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Dynamic Coast - National Coastal Change Assessment: Cell 3 - Cairnbulg Point to Duncansby Head

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National Coastal Change Assessment
Steering Committee

Coastal Change & Vulnerability Assessment

Dynamic Coast – Scotland's National Coastal Change Assessment

Executive Summary

- Cell 3 extends from Cairnbulg Point to Duncansby Head.
- In Cell 3 Mean High Water Springs extends to 1,024 km which makes up around 5% of the Scottish coastline (excluding tidal inlets). Of this length, 32% (332 km) is categorised as hard and mixed, 9% (89 km) as artificial, and 59% (603 km) as soft coast.
- Within the historical period almost half of the soft shoreline (49%) has not changed significantly, however 34% by length has accreted (advance) with 17% retreating (erosion).
- The period from the 1970s to modern spans 37 years, so the historical period data has been normalised to 37 years to allow comparisons with the modern period
- When this adjustment is applied the extent of retreat (erosion) increased from 7% historically to over 22% post 1970s, the extent of stability reduced from 76% to 62% and the extent of accretion remained the same.
- In addition to the increases in the extents of erosion and accretion in Cell 3, there has been a substantial increase in the rate of erosion, with the fastest rates (30m+ over 37 years) now affecting 11% of the retreating shore, up from 3% historically.
- Accretion rates remained the same although the fastest rates (30m+ over 37 years) now affect 9% of the advancing shore, a fall from 8% historically.
- Increase in the average rate of erosion and the changes in erosion extent suggests there may have been a shift in the status of soft coast of Cell 3 in the modern period from a bias of accretion toward an erosional bias.

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 in order 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.

Contents

Document Structure

This document is structured to conform with the Scottish coastal sediment cell and sub-cell boundaries that were first delimited by Ramsay and Brampton (2000) in a series of 11 reports. The concept of Coastal Cells as a science based management unit for the coast is based on a recognition that the processes that shape and alter the coast are unrelated to administrative boundaries but are more accurately related to changes in sediment availability and interruptions to that availability. So, as a coastal management unit, the sediment cell can be seen to fulfil a similar function at the coast as does the catchment area of a river does for terrestrial flood management. Changes in erosion, accretion and sediment supply in one coastal cell are seen to be largely unrelated to, and unaffected by, conditions in adjacent coastal cells. 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 but not vice versa given the "one-way" nature of sediment movement. As key sediment sinks, estuaries might be suitable cell boundaries, however subdivision of an estuary where sediment may circulate freely between both banks is inconvenient as so the inner portions of major firths and estuaries have been defined as sub-cells (Ramsey and Brampton, 2000). Whilst the cell system is ideal from a scientific perspective, it remains that Local Authorities may straddle a cell boundary. The results and statistics for each Local Authority area and for Marine Planning Regions are contained in a separate report.

Commencing with a national overview, this report summarises key locations whose positions of MHWS have changed between the periods 1890s to 1970s and 1970s to modern time. The locations are arranged within sub-cells, which progress around Scotland in an anticlockwise direction, followed by the Western Isles, Orkney and Shetland. A short narrative summarises the historical changes and current situation at each location, followed by a vulnerability assessment which considers the implications of assets adjacent to areas of erosion. This narrative is to allow the reader to appreciate much of the evidence on coastal changes. However, the full results are available on the webmaps (www.dynamiccoast.com) and have been designed to be highly accessible. Within the webmaps the user is able to navigate across the whole country, display various shorelines and click on the line, to quantify the changes. This report is concluded by a series of tables summarising the statistics for each cell. Each of the 11 coastal cells has a similar report to this, which sits alongside a national overview which collates the national picture and considers the implication for Scotland's coastal assets. Where appropriate, mention is made of the existence of a shoreline management plan for any particular section of the coast.

The National Context

For a full national overview of the aims, methodology, characteristics and underlying factors that control Scotland's coastline, the reader is directed to the National Overview report where a Whole Coast Assessment and results from the historical and recent changes are presented. Here only a short summary of the national changes identified are presented to place this individual coastal cell report into context.

Since the 1970s, 12% of the soft coast length across Scotland has retreated landwards (erosion), 11% has advanced seawards (accretion) and 77% stable or has shown insignificant change (Figure 1). National comparisons from the historical period (1890 to 1970) to recent period (1970-modern), accounting for the different time periods, show an increasing proportion of erosion (8% to 12%), similar stability (from 78% to 77%) and falling accretion (14% to 11%). Where coastal changes occur, they are faster than before. Nationally, average erosion rates after the 1970s have doubled to 1.0 m/yr whilst accretion has almost doubled to 1.5 m/yr.

The national pattern is an aggregation of different results from different parts of the country (Figure 2). 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. 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. Considering the changes through time, the exposed coastal cells of the east coast have seen greater increases in change, with more modest changes occurring on the rock-dominated cells.

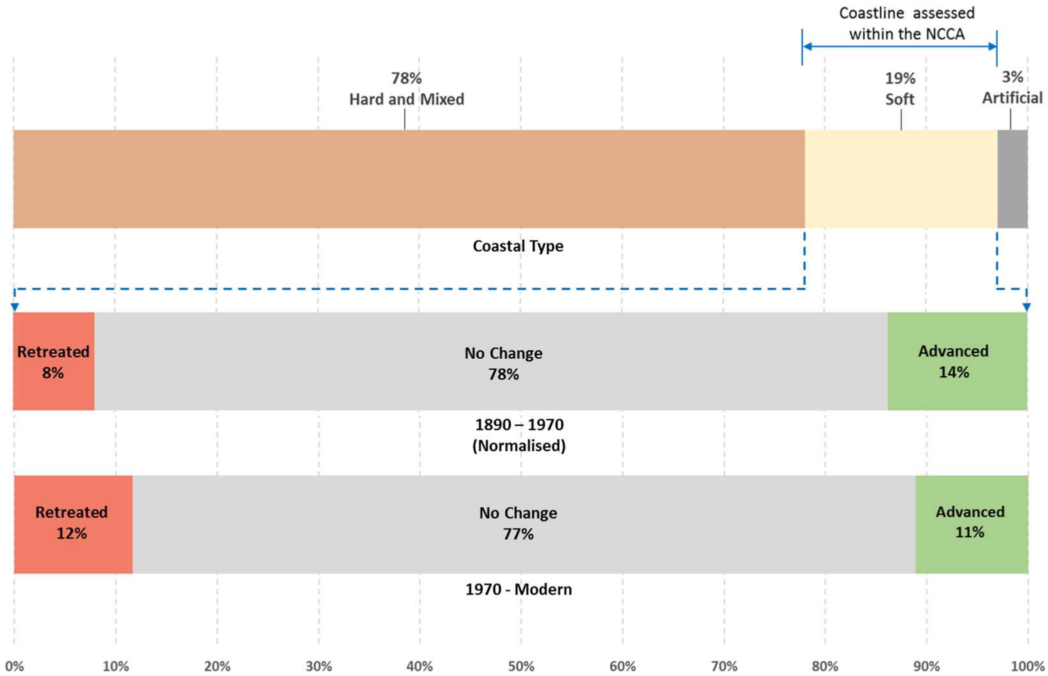

Figure 1: National coastal change results showing the proportion of soft coast retreating, stable and advancing within each change category in the historical (ca. 1890-1970 normalised for time period) and recent (ca. 1970-Present) time periods.

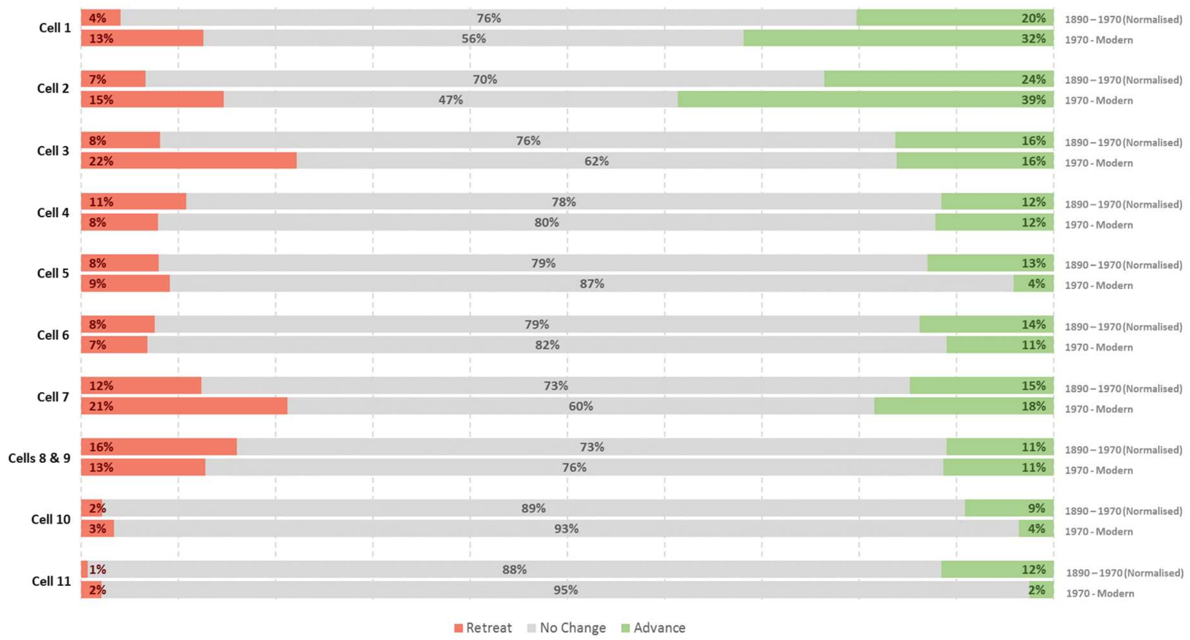

Figure 2: National coastal change results showing historical (ca. 1890-1970, normalised for time period) and recent (ca. 1970 Present.) % of coastal cell showing retreat (red), stability (grey) and advance (green) for soft coast within each cell.

Two other trends are worthy of mention here. The first relates to the propensity for the outer coast to be more exposed to wave impact than the inlets, bays and firths of the inner coast and so the potential for wave-driven erosion is greater along the outer coast. This is exacerbated by a reduction in sediment supply to the outer coast from the higher levels experienced a few thousand years ago. These outer coasts constantly lose sediments to inlet infilling via longshore drift (currents that transport sediment from a source area updrift to an accepting area downdrift). As such, erosion has progressively become the dominant trend on the outer coast in all places except where the import of longshore drift sediments feeds downdrift beaches. Conversely inlets, embayments and firths are sediment sinks that accept soft coastal sediments derived from erosion of the outer coast (the sediment sources) in addition to sediment freshly delivered by rivers. The result is that whilst the inner coast has a bias toward accretion, the outer coast, hard or soft, has a bias toward erosion.

A second trend is the close coincidence between coastal defences and erosion of the adjacent coast. Unsurprisingly, the insertion of defences is in response to a coastal erosion or flooding event, yet there are many instances where the defences themselves have exacerbated the pre-existing erosional condition, either on-site or on adjacent coastline downdrift. The reasons are three-fold. First, a defence structure is aimed at halting or slowing an existing erosion condition and so a successful structure not only halts erosion but also the supply of eroded sediment that had previously reached the fronting beach. The result is a reduced sediment supply and beach lowering. Second, most structures reflect wave energy and, indirectly, sediment leading to beach lowering. Third, the insertion of a defence structure on a coast that is affected by longshore currents not only prevents the supply of sediment to the fronting beach, it also reduces the supply of sediment previously exported leading to downdrift beach lowering and erosion.

Cell 3 - Cairnbulg Point to Duncansby Head

Cell 3 extends from Cairnbulg Point to Duncansby Head. The sub-cell boundaries are shown in Figure 3.1. Further contextual information about the processes operating in Cell 3 can be found in Ramsay & Brampton (2000).

