CREW CENTRE OF EXPERTISE FOR WATERS

Dynamic Coast

The National Overview (2021)

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A.F. Rennie, J.D. Hansom, M.D. Hurst, F.M.E Muir, L.A. Naylor, R.A. Dunkley, & C.J. MacDonell

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The cover image shows: (Top) Storm waves reflecting and undermining artificial defences at Golspie, Highland. Copyright: A. MacDonald (2020). (Bottom left) coastal erosion of the beach crest adjacent to the World Heritage Site at Skara Brae, Bay of Skaill in Orkney. Copyright: A Rennie / NatureScot (2019). (Bottom right) an oblique aerial image of the Splash play park at Montrose looking north. In the 1980s the play park was set-back within the dune, due to the subsequent coastal erosion, now it is in a more exposed position relying on artificial coastal defences. Copyright: F. McCaw (2021).

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Dynamic Coast Aims

The Dynamic Coast project aims to provide the strategic evidence base on the extent of coastal erosion in Scotland. This will support the Scottish Government and the Scottish Public Sector decision-making and indicate areas of highest coastal erosion risk, where a more detailed evidence base may be required. The initial research published in 2017, provided businesses and communities with readily interpretable evidence and modelling, based on historic erosion, of anticipated erosion extents and rates. This 2021 publication updates and supersedes the 2017 work, by including increased extents of eroding shoreline and the latest climate change projections on sea level rise, with an aim to help society become 'sea level wise' by planning now for our changing climate.

There is international recognition that, for many countries, some of the first and most obvious effects of climate change will be through increased erosion and flood impacts on the coastline. Governments and organisations around the world are undertaking risk assessments to inform and shape new flexible adaptive approaches to better manage these growing risks. Many European partners and fellow UK administrations are searching for more sustainable approaches to address anticipated changes to our coastal assets. As relative sea level continues to rise, and storm impacts increase, many are questioning the assumption that existing artificial coastal defences should be raised and extended. The United Nations Intergovernmental Panel on Climate Change (IPCC) anticipates that the default management approach on the coast will become 'avoidance and adaptation' rather than the current 'hold-the line' via artificial defences. But where, when and how might adaptation be implemented? Given the lifespan of Scoland's coastal infrastructure and other assets, together with the IPCC predictions of anticipate climate change, the most appropriate route forward is by framing proposals within the precautionary principle, supported by a robust evidence-base of past changes and modelling of anticipated future changes, checked against appropriate coastal monitoring.

Coastal erosion is widely acknowledged to be a cross cutting issue affecting disparate interests (infrastructure, cultural and natural heritage, port facilities etc.) and a coordinated approach to align effort across sectors is essential. The need for coordination underpins the Scottish Climate Change Adaptation Programme and the Scottish Government's Water Resilient Places strategy, with adaptation and new ways of thinking at its core. Recognition of adaptive approaches are necessary is starting to occur, within these linked policy areas (i.e. infrastructure planning etc.), but mainstreaming these concepts is essential. Coastal systems are dynamic, complex and uncertain and so using models as a definitive prediction of future change is problematic. Many of the local-scale interactions on coasts are imperfectly understood both individually and in their future interaction with other variables, such as sea level rise and storm impact. There is relative confidence globally of the overall trend of sea level rise, irrespective of the level of future greenhouse gas emissions (IPCC), but less confidence relates to trends in storm frequency and impact. Coastal erosion is rarely a continuous process and depends on storm severity and frequency, yet the anticipated trends in these are not well understood (IPCC). As a result, both monitoring of the coast and agreeing trigger points for implementing action are required, alongside the political and involvement of local communities and asset owners. Future local and national coastal management decisions add to the above uncertainties and are acknowledged within the Scottish Planning System, which emphasises the importance of the 'precautionary principle'; namely where there is doubt, we should err the side of caution.

