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Title: Coastal erosion in Scotland: The effectiveness of flood risk management in mitigating the loss of natural coastal habitats

Abstract:

Coastal erosion has become an increasingly dire issue for Scotland's coast. The region's natural geomorphology makes it more susceptible to erosion and subsequent risks. The Scottish coast boasts a complex marine ecosystem, currently threatened by erosion and its associated flood risks, a loss creating a ripple effect on local sectors benefiting from the economic and asset value of coastal habitats. With the commercial fishing industries, agriculture, and coastal infrastructure at risk, concerns for long-term sustainability and coastal maintenance are increasing. In response, governmental policies aim to offset shoreline degradation through risk management plans. However, the feasibility of these large-scale strategies remains debatable, particularly at local scales and when considering uncertain climate changes and ever-changing government priorities. Without appropriate action, the future of Scottish land management risks to deteriorate further. The paper discusses the causes and consequences of coastal erosions in Scotland, considering current flood risk management initiatives and their discrepancies. Bringing the disconnect between scientists and policy-makers to the forefront, so that long-term

conservation can be ensured. Careful scientific communication will help bridge this gap between scientific understanding and conservation, ultimately preventing policy upheaval and ensuring coastal conservation in the long term.

Introduction:

Coastal erosion is becoming an increasingly destructive impact of climate change. Rising sea levels are posing threats to coastlines worldwide, increasing their vulnerability to erosion and subsequent flood risks (Von Holle, 2019). In Scotland, the mainland coastline spans about 7,550km, but is threatened by coastal squeezing which is reducing the land area exponentially (Jackson, 2011). The coastline is experiencing accelerated changes compared to historical models. Having moved approximately 10 metres since the 1970s (National Coastal Change Assessment, 2017), the soft coast shows that erosion rates are doubling from what they were prior to 1970. Furthermore, where coastal erosion occurs, fluvial and coastal flooding follows (NatureScot, 2022) and aggravates risks on intertidal zones and local communities. With approximately 3.5 million people living within 10km of the coast (Scottish Executive, 2005), over 60% of the total Scottish population is at risk of being impacted by coastal erosion. These coastal communities depend on the economic and intrinsic value of coastal ecosystems, making them central stakeholders to climate effects on their shores.

Coastal Erosion is mainly influenced by wind-driven waves, causing currents that drag sediments from the shore away from land (Pang, 2023: Bagheri et all., 2022). This transportation exposes large segments of coastal areas, increasing the coastal vulnerability to flooding (Prasad, 2014). Alongside, climate uncertainties regarding sea-level rise and wave behaviour are increasing vulnerability of coasts to erosion. Studies have shown that up to 30% of change in shoreline position may occur globally over time (Mendiguren et al. 2023). This represents the crucial need to manage coastline (Da Silva er al. 2021: Bagheri et al., 2022). Scientific evidence, historical data, and monitoring must be integrated for coastal management policies to successfully respond to the risks of coastal erosion, and provide frameworks for sustainable development and adaptation. Understanding the mechanisms and uncertainties of coastal erosion is key to evaluating current risk-management policies and provide efficient adaptation frameworks to prevent further catastrophe.

Uncertainties

While change is visibly apparent, quantifying the exact volume of sediment loss across the entire region is difficult. Some earth observation technologies used to map coastal changes from satellite data, such as LiDAR, lack accuracy (Fitton, 2021). LiDAR is efficient in collecting land data, but land features cannot be interpreted easily due to positioning of measured land masses (Wang et al. 2023). While it has limitations, LiDAR is a small part of the larger earth observation network that monitors earth's surface. This includes data from the National Coastal Change Assessment (NCCA). Flaws in observational capacity make it difficult to interpret scientific evidence, potentially dissuading policy-action and hindering progress.

Additionally, coastal erosion is long debated by government officials as there remains uncertainty around evidence surrounding the issue (Nichols et al., 1999). There seems to be a disconnect between scientific evidence of coastal erosion and its transmission to policy implementation. Uncertainties surrounding the future of coastal erosion and climate unpredictability, the issue is not brought to public and inter-governmental attention to a degree that would spark interventionist policies and initiatives.