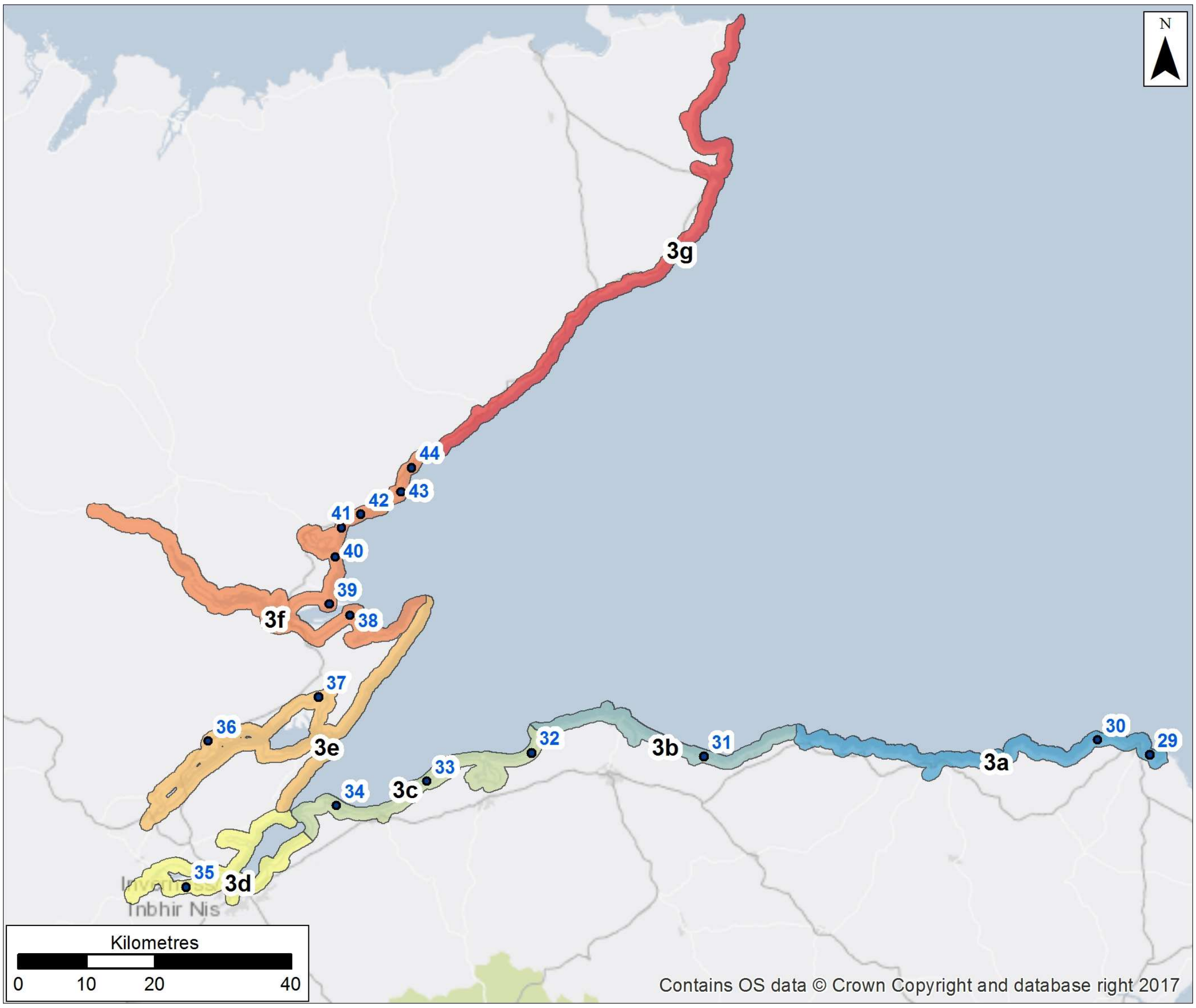

Figure 3.1: The sub-cell boundaries of Cell 3 and locations of sites discussed in this report (blue numbers).

Physical Overview

In Cell 3, MHWS extends to 1,024 km which makes up around 5% of the Scottish coastline (excluding tidal inlets). Of this length, 32% (332 km) is categorised as hard and mixed, 9% (89 km) as artificial, and 59% (603 km) as soft coast (Table 3.1). Within the historical period of 74 years (1890-1970) almost half of the soft shoreline (49%) has not changed significantly, however accretion (advance) has dominated 34% by length with 17% retreating (erosion). The period from the 1970s to modern spans 37 years, so the historical period data has been normalised to 37 years to allow comparisons with the modern period. (Figure 3.2).

When this adjustment is applied the extent of retreat (erosion) increased from 7% historically to over 22% post 1970s, the extent of stability reduced from 76% to 62% and the extent of accretion remained the same. In addition to the increases in the extents of erosion and accretion in Cell 3, there has been a substantial increase in the rate of erosion, with the fastest rates (30m+ over 37 years) now affecting 11% of the retreating shore, up from 3% historically. Accretion rates remained the same although the fastest rates (30m+ over 37 years) now affect 9% of the advancing shore, a fall from 8% historically (Figure 3.2).

This trend is consistent with a move from accretion (reducing), through a transitional condition of no change (increasing), toward erosion (increasing) with the average rate of erosion increasing from the historical to the recent period. Further statistics for Cell 3 can be found in in Table 3.2 and Table 3.3 at the end of this report.

Table 3.1: Proportion of each coastal type within Cell 3.

Modern Coastal Type	Length	
	km	%
Soft	602.8	59%
Artificial	88.8	9%
Hard and Mixed	332.2	32%
Total Length (excluding tidally influenced inlets)	1023.8	100%

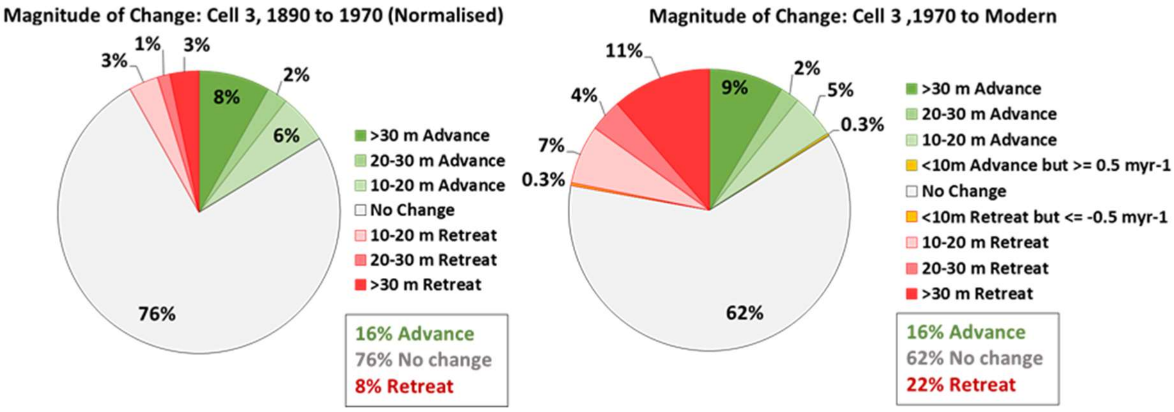

Figure 3.2: Coastal change results for Cell 3 showing the proportional amount of change in the historical (ca. 1890-1970 normalised) and recent (ca. 1970-Present) time periods. Rounding errors may produce small % differences between Figure 2 and Figure 3.2.

Asset Vulnerability Overview

The Vulnerability Assessment methodology serves to project the known past erosion rates forward into the future to the years 2050 and 2100, although only the 2050 projections are discussed here. Both 2050 and 2100 are included in the online webmaps at www.dynamiccoast.com. Within Cell 3 there are no residential and non-residential properties within the areas expected to be eroded by 2050. Further areas of land supporting various types of assets are anticipated to be lost by 2050, although since some of these areas are co-designated, the loss is likely to be less than that anticipated. When the erosion influenced sections are included then one residential property is anticipated to be affected. For a full summary of vulnerable see Table 3.4 at the end of this report.

Sub-cell Summaries

Subcell 4a - Cairnbulg Point to Portknockie

4a.1 Fraserburgh Bay (Site 29)

Historic Change: Whilst the central section of Fraserburgh Bay has remained stable between 1901 and 1963, the western and eastern ends of the beach have advanced modest and reasonable amounts respectively. The central section of the beach remains stable until 2011, and accretion continues at the ends of the beach (Figure 3.3).

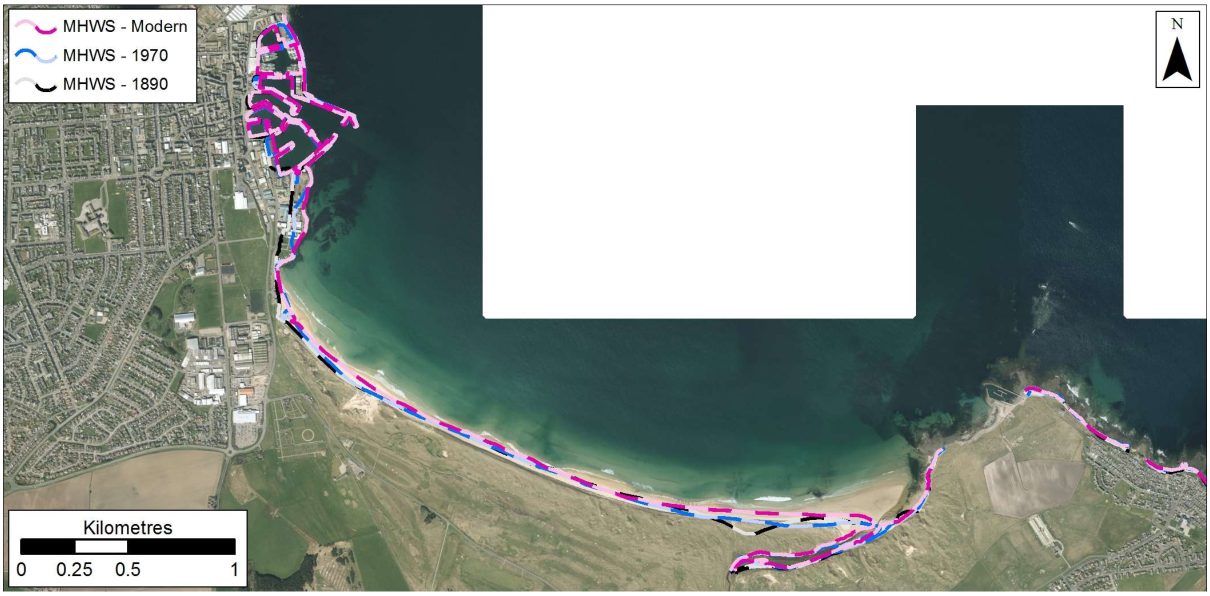

Figure 3.3: MHWS position in 1890, 1970s, and Modern datasets at Fraserburgh Bay. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

Future Vulnerability: As no erosion has occurred within Fraserburgh Bay, no future vulnerability exists at this location.

4a.2 Rosehearty (Site 30)

Historic Change: Rosehearty's eastern pier was in place by 1901 and may have led to up to 60m of accretion to the east up until 1971. Between 1971 and 2011 much of the beach has remained largely stable, apart from its eastern limit, which advanced some 10 m up to 1971 with the present shoreline now landward of its 1901 position (Figure 3.4).

Future Vulnerability: Should the past erosion rates continue at the historical rate, without intervention, the road which runs along the shore (B9031) may be within 21 m of the position of MHWS by 2050 (i.e. erosion vicinity) and within 6m of MHWS by 2100 (i.e. erosion influence) (Figure 3.5). Rosehearty to Fraserburgh Coast Site of Special Scientific Interest (SSSI) occupies the foreshore; any increase in intertidal foreshore may increase the scientific interest of the site. This coast falls within the Fraserburgh and Rosehearty Potentially Vulnerable Area.

Figure 3.4: MHWS position in 1890, 1970s, and Modern datasets at Rosehearty. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

Figure 3.5: Possible future coastline position in 2050 based on rates between 1970 and Modern MHWS data at Rosehearty. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

Subcell 4b - Portknockie to Burghead

4b.1 Spey Bay (Site 31)

Historic Change: Spey Bay is a remarkable shingle and sand beach, fed by one of the largest rivers in Scotland. Whilst the mapping evidence considered here reflects change since the turn of the twentieth century there is evidence of coastal changes here stretching back several thousand years. As a result, Spey Bay is one of several adjacent beaches whose history and development are linked. The River Spey fed sediments on to a shoreline several thousand years ago which looked very different, where Burghhead was an island and the Spey sediments joined those of the River Findhorn creating the enormous dunes at Culbin Sands. As sediments accumulated and sea levels fell, Burghead was eventually joined to the mainland. At this period, the extensive and parallel shingle ridges at Spey Bay started to be laid down (Hansom, 2003).

To the east of the mouth of the River Spey between 1903 and 1966 the beach remained largely stable with some areas extending seawards some 20 m or so (Figure 3.6). The exception to this is the eastern limit of the bay, towards Port Gordon, which experienced up to 38 m of erosion between 1903 and 1966. Sediments lost from here are carried westwards, which are likely to have contributed to the stability and accretion seen towards the river's mouth. The River Spey still contributes considerable volumes of sand and gravel, in turn contributing to the health of the visible and subtidal delta.

The changes seen over the past 113 years at the river's mouth are too complex to consider here, although they have been summarised by Gemmell et al, (2001). The river and coastal dynamism has been capricious in the past and still presents a very real issue for some landowners.

Figure 3.6: MHWS position in 1890, 1970s, and Modern datasets east of the River Spey mouth. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

To the west of the River Spey towards Board Rock the shoreline has accreted between 1903 and 1966 (Figure 3.7). Further west however, towards the mouth of the River Lossie, erosion dominated with up to 50m being lost over the same period. The contribution of sediments from the River Lossie offset the losses resulting in some stability at the western end of Spey Bay.