Key Findings

Coastal erosion is expected to affect an increasing proportion of Scotland's shoreline in the future, and at an increasing rate. The current Dynamic Coast project has investigated the soft / erodible shoreline in Scotland (excluding salt marshes), identifying that coastal erosion now affects 46% of the soft coast, an increase over the 38% identified in 2017. The average rate of erosion currently is 0.43 m/yr, though core methodological differences mean that comparisons with the 2017 average of 1 m/yr should not be made. The proportion of shorelines experiencing coastal erosion, and the rate of erosion, increases under all climate change emissions scenarios. **Effective monitoring of our shore position is essential, to ensure decision makers and communities have up to date evidence of how the coast is changing.**

Current and anticipated coastal erosion has substantial implications for society's assets. Under a High Emission climate scenario[1] if we do not maintain our artificial and natural defences (no action is taken) then an estimated £ 1.2B of assets are likely to be at risk of erosion, increased flood risk and loss of services by 2050. This includes approximately 647 residential properties, 5km of rail and 55km of road likely to be affected by erosion in the next thirty years. **Society and businesses need to critically recognise and invest in resilience and adaptation measures for both artificial and natural coastal defences.**

Mapping all artificial and natural coastal defences allows their relative contribution to be assessed nationally. Artificial defences protect £ 5B of assets with natural defences protecting £ 14.5B of assets. Asset risk assessments must be framed along a spectrum from cautious to optimistic: a cautious approach quantifies assets at risk, without the assumption that coastal defences will be maintained in perpetuity; an optimistic approach assumes the future maintenance of these defences is assured and then considers any residual impacts. Whilst society is currently content to install, maintain and fund artificial structures, international recognition is growing of the importance of maintaining and enhancing natural coastal defences, for example by Building with Nature. **Nationally, society needs to value both natural defences and artificial defences, strategically investing in resilience where needed, and adaption where possible, to secure a sustainable lower-cost future.**

The time lag between atmospheric temperature rise and subsequent sea level rise means that, regardless of how effectively we cut the emission of greenhouse gases, we are already on track for future sea level rise and associated coastal change. By 2100, 84% of soft shorelines are anticipated to be erosional under a High Emissions Scenario, this falling to 56% under Low Emissions Scenario. A partial costing of the assets at risk was undertaken by Dynamic Coast as follows: Under a High Emissions Scenario and 'do nothing coastal management strategy' (the precautionary baseline for risk assessments where artificial and natural defences are not maintained), an estimated £1.2B worth of assets are expected to be affected by erosion in the next 30 years, this falling to an estimated £ 814M under a Low Emissions Scenario. **Whilst it is critical that we mitigate climate change by reducing emissions, we also need to adapt to the sea level changes that are already under way by altering our approach to coastal planning and land-use.**

Most of the coastal erosion risk clusters within a few local authority areas. Most affected are Highland and Argyll and Bute, however few coastal local authorities are immune from risk to property and infrastructure near the coast, including residential and non-residential properties, industry, utilities and transport infrastructure. This does not include where current defences have prevented coastal change to date but may not in the future. **Local authorities can use Dynamic Coast to identify their areas of greatest concern, but effective and appropriate resilience and adaptation actions may need further evidence gathering and consensus building to succeed.**

Behind these national and regional assessments, detailed local assessments inform more complex changes, which threaten some of Scotland's treasured coastal assets. Working with partners we have investigated six super sites as exemplars of how any combined localised coastal erosion and flood risks may change in the future. **Detailed assessments at super sites demonstrate that short-term resilience measures enacted now can buy time and space for adaptive planning to be put in place for the medium and long-term future.**

Coastal erosion, coupled with sea level rise, increases the frequency of flooding such that long term inundation will become more common in the near future. Dynamic Coast shows that coastal erosion and erosion-enhanced flooding is a current threat with the greatest number of current coastal flood-prone areas expected to be breached within this decade, rather than later in the century. **Coastal erosion and enhanced flooding are anticipated to increase into the future.**

Coastal erosion is expected to contribute to more frequent coastal flooding causing damage and disruption to land-owners, residents and travel networks. It is not possible to separate erosion and coastal flooding where an eroding coast fronts, or is adjacent to, a low-lying area. Dynamic Coast shows that erosion of the shoreline increases the coastal flood risk via the potential to breach or remove a protective natural barrier, for example, beach or dunes. **Maintaining the health of natural protective barriers is key since coastal erosion enhanced flooding is a growing threat, impacting greater numbers of people and assets than coastal erosion alone.**

