Bay	3b	Moray
32	Burghead Bay to Findhorn	3c	Moray
33	Culbin (incl Nairn)	3c	Moray
34	Whiteness Head	3c	Highland
35	Beauly Firth (south)	3d	Highland
36	Cromarty Firth – various including A9 and rail	3e	Highland
37	Nigg Bay	3e	Highland
38	Morrich More / RAF Tain	3f	Highland
39	Dornoch Point and Sands	3f	Highland
40	Coul Links	3f	Highland
41	Golspie Links	3f	Highland
42	Dunrobin castle	3f	Highland
43	Brora	3f	Highland
44	Brora to Helmsdale	3f	Highland
45	Dunnet Sands	4	Highland
46	Strathy Beach	4	Highland
47	Bettyhill and Torrisdale Bay	4	Highland
48	Kyle of Tongue	4	Highland
49	Durness, Balnakeil and Kyle of Sutherland	4	Highland
50	Kinlochbervie	5a	Highland
51	Clachtoll	5a	Highland
52	Opinan	5b	Highland
53	Loch Carron (Attadale)	5b	Highland
54	Inverie (Knoydart)	5b	Highland
55	Arisaig (Back of Keppoch)	5b	Highland
56	Kylerhea (Isle of Skye)	5b	Highland
57	Loch Eil (Corpach)	5c	Highland
58	Isle of Eriska (Appin)	5c	Argyll and Bute
59	Rhunahaorine Point (Kinytre)	5c	Argyll and Bute
60	Machrihanish (Kintyre)	5c	Argyll and Bute
61	Laggan Bay (Islay)	5c	Argyll and Bute
62	Killinallan Point (Loch Gruinart, Islay)	5c	Argyll and Bute
63	Hogh and Crossapol Bays, Loch Breachach (Coll)	5c	Argyll and Bute
64	Traigh Mhor and Salum (Tiree)	5c	Argyll and Bute
65	Balephetrish Bay (Tiree)	5c	Argyll and Bute
66	Traigh Bhi (Tiree)	5c	Argyll and Bute
67	Traigh Shorobaidh (Tiree)	5c	Argyll and Bute
68	Traigh Bhaig (Tiree)	5c	Argyll and Bute
69	Brunerican Bay	6a	Argyll and Bute
70	North Headland at Campbelton Bay	6a	Argyll and Bute
71	Claonaig Bay	6a	Argyll and Bute
72	Brodick Bay (Arran)	6a	North Ayrshire
73	Lamlash (Arran)	6a	North Ayrshire
74	Machrie (Arran)	6a	North Ayrshire
75	Kilchattan Bay (Bute)	6b	Argyll and Bute
76	Bargehouse Point & South Hall shore, Kyles of Bute	6b	Argyll and Bute
77	Toward Point to Toward Quay, Cowal Peninsula	6b	Argyll and Bute
78	Toward	6b	Argyll and Bute
79	East of Ardmore Point	6b	Argyll and Bute
80	Cardross	6b	Argyll and Bute
81	Dumbarton Castle Bay	6b	West Dunbartonshire
82	Hunterston B Nuclear Power Station access road	6b	North Ayrshire
83	Ardrossan	6c	North Ayrshire
84	Saltcoats	6c	North Ayrshire
85	Ardeer	6c	North Ayrshire
86	A77 to the south of Girvan	6c	South Ayrshire
87	Ballantrae	6d	South Ayrshire
88	Cairnryan Old Pier	6d	Dumfries & Galloway
89	Luce Sands	7	Dumfries & Galloway
90	Wigton Sands	7	Dumfries & Galloway
91	Kirkcubright	7	Dumfries & Galloway
92	Mersehead Sands and Southerness	7	Dumfries & Galloway
93	Southerness	7	Dumfries & Galloway
94	Caerlaverock	7	Dumfries & Galloway
95	Priestside Bank	7	Dumfries & Galloway
96	Newbie	7	Dumfries & Galloway
97	East of the Annan mouth to Seafield	7	Dumfries & Galloway
98	Torduff Point (HM Factory, Gretna) to Redkirk Point (Gretna)	7	Dumfries & Galloway
99	Traigh Mhor Eoligarry, Barra	8a	Na h-Eileanan an Iar
100	Holm (SW of Braigh)	8b	Na h-Eileanan an Iar
101	The Braigh	8b	Na h-Eileanan an Iar
102	Stornoway Airport	8c	Na h-Eileanan an Iar
103	Sands of Tong	8c	Na h-Eileanan an Iar
104	Eoropie	9a	Na h-Eileanan an Iar
105	Luskentyre and Taransay	9c	Na h-Eileanan an Iar
106	Seilebost	9c	Na h-Eileanan an Iar
107	Northton Bay SSSI (Traigh Scarista)	9c	Na h-Eileanan an Iar
108	Berneray	9d	Na h-Eileanan an Iar
109	Udal and Solas Peninsula	9d	Na h-Eileanan an Iar
110	Paible	9e	Na h-Eileanan an Iar
111	Kirkibost	9e	Na h-Eileanan an Iar
112	Baleshare	9e	Na h-Eileanan an Iar
113	Benbecula Airport and Balivanich	9e	Na h-Eileanan an Iar
114	Balivanich Primary school and the B892 through Balivanich	9e	Na h-Eileanan an Iar
115	Borve to Liniclate	9e	Na h-Eileanan an Iar
116	Gualan Island	9e	Na h-Eileanan an Iar
117	Stoneybridge	9e	Na h-Eileanan an Iar
118	Kilpheder	9e	Na h-Eileanan an Iar
119	North Boisdale	9e	Na h-Eileanan an Iar
120	Eriskay	9e	Na h-Eileanan an Iar
121	Vatersay Tombolo	9f	Na h-Eileanan an Iar
122	Bay of Skaill	10a	Orkney Islands
123	Brough of Birsay & Birsay Bay	10a	Orkney Islands
124	Tankerness	10a	Orkney Islands
125	Dingyshowe Bay (Deerness)	10a	Orkney Islands
126	Churchill Barriers 1-4		
127	Long Ayre on Inganess Bay	10c	Orkney Islands
128	Sands of Essonquoy & Sand of Wideford (Kirkwall Airport)	10c	Orkney Islands
129	Bay of Weyland	10c	Orkney Islands
130	Kirkwall Bay	10c	Orkney Islands
131	Mae Sand, Rousay	10d	Orkney Islands
132	Bay of Tuquoy, Westray	10d	Orkney Islands
133	Links of Notland, Westray	10d	Orkney Islands
134	Papa Westray	10d	Orkney Islands
135	Bay of London and Sand of Doomy/Sands of M	10d	Orkney Islands
136	Backaskail Bay, Sanday	10d	Orkney Islands
137	Start Point, Sanday	10d	Orkney Islands
138	Bay of Sandquoy and Lopness, Sanday	10d	Orkney Islands
139	Cata Sands, Sanday	10d	Orkney Islands
140	Little Sea, Sanday	10d	Orkney Islands
141	Otterswick, Sanday	10d	Orkney Islands
142	Sands of Rothiesholm, Stronsay	10d	Orkney Islands
143	Sandwick	11a	Shetland Islands
144	Sullom Voe	11a	Shetland Islands
145	Banna Minn	11b	Shetland Islands
146	St. Ninian's Isle	11b	Shetland Islands
147	Sumburgh West Voe	11b	Shetland Islands

2.3 Implications of erosion

The implications of continued erosion are considered via two sets of analyses within the NCCA: the Whole Coast Assessment (NCCA Report 9) and Vulnerability Assessment (NCCA Report 10) and only a summary is presented here. The Vulnerability Assessment is precautionary in its approach, in that it has identified assets adjacent to areas which have experienced significant erosion, greater than 10m, and which cannot be due to methodological error. As a result, this indicative assessment only considers assets within the 442km of shoreline where the 10m threshold criteria is met. This excludes areas where erosion is less than 10m (which could be attributable to methodological error) and new areas of erosion. By using both analyses together, those assets that will be at risk if recent change continue unchanged into the future can be identified, along with assets nearby that may also be affected.

2.3.1 Whole Coast Assessment

To provide an indication of the proximity of assets to Mean High Water Springs, built and natural assets were appraised against two areas (polygons) extending 10m and 50m landwards of Mean High Water Springs. Whilst 50m may seem a reasonable distance from the shore, 180km of shoreline had undergone more than 30m of erosion inland since the 1970s (5% of the soft coast). Assets falling within these distances were then aggregated within coastal cells, Local Authority Areas and areas with Shoreline Management Plans. A full description of the methods employed is available within the Methodology Report (NCCA Report 4). The tables and figures separate the data based on coastal type (hard & mixed, soft and artificial) and a comment also notes what proportion of the assets lie on land identified to be inherently erodible irrespective of defences (based on Coastal Erosion Susceptibility Model, Fitton et al. 2015).

Table 2.5 summarises the national figures and Figure 2.10 summarises the number and lengths of assets per coastal cell. Whilst many of the asset types are self-explanatory, Community Services include Fire Station, School etc., Utilities include electrify substations, Cultural Heritage and Environment incorporate designated sites for our built and natural heritage interests. Table 2.5 shows that a considerable number of assets occur close to the coast, the large proportion of which occur on soft, artificial and erodible shores.