Figure 1. Spatial distribution of observed and projected coastal change in Scotland, derived from the National Coastal Change Assessment

The coast eroding has repercussions that ripple across vital ecosystems. Intertidal zones are ecological hotspots, connecting marine and terrestrial systems by providing ecosystem services to life on land in addition to marine habitats. As coastal erosion worsens, these zones shrink, weakening overall biological productivity in these areas. This has direct socioeconomic consequences. The Scottish fishing industry contributes to 7% of the marine economy (Scottish Government, 2022), making such a geographically small country an important stakeholder of long-term sustainability of Northern fisheries. The decline in productivity of coastal fisheries poses increasing pressures on the fishing industry in Scotland and the sustainability of coastal livelihoods. This threatens 71,000 opportunities in employment brought by the Scottish marine economy (Scottish Government, 2022). The loss of intertidal zones poses issues to blue carbon sequestration. The Scottish coast boasts incredibly high sequestration capacity. However, current trends threaten to hinder the capability of coastal habitats to properly sequester carbon. This affects the economy as well, greatly decreasing the value of carbon sequestration services (Beaumont 2014). Threats to stored carbon make coastal erosion a global climate issue. Going beyond a local land issue because the degradation of intertidal zones releases sequestered Carbon back into the atmosphere, hindering the IPCC target of achieving net-zero CO2 emissions by 2050 (Davis, 2015: IPCC, 2022).

Figure 1 shows the extent to which the Scottish coast is affected by erosion. The pink areas highlight that land loss is not restricted to a single region but is a national phenomenon impacting both the soft-cliff coastlines and vital intertidal zones.

Though despite innovation, major uncertainties are at stake when it comes to mapping out projections. Current sediment loss may not be accurately measured due to LiDAR's shortcomings. This makes it harder for CESM and similar models to make exact regional predictions, compromising strategic mitigation and adaptation plans.

Projected Trajectory

Table 1. Increasing severity of coastal erosion in Scotland under a high-emissions scenario (Dynamic Coast / National Coastal Change Assessment Data).

Indicator	**2050**	**2100**	**Impact**
Mean shoreline change (m/yr)	-0.33	-0.65	Erosion nearly doubles by 2100
Percentage of coastline eroding	77.5%	79.2%	Most of Scotland's coast is retreating
Maximum erosion rate (m/yr)	-9.84	-21.76	Local hotspots worsen dramatically
Total shoreline transects	207,042	207,042	National-scale assessment

Table 1 illustrated projections based on long-term shoreline monitoring data sets such as the NCCA. As seen, scientific data suggests a significant acceleration in 'coastal squeezing'. While the mean shoreline change is currently -0.33 metres per year, it is projected to nearly double to -0.65 metres per year by 2100 under high-emissions scenarios. The maximum erosion rate could reach -21.76 metres per year in hotspot areas. This is particularly striking as it represents a surge compared to the 10 metre total change observed since the 1970s (NCCA, 2017). This seems to be because of hotspots lying on the soft-cliff coastline, and highlights the need for localized intervention.

The Scottish mainland is predicted to reduce in land area by an estimated 25-50% by 2100 from the effects of coastal squeezing (Jackson, 2011). The model shows that cliffs are to increase in steepness, simultaneously causing a decrease in intertidal area. Climate changes will exacerbate the impact on marine ecology in these intertidal zones, likely causing a decline in biological productivity. This will create a feedback loop, where densities of marine organisms will likely increase (Goss-Custard 1990), causing a decrease in abundance because of changes in interactions causing an overall decline in fauna at these steepening shores (Fuji, 2008).

A proposed Coastal Erosion Susceptibility Model (CESM), acts as a preparedness model rather than a large-scale projection of future erosion (Filton, 2016). CESM models where erosion may occur and are used to assess socio-economic vulnerability for communities exposed to erosion. This proactive approach forecasts long term trends and helps inform on safety and risk management through localized intervention. Future projections of erosion, such as Jackson, 2011's model of coastal squeezing, can use CESM to mediate the issue with strategic planning (Filton, 2016). A model such as CESM is an important tool to improve understanding of the risks in areas affected by erosion on a national or even international scale. This adds a second dimension to risk-preparedness by assessing where intervention is necessary given the susceptibility by location.