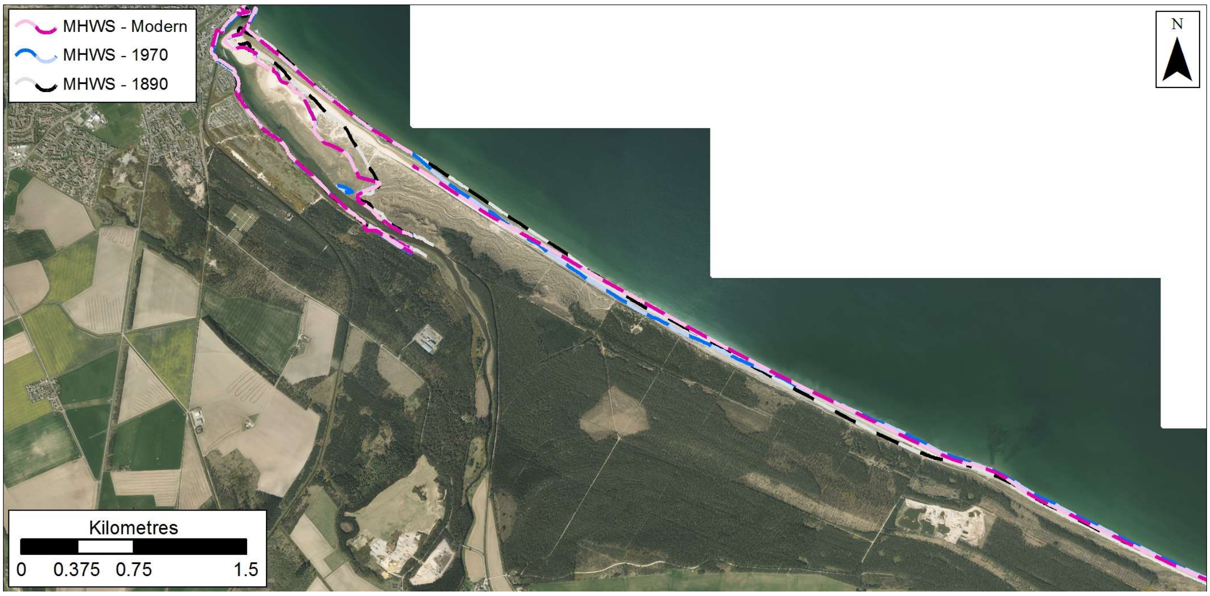

Figure 3.7: MHWS position in 1890, 1970s, and Modern datasets west of the River Spey mouth. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

To the east of the mouth of the River Spey, between 1966 and 2003, the shoreline has retreated across most of this part of the bay. Between 20 m and 37 m of erosion has occurred along large sections of the shoreline, which has not been reflected in the OS mapping which remained largely unchanged through this period. Recent air photography clearly shows shingle being re-worked landwards as the storm beach adjusts landwards through time. The erosion in the east fuels stability and reasonable accretion (20m between 1966 and 2003) within the vicinity of Tugnet and Spey Bay Golf Course. Given the limited modern sediment supply entering the east of the bay, the erosional trend is likely to pass westwards until the influence of the river-fed sediments are realised. This can be seen by the westward progression of the point of stability (between easterly erosion and westerly accretion) that has moved westwards since 1966.

Since 1966, to the west of the mouth of the River Spey, erosion dominates more areas than in the earlier period. Whilst there are sections of coast (e.g. Boar's Head Rock) which have been stable, these are the minority. Within 1.5 km of Lossiemouth the Historical Change Assessment is curtailed given the lack of useable data to update the inaccurate OS MHWS line. Whilst SEPA and Moray Council have a LiDAR dataset from 2003, SEPA were unable to provide it due to licencing restrictions. Based on recent air photos the erosion appears to continue in a consistent manner over the last 2 km with between 30 and 50m of erosion being experienced between 1966 and 2003.

Spey Bay falls within the Buckie Potentially Vulnerable Area and makes up part of the Moray Firth Special Protection Area and has a Site of Special Scientific Interest.

Future Vulnerability: In a similar structure to the Historical Change section (above) Spey Bay will be discussed in sections. To the east of the mouth of the river much of the bay is dominated by agricultural fields, however adjacent to the Burn of Tynet (600 m west of Portgordon) two sets of electricity cable landfalls are expected to be installed. These provide supplementary grid connection for the Northern Isles and the Beatrice Offshore wind farm. Together these represent significant infrastructure projects and as such, the erosional nature has been raised with the developers to ensure the designs for cable landfall and associated land-based infrastructure are future-proof. To the immediate east of the river's mouth, the village of Tugnet lies alongside Spay Bay Golf Course. Whilst reasonable accretion has occurred between 1966 and 2003, the erosional trend is moving westwards towards these assets (Figure 3.9). The recent granting of planning permission for several houses within this recently stable / accretional section of coast, that is likely to become erosional in the future, presents planners with an interesting question – how far ahead should we be looking when implementing planning guidance?

Figure 3.8: Possible future coastline position in 2050 based on rates between 1970 and Modern MHWS data east of the River Spey mouth. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

Given the strategic level of the NCCA the combined threats posed by the River Spey and Spey Bay between 1966 and 2003 are too complex to explore here. However, the Spey's main channel moved close to the westerly houses in Kingston-upon-Spey, which led to the repositioning of the channel. Whilst this threat remains, residents are aware and Moray Council are undertaking routine monitoring of the changes. Some plans are in place for emergency works in the former river channel (now lagoon) should this be deemed necessary. Given the energetic nature of the bay and river, it is likely that the dynamism will continue for the foreseeable future, perhaps despite the efforts to resist them.

To the west of the river's mouth and beyond Kingston-upon-Spey there are few built structures apart from an MOD rifle firing range which is surrounded by nature conservation designated sites (Special Area of Conservation (SAC) & SSSI). Further westwards within 1.5 km of Lossiemouth the Vulnerability Assessment is incomplete given the lack of useable data to update the inaccurate OS MHWS line. Based on recent air photos the erosion appears to continue in a consistent manner over the last 2 km with between 30 and 50 m of erosion being experienced between 1966 and 2003. Sediments are visibly extending around the harbour and headland at Lossiemouth, which is evidently a leaky sub-cell boundary. This westerly leakage of sediment from Spey Bay means that, despite updrift erosion supplying sediment to these beaches, this sediment transits through and in future erosion is likely to continue.

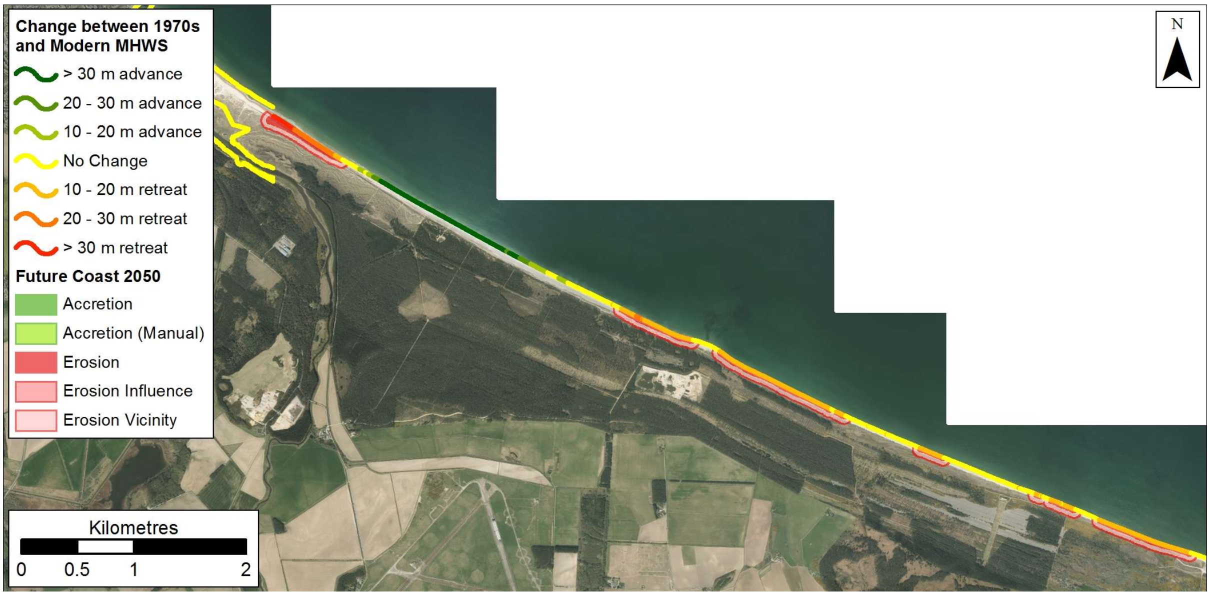

Figure 3.9: Possible future coastline position in 2050 based on rates between 1970 and Modern MHWS data west of the River Spey mouth. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

Subcell 4c - Burghead to Fort George

4c.1 Burghead Bay to Findhorn (Site 32)

Historic Change: First impressions of the 1904 map show a familiar arced shoreline from the lee of Burghead to the mouth of the River Findhorn (Figure 3.10 and Figure 3.11). These geometries are characteristic of beaches in equilibrium with their wave climate and sediment supply. Nevertheless, the beach has experienced coastal erosion between 1904 and 1969 across most of its length. Although losses are more modest towards Burghead, they increase to over 80 m of retreat towards the mouth of the River Findhorn, with a rate of 1.1 m/yr.

Since 1969 erosion has occurred from the caravan park to the south of Burghead which extends some 700m (Figure 3.10). Beyond this section, the shoreline has remained largely stable for the next 3.7 km with little changes between 1969 and 2011. Erosion starts to dominate along the shoreline in front of RAF Kinloss (Figure 3.11), which has experienced losses between 15 and 25 m over the 42 years (max rate of 0.6 m/yr). The recent erosion continues to within vicinity of the beach car park, where stability and some accretion has occurred (up to 18 m between 1969 and 2011, 0.5 m/yr). A proportion of the sediments released from the erosion in the remainder of the bay have contributed to the westerly movement of the spit at the mouth of the River Findhorn, with a consequential effect on the easternmost dunes at Culbin Sands. Air photographs show extensive sand banks crossing the mouth of the River Findhorn and linking up with the intertidal and subtidal areas adjacent to Culbin Sands. The very modest foreshore gains at the eastern end of Findhorn beach are dwarfed by the substantial and long-lived retreat which has occurred across much of the bay since 1904.

Figure 3.10: MHWS position in 1890, 1970s, and Modern datasets south of Burghead. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

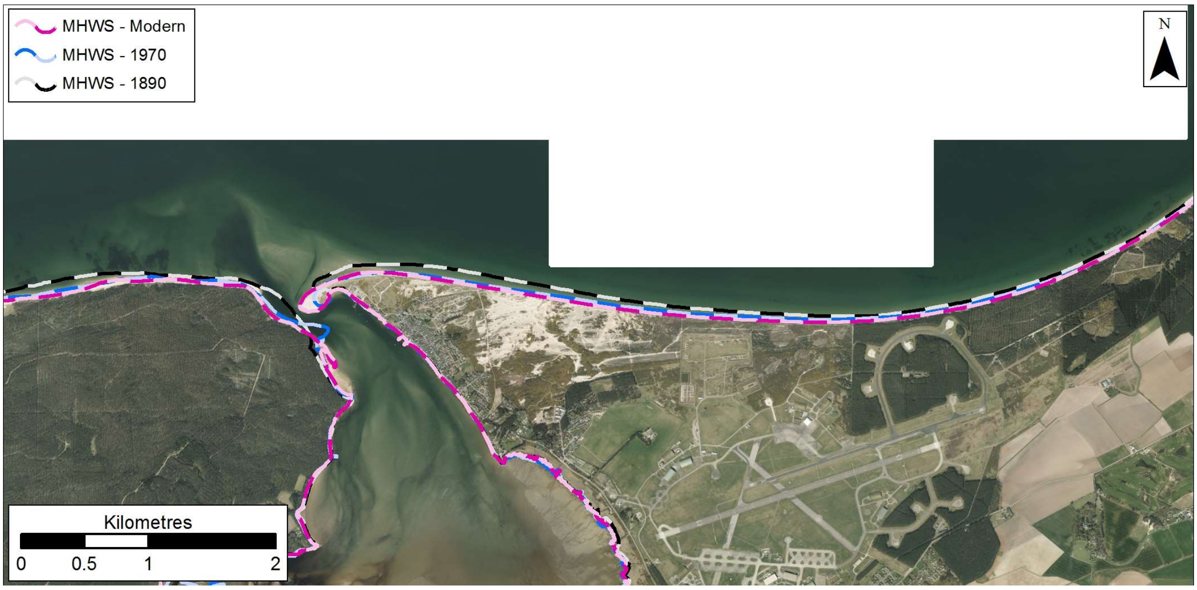

Figure 3.11: MHWS position in 1890, 1970s, and Modern datasets at Findhorn. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

Figure 3.12: Possible future coastline position in 2050 based on rates between 1970 and Modern MHWS data at Findhorn. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

Future Vulnerability: The principal assets within Burghead Bay are the MoD base at RAF Kinloss. If the past erosion rates were to continue unchanged, then the service road for former aircraft parking areas lie within 40 m of the anticipated position of MHWS in 2050 (Figure 3.12) and within 23 m of MHWS in 2100. Further west, more tracks and structures visible in the air photos lie within 10m of the anticipated position of MHWS in 2050 and extensive areas would lie seaward of the anticipated MHWS in 2100. It is not clear from air photos what other structures and former land uses may have occurred within the vulnerable coastal dunes, but given the longstanding use of this area as a military facility further investigations may be appropriate.