The implications of Table 2.5 are that between 25% and 50% of all coastal assets are located on only 20% of the coast.

Table 2.5: Assets within close proximity to MHWS. See the Whole Coast Assessment and Methodology Reports for further detail.

		Within 10m of MHWs					Within 50m of MHWS				
			Coastal Type					Coastal Type			
Asset / Receptor	**Unit**	**All**	**Hard & Mixed**	**Soft**	**Artificial**	**Erodable (UPSM40+)**	**All**	**Hard & Mixed**	**Soft**	**Artificial**	**Erodable (UPSM40+)**
Community Services	#	1	1	0	0	0	78	48	20	10	45
Non Residential Property	#	463	197	103	163	245	9,045	4,393	2,309	2,343	5,101
Residential Prop	#	458	107	109	242	332	24,449	9,966	7,194	7,289	15,276
Septic Water Tanks	#	367	219	139	9	181	1,656	954	677	25	769
Utilities	#	25	10	7	8	14	312	137	80	95	184
Rail	km	15	2	9	3	9	104	27	58	18	61
Roads	km	156	87	53	16	68	1,336	733	497	107	590
Clean Water Network	km	87	50	22	16	41	931	507	304	120	452
Cultural Heritage	ha	135	63	55	17	74	1,029	471	438	120	529
Environment	ha	4,204	2,575	1,586	43	1,790	23,430	14,873	8,424	133	8,615
Runway	ha	0	0	0	0	0	3	2	0	1	2

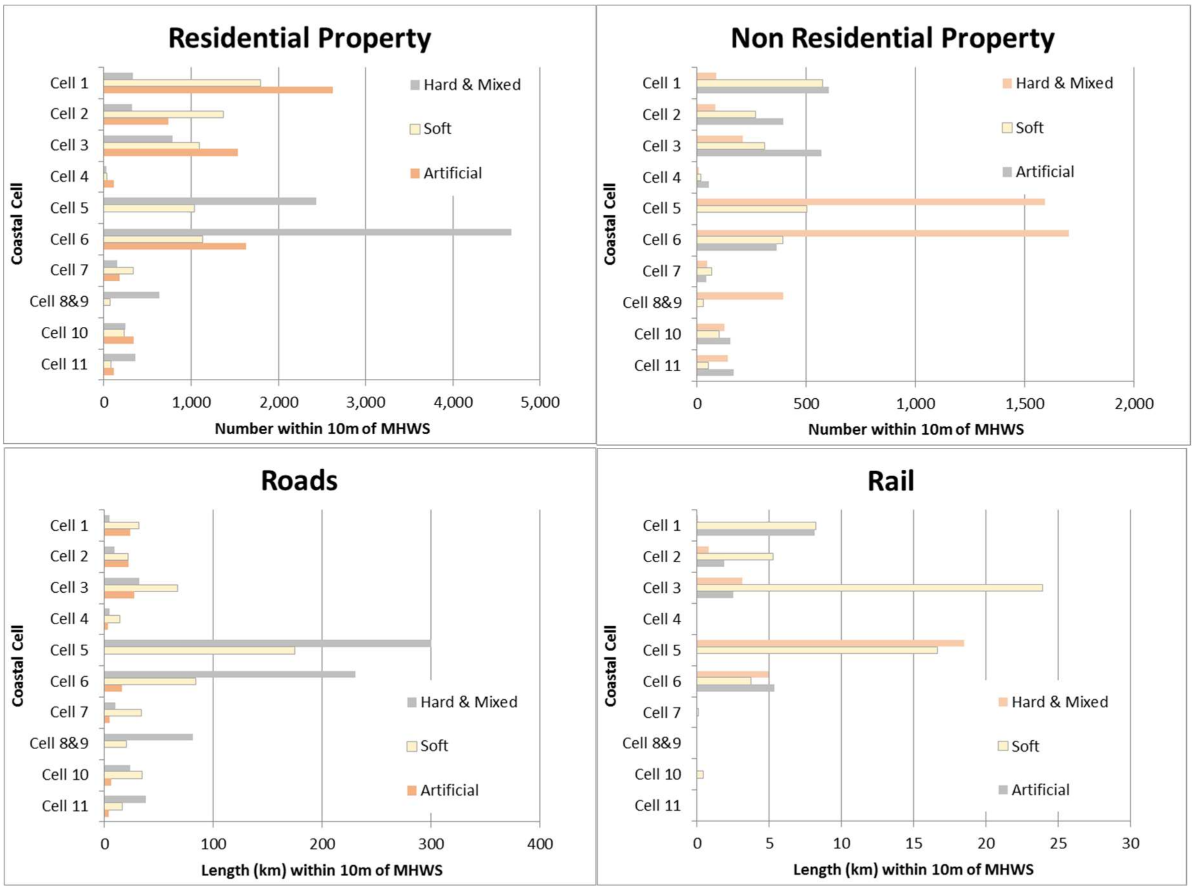

Figure 2.10 A selection of assets within 50m of MHWS grouped by coastal cell. A complete list of assets is available within the Whole Coast Assessment Report. Data for assets within 10m is also available.

Given the figures above, Table 2.6 identifies the proportion of assets that lie in Local Authorities that either have Shoreline Management Plans (SMPs) or have no SMP.

Table 2.6: Number of assets in close proximity to MHWS and included within SMPs

Asset / Receptor	Unit	10m			50m		
		All	Covered by an SMP		All	Covered by an SMP	
			#	%		#	%
Community Services	#	1	1	100	78	14	18
Non Residential Property	#	463	123	27	9,045	1511	17
Residential Property	#	458	258	56	24,449	6379	26
Septic Water Tanks	#	367	14	4	1,656	70	4
Utilities	#	25	6	24	312	61	20
Rail	Length (km)	15	3.7	26	104	20	19
Roads	Length (km)	156	11.7	7	1336	140	10
Clean Water Network	Length (km)	87	6.3	7	931	111	12
Cultural Heritage	ha	-	-	-	3	-	-
Environment	ha	135	29	22	1029	263	26
Runways	ha	4,204	218	5	23430	1003	4

2.3.2 Vulnerability Assessment

The figures above provide an indication of the total number of assets close to the shoreline, and the type of shoreline they are on (Hard & Mixed, Soft, Artificial and potentially erodible). Contrasting this, the vulnerability assessment considers a subset of this data identifying the number and type of assets which are located on soft undefended shores which have experienced significant erosion since the 1970s. Thus, the following data can be considered as the minimum number of assets at risk, assuming recent rates of erosion continue, but exclude adjacent areas which may experience erosion associated with future sea level rise or in response to the construction of adjacent coastal defences (Table 2.7).

If past erosion rates continue, by 2050 at least 50 residential and non-residential buildings, 1.6 km of railway, 5.2 km of road and 2.4 km of clean water network as well as significant areas of airport runway, cultural and natural heritage sites are expected to be affected by coastal erosion. These figures are based on the 'erosion' area (as calculated from the anticipated position of MHWS in 2050 under recent rates) and an 'erosion influence' area which is a 10m landward buffer. Both the erosion and erosion Influence should be considered together to summarise assets at risk, assuming rates continue. A further 50m buffer is also shown, to give an impression of adjacent assets from the anticipated 2050 shoreline (erosion vicinity). Given the precision of the data and the stochastic/intermittent nature of coastal change, these figures are indicative. The 2050 figures also assume that the future erosion continues at the modern rate experienced since the 1970s. Given rising sea levels, falling sediment supplies and the expansion of coastal defences future rates may well be faster than past rates. To reflect the increased risk, a 2050+ scenario, based on a near doubling of recent rates, is also presented below (Table 2.7 and Table 2.8).

Table 2.7: Vulnerability Assessment of assets within areas of anticipated erosion by 2050, if recent rates of erosion continue. The 2050+ column gives an estimate of asset numbers should erosion rates double beyond 2050.

Asset/Receptor	Units	Modern to 2050				2050+			
		Erosion	Erosion Influence	Erosion Vicinity	Total	Erosion	Erosion Influence	Erosion Vicinity	Total
Community Services	#	0	0	1	1	0	0	1	1
Non Residential Property	#	12	7	66	85	24	14	88	126
Residential Property	#	17	16	382	415	72	40	537	649
Septic Water Tanks	#	2	0	17	19	3	4	15	22
Utilities	#	1	0	3	4	1	0	6	7
Rail	Length (km)	1.0	0.6	2.5	4.0	1.6	0.4	3.0	4.9
Roads	Length (km)	2.8	2.5	15.3	20.5	7.5	2.4	17.8	27.7
Clean Water Network	Length (km)	0.8	1.6	11.5	13.9	4.5	1.8	14.1	20.4
Cultural Heritage	ha	19.8	6.0	41.1	66.9	20.9	6.3	40.5	67.7
Environment	ha	355.7	91.1	436.6	883.4	672.6	87.1	409.8	1,169.5
Runways	ha	0.4	0.4	2.3	3.2	3.2	0.6	2.8	6.6

Whilst Table 2.7 details the length of assets at risk, for linear assets it is helpful to consider the number of locations which are expected to be affected. The recent example of the Dawlish railway in 2014 shows that although only 80m of track was damaged the remaining section of the network was impacted and as well as regional businesses affected for months.