<u>Risk Management/Policy Intervention</u>

Scientific models show clear evidence of accelerated erosion at coastlines and its documented change over time. Visual evidence of coastal erosion confirms its existence and nation-wide prevalence. As seen in *Figure 1*, the majority of Scotland's coast is and is expected to be eroded. Visual evidence shows that erosion is not uniform throughout Scotland, and varies by region. This brings Scotland's geographic diversity to the forefront for policy discussion. However, it is not only a geomorphological process. It is also a risk management challenge, requiring careful government intervention, paired with community resilience and nature-based solutions. The Climate change (Scotland) Act of, 2009 outlines several outcomes part of the Scottish National Climate Change Adaptation Program that Scottish Ministers are required to uphold (Scottish Government, 2022). By regulations they must set a national carbon budget each year and ensure that each budget meets its respective target (Climate Change Scotland Act, 2009). Unlike other interventionist policies, this act operates on a governmental scale and outlines outcomes across different sectors. By recognizing the intrinsic value of Scotland's natural environment, the act advocates nature-based solutions. Protecting the impacted ecosystems while taking socioeconomic circumstances into account provides an inclusive approach. The 'Nature Outcome' combines both human and nature centric interest provides a balance. This approach may be more effective than eco-centric approaches. There are several 'Regional Marine Plans' under development focused on locally specific policies. Since coastal erosion rates differ by location, localized intervention is productive as opposed to large scale policies as local governments and priorities vary. The plans give people a voice by promoting community decision-making. Nature and community-based models offer sustainable approaches in responding to coastal erosion. However, the extent of progress such a model can provide depends on the severity of the problem in an area. More affected areas may not fully benefit from many of these policies as they are largely reactive to observed erosion. Some cases may benefit from intervention using scientific models for emission-driven policies that focus on mitigation.

On the socio-economic angle the business outcome aims to increase public knowledge on how climate impacts business. This builds on the localized intervention angle, by supporting local business resilience against climate risks such as flooding and coastal change.

The overall Blue Economy Vision for Scotland aims to restore marine, freshwater and coastal environments by, 2045. By ensuring sustainable management of their adaptation capabilities and resilience to environmental changes, vital jobs in coastal communities are protected. However, while ambitious, the 2045 target lacks framework. Without benchmarks, the ability to track progress toward the end goal may be limited. Considering 77.5% of Scotland's coastline is estimated to erode by 2050 (*Table 1*), much of this erosion will happen if goals remain unchecked. This means irreversible damage to the coast will have already occurred making corrective action much more difficult by the target date.

There have been some tangible policy plans, however implementation varies. The UK Coastal Change Adaptation Plans (CCAP), are developed by local authorities (Dynamic Coast, 2026). Plans are centered on coastal risk management from erosion and sea-level rise effect most pertinent to the respective regions.

The Orkney Islands Council have begun adopting CCAP's, which could eventually feed into local development plans. The CCAP aims to prepare for coastal erosion risks while increasing long-term resilience and adaptation. By implementing CCAP's, the Orkney Islands Council can mitigate further land deterioration from coastal erosion (Orkney Islands Council, 2025). Furthermore, this fosters the Islands' development by promoting community education with stakeholder engagement initiatives, allowing locals to contribute to helping environmental issues in their environment (Dynamic Coast, 2023).

Along with these smaller scale cases, the CCAP is beginning to gain wider attention, with large cities, such as Edinburgh, beginning conversation on CCAP schemes to implement later in 2026 (The City of Edinburgh Council, 2026).

Nature-based localised intervention provides advantages beyond erosion control. As opposed to harsher intervention, nature-based solutions protect the integrity of natural ecosystems at the shores. Artificial defenses such as seawalls help tame violent wave energy to protect the coastline from degrading (Marine Scotland). However, this disrupts marine habitats by preventing migration routes and further decreasing biological productivity. Natural longshore drifts are likely to be disrupted as well, failing to provide sediment with essential nutrients, which itself accelerated erosion further down the coast. Although geoengineering can provide coastal defense against erosion, they could also change intertidal dynamics and exacerbate erosion in the long term (EEA, 2016).

Perspective and Future Directions

Scotland signed up to the United Nation's Sustainable Development Goals (SDGs) as one of the first participating nations in, 2015 (Brooker, 2018). However, UN frameworks rely on participating nations to implement UN suggestions and have no jurisdictions on governments. Therefore, government incentives to implement policies will differ based on their respective political priorities and economic constraints. As a result, adhering to sustainability targets remains largely dependent on local political priorities, and economic considerations. This shows a disconnect between global commitments and implementation on smaller scales.

This suggests an apparent gap between scientific evidence and proactive policy making, as some policy models provide. Models like the NCCA and localized CCAP's provide solid foundation for illustrating changes caused by coastal erosion. Though, current scientific understanding still lacks the ability to quantify change due to uncertainties regarding future climate and challenges with technological accuracy. Combining NCCA datasets with LiDAR monitoring can provide a solid foundation for policy making, possibly influencing CCAP's. Meshing these tools creates a more understandable assessment of trends, clearing up discrepancies in terms of quantifying damage for policymakers to act appropriately based on trends. The Climate Change Scotland Act of 2009 and the Blue Economy Vision establish the governmental frameworks which would mesh perfectly with complimenting scientific evidence. However, these are merely aspirational and insufficient on their own as they lack clear structure and enforcement to track development, which is a necessary process to prevent erosion. Furthermore, many strong policies are based on scientific evidence, though they remain as reactive responses centered on adaptaion. Understanding the science behind coastal erosion is therefore crucial when evaluating current initiatives. This will allow policy makers to develop policy responses rooted in mitigation rather than adaptation, to ensure long-term sustainability.

