climate change
Scotland's centre of expertise connecting climate change research and policy

Scottish saltmarsh, sea-level rise, and the potential for managed realignment to deliver blue carbon gains

William Austin*, Craig Smeaton, Alex Houston (University of St Andrews) and Thorsten Balke (University of Glasgow)

March 2022

DOI: http://dx.doi.org/10.7488/era/2370

1 Executive summary

1.1 Background

Vegetated coastlines, including seagrass, mangroves, and salt marshes, are valued for their capacity to sequester and store large amounts of organic carbon in their soils. The importance of 'blue carbon[1]' habitats in mitigating against climate change is now widely recognised, especially given that blue carbon accumulation rates are expected to increase in response to sea-level rise, temperature increase, and precipitation change.

However, coastal habitats are degrading globally, raising fears that blue carbon habitats could largely disappear by the end of this century unless significant protection and restoration efforts are enacted. The widespread conversion of Scotland's saltmarshes to agricultural and development land, especially during the 18th and 19th centuries, together with more recent acceleration of sea-level rise, places this important coastal habitat under extreme pressures. Reversing these trends is important. Scotland's saltmarshes are currently estimated to cover an area of 58.4 km^2, which represents around 13% of the UK total.

Measuring the amount of stored carbon accurately is crucial for understanding the cost of habitat loss, and for justifying financial investment in protecting and enhancing the carbon storage capacity of coastal habitats

The Scottish Government has recognised their importance in the Climate Change Plan Update[2], and the inclusion of saltmarsh in the national greenhouse gas inventory is

---

[*] wena@st-andrews.ac.uk (corresponding author)

[1] Blue carbon is defined as marine and coastal carbon which can be managed to contribute to greenhouse gas (GHG) mitigation.

[2] https://www.gov.scot/publications/securing-green-recovery-path-net-zero-update-climate-change-plan-20182032/

being progressed by the UK Department of Business, Energy and Industrial Strategy (BEIS), following recent recommendations to do so by the UK Climate Change Committee[3]. Such inclusion would allow saltmarsh restoration to contribute to meeting our emissions reduction targets.

1.2 Aims

This study assesses the potential for managed realignment of Scotland's coastline to create suitable areas for saltmarsh habitats within the intertidal environment specifically for blue carbon benefits.

It examines existing evidence and uses modelling to explore the potential for additional blue carbon sequestration. It also explores the likely effects from future sea-level changes on these newly created saltmarsh habitats and their associated soil carbon stocks. We recognise there are other approaches to restoration, but they will not be addressed here.

1.3 Findings

- There is significant potential for managed realignment in Scotland. Well-defined opportunities were identified for new saltmarsh habitat creation, with blue carbon gains. There is evidence to support the longevity associated with the new habitats and their additional blue carbon stocks.
- However significant evidence gaps are also identified. The rates at which additional carbon stores are accumulating are not clear at these sites nor is their potential to contribute GHG emissions back to the atmosphere.
- We found evidence supporting a perceived growing threat of rising sea-levels, particularly associated with the potential loss of saltmarsh area, and associated soil carbon, but the evidence for loss of habitat from sea-level rise around Scotland is not yet established.
- Managed realignment and the creation of new saltmarsh offers a net gain at most sites over the existing saltmarsh area (and associated soil organic carbon stock). This is for all but the most extreme scenario of sea-level rise.
- We found considerable variation in the relative levels between saltmarsh elevation and local tidal conditions. The lower saltmarsh edge only extends down to the mean high water neap level in a few cases. This means local monitoring of vegetation in relation to tidal variation prior to restoration is needed to model future marsh extent. Such work could be carried out at the 15 potential candidate managed realignment sites identified in this study.
- Sea-level projections are complex and depend on several key variables. To fully assess marsh vulnerability to relative sea-level rise, evidence suggests inclusion of high-tide levels, especially neap and spring levels, as they can differ from mean sea level trends locally. Understanding local sediment supply is also important, but this is not normally included in sea-level projections.
- It is still not possible to estimate the time taken for a managed realignment site to reach a stable state with natural rates of carbon sequestration. The approach taken in this study to estimate potential blue carbon gains assumes that the realigned saltmarsh will reach a state where it buries and stores organic carbon in a similar way to a natural saltmarsh but does not include this time-dependent process. Detailed monitoring of existing restored sites across Scotland would improve our understanding of the additional blue carbon gains in soil profiles at these sites, and to also understand the extent of any losses, including GHG emissions, over recorded periods of time.

---

[3] https://www.theccc.org.uk/publication/briefing-blue-carbon/

Contents

Glossary

Key terms	Definition
allochthonous	Allochthonous sources of carbon come from outside the habitat; in the case of saltmarshes, these can be derived from both adjacent terrestrial and marine sources.
autochthonous	Autochthonous sources of carbon come from within the system, such as algae and the microbial breakdown of saltmarsh plant-derived organic carbon.
blue carbon	Blue carbon is the carbon stored in coastal and marine ecosystems.
managed realignment	Managed realignment – the deliberate breaching of coastal defences and subsequent tidal inundation to restore intertidal habitat
nature-based solutions	Nature-based solutions are actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits.
surficial soil carbon stocks	Refers to the top 10cm of saltmarsh soil and is used specifically here to capture soil organic carbon associated with the contemporary saltmarsh habitat.

List of abbreviations

C	Carbon
GHG	Greenhouse Gas
GHGI	Greenhouse Gas Inventory
GIS	Geographic Information System
HAT	Highest Astronomical Tide
IPCC	Intergovernmental Panel on Climate Change

MHW	Mean High Water
MHWN	Mean High Water Neap
MHWS	Mean High Water Spring
MR	Managed Realignment
MSL	Mean Sea Level
OC	Organic Carbon
OM	Organic Matter
RCP	Representative Concentration Pathway
RSL	Relative Sea Level
RSLR	Relative Sea Level Rise
UNFCCC	United Nations Framework Convention on Climate Change

Data

The GIS outputs from the spatial model are archived with Marine Scotland Data and can be found at: https://doi.org/10.7489/12417-1

Acknowledgements

This work was commissioned on behalf of the Scottish Government via an open tender call through CXC. We would like to thank Sarah Govan (CXC) for her support and patience in guiding us through the reporting process and acknowledge advice from our steering group (Barbara Berx, Bill Turrell and Cathy Tilbrook) with additional comments from Alistair Rennie, Stewart Angus, Nick Everett and Corallie Hunt. We are also grateful to Colin Scott (ABPmer) for his invaluable and constructive conversations during the initial stages of this work, and to our partners Jo Smith (University of Aberdeen), Daniel Crockett (Blue Marine Foundation) and Caroline Chambers (GoBe Consultants) who supported the original project development.

Figure 1. The newly flooded Skinflats, Forth Estuary managed realignment (October 2018), taken shortly before a 6.2m tide (photo credit: J Leonard).

2 Introduction

2.1 Scotland’s saltmarsh habitats

Vegetated coastlines, including seagrass, mangroves, and salt marshes, are valued for their capacity to sequester and store large amounts of organic carbon in their soils (Mcleod *et al*., 2011). The importance of ‘blue carbon’ habitats in mitigating against climate change is now widely recognised (Macreadie *et al*., 2019), especially given that blue carbon (C) accumulation rates are expected to increase in response to sea level rise, temperature increase, and precipitation change (Rogers *et al*., 2019a; Wang *et al*. 2021; Herbert *et al*., 2021).

However, coastal habitats are degrading globally, raising fears that blue carbon habitats could largely disappear by the end of this century (Crosby *et al*., 2016; Horton *et al*., 2018) unless significant protection and restoration efforts are enacted (Schuerch *et al*., 2018). Measuring the amount of stored C accurately is crucial for understanding the C-equivalent cost of habitat loss, and for justifying financial investment in protecting and enhancing the C storage capacity of coastal habitats (Theuerkauf *et al*., 2015; Rogers *et al*., 2019b; Smith and Kirwan, 2021).

Saltmarsh is the most widespread of the intertidal habitats in temperate regions (Mcleod *et al*., 2011) and through the burial and storage of carbon in their soils they potentially provide a globally significant climate regulation service, alongside other ecosystem services (Duarte *et al.*, 2013).

Scotland’s saltmarshes are estimated to cover an area of 58.4 km^2 (Fig. 2A) which represents approximately 13% of all saltmarshes in the United Kingdom (Burden *et al*., 2020; Haynes, 2016). The geomorphology of the Scottish coastline results in a high number (*240 surveyed*) of small (mean size: 0.25 km^2) saltmarshes with only nine Scottish saltmarshes extending to 1 km^2 in size (Fig. 2A). Within the surficial soil (top 10 cm) of Scottish saltmarsh it is estimated that 367,888 ± 102,278 tonnes of organic carbon are stored (Austin *et al.,* 2021); a complete soil organic carbon stock (1 m) for saltmarsh habitats across Scotland and the rest of the UK has not yet been published.

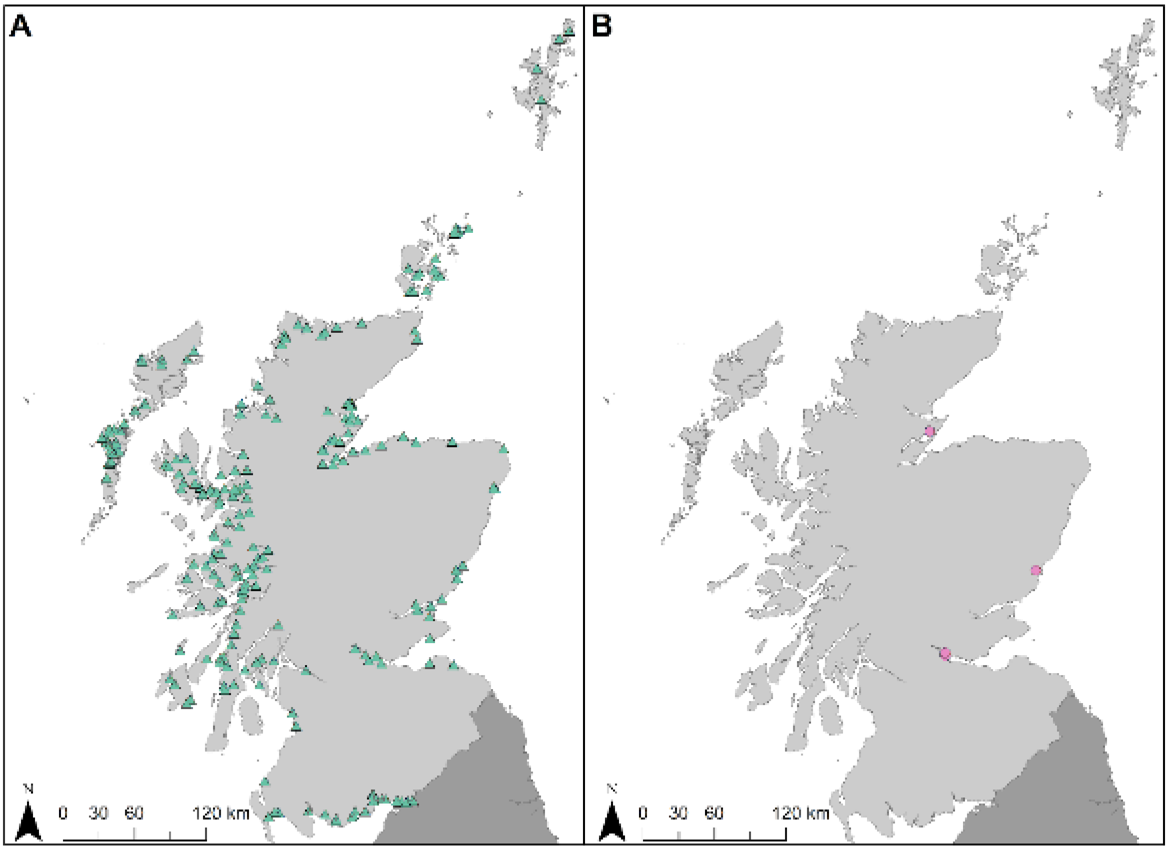

Figure 2. Maps showing: (**A**) the extent of Scottish saltmarsh habitats (green symbols) >3 ha (Haynes, 2016); and (**B**) existing Managed Realignment sites (pink symbols). Details given in Table 1. (ABPmer, 2021b).

2.2 Managed realignment

Practical guidance on restoring and creating saltmarsh habitat across the UK and Ireland has recently been published by the Environment Agency[4] (Hudson *et al*., 2021). A diverse mix of approaches are required in saltmarsh restoration depending on the location, surrounding landscape and condition. Managed realignment – the deliberate breaching of coastal defences and subsequent tidal inundation to restore intertidal habitat – is the predominant method of saltmarsh restoration in the UK (Burden *et al.,* 2019).

The first managed realignment scheme in the UK was carried out in 1991 at the Northey Island project site on the Blackwater Estuary in South-East England as a demonstration for coastal defence (Doody, 2013), and there are now at least 46 sites that have created saltmarsh habitat across the UK, identified by the *Online managed realignment Guide*[5]

---

[4] https://catchmentbasedapproach.org/learn/saltmarsh-restoration-handbook/

[5] https://www.omreg.net/

(OMReg, ABPmer, 2021b). These schemes have been a core strategy to protect coastlines and reduce flood costs, as well as a principal method for habitat provision and compensation for historic losses of intertidal habitat, in line with the EU Habitats Directive (Esteves, 2013; Brady & Boda, 2017; ABPmer, 2021a).

To date only four managed realignment schemes have been established in Scotland, some of these to create new habitat for biodiversity gains, e.g., RSPB Nigg Bay and Skinflats (Fig. 2B and Table 1). Yet with sea-levels expected to rise significantly over the coming decades (Horton *et al.,* 2014; IPCC, 2021) the creation of new saltmarsh through managed realignment represents an emerging opportunity to improve the resilience of Scotland's coastlines. This includes creating potential for increased climate adaptation and mitigation, notably through additional organic carbon burial and storage in these blue carbon habitats.

Table 1. Details of the four current saltmarshes created in Scotland through managed realignment. See Fig. 2. Data soured from OMReg (ABPmer, 2021a).

Site	Local Authority	Year Realigned	Latitude	Longitude	Area (km^2)
Meddat Marsh (Nigg Bay)	Highland	2003	57.7389	-4.0332	0.25
Montrose Basin	Angus	1997	56.7098	-2.5326	0.003
Skinflats	Falkirk	2018	56.0557	-3.734	0.11
Kennet Pans	Fife	2007	56.0777	-3.7373	0.082

2.3 Managed realignment and blue carbon

The blue carbon storage of Scotland's naturally distributed saltmarsh habitats (Austin et al., 2021), highlights the significance of the surficial soil carbon stocks across all saltmarshes of more than 3 ha. However, to date, saltmarsh carbon storage and climate benefits have neither been a reason for restoration, nor a criterion to measure the success, (or failure) of such schemes in the UK (Burden *et al.,* 2013).

The emerging role of blue carbon as a means for emission reductions in line with national targets has gained importance in climate policy and, in relation to saltmarsh, relies on both the successful management and restoration of coastal wetlands (Kelleway *et al*., 2020). Managed realignment and the creation of new saltmarsh habitats therefore represents an important management intervention in a UK context (Hudson *et al*., 2021).

The Intergovernmental Panel on Climate Change (IPCC) Wetland Supplement (IPCC, 2014) includes guidelines for the quantification and accounting of GHG emissions and removals associated with the management of different wetland types, including drainage and rewetting of tidal marsh.

Inclusion of saltmarshes in the UK GHGI is therefore considered by many as a key objective that will enhance current efforts to account for, protect, and restore these long-term carbon stores, realising their potential for climate change mitigation. The UK has set a precedent for their inclusion by electing to report emissions from peatlands in its national inventory[6]. By implementing restoration of saltmarsh (mostly via managed

---

[6] for the second commitment period of the Kyoto Protocol under the obligations of the UN Framework Convention on Climate Change (UNFCCC)

realignment) as a nature-based solution (NBS) to capture carbon and therefore remove GHG from the atmosphere, saltmarsh can contribute to the Scottish Government’s commitment to reduce GHG emissions and achieve net zero by 2045. Greenhouse gas emissions and removals resulting from changes in saltmarsh management can be included in UK national emission accounting under the Land Use, Land Use Change and Forestry (LULUCF) sector according to the IPCC guidelines. However, saltmarsh habitats are not included in the UK GHG inventory (GHGI) at this time, but a recent briefing on blue carbon (March 2022) by the UK Climate Change Committee recommends their urgent implementation into the GHGI.

2.4 Managed realignment and sea-level rise

Saltmarshes are recognised as globally significant in their capacity to store carbon (McLeod *et al.* 2011; Duarte *et al.* 2013; Beaumont *et al.* 2014; Ouyang and Lee 2014; Macreadie *et al.* 2019). Sea-level is also seen as a potentially dominant control on accretion of saltmarsh sediments, and several studies have therefore explored the relationship between relative sea-level rise (RSLR) and net organic carbon accumulation in saltmarshes (e.g., Kirwan and Mudd 2012; FitzGerald and Hughes 2019; Gonneea *et al.* 2019; McTigue *et al.* 2019; Rogers *et al.* 2019a; Haywood *at al.* 2020; Herbert *et al.* 2021).

One current hypothesis is that, instead of being vulnerable to increased RSLR, saltmarshes in areas of accelerated sea-level rise are responding by accretion and hence burying even more carbon in their soils. This is due to the creation of additional vertical accommodation space (space for particle settlement) but is only sustainable if there is adequate sediment supply and room for coastal wetlands to migrate inland (Rogers *et al.* 2019a). However, inland migration is not always possible due to both natural and man-made barriers, resulting in “coastal squeeze” (Torio and Chmura, 2013).

Other studies (Kirwan *et al.* 2016; Gonneea *et al.* 2019) suggest that the high rates of RSLR projected for the 21st century are likely to cause a change in vegetation types (i.e., high-marsh plant communities replaced by low-marsh communities). Therefore, if existing plant communities are unable to adapt to projected sea-level rise, there is a risk of further loss.

As the rate of RSLR is thought to be one of the dominant controls on saltmarsh accretion and net organic carbon accumulation, Scotland is considered an excellent location to test the hypothesis that the recent acceleration in (and projection of future) RSLR has (and will) increase the capacity of Scottish saltmarshes (Fig. 2) to store carbon. Unlike other regions across the UK, Scotland’s RSLR history (and projections of future RSLR) mean that its coastal wetlands are likely to be less severely impacted by the extremes of high RSLR projected for the 21st century, offering improved longevity to any additional carbon that accumulates in newly formed saltmarsh habitats.

2.5 This project

In addressing the theme of climate and coastal (and specifically sea-level) change outlined in this report, we aim to deliver a new understanding of the blue carbon potential of Scottish intertidal wetlands to deliver additional gains in carbon sequestration and storage in saltmarsh habitats, while considering some of the long-term risks posed by the potential loss of these vulnerable coastal habitats.

In this report, we predict potential land areas available for saltmarsh habitat restoration in Scotland and derive first-order assessments of the blue carbon potential for climate mitigation from managed realignment. It should be highlighted that while the focus of this report is on the blue carbon potential deriving from saltmarsh habitat creation, multiple additional benefits can be expected to derive from managed realignment (Hudson *et al*., 2021).

3 Methods

Full details of the methods are provided in Appendix 1 to this report. These comprised the following steps:

(i) A Rapid Evidence Assessment of the available literature (see Appendix 2).
(ii) An assessment of current saltmarsh inundation by the tide (frequency and duration) and area of the transition zone of lower tidal marsh to adjacent intertidal flats across Scotland.
(iii) Spatial modelling of contemporary intertidal saltmarsh habitats.
(iv) An assessment of the potential for new intertidal saltmarsh habitat creation through coastal managed realignment across Scotland.
(v) An assessment of potential saltmarsh extent under scenarios of future sea-level change.
(vi) An assessment of the additional blue carbon potential of the realigned saltmarsh sites in Scotland.

4 Results

4.1 Rapid evidence assessment: Summary

The detailed results of a rapid evidence assessment of the available literature are presented in Appendix 2.

Overall, the available evidence for managed realignment shows that realigned saltmarshes accumulate sediments (and organic carbon) at high rates initially, which slow over time as the marsh develops and approaches equilibrium within the local tidal frame. This evidence remains subjective and is limited by conceptual modelling at the present time. We found no data on the greenhouse gas emissions from managed saltmarshes over time, highlighting the difficulty to get a clear understanding of how such GHG emissions are balanced out against the overall carbon sequestration at these sites.

It has been shown in some studies that managed realigned saltmarshes have a higher allochthonous (external source) to autochthonous (internal source) carbon ratio than mature habitats, which may complicate carbon accounting and the net balance of carbon sequestration achieved over time following any intervention (Rogers *et al*., 2019). There is insufficient evidence at the current time to provide indicative values.

It is acknowledged (e.g., Burden *et al*., 2020) that newly created saltmarshes function quite differently to mature saltmarshes, often with differing sediment properties, hydrology, and less diverse vegetation assemblages and topographies. Despite these differences, they offer many of the same benefits as mature marshes, such as flood protection, carbon storage, and unique coastal ecosystems and associated biodiversity. Some studies highlight that it may be most useful to compare the created habitat to the habitat prior to breaching when assessing the overall benefits deriving from managed retreat.

The evidence suggests that most of the available area for managed retreat in Scotland will be in low-lying estuaries on the east coast that have high degrees of historical reclamation and high sediment availabilities, such as the Firth of Forth. A key constraint is the potential difficulty of finding suitable sites where landowners may be willing to co-operate. However, it is possible that, as sea-level rise accelerates, this situation may change in favour of greater co-operation from landowners as, for example, farming of such low-lying land becomes increasingly difficult to sustain.

4.1.1 Salinity

Net carbon sequestration is also constrained by salinity because repeated tidal inundation suppresses saltmarsh methane (CH_4) emissions (due to seawater sulphate SO_4; Kroeger *et al*., 2017) and negligible methane emissions were reported from a re-wetted saltmarsh experiment at normal salinity (Wollenberg *et al*., 2018).

Below a salinity of 5, saltmarsh is unlikely to form (instead terrestrial wetlands are likely); while at salinities below 18 there is potential for increased methane emissions, reducing the effective carbon sequestration potential of the new saltmarsh habitat. Salinities above 18 are therefore likely to be optimal, with minimized methane emissions, and should be incorporated into managed realignment scheme designs. However, it should be noted that research has shown short-term increases in GHG fluxes (methane and nitrous oxide) following saltmarsh rewetting of agricultural land, but that these are outweighed (as a net climate effect) by large reductions in carbon dioxide emissions (Wollenberg *et al*., 2018).

4.1.2 Site design

Where suitable sites have been identified and the project meets other criteria (e.g., appropriate flood protection measures), site-design is vital to ensure a productive saltmarsh. Initially, sediments can accumulate rapidly to fill the newly created accommodation space from managed retreat. As sedimentation rates decrease and approach equilibrium within the tidal frame, productive vegetation becomes increasingly important and contributes to the development of a significant autochthonous (*in situ*) carbon sink. Additionally, this autochthonous carbon constitutes a clearer additional source of carbon sequestration than allochthonous organic carbon sources, which may have been reworked and deposited from adjacent sediment stores. However, ensuring a greater proportion of *in situ* carbon sequestration makes the saltmarsh habitat creation from managed realignment more favourable for blue carbon financing.