Table 2.8: Vulnerability assessment results showing the number of locations expected to be affected by coastal erosion, if recent rates continue to 2050. Note 2050+ figures are based on a near doubling of rates of erosion, to give a sense of additional risk if future erosion rates increase.

	Modern to 2050		Modern to 2050+	
Cell	Roads	Rail	Roads	Rail
1	17	1	26	1
2	10	1	13	1
3	11	3	18	3
4	4	0	4	0
5	21	5	28	5
6	24	5	26	5
7	12	3	14	8
8&9	7	0	10	0
10	8	0	8	0
11	2	0	4	0
total	116	18	151	23

3.0 Limitations

A full account of the NCCA data limitations is contained within the Methodology report (NCCA Report 5). However, it is useful here to flag the key constraints with the source data used within the NCCA.

3.1 Accuracy of the aerial photography

The NCCA used national aerial photography under the One Scotland Mapping Agreement, provided by GetMapping, where the imagery is stated as less than five years old. Any coastal change within this time frame is thus missing. Also, vertical aerial photography may differ from the view from the ground: a grassy bank covering vertical coastal defences may be invisible in aerial photography. In mitigation, NCCA used expert knowledge of the coast, supplemented where possible by Google street view (and similar alternatives).

3.2 Accuracy of historical mapping

At 1:10,000, the MHWS line width depicted in the 1890s and 1970s mapping represents 10 m on the ground, so any changes detected by the NCCA are more than 10 m to be confident of real change (Figure 3.1). A second criteria was added where the change between any two dates exceeded 0.5 m/yr allowed capture of recent changes that had not had time to move more than ±10 m. Extensive areas of the modern tide line (based on OS Mastermap or LiDAR updates) have accuracies better than 10 m (often less than 2.5 m).

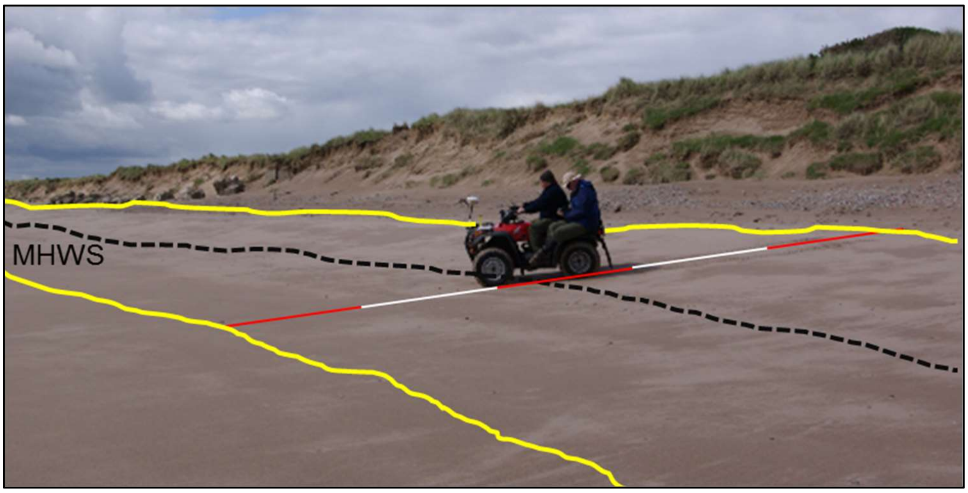

Figure 3.1: Annotated picture of surveyors using quad bike. Whilst MHWS is perceived to be a narrow line along the upper beach (black dotted line) the 1890s and 1970s line is 10 m wide (distance between two yellow lines).

Comparisons between LiDAR-derived digital terrain models (DTMs) and aerial photography-derived DTMs may introduce some differences which are not 'real'. LiDAR uses individual ground surface points whilst aerial photography derived surfaces uses the average height within each pixel. This difference is compounded where upstanding vegetation occurs and LiDAR-derived DTMs become more reliable than photography-derived DTMs.

In some cases, the publication date of the map is not the same as the time frame of survey (which may itself span several years). This problem is compounded by the uncertainty the Ordnance Survey (OS) have over the reliability of their data 'update' field where this attribute has conflated survey revisions and other updates, rending these problematic. Such uncertainty about survey date and published date make calculation of absolute rates of movement of MHWS uncertain and require averages to be employed.

3.3 Accuracy of OS MasterMap MHWS lines

Comparisons of OS MasterMap MHWS with recent aerial photography MHWS highlighted discrepancies, particularly along the soft coast, where updated mapping had not occurred. NCCA identified that 463 km or 17 % of the soft coast areas had not been updated. Whilst it is inevitable that the published data on dynamic shores will become out of date relatively

3.4 Positional accuracy in areas of very low gradient

The topography of areas of low gradient such estuaries or saltmarshes mean that change may occur on lower sections of foreshore well away from MHWS and may be undetected by the NCCA methodology. This is problematic where a large fluctuation in the saltmarsh edge position has occurred or where the saltmarsh edge has been unreliably mapped. Saltmarsh edges are difficult to identify except where the edge is marked by a small eroding bluff. This is problematic within the OS 1970s aerial photogrammetry mapping of MHWS positions without adequate checking of their altitude and ground position.

3.5 MHWS as a proxy of coastal position

The NCCA used MHWS as a proxy to describe coastal position and used changes in its position to infer changes within the wider beach. As MHWS is the legal boundary of the shoreline, such an assumption is reasonable as in most cases the lower, mid and upper beach retreat or advance together. Whilst there are likely to be variations this is the typical or normal way coastal erosion occurs. The coastal retreat at Montrose is shown in Figure 3.2 with the 1890s, 1970s and 2011 shoreline clearly retreating landwards, along with the edge of the vegetation. A few locations are known where beaches are operating in more complex ways and MHWS may not be a good proxy for coastal change. This aspect is considered in greater detail in the Methodology Report, which contrasts two dimensional techniques (identifying changes in area) with three dimensional techniques (identifying volumetric changes). Further to these descriptions, visualisation of three dimensional changes within the 3D viewers can be seen at www.dynamiccoast.com/outputs.

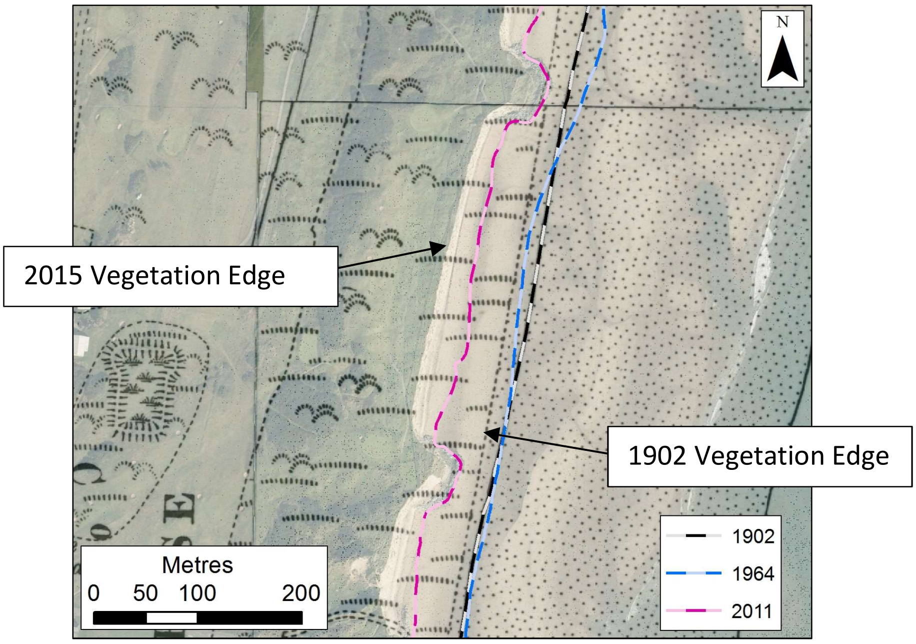

Figure 3.2: Coastal erosion at Montrose, shown by the landward movement of MHWS, the dashed lines, and the vegetation edge. Historic base map is from 1902, with aerial photography from 2015.

3.6 Erosion trends moving along the shore

The NCCA has identified the retreat or advance of MHWS measured perpendicular to the shoreline. However, erosion can also advance along (parallel) the shoreline. Common at the end of coastal defences, or where strong alongshore movement of sediment occurs, caution is needed in interpretation of future erosional extent. Such examples where an erosion trend in one part of the coast is expected to increasingly affect the coast nearby, such as within Montrose Bay, Aberdeen Bay, Spey Bay, Burghead Bay, and at Nairn and Whiteness Head.

3.7 Assessment of future climate changes

The NCCA incorporated past climate change within its analysis as reflected in observed historical and recent changes, including direct human influences (construction of sea walls, extraction of sediment etc.) as well as past anthropogenic climate change through increases in sea level. It does not attempt to incorporate future climate change since much of the coastal response will be dependent upon the human response to any real or perceived impact. Such a 'simple' approach avoids some of the risks of legal challenge based on the use of climate scenarios (that may themselves be inaccurate) and the coastal response. However, it means the NCCA will underestimate future coastal changes driven by accelerations in climate change. UK national guidance for climate change is currently provided by UKCP09 but upward revisions of future climate change projections (e.g. changes in relative sea level) are expected in UKCP18. By 2080, an uplift of 20% to 30% for future Relative Sea Level Rise over current estimates is thought to be appropriate (MetOffice, 2017), and between 24% to 56% increase for river flood peak flows: the use of both predictions is now being encouraged by SEPA. As a result, the NCCA is an initial assessment of historical and recent coastal changes and any anticipated changes to sediment supply, sea level and coastal flood frequency will cause the NCCA assessments to be underestimates of the actual future change.