Further to the west the next built assets are Findhorn Sands Caravan Park; modest amounts of the northern access roads are located within 10 m of the anticipated position of MHWS in 2050. The

Beach Chalets (to the north-west of the caravan park) lie within 60 m of the anticipated position of MHWS by 2100. Burghead Bay falls within the Burghead to Lossiemouth Potentially Vulnerable Area.

4c.2 Culbin (including Nairn) (Site 33)

Historic Change: The beaches and sand dunes at Culbin stretch between the mouth of the River Findhorn and Nairn, its inland dunes and beach ridges covering an area of 5,000 hectares. Whilst much of the dunes were stabilised after the First World War and now contain extensive pine plantations, the beaches are some of the most spectacular in Scotland and are our most dynamic beaches. The gravel ridges which underlie and form the foundation to the dunes at Culbin started to form about six thousand years ago from sediments sourced from the Rivers Findhorn, Lossie and Spey bypassing the then island which is now Burghead (Hansom, 2003). More recently Burghead acts as a partial barrier to sediment moving along the coast from the Lossie and Spey catchments. However, the longstanding erosion which has occurred within Burghead Bay extends across the mouth of the Findhorn and affects the most easterly 3km of Culbin Sands. Between 1906 and 1976 over 100m of dunes were lost along the left (west) bank of the River Findhorn as it enters the sea (1.4 m/yr) (Figure 3.13). Further west the beach has retreated some 80m in the intervening 70 years (1.1 m/yr). The sediments released from the high cliffed dunes moves westwards along with coarser gravels to form a spectacular array of re-curved ridges (Figure 3.14).

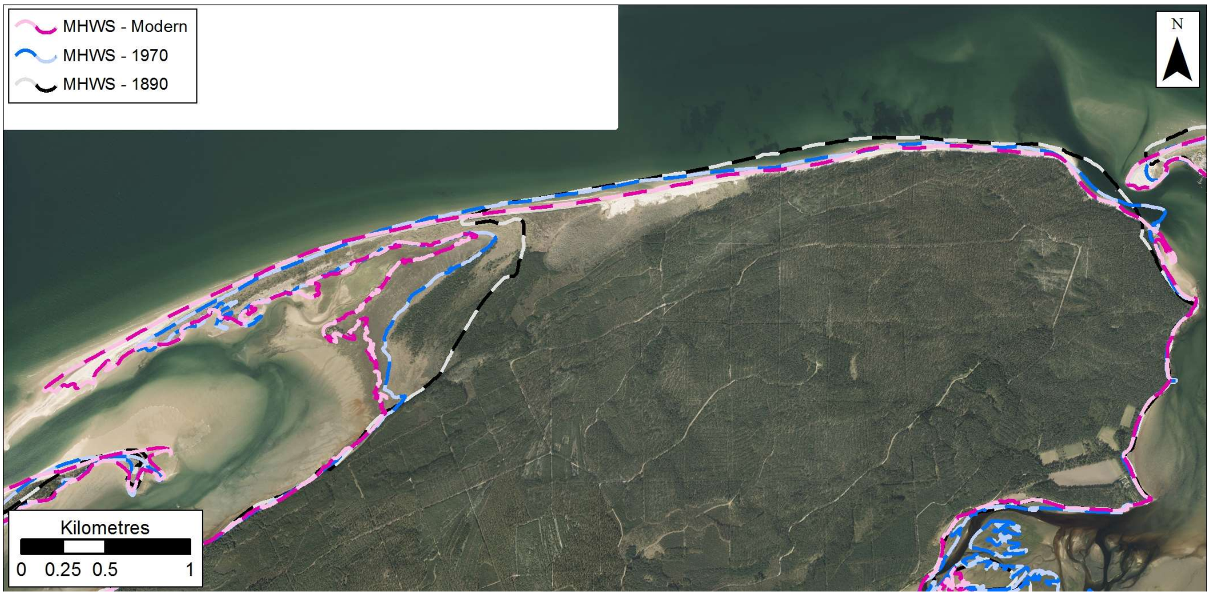

Figure 3.13: MHWS position in 1890, 1970s, and Modern datasets at Culbin Sands. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

The tip of the eastern recurve (the Buckie Loch Spit) has extended westwards 2 km between 1904 and 1976 (28 m/yr). Since 1976 the OS MHWS line has seen little update even though the spit extends another 600m up to 2011 (17 m/yr). The remnant features of older ridges form the central spit. Its eastern part is more sheltered and has been subject to much less adjustment since 1904. The western section however, has seen substantial losses, which have fuelled equally impressive gains to the west. 600 m of losses occurred between 1904 and 1976 at the eastern end of the Flying Bar which led to 870 m of gains, extending the gravels towards Nairn (25 m/yr). Since 1976 there have been comparable losses (740 m, 21 m/yr) and gains (780 m, 22 m/yr) at the eastern and western ends of the Flying Bar, respectively (Figure 3.14).

Culbin Forest contains a Scheduled Monument for its anti-landing obstacles and makes up part of the Moray and Nairn Coast Special Protection Area and Culbin Sands Site of Special Scientific Interest.

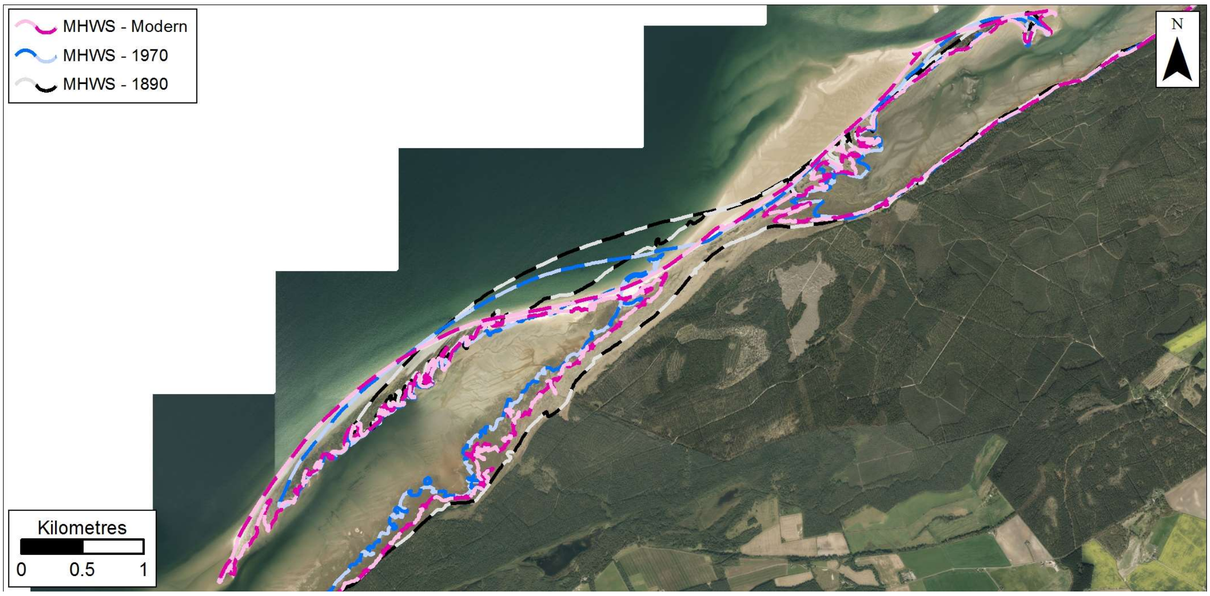

Figure 3.14: MHWS position in 1890, 1970s, and Modern datasets at Culbin Sands. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

Future Vulnerability: The Vulnerability Assessment projects the past erosion rate (since the 1970s) into the future to 2050 and 2100. For Culbin Sands and Forest this continues the well documented past changes, namely the erosion of high dunes along the eastern part of the site will continue to fuel accretion and spit extension within the Buckie Loch Spit and Flying Bar (Figure 3.15). Whilst the sheltered shorelines in the lee of the recurves may experience some accretion this is expected to be short-lived until the eastern end of the bar passes over them.

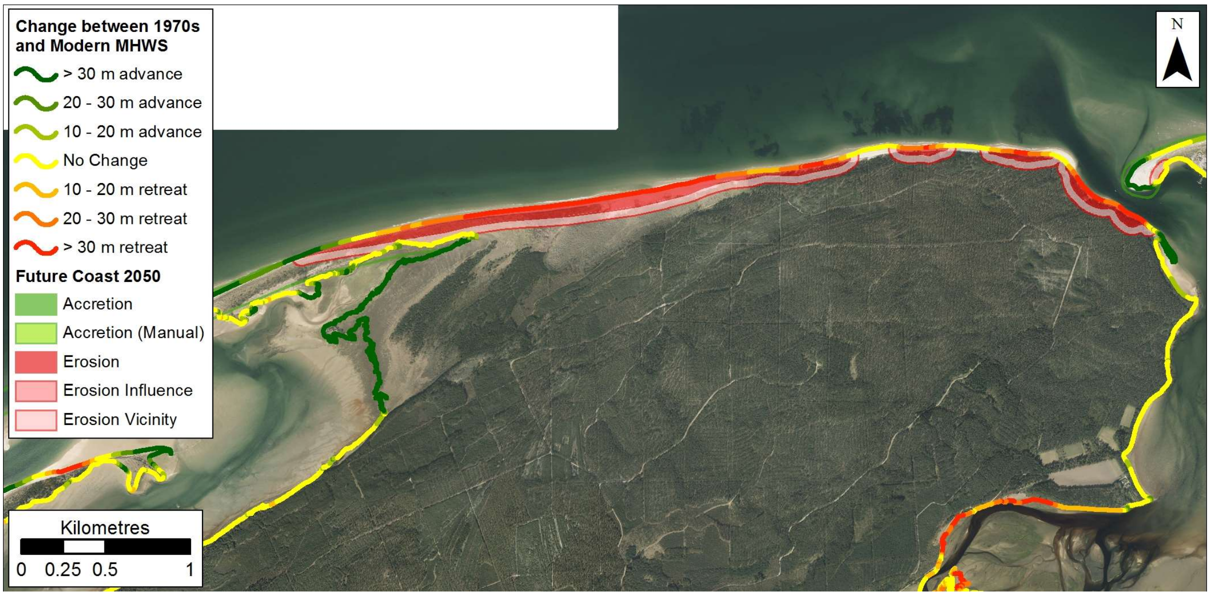

Figure 3.15: Possible future coastline position in 2050 based on rates between 1970 and Modern MHWS data at Culbin Sands. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

Alongside the forestry plantation, there are cultural and natural heritage interests, but very few built structures. Whilst the loss of forestry has been mitigated through pre-emptive harvesting in erosional areas, the negative consequences of erosion and accretion are limited within the dunes and forestry. It is more likely that the sedimentation off Nairn (Figure 3.16) will present more of a concern for the existing pleasure-craft navigation (already tidally limited) and for flood risk as the lower reaches of the River Nairn become ever shallower. Given the rapid westerly movement of the Flying Bar (22 m/yr) and the fact it extends below tide level may mean that it is off Nairn within a decade or so. Whilst this may be 'Scotland's SandMotor' it may present safety issues as have been reported with the Dutch Sand Motor (link). This also results in the 'sea views' Nairn current enjoys changing in the coming years (Nairn is behind the bar in 113 yrs and out again in 272 yrs).