4.1.3 Rising sea-levels

Little consideration has been given to rising sea-levels and the most recent projections of sea-level rise (e.g., IPCC, 2021) do not feature clearly in the management of existing saltmarsh habitats, their restoration nor in the potential for their creation through managed realignment.

Important evidence gaps remain in relation to our understanding of natural changes and security of organic carbon stocks within our existing saltmarsh habitats and the pressures acting on these (of which sea level rise is one factor).

There are funding barriers and stakeholder issues which may inhibit managed realignment implementation in Scotland; however, these are beyond the scope of this report.

4.2 Assessment of current saltmarsh inundation

In-situ monitoring (Fig. 3) confirmed that the lower transition zone of the surveyed saltmarshes of Scotland typically experience inundation characteristics as for elevations above the mean high water neap (MHWN) datum. The seaward saltmarsh edge (i.e., transition from marsh vegetation to the adjacent intertidal flats) at Caerlaverock and at the loch-head marsh of Loch Caolisport on the west coast were considerably less often flooded by tides (i.e. 5% of the time) and experienced inundation characteristics typical of elevations above MHW. Only the transition zone of the brackish marsh in the Firth of Tay experienced longer inundation durations (35% of the time) which would normally be typical for MHWN elevations. None of the surveyed marshes extended down to Mean Sea Level.

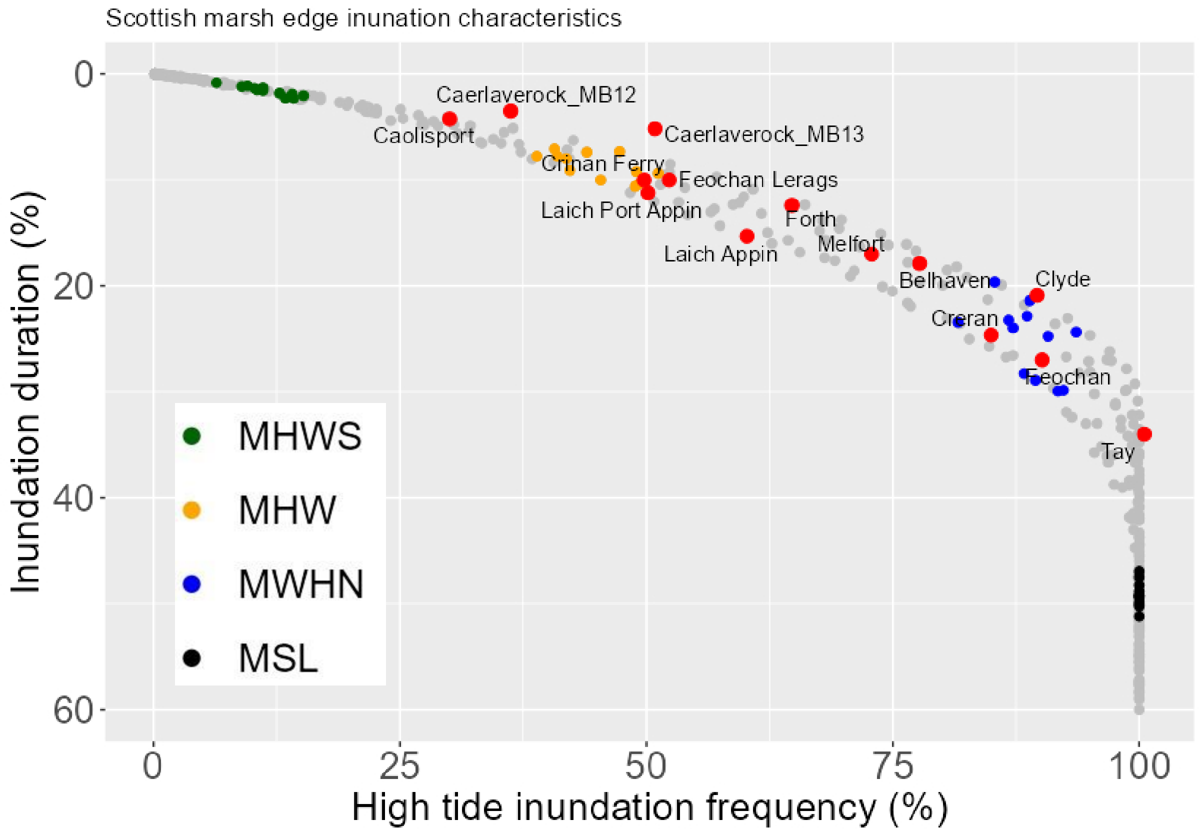

Figure 3. In-situ inundation field data (red dots) collected between 2019 and 2021 at the seaward limit of Scottish saltmarshes. Tidal datum's are calculated from Scottish tide gauge data. Most of the monitored saltmarshes do not extend down to the Mean High Water Neap (MHWN) datum and are inundated for less than 30% of the time on average. The grey dots show the relationship between annual average high tide inundation frequency and inundation duration (at 10cm water-level i.e. elevation intervals) at tide gauges near Scottish marshes (Moray Firth, Port Ellen, Wick, Lerwick, Stornoway, Kinlochbervie, Leith, Ullapool, Tobermory, Millport, Portpatrick, Workington, Aberdeen). Inundation duration (%) = (total inundation duration during monitoring period/total duration of monitoring period)*100. High tide inundation frequency (%) = (No. of high tides reaching the stated datum during the monitoring period /No. of all high tides during the monitoring period)*100.

Linear regression analyses of Scottish tide-gauge records confirm that mean sea level (MSL) trends, as presented in Section (v) below, are in some cases representative of trends in MHWN. However, at Ullapool in the Northwest of Scotland, annual MHWN rose faster than MSL and at Aberdeen tide-gauge records show that MSL rose faster than MHWN during the period over which data are available. It is also evident from the tide-gauge data, that neap and spring tides are affected by the 18.6 year nodal tidal cycle (Dargie, 2017).

4.3 Spatial modelling of contemporary saltmarsh habitats

Spatial modelling of saltmarsh habitats (see Appendix 1 - methods section – for details of the spatial model) allows coastal areas to be identified where saltmarsh is likely to form under the present day conditions of tidal inundation. Because Scotland's saltmarsh habitats are already largely mapped, the approach allowed a direct comparison of the currently mapped saltmarsh area (Haynes, 2016) against the outputs from the spatial model (Fig. 4). In addition, while the spatial model highlights the extent of present saltmarsh, it can also be used as a novel tool to map the potential extent of saltmarsh created by managed realignment at these sites (Fig. 5).

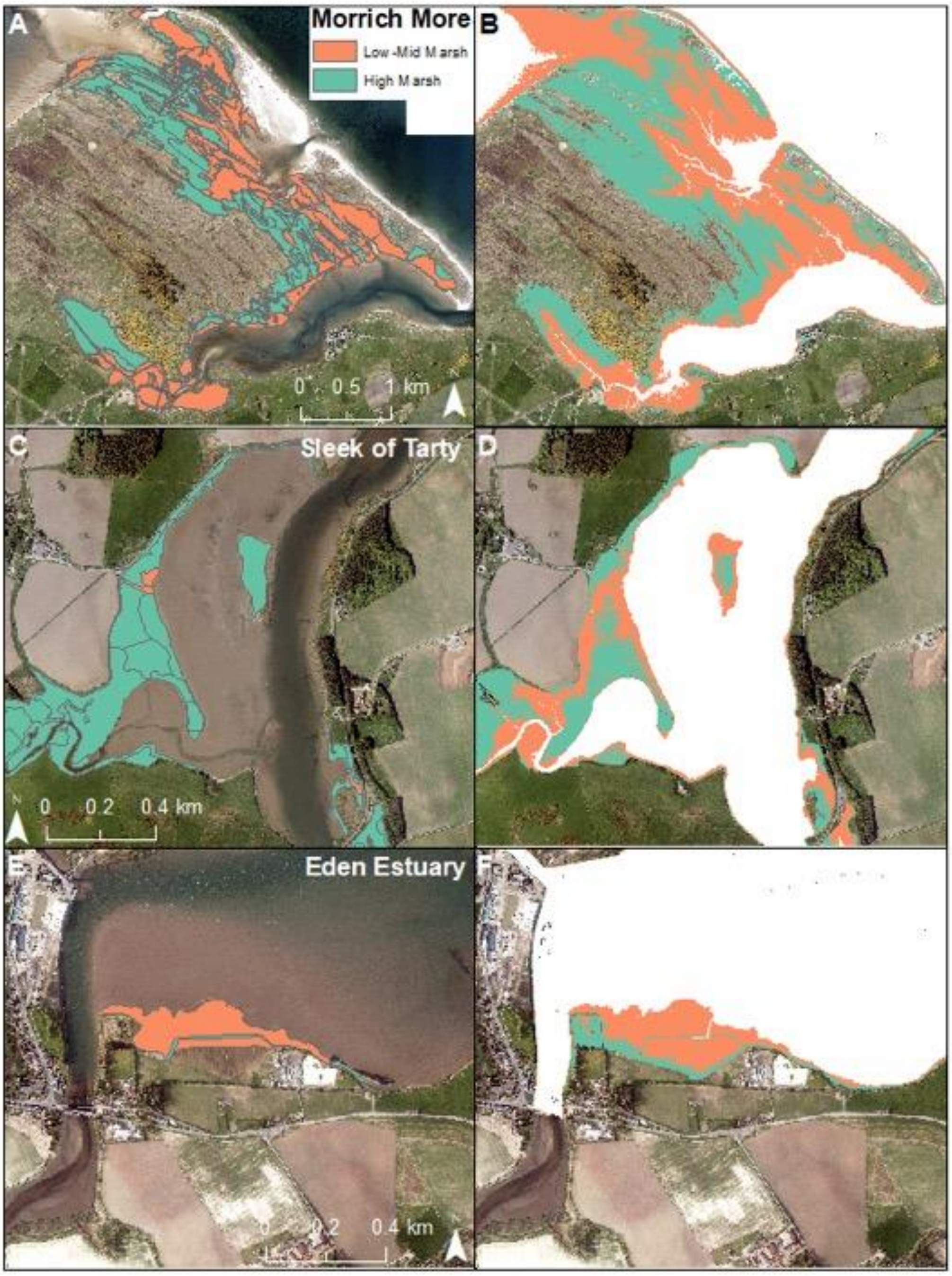

Figure 4. Comparison of currently available saltmarsh mapping (Haynes, 2016) and the outputs from the spatial model. (**A-B**) Morrich More, Dornoch Firth; (**C-D**) Sleek of Tarty, Aberdeenshire; (**E-F**) Eden Estuary, Fife.

Figure 5. An example of spatial model highlighting (**A**) the extent of present saltmarsh at Tyninghame (Haynes, 2016) - inset map of Scotland shows site location; (**B**) the potential extent of saltmarsh created by managed realignment at this site. High Marsh (green); Low-Mid Marsh (orange).

4.4 Potential for managed realignment sites

Employing a spatial mapping approach, the modelling in this study has identified 15 sites, all located on the east coast of Scotland, where the potential for managed realignment of the coastline exists (Fig. 6) (Appendix 4).

These sites are concentrated around low-lying land, in many cases associated with historic land reclamation prior to 1830 (Smout, 1972; Smout & Stewart, 2012). Further details of these 15 sites are outlined in Table 2, including the extent of any existing saltmarsh at these sites. An assessment of site suitability for managed realignment is summarized (Fig. 7) according to a 4-part categorization scheme (see Appendix 1 for more details).

Category 1	Highly Suitable	High likelihood saltmarsh will establish (saltmarsh present at site), significant Infrastructure absent at site, low impact on local populations.
Category 2	Suitable	Low likelihood saltmarsh will establish (no saltmarsh present at site), significant infrastructure absent at site, low impact on local populations.

Category 3	Less Suitable	Saltmarsh likely to establish (saltmarsh present at site or was present), significant infrastructure present, medium impact on local populations.
Category 4	Not Suitable	– Low likelihood saltmarsh will establish (no saltmarsh present at site), nationally/regionally significant infrastructure present, medium impact on local populations.

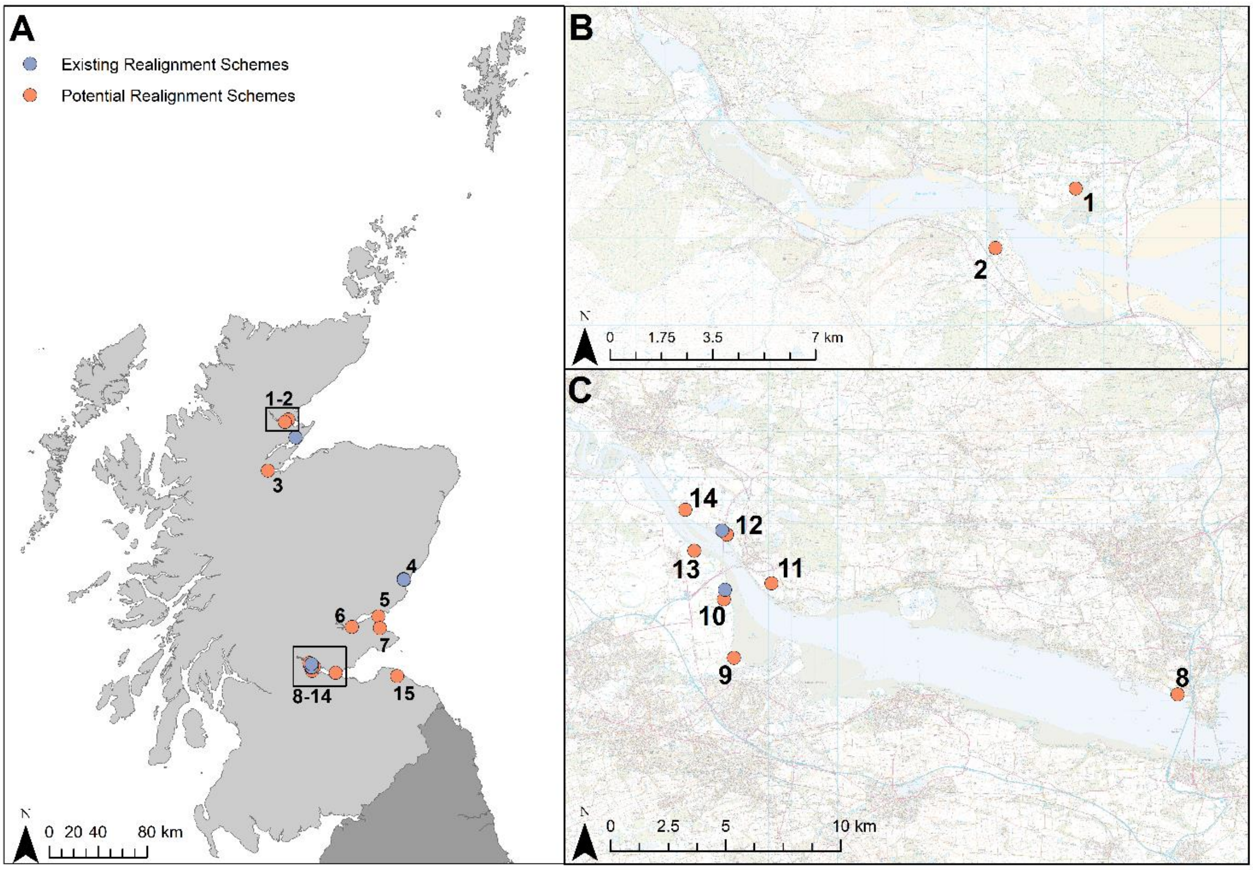

Figure 6. Map showing: (**A**) existing (blue) and potential (orange) managed realignment sites across Scotland; (**B**) Dornoch Firth (**C**). Firth of Forth. Table 2 for details of each site.

ID	Site	Local Authority	Latitude	Longitude	Existing Saltmarsh (km^2)
1	Baldruim	Highland	57.869527	-4.1418857	—
2	Ardmore	Highland	57.850465	-4.1869961	—
3	Kirkhill	Highland	57.489692	-4.398732	0.340
4	Montrose	Angus	56.714693	-2.5342417	0.168
5	Tayport	Fife	56.438899	-2.8634542	0.061

ID	Site	Local Authority	Latitude	Longitude	Existing Saltmarsh (km^2)
6	Newburgh	Fife	56.358626	-3.2135737	—
7	Eden Estuary	Fife	56.352736	-2.8427995	0.030
8	Inverkeithing	Fife	56.01888	-3.416601	—
9	Carron Pools	Falkirk	56.029262	-3.7265922	0.186
10	Skinflats	Falkirk	56.051992	-3.734609	0.103
11	Longannet	Fife	56.058697	-3.7016167	—
12	Hawkhill	Fife	56.077301	-3.7336895	—
13	Dunmore	Falkirk	56.070675	-3.7561408	0.144
14	Inch of Ferryton	Clackmannanshire	56.086596	-3.7632622	—
15	Tyninghame	East Lothian	56.000942	-2.6083192	0.400

Table 2. Details of each of the 15 sites identified as potential candidates for managed realignment as displayed in Fig. 7; criteria explaining site suitability for restoration are also detailed in Appendix 4.

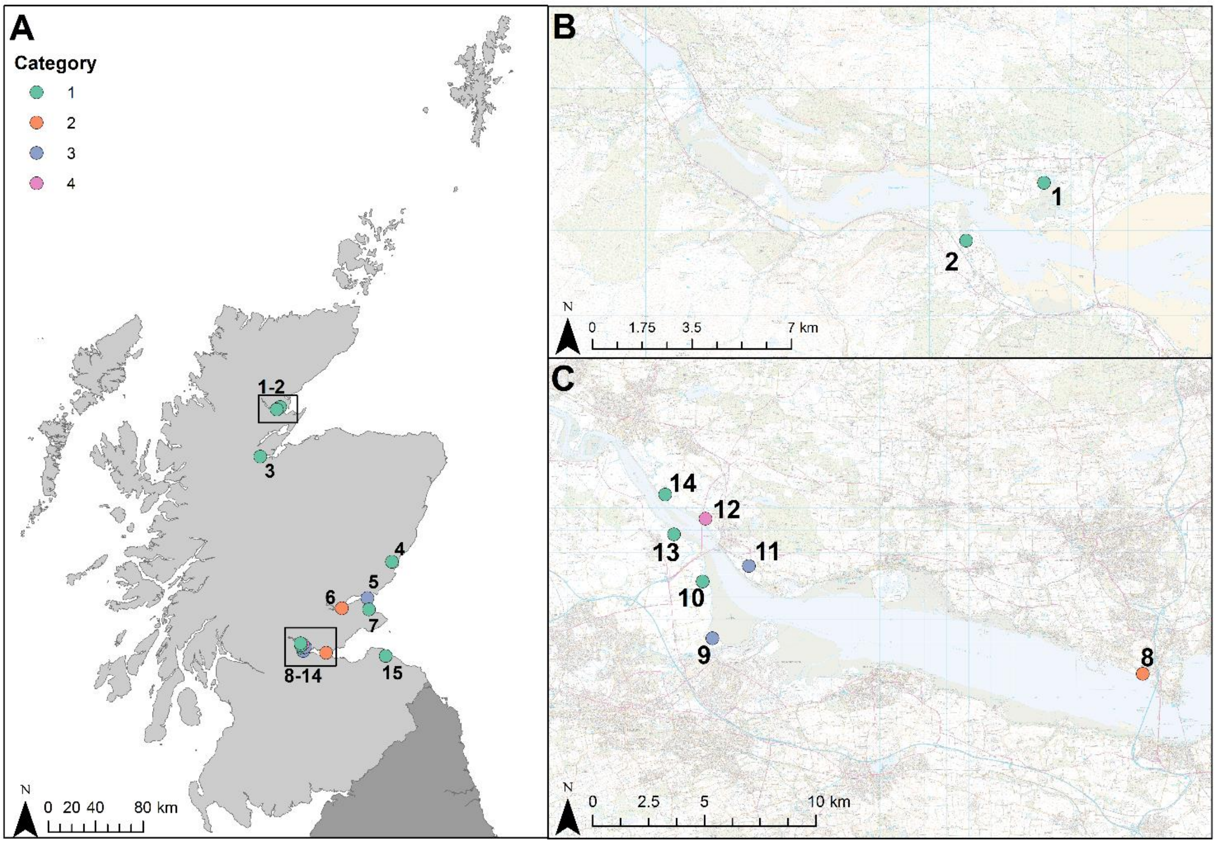

Figure 7. Map showing: (**A**) potential managed realignment sites with suitability category across Scotland; (**B**) Dornoch Firth (**C**) Firth of Forth. Table 2 details each site; criteria explaining site suitability for restoration are also detailed in Appendix 4.

A further site-by-site breakdown of the existing area and the potential for additional saltmarsh habitat creation from managed realignment is outlined in Fig. 8A, together with the anticipated extent of High Marsh and Low-Mid Marsh for potential new managed realignment of these saltmarsh habitats across Scotland (Fig. 8B). Further breakdown of the potential areal extent of the MR saltmarshes can be found in Appendix 4.

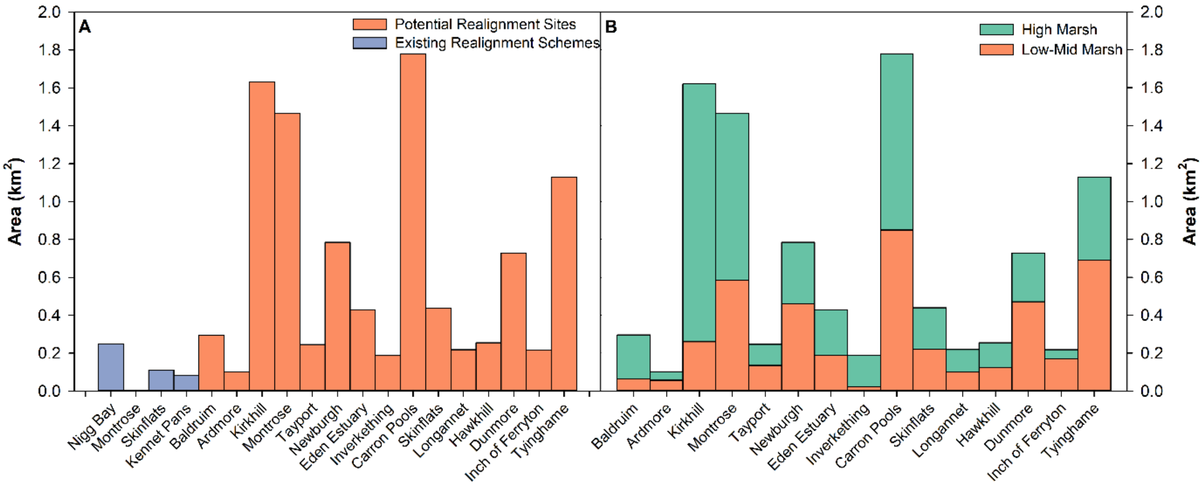

Figure 8. Summary of existing (blue) and potential new sites (orange) for MR of saltmarsh habitats across Scotland: (A) area (km^2) of each site after MR; (B) Anticipated extent of High Marsh (green) and Low-Mid Marsh (orange) for potential new MR of saltmarsh habitats across Scotland. Full breakdown of the potential areal extent of the MR saltmarshes can be found in Appendix 3. v) Potential saltmarsh extent at proposed sites under future sea-level projections

We have used future sea-level rise projections from three climate scenarios that represent different future GHG emission scenarios and illustrate the implications of these differing future mean sea-levels at one of our sites, Tyninghame (Fig. 9) (see Appendix 3 for further technical details). These sea-level scenarios are then projected over the coastal elevation model at each of the 15 candidate MR sites to estimate the area of the existing and newly created saltmarsh that would potentially be converted to mudflat and lost at set time periods (2032, 2045, 2070, and 2100).