4.0 Factors Influencing Coastal Change

In addition to responding to short term dynamism, coastal change is also driven by a range of factors effect operating over longer time periods. The coast has rarely been stable. In the aftermath of the last glacial period Scottish sea levels rose rapidly from -120m to within a few tens of metres of present between 18,000 and 7,000 years before present (Clayton, 2003). These changes drove dramatic movements in coastal position that were compounded by coastal gradient and the rates of land uplift or subsidence. Since about 7,000 years ago, sea level has undergone a much slower rate of rise. However, the effect on shoreline position is also dictated by the elevation and gradient of the land, sediment supply and the relative interaction of land level and sea level. These contextual factors are briefly introduced below.

4.1 Land levels

Land elevation has an important impact on the current and long-term issue of coastal erosion and coastal flooding. Many coasts have hinterland areas that lie below the altitude of MHWS and may be seasonally or permanently flooded as lochs, ponds or lagoons. However, these and other such low-lying areas may remain dry for a large proportion of the year and are particularly vulnerable to rising sea levels and erosion. They are of added concern if they support agricultural production and infrastructure. There are many areas in Scotland where land levels reduce inland from the coast (areas of negative gradient) and where coastal erosion may lead to barrier breaching and overwash (Figure 4.1). Such areas are widely distributed and are highly vulnerable to rapid change in coastal position due to coastal erosion-enhanced coastal flooding (Figure 4.2).

Figure 4.1: Aerial image of breaching, overwash (A) resulting in flooding of road (B) enhanced by low-lying and landward sloping interior (negative gradient). SW of Cleat, Little Sea, Sanday, Orkney.

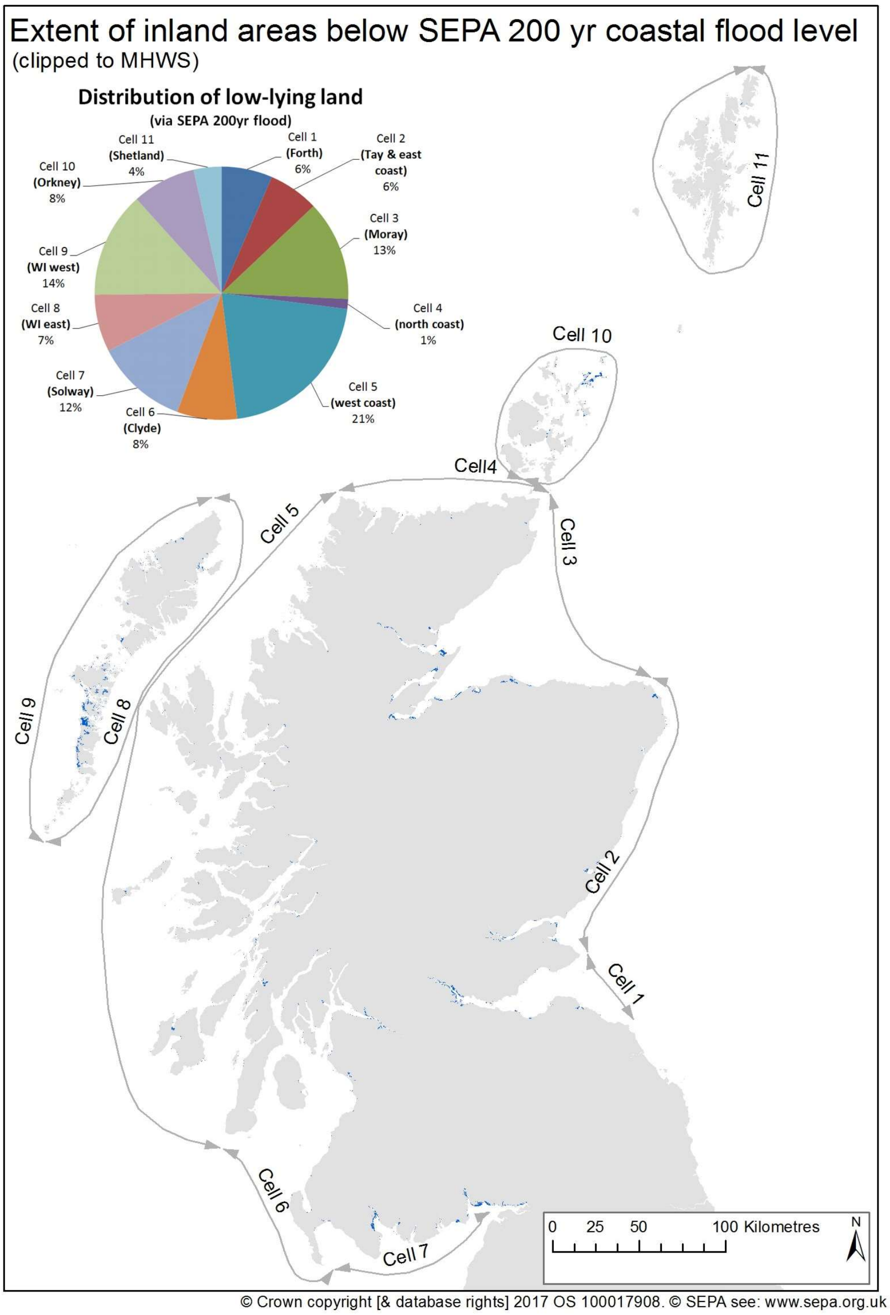

Figure 4.2: Altitude map of 1:200 year coastal flood leve, with pie chart showing the breakdown per coastal cell (© SEPA, see www.sepa.org.uk: (Source: NCCA).

4.2 Sediment supply

Sediment supply is the transport of sediment around the coast principally by wave energy but also by tidal flows and wind. If there is an influx (net gain) of sediments within a section of coast then MHWS generally will move seawards, where there is a deficit (net loss) of sediment then MHWS will generally move landwards. Often there is a local influx of sediment at the mouths of rivers, forming deltas, which will remain locally intact if wave processes are modest (e.g. west coast sea lochs) or may be distributed along the rest of the coastal cell where wave or tidal currents are more prevalent (e.g. east coast beaches which stretch tens of kilometres). There is mounting evidence that the supply of sediment to beaches both from offshore and river sources is much reduced from the higher levels of the past and this has clear implications for coastal erosion. For example, when negatively impacted by storm events or sea level rise, beaches may not be as readily recharged with new sediment as they were in the past (Hansom, 2001; May and Hansom 2003).

4.3 Rockhead elevation

The presence and elevation of rockhead (i.e. hard resistant bedrock) greatly influences the large-scale geometry of the land and coast. For example, the landscape character of the Western Highlands can be attributed to the resilient lithology and repeated glacial erosion, which is contrasted by the softer lithologies and deposition of glacially derived sediments within central belt of Scotland. Whilst this differing geological inheritance seems obvious, it influences the erodability of the coastal zone. At a local scale the altitude of rockhead and the depth of (erodible) superficial deposits greatly influence the erodability of coast. Areas where the rockhead elevation is low and there is superficial (erodible) deposits above rockhead the land is potentially susceptible to erosion (Figure 4.3). Whereas areas with high rockhead elevations (e.g. hard rock cliffs), the land is more resilient to erosion. The Methodology Report outlines how this factor has been incorporated within the assessment.

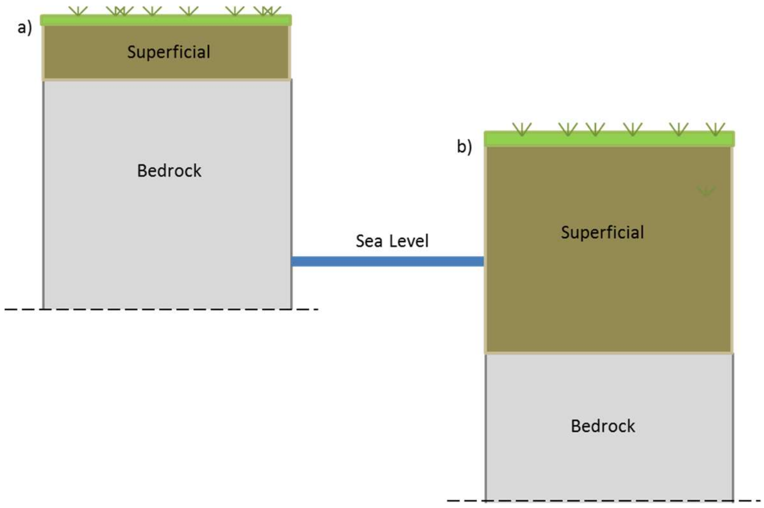

Figure 4.3: Hypothetical scenarios of the influence of rockhead on coastal change. In scenario a) resistant bedrock is at sea level with minimal erosion expected. In scenario b), the rockhead elevation is below sea level and capped by soft superficial deposits (e.g. fluvial or glacial deposits) that are more easily eroded.