The evidence base for change on salt marsh shores requires an alternative approach. This needs to track both the changes in saltmarsh extent (informed by the seaward vegetation edge) and height changes (through repeated three-dimensional surveys including time-lapse LiDAR). Although salt marshes occupy a small percentage of Scotland's coastline they provide important ecosystem services, including habitat for internationally and nationally important species, sequestration of atmospheric carbon dioxide, as well as flood protection. NatureScot is investigating the semi-automatic extraction of vegetation edges from historic and current aerial imagery as a promising approach to establishing the extent and changes to these important areas. **Enhancing the evidence base of changes in extent and height on salt marsh shores is an important area for flood risk management, nature conservation and blue carbon estimates.**

Maintaining the health of natural protective barriers is possible by artificially delivering natural sediment to recharge protective beaches and dunes. Declining sediment supply to beaches aids erosion and sea level rise drives a need for more sediment to maintain beach equilibrium. One environmentally beneficial source is from recycled dredged sediment from navigation channels and offshore. Such use of Nature-based Solutions (NbS), known internationally as Building with Nature (BwN), is widely recognised as an important resilience and

adaptation tool, but it remains clear that adaptation and avoidance will also be required in the future. **Recycling sediment dredged from navigation channels, alongside offshore marine sources, will become increasingly important for beneficially recharging some coastal systems, albeit with due diligence to avoid unintended impacts at source and deposition areas.**

Social vulnerability to coastal erosion is unevenly distributed. Dynamic Coast's initial assessment shows uneven social vulnerability across coastal local authorities and data is available for those local authorities most affected to take forward. More detailed and targeted work is needed. **Dynamic Coast data can be used as part of a Just Transition to ensure those coastal residents more vulnerable to the effects of climate change can be provided with greater assistance.**

Climate change is exacerbating coastal erosion, increasingly threatening society assets, however with Dynamic Coast evidence our ability to act and adapt is greatly enhanced. Dynamic Coast used enhanced monitoring and computer modelling of future shorelines with future anticipated sea level changes. Anticipated coastal changes for each decade in the 21st century were calculated for three different climate scenarios (UKCP18 RCP8.5 95th%, RCP4.5 50th% and RCP2.6 50th%). Thousands of kilometres of updated shore positions were analysed to assess coastal change: all showing similar results and providing greater confidence in the results. New satellite-based, air-borne and ground-based monitoring techniques offer significant opportunities to further inform future changes, and support improved decision making. **Such updated evidence of coastal changes provides us with enhanced ability to act and adapt to stay resilient.**

Our coastal management approaches nationally have been slow to change. In view of the pace and extent of anticipated coastal change, and the pace of sea level rise, we need dynamic flexible adaptive pathways to maximise accommodation space to allow the coast to move. While best secured through both terrestrial and marine planning to create windows of opportunity, in practice this involves maximising resilience by freeing up space on land to: 1) allow the coast to relocate landward of its current position; 2) avoid redevelopment of coastal assets at risk of erosion; and 3) allocate land for coastal assets to be relocated to less risky sites. Such appropriate adaptive pathway measures are key and may differ from those used for managing flood risk. **Scotland's coastal management and land planning approach needs to change ahead of climate change. The planning system and society must become 'sea level wise'.**