Again, for illustrative purposes, we provide an example of the changing saltmarsh extent following a hypothetical managed realignment at Tyninghame, Scotland (Fig. 10), assuming a simple drowning of the saltmarsh surface as sea-level rises and no inland expansion of the saltmarsh habitat. Employing this highly conservative (“zero geomorphic change” response) loss estimate of saltmarsh area over time following a hypothetical managed realignment at all 15 sites across Scotland our results highlight (Fig. 11), even under the most extreme scenarios of future sea-level rise, that managed realignment of all 15 sites would still deliver net gains in saltmarsh area by the end of the century.

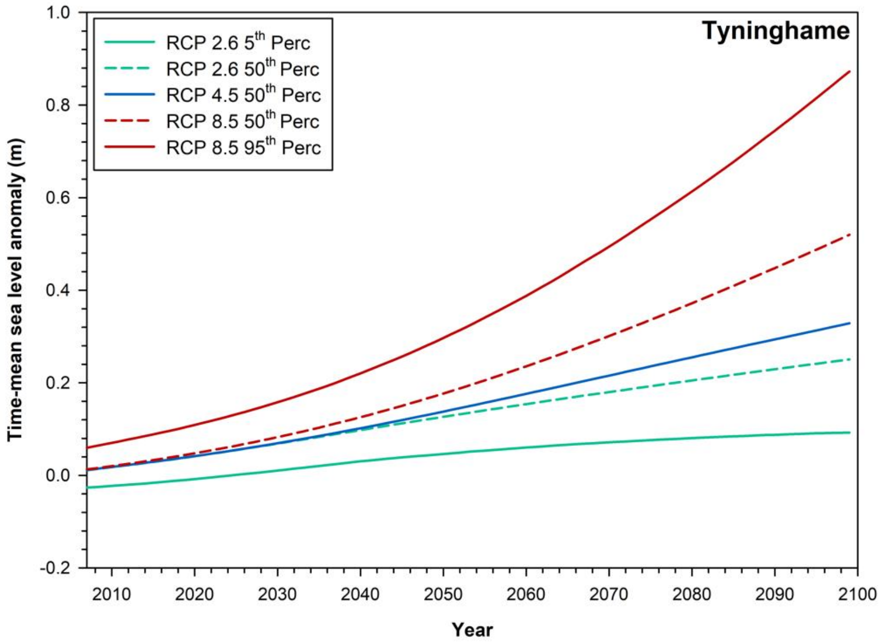

Figure 9. An example of sea-level change projections (mean sea-level anomalies (m)) under different climate scenarios for Tyninghame, Scotland. RCP 2.6 represents a low-emissions scenario, RCP4.5 medium emissions, RCP 8.5 high emissions.

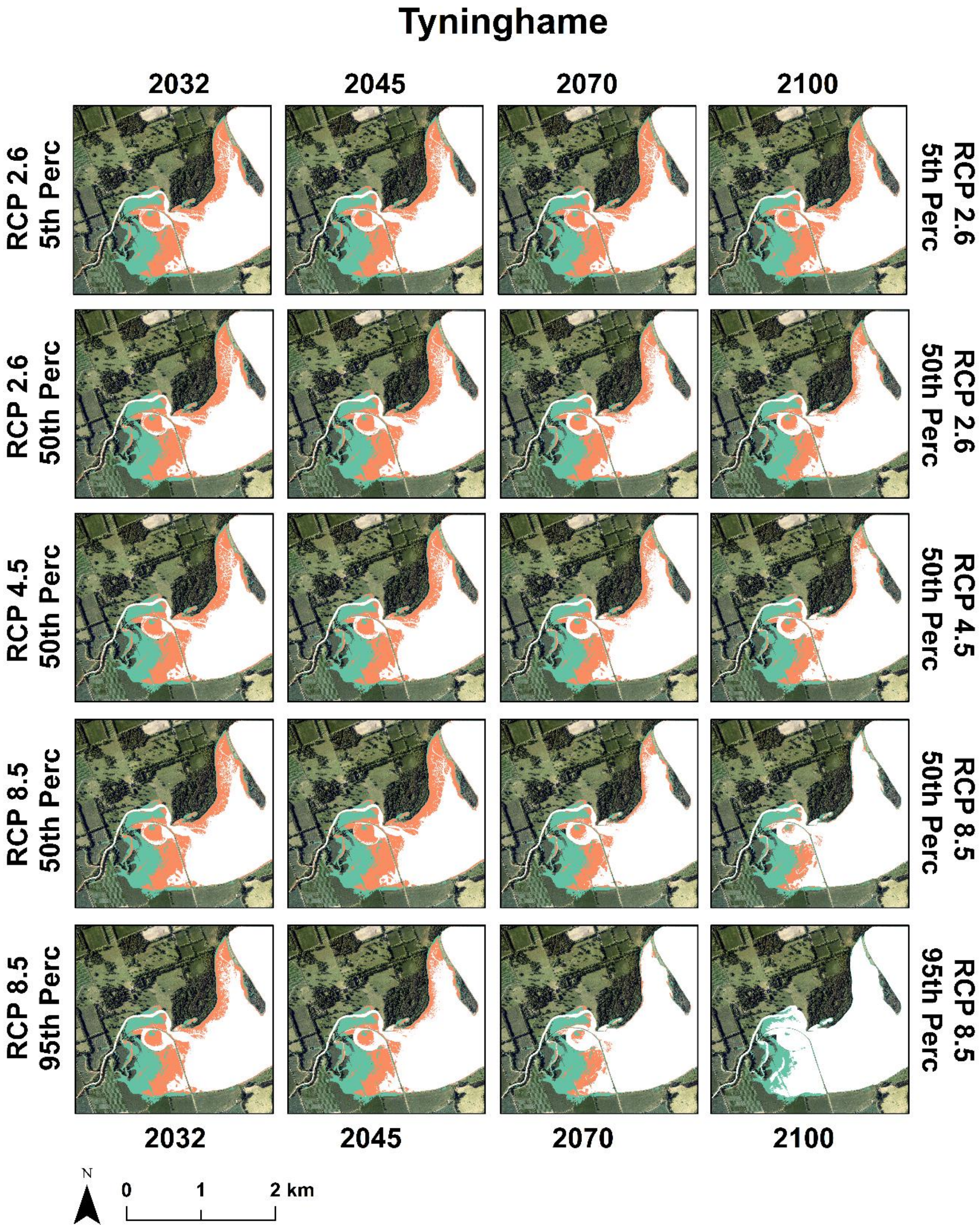

Figure 10. An example of changing saltmarsh extent following a hypothetical managed realignment at Tyninghame, Scotland and including subsequent habitat loss (assuming no landward migration of the coastline nor any vertical accretion of the marsh surface).

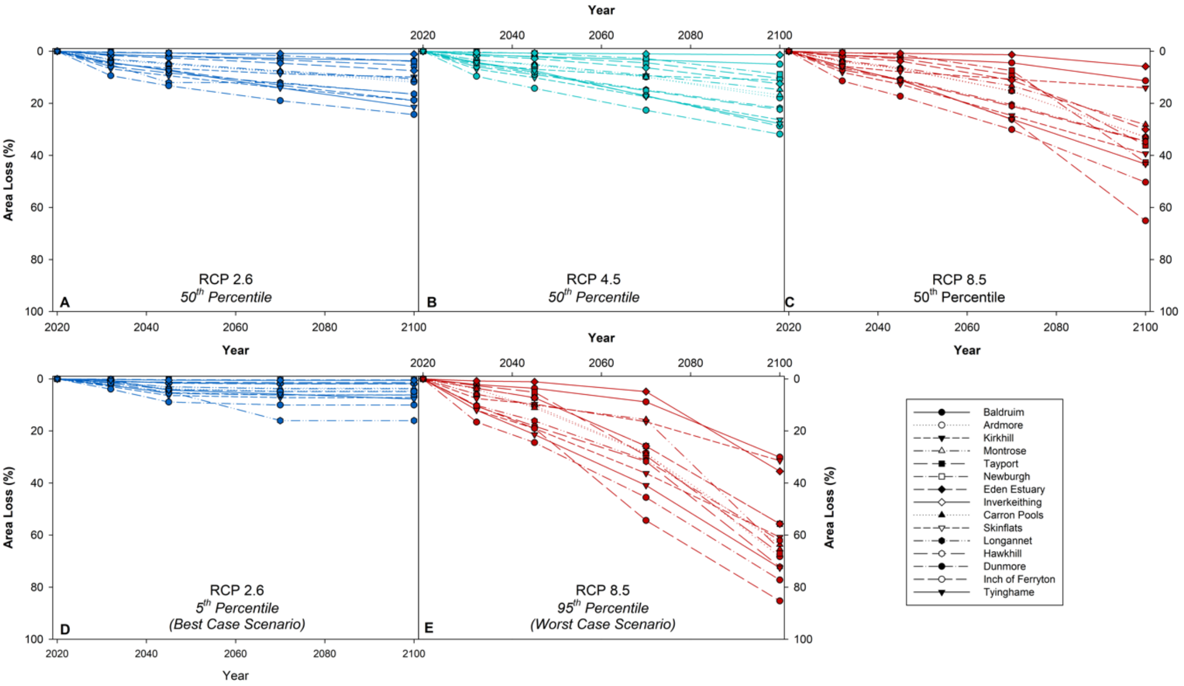

Figure 11. Change in saltmarsh extent (%), assuming a simple ("zero geomorphic change" response) loss of saltmarsh area over time following a hypothetical managed realignment at all sites across Scotland. Sea-level change projections under different emissions scenarios are shown for the 5th and 95th percentiles for RCP2.6 (low emissions), RCP4.5 (medium emissions) and RCP8.5 (high emissions) for 2032, 2045, 2070 and 2100. Full breakdown of these data can be found in Appendix 3.

4.5 Blue carbon potential of the realigned saltmarsh sites

In this study the potential blue carbon gains from MR in Scotland focuses on the potential organic carbon storage capacity of the surficial (top 10 cm) in saltmarsh soils (Fig. 12). To determine this soil organic carbon stock for the 15 potential MR sites, the modelled spatial extent of the low-mid and high marsh was combined with mean dry bulk density and organic carbon content data (see Appendix 3 for further technical detail), which were compiled from Scottish saltmarshes (Austin *et al.,* 2021). The surficial organic carbon stocks from these 15 managed realignment sites would contribute an additional 63,139 ± 32,778 tonnes of carbon in their top 10 cm of soil. Again, under the most extreme scenarios of future sea-level rise (and with the same highly conservative "zero geomorphic change" response in saltmarsh area), we see that nearly 50% of the additional surficial carbon is retained by the end of the century (Fig. 13).

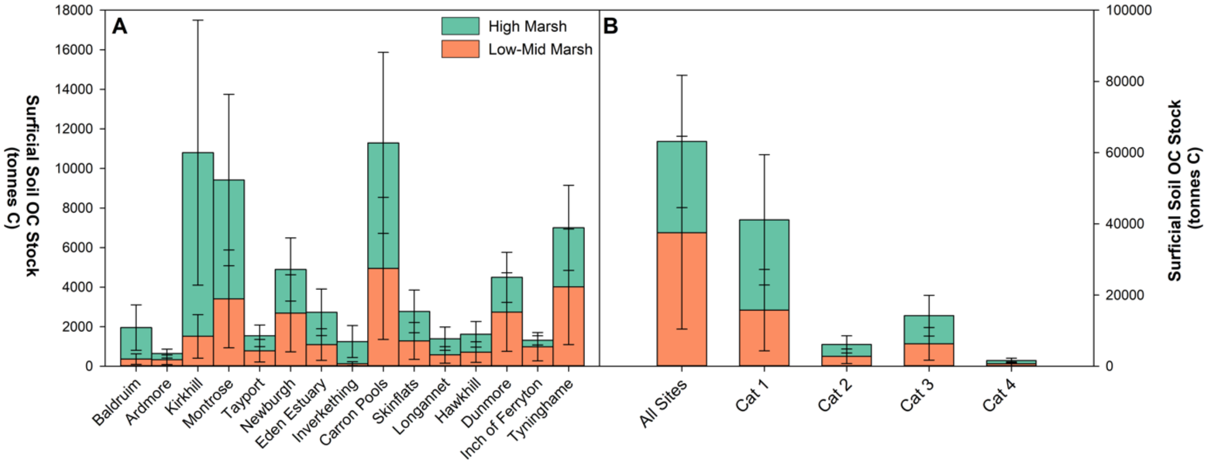

Figure 12. Summary of (**A**) potential surficial (10 cm) soil organic carbon (OC) stock (tonnes C) across new sites identified as suitable for managed realignment of saltmarsh habitats across Scotland, showing soil OC stock in Low-Mid and High Marsh; (**B**) Potential surficial (10 cm) soil organic carbon (OC) stock (tonnes C) across all new sites (and categories) identified as suitable for MR of saltmarsh habitats across Scotland, showing soil OC stock in High Marsh (green) and Low-Mid Marsh (orange). Full breakdown of potential surficial OC stocks for the MR site can be found in Appendix 3.

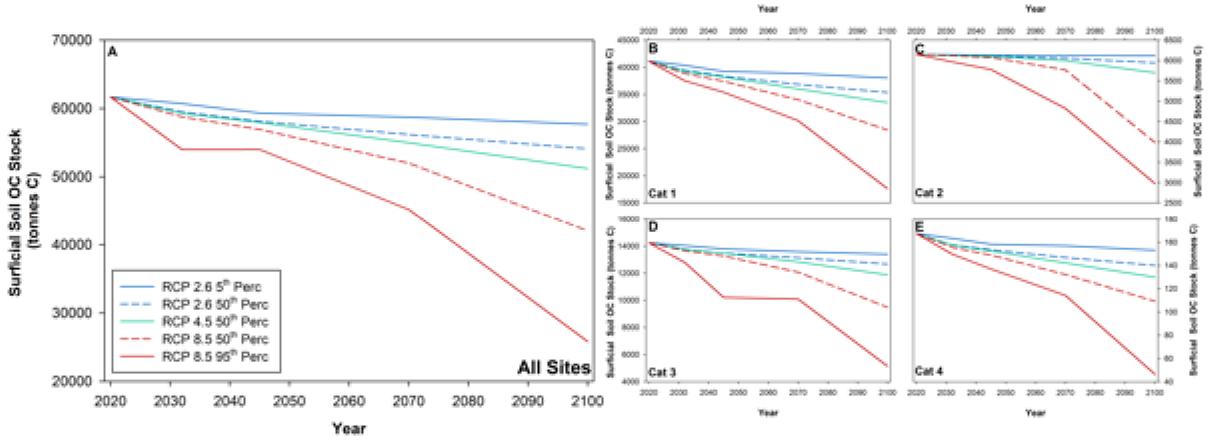

Figure 13. Changes in the potential surficial (top 10 cm) soil OC stock for the MR sites across Scotland due to changing RSL under differing climate scenarios. (**A**) All Sites (*n=15*), (**B**) Cat 1 sites (*n=9*); (**C**) Cat 2 sites (*n=2*); (**D**) Cat 3 sites (*n=3*) and (**E**) Cat 4 sites (*n=1*). Full breakdown of this data can be found in Appendix 2.

5 Discussion

Marsh elevations in relation to tidal datums (local tidal reference points) vary considerably across sites in Scotland and the lower saltmarsh edge only extends down to MHWN in a few cases (Fig. 3). Local monitoring of the vegetation zonation in relation to tidal datums at a nearby reference site prior to restoration is therefore needed to model future marsh extent at each restoration site. It would be possible to carry out such monitoring at the 15 candidate managed realignment sites identified in this study (Figs. 6, 7 and Table 2); this work could be conducted initially over a one-year interval to define the lower saltmarsh edges within the local tidal frame at these sites (see Fig. 3).

Sea-level projections to assess marsh vulnerability to sea-level rise should include high-tide levels, especially the mean high water of neap and spring tides, because these can differ locally from mean sea level trends. Sea-level projections alone do not include considerations around local sediment supply to the marsh; it is increasingly recognized that local sediment supply should be evaluated in addition to trends in tidal datums to assess future marsh vulnerability (see Ladd *et al*. 2019).

The approach taken in this study to estimate potential blue carbon gains from managed realignment activities assumes that the realigned saltmarsh will instantly reach a state where it buries and stores OC in a similar way to a natural saltmarsh. The time taken for a managed realignment site to reach this state is unknown and there is scope for a study of the existing managed realignment sites across Scotland to be undertaken to assess the available chrono sequence of additional blue carbon gains at these sites.

This study highlights the acknowledged global threat of rising sea-levels, particularly associated with the potential for loss of saltmarsh area around Scotland (Fig. 11) and the associated loss in surficial soil OC stock (Fig. 13). However, managed realignment and the creation of new saltmarsh offers, in all but the most extreme scenario of sea-level rise by the end of this century, clear net gains over the existing saltmarsh area (and associated soil OC stock) (Appendix 4). Given the urgency of sea-level rise considerations, the long-term threats from accelerating sea-level rise, the potential for saltmarsh habitat loss across Scotland, and the negative implications of these habitat losses to future national GHG accounting, the implementation of managed realignment across key sites in Scotland would be advantageous. It is acknowledged, however, that further assessment of the engineering, social and economic viability of the key sites reported here is required to stimulate coastal restoration opportunities across Scotland.

In this study, the potential blue carbon gains reported (Fig. 12) are calculated only as an equivalent surficial soil OC stock and are therefore much more conservative than other approaches currently being utilised to promote the blue carbon potential of managed realignment for saltmarsh creation (Mossman *et al*., 2021). Given the limited evidence available, existing and future saltmarsh restoration projects in Scotland that include a quantitative blue carbon assessment would be extremely valuable (see Hudson *et al*., 2021).

The most common approach used to calculate blue carbon gains is the Blue Carbon Calculator developed by ABPmer (www.abpmer.co.uk/blog/abpmers-blue-carbon-calculator/) which uses accretion rates and sediment yields to estimate C sequestration rates. This approach results in OC sequestration rates ranging between 221-1,849 g C m^{-2} yr^{-1} (ABPmer, 2021a; Mossman *et al.,* 2021). Globally, it is estimated that natural saltmarshes bury 218 ± 24 g C m^{-2} yr^{-1} (Duarte *et al.,* 2013), this figure includes highly productive saltmarshes from the tropics.

It seems unlikely that temperate UK saltmarshes are capturing an order of magnitude more OC than their tropical counterparts. The most likely explanation for this disparity in the data is that the accommodation space created in these newly realigned sites rapidly fills with sediments from the adjacent intertidal flats (mud or sand) until it reaches an equilibrium point where the correct tidal window is created for the establishment of saltmarsh. The very high initial rates of OC sequestration calculated from managed realignment sites in England may therefore be a product of the rapid accommodation of highly mobile organic-rich sediments at these sites. The OC in this redeposited sediment will be allochthonous (external source), it is unlikely to be directly sequestered from the atmosphere yet contributes through burial to an effective saltmarsh soil OC store.

In view of these complex processes and the lack of evidence, the existing managed realignment sites across Scotland offer an excellent opportunity to assess the sources, age, and burial histories of OC in their soils.

Key knowledge gaps identified

Beyond some of the physical, biological and biogeochemical knowledge gaps in our understanding of saltmarsh functioning, we identified the following key knowledge gaps during this study:

(i) rates of organic carbon burial over time following the creation of new saltmarsh habitat are poorly defined beyond simple conceptual models and lack constraining evidence;
(ii) reliable estimates of GHG emissions from newly created saltmarsh soils are unavailable;
(iii) rates of saltmarsh habitat establishment and the development of saltmarsh soil carbon stocks after managed realignment take time, but while those chrono sequences are available, they have not yet been studied and reported;
(iv) the sources of organic carbon which accumulated in saltmarsh soils, particularly immediately after managed realignment, are not well-constrained and may contain significant quantities of redeposited, aged organic matter from non-saltmarsh sources.

This research would have benefitted from more refined data on the natural functioning of saltmarsh ecosystems, particularly in their geomorphic response to future sea-level changes, where coastal geometry, tidal ranges and sediment supply (among other natural environmental variables) are largely unknown.

While these represent clear knowledge gaps, they also pose limitations on our ability to model some of the changes in these systems.

These include

(i) limitations in the quality and coverage of digital elevation data for Scotland’s coastlines;
(ii) limitations in data to constrain prevailing rates of sediment supply to Scottish saltmarshes;
(iii) limitations in the geomorphic models that simulate changes in habitat area in response to sea-level change.

A particular limitation at the present time, with considerable relevance to GHG accounting, is therefore uncertainty over the extent to which managed realignment saltmarsh sites contribute to reducing net GHG emissions. The actual strength of the net carbon sequestration at these sites is yet to be fully determined, despite much evidence of an effective long-term carbon sink at salinities above 18.

6 Conclusions

This study has identified 15 coastal sites in Scotland where existing low-lying land is potentially suitable for managed realignment and the creation of new saltmarsh habitat. The additional area of saltmarsh habitat that would be created allows for a first-order estimate of additional blue carbon storage potential across these sites. Projected future sea-level rise, driven by uncertain greenhouse gas emissions, will likely reduce the additionality gained from the initial blue carbon in these realigned coastal habitats, but nearly all sites highlight long-term carbon additionality and net habitat gains. Further work will be required to explore how they might be applied in specific land use management and policy contexts, and to understand the impacts, if any, of interactions between the indicators of saltmarsh habitat and blue carbon gains under changing future conditions.

7 References

ABPmer, 2021a. Blue Carbon in Managed Realignments: an Overview with Comparative Analysis and Valuation of Ten Different UK Sites (White Paper). URL https://www.abpmer.co.uk/resources?resource=BlueCarbon

ABPmer, 2021b. OMReg Map [WWW Document]. OMreg View Map. URL https://www.omreg.net/view-map/ (accessed 10.29.21).

Adams, J.B., Raw, J.L., Riddin, T., Wasserman, J. and Van Niekerk, L., 2021. Salt Marsh Restoration for the Provision of Multiple Ecosystem Services. Diversity, 13(12), p.680.

Austin, W.E.N., Smeaton, C., Riegel, S., Ruranska, P., Miller, L., 2021. Blue carbon stock in Scottish saltmarsh soils: Scottish Marine and Freshwater Science Vol 12 No 13. https://doi.org/10.7489/12372-1

Balke, T., Stock, M., Jensen, K., Bouma, T. J. and Kleyer, M. (2016) A global analysis of the seaward salt marsh extent: the importance of tidal range. Water Resources Research, 52(5), pp. 3775-3786.