4.4 Sea level change

Key to coastal response is the relative interaction of global sea level and its local effect on land level changes, the combined effect is known as relative sea level (RSL) change. Across the 20th century[1] global average sea levels rose by around 10-15 cm but since 2000[2] they have risen by around 4.5 cm. The average rate of 20th century sea level rise around the British Isles is 1.4 mm/yr [3] but with higher rates more recently. Sea levels measured from tidal gauges can provide an integrated view of relative sea level change and although Scottish tidal records are highly variable in space and time, they show an average of 3 mm/yr relative sea level rise over the last 20 years (Table 4.1)[4]. Land-uplift in Scotland

[1] Hay et al., (2015) rate of 1.0-1.2mm/yr replaces the 2mm/yr rate previously used for 20th century Global MSLR.
[2] Hay et al, (2015) – i.e. 15yrs @ 3mm/yr = 4.5cm
[3] Gehrels, (2010)
[4] Updated tidal analysis from Rennie and Hansom (2011).

continues[5] with much of the coast rising at rates close to 1 mm/yr (with a maximum of 1.7 mm/yr). This is insufficient to negate the average rate of 3 mm/yr noted by tide gauges and as such, relative sea level rise (RSLR) is now recognised to occur on all Scottish coasts. It is expected to accelerate in coming decades to result in between 7 and 93 cm of RLSR by 2100, with an average central estimate of 43 cm by 2100 (UKCP09, High Emissions Scenario [6]).

Table 4.1. Scottish tide gauge trends (Source: updated from Rennie and Hansom (2011).

	Long-Term mm/yr	**1992-2007** mm/yr	**1992-2013** mm/yr
Kinlochbervie	-	3.57	2.92
Stornoway	2.20 ±0.90	5.70	4.29
Islay	-	6.23	8.39
Wick	1.55 ±0.43	5.54	3.06
Inverness	-	2.66	-
Portpatrick	1.95 ±0.44	4.80	4.35
Lerwick	-0.68 ±0.34	3.18	2.77
Aberdeen	0.87 ±0.1	6.03	1.76
Leith	-	4.04	2.54

Estimations of RSLR from tide gauges can be influenced by other factors that may blur any climate change-driven sea level rise including variations in the lunar cycle and atmospheric effects (storm surges due to low air pressure). For example, the Aberdeen gauge shows some of these effects (Figure 4.4) but despite periodic fluctuations, there remains an overall upward trend of RSLR at Aberdeen between 1950 and 2009.

Whilst this study does not formally consider the future changes associated with climate change, the choice of Emissions Scenario is important. Whilst some estimates use a Medium Emission Scenario (MES), the recent global emissions levels align with a High Emission Scenario (HES), leading Scottish Natural Heritage (SNH) and Scottish Environment Protection Agency (SEPA) (amongst others) to adopt the HES rates.

[5] 1.7mm/yr max with much of the coast closer to 1mm/yr from Bradley et al (2011)

[6] UKCP09 climate projections for Scotland in 2100.

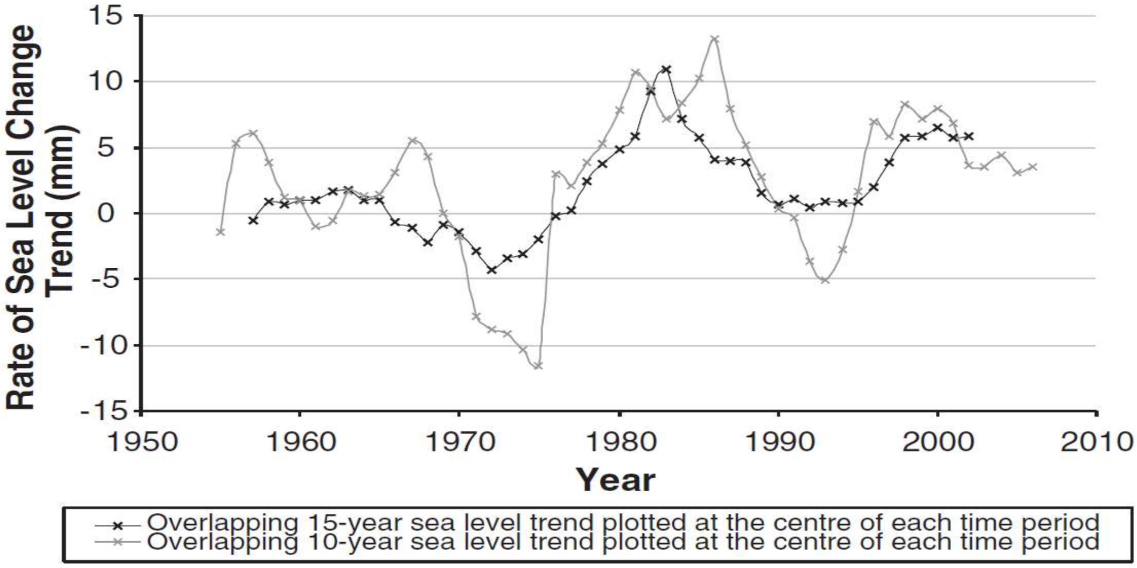

Figure 4.4: Observed changes in the rate of 10 and 15 year sea level trends between 1950 and 2009 from Aberdeen (Dawson et al 2012).

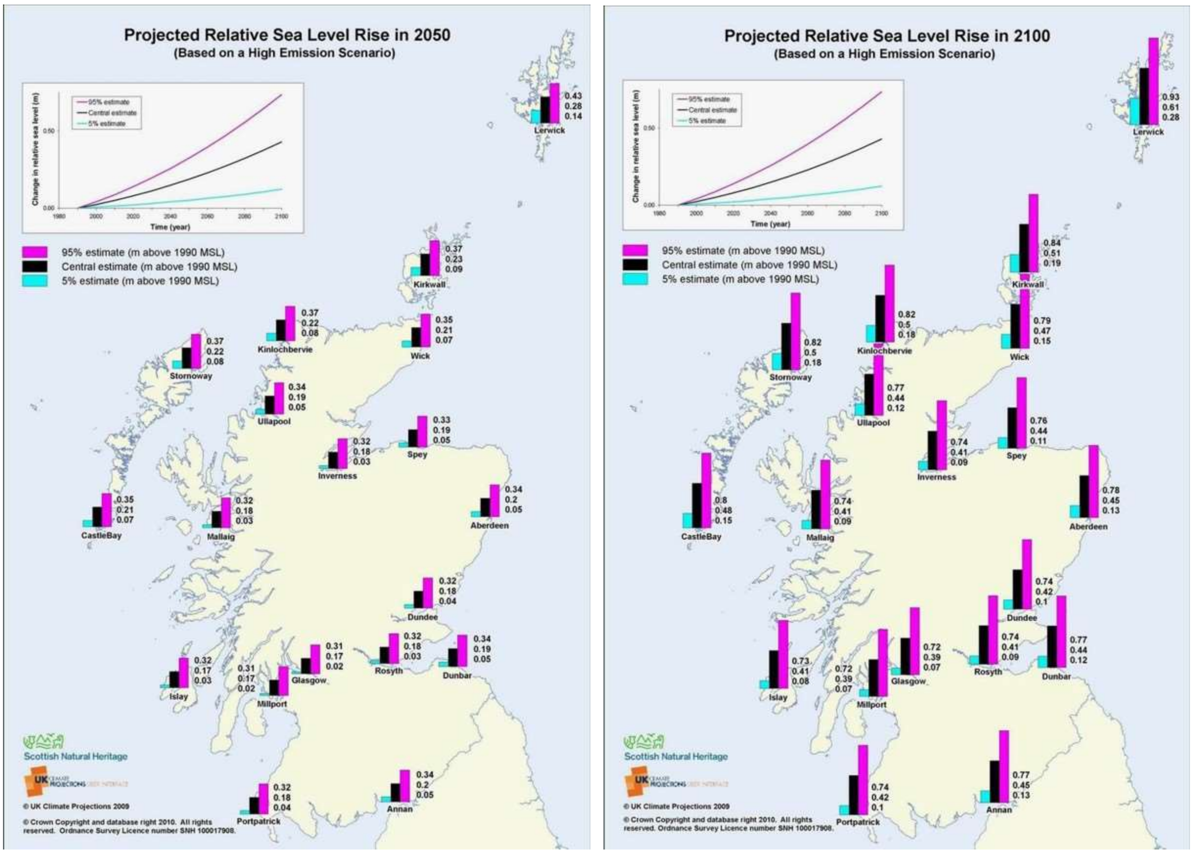

Figure 4.5: Projected relative sea level rise for Scottish ports in 2050 and 2100 (based on UKCP09).

Using the UKCP09 HES, Figure 4.5 shows the expected rates of relative sea level rise at Scottish ports by 2050 and 2100 with the colour bars showing the 5%, central and 95% estimates in metres above the 1990 levels. These projections are being revised as part of UKCP18, which incorporates the changing climate since 2009 and improvements in scientific understanding. Prior to the publication of UKCP18, DEFRA have advised an uplift of 20% to 30% by 2080 for future relative sea level rise estimates (MetOffice, 2017).