References

A Blue Economy Vision for Scotland (no date). Available at: https://www.gov.scot/publications/blue-economy-vision-scotland/ (Accessed: January 24, 2026).

Bagheri, M. et al. (2023) "Hazard Assessment and Modeling of Erosion and Sea Level Rise under Global Climate Change Conditions for Coastal City Management," Natural Hazards Review, 24(1), p. 04022038. Available at: https://doi.org/10.1061/(ASCE)NH.1527-6996.0000593.

Barkwith, A. et al. (2014) "Coastal vulnerability of a pinned, soft-cliff coastline – Part I: Assessing the natural sensitivity to wave climate," Earth Surface Dynamics, 2(1), pp. 295–308. Available at: https://doi.org/10.5194/esurf-2-295-2014.

Beaumont, N.J. et al. (2014) "The value of carbon sequestration and storage in coastal habitats," Estuarine, Coastal and Shelf Science, 137, pp. 32–40. Available at: https://doi.org/10.1016/j.ecss.2013.11.022.

Brooker, E. et al. (2018) "Scotland as a case study for how benefits of marine ecosystem services may contribute to the commercial fishing industry," Marine Policy, 93, pp. 271–283. Available at: https://doi.org/10.1016/j.marpol.2017.06.009.

Davis, J.L. et al. (2015) "Living Shorelines: Coastal Resilience with a Blue Carbon Benefit," PLOS ONE, 10(11), p. e0142595. Available at: https://doi.org/10.1371/journal.pone.0142595.

Edinburgh Coastal Change Adaptation Plan - City of Edinburgh Council - Citizen Space (no date). Available at: https://consultationhub.edinburgh.gov.uk/sfc/edinburgh-coastal-change-adaptation-plan/ (Accessed: February 14, 2026).

Fishing (no date). Available at: https://www.gov.scot/publications/scotlands-marine-economic-statistics-2022/pages/fishing/ (Accessed: January 28, 2026).

Fitton, J. et al. (2016a) "A national coastal erosion susceptibility model for Scotland," Ocean & Coastal Management, 132, pp. 80–89. Available at: https://doi.org/10.1016/j.ocecoaman.2016.08.018.

Fitton, J. et al. (2016b) "A national coastal erosion susceptibility model for Scotland," Ocean & Coastal Management, 132, pp. 80–89. Available at: https://doi.org/10.1016/j.ocecoaman.2016.08.018.

Fitton, J.M. et al. (2021) "Remotely sensed mapping of the intertidal zone: A Sentinel-2 and Google Earth Engine methodology," Remote Sensing Applications: Society and Environment, 22, p. 100499. Available at: https://doi.org/10.1016/j.rsase.2021.100499.

Fitton, J.M., Hansom, J.D. and Rennie, A.F. (2016) "A national coastal erosion susceptibility model for Scotland," Ocean & Coastal Management, 132, pp. 80–89. Available at: https://doi.org/10.1016/j.ocecoaman.2016.08.018.

Fujii, T. and Raffaelli, D. (2008) "Sea-level rise, expected environmental changes, and responses of intertidal benthic macrofauna in the Humber estuary, UK," Marine Ecology Progress Series, 371, pp. 23–35. Available at: https://doi.org/10.3354/meps07652.

Goss-Custard, J.D., McGrorty, S. and Kirby, R. (1990) "Inshore Birds of the Soft Coasts and Sea-Level Rise," in J.J. Beukema, W.J. Wolff, and J.J.W.M. Brouns (eds.) Expected Effects of Climatic Change on Marine Coastal Ecosystems. Dordrecht: Springer Netherlands, pp. 189–193. Available at: https://doi.org/10.1007/978-94-009-2003-3_22.

Goudie, A.S. and Viles, H.A. (eds.) (2016) "Coastal Processes and Forms in the Anthropocene," Geomorphology in the Anthropocene. Cambridge: Cambridge University Press, pp. 193–222. Available at: https://doi.org/10.1017/CBO9781316498910.009.