Balke, T., Vovides, A., Schwarz, C., Chmura, G. L., Ladd, C., and Basyuni, M.: Monitoring tidal hydrology in coastal wetlands with the "Mini Buoy": applications for mangrove restoration (2021) Hydrol. Earth Syst. Sci., 25, pp. 1229–1244.

Beaumont, N.J., Jones, L., Garbutt, A., Hansom, J.D., Toberman, M., 2014. The value of carbon sequestration and storage in coastal habitats. Estuar. Coast. Shelf Sci. 137, 32–40. https://doi.org/10.1016/j.ecss.2013.11.022

Bianchi, T.S., Arndt, S., Austin, W.E., Benn, D.I., Bertrand, S., Cui, X., Faust, J.C., Koziorowska-Makuch, K., Moy, C.M., Savage, C. and Smeaton, C., 2020. Fjords as aquatic critical zones (ACZs). Earth-Science Reviews, 203, p.103145.

Brady, A.F., Boda, C.S., 2017. How do we know if managed realignment for coastal habitat compensation is successful? Insights from the implementation of the EU Birds and Habitats Directive in England. Ocean Coast. Manag. 143, 164–174. https://doi.org/10.1016/j.ocecoaman.2016.11.013

Burden A, Garbutt RA, Evans CD, Jones DL, Cooper DM., 2013. Carbon sequestration and biogeochemical cycling in a saltmarsh subject to coastal managed realignment. Estuar. Coast Shelf Sci. 2013;120:12-20. doi:10.1016/j.ecss.2013.01.014

Burden, A., Garbutt, A., Evans, C.D., 2019. Effect of restoration on saltmarsh carbon accumulation in Eastern England. Biol. Lett. 15. https://doi.org/10.1098/rsbl.2018.0773

Burden, A., Smeaton, C., Angus, S., Garbutt, A., Jones, L., Lewis, H., Rees, S., 2020. Impacts of climate change on coastal habitats, relevant to the coastal and marine environment around the UK. MCCIP Sci. Rev. 2020.

Clark, C.D., Ely, J.C., Greenwood, S.L., Hughes, A.L., Meehan, R., Barr, I.D., Bateman, M.D., Bradwell, T., Doole, J., Evans, D.J. and Jordan, C.J., 2018. BRITICE Glacial Map, version 2: a map and GIS database of glacial landforms of the last British–Irish Ice Sheet. Boreas, 47(1), pp.11-e8.

Crosby, S.C., Sax, D.F., Palmer, M.E., Booth, H.S., Deegan, L.A., Bertness, M.D., Leslie, H.M., 2016. Salt marsh persistence is threatened by predicted sea-level rise. Estuar. Coast. Shelf Sci. 181, 93–99. https://doi.org/10.1016/j.ecss.2016.08.018

Dargie, T. 2017. Morrich More coastal change analysis 1987 to 2015. Scottish Natural Heritage Commissioned Report No. 927.

Doody, J.P., 2013. Coastal squeeze and managed realignment in southeast England, does it tell us anything about the future? Ocean Coast. Manag. 79, 34–41. https://doi.org/10.1016/j.ocecoaman.2012.05.008

Duarte, C.M., Losada, I.J., Hendriks, I.E., Mazarrasa, I., Marbà, N., 2013. The role of coastal plant communities for climate change mitigation and adaptation. Nat. Clim. Chang. 3, 961–968.

Esteves, L.S., 2013. Is managed realignment a sustainable long-term coastal management approach? J. Coast. Res. 933–938. https://doi.org/10.2112/SI65-158

FitzGerald, D.M., Hughes, Z., 2019. Marsh Processes and Their Response to Climate Change and Sea-Level Rise. Annu. Rev. Earth Planet. Sci. 47, 481–517. https://doi.org/10.1146/annurev-earth-082517-010255

Gonneea, M.E., Maio, C.V., Kroeger, K.D., Hawkes, A.D., Mora, J., Sullivan, R., Madsen, S., Buzard, R.M., Cahill, N., Donnelly, J.P., 2019. Salt marsh ecosystem restructuring enhances elevation resilience and carbon storage during accelerating relative sea-level rise. Estuar. Coast. Shelf Sci. 217, 56–68. https://doi.org/10.1016/j.ecss.2018.11.003

Haynes TA., 2016. Scottish saltmarsh survey national report. Scottish Natural Heritage Commissioned Report No. 786.:204.

Haywood, B.J., Hayes, M.P., White, J.R., Cook, R.L., 2020. Potential fate of wetland soil carbon in a deltaic coastal wetland subjected to high relative sea level rise. Sci. Total Environ. 711, 135185. https://doi.org/10.1016/j.scitotenv.2019.135185

Herbert, E.R., Windham-Myers, L., Kirwan, M.L., 2021. Sea-level rise enhances carbon accumulation in United States tidal wetlands. One Earth 4, 425–433. https://doi.org/10.1016/j.oneear.2021.02.011

Horton, B.P., Rahmstorf, S., Engelhart, S.E. and Kemp, A.C., 2014. Expert assessment of sea-level rise by AD 2100 and AD 2300. Quaternary Science Reviews, 84, pp.1-6.

Horton, B.P., Shennan, I., Bradley, S.L., Cahill, N., Kirwan, M., Kopp, R.E., Shaw, T.A., 2018. Predicting marsh vulnerability to sea-level rise using Holocene relative sea-level data. Nat. Commun. 9, 2687. https://doi.org/10.1038/s41467-018-05080-0

Hudson, R., Kenworthy, J., Best, M., 2021. Saltmarsh Restoration Handbook: UK and Ireland. Environment Agency, Bristol, UK.

IPCC., 2021. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

IPCC., 2014. 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands Methodological Guidance on Lands with Wet and Drained Soils, and Constructed Wetlands for Wastewater Treatment.

Kelleway, J.J., Serrano, O., Baldock, J.A., Burgess, R., Cannard, T., Lavery, P.S., Lovelock, C.E., Macreadie, P.I., Masqué, P., Newnham, M., Saintilan, N., Steven, A.D.L., 2020. A national approach to greenhouse gas abatement through blue carbon management. Glob. Environ. Change 63, 102083. https://doi.org/10.1016/j.gloenvcha.2020.102083

Kirwan, M.L., Mudd, S.M., 2012. Response of salt-marsh carbon accumulation to climate change. Nature 489, 550–553. https://doi.org/10.1038/nature11440

Kirwan, M.L., Temmerman, S., Skeehan, E.E., Guntenspergen, G.R., Fagherazzi, S., 2016. Overestimation of marsh vulnerability to sea level rise. Nat. Clim. Change 6, 253–260. https://doi.org/10.1038/nclimate2909

Kroeger, K.D., Crooks, S., Moseman-Valtierra, S., Tang, J., 2017. Restoring tides to reduce methane emissions in impounded wetlands: A new and potent Blue Carbon climate change intervention. Sci. Rep. 7, 11914. https://doi.org/10.1038/s41598-017-12138-4

Ladd, C. J.T., Duggan-Edwards, M. F., Bouma, T. J., Pagès, J. F. and Skov, M. W., 2019. Sediment supply explains long-term and large-scale patterns in salt marsh lateral expansion and erosion. Geophysical Research Letters, 46(20), pp. 11178-11187. (doi: 10.1029/2019GL083315).

Lunn, D., Spiegelhalter, D., Thomas, A., Best, N., 2009. The BUGS project: Evolution, critique and future directions. Stat. Med. 28, 3049–3067.

Mcleod E., Chmura GL., Bouillon S., Salm, R., Bjork, M., Duarte, C. M., Lovelock, C. E., Schlesinger, W. H., Silliman, B. R., 2011. A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. Front Ecol Environ. 9(10):552-560. doi:10.1890/110004

McTigue, N., Davis, J., Rodriguez, A.B., McKee, B., Atencio, A., Currin, C., 2019. Sea Level Rise Explains Changing Carbon Accumulation Rates in a Salt Marsh Over the Past Two Millennia. J. Geophys. Res. Biogeosciences 124, 2945–2957. https://doi.org/10.1029/2019JG005207

Mossman HL, Pontee N, Born K., Lawrence, P. J., Rae, S., Scott, J., Serato, B., Sparkes R. B., Sullivan, M. J. P., Dunk, R. M. Rapid Carbon Accumulation at a Saltmarsh Restored by Managed Realignment Far Exceeds Carbon Emitted in Site Construction.; unpublished. 2021:2021.10.12.464124. doi:10.1101/2021.10.12.464124

Ouyang, X., Lee, S.Y., 2014. Updated estimates of carbon accumulation rates in coastal marsh sediments. Biogeosciences 11, 5057–5071. https://doi.org/10.5194/bg-11-5057-2014

Rogers, K., Macreadie, P.I., Kelleway, J.J., Saintilan, N., 2019. Blue carbon in coastal landscapes: a spatial framework for assessment of stocks and additionality. Sustain. Sci. 14, 453–467. https://doi.org/10.1007/s11625-018-0575-0

Rogers, Kerrylee, Kelleway, J., Saintilan, N., 2019. Rising seas allow coastal wetlands to store more carbon. Fac. Sci. Med. Health - Pap. Part B 1–5. https://ro.uow.edu.au/smhpapers1/583

Schuerch, M., Spencer, T., Temmerman, S., Kirwan, M.L., Wolff, C., Lincke, D., McOwen, C.J., Pickering, M.D., Reef, R., Vafeidis, A.T., Hinkel, J., Nicholls, R.J., Brown, S., 2018. Future response of global coastal wetlands to sea-level rise. Nature 561, 231–234. https://doi.org/10.1038/s41586-018-0476-5

Smeaton, C., Austin, W.E., Davies, A.L., Baltzer, A., Howe, J.A. and Baxter, J.M., 2017. Scotland's forgotten carbon: a national assessment of mid-latitude fjord sedimentary carbon stocks. Biogeosciences, 14(24), pp.5663-5674.

Smith, A.J., Kirwan, M.L., 2021. Sea Level-Driven Marsh Migration Results in Rapid Net Loss of Carbon. Geophys. Res. Lett. 48, e2021GL092420. https://doi.org/10.1029/2021GL092420

Smout, T.C. & Stewart, M. 2012. The Firth of Forth: an environmental history. Birlinn, Edinburgh.

Smout, T.C. (Ed.), 1993. Scotland Since Prehistory: Natural Change and Human Impact. Scottish Cultural Press.

Smout, T.C., 1972. A history of the Scottish people, 1560-1830 (Vol. 2954). Fontana press.

Theuerkauf, E.J., Stephens, J.D., Ridge, J.T., Fodrie, F.J., Rodriguez, A.B., 2015. Carbon export from fringing saltmarsh shoreline erosion overwhelms carbon storage across a critical width threshold. Estuar. Coast. Shelf Sci. 164, 367–378. https://doi.org/10.1016/j.ecss.2015.08.001

Torio, D.D., Chmura, G.L., 2013. Assessing Coastal Squeeze of Tidal Wetlands. J. Coast. Res. 29, 1049–1061. https://doi.org/10.2112/JCOASTRES-D-12-00162.1

Wang, F., Sanders, C.J., Santos, I.R., Tang, J., Schuerch, M., Kirwan, M.L., Kopp, R.E., Zhu, K., Li, X., Yuan, J., Liu, W., Li, Z., 2021. Global blue carbon accumulation in tidal wetlands increases with climate change. Natl. Sci. Rev. 8, nwaa296. https://doi.org/10.1093/nsr/nwaa296

Wiltshire J, Freeman D, Willcocks J, Wood C., 2021. The Potential for Leguminous Crops in Scotland. Ricardo Energy & Environment. doi:10.7488/era/763

Wollenberg JT, Ollerhead J, Chmura GL. Rapid carbon accumulation following managed realignment on the Bay of Fundy., 2018. PLOS ONE. 2018;13(3):e0193930. doi:10.1371/journal.pone.01939302

8 Appendix 1 – Methods

8.1 Rapid evidence assessment (managed realignment)

A rapid evidence assessment literature review summarizes the potential for implementing managed realignment (MR) projects to create new coastal wetland (saltmarsh) blue carbon habitats in Scotland. The articles which have been reviewed are sorted alphabetically by author, and each has a summary followed by analysis of the relevant points made. Some papers contained much more relevant information than others because their subject matter is more closely aligned to this project.

The methods for this literature search closely follow those by Wiltshire *et al.* (2021). A key term search (Table A1.1) was carried out to identify as many peer-reviewed articles, grey literature, industry and NGO studies, and theses/dissertations as possible that were relevant to this study. The search engines "Google Scholar" and "SCOPUS" were used as these would pick up most if not all relevant studies, negating the time consuming need to use multiple search engines.

Table A1.1. The phrases used for the key term searches.

Words and Terms	Notes
United Kingdom	
Scotland	
Coastal Habitats	
Saltmarsh	Or Salt Marsh
Blue Carbon	
Sea Level Change	Or Sea-level Change; Sea-level Rise; Sea Level Rise
Tidal Elevation	
Erosion	
Accretion	
Coastal Management	
Managed Realignment	Coastal Realignment

The key term search used the following search string: "United Kingdom" OR "Scotland" AND "Coastal Habitats" OR "Saltmarsh" OR "Salt Marsh" AND "Blue Carbon" OR "Sea-level Change" OR "Tidal Elevation" OR "Erosion" OR "Accretion" OR "Coastal Management" OR "Managed Realignment" OR "Coastal Realignment". Results were initially screened by title, then by abstract, and then by the full article. All remaining relevant papers were read in full. The SCOPUS search was carried out first and any duplicate results from Google Scholar were excluded. Additional papers were found through reference list searching (backreferencing) and by searching specifically for grey literature, as some of this was missed out in the key terms search.

Table A1.2. Key term Search Results.

Search Method	Results	Screened Results (duplicates>title>abstract>full article)	Cited in this Review
Scholar	14,700	17	7
SCOPUS	211	73	18
Backreferencing/grey literature	N/A	56	36

Papers were organised in Zotero, a popular reference manager. The literature review was carried out in a Word document, with the papers separated by title in alphabetical order. For each paper there is a summary and then notes have been included to highlight key points that are relevant to this study. The cited papers were then exported to Excel to ensure this project is replicable. This spreadsheet highlights the key information about the paper (title, authors, date, document type, publication, DOI, URL, when it was accessed, and the source). This could be used by anyone attempting to replicate this project to see what was out there at the time of this report. A more detailed Excel spreadsheet was also produced for all the papers exported in Zotero. This contains all the metadata stored within the Zotero bibliography and is split into three sheets: one for each source (Scholar, SCOPUS, backreferencing).

If this literature review were to be repeated, the same search terms could be used on Google Scholar and SCOPUS, excluding results from before 28/09/2021 (the date the original search was carried out). Any new findings could be cross referenced with an Excel spreadsheet which lists all the sources cited, key information, date searched, and where they were found.

Author(s)	Date	Title	Document Type	Publisher/Publication	DOI	URL	Accessed	Source	Column1
ABPmer	2021a	Meddat M	WWW Document			https://ww	04/10/2021	Backreferencing	
ABPmer	2021b	Blue Carb	White Paper			https://ww	20/11/2021	Backreferencing	
ABPmer	2015	The cost	Briefing Note			https://ww	29/10/2021	Backreferencing	
ABPmer	2011	Case Stu	White Paper			https://ww	29/10/2021	Backreferencing	
ABPmer	2021c	OMreg Vi	WWW Document			https://ww	29/10/2021	Backreferencing	
Adam, P.	2019	Chapter 2	Book Chapter	Elsevier, Pgs. 817-861.	10.1016/B9	https://ww	28/09/2021	Scholar	
Adams, C.A.,	2012	Nitrous o	Journal Article	Science of the Total Envir	10.1016/j.s	https://ww	28/09/2021	SCOPUS	
Andrews, J.E	2008	Historical	Journal Article	Science of the Total Envir	10.1016/j.s	https://ww	17/11/2021	SCOPUS	
Austin, W.E.N	2021	Blue Carb	Journal Article	Scottish Marine and Fresh	10.7489/12	Blue carb	29/10/2021	Backreferencing	
Beaumont, N	2014	The value	Journal Article	Estuarine, Coastal and Sh	10.1016/j.e	https://ww	28/09/2021	Backreferencing	
Boorman, L.A	2017	Managed	Journal Article	Wetlands Ecology and Ma	10.1007/s1	https://ww	28/09/2021	SCOPUS	
Bradfer-Lawr	2021	The poten	Journal Article	Journal of Applied Ecology	10.1111/13	https://onl	12/10/2021	Backreferencing	
Burden, A., G	2019	Effect of r	Journal Article	Biology Letters, Vol. 15, Is	10.1098/rsb	https://ww	28/09/2021	SCOPUS	
Burden, A., G	2013	Carbon se	Journal Article	Estuarine, Coastal and Sh	10.1016/j.e	https://ww	28/09/2021	SCOPUS	
Burden, A., S	2020	Impacts o	Journal Article	MCCIP Science Review 2	10.14465/2	Impacts o	28/09/2021	Scholar	
Cooper, N.J.	2001	25 years	Journal Article	Journal of Coastal Conser	10.1007/BF	https://ww	28/09/2021	SCOPUS	
Crooks, S., S	2002	Drainage	Journal Article	Restoration Ecology, Vol.	10.1046/j.1	https://ww	28/09/2021	SCOPUS	
Dale, J., Burg	2018	Hydrodyn	Journal Article	Estuarine, Coastal and Sh	10.1016/j.e	https://ww	28/09/2021	SCOPUS	
Dale, J., Cun	2019	Sediment	Journal Article	Science of the Total Envir	10.1016/j.s	https://ww	28/09/2021	SCOPUS	
Densham, J.	2017	European	Conference Present	European Climate Change Adaptation		Research	22/10/2021	Backreferencing	
Doody, J.P.	2013	Coastal s	Journal Article	Ocean Coastal Managem	10.1016/j.o	https://ww	28/09/2021	SCOPUS	
Drexler, J.Z.,	2020	Carbon S	Journal Article	Estuaries and Coasts, Vol	10.1007/s1	https://doi	17/11/2021	Backreferencing	
Elliott, S.	2015	Coastal R	Report	RSPB		CoastalR	29/09/2021	Backreferencing	
Environment	2007	Saltmarsh	Technical Report	Environment Agency		https://ww	17/11/2021	Backreferencing	
Environment	2015	Cost estir	Report	Environment Agency		https://ass	22/11/2021	Backreferencing	
Esteves, L.S.	2013	Is manage	Journal Article	Journal of Coastal Resour	10.2112/SI	https://ww	28/09/2021	SCOPUS	
Fitton, J.M.,	2016	A nationa	Journal Article	Ocean Coastal Managem	10.1016/j.o	https://ww	28/09/2021	SCOPUS	
Halcrow Gro	2016a	Angus Sh	Report	Angus Council		https://ww	08/11/2021	Backreferencing	
Halcrow Gro	2016b	Angus Sh	Report	Angus Council		https://ww	08/11/2021	Backreferencing	
Howard, J., S	2017	Clarifying	Journal Article	Frontiers in Ecology and t	10.1002/fee	https://onl	01/10/2021	Backreferencing	
HR Wallingfo	2005	Dumfries	Report	Dumfries and Galloway Council		https://ww	08/11/2021	Backreferencing	
Hudson, R.,	2021	Saltmarsh	Report	Environment Agency		https://cat	01/12/2021	Backreferencing	
Hurst, M.D.,	2021	Dynamic	Report	Scotland’s Centre of Expertise for Wat		https://ww	12/10/2021	Backreferencing	
IPCC	2014	2013 Sup	Technical Report	IPCC, Switzerland		https://ww	03/10/2021	Backreferencing	
Kelleway, J.J	2020	A nationa	Journal Article	Global Environmental Cha	10.1016/j.g	https://ww	28/09/2021	Backreferencing	
Kiesel, J., Sc	2019	Attenuatio	Journal Article	Ecological Engineering, V	10.1016/j.e	https://ww	28/09/2021	SCOPUS	
Ladd, C.J.T.	2021	Review o	Journal Article	Proceedings of the Geolo	10.1016/j.p	https://ww	28/09/2021	SCOPUS	
Lawrence, P.	2018	Restored	Journal Article	Ecological Engineering, V	10.1016/j.e	https://ww	28/09/2021	Scholar	
Liski, A.H., A	2019	Governan	Journal Article	Regional Environmental C	10.1007/s1	https://doi	28/09/2021	Scholar	
MacDonald,	2020	Benefits o	Journal Article	Estuarine, Coastal and S	10.1016/j.e	https://ww	28/09/2021	Scholar	
Marine Mana	2019	Identifying	A report produced fo	Marine Management Organisation		https://ass	22/11/2021	Backreferencing	
Mossman, H.	2012	Does mar	Journal Article	Journal of Applied Ecology	10.1111/j.1	https://onl	28/09/2021	Scholar	
Mossman, H.	In Review	Rapid car	Journal Article	BioRxiv	10.1101/20	https://ww	19/10/2021	Backreferencing	
Mouchel	2011	Fife Shor	Report	Fife Council		https://ww	08/11/2021	Backreferencing	
NatureScot	1999	Use of GI	Management Report	NatureScot			20/11/2021	Backreferencing	
Needham, K.	2019	Valuing a	Journal Article	Ocean and Coastal Mana	10.1016/j.o	https://ww	28/09/2021	Scholar	
Poppe, K.L.,	2021	Tidal mar	Journal Article	PLOS ONE, Vol. 16, Pgs.	10.1371/jou	https://jou	19/10/2021	Backreferencing	
Reed, D.J., S	1999	Marsh su	Journal Article	Journal of Coastal Conser	10.1007/BF	https://doi	01/10/2021	Backreferencing	
Rennie, A.F.,	2021	Dynamic	Report	Scotland’s Centre of Expertise for Wat		https://ww	04/10/2021	Backreferencing	
Rotman, R.,	2008	Sediment	Journal Article	Geomorphology, Vol. 100,	10.1016/j.g	https://ww	28/09/2021	SCOPUS	
RPS	2018	Ayrshire S	Report	North and South Ayrshire Councils		https://ww	08/11/2021	Backreferencing	
RSPB	2018	Sustainab	Technical Report	RSPB		https://ww	28/10/2021	Backreferencing	
RSPB	2016	GLORIOU	Report	RSPB		https://ww	29/09/2021	Backreferencing	
RSPB	2002	Seas of C	Report	RSPB		http://ww2	27/10/2021	Backreferencing	
SEPA	2015	Natural Fl	Report	SEPA		https://ww	28/10/2021	Backreferencing	
Shepherd, D.	2007	Modelling	Journal Article	Estuarine, Coastal and Sh	10.1016/j.e	https://ww	18/10/2021	Backreferencing	
Spencer, T.,	2012	Surface e	Journal Article	Wetlands Ecology and Ma	10.1007/s1	https://ww	28/09/2021	SCOPUS	
Stafford, R.,	2021	Nature-ba	Report	British Ecological Society.		https://ww	26/10/2021	Backreferencing	
Sullivan, M.J	2018	Is saltma	Journal Article	Journal of Applied Ecology	10.1111/13	https://ww	28/09/2021	SCOPUS	
Tempest, J.A	2015	Modified	Journal Article	Hydrological Processes,	10.1002/hy	https://ww	28/09/2021	SCOPUS	
Wollenberg,	2018	Rapid car	Journal Article	PLOS ONE, Vol. 13, Iss. 3	10.1371/jou	https://jou	28/09/2021	Backreferencing	

8.2 Mapping potential sites for managed realignment

To identify and quantify areas of Scotland’s coastline suitable for realignment a spatial modelling approach was utilised (Fig. A1.1). The methodology projects regional tidal data onto coastal elevation models to highlight suitable areas for MR. This approach allows the extent of the low-mid and high marsh to be estimated if tidal flooding was reintroduced (i.e., removal of hard flood defences). The presence of saltmarsh within the vicinity of potential MR sites significantly improves the likelihood of saltmarsh establishment post-realignment. Outputs from the spatial models are compared to high resolution (25 cm) aerial photographs, historic maps (1840 onwards) and current saltmarsh extent mapping (Haynes, 2016) to assess if saltmarsh is currently present or has been present at the site in the past.