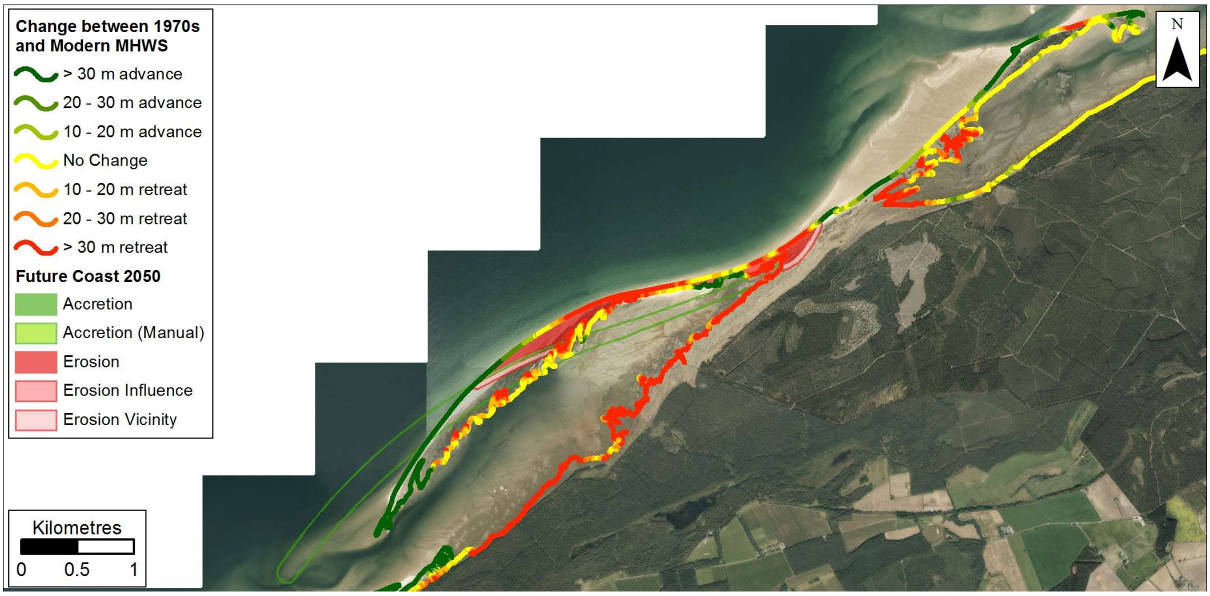

Figure 3.16: Possible future coastline position in 2050 based on rates between 1970 and Modern MHWS data at Culbin Sands. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

4c.3 Whiteness Head (Site 34)

Historic Change: Whiteness Head lies 5km to the west of Nairn. In 1903, it was composed of a 2.6 km long spit extending northwest from the Carse of Delnies, which enclosed an area of sand flat and salt marsh (Figure 3.17). By 1976, the spit had extended a further 1.2km (16 m/yr) enclosing a tidal channel which along with the surrounding area, was developed into an oilrig fabrication yard in the early 1970s (Hansom, 2003). Substantial volumes of sediment were dredged to deepen the shallow tidal channel which was reused to claim an extensive area of land for the yard. The eastern end of the spit experienced up to 60 m of erosion over this period (0.9 m/yr) which was carried westwards extending the spit towards the northwest. Following creation of the yard, substantial volumes of sediments have been removed from the tip of the spit and deposited within the dunes to the south of the navigation channel. These gains have been substantial and long-lived. Maintenance dredging continued until the yard closed in 2001. This has resulted in the spit being held in largely the same position as it was in the 1970s. In contrast, the dredged sediments were deposited south of the channel with resultant gains on the coast adjacent to White Ness Sands.

Along its entire length, the north-eastern facing coast of Whiteness Head has retreated between 25 and 40 m between 1976 and 2011 (up to 1.1 m/yr) (Figure 3.18). Following the closure of the yard, dredging ceased and the sediments accumulated at the tip of the spit once again. The orientation of growth was now to the west and south west, as the spit was entering deeper water than before. This orientation change has forced the tidal channel southwards which has eroded up to 120 m of dunes.

Air photography confirms the infilling of subtidal sediment within the former dredged channel which now spills sediments into the former harbour (to the east) but also southwards on to Whiteness Head Sands. Whilst some of the adjacent dunes have seen up to 48 m of erosion between 1976 and 2011, a southerly spit has formed extending some 200 m in the intervening 35 years (5.6 m/yr). Separate studies have estimated the sediment supply passing around the point at Whiteness Head in the order of 160,000m^3/yr.

Whiteness Head falls within Nairn West and Ardersier Potentially Vulnerable Area and contributes to the Inner Moray Firth Special Protection Area and Whiteness Head Site of Special Scientific Interest.

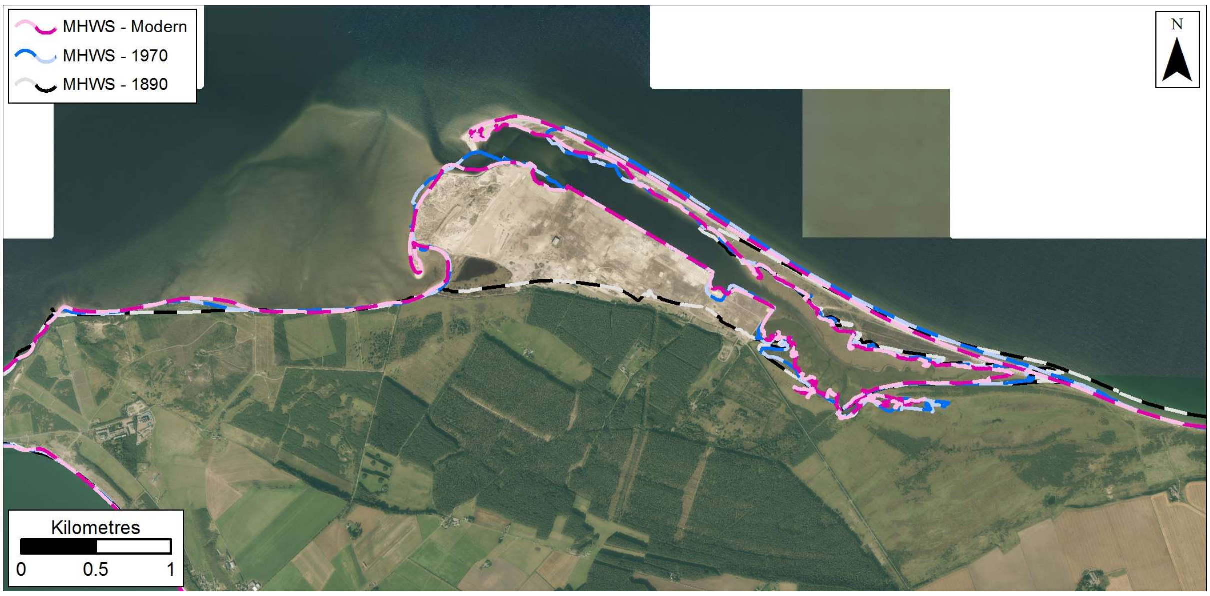

Figure 3.17: MHWS position in 1890, 1970s, and Modern datasets at Whiteness Head. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

Future Vulnerability: The vulnerability assessment projects the past erosion rate into the future to 2050 and 2100 and considers which assets may be affected. The dominance of erosion along the majority of the east-facing coast since 1976 is readily verified on the ground with over-wash sediments evident along the spit. A narrow area within the western third of the spit (intentionally dredged to allow rigs to turn in the channel) was partially breached during winter storms in 2014. Erosion is expected to continue between the Carse of Delnies and all but the tip of the spit (Figure 3.18). Given the narrow character of the spit in 2011 (often 25-50 m wide, but has already reduced to less than 15m in places, there is ample evidence for further narrowing and reworking of sediments over the spit (southwards). Such changes should be entirely expected and borne in mind with respect of future development proposals on this brown-field site. Currently the site has planning permissions for both a new town development (postponed after 2006) and a renewables fabrication yard, which has yet to advance due to the Port of Ardersier going into administration. The past, recent and anticipated changes do not present a risk or threat to the nature conservation designation interest of the site.

Figure 3.18: Possible future coastline position in 2050 based on rates between 1970 and Modern MHWS data Whiteness Head. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

Subcell 4d - Inner Moray Firth (Fort George to Chanonry Point)

4d.1 Beauly Firth (south) (Site 35)

Historic Change: Whilst much of the southern side of the Beauly Firth (located to the west of Inverness) has remained stable, a small 25 m section of shore has retreated more than 7m between 2009 and 1994. Whilst this erosion is smaller than the standard threshold of significance, as the time gap is small (1994 to 2009), it does meet the secondary criteria of equal or greater than 0.5 m/yr. The railway line embankment forms the shoreline in 1890 and the area in question, appears to have advanced 15 m up to 1994 then retreated 7m by 2009 (Figure 3.19).

The shore in this section is part of the Inner Moray Firth Special Protection Area and the Beauly Firth Site of Special Scientific Interest.

Figure 3.19: MHWS position in 1890, 1970s, and Modern datasets on the south bank of the Beauly Firth. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

Future Vulnerability: When projected forward for 2050, 40 m of the Inverness to Beauly railway line is intersected and the A862 Inverness to Beauly Road lies within 14m of MHWS 2050 (Figure 3.20). By 2100 (with the continuation of past rates) both road and railway would be within the area eroded.

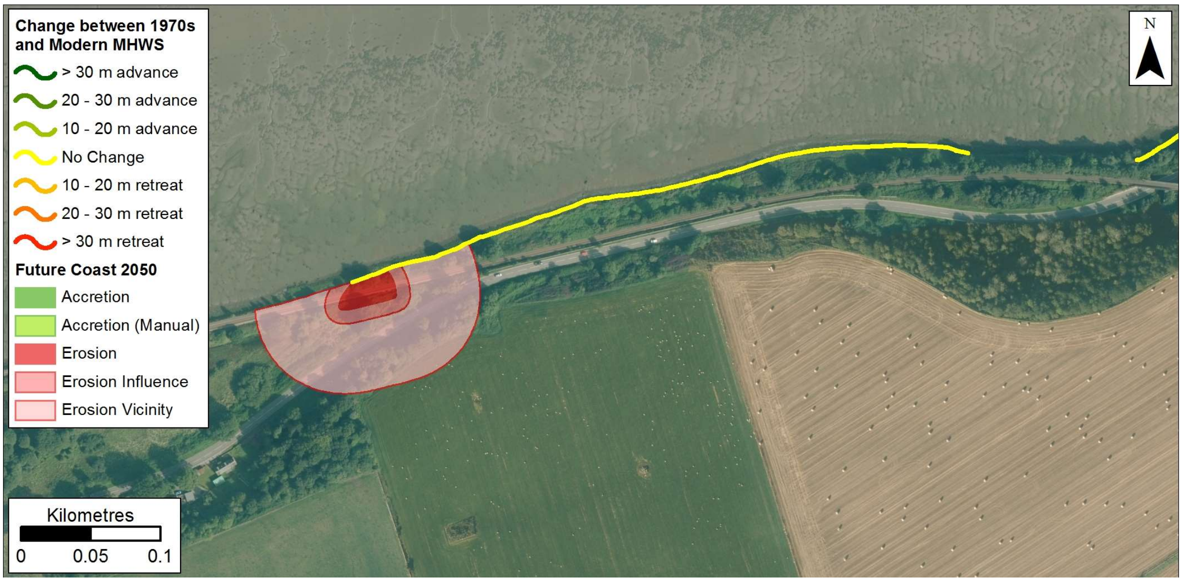

Figure 3.20: Possible future coastline position in 2050 based on rates between 1970 and Modern MHWS data on the south bank of the Beauly Firth. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

Subcell 4e - Chanonry Point to Tarbat Ness

4e.1 Cromarty Firth (Site 36)

Historic Change: Since the 1890s much of the soft coast of the Cromarty Firth has remained stable with most change associated with river / burn mouths and salt marshes. As with other sections of salt marsh, considerable change appears to have occurred since the 1970s although there is some uncertainty in these changes (Figure 3.21). Whilst the modern-day salt marsh extent appears to be consistent with much of the MHWS line in 1904 and 1989, the 2011 position seems further landward, 60m in the case below, to the south of Alness.

This shore forms part of the Alness Potentially Vulnerable Area, and the foreshore contributes towards the Cromarty Firth Special Protection Area and Site of Special Scientific Interest.

Figure 3.21: MHWS position in 1890, 1970s, and Modern datasets near Wester Teaninich in the Cromarty Firth. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

Future Vulnerability: The vulnerability assessment projects the recent past changes (since the 1970s maps) forward to produce a MHWS line in 2050 and 2100. Given the conflicting position of the vegetation extent and changes occurred with the modern shoreline, there is greater uncertainty in these future shorelines. If the MHWS retreats as it has done then in 2050 the A9 may experience erosion (Figure 3.22). The salt marshes are nature conservation designated sites.

Figure 3.22: Possible future coastline position in 2050 based on rates between 1970 and Modern MHWS data near Culcairn in the Cromarty Firth. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

4e.2 Nigg Bay (Site 37)

Historic Change: Much of the dynamism that has occurred within the Cromarty Firth has occurred at river mouths and salt marshes. Nigg Bay forms the northern end of the Cromarty Firth and has been subject to land claim in the first half of the twentieth century. A sediment embankment was constructed across the mouth of an inlet forming a field, as shown in the 1991 mapping (Figure 3.23). Some thirty years after the field was claimed, the RSPB purchased the land and breached the embankment in two places allowing the sea to reoccupy the low-lying ground.