Actionable recommendations

1. Disseminate to all relevant agencies, local authorities etc. to **encourage coastal land use, resilience and adaptation planning** based on this latest national, regional and detailed evidence gathering and assessments. High level commitment is needed to address funding issues. Training packages are needed to enable local authorities to deliver adaptational shoreline management planning.
2. Improve **monitoring of coastal change and natural coastal flood protection features** (wave and tidal dominated shores), as these become affected by erosion in the future. Scotland is the only UK nation without (or not yet committed to) a funded coastal monitoring strategy. Strategic appraisals at erosion and flood vulnerable locations are needed to advise where enhancements are merited.
3. Encourage local authorities and asset managers to take forward a planning approach with **sustainable coastal management** at its core, not only to identify short-term resilience measures, but also to develop adaptation actions and identify trigger-points for dynamic adaptive pathways that span the short, medium and long-term. An adaptive pathways route must also include coastal communities that are properly informed of best practice as well as encouraged to help build the evidence base. This supports communities to have a real role in adaptation planning and good decision making.
4. Recognise the scale of anticipated changes and ensure **terrestrial planning adequately safeguards accommodation space now**, to ensure future resilience and adaptation actions are achievable in the future. This enables greater adaptation flexibility for current and future generations. Scottish Government should issue guidance for local authorities to support this activity.
5. Develop a **coastal change and adaptation fund** to support local authorities and national infrastructure providers in appreciating opportunities for Building with Nature/Nature based Solutions to secure natural coastal defences in the future, and to re-enhance action toward sustainable adaptation at the coast. Scottish Government has confirmed that £ 12M will be available over four years for coastal adaptation from 2022-23.

In order to deliver recommendations 1-6 above we need to:

1. **Encourage and improve data collection, change analysis and risk-based coastal monitoring** for Scotland, and the rest of UK, via regional and local partnerships. Funding is key to resource systematic

time-series data coastal data gathering, such as terrestrial LiDAR or marine LiDAR, to connect coastal plans with the National Marine Plan.

2. **Enhance partnership and co-operative effort** between all agencies, infrastructure providers, Non-Government Organisations and businesses with a coastal remit or interest; but a funding stream is needed to action this.
3. **Embrace transformative change** to foster a shift in perspective away from viewing the coastline as static, linear and fixed, toward a coastal zone approach that values its inherent natural capital of dynamic coastal landforms that serve to improve society's resilience to coastal climate change risk.

Dynamic Coast project key workstream outputs

The research findings above rest on the outcomes of each of the following Dynamic Coast project work streams. Whilst full technical annex reports are available for each work stream (www.DynamicCoast.com/reports), a summary is presented below:

WS1: Coastal erosion, erosion-enhanced flooding and coastal flooding are recognised early impacts of climate change yet have been considered as separate risks despite often occurring together. Dynamic Coast set out to address this fundamental gap. Dynamic Coast juxtaposed anticipated coastal erosion and coastal flood polygons with low-lying flood-prone areas whose flood frequency and extent may increase, due to the erosional loss of protective coastal dune cordons. We also identified areas where flood risk is not linked to coastal erosion. Both set of areas were provided to Scottish Environment Protection Agency and local authorities to support their duties under the Flood Risk Management (Scotland) Act 2009. This analysis provided a first order estimate of the linkages between present and anticipated erosion risk on coastal flood risk that can be supported by more detailed inspection of the inland flood envelopes and proximity to low lying areas. The work validated concerns over erosion-enhanced flood risk, and ***the need for more detailed assessment of the relative resilience of the flood protection features.***

WS2: Dynamic Coast modelled anticipated coastal erosion where recent coastal changes are considered alongside recent relative sea level rise, projecting forward to estimate future rates of change based on anticipated relative sea level rise. The change mapping was repeated under the High, Medium and Low Emissions Scenarios (UKCP18 RCP8.5 95th%, RCP4.5 50th% and RCP2.6 50th%) and anticipated coastal erosion areas formed between the known modern (2020) shoreline and the anticipated 2050 and 2100 shorelines, respectively and compared against society's mapped assets. Recent tidal updates, alongside the anticipated increasing effect of relative sea level rise shows coastal erosion is anticipated to affect more shoreline than was reported in the 2017 research. ***The decade where erosion first occurs is commonly the 2020s, so the time for resilience and adaptation planning is now.***

WS2RA: Society's assets are at risk from coastal erosion in Scotland, with all coasts and asset types exposed to increasing risk associated with climate change. Under a high emissions scenario and a 'do nothing' coastal management scenario, £ 1.2B of residential buildings, roads and railways are at risk within the next 30 years. Current coastal defence structures protect at least £ 5B of assets, alongside £ 14.5B of assets protected by natural defences. Tideline positions, updated from Dynamic Coast 2017, suggested that a greater proportion of the coast is now experiencing coastal erosion. Whilst erosion rates are expected to quicken with rising relative sea level rise, our enhanced analysis here shows that the first decades where erosion is most commonly anticipated is the 2020-2030s. Thus, whilst our natural coastal defences still retain some capacity to cope, accelerating coastal erosion and associated erosion-enhanced coastal flood risk, is expected to have an increasingly disruptive influence on society's coastal assets. ***It follows that society should start resilience and adaptation planning now.***