The spatial model therefore identifies areas where saltmarsh is likely to form if tidal inundation is introduced and does not in itself indicate that the site is suitable for MR (i.e., infrastructure, population centres, agriculture). Aerial photographs alongside land cover maps were utilised to assess these factors and group each site into 1 of 4 categories indicating suitability for MR:

Category 1	Highly Suitable	High likelihood saltmarsh will establish (saltmarsh present at site), significant Infrastructure absent at site, low impact on local populations.
Category 2	Suitable	Low likelihood saltmarsh will establish (no saltmarsh present at site), significant infrastructure absent at site, low impact on local populations.
Category 3	Less Suitable	Saltmarsh likely to establish (saltmarsh present at site or was present), significant infrastructure present, medium impact on local populations.
Category 4	Not Suitable	– Low likelihood saltmarsh will establish (no saltmarsh present at site), nationally/regionally significant infrastructure present, medium impact on local populations.

This report focuses on assessing the physical suitability of each site and does not take into consideration any social or economic factors that are vital to the success of any MR project (Adams et al., 2021).

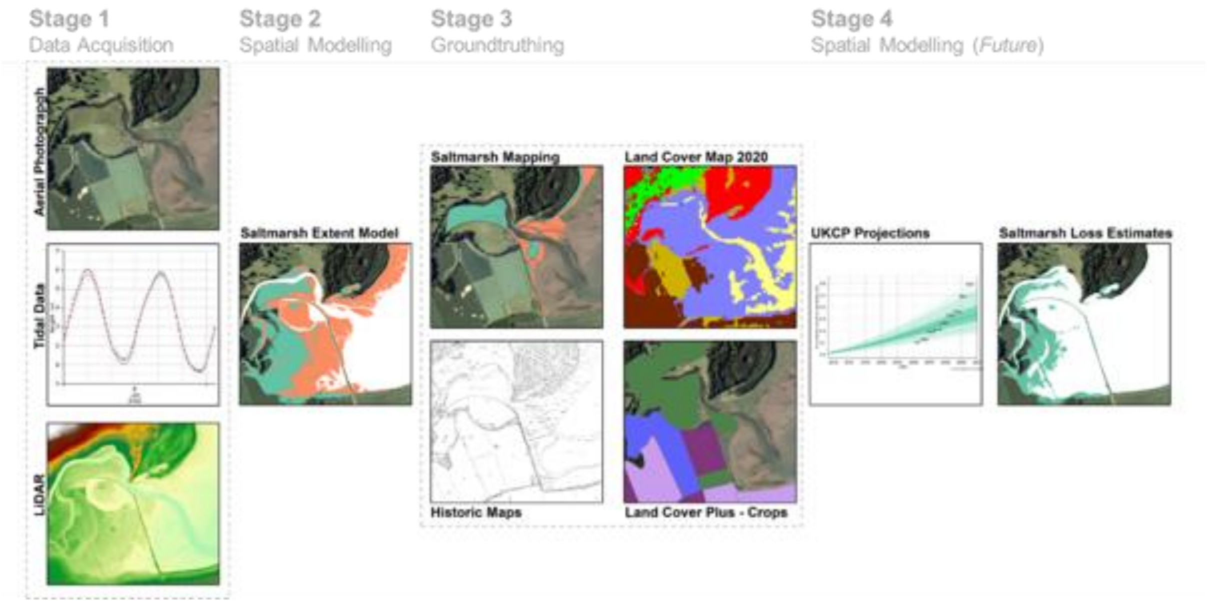

Figure A1.1. Schematic diagram to highlight the methodological process: **Step 1:** data acquisition; **Step 2:** spatial modelling (present day); **Step 3:** ground-truthing; **Step 4:** spatial modelling (future).

Further, future RSL data for 2032, 2045 and 2100 were accessed from the UK climate projections portal operated by the Met Office. This data was be integrated with the spatial model to estimate how much of the realigned marshes would be converted to mud flat and lost due to flooding. These four years have been chosen to correspond to key climate milestones:

2032: Conclusion of Scotland’s current climate plan (2018-2032)

2045: Scotland’s net-zero emissions target.

2100: Extent of future RSL data for the UK using the standard calculation method.

To determine the blue carbon potential of the identified MR sites the outputs from the spatial model were combined with dry bulk density and OC data (Austin *et al*., 2021) to estimate the potential surficial (top 10 cm) soil OC stock of these MR marshes, assuming they reach the point where they function as a natural saltmarsh. Additionally, the changes in saltmarsh extent due to RSLR have been integrated into these calculations to estimate the surficial OC stock of the saltmarsh in 2032, 2045 and 2100.

All data used in this study are outlined in the proceeding sections and the sources of the data can be found in Table A1.3.

Table A1.3. Data sources used within this study.

Data Type	Source	Link
LiDAR	Digimap	https://digimap.edina.ac.uk/lidar
Aerial Photographs	Digimap	https://digimap.edina.ac.uk/aerial
Historic Maps	Digimap	https://digimap.edina.ac.uk/roam/download/historic
Ordnance Survey Maps	Digimap	https://digimap.edina.ac.uk/roam/download/os
Land Cover Data	Digimap	https://digimap.edina.ac.uk/environment
Tidal Data	National Tidal and Sea Level Facility	https://ntslf.org/data/uk-network-real-time
Future Sea Level Estimates	Met Office	https://ukclimateprojections-ui.metoffice.gov.uk/ui/home
Current Saltmarsh Mapping	Nature Scotland	https://www.nature.scot/landscapes-and-habitats/habitat-map-scotland
Dry Bulk Density and OC Data	Marine Scotland Data	https://data.marine.gov.scot/dataset/organic-carbon-density-surficial-soils-across-scottish-saltmarshes

8.3 Tidal elevation and Scottish saltmarsh

The elevation of the seaward edge of a saltmarsh relative to Mean High Water (MHW) or Mean Sea Level (MSL) depends on the local tidal range (Balke *et al*. 2016). Predictions in changes of MSL to assess future positioning of saltmarsh in the intertidal zone do not fully acknowledge the interactions between sea-level rise and tidal range and the regionally different ability for saltmarsh vegetation to accrete and for surface-elevation gain to keep pace with sea-level rise (Ladd *et al*. 2019).

In this report, we present unpublished in-situ inundation monitoring data collated from past research projects across central Scotland by the research group of Thorsten Balke.

Inundation was either monitored using pressure sensors installed on the tidal flat or using Mini Buoys (Balke *et al.,* 2021) and the monitoring duration ranged from several months to several years (i.e., for Clyde, Forth, Tay and Tyninghame). For example, pressure sensor data were recorded near the Skinflats realignment site between 2019 and 2021 (Fig. A1.2).

Inundation characteristics were further standardized to characterise the inundation at the saltmarsh – tidal flat transition and expressed as percentage inundation duration and percentage of high tides reaching the lower saltmarsh edge.

Percentage inundation duration is calculated as follows:

Inundation duration (%) = (Inundation duration during monitoring period (h) /duration of monitoring period (h))*100

High tide inundation frequency (%) is calculated as follows:

> High tide inundation frequency (%) = (No. of high tides reaching the salt marsh during monitoring period /No. of all high tides during monitoring period)*100

All saltmarsh transition zones were, at least partially, characterised by the presence of *Puccinellia maritima* with the exception of the site in the Tay estuary which was characterised by *Bolboeschoenus maritimus.*

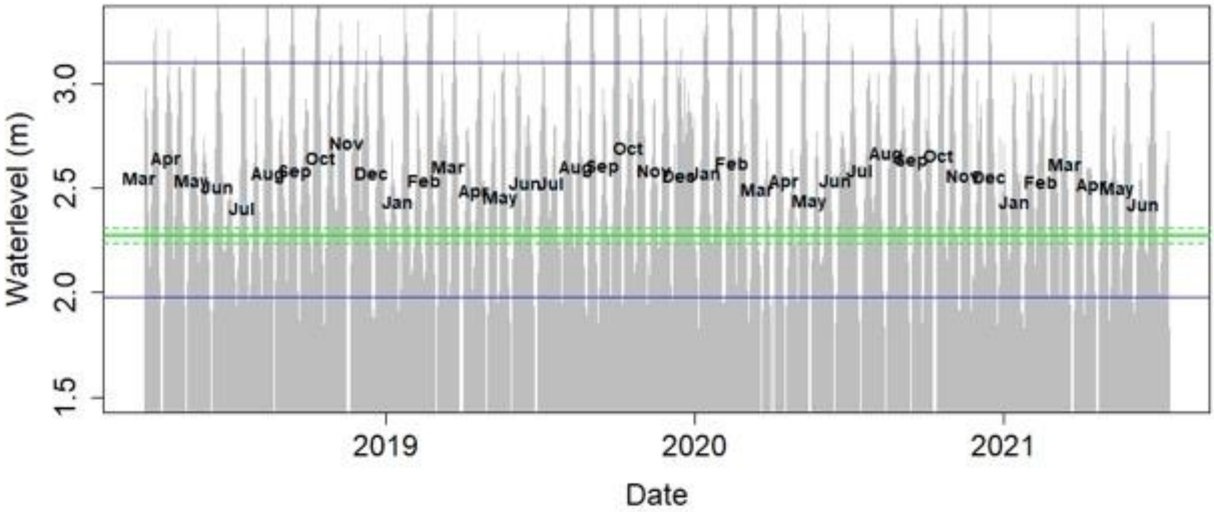

Figure A1.2. Water levels at a saltmarsh in the Firth of Forth near Kincardine Bridge. The green line indicates the surveyed elevation (± SD) of the lower saltmarsh edge where vegetation transitions into unvegetated tidal flat. Monthly MHW are indicated by abbreviated month tags. The blue lines indicate overall MHWN and MHWS respectively.

Further to the in-situ monitoring data, inundation characteristics were extracted from hourly tide gauge records across Scotland (downloaded from the https://www.bodc.ac.uk). Individual high and low tides were extracted from the hourly data using a 12h 25min moving window. The high tide time series was then used to identify mean spring and neap high tides, defined as "the average of two highest tides during a 24h period at spring/neap tide" (https://www.ntslf.org/tgi/definitions). The spring and neap tide times were extracted from the high tide time series by identifying maximum and minimum values in a moving window of 29.530588 days. Annual mean MHWS, MHWN, MHW and MSL elevations were subsequently extracted and used to calculate inundation duration and frequency relationships at those elevations in addition to inundation characteristics for 10 cm elevation intervals across all Scottish tide gauges (Fig. 3).

8.4 Coastal elevation model

The primary data used to create the coastal elevation models was light detection and ranging data (LiDAR). The LiDAR data was processed as a digital terrain model (DTM) opposed to a digital surface model (DSM) as DTM reveal the underlying terrain removing objects from the built (e.g., buildings, pylons) and natural (e.g., trees) environment.

In Scotland the majority of LiDAR data has been collected for flood risk purposes and covers all the major east coast estuaries and the Clyde and Solway regions (Fig. A1.3).

Fortunately, these are important locations for saltmarsh development in Scotland (Fig. 2) and are the locations most likely to have undergone historical reclamation and are likely the area's best suited to MR. The west coast of Scotland and the islands are largely devoid of LiDAR data, although additional surveys are likely to become available in the near future. These coastlines are characterised by glacial geomorphology resulting in a coastline dominated by fjords (Smeaton *et al*., 2017). The historically low human presence in these regions (Smout, 1993) in combination with the glacial geomorphology (Bianchi *et al*., 2020, Clark *et al*., 2018) at the heads of these fjords likely means these saltmarshes have not been as heavily impacted as their east coast counterparts. The likelihood of MR activities in these areas being suitable or beneficial is low therefore the lack of LiDAR data in these regions is unlikely to significantly impact the outcomes of this study.

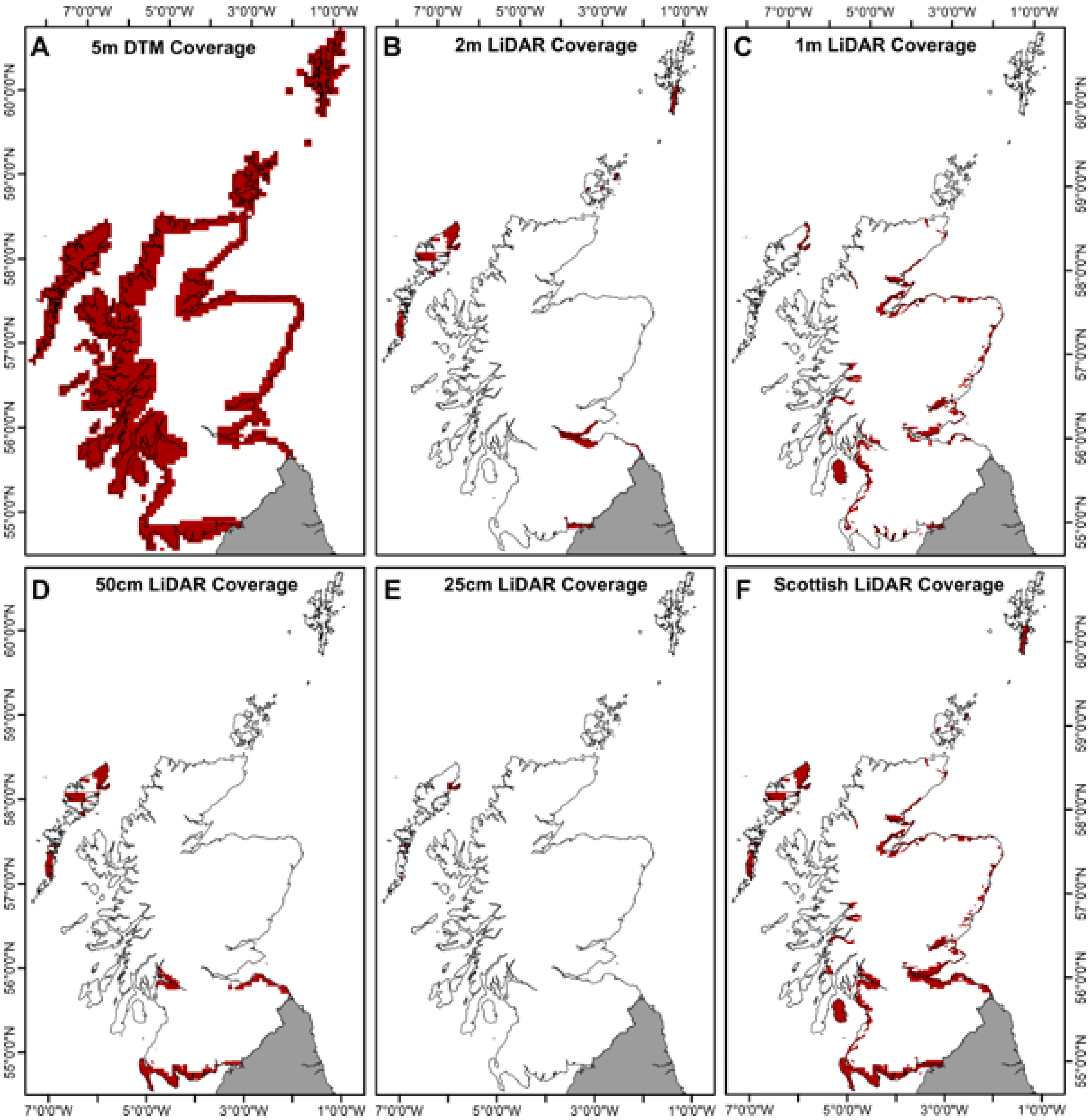

Figure A1.3. Map showing the spatial coverage of Scottish coastal elevation data available at the time of this study: (**A**) 5 m Ordnance Survey Digital Terrain Model; (**B**) 2 m LiDAR; (**C**) 1 m LiDAR; (**D**) 50 cm LiDAR; (**E**) 25 cm LiDAR; (**F**) Total Scottish LiDAR coverage.

The resolution of the LiDAR data in Scotland varies significantly between regions (Fig. A1.3). The rarest data is 25 cm resolution and was collected for archeological purposes on the Outer Hebrides, this data has not been utilized in this study. LiDAR data of 1 m and 2 m resolution is the most common and found in all the major estuaries of Scotland. The latest LiDAR data available is of 50 cm resolution and is concentrated around the borders and the Clyde. A 5 m DTM of the entire coastline is also available. This data is built from Ordnance Survey contour data and is coarser in resolution than LiDAR (Fig. A1.4). This dataset cannot be used in isolation but has been used to fill gaps in the LiDAR coverage at individual saltmarshes. These datasets were compiled into a single raster dataset creating a high-resolution coastal elevation model with the largest possible spatial coverage.

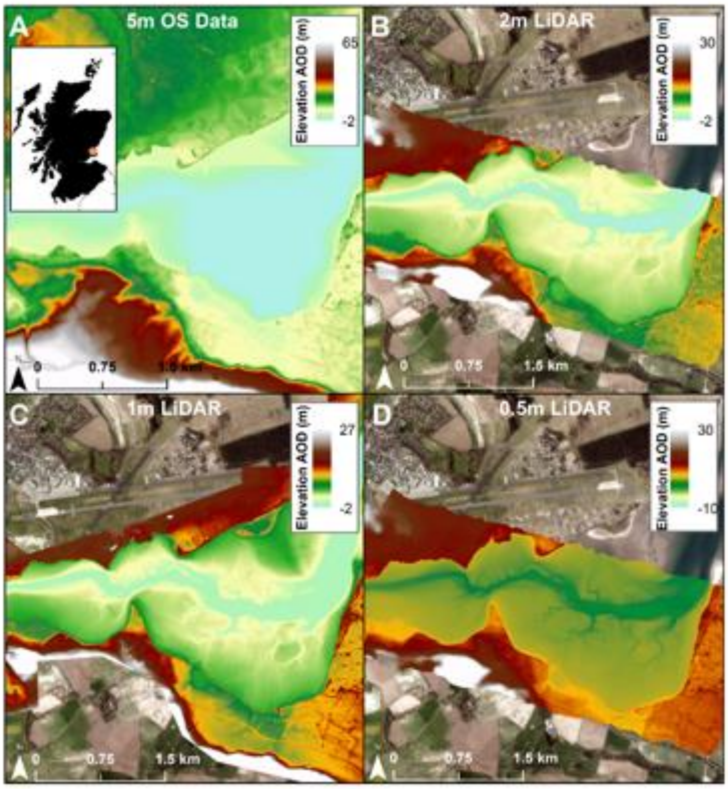

Figure A1.4. Map illustrating the differences in coverage and resolution of elevation data available from the Eden Estuary, Fife: (A) 5 m OS data; (B) 2 m LiDAR; (C) 1 m LiDAR; (D) 50 cm LiDAR.

8.5 Spatial modelling

Spatial models of saltmarsh extent were created by combing the coastal elevation models and our understanding of tidal inundation and saltmarsh formation in Scotland. The raster calculator function of ArcGIS was used to project regional tidal elevation data across the DTMs for each tide (i.e., HAT, MHWS, MHWN, and MTL). The difference between these individual rasters allowed the area of the low-mid marsh (HAT - MHWS) and high marsh (MHWS - MTL) to be mapped and quantified. Initially this process was conducted coarsely across all LiDAR datasets to identify areas potential suitable for MR.

Saltmarsh is not the only environment to form between HAT and MTL, beaches and shingle deposits are also common. To resolve this issue, the outputs from this phase of modelling were compared to currently available saltmarsh mapping (Haynes, 2016) and aerial photographs to ground-truth the output. From this process sites identified as beaches and shingle were discarded. The remaining sites underwent a second phase of spatial modelling following the above methodology to allow the potential areal extent of each individual MR saltmarsh to be quantified.

This spatial modelling approach is well suited to achieve the goals of this study but there are several factors that must be understood when interpreting the outputs. (**i**) The model uses regional tidal data, the tide gauges are largely situated on the coast so do not consider tidal restriction and its impact of tidal elevations in the upper regions of estuaries. (**ii**) The model assumes zero net geomorphic change across coastal elevation models once flooded. (**iii**) The outputs from the model represent the maximum potential extent of the saltmarsh. (**iv**) The model is not temporally constrained; it assumes saltmarshes establish at the point when tidal inundation is restored.

8.6 Future sea-level projections

Following the methodology outlined in this report, future sea-level projections (sea level anomalies) from each of the regions where a potential MR site has been identified were projected over the coastal elevation model to estimate the area of the MR saltmarsh that will potentially be converted to mudflat and lost. Future sea level data represent three climate scenarios (Representative Concentration Pathway (RCP) 2.6, 4.5, 8.5) at set time periods (2032, 2045, 2070, and 2100). The 50th percentile sea-level projections have been utilised from each climate scenario (*Appendix 3*). Alongside these the 5th percentile and 95th percentile projections from RCP 2.6 and RCP 8.5 respectively have been used to represent the best- and worst-case scenarios. Together the datasets allow us to estimate the full range of possible outcomes, including the extremes (Fig. A1.5).

It is important to note that the future sea-level projections are for MSL and do not incorporate tidal competence; future estimates of saltmarsh loss therefore include inherent uncertainties that are deemed beyond scope for the present report to tackle. It would be expected as RSL rises that the high marsh would transition to low-mid marsh; the lack of tidal elevation data over this period (2032-2100) means that we are unable to map such changes. Additionally, without tidal data it is not possible to map the potential migration of the saltmarsh inland, all that can be achieved with the data is to estimate the area of the newly created MR that will be lost under each of the three climate scenarios.