HANSOM, J.D. et al. (2004) "Shoreline Management Plans and Coastal Cells in Scotland," Coastal Management, 32(3), pp. 227–242. Available at: https://doi.org/10.1080/08920750490448505.

Hansom, J.D. et al. (2017a) Dynamic Coast - National Coastal Change Assessment: National Overview. Aberdeen, Scotland: CREW – Scotland's Centre of Expertise for Waters.

Hansom, J.D. et al. (2017b) Dynamic Coast - National Coastal Change Assessment: National Overview. Aberdeen, Scotland: CREW – Scotland's Centre of Expertise for Waters.

Hazard Assessment and Modeling of Erosion and Sea Level Rise under Global Climate Change Conditions for Coastal City Management | Natural Hazards Review | Vol 24, No 1 (no date). Available at: https://ascelibrary.org/doi/10.1061/%28ASCE%29NH.1527-6996.0000593 (Accessed: February 17, 2026).

Impacts on the coast | NatureScot (2025). Available at: https://www.nature.scot/climate-change/climate-change-impacts-scotland/impacts-coast (Accessed: January 25, 2026).

Jackson, A.C. and McIlvenny, J. (2011) "Coastal squeeze on rocky shores in northern Scotland and some possible ecological impacts," Journal of Experimental Marine Biology *and Ecology, 400(1), pp. 314–321. Available at: https://doi.org/10.1016/j.jembe.2011.02.012.*

Mendiguren, B. et al. (2023) "Coastline behavior under climate change and sea-level rise scenarios: a western Portuguese littoral case study," Journal of Coastal Conservation, 27(5), p. 51. Available at: https://doi.org/10.1007/s11852-023-00980-w.

National Coastal Change Assessment (NCCA) 2017 | marine.gov.scot (no date). Available at: https://marine.gov.scot/?q=information/national-coastal-change-assessment-ncca-2017 (Accessed: January 30, 2026).

Nicholls, R., Hoozemans, F. and Marchand, M. (1999) "Increasing flood risk and wetland losses due to global sea-level rise: regional and global analyses," Global Environmental Change, 9, pp. S69–S87. Available at: https://doi.org/10.1016/S0959-3780(99)00019-9.

Orkney Island Coastal Change Adaptation Plan Consultation (2025) ArcGIS StoryMaps. Available at: https://storymaps.arcgis.com/stories/65e1d882227749e48afb564e8aba401c (Accessed: February 14, 2026).

Outcome Four: Economy, Business, and Industry (B) (no date). Available at: https://www.gov.scot/publications/scottish-national-adaptation-plan-2024-2029-2/pages/9/ (Accessed: January 24, 2026).

Participation, E. (no date) Climate Change (Scotland) Act 2009. Statute Law Database. Available at: https://www.legislation.gov.uk/asp/2009/12 (Accessed: January 29, 2026).

Prasad, D.H. and Kumar, N.D. (2014) "Coastal Erosion Studies—A Review," International Journal of Geosciences, 5(3), pp. 341–345. Available at: https://doi.org/10.4236/ijg.2014.53033.

Seawalls and jetties (no date). Available at: https://climate-adapt.eea.europa.eu/en/metadata/adaptation-options/seawalls-and-jetties (Accessed: February 15, 2026).

"SME Resilience Checklist" (no date) Adaptation Scotland. Available at: https://adaptation.scot/take-action/coastal-change-adaptation-plan-guidance/ (Accessed: January 14, 2026).

Vieira da Silva, G. et al. (2021) "Building coastal resilience via sand backpassing - A framework for developing a decision support tool for sand management," Ocean & Coastal

Management, 213, p. 105887. Available at: https://doi.org/10.1016/j.ocecoaman.2021.105887.

Von Holle, B. et al. (2019) "Effects of future sea level rise on coastal habitat," The Journal of Wildlife Management, 83(3), pp. 694–704. Available at: https://doi.org/10.1002/jwmg.21633.

Wang, J. et al. (2023) "An Overview of Shoreline Mapping by Using Airborne LiDAR," Remote Sensing, 15, p. 253. Available at: https://doi.org/10.3390/rs15010253.

Withouck, I. et al. (2023) "Diving into a just transition: How are fisheries considered during the emergence of renewable energy production in Scottish waters?," Energy Research & Social Science, 101, p. 103135. Available at: https://doi.org/10.1016/j.erss.2023.103135.

Zotero | Your personal research assistant (no date). Available at: https://www.zotero.org/download/ (Accessed: January 14, 2026).