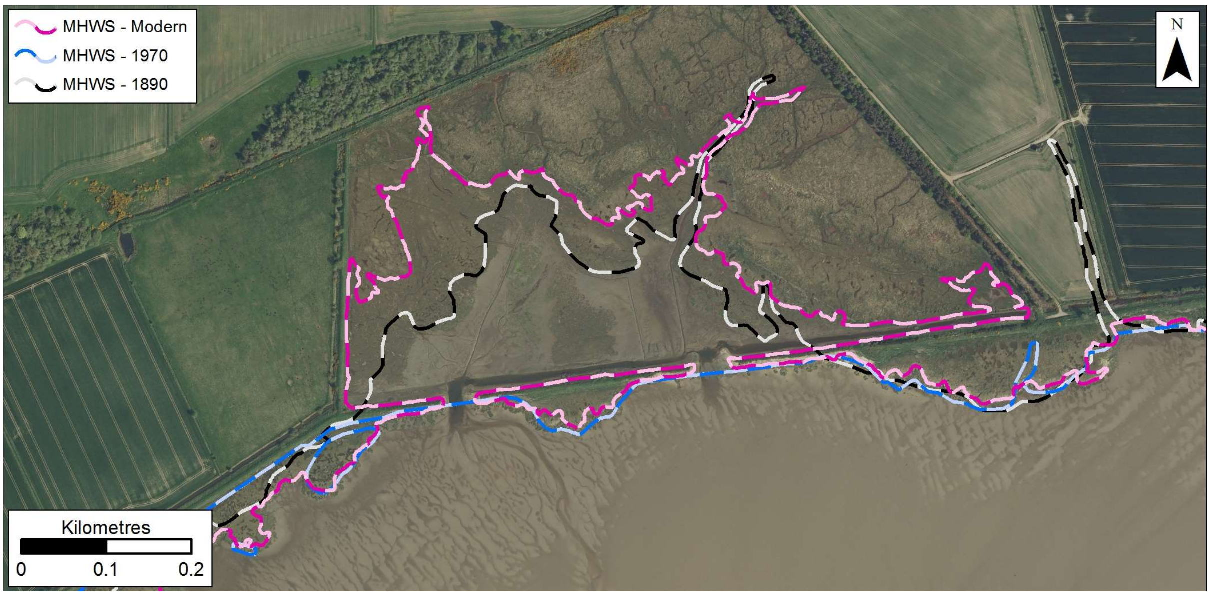

Figure 3.23: MHWS position in 1890, 1970s, and Modern datasets at Nigg Bay. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

This was done to allow natural processes to reoccupy land and reintroduce flora and fauna to these intertidal areas. Salt marsh has advanced up to 50m seawards of the embankment since its installation, and whilst a proportion of this remains, there has been between 5 and 10 m erosion, most likely due to the increased flows passing through breach points. The shore at Nigg Bay contributes to the Cromarty Firth Special Protection Area and Site of Special Scientific Interest.

Future Vulnerability: The 2011 MHWS line lies landwards of its position it did in 1904, however it has been classified as an accretional shoreline. Whilst this may appear contradictory, the remainder of the embankment (between the breach points) will assist in the build-up of sedimentation within the realignment site.

Subcell 4f - Tarbat Ness to Lothbeg Point

4f.1 Morrich More / RAF Tain (Site 38)

Historic Change: Morrich More is an extensive sand dune and salt marsh system stretching over 2,900 hectares into the southern side of the Dornoch Firth. The interior of Morrich More is composed of gravel ridges capped with sand dunes running parallel with the open North Sea coast. The oldest gravel ridge is located east (and inland) from Tain, lies around 9m above mean sea level and was deposited on an open coast some 7,000 years ago (Firth et al., 1995, Hansom, 2003). Over the intervening period subsequent sets of ridges have been laid down as relative sea levels have fallen. Over millennia whilst this has occurred the western-facing shore has experienced erosion, fuelling accretion on the eastern-facing shore. This has resulted in the near shore at Inver becoming increasingly chocked with sediment. Spanish galleons were once reputed to dock at Inver and now you can walk out from the harbour at low tide.

The southern facing shore of Morrich More (closest to Inver) has seen the smallest changes up to 1940, with very modest erosion occurring since. The western and eastern facing shores of Morrich More have seen very significant changes and will be discussed in turn.

The western flank of Morrich More extends 7 km from Tain to the Island of Innes Mhor. Between 1904 and 1977 almost all of it has experienced substantial erosion, resulting in the loss of approximately 14 ha of mainly high dunes (Figure 3.24). In places this reached over 100 m (1.3 m/yr) but most sections lost closer to 60 to 70 m. These losses are substantiated by the presence of former terrestrial peat deposits becoming exposed on the foreshore. Changes on the easterly facing shore are equally dramatic where substantial accretion has occurred. Behind Innes Mhor, in the 73 years after 1904, MHWS has advanced seawards some 460 m and 78 ha of new habitat above MHWS has been formed. Paterson Island (the southerly barrier island) has also formed in this period, resulting in 54 ha of new land. Taken together the 132 ha equates to 1.8 ha/yr (or one and a half football pitches every year).

Figure 3.24: MHWS position in 1890, 1970s, and Modern datasets at Morrich More. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

The 1977 OS maps have seen little update, as a result our analysis relies on the Scottish Government's LiDAR survey in 2011. The erosion on the westerly facing coast produced up to 42 m of erosion in 34 years (1.2 m/yr) and this continued to infill and join the former island of Innes Mhor and Patterson Island to the remainder of the site. The 700 m gap to the south of Innes Mhor has been in-filled by up to 148 ha of new land, mainly salt marsh. The former island of Paterson Island has seen 28 ha gained, although there are losses adjacent to Inver where MHWS has retreated several hundred meters into the interior which has lost 67 ha. The net gain is 106 ha in 34 years equating to 3.1 ha/yr (two football pitches every year).

Morrich More lies within part of the Tarbat Ness Potentially Vulnerable Area and it also contributes towards the Dornoch Firth and Loch Fleet Special Protection Area and Morrich More Site of Special Scientific Interest.

Future Vulnerability: The vulnerability assessment projects the past rate of change into the future for a 2050 and 2100-year shoreline, which is then compared with assets. The initial section of shore from Tain is protected with rock armour then a series of near-shore breakwaters. The methodology excludes these defended areas from the projections for the future coast. However, to the northern limit of the breakwater a 25 m deep erosional bight already exists and by 2050 this is expected to retreat a further 50 m, exacerbating the losses to the forestry plantation (Figure 3.25). The remainder of the western-facing flank of Morrich More is expected to continue to erode as it has for the last 7,000 years. This will result in the loss of some forestry plantation, something Forestry Commission Scotland anticipates within their harvesting schedule. Alongside the trees, nature conservation designated sites will be eroded. The analysis here suggests in area terms at least, the gains are more than compensating for the losses, however the scientific quality and ecosystem services are defined by more than a measure of extent.

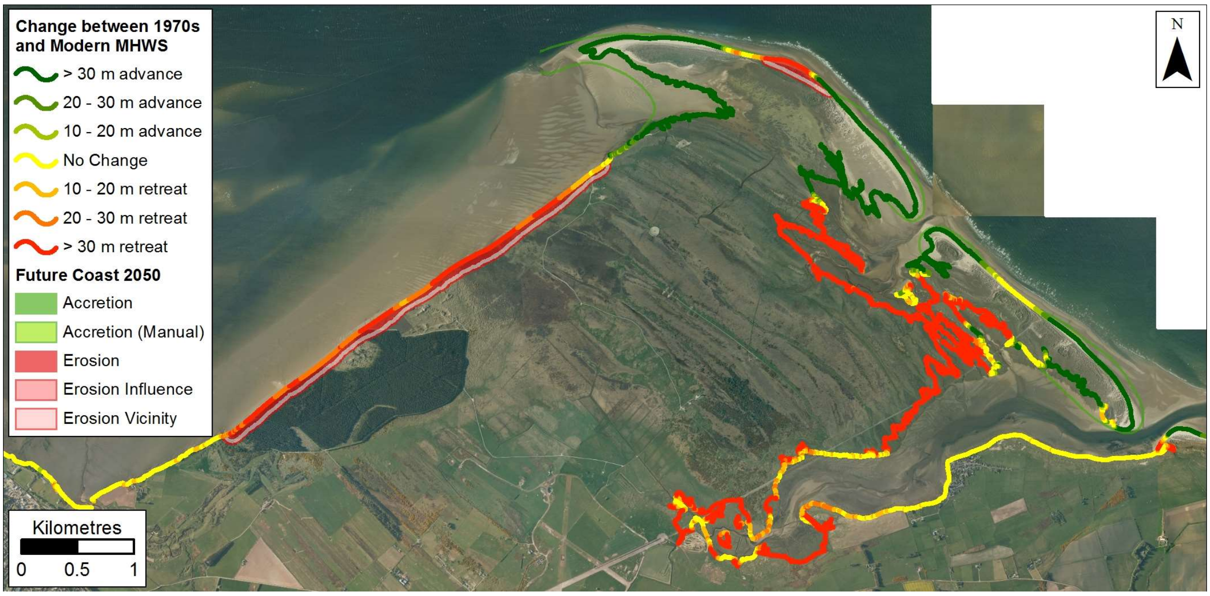

Figure 3.25: Possible future coastline position in 2050 based on rates between 1970 and Modern MHWS data at Morrich More. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

4f.2 Dornoch Point and Sands (Site 39)

Historic Change: The beaches at Dornoch can be subdivided into three sections: North beach towards Embo Pier, Middle beach (north east of the town) and South beach (towards the point). Dornoch Sands extend westwards from the point towards the A9 road bridge.

Much of North beach has remained stable between 1905 and 1980. However, a 280m section of beach did retreat between 20 or 30 m (up to 0.3 m/yr) during this period (Figure 3.26). Middle beach was also stable with insignificant changes up to 1977. The bulk of the changes have occurred on South beach where the shoreline has advanced seawards up to 100m between 1905 and 1980 (1.4 m/yr). Parallel dune ridges and hollows lie where the beach was in 1905. The southern tip of Dornoch Point has been clipped back almost 100m in 75 years, and has moved westwards with a 1905 spit extending some 400m to the west. These active dunes enclose 38ha of salt marsh that has accumulated in the intervening 75 years, with remarkable seaward advances of MHWS (above 400m). Within Dornoch Sands, much of the coast is stable with only a small section of minor erosion fronting the Struie golf course.

Once again, the modern OS MHWS has seen little update, with only minor revisions at the northern end of South beach. The analysis here therefore relies on the 2011 Scottish Government LiDAR survey. North beach has seen accretion within the vicinity of the earlier losses, largely negating them. Middle beach has advanced up to 30m between 1977 and 2011 (0.9 m/yr), and the accretion at South beach has accelerated. Here since 1979, MHWS has advanced seawards up to 220 m (6.8 m/yr). The advances, like the earlier period, are curtailed towards the Point where erosion dominates on the easterly facing edge. Since 1979 Dornoch Point continued to move south up to 250 m, occupying its most southerly position yet. Further accretion occurred within the enclosed spit, however much of the 1.5 km of shore remained largely stable since 1979. The notable exception to this is a small area of erosion abutting the Struie golf course that is now the subject of a proposed rehabilitation project. Recent erosion has also occurred on adjacent farm land, however the remainder of the bay to the west is largely stable.

Figure 3.26: MHWS position in 1890, 1970s, and Modern datasets at Dornoch Point. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

Dornoch Sands lies within part of the Dornoch Potentially Vulnerable Area and contributes towards the Dornoch Firth and Loch Fleet Special Protection Area and Morrich More Site of Special Scientific Interest.

Future Vulnerability: The future shorelines on North, Middle and South beach at Dornoch are expected to be stable or accretional in the future. Dornoch Point is expected to continue to broaden and move westwards, as it has done over the last 111 years (Figure 3.27). Further west however, the historical retreat rates have been projected landwards and erosion is anticipated within the Struie golf course and farmland 1km to the west. Apart from the farmland there are few built assets in this area, although there are two houses which are about 60m from the 2100 MHWS line. The nature conservation designated sites are unlikely to be negatively impacted by the erosion.

Figure 3.27: Possible future coastline position in 2050 based on rates between 1970 and Modern MHWS data at Dornoch Point. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

4f.3 Coul Links (Site 40)

Historic Change: Coul Links lies between Dornoch and Loch Fleet and contains an extensive and (currently) undeveloped dune system, with high coastal dunes, low-lying dune slacks and extensive dune heath. At the time of writing, the dunes are currently subject to pre-application discussions with the Highland Council regarding a possible golf course development.

The southern section of Coul Links has seen modest retreat between 1904 and 1977 of generally less than 20 m (0.4 m/yr). The last kilometre before the mouth of Loch Fleet saw the greatest changes with losses up to 80 m and gains up to 50 m (Figure 3.28).

Since the 1977 survey the OS mapping has not been updated and pre-existing 3-dimensional data does not exist. Despite commissioning an aerial survey in 2015 the production of height data has proved troublesome. Whilst efforts are still ongoing, some analysis has been done to compare the position of the vegetation edge in recent years. Aerial imagery, taken in 2009 and 2015, are compared and supplemented here with field survey in 2016. Figure 3.29 depicts the changes over recent years which support earlier field evidence that between 5 and 15 m of dunes were lost in the winter storms in 2014. The changes between 2015 and 2016 are lower and large areas remainedy stable (in orange), some recent erosion continues in places (in pink) fuelling growth towards the mouth of Loch Fleet. Coul Links lies within part of the Dornoch Potentially Vulnerable Area and contributes towards the Dornoch Firth and Loch Fleet SPA and Morrich More SSSI.