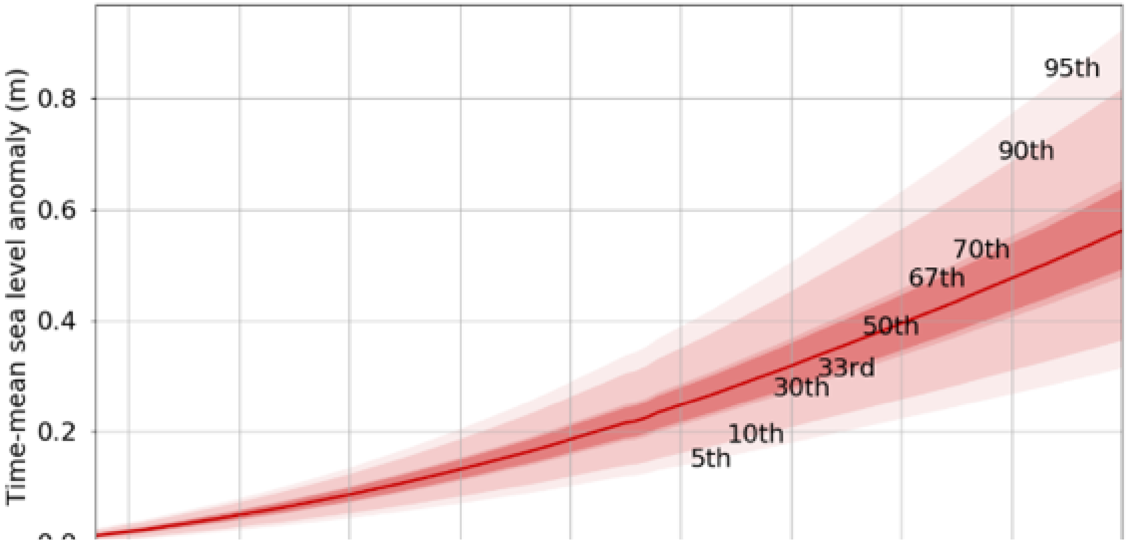

Figure A1.5. An example of the RCP 8.5 time-mean sea level anomaly projection (Tyninghame Bay), highlighting 5th to 95th percentiles (UKCP, 2021).

8.7 Estimating potential MR saltmarsh blue carbon resources

For the purposes of estimating the potential blue carbon gains from MR in Scotland this study focuses on the potential OC storage capacity of the surficial (top 10 cm) in saltmarsh soils. This approach assumes that the MR saltmarshes will reach a point where they bury and store OC similar to natural systems. This approach uses readily available data from Scottish saltmarshes (Austin *et al*., 2021) and produces relatively conservative estimates with robust uncertainty estimations in comparison to alternative approaches to calculating potential blue carbon gains from MR (ABPmer, 2021a; Mossman *et al.,* 2021).

To determine the potential surficial (top 10 cm) soil OC stock of the sites suitable of MR the modelled spatial extent of the low-mid and high marsh was combined with mean dry bulk density and OC content data (Table A1.4) compiled from Scottish saltmarshes (Austin *et al.,* 2021). The surficial OC stock was calculated following *eq 1-3*.

$$\text{Volume } (m^3) = \text{Area } (m^2) \times \text{Depth } (m) \qquad \textit{eq.1}$$

$$\text{Mass (kg)} = \text{Volume } (m^3) \times \text{Dry Bulk Density } (kg\ m^{-3}) \qquad \textit{eq.2}$$

$$\text{OC Stock (kg)} = \text{Mass (kg)} \times \text{OC Content } (\%) \qquad \textit{eq.3}$$

These calculations were undertaken in a Markov Chain Monte Carlo (MCMC) framework using the OpenBUGS software package (Lunn *et al*., 2009). MCMC analysis was applied by taking 1,000,000 out of 100,000,000 random samples from a normal distribution of each variable (dry bulk density, OC content) to populate equations (*eq.1–3*). This process generates a significant quantity of solutions which follow a normal distribution. The application of standard descriptive statistical techniques to the pool of generated solutions allows the mean, standard deviation, 5th and 95th percentiles to be calculated.

Marsh Zone	Number of Samples	Dry Bulk Density (g cm^{-3})	Number of Samples	OC (%)
Pioneer	18	0.50 ± 0.24	18	9.94 ± 5.56
Lower	126	0.36 ± 0.20	109	14.80 ± 8.31
Upper	234	0.48 ± 0.27	300	13.05 ± 7.25

Table A1.4. Dry bulk density and OC data from across the surficial (top 10cm) soils of Scotland's saltmarsh (Austin et al., 2021).

To determine the potential change in surficial OC stock due to RSLR the calculations (*eq.1-3*) were repeated using the estimated marsh extent for each time period (2032, 2045 and 2100) under the projected RSL associated with each of the climate scenarios (RCP 2.6, RCP 4.5 and RCP 8.5).

9 Appendix 2 –Evidence assessment resources

9.1 Introduction

This rapid evidence assessment style literature review summarizes the evidence for implementing managed realignment (MR) projects to create new blue carbon stores in Scotland. The articles are sorted alphabetically by author, and each has a summary followed by analysis of the relevant points made. Some papers contained much more relevant information that others, due to being more closely aligned to this project.

A methods document for the selection of the papers is provided in appendix one.

If this study was to be repeated, the same search terms could be used on Google Scholar and SCOPUS, excluding results from before 28/09/2021 (the date the original search was carried out). The findings could be cross referenced with an Excel spreadsheet which lists all the sources cited, key information, date searched, and where they were found (appendix three).

9.2 Summary

Overall, the available evidence shows that realigned saltmarshes accumulate carbon at initially high rates which slow over time as the marsh moves up into equilibrium with the tidal frame. There is a need for empirical data on the emissions from MR saltmarshes and how they balance out the overall carbon sequestration (Cseq). It has been shown in some reports that MR saltmarshes have a higher allochthonous:autochthonous carbon ratio than mature ones, which can complicate carbon accounting. It is widely acknowledged that MR saltmarshes function quite differently to mature saltmarshes, often with differing sediment properties, hydrology, and less diverse vegetation assemblages and topographies. Despite this they offer many of the same benefits as mature marshes, such as flood protection, carbon storage, and unique biodiversity. It is highlighted in some reports that it may be wiser to compare the created habitat to the habitat prior to breaching when assessing its benefits.

The available evidence suggests that most of the available area for MR in Scotland will be in low-lying estuaries on the East coast which have high degrees of reclamation and high sediment availabilities, such as the Firth of Forth. A key constraint which is highlighted is finding sites which are suitable for MR which have landowners who are willing to co-operate or to sell their land. Another is salinity: below 5 saltmarsh is unlikely to form, instead terrestrial wetlands are likely, and below 18 there are likely going to be significant methane emissions, reducing the Cseq of the site.

Where suitable sites have been found and the project can go ahead, the design of the site is vital to get right to form a productive saltmarsh. As the sedimentation rate decreases to be in equilibrium with the tidal frame, productive vegetation becomes more and more important in contributing to the carbon sink. Additionally, autochthonous carbon is much simpler to account for than allochthonous, so ensuring a greater proportion of the former likely makes the saltmarsh more favourable for blue carbon financing. However, the reactivity of autochthonous-sourced plant material is potentially greater than aged terrestrial/marine carbon (further work is required to determine this), which could decrease the Cseq of the marsh and its climate mitigation benefits.

There are funding barriers and social issues which inhibit MR implementation in Scotland, and these are mentioned throughout but are not the key point of this report.

10 Appendix 3 – Outputs from the Spatial Model

Table A3.1. Regional tidal elevation (m) data from across Scotland and Northern England. *Data Source: National Tidal and Sea Level Facility*

Tide Gauge	Latitude	Longitude	HAT (m)	LAT (m)	MHWS (m)	MHWN (m)	MLWS (m)	MLWN (m)	MSR (m)	MNR (m)
Aberdeen	57.144	-2.0803	2.6	-2.2	2.07	1.21	-0.55	-1.55	1.37	-0.49
Kinlochbervie	58.4568	-5.0502	3.02	-2.53	2.39	1.25	-0.49	-1.78	1.67	-0.76
Leith	55.989833	-3.1817	3.34	-2.97	2.71	1.6	-0.8	-2.18	1.99	-0.5
Lerwick	60.154067	-1.140217	1.26	-1.22	0.95	0.46	-0.28	-0.78	0.51	-0.48
Millport	55.7498	-4.906	2.24	-1.66	1.77	1.21	-0.56	-1.18	1.33	0.15
Moray Firth	57.598367	-3.99955	2.77	-2.14	2.21	1.27	-0.42	-1.42	1.41	-0.53
Port Ellen	55.6276	-6.18975	0.89	-0.49	0.59	0.35	0.23	-0.07	0.47	-0.07
Portpatrick	54.84255	-5.120017	2.52	-1.87	2.06	1.39	-0.64	-1.36	1.62	0.23
Stornoway	58.207733	-6.3888	2.82	-2.7	2.15	1.00	-0.66	-1.99	1.43	-1.05
Tobermory	56.623117	-6.064217	2.84	-2.23	2.22	1.03	-0.45	-1.62	1.45	-0.91
Ullapool	57.89525	-5.15805	3.12	-2.72	2.46	1.23	-0.57	-1.99	1.7	-0.95
Wick	58.440967	-3.086317	2.26	-1.65	1.8	1.07	-0.28	-1.08	1.17	-0.36
North Shields	55.0074	-1.4398	3.13	-2.6	2.52	1.48	-0.7	-1.87	1.79	-0.42
Workington	54.650717	-3.567183	5.07	-4.16	4.15	2.32	-1.55	-3.27	3.22	-0.33

Table A3.2. Time-mean seal level anomaly (m) data used within this study *Data Source: UK Climate Projections – Met Office*

		Time-mean sea level anomaly (m)								
		RCP 2.6			RCP 4.5			RCP 8.5		
Site	Year	5th	50th	95th	5th	50th	95th	5th	50th	95th
Dornoch	2032	0.048	0.090	0.145	0.052	0.092	0.147	0.063	0.108	0.159
	2045	0.070	0.131	0.212	0.081	0.141	0.225	0.102	0.173	0.258
	2070	0.103	0.205	0.352	0.138	0.248	0.409	0.199	0.337	0.523
	2100	0.127	0.281	0.537	0.196	0.373	0.654	0.333	0.577	0.939
Inner Moray Firth	2032	0.042	0.085	0.140	0.047	0.087	0.142	0.057	0.102	0.154
	2045	0.063	0.124	0.205	0.074	0.134	0.218	0.095	0.166	0.252
	2070	0.093	0.195	0.343	0.128	0.238	0.399	0.190	0.327	0.513
	2100	0.113	0.268	0.523	0.182	0.359	0.641	0.320	0.565	0.926
Montrose	2032	0.034	0.078	0.133	0.039	0.080	0.136	0.049	0.095	0.148
	2045	0.053	0.115	0.197	0.064	0.125	0.210	0.086	0.158	0.244
	2070	0.079	0.182	0.331	0.115	0.226	0.388	0.178	0.318	0.504
	2100	0.094	0.251	0.507	0.166	0.345	0.627	0.311	0.558	0.919
	2032	0.031	0.074	0.129	0.035	0.076	0.132	0.046	0.091	0.144

		Time-mean sea level anomaly (m)								
		RCP 2.6			RCP 4.5			RCP 8.5		
Site	Year	5th	50th	95th	5th	50th	95th	5th	50th	95th
Tay & Eden Estuary	2045	0.048	0.110	0.192	0.059	0.120	0.205	0.081	0.152	0.239
	2070	0.072	0.175	0.323	0.108	0.218	0.380	0.172	0.311	0.497
	2100	0.085	0.241	0.497	0.156	0.335	0.617	0.302	0.549	0.910
Inner Firth of Forth	2032	0.028	0.071	0.126	0.032	0.073	0.128	0.043	0.089	0.141
	2045	0.045	0.106	0.188	0.055	0.116	0.201	0.077	0.149	0.235
	2070	0.067	0.169	0.318	0.103	0.213	0.375	0.167	0.305	0.491
	2100	0.077	0.233	0.489	0.149	0.327	0.609	0.296	0.542	0.904
Tyninghame	2032	0.015	0.075	0.152	0.014	0.076	0.157	0.023	0.091	0.169
	2045	0.039	0.113	0.211	0.043	0.119	0.226	0.065	0.150	0.257
	2070	0.072	0.180	0.338	0.098	0.216	0.391	0.160	0.301	0.494
	2100	0.093	0.251	0.506	0.150	0.329	0.613	0.286	0.520	0.873

Table A3.3. Area extent (km^2) of saltmarsh at the 15 MR sites. Existing saltmarsh extent estimate from Haynes, (2016) mapping. The potential saltmarsh area has been calculated from the spatial model outputs.

	Existing Saltmarsh Area (km^2)			Potential Saltmarsh Area (km^2)			Total Increase (%)
Site	Low-Mid	High	Total	Low-Mid	High	Total	
Baldruim	—	—	—	0.06	0.23	0.30	100.00
Ardmore	—	—	—	0.06	0.05	0.10	100.00
Kirkhill	0.01	0.33	0.34	0.26	1.36	1.63	79.15
Montrose	0.02	0.15	0.17	0.58	0.88	1.47	88.51
Tayport	0.00	0.06	0.06	0.13	0.11	0.25	75.08
Newburgh	—	—	—	0.46	0.32	0.78	100.00
Eden Estuary	0.01	0.02	0.03	0.19	0.24	0.43	93.03
Inverkeithing	—	—	—	0.02	0.16	0.19	100.00
Carron Pools	0.09	0.10	0.19	0.85	0.93	1.78	89.57
Skinflats	0.01	0.10	0.10	0.22	0.22	0.44	76.49
Longannet	—	—	—	0.10	0.12	0.22	100.00
Hawkhill	—	—	—	0.12	0.13	0.26	100.00
Dunmore	0.10	0.04	0.14	0.47	0.26	0.73	80.29
Inch of Ferryton	—	—	—	0.17	0.05	0.22	100.00
Tyninghame	0.22	0.17	0.40	0.69	0.44	1.13	64.96

Table A3.4. Potential surficial (Top 10cm) soil OC stock (tonnes C) of the realigned marshes.

	Surficial (Top 10cm) Soil OC Stock (tonnes C)					
	Low-Mid Marsh		High Marsh		Total	
Site	Mean	SD	Mean	SD	Mean	SD
Baldruim	366.9	266.3	1,590.8	1,147.4	1,957.7	1,176.9
Ardmore	331.9	240.9	314.1	226.5	646.0	330.1
Kirkhill	1,514.1	1,099.0	9,285.6	6,697.4	10,799.8	6,782.7
Montrose	3,406.8	2,472.8	6,008.4	4,333.6	9,415.1	4,981.1
Tayport	786.2	570.6	757.9	546.6	1,544.0	788.7
Newburgh	2,684.6	1,948.7	2,212.2	1,595.5	4,896.8	2,513.7
Eden Estuary	1,100.6	798.9	1,631.8	1,177.0	2,732.5	1,419.9
Inverkeithing	133.9	97.2	1,119.7	807.6	1,253.7	813.1
Carron Pools	4,950.0	3,593.0	6,342.9	4,574.9	11,292.9	5,806.1
Skinflats	1,281.2	929.9	1,495.3	1,078.5	2,776.4	1,421.3
Longannet	576.5	418.5	819.3	590.9	1,395.8	722.8
Hawkhill	716.3	519.9	901.3	650.0	1,617.5	830.8
Dunmore	2,742.9	1,990.9	1,754.7	1,265.6	4,497.6	2,355.0
Inch of Ferryton	990.0	718.6	320.9	231.5	1,310.9	754.1
Tyninghame	4,018.2	2,916.6	2,983.7	2,152.0	7,001.9	3,617.9
All Sites	25,600.2	18,581.9	37,538.5	27,075.0	63,138.8	32,778.4
Cat 1	15,752.6	11,434.1	25,385.3	18,309.4	41,137.9	21,548.6
Cat 2	2,818.6	2,045.9	3,331.9	2,403.2	6,150.5	3,150.0
Cat 3	6,312.7	4,582.1	7,920.1	5,712.4	14,232.8	7,309.1
Cat 4	716.3	519.9	901.3	650.0	1,617.5	830.8

Table A3.5. Percentage change in MR saltmarsh area due to RSLR under different climate scenarios. Numbers represents each marsh see table.2 in the main document for details.

	Reduction in Saltmarsh Area (%)														
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RCP 2.6 5th Percentile (Best Case Scenario)															
2032	0.76	1.56	2.55	1.29	1.24	0.13	0.72	0.23	1.29	2.95	2.05	2.44	3.95	1.56	0.54
2045	1.52	3.76	5.28	2.99	1.24	0.34	1.63	0.51	3.12	6.41	4.89	5.52	8.94	4.10	4.30
2070	1.80	4.70	6.15	3.81	1.41	0.41	1.92	0.56	3.57	7.21	16.06	6.25	10.07	4.86	5.82
2100	1.80	4.70	6.15	3.81	1.41	0.41	1.92	0.56	3.57	7.21	16.06	6.25	10.07	4.86	7.76
RCP 2.6 50th Percentile															
2032	1.38	3.35	4.79	2.99	1.24	0.34	1.67	0.54	3.29	6.73	5.18	5.82	9.40	4.41	4.30
2045	1.87	4.96	6.55	4.64	1.95	0.69	2.53	0.69	4.91	9.41	12.04	8.35	13.27	7.20	7.45
2070	2.74	7.98	8.64	7.55	3.31	1.70	4.59	0.90	7.83	14.13	12.04	12.34	19.01	13.03	14.05
2100	3.7	11.84	9.89	10.54	5.44	3.93	7.44	1.11	11.04	18.92	16.50	16.40	24.33	18.87	21.42
RCP 4.5 50th Percentile															
2032	1.39	3.36	4.79	3.40	1.24	0.34	1.71	0.54	3.38	6.88	5.33	5.98	9.62	4.54	4.30
2045	2.00	5.34	6.92	5.07	2.15	0.81	2.81	0.73	5.36	10.16	8.43	8.96	14.28	8.08	7.45
2070	3.25	9.91	9.42	9.25	4.42	2.81	6.34	1.05	9.98	17.46	14.81	15.12	22.69	17.05	17.22
2100	5.01	17.95	11.11	14.72	10.40	8.84	12.49	1.45	16.75	26.35	21.81	22.40	31.87	28.77	27.80
RCP 8.5 50th Percentile															
2032	1.56	3.89	5.73	3.56	1.58	0.49	2.11	0.61	4.11	8.10	6.48	7.13	11.41	5.81	5.82
2045	2.36	6.6	7.88	6.29	2.81	1.29	3.81	0.83	6.87	12.66	10.74	11.08	17.30	11.12	11.07
2070	4.46	15.27	10.71	13.28	9.06	7.43	11.09	1.34	15.33	24.71	20.54	21.09	30.09	26.18	26.12
2100	11.37	33.02	14.03	28.20	36.20	42.71	30.08	5.86	32.88	39.35	34.52	34.76	50.32	65.11	43.34
RCP 8.5 95th Percentile (Worst Case Scenario)															
2032	2.18	5.89	7.59	5.89	2.58	3.55	3.55	0.81	32.88	12.08	10.21	10.57	16.62	10.43	12.04
2045	3.63	10.4	9.73	10.09	5.08	7.27	7.27	1.12	11.14	19.09	16.18	18.19	24.50	19.06	21.42
2070	8.88	28.46	16.48	15.70	29.57	25.88	25.88	4.90	28.77	36.32	31.31	31.78	45.57	54.40	40.93
2100	30.11	68.31	31.45	65.42	67.07	55.72	55.72	35.54	63.65	60.81	62.11	72.23	77.26	85.31	72.63

Table A3.6. Changes in the potential surficial (Top 10cm) soil OC stock (tonnes) of the realigned marshes due to RSLR under different climate scenarios. Numbers represents each marsh see table.2 in the main document for details.

	Surficial Soil OC Stock (tonnes C)														
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RCP 2.6 5th Percentile (Best Case Scenario)															
2032	635.9	10524.4	9293.4	1524.9	4890.7	2712.8	1250.8	11147.1	2694.4	1367.1	163.4	4320.0	1290.5	6963.9	635.9
2045	621.7	10229.6	9133.2	1524.9	4880.4	2688.0	1247.4	10941.0	2598.3	1327.6	158.3	4095.6	1257.1	6700.6	621.7
2070	615.6	10135.6	9056.2	1522.2	4876.8	2680.0	1246.7	10889.7	2576.1	1171.7	157.0	4044.7	1247.2	6594.7	615.6
2100	606.0	9877.2	8939.2	1503.4	4870.7	2660.7	1243.8	10749.1	2500.0	1147.6	153.2	3884.9	1227.7	6423.5	606.0
RCP 2.6 50th Percentile															
2032	624.4	10282.5	9133.2	1524.9	4880.4	2686.9	1247.0	10921.2	2776.4	1323.6	157.7	4074.8	1253.1	6700.6	624.4
2045	614.0	10092.4	8978.0	1513.8	4863.1	2663.4	1245.0	10738.9	2515.2	1227.8	153.5	3900.8	1216.5	6480.0	614.0
2070	594.4	9866.7	8703.8	1492.9	4813.6	2607.1	1242.4	10408.8	2384.2	1227.8	146.8	3642.6	1140.1	6017.9	594.4
2100	569.5	9731.7	8422.3	1460.0	4704.5	2529.2	1239.8	10046.6	2251.1	1165.5	140.0	3403.4	1063.5	5502.1	569.5
RCP 4.5 50th Percentile															
2032	624.3	10282.5	9094.7	1524.9	4880.4	2685.8	1246.9	10910.7	2585.3	1321.4	157.5	4064.7	1251.4	6700.6	624.3
2045	611.5	10052.5	8938.2	1510.8	4857.1	2655.7	1244.5	10687.4	2494.3	1278.1	152.5	3855.4	1205.0	6480.0	611.5
2070	582.0	9782.5	8544.6	1475.8	4759.3	2559.3	1240.6	10166.4	2291.6	1189.1	142.2	3477.2	1087.4	5796.4	582.0
2100	530.0	9599.9	8029.2	1383.5	4464.0	2391.2	1235.5	9401.3	2044.8	1091.4	130.0	3064.3	933.8	5055.4	530.0
RCP 8.5 50th Percentile															
2032	620.9	10181.0	9079.7	1519.5	4872.8	2674.8	1246.1	10828.3	2551.4	1305.3	155.6	3984.3	1234.7	6594.7	620.9
2045	603.4	9948.8	8823.1	1500.6	4833.6	2628.4	1243.3	10517.4	2425.0	1245.9	148.9	3719.4	1165.1	6226.6	603.4
2070	547.4	9643.1	8165.0	1404.0	4533.0	2429.5	1236.8	9561.1	2090.3	1109.2	132.2	3144.4	967.7	5173.1	547.4
2100	432.7	9284.6	6759.6	985.0	2805.4	1910.6	1180.3	7579.6	1684.0	913.9	109.3	2234.5	457.3	3967.3	432.7
RCP 8.5 95th Percentile (Worst Case Scenario)															
2032	608.0	9980.1	8860.7	1504.1	4723.0	2635.5	1243.5	10034.7	2441.1	1253.2	149.8	3750.1	1174.1	6158.8	608.0
2045	578.8	9749.0	8464.7	1465.5	4540.8	2533.8	1239.7	7579.6	2246.5	1169.9	137.0	3395.6	1061.1	5502.0	578.8
2070	462.1	9020.0	7937.4	1087.4	3629.5	2025.3	1192.3	8044.5	1767.9	958.8	114.3	2447.9	597.7	4135.9	462.1
2100	204.7	7403.3	3255.5	508.5	2168.3	1210.0	808.1	4105.3	1088.1	528.9	46.5	1022.6	192.6	1916.4	204.7

Table A3.7. Changes in the potential surficial (Top 10cm) soil OC stock (tonnes C) of the realigned marshes due to RSLR under different climate scenarios.