4.5 Sea level change and increased coastal flood risk

The influence of rising relative sea level on coastal flood frequency is well understood; where an additional sea level increment allows both more frequent flooding as well as events of less magnitude to eventually reach the same levels as less frequent larger flood events (Dixon & Tawn, 1997). The UK CCRA (2012) has considered the implications for flood frequency (Figure 4.6) for various Scottish locations. For example, under a medium emissions scenario by 2090, Leith may have an extra 0.3 m of sea level rise which reduces a 1:100 yr event into a 1:8 yr event. Three of Scotland's longest running tide gauges were investigated to identify changes in flood frequency (Ball et al 2008). These studies found that although there was an increasing frequency of flood events within the tidal record, these events were attributed mainly to underlying changes in mean sea level, rather than driven by meteorological effects and suggests that increased coastal flood risk is driven largely by sea level rise. This indicates that the areas identified in the NCCA as erosional are likely to be those areas that will be further impacted by sea level rise.

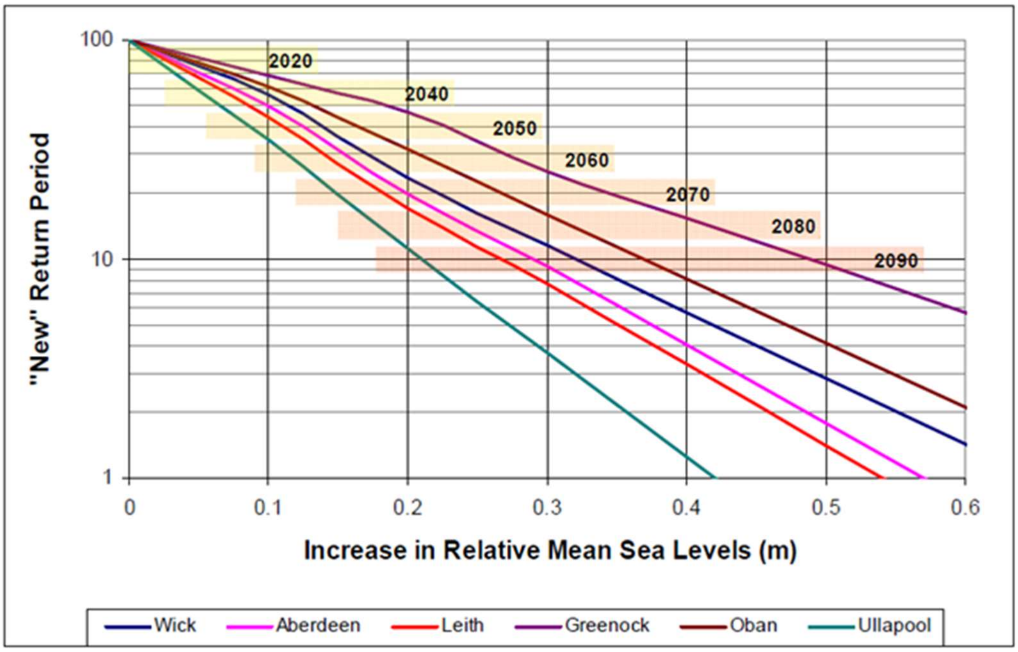

Figure 4.6: Reduction in flood return period given increases in mean sea level (Defra (2012) UKCCRA for Scotland – Technical Report. Fig3.5 p43, based on the central estimate of the Medium Emissions Scenario, locations are approximate)

Modifying the analysis within Figure 4.6, the Met Office (2017) have advised that the UKCP18 projected sea level rise under a high emissions scenario is likely to be 20-30% larger than UKCP09 figures. This will further shorten the return period and enhance the potential for coastal erosion. Over and above the effect of sea level rise on increased flood risk, what remains relatively underestimated at a national scale is the effect that coastal erosion might have on enhancing the impact of flooding due to the removal of features that currently provide a flood protection function. The NCCA seeks to identify the areas that might be affected in this regard.

4.6 Human Intervention

Whilst humans have influenced the landscape for millennia, evidence of our influence on the coast stretches back over the last few centuries. Subsequently land claim and coastal protection has become common-place on many of our coasts. Whilst much of the protective defences are deemed necessary they have, protected the land {at the expense of} with consequences for the adjacent coast. Assessments of the English and Welsh coast have identified that whilst hard coastal defences have curtailed the landward erosion of high water mark, low water has continued to erode landwards, steepening the intertidal gradient and worsening flood risk as a result (Taylor et al., 2004). The sealing up of coastal sediments behind defences, along with the reduction in river-born sediment supply (due to river defences and other land use improvements within the catchment) has contributed to a reduction in coastal sediment supply (Komar, 2011). Such effects are occurring at the same time as sea levels are rising, further reducing the ability of the soft shoreline to experience and repair following storms.

5.0 Discussion

This section of the report poses a series of questions and discusses the evidence that emerges from the NCCA.

5.1 Is the extent of erosion and accretion changing through time?

Since the 1970s 12% of Scotland's soft coast can be classified as erosional, 11% accretional and 77% stable or showing insignificant change (see Figure 2.4). Comparing these recent national figures with the historical period (normalised for differing time periods), then there has been a 39% increase in the extent of soft coast experiencing erosion and a 22% fall in the extent of soft coast experiencing accretion.

However, these national data obscure changes in the balance of erosion and accretion occurring within different cells. There are very clear differences between the performance of the soft coast on a cell by cell basis since some cells are dominated by hard rocky coast offering shelter to their soft sections (north and west coasts and islands) and others by extensive lengths of potentially erodible soft coast with few rock headlands to provide shelter (mainland east coast and Solway Firth). Greater amounts of erosional change occur within the open and mobile soft coasts of the east, compared with the rock-enclosed coastal cells of the west and north which show greater stability within their soft coast sections.

There are also increases in the amount of accretion, particularly within Cells 1 & 2 (Firth of Forth to Fraserburgh) but these are small when compared to the increases in both extent and rates of erosion in these cells. Accretion is much more modest and varied in direction in the other cells.

The changes identified in the national results of falling accretion extent, increasing extent of erosion and faster rates of change are consistent with the anticipated coastal impact of climate change. The differing performance of individual coastal cells, also agrees with expectations that the more resilient sections of coast lie in the west and north whereas the softer east coast is more exposed and susceptible to climate change impact.

The projected Future Coast 2050 is based on a continuation of recent rates and informs the indicative vulnerability assessment. However, if the past 39% increase in erosion extent and 22% reduction in accretion is viewed as a trend that can be extrapolated forward to 2050, then an estimated 16% of our soft coast might be anticipated to be affected by coastal erosion (608 km) and 9% might be accretional (342 km). Whilst the potential causes of this increase are discussed above (Section 4.0), the influence of rising sea levels in the coming decades, along with storm impacts and associated increased frequency of flood events means that past changes in extents may underestimate future erosion. However, the past increases in extent also sit alongside observed increases in the rates of erosion (and to a lesser extent, accretion) and these may also increase into the future.

5.2 Is erosion occurring preferentially on the outer coast with accretion within the inner coast and firths?

Scotland's shoreline has been adjusting to changes in sea level, wave energy and sediment supply for millennia. This results in a mixed picture where those sections of the outer coast that are exposed to wave activity are highly dynamic and have the propensity for changes in sediment supply to profoundly affect coastal stability. Since sediment supplies to the outer coast are generally accepted to be much reduced from the higher levels experienced a few thousand years ago and since these outer coasts constantly lose sediments via longshore drift to infill inlets and embayments then erosion has progressively become the dominant trend on the outer coast. On the other hand, inlets, embayments and firths are sediment sinks, whereby soft coastal sediments derived from erosion of the outer coast are joined by sediments freshly delivered to the coast by rivers to produce a bias toward accretion. Within some of our inner firths, areas of land claim have been constructed well seaward of the natural alignment of the coast and so have required the construction of enclosing coastal defences which themselves since become the focus of erosion. In recognition of the interconnectedness of the coast, the historical and recent changes observed by NCCA align well with the cell and sub-cell patterns identified by Ramsey and Brampton (2000).

Set against this backdrop, the influence of relative sea level rise is overprinted onto a canvas of variable outer coast sediment deficits and inner coast sediment gain. Recent rises in sea level as measured by Scottish tide gauges suggest erosion to both continue and increase in extent on the outer coast, for example in Montrose Bay, Aberdeen Bay, Spey Bay, Culbin, north of Dornoch and Golspie, and along the western shores of the Uists, amongst others. Conversely, there are sections of the coast which continue to benefit from net gains in sediment and that may serve to offset the impact of increased sea-level driven erosion. For example, dynamic accretion of fluvial sediments at the exits of rivers and at the heads of inlets serves to favour accretion and locally reverse the erosional effect of relative sea level rise, for example at Tentsmuir Point.

Whilst the changes presented within the NCCA are valuable at a local scale, these broader patterns are important and should be taken into consideration by both terrestrial and marine planning, including flood risk management planning. Taking the northern shore of the Moray/Dornoch Firth as an example which straddles the 'erosional outer coast' and 'depositional inner coast' divide, all six of the existing links golf courses are experiencing coastal erosion (i.e. Brora, Golspie, two courses at Dornoch, Skibo & Tain), that is likely to worsen in coming decades. This is particularly relevant when a seventh course is being planned on a currently stable section of dunes (Coul Links near Loch Fleet).