Figure 3.28: MHWS position in 1890, 1970s, and Modern datasets at Coul Links. 1970 MHWS line is obscured by the Modern MHWS line as it has not been updated recently. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

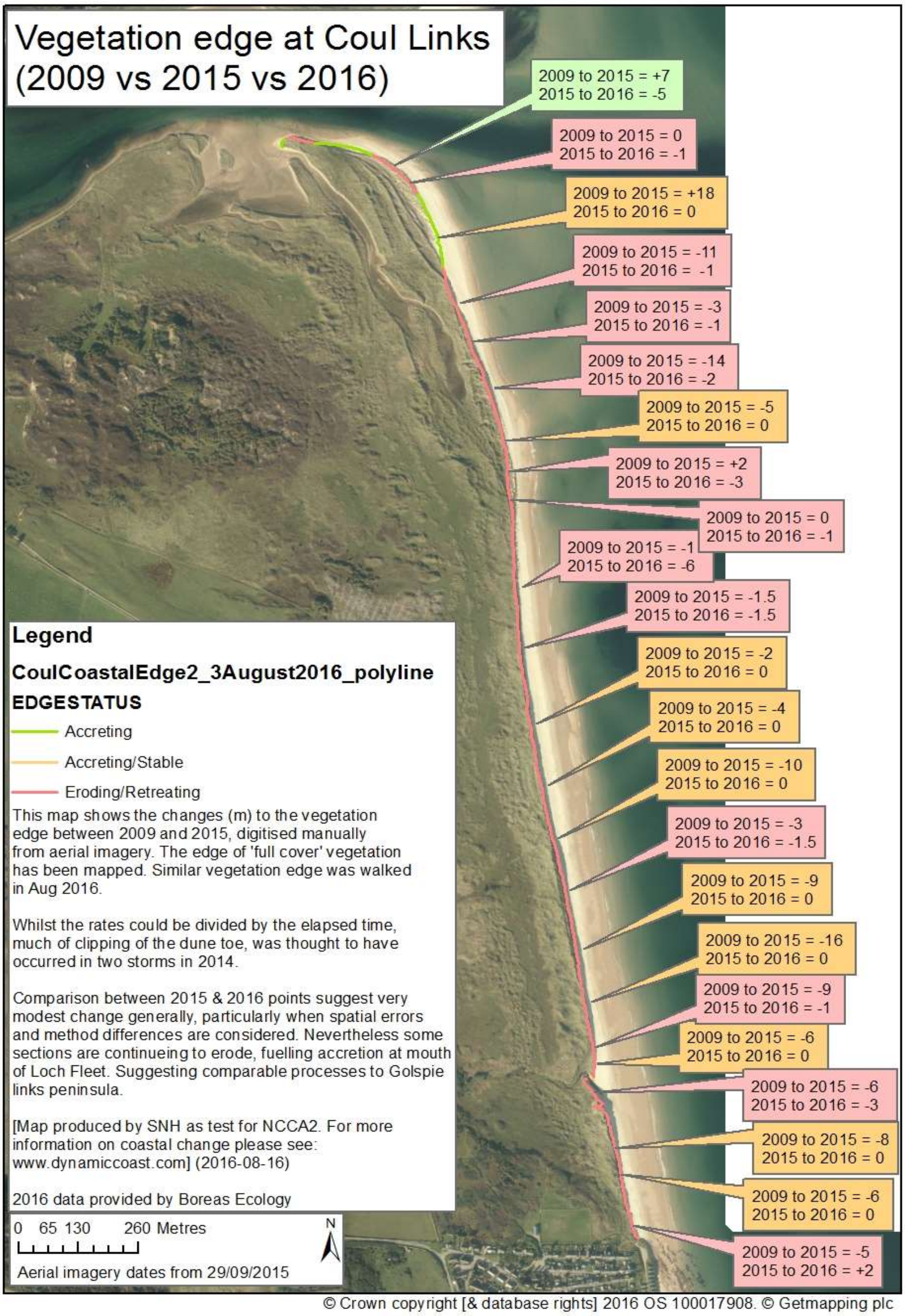

Figure 3.29: Position of the vegetation edge at Coul Links over time.

Future Vulnerability: Given the absence of modern MHWS data the shoreline changes cannot be projected forward and therefore no Vulnerability Assessment can be carried out. Nevertheless, there are no built structures within the coastal dunes in Coul Links, although the site is designated for its natural heritage interests.

4f.4 Golspie Links (Site 41)

Historic Change: The Golspie Links comprise the dune capped peninsula extending southwards from the town of Golspie to the mouth of Loch Fleet. There have been substantial changes between 1904 and 1970 (Figure 3.30) along the golf course frontage with erosion causing MHWS to retreat between 25 and 35 m (up to 0.5 m/yr). This was sufficient to erode the initial Golspie Golf Club House, whose foundations would now lie seawards of MHWS at the northern end of the golf course. The amount of erosion slowed within the current position of the Caravan Park and Kart Track during this period, with losses typically 15 m or (0.2 m/yr). Further south the amount of erosion increased again along the southern half of the links towards Loch Fleet, with some areas retreating more than 120 m over the 73 years.

Figure 3.30: MHWS position in 1890, 1970s, and Modern datasets at Golspie. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

The 1970s saw the installation of coastal defences along the upper beach, which has curtailed the landward movement of MHWS, however this has led to the ubiquitous foreshore lowering (due to increased wave reflection off the defences) and an erosional bite appearing at the southern end of the defences.

The OS MHWS line has seen little update within the northern two thirds of Golspie Links, although it was updated towards Loch Fleet. Fortunately, aerial survey in 2013 and ground survey in 2014 (SNH commissioned) allowed the extraction and update of the modern MHWS. Along the northern section of the golf course the MHWS has retreated up to 17 m (0.4 m/yr), and the central and southern sections have seen losses, as well as the area to the south that shows both recession and beach lowering (Hansom et al., 2013). Winter storms in 2013 and 2014 caused substantial damage to the boulder revetment that extends the full length of the golf course frontage, requiring an emergency rebuild as well as repairs to the seawall at Golspie town. The storms removed substantial volumes of sands and gravels from the golf course beach as well as from the beaches to the south at the caravan park and kart track, transporting these southwards into the National Nature Reserve, well beyond the limit of the Kart Track so that this southern area has shown accretion as a result. This is a continuation of a long-standing trend of erosion in the north and accretion in the south noted by Hansom et al., (2013). At the southern limit of the golf course revetment, erosion of the main beach ridge has progressed leading to lowering and landward movement of the beach crest in multiple locations. This led to flooding and inundation of the caravan park and kart track facilities in 2014. Several sets of repairs have recently been implemented, to reform by bulldozer, the fronting gravel ridge to the caravan park and a rubble embankment placed along the kart track frontage. To date, ground inspection reveals that the reformed gravel ridge has successfully maintained its position but the kart track rubble embankment has seen significant erosion. A beach feed proposal has been developed to address the issues but have not yet been actioned.

Further south, the NNR has received much of the eroded sediments from the north and has experienced considerable accretion.

The Golspie Links fall within the Golspie Potentially Vulnerable Area and form part of the Dornoch and Loch Fleet Special Protection Area, Loch Fleet Special Area of Conservation, Site of Special Scientific Interest and National Nature Reserve.

Future Vulnerability: When the past rates of change are projected forward on the undefended sections of coast, there are three areas of major change. The central and southern section of the 2050 future shoreline show substantial retreat through the main dune ridge and into the interior of the National Nature Reserve. Whilst this is likely to result in the loss of habitats, given the anticipated dominance of natural processes this is unlikely to be interpreted as damage, rather natural change. Closer to the kart track and the golf club, the influence of defences is likely to be greater. The erosion initiates at the end of the defences, and may open a flood channel (if the dune ridge is breached). Two buildings at the kart track lie some 60m from the 2050 MHWS line (Figure 3.31), however these buildings are likely to be flooded before they are eroded (as was the case in 2014).

The future coast 2050 also shows an erosional bight along the golf course frontage. Whilst the shore is defended and has been since the early 1970s; there is a low-lying section of coast whose defences approaching the fifth green, have deteriorated through time (confirmed by time-series air photos). During two east-coast storms in 2014, substantial damage occurred along the whole of the links, and sections of the boulder defence at the golf course failed and erosion propagated inland. For this reason and the continued weak point here, the shoreline has been projected landward at the past rate (this is not normally done for defended shores).

Figure 3.31: Possible future coastline position in 2050 based on rates between 1970 and Modern MHWS data at Golspie. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

4f.5 Dunrobin Castle (Site 42)

Historic Change: Dunrobin Castle is listed as a Garden of Designed Landscape. The shoreline at Dunrobin Castle reflects both human intervention and the subsequent adjustment of the shoreline under natural processes. Along much of the shoreline at the castle and gardens the position of MHWS in 1904 was landward of its position in 1962 and its current position (Figure 3.32). Much of the shoreline advanced prior to the position in 1962, and given the angular geometry this is assumed to be land claim. Much of the shoreline has then subsequently eroded to its position in 2013 (Figure 3.33). Given the continued presence of coastal defences, the NCCA has assumed these will hold MHWS at or near its present position.

Figure 3.32: MHWS position in 1890, 1970s, and Modern datasets at Dunrobin Castle. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

Figure 3.33: Evidence of erosion at Dunbrobin Castle in 2000.

Future Vulnerability: Whilst much of the shoreline at Dunrobin Castle and gardens are defended and therefore have not had erosion rates projected landwards, there are some undefended sections where the position of the future coast has been estimated. Two pockets of erosion occur to the north of the castle and threaten the adjacent land (Figure 3.34). The assets anticipated to be threatened by 2050 are an access road and the designed landscape adjacent to Dunrobin Castle, listed on Historic Environment Scotland's Inventory of Garden and Designed Landscapes.

Figure 3.34: MHWS position in 1890 and 1970s, and the change between 1970s and Modern MHWS position at Dunrobin Castle. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

4f.6 Brora (Site 43)

Historic Change: To the south of the River Brora, the 1904 shoreline saw significant erosion up to 1962. Subsequently the shoreline has recovered slightly although in places this advance is due to coastal defences and land claim. Between 1962 and 2013 there were reasonable intermittent areas of accretion to the south of the river's mouth (Figure 3.35).

To the north of the river's mouth, the 2013 shoreline has fluctuated within 10 m of the 1904 position, however in 1964 MHWS was located further landward than the 2013 position. Unfortunately, the Brora shore experienced storm damage (as did adjacent shores) in two storms in 2014, which post-dates the 2013 LiDAR survey. A 2015 air survey was commissioned by SNH which at the time of writing has not yet been processed into a quality assurance approved surface.

Future Vulnerability: Given the absence of data following the 2014 storm, there is erosion occurring which is not fully apparent within this analysis. Although projections of the anticipated future 2050 shoreline are not possible at present, the area north of the river Brora is of concern in view of the likelihood of artificial defences being inserted by the golf course to restrict shoreface movement on a shore that is currently largely natural.

Figure 3.35: MHWS position in 1890, 1970s, and Modern datasets at Brora. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

4f.7 Brora to Helmsdale (Site 44)

Historic Change: North of Brora the coastal strip becomes increasingly confined by steeper land to the west. The main trunk road (A9) and Inverness to Wick rail line runs along this narrow strip of land, which also contains much of the housing and other assets. A comparison between the 1904 maps and modern maps shows that in several places the railway line was built immediately adjacent to or vertically above MHWS (or HWMOST as it was then). This would suggest that many stretches of the rail line were defended then and so have been defended for over 110 years. Fluctuating beach levels and hydraulic plucking of the masonry is unlikely to be a new problem for these sections. At the time of writing, repairs are being planned on a section of seawall 1.5 km west of Lothbeg Point. 0.5 km north of Dunchalm has experienced significant erosion in the past where the 1962 MHWS line has retreated by up to 17m to within 5m of the MHWS position of 1904 and within 15 m of the railtrack centre line (Figure 3.36). More generally much of this shoreline has fluctuated by modest amounts since 1904. There are over 6 kms of railway line within 50 m, and 130 m within 10 m f MHWS between Brora and Helmsdale. Helmsdale is notified as a Site of Special Scientific Interest. On the images the rail line (depicted in brown) generally sits closer to the coast than the A9 (depicted in grey).

Figure 3.36: MHWS position in 1890, 1970s, and Modern datasets between Brora and Lothbeg Point. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

Future Vulnerability: Whilst there are numerous sections of coastline where the railway line runs along MHWS or adjacent to it, it is to the north of Dunchalm where the past rates suggest the railway may be affected by erosion by 2050 (Figure 3.37). Whilst the 2050 MHWS lies within 10m of the line, this is likely to be close enough for wave carried sediments and water to hinder its use. In addition, the proximity of the A9 to the anticipated future MHWS along this stretch of coast gives cause for concern.

Figure 3.37: Possible future coastline position in 2050 based on rates between 1970 and Modern MHWS data between Brora and Lothbeg Point. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

Subcell 4g - Lothbeg Point to Duncansby Head

This sub-cell section is dominated by rocky cliffs that are high and resistant to erosion. Other than at Lothbeg Point itself, which is stable, the cliff-foot beaches that exist are small, coarse and gravely.