	Surficial Soil OC Stock (tonnes C)				
Year	All Sites	Cat 1	Cat 2	Cat 3	Cat 4
RCP 2.6 5th Percentile (Best Case Scenario)					
2032	60722.2	40378.2	6141.4	14039.2	163.4
2045	59331.5	39252.1	6127.7	13793.5	158.3
2070	58736.7	38872.6	6123.5	13583.6	157.0
2100	57694.9	38027.1	6114.5	13400.1	153.2
RCP 2.6 50th Percentile					
2032	59517.2	39462.5	6127.3	13769.6	157.7
2045	58123.6	38381.5	6108.1	13480.5	153.5
2070	56193.2	36860.9	6056.0	13129.5	146.8
2100	54114.5	35358.1	5944.3	12672.0	140.0
RCP 4.5 50th Percentile					
2032	59261.5	39219.8	6127.2	13757.0	157.5
2045	57941.6	38211.2	6101.6	13476.3	152.5
2070	54988.3	36015.0	5999.9	12831.3	142.2
2100	51213.9	33508.2	5699.5	11876.2	130.0
RCP 8.5 50th Percentile					
2032	58776.3	38848.7	6118.9	13653.1	155.6
2045	56941.0	37451.2	6076.9	13263.9	148.9
2070	52007.2	34030.8	5769.8	12074.4	132.2
2100	42039.1	28465.6	3985.7	9478.5	109.3
RCP 8.5 95th Percentile (Worst Case Scenario)					
2032	56431.8	37523.5	5966.5	12792.0	149.8
2045	51550.6	35418.1	5780.5	10215.0	137.0
2070	45204.8	30178.1	4821.8	10090.7	114.3
2100	25827.0	17661.4	2976.4	5142.6	46.5

11 Appendix 4 – Site Summaries

11.1 Baldruim

The site at Baldruim is found in an embayment within the Dornoch Firth (Fig. A4.1). The site is currently occupied by arable agriculture and commercial coniferous forestry and is free from any infrastructure. Review of historic maps suggest this site was reclaimed prior to 1846.

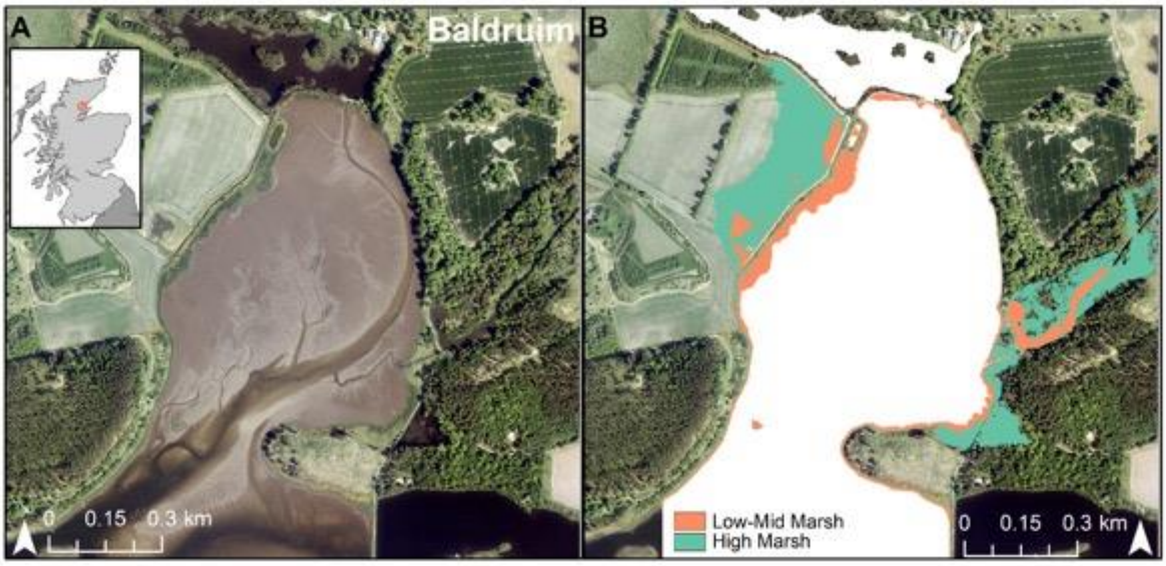

Figure A4.1. Spatial model for Baldruim (**A**) the extent of present saltmarsh at Baldruim (Haynes. 2016) - inset map of Scotland shows site location; (**B**) the potential extent of saltmarsh created by managed realignment at this site. High Marsh (green); Low-Mid Marsh (orange).

Realignment of the site could potentially create **0.30 km^2** of saltmarsh comprised of **0.06 km^2** of low-mid marsh and **0.23 km^2** of high marsh. Aerial photography (Fig. A4.1) confirms the presence of saltmarsh (<0.03 km^2, and therefore not mapped as part of current mapping efforts (Haynes, 2016)) increasing the likelihood of successful saltmarsh establishment at the site after realignment activities. These factors have resulted is the site being categorised as **highly suitable** for realignment.

If saltmarsh was successfully established at the site and reached a point where its carbon burial and storage capacity mirrored natural sites the surficial (top 10cm) soils in the low-mid marsh could potential hold **367 ± 266 tonnes OC**, while the high marsh could hold **1,591 ± 1,147 tonnes OC**. In total the surficial saltmarsh soil (top 10cm) stock at this site **1,958 ± 1,177 tonnes OC** which would represent a **0.53%** increase in Scotland's current saltmarsh surficial soil OC stock (Austin *et al*., 2021).

Under future median (50th Percentile) predications of relative sea level rise the extent of the realigned saltmarsh area will reduce by between **1.38 – 1.56% by 2032**, **1.87 – 4.46% by 2045**, **2.74 – 4.46% by 2070** and **3.7 – 11.37% by 2100**. Under the worst (RCP 8.5 95th percentile) future relative sea level predications the realigned marsh will be reduced in size by **30.11%** by 2100 (Fig. A4.2) reducing the surficial soil organic carbon stock to **1368 tonnes.**

Figure A4.2. Saltmarsh extent following a hypothetical managed realignment at Baldruim, Scotland and including subsequent habitat loss (assuming no landward migration of the coastline nor any vertical accretion of the marsh surface as sea-level rise occurs) from a simple drowning of the saltmarsh surface. Sea-level change projections under different emissions scenarios are shown for the 50th and 95th percentiles for RCP 2.6 (low emissions), RCP 4.5 (medium emissions) and RCP 8.5 (high emissions) for 2032, 2045, 2070 and 2100.

11.2 Ardmore

The site at Ardmore is found in an embayment within the Dornoch Firth (Fig. A4.3). The site is currently occupied by arable agriculture grassland and is free from any infrastructure. Review of historic maps suggest this site was reclaimed prior to 1846.

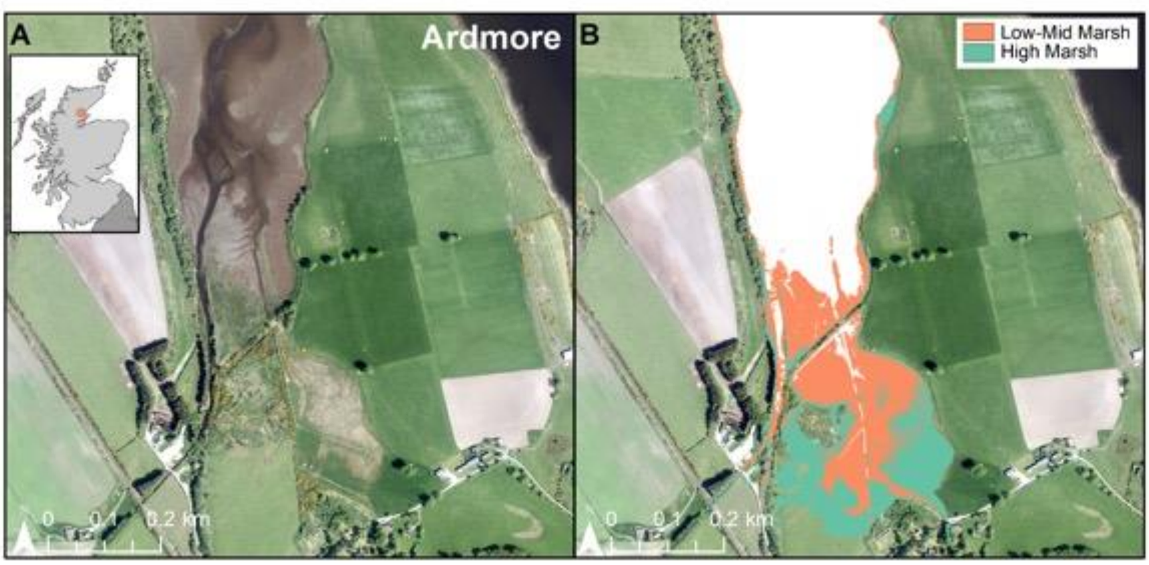

Figure A4.3. Spatial model for Ardmore (**A**) the extent of present saltmarsh at Ardmore (Haynes. 2016) - inset map of Scotland shows site location; (**B**) the potential extent of saltmarsh created by managed realignment at this site. High Marsh (green); Low-Mid Marsh (orange).

Realignment of the site could potentially create **0.10 km^2** of saltmarsh comprised of **0.06 km^2** of low-mid marsh and **0.05 km^2** of high marsh. Aerial photography (Fig. A4.3) confirms the presence of saltmarsh (<0.03 km^2, and therefore not mapped as part of current mapping efforts (Haynes, 2016)) increasing the likelihood of successful saltmarsh establishment at the site after realignment activities. These factors have resulted is the site being categorised as **highly suitable** for realignment.

If saltmarsh was successfully established at the site and reached a point where its carbon burial and storage capacity mirrored natural sites the surficial (top 10cm) soils in the low-mid marsh could potential hold **332 ± 241 tonnes OC**, while the high marsh could hold **314 ± 227 tonnes OC**. In total the surficial saltmarsh soil (top 10cm) stock at this site **646 ± 330 tonnes OC** which would represent a **0.18%** increase in Scotland's current saltmarsh surficial soil OC stock (Austin *et al*., 2021).

Under future median (50th Percentile) predications of relative sea level rise the extent of the realigned saltmarsh area will reduce by between **3.35 – 13.89% by 2032**, **4.96 – 6.6% by 2045**, **7.98 – 15.27% by 2070** and **11.84 – 33.02% by 2100**. Under the worst (RCP 8.5 95th percentile) future relative sea level predications the realigned marsh will be reduced in size by **68.31%** by 2100 (Fig. A4.4) reducing the surficial soil organic carbon stock to **205 tonnes.**

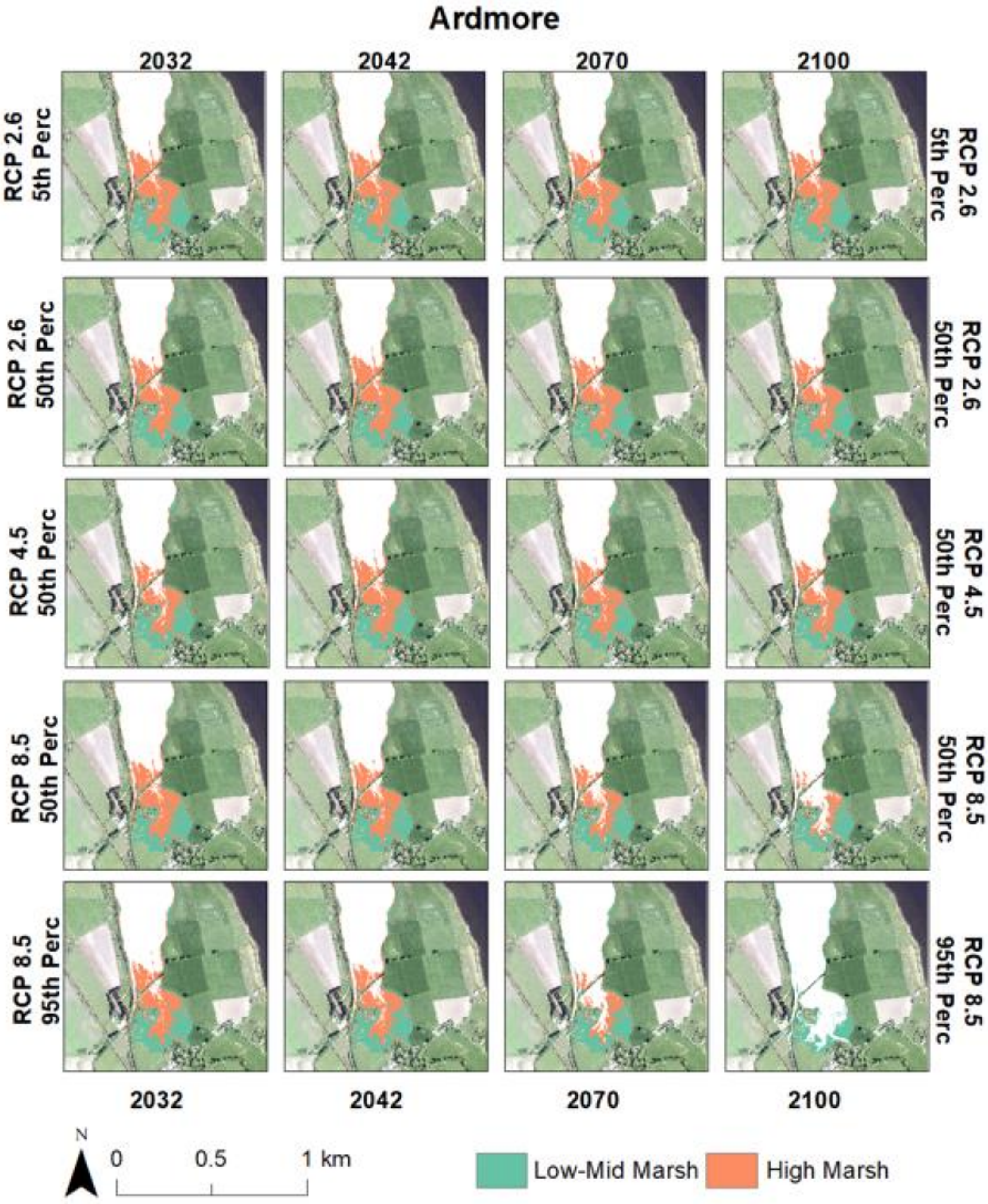

Figure A4.4. Saltmarsh extent following a hypothetical managed realignment at Ardmore, Scotland and including subsequent habitat loss (assuming no landward migration of the coastline nor any vertical accretion of the marsh surface as sea-level rise occurs) from a simple drowning of the saltmarsh surface. Sea-level change projections under different emissions scenarios are shown for the 50th and 95th percentiles for RCP 2.6 (low emissions), RCP 4.5 (medium emissions) and RCP 8.5 (high emissions) for 2032, 2045, 2070 and 2100.

11.3 Kirkhill

The site at Kirkhill is found in the upper reaches of the Moray Firth (Fig. A4.5). The site is currently occupied by arable agriculture. The south east corner of the Kirkhill site is currently occupied by rail lines. It is envisaged that the realignment project could proceed while maintaining the protection afford to the infrastructure. Review of historic maps suggest this site was reclaimed prior to 1846.

Figure A4.5. Spatial model for Kirkhill (**A**) the extent of present saltmarsh at Kirkhill (Haynes. 2016) - inset map of Scotland shows site location; (**B**) the potential extent of saltmarsh created by managed realignment at this site. High Marsh (green); Low-Mid Marsh (orange).

Realignment of the site could potentially create **1.63 km^2** of saltmarsh comprised of **0.26 km^2** of low-mid marsh and **0.36 km^2** of high marsh. Aerial photography and current mapping (Fig. A4.5) confirms the presence of saltmarsh increasing the likelihood of successful saltmarsh establishment at the site after realignment activities. These factors have resulted is the site being categorised as **highly suitable** for realignment.

If saltmarsh was successfully established at the site and reached a point where its carbon burial and storage capacity mirrored natural sites the surficial (top 10cm) soils in the low-mid marsh could potential hold **1,514 ± 1,099 tonnes OC**, while the high marsh could hold **9,286 ± 6,697 tonnes OC**. In total the surficial saltmarsh soil (top 10cm) stock at this site **10,800 ± 6,783 tonnes OC** which would represent a **2.93 %** increase in Scotland's current saltmarsh surficial soil OC stock (Austin *et al*., 2021).

Under future median (50th Percentile) predications of relative sea level rise the extent of the realigned saltmarsh area will reduce by between **4.79 – 5.73% by 2032**, **6.55 – 7.88% by 2045**, **8.64 – 9.42 % by 2070** and **9.89 – 14.03% by 2100**. Under the worst (RCP 8.5 95th percentile) future relative sea level predications the realigned marsh will be reduced in size by **31.45%** by 2100 (Fig. A4.6) reducing the surficial soil organic carbon stock to **7403 tonnes.**

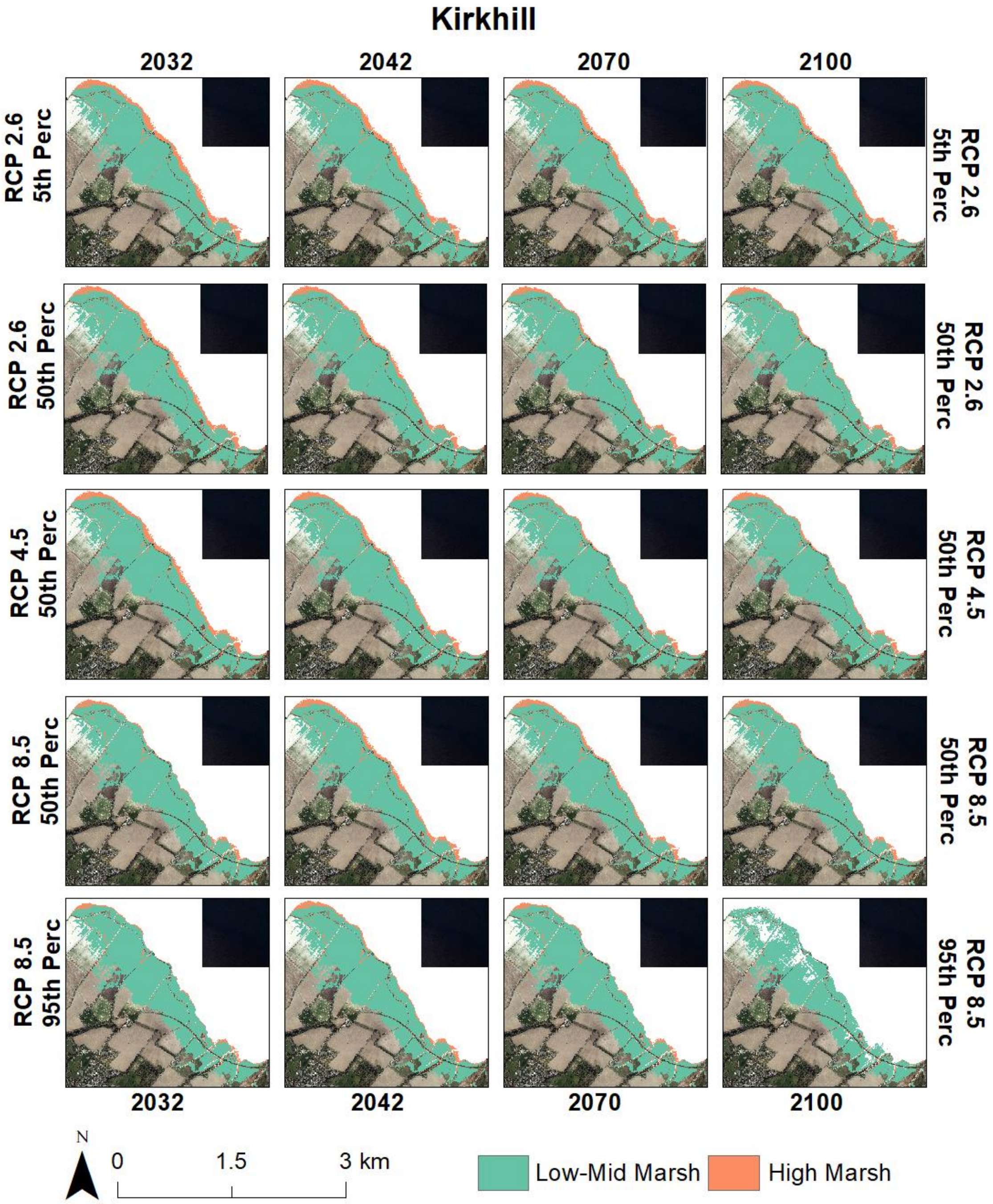

Figure A4.6. Saltmarsh extent following a hypothetical managed realignment at Kirkhill, Scotland and including subsequent habitat loss (assuming no landward migration of the coastline nor any vertical accretion of the marsh surface as sea-level rise occurs) from a simple drowning of the saltmarsh surface. Sea-level change projections under different emissions scenarios are shown for the 50th and 95th percentiles for RCP 2.6 (low emissions), RCP 4.5 (medium emissions) and RCP 8.5 (high emissions) for 2032, 2045, 2070 and 2100.

11.4 Montrose

The site at Montrose is found in the Montrose Basin (Fig. A4.7). The site is currently occupied by arable agriculture and is free from infrastructure. Review of historic maps suggest this site was reclaimed prior to 1846.

Figure A4.7. Spatial model for Montrose (**A**) the extent of present saltmarsh at Montrose (Haynes. 2016) - inset map of Scotland shows site location; (**B**) the potential extent of saltmarsh created by managed realignment at this site. High Marsh (green); Low-Mid Marsh (orange).

Realignment of the site could potentially create **1.47 km^2** of saltmarsh comprised of **0.58 km^2** of low-mid marsh and **0.88 km^2** of high marsh. Aerial photography and current mapping (Fig.25) confirms the presence of saltmarsh increasing the likelihood of successful saltmarsh establishment at the site after realignment activities. These factors have resulted is the site being categorised as **highly suitable** for realignment.

If saltmarsh was successfully established at the site and reached a point where its carbon burial and storage capacity mirrored natural sites the surficial (top 10cm) soils in the low-mid marsh could potential hold **3,407 ± 2,473 tonnes OC**, while the high marsh could hold **6,008 ± 4,334 tonnes OC**. In total the surficial saltmarsh soil (top 10cm) stock at this site **9,415 ± 4,981 tonnes OC** which would represent a **2.56 %** increase in Scotland's current saltmarsh surficial soil OC stock (Austin *et al*., 2021).