WS3: Capturing changes to the seaward vegetation edge provides an additional and important measure to identify the seasonal fluctuations and long-term changes in our natural coastal defences. The vegetation edge is the distinct line that is popularly used to define the 'limit of the land' where society's assets lie, and of the coastline itself. Using the position of the vegetation edge in conjunction with the position of the high and low waterlines (Mean High Water Springs / Mean Low Water Springs) creates a '3-line approach' in change detection, which provides an opportunity to revolutionise coastal monitoring in Scotland. Dynamic Coast has developed a network of sites, where the position of vegetation edge in historic and current aerial imagery, drone surveys, Earth Observation satellite data and ground surveys are compared. Future efficiencies are being explored with the Dynamic Coast partners to ***deliver enhanced change detection at a national scale across the public sector and at local scales with community groups.***

WS4: For six super sites detailed information was collected to investigate how more in-depth analyses can locally enhance the utility of the national context provided by Dynamic Coast. The sites were selected to represent a range of contexts to reflect cultural heritage, natural heritage, an island site, an open coast rural/town site, an estuarine urban site etc. These sites are Bay of Skaill (Orkney), Golspie (Highland), Tiree (Argyll and Bute), St Andrews (Fife), Montrose (Angus) and Dumbarton (West

Dunbartonshire). For each of these sites detailed data on coastal change and flooding were modelled and projected into the future. ***The anticipated local changes and impacts were mapped against the distribution of present assets and future development to identify potential resilience and adaptation planning pathways and inform coastal and land management scenarios.***

WS5: Single page report cards have been developed for several sectors of coastal land use to summarise the anticipated future impact of coastal change on assets within the areas directly affected by erosion (Erosion Area, EA) and the adjacent areas to the EA areas that may be affected by storm damage or flooding (Erosion Influence, EI). ***These cards present "at-a-glance" summary information for each of the sectors depicted: Transport Networks; Water Infrastructure; Built Environment; Natural Heritage; Cultural Heritage and Golf Courses.***

WS6: The social vulnerability of coastal communities to coastal erosion influences are significant, whether direct or indirect, such as the risk to a lifeline transport link by road or rail. This initial assessment provided insights ***to support Scotland's Just Transition, and help ensure that any disadvantaged coastal dwellers, who are likely less able to cope with the impacts of climate change, are offered additional assistance to enhance their resilience.***

WS7: Dynamic Coast's Coast X-Ray is a novel automated coastal change detection tool aimed at establishing intertidal changes rapidly and cost-effectively. We used periodically updated satellite imagery to track spatial change in the intertidal area (between Mean High and Low Water Springs). Time-series positional change in water cover is detected within satellite images and, when images are amalgamated, can be used to establish the intertidal geomorphology including tidelines with tidal stage identified using a tidal model. This allows images to be linked to tidal stage and create an intertidal elevation similar to a digital elevation model. The intertidal topography produced by Coast X-Ray has been successfully quality assured against independently derived high-resolution digital elevation models. Intertidal datasets *per se* are valuable, however Coast X-Ray's online web maps allow users to rapidly view individual satellite images and assess the usefulness of the approach for their own applications. ***Coast X-Ray is a step change in the national coverage and currency of intertidal information for all beaches, however remote or unstudied. It allows previously 'too expensive to answer' questions to be answered at a fraction of the cost.***

Links to supplementary materials

A Research Summary and technical annexes follow this National Overview. Each of the Work Streams has a technical annexes outlining the aims, methods and representative results.

The Research Summary can found at www.crew.ac.uk/dynamic-coast.

The Work Stream Technical Annex Reports can be found at www.DynamicCoast.com/reports.

Endnotes

1 UKCP18, RCP8.5 95%

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