Coastal Change Statistics for Cell 3

Within the soft sections of Cell 3, **34%** has been **advancing** between **1890 and 1970**; compared with **16%** between **1970 and modern data**.
Within the soft sections of Cell 3, **17%** has been **retreating** between **1890 and 1970**; compared with **22%** between **1970 and modern data**.
Within the soft sections of Cell 3, the **average rate of advance** is **1.5 m/yr** between **1890 and 1970**, and **2.3 m/yr** between **1970 and modern data**.
Within the soft sections of Cell 3, the **average rate of retreat** is **-0.5 m/yr** between **1890 and 1970**, and **-1.8 m/yr** between **1970 and modern data**.
Within the soft sections of Cell 3, **49%** has **not changed** significantly between **1890 and 1970**; compared with **62%** between **1970 and the modern data**.

Table 3.2: A summary of the average rates, average change distances, and lengths of advance, retreat, and no change within sub-cells of Cell 3.

Coastal Cell	Overall change (1)			Advance (2)			Retreat (3)			Insignificant change (4)		
	Average 1890 to 1970 Change on Soft Coast (m)	Average 1890 to 1970 Change Rate on Soft Coast (m/year)	Length of Soft Coast (km)	Average 1890 to 1970 Soft Coast Advance (m)	Average 1890 to 1970 Advance Rate on Soft Coast (m/year)	Length of Soft Coast Advance (km)	Average 1890 to 1970 Soft Coast Retreat (m)	Average 1890 to 1970 Retreat Rate on Soft Coast (m/year)	Length of Soft Coast Retreat (km)	Average 1890 to 1970 Soft Coast Insignificant Change (m)	Average 1890 to 1970 Retreat Rate on Soft Coast (m/year)	Length of Soft Insignificant Change (km)
Sub-cell 3a	1.6	0.02	28.0	22.2	0.30	4.3	-22.4	-0.30	2.9	0.6	0.01	20.9
Sub-cell 3b	6.6	0.09	50.5	46.4	0.63	15.3	-32.2	-0.43	11.8	0.0	0.00	23.5
Sub-cell 3c	92.7	1.27	115.1	189.7	2.60	61.6	-41.1	-0.58	25.1	0.5	0.01	28.3
Sub-cell 3d	3.6	0.04	48.9	22.9	0.27	11.7	-36.0	-0.47	4.5	2.1	0.03	32.7
Sub-cell 3e	5.2	0.06	128.7	29.5	0.55	36.0	-27.0	-0.33	17.9	1.1	0.01	74.8
Sub-cell 3f	39.3	0.53	168.3	141.9	19.26	54.7	-39.1	-0.56	30.3	0.5	0.01	83.4
Sub-cell 3g	9.1	0.14	36.7	38.0	0.59	11.6	-18.9	-0.30	5.5	-0.2	0.00	19.7
Cell 3	32.6	0.44	576.3	112.7	1.53	195.2	-34.8	-0.48	97.8	0.8	0.01	283.3
	-	-	-	-	-	33.9%	-	-	17.0%	-	-	49.2%

Coastal Cell	Overall change			Advance			Retreat			Insignificant change (4)		
	Average 1970 to Modern Change on Soft Coast (m)	Average 1970 to Modern Change Rate on Soft Coast (m/year)	Length of Soft Coast (km)	Average 1970 to Modern Soft Coast Advance (m)	Average 1970 to Modern Advance Rate on Soft Coast (m/year)	Length of Soft Coast Advance (km)	Average 1970 to Modern Soft Coast Retreat (m)	Average 1970 to Modern Retreat Rate on Soft Coast (m/year)	Length of Soft Coast Retreat (km)	Average 1890 to 1970 Soft Coast Insignificant Change (m)	Average 1890 to 1970 Retreat Rate on Soft Coast (m/year)	Length of Soft Insignificant Change (km)
Sub-cell 3a	2.3	0.18	27.4	18.8	0.63	6.9	-18.1	-0.53	0.6	1.3	-0.04	19.9
Sub-cell 3b	0.0	-0.04	43.4	26.6	0.87	8.3	-22.1	-0.94	9.9	-0.2	0.01	25.2
Sub-cell 3c	5.7	0.19	123.8	96.6	2.86	29.8	-42.1	-1.19	51.5	-0.3	0.00	42.5
Sub-cell 3d	0.9	0.03	53.8	34.2	1.75	5.1	-31.0	-1.74	4.5	0.0	-0.01	44.8
Sub-cell 3e	-5.6	-0.28	128.7	23.6	0.96	12.4	-53.3	-2.49	19.5	0.2	0.01	96.8
Sub-cell 3f	-1.2	-0.05	191.2	104.2	3.10	32.8	-7.3	-2.33	47.3	-0.4	0.00	111.2
Sub-cell 3g	0.6	0.01	34.5	14.4	0.30	1.9	-15.5	-0.35	0.7	-0.1	-0.01	31.6
Cell 3	-0.1	-0.03	602.8	73.5	2.26	97.3	-53.7	-1.78	133.7	0.0	0.00	371.8
	-	-	-	-	-	16.1%	-	-	22.2%	-	-	61.7%

1 Overall change shows the mean value for the whole cell / sub-cell, averaging gains and losses.
2 Advance shows the mean value for the shoreline gains, where there has been greater than 10 m of change, or change which is faster than 0.5 m/yr.
3 Retreat shows the mean value for the shoreline losses, where there has been greater than 10 m of change, or change which is faster than 0.5 m/yr.
4 Insignificant change shows the lengths of coastline which have changed less than 10 m.

NB: Avoid comparing distances of change (i.e. km) but rather use proportions (i.e. %) to avoid cartographic differences between the years.

Table 3.3: A summary of the length of change within each change distance category in the historical (ca. 1890-1970) and recent (ca. 1970-Present) time periods in Cell 3.

1890-1970	Cell 3		Cell 3a		Cell 3b		Cell 3c		Cell 3d		Cell 3e		Cell 3f		Cell 3g	
	Length (km)	**Length (%)**	**(km)**	**(%)**	**(km)**	**(%)**	**(km)**	**(%)**	**(km)**	**(%)**	**(km)**	**(%)**	**(km)**	**(%)**	**(km)**	**(%)**
>30 m Advance	97.9	17%	0.9	0%	7.4	1%	44.3	8%	2.5	0%	9.44	2%	31.09	5%	2.33	0%
20-30 m Advance	28.9	5%	0.7	0%	3.2	1%	6.9	1%	1.8	0%	7.04	1%	5.7	1%	3.6	1%
10-20 m Advance	68.4	12%	2.7	0%	4.8	1%	10.4	2%	7.5	1%	19.52	3%	17.88	3%	5.68	1%
No Change	283.3	49%	20.9	4%	23.5	4%	28.3	5%	32.7	6%	74.8	13%	83.4	14%	19.7	3%
10-20 m Retreat	40.6	7%	1.8	0%	3.2	1%	7.2	1%	2.1	0%	10.44	2%	11.64	2%	4.15	1%
20-30 m Retreat	17.1	3%	0.4	0%	2.4	0%	5.6	1%	0.9	0%	2.97	1%	4.47	1%	0.41	0%
>30 m Retreat	39.9	7%	0.7	0%	6.1	1%	12.4	2%	1.5	0%	4.46	1%	13.83	2%	0.91	0%
Total length	**576.0**	**100%**	**28.0**	**5%**	**50.6**	**9%**	**115.1**	**20%**	**49.0**	**8%**	**128.7**	**22%**	**168.0**	**29%**	**36.7**	**6%**
Max advance (m)	1120.9	Culbin	74		180		1121		97		249		829		773	
Average change (m)	32.6		1.6		6.6		92.7		3.6		5.2		39.3		9.1	
Max retreat (m)	-177	Loch Fleet	-57		-99		-146		-121		-162		-177		-76	

1970-Modern	Cell 3		Cell 3a		Cell 3b		Cell 3c		Cell 3d		Cell 3e		Cell 3f		Cell 3g	
	Length (km)	**Length (%)**	**(km)**	**(%)**	**(km)**	**(%)**	**(km)**	**(%)**	**(km)**	**(%)**	**(km)**	**(%)**	**(km)**	**(%)**	**(km)**	**(%)**
>30 m Advance	51.6	9%	1.1	0%	2.6	0%	20.3	3%	2.4	0%	3.2	1%	22.1	4%	0.1	0%
20-30 m Advance	13.5	2%	0.8	0%	1.6	0%	3.6	1%	1.1	0%	2.5	0%	3.7	1%	0.2	0%
10-20 m Advance	30.4	5%	4.8	1%	3.6	1%	5.8	1%	1.6	0%	6.2	1%	6.8	1%	1.7	0%
<10m Advance but >= 0.5 myr^{-1}	1.8	0%	0.3	0%	0.5	0%	0.1	0%	0.1	0%	0.5	0%	0.3	0%	0.1	0%
No Change	371.8	62%	19.9	3%	25.2	4%	42.5	7%	44.8	7%	96.8	16%	111.2	18%	31.6	5%
<10m Retreat but <= -0.5 myr^{-1}	1.8	0%	0.0	0%	0.1	0%	0.0	0%	0.8	0%	0.6	0%	0.3	0%	0.0	0%
10-20 m Retreat	40.9	7%	0.4	0%	5.3	1%	13.9	2%	1.4	0%	7.4	1%	11.9	2%	0.6	0%
20-30 m Retreat	22.5	4%	0.1	0%	2.3	0%	11.5	2%	0.5	0%	2.8	0%	5.2	1%	0.1	0%
>30 m Retreat	68.6	11%	0.1	0%	2.1	0%	26.1	4%	1.7	0%	8.7	1%	29.9	5%	0.0	0%
Total length	**602.8**	**100%**	**27.4**	**5%**	**43.4**	**7%**	**123.7**	**21%**	**54.4**	**9%**	**128.7**	**21%**	**191.3**	**32%**	**34.2**	**6%**
Max advance (m)	652	Culbin	58		102		652		128		93		642		49	
Average change (m)	-0.1		2.3		0.0		5.7		0.9		-5.6		-1.2		0.6	
Max retreat (m)	-421	Morrich More	-42		-86		-183		-124		-349		-421		-29	

Asset Vulnerability Statistics for Cell 3

Table 3.4: A summary of the number, length, or area of assets within the erosion, erosion influence, and erosion vicinity buffers of the future coastline projections for Cell 3.

Cell 3	Units	Modern to 2050				2050+			
		Erosion	Erosion Influence	Erosion Vicinity	Total	Erosion	Erosion Influence	Erosion Vicinity	Total
Community Services	Number	-	-	-	-	-	-	-	-
Non Residential Property		-	-	2	2	1	-	6	7
Residential Property		-	1	4	5	-	1	7	8
Septic Water Tanks		-	-	1	1	-	-	1	1
Utilities		-	-	-	-	-	-	-	-
Rail	Length (km)	0.0	0.0	0.6	0.7	0.1	0.1	0.5	0.7
Roads (SEPA)		0.6	0.2	1.3	2.1	1.1	0.2	1.5	2.8
Roads (OS)		0.2	0.2	0.3	0.7	0.5	0.1	0.5	1.1
Clean Water Network		0.2	0.1	0.6	0.8	0.4	0.0	0.9	1.3
Total Anticipated Erosion	Area (hectares)	145.3	38.8	218.8	403.0	307.4	40.7	232.0	580.1
Runways		-	-	-	-	-	-	-	-
Cultural Heritage		0.7	0.4	3.6	4.7	1.6	0.6	4.3	6.4
Environment		85.9	19.5	94.9	200.3	173.6	18.0	87.3	278.9
Flooding (200 year envelope)		84.0	12.5	64.4	160.8	143.3	13.2	69.5	226.0
Flooding (1000 year envelope)		90.6	14.3	73.8	178.7	156.5	14.8	79.5	250.8
Erosion within PVAs		48.2	15.0	82.6	145.8	103.7	14.8	86.6	205.0
Erosion outwith of PVAs		97.2	23.8	136.2	257.2	203.8	25.8	145.5	375.1
Battlefields		-	-	-	-	-	-	-	-
Gardens and Designed Landscapes		0.1	0.2	2.0	2.4	0.3	0.3	2.3	2.8
Properties in Care		-	-	-	-	-	-	-	-
Scheduled Monuments		8.1	0.9	9.4	18.4	12.3	2.0	12.2	26.5
Nature Conservation Marine Protected Areas		-	-	-	-	-	-	-	-
National Nature Reserves (NNR)		7.3	1.7	8.8	17.7	17.7	1.6	8.7	28.0
Special Areas of Conservation (SAC)		50.4	10.2	50.6	111.1	98.9	10.7	50.1	159.7
Special Protection Areas (SPAs)		76.0	13.6	65.5	155.1	153.0	12.6	62.9	228.4
Sites of Special Scientific Interest (SSSI)		93.7	20.5	100.8	215.1	193.0	19.8	97.0	309.7

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