5.3 Is erosion occurring down-coast (and in front of) coastal defences?

Erosion occurrence adjacent to coastal defences is commonplace within every cell in Scotland, since the insertion of defences is generally in direct response to an erosional or flooding event. Nevertheless, there are instances where the defences themselves have exacerbated the pre-existing condition, either on-site or down drift of the site. The reasons for this condition are three-fold: defence structures not only halt erosion but also the supply of eroded sediment to the fronting beach which suffers reduced beach levels (beach lowering) that may undermine the structure foundations; second, the reflected wave energy from structures leads to toe scour undermining; third, defence structures on a coast affected by longshore currents (currents that transport sediment from updrift to downdrift) halts the supply of sediment to beaches downdrift, leading to beach lowering and erosion. For example, at Monifieth and Montrose (Angus) and Golspie (Highland) defences have been several times extended as erosion has been exported downdrift. Often the most severely affected area is immediately downdrift of the end of the defence structures where an erosional bight is commonly found (eg at Barry Links (Angus) and at Tain (Highland).

5.4 Does erosion exacerbate flooding?

Whilst a systematic answer to this question is beyond the scope of the work, there are examples where erosion is known to have exacerbated flooding. A few recent examples include multiple sites in the Uists (2005), Golspie (2014, and 2015), Eden Estuary (2014) and Whiteness Head (2014). Evidence from Scotland's longest tide gauges (Ball et al 2009) indicates that there is already evidence of increased flood occurrence, related to increases in mean sea level. Taken together with the recent increase in erosion (particularly along the east coast), increased flood levels are expected to worsen erosion enhanced coastal flood risk in the coming decades. Such a prognosis is shared by the UK Climate Change Risk Assessment Reports Adaptation Sub-Committee (ASC) reports (2016 a, b & c) which calls for greater attention and consideration of integrated approaches to managing shared risks.

The extent, scale and temporal changes to mobility demonstrated within the NCCA is remarkable. The Whole Coast Assessment (NCCA Report 9) and indicative Vulnerability Assessment (NCCA Report 11) identify the strong coincidence of areas at increased risk from coastal erosion and flooding. Whilst this may not be surprising, the implications nationally are important. Scotland's coastal flood risk assessment assumes a static land surface and a modelled still water level, on which waves (and other dynamic effects) would then need to be added. SEPA is undertaking research to better understand the wave overtopping risk, and the NCCA can now inform the mobility of the coastal edge and efficacy of natural coastal defences. Where coastal erosion is anticipated within coastal flood envelopes then there may be an increase in flood frequency. Where erosion extends landwards of the coastal flood envelope then there is likely to be a change in the frequency and extent of coastal flooding. Initial analysis within the NCCA provides proof of concept for the investigation of low-lying flood prone areas and the resilience or vulnerability of the protective soft shoreline. The approach presented here used open-data digital terrain models from the Ordnance Survey but the currency of such data is key and must be considered when commissioning future surveys. They also allow an appreciation of where natural defences are becoming more resilient or less, due to accretion or erosion. Such understanding is critical in informing Section 19 of the Flood Risk Management Act.

5.5 What are the likely impacts of climate change on coastal change and flood risk?

Given the NCCA's evidence of an increasing erosional trend and a decreasing accretion trend (both of which have regional variations), the evidence of relative rise in sea level within tide gauges (Rennie & Hansom, 2011) and the anticipated increases in sea level anticipated beyond UKCP09 levels (UKCP18 briefings), the risk of erosion and erosion enhanced coastal flooding is likely to significantly increase over the coming decades. The rising mean sea level also shortens the anticipated return period for flood events (being investigated within the UKCP18 revision) which is expected to affect the duration between erosion events and the necessary time for beach repair. Such issues are particularly apparent on shorelines with negative gradients, as exemplified at Golspie Links following the 2014 and 2015 storms (Fitton and Hansom, 2015).

Given the above, and the recent and anticipated changes to the processes causing erosion and flooding, the rates derived by the NCCA since the 1970s may well underestimate future rates that will be enhanced by climate change, although any acceleration may not be noticeable or statistically proven for some decades (RSE conference presentations). In the absence of scenarios based on accelerated trends, the data within the NCCA represent the best available national data for considering the minimum impacts on adjacent assets (particularly the 2050 Erosion Influence (10m buffer added to the erosion affected area).

Further consideration of the climate change implications on future rates of change would be beneficial and is a recommendation, not only on the shores with significant change but also along those which have been stable or have experienced insignificant erosion, even if these are at a greater risk of legal challenge. An equally valuable parallel approach would be to consider the natural coastal defences at greatest risk of any acceleration to provide an additional management tool for policy makers and practitioners alike.

5.6 Improving the utility of the NCCA

The NCCA has shown that use of MHWS to show national coastal changes is successful and demonstrates that substantial changes have occurred over the time periods employed which, if they continue, will present future management challenges. When plotted against the coincident assets at the coast, these changes provide a novel and informative approach to appraise the individual and shared indicative risk across society's coastal assets.

NCCA provides intelligence of change to inform monitoring as well as multiple policy areas. For example, it helps direct the OS to target updates to national mapping, it allows SEPA to appreciate the changing resilience of natural flood defence structures, it informs Local Authorities and Marine Planning Partnerships to appraise the risk and resilience of the coastal zone in planning terms, and it allows SNH to appreciate the value of natural coastal defences and encourage their appreciation, conservation and broader use. At a national level, there is a cumulative benefit from the NCCA in that it informs multiple strands within the Scottish Climate Change Adaptation Programme, allowing a step change in the evaluation of risk and resilience of society's assets. However, as the NCCA has developed, some areas have emerged where further work could profitably extend its utility.

Data availability is key and analysis has worked best where data has been shared. However, there remain some sections of the public sector whose data provision falls short of the open data agenda. Looking ahead data sharing across organisations will allow insights and efficiencies to be realised.

In addition to availability, data quality and currency is central and there is a need for accurate and up-to-date imagery collection to allow time series DTMs to be produced. The NCCA progress has been hampered by lack of accurate and timely data. In this respect, coordination is essential between the data acquisition and users, including the Scottish Government and its agencies, who rely upon the timely delivery of data.

The NCCA relied upon MHWS as the key nationally available dataset to identify coastal change. This has proved an excellent baseline measure but it can be improved upon. For example, beach lowering on the lower intertidal area may not be of sufficient magnitude to affect the position of MHWS on the upper intertidal area and where very low gradients and dense vegetation occur the DTMs produced from photography may not be strictly comparable with those produced via LiDAR. A universal move toward LiDAR would circumvent this as an issue. In addition, in some situations MHWS lies some distance seaward of a clearly eroding coastal edge that is marked by the limit of vegetation, for example a cliffed sand dune edge. Inclusion of an additional parameter that defines the coastal edge (e.g. defined as the vegetation limit) would be a useful diagnostic to use in conjunction with MHWS. Although not developed further within NCCA, a dataset and methodology to achieve this has been identified.

The bulk of the sites investigated by the NCCA rely on a two-dimensional analysis whilst coastal changes are three-dimensional. Upgrading all data to three-dimensions (eg. via LiDAR) would provide a step change our ability to understand the coastal sediment budget and identify sites where sediments are lost and gained. With a two-dimensional analysis, we may be underappreciating the risk (particularly with Historic Environment Scotland sites).

6.0 Implications for a Coastal Strategy

6.1 What limits our approach to coastal erosion issues?

A key issue highlighted within the NCCA process is the devolved nature of responsibility for coastal erosion. If the landowner is ultimately responsible and Local Authorities have powers but not obligations, it follows that no one organisation 'owns the erosion problem nationally'. Whilst the UKCCRA, Scottish Climate Change Adaptation Programme and SEPA's Flood Risk Management responsibilities have contributed to the call for action, the question of leadership and ownership of the national coastal erosion issue remains unresolved (ASC 2016 c). However, the expectations are clear within the UKCCRA (Defra 2012) and UKCCRA2 Synthesis and Scotland report (ASC 2016 a & b), with a Scottish Government response expected in the near future.

A second strand is that recent funding arrangements for flooding in general may be contributing to a lack of focus on coastal erosion or erosion adaptation. The COSLA agreement (2014) means all Scottish Government funding to Local Authorities is ring-fenced for flooding. Whether this is entirely justified is questionable given the plethora of defences that were funded by the European Commission in the 1970s & 1980s and are now perceived by some as ill-conceived and may be exacerbating problems in front and adjacent, whilst having encouraged development in vulnerable locations. This apart, given the assets at risk identified by NCCA (which are likely underestimated), and broader considerations of how to empower the public sector to make assets and communities more resilient into the future, a focus on adaptation and mitigation would be a logical and more sustainable route than one that focuses entirely on protection. Whilst the Scottish Government long term commitment of £240m for 2016-2022 provides a welcome long term commitment for flood schemes, there will inevitably be places that cannot be funded each cycle. So, although there may be sufficient planning and funding mechanisms available to protect existing assets, what is lacking is the funding to develop the adaptation measures called for within the Scottish Climate Change Adaptation Programme that would offer sustainable options for communities whose coastal assets are at risk.

The Flood Risk Management Act (2009) does not explicitly refer to coastal erosion *per se* and this has had unintended consequences. Whilst few would argue that coastal flood risk cannot be appreciated without coastal erosion, this relies on the interpretation of the Act, rather than an explicit requirement of it and so explicit requirements may be prioritized over implicit ones by officials. Knock on implications also exist where explicit requirements may be tightly defined without adequate consideration of the broader benefits of the work, thereby limiting the use of the research beyond priority flooding areas (i.e. terrestrially biased Potentially Vulnerable Areas for example). This hinders integrated approaches which would benefit adjacent aspects of sustainability and broader land use.

At least some of this problem may be a gap between the organisational understanding of the risks and the requirement and resources available for action, for if there is, then adaptation is unlikely to occur. There may be issues of organisational inertia within both the public (and private) sector, where adjusting to an uncertain future via adaptation is both unfamiliar and challenging in a harsh fiscal environment where limited resources need to deliver on well understood statutory responsibilities rather than new, uncertain tasks for a future benefit. This may be another example (as pointed out by ASC 2016c) where implementation is falling short of expectations. Re-framing this in the light of duties under the Climate Change Act may provide the impetus for the public sector to act more confidently and effectively.

6.2 A coastal strategy

It is becoming clear that coastal erosion both individually and jointly with associated coastal flooding has the potential, both now and into the future, to impact on coastal assets whether they be protected or otherwise. It is also clear that although current policy instruments may be adequate and available to allow authorities and government to act in a strategic fashion, their implementation has been hampered by a lack of accurate national data concerning coastal change, together with the absence of a strategic overview that might be underpinned by such data. As a result, management of large sections of the coast has been reactive and *ad hoc* and there is now a pressing need for a common shared approach to manage the impact of coastal erosion and flooding and to develop shared mitigation and adaptation plans for the coastal assets affected, a view shared by the ASC report (2016 c). There is now a momentum building with the development of Marine Planning Partnerships to take forward the National and Regional Marine Plans, the recent publication of Flood Strategies (in 2016) and the second cycle of Flood Risk Management Plans (2017), the development of Shoreline Management Plans (SMPs) within North and South Ayrshire and possibly within Dumfries and Galloway. Collaboration across the public sector is becoming more commonplace, as is the availability of data to support joint approaches to problems. This welcome activity may herald a new opportunity in integrated management of the coastal zone.

The NCCA analysis highlights a substantial number of coastal assets managed by a variety of different organisations exist. At the centre of this aspect is that coastal erosion is legally the responsibility of the land owner, and whilst some public bodies have powers or an interest, none have taken ownership of the issue at a national level. The resultant fragmentation of this issue hinders integrated approaches. As part of any implementation of a shared approach it is important that each organisation with a coastal remit or responsibility appraise their own identified risks, responsibilities, and opportunities with those organisations with similar or coincident interests. To be fully effective it is likely that such coordination is best supported via the Scottish Government so that partnerships can develop across the public sector together with other interested parties/stakeholders. The opportunities extend beyond case-by-case examples on the foreshore, to policy implementation spanning disciplines. The NCCA and its associated datasets now need to be used to inform, support and influence various policy areas in a holistic, inclusive and joined–up fashion. Integrating or supporting a range of policy areas is needed including erosion and flood risk management, shoreline management planning, the Water Framework Directive, management of designated sites and supporting marine and terrestrial planning. This is essential, not only for cost saving reasons but to maximise outcomes and support a sustainable future coast. It may well prove useful to be flexible and opportunistic over the coming years as any such strategy is developed and applied. For example, the revision of National Flood Risk Assessment and Flood Risk Management Strategies toward including more coastal provision may provide a profitable route to incorporate NCCA data and provide an alternative/supplementary mechanism to Shoreline Management Plans and aid the drive toward truly sustainable coastal management.

What the NCCA demonstrates is an impressive scale of dynamism and mobility along the Scottish coast. Since the 1970s, 11 % of the soft coast is accreting and 77 % is stable with the 12% that is eroding biased toward the developed east and some parts of the exposed west coasts. However, stable does not mean static and it is possible that the increase in stability represents a transitional phase between past accretion and future erosion. If so then any window of opportunity for the development and implementation of integrated management of our coastal zone and its assets may be shorter than anticipated. Identifying this dynamism and adjusting to changing trends is key to the future management options that we might employ so that, working with natural processes rather than against them, we give ourselves an opportunity to move toward more sustainable management of our shores. In some locations, this may involve mitigation measures to control the rate of coastal erosion and flooding but in others it may increasingly involve adaptation measures and the inland migration of impacted assets or activities away from the coastal fringe.

7.0 Recommendations

7.1 General Strategy and Collaboration

1. Coastal erosion is a shared problem and its solution needs to be shared across government, its public bodies, private sector, and communities.
2. Coastal erosion and coastal flooding are not mutually exclusive and need to be considered jointly. The wording in both the FRM Act and Coast Protection Act 1949 require adjustment, particularly in the light of climate change, and a broader need for an integrated approach. We recommend the Scottish Government consider this and direct the public sector to take greater consideration of coastal erosion.
3. Whilst Scottish Government leadership is clear within the Climate Change Act and Scottish Climate Change Adaptation Programme, with explicit duties across the public sector, strategic ownership and resource throughout organisations is recommended to ensure delivery via identified senior "coastal champions" within each organisation.
4. Such an approach may find greater traction if contained within a Scottish Coastal Adaptation Plan, underpinned by NCCA data, and is a recommendation.
5. There is also an urgent need for the resources to make adaptation planning happen and provisioned to grow in the longer-term as the need increases. Establishment of a parallel fund to facilitate the relocational adaptation of erosion-impacted residents should be explored, urging society toward adaptive resilience ahead of climate change impacts.
6. ASC (2016) identifies a lack of (and implementation of) well-developed specific polices for large sections of the Scottish coast with no Shoreline Management Plan (SMP). The NCCA can serve as a tool to develop targeted SMPs for only key vulnerable areas within a local authority's coast (rather than all of it) and this is a recommendation here.
7. ASC report (2016) suggests the Scottish Government set a long-term target for intertidal habitat areas created through managed realignment and the appropriate policy mechanisms to deliver. We recommend that reliable implementation data is gathered and funding sources identified to support managed realignment for flood benefit.
8. SEPA's Flood Risk Management Strategies (FRMS) focus on reducing vulnerability on developed coast where most people and property occur and may underestimate the importance of stretches of Scotland's undeveloped coastline vulnerable to flooding. Whether this accentuates the urban-rural divide and contributes to social disadvantage is a moot point. We recommend research to establish whether linkages exist between social vulnerability and coastal erosion and coastal flooding vulnerability.
9. The NCCA outputs, together with flooding and topographic data, provide support for Section 19 of the Flood Risk Management (Scotland) Act and informs SEPA's assessment of the utility of natural coastal protection features. A strategic position paper on coastal Natural Flood Management is recommended, including consideration of the need to assess any funding bias toward hard solutions for highest value assets.
10. The currency of some OS data has been problematic for the NCCA: some OS MasterMap MHWS changes have not been updated since the 1970s and the line metadata fails to detail the survey date, limiting its utility for calculating dates, time periods and rates of change. If this continues, NCCA-type assessments will avoid modern OS data. A key recommendation is that OS enact improvements in the survey interval of MHWS and publish accurate and more informative

metadata.

7.2 Within the NCCA: next phase

1. The NCCA at a national level informs multiple strands within the SCCAP (2014) and ASC Report (2016 b & c), enabling a step change in the evaluation of risk and resilience of society's coastal assets. It is recommended that the NCCA is used to assess local risk and resilience assessments by Local Authorities.

2. The NCCA has identified that data availability is key and analysis works well where data has been promptly shared. However, in some sections of the public sector, data provision falls short of the open data agenda and INSPIRE compliance, if not in letter but in spirit. We recommend that data gathered and funded by the public purse is freely available to allow data sharing across organisations and enable insights and efficiencies to be realised.

3. Most of the sites investigated by the NCCA rely on a two-dimensional time series analysis whilst coastal changes are three-dimensional (3-D). An upgrade to 3D time series would provide a step change in understanding the local coastal sediment budget and, crucially, identify areas of sediment loss and gains. Whole-coast acquisition of regularly updated 3D time series data (e.g. via airborne LiDAR) is recommended.

4. NCCA reliance on MHWS as the key nationally available dataset to identify coastal change falls short where very low gradients and dense vegetation occur and where the coastal edge has receded independent of MHWS (e.g. within cultural and natural heritage sites). We recommend research to better diagnose change within such situations using, for example, coastal vegetation datasets.

5. Post-NCCA we recommend work to identify a methodology to inform SEPA's National Flood Risk Assessments 2 with erosion-enhanced coastal flood risk. Merging SEPA's coastal flood risk maps with inland extents of land below MHWS would enable the resilience or vulnerability of natural defence features to be established and better inform risk to adjacent assets. Such work supports SEPA's duties under Section 19 of the Flood Risk Management Act and would benefit many other stakeholders.

6. In support of Section 19 of the Flood Risk Management Act, the development of a national dataset for natural and artificial coastal flood/erosion defence structures is recommended (see Defence Asset Database NCCA Report 7).

7. It is recommended that the NCCA data be compared against datasets for Critical National Infrastructure, Ministry of Defence and Waste Water Network alongside any other new data to identify any other areas at risk in the future.

8. The NCCA did not consider climate change risk. Reduction in accretion (all cells) and increases of erosion (east coast), an anticipated 20-30% uplift required for future sea level rise (Met Office, 2017) and the effects on flood frequency, indicate an assessment of the impact of climate change on coastal erosion is overdue and recommended.

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