Under future median (50th Percentile) predications of relative sea level rise the extent of the realigned saltmarsh area will reduce by between **2.99 – 3.56% by 2032**, **4.64 – 6.29% by 2045**, **7.55 – 13.28% by 2070** and **10.54 – 28.20% by 2100**. Under the worst (RCP 8.5 95th percentile) future relative sea level predications the realigned marsh will be reduced in size by **65.42%** by 2100 (Fig. A4.8) reducing the surficial soil organic carbon stock to **3256 tonnes.**

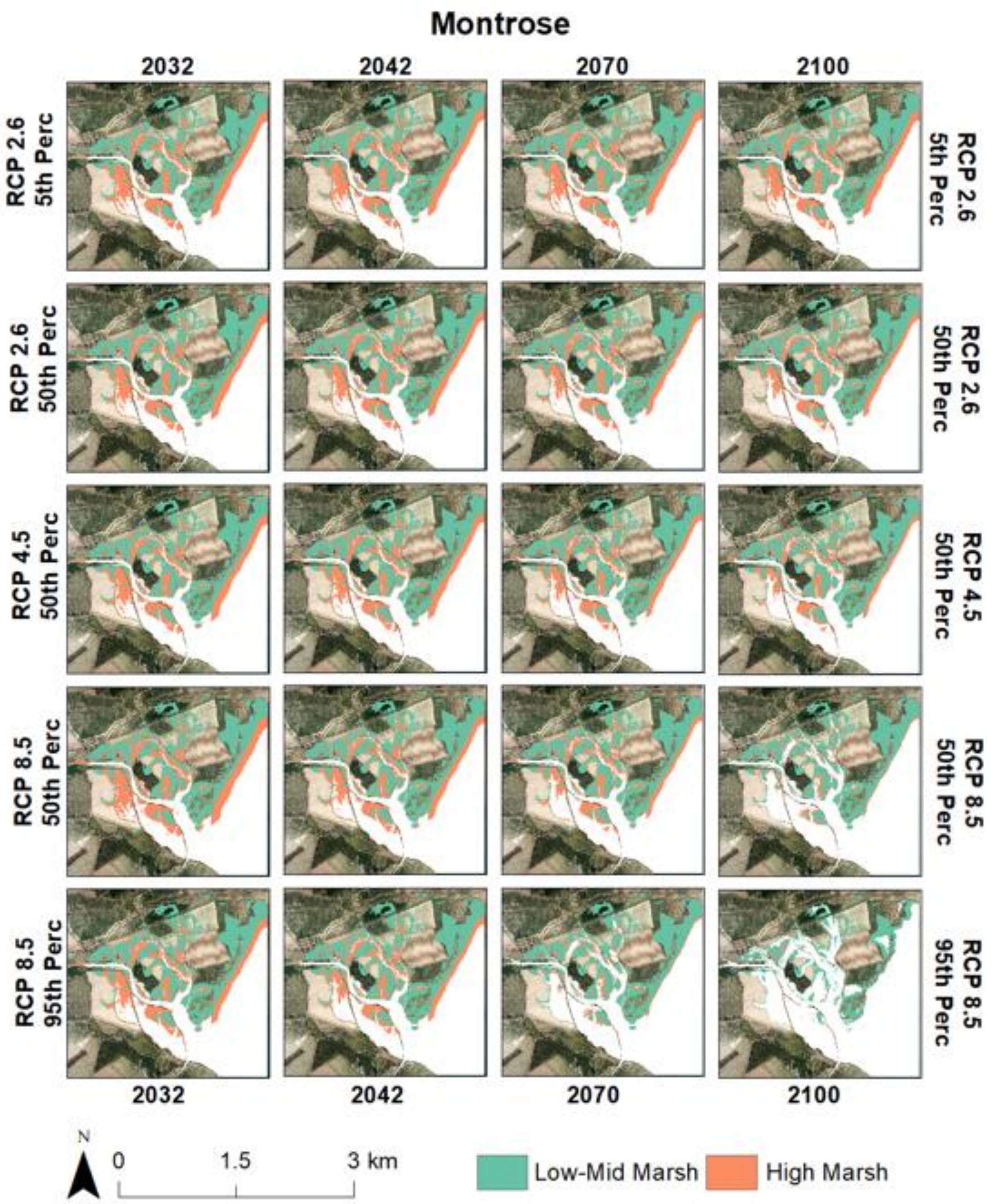

Figure A4.8. Saltmarsh extent following a hypothetical managed realignment at Montrose, Scotland and including subsequent habitat loss (assuming no landward migration of the coastline nor any vertical accretion of the marsh surface as sea-level rise occurs) from a simple drowning of the saltmarsh surface. Sea-level change projections under different emissions scenarios are shown for the 50th and 95th percentiles for RCP 2.6 (low emissions), RCP 4.5 (medium emissions) and RCP 8.5 (high emissions) for 2032, 2045, 2070 and 2100.

11.5 Tayport

The site in the Tayport is found the mouth of the estuary (Fig. A4.9). The site is currently occupied by arable agriculture. The site is situated in close proximity to Tayport. It is envisaged that it would be difficult to undertake realignment activities at this site without a significant engineering involvement. Review of historic maps suggest this site was reclaimed prior to 1846.

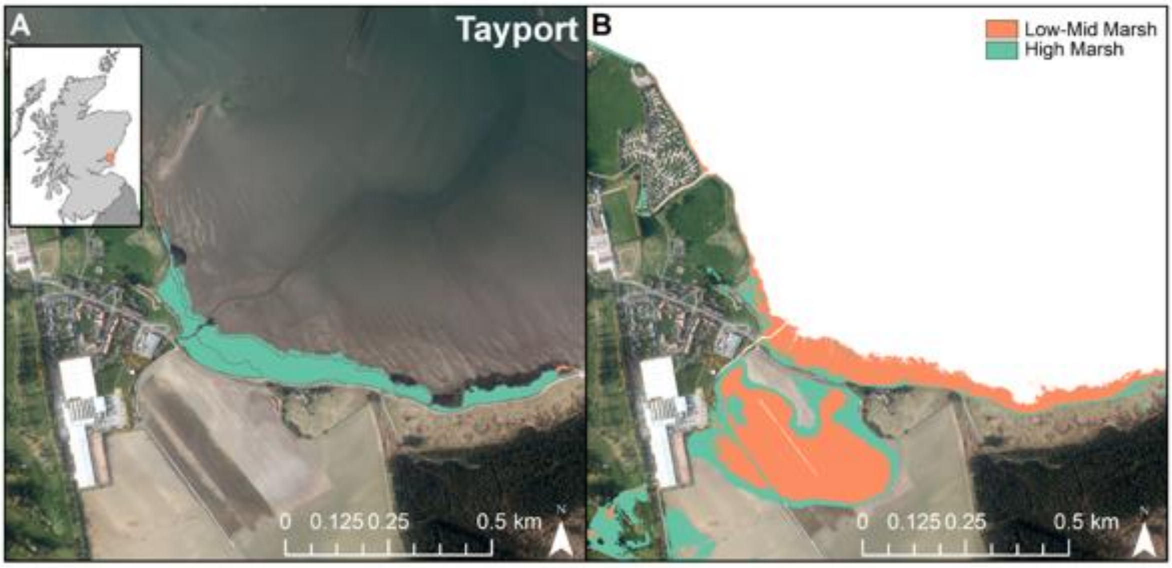

Figure A4.9. Spatial model for Tayport (**A**) the extent of present saltmarsh at Tayport (Haynes. 2016) - inset map of Scotland shows site location; (**B**) the potential extent of saltmarsh created by managed realignment at this site. High Marsh (green); Low-Mid Marsh (orange).

Realignment of the site could potentially create **0.25 km^2** of saltmarsh comprised of **0.13 km^2** of low-mid marsh and **0.11 km^2** of high marsh Aerial photography and current mapping (Fig.27) confirms the presence of saltmarsh increasing the likelihood of successful saltmarsh establishment at the site after realignment activities These factors have resulted is the site being categorised as **suitable** for realignment.

If saltmarsh was successfully established at the site and reached a point where its carbon burial and storage capacity mirrored natural sites the surficial (top 10cm) soils in the low-mid marsh could potential hold **786 ± 570 tonnes OC**, while the high marsh could hold **758 ± 547 tonnes OC**. In total the surficial saltmarsh soil (top 10cm) stock at this site **1,544 ± 789 tonnes OC** which would represent a **0.42%** increase in Scotland's current saltmarsh surficial soil OC stock (Austin *et al*., 2021).

Under future median (50th Percentile) predications of relative sea level rise the extent of the realigned saltmarsh area will reduce by between **1.24 – 1.58% by 2032**, **1.95 – 2.81% by 2045**, **3.31 – 9.06% by 2070** and **5.44 – 36.20% by 2100**. Under the worst (RCP 8.5 95th percentile) future relative sea level predications the realigned marsh will be reduced in size by **67.07%** by 2100 (Fig. A4.10) reducing the surficial soil organic carbon stock to **509 tonnes.**

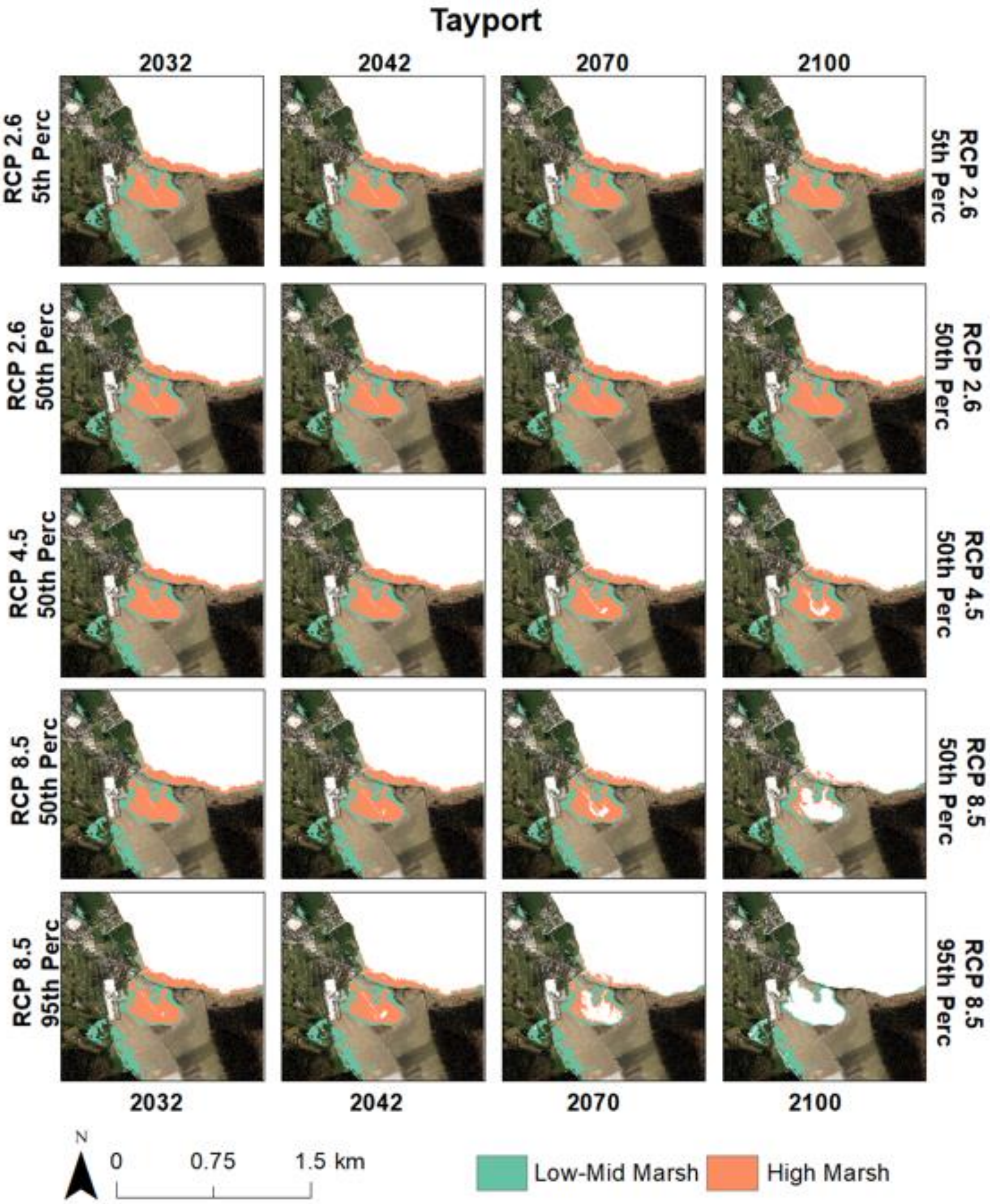

Figure A4.10. Saltmarsh extent following a hypothetical managed realignment at Tayport, Scotland and including subsequent habitat loss (assuming no landward migration of the coastline nor any vertical accretion of the marsh surface as sea-level rise occurs) from a simple drowning of the saltmarsh surface. Sea-level change projections under different emissions scenarios are shown for the 50th and 95th percentiles for RCP 2.6 (low emissions), RCP 4.5 (medium emissions) and RCP 8.5 (high emissions) for 2032, 2045, 2070 and 2100.

11.6 Newburgh

The site at Newburgh is found in the southern bank of the upper Tay estuary (Fig. A4.11). The site is currently occupied by arable agriculture and is free from infrastructure. Review of historic maps suggest this site was reclaimed prior to 1846.

Figure 4.11. Spatial model for Newburgh (**A**) the extent of present saltmarsh at Newburgh (Haynes. 2016) - inset map of Scotland shows site location; (**B**) the potential extent of saltmarsh created by managed realignment at this site. High Marsh (green); Low-Mid Marsh (orange).

Realignment of the site could potentially create **0.78 km^2** of saltmarsh comprised of **0.46 km^2** of low-mid marsh and **0.32 km^2** of high marsh. Aerial photography and current mapping efforts (Haynes, 2016)) confirm that saltmarsh is not present at the site (Fig. A4.11), nearby wetlands would suggest it is more likely that a brackish marsh will develop dominated by reed beds (*Phragmites australis*). These factors have resulted is the site being categorised as **less suitable** for realignment.

If saltmarsh was successfully established at the site and reached a point where its carbon burial and storage capacity mirrored natural sites the surficial (top 10cm) soils in the low-mid marsh could potential hold **2,685 ± 1,949 tonnes OC**, while the high marsh could hold **2,212 ± 1,596 tonnes OC**. In total the surficial saltmarsh soil (top 10cm) stock at this site **4,897 ± 2,514 tonnes OC** which would represent a **1.33%** increase in Scotland's current saltmarsh surficial soil OC stock (Austin *et al*., 2021).

Under future median (50th Percentile) predications of relative sea level rise the extent of the realigned saltmarsh area will reduce by between **0.34 – 0.49% by 2032**, **0.69 – 1.29% by 2045**, **1.70 – 7.43% by 2070** and **3.93 – 42.71% by 2100**. Under the worst (RCP 8.5 95th percentile) future relative sea level predications the realigned marsh will be reduced in size by **73.36%** by 2100 (Fig.30) reducing the surficial soil organic carbon stock to **2,168 tonnes.**

Figure A4.12. Saltmarsh extent following a hypothetical managed realignment at Newburgh, Scotland and including subsequent habitat loss (assuming no landward migration of the coastline nor any vertical accretion of the marsh surface as sea-level rise occurs) from a simple drowning of the saltmarsh surface. Sea-level change projections under different emissions scenarios are shown for the 50th and 95th percentiles for RCP 2.6 (low emissions), RCP 4.5 (medium emissions) and RCP 8.5 (high emissions) for 2032, 2045, 2070 and 2100.

11.7 Eden Estuary

The site in the Eden Estuary is found the southern banks of the estuary (Fig. A4.13). The site is currently occupied by arable agriculture and improved grassland (golf courses). The south site is currently occupied by the main road from the North to St Andrews. It is envisaged that the realignment project could proceed while maintaining the protection afford to the infrastructure. Review of historic maps suggest this site was reclaimed prior to 1846.

Figure A4.13. Spatial model for Eden Estuary (**A**) the extent of present saltmarsh at Eden Estuary (Haynes. 2016) - inset map of Scotland shows site location; (**B**) the potential extent of saltmarsh created by managed realignment at this site. High Marsh (green); Low-Mid Marsh (orange).

Realignment of the site could potentially create **0.43 km^2** of saltmarsh comprised of **0.19 km^2** of low-mid marsh and **0.24 km^2** of high marsh. Aerial photography and current mapping (Fig.31) confirms the presence of saltmarsh increasing the likelihood of successful saltmarsh establishment at the site after realignment activities. These factors have resulted is the site being categorised as **highly suitable** for realignment.

If saltmarsh was successfully established at the site and reached a point where its carbon burial and storage capacity mirrored natural sites the surficial (top 10cm) soils in the low-mid marsh could potential hold **1,101 ± 799 tonnes OC**, while the high marsh could hold **1,632 ± 1,177 tonnes OC**. In total the surficial saltmarsh soil (top 10cm) stock at this site **2,733 ± 1,420 tonnes OC** which would represent a **0.74%** increase in Scotland's current saltmarsh surficial soil OC stock (Austin *et al*., 2021).

Under future median (50th Percentile) predications of relative sea level rise the extent of the realigned saltmarsh area will reduce by between **1.67 – 2.11% by 2032**, **2.53 – 3.81% by 2045**, **4.59 – 11.09% by 2070** and **7.44 – 30.08% by 2100**. Under the worst (RCP 8.5 95th percentile) future relative sea level predications the realigned marsh will be reduced in size by **55.72%** by 2100 (Fig. A4.14) reducing the surficial soil organic carbon stock to **1,210 tonnes.**

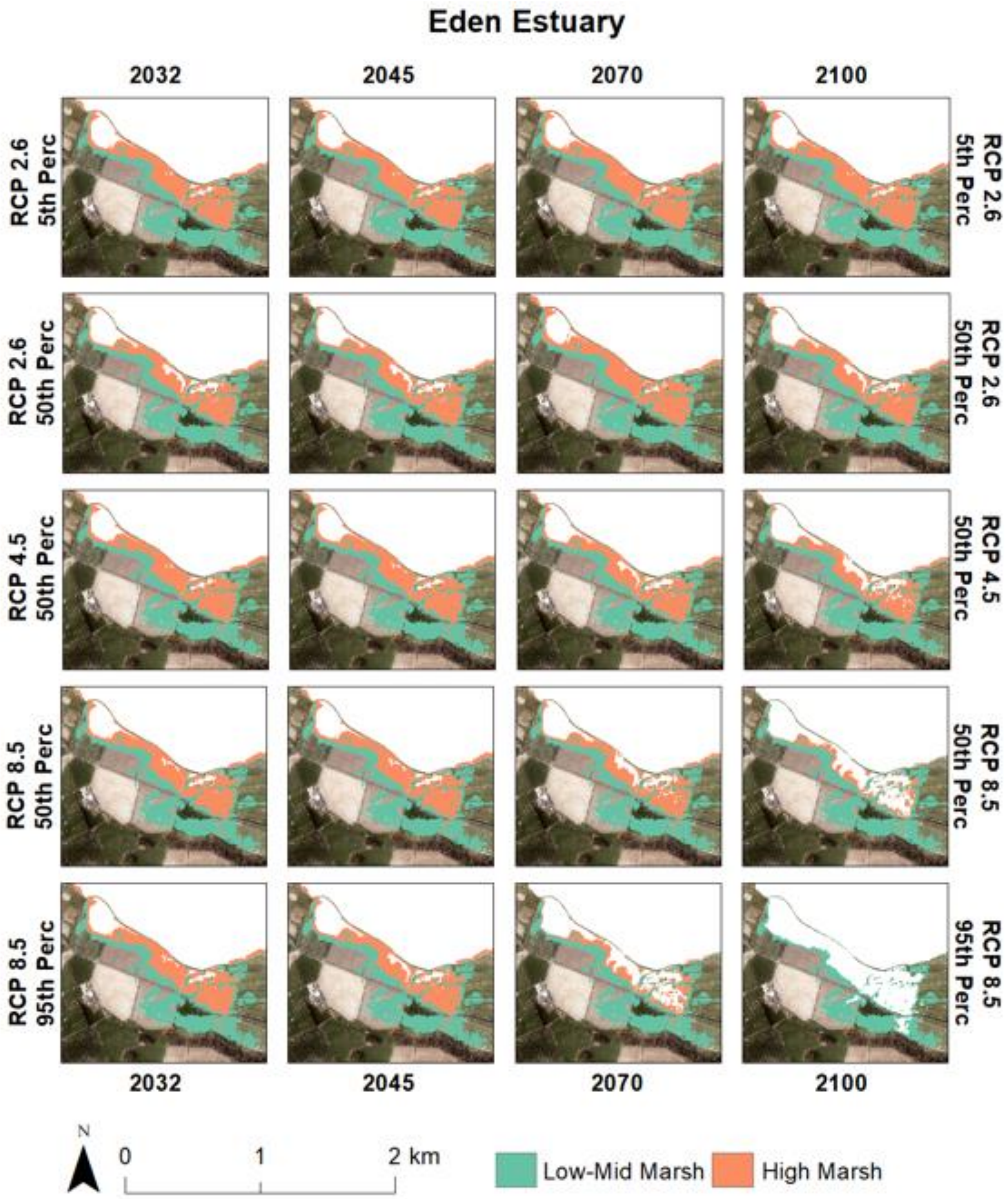

Figure A4.14. Saltmarsh extent following a hypothetical managed realignment at Eden Estuary, Scotland and including subsequent habitat loss (assuming no landward migration of the coastline nor any vertical accretion of the marsh surface as sea-level rise occurs) from a simple drowning of the saltmarsh surface. Sea-level change projections under different emissions scenarios are shown for the 50th and 95th percentiles for RCP 2.6 (low emissions), RCP 4.5 (medium emissions) and RCP 8.5 (high emissions) for 2032, 2045, 2070 and 2100.

11.8 Inverkeithing

The site in the Inverkeithing is found in the outer reaches of the Firth of Forth (Fig.A4.15). The site is currently waste ground unoccupied. The site is found at the base of the Queensferry crossing. It is envisaged that it would be difficult to undertake realignment activities at this site without a significant engineering involvement. Review of historic maps suggest this site has undergone multiple phases of reclamation changing from intertidal flat dominated by sand in 1846 to its current configuration prior to 1969.

Figure A4.15. Spatial model for Inverkeithing (**A**) the extent of present saltmarsh at Inverkeithing (Haynes. 2016) - inset map of Scotland shows site location; (**B**) the potential extent of saltmarsh created by managed realignment at this site. High Marsh (green); Low-Mid Marsh (orange).

Realignment of the site could potentially create **0.02 km^2** of saltmarsh comprised of **0.16 km^2** of low-mid marsh and **0.19 km^2** of high marsh. Aerial photography and current mapping efforts (Haynes, 2016)) confirm that saltmarsh is not present at the site (Fig. 4.15) decreasing the likelihood of successful saltmarsh establishment at the site after realignment activities. These factors have resulted is the site being categorised as **less suitable** for realignment.

If saltmarsh was successfully established at the site and reached a point where its carbon burial and storage capacity mirrored natural sites the surficial (top 10cm) soils in the low-mid marsh could potential hold **134 ± 97 tonnes OC**, while the high marsh could hold **1,120 ± 1,808 tonnes OC**. In total the surficial saltmarsh soil (top 10cm) stock at this site **1,254 ± 813 tonnes OC** which would represent a **0.34%** increase in Scotland's current saltmarsh surficial soil OC stock (Austin *et al*., 2021).

Under future median (50th Percentile) predications of relative sea level rise the extent of the realigned saltmarsh area will reduce by between **0.54 – 0.61% by 2032**, **0.69 – 0.83% by 2045**, **0.90 – 1.34% by 2070** and **1.11 – 5.86% by 2100**. Under the worst (RCP 8.5 95th percentile) future relative sea level predications the realigned marsh will be reduced in size by **35.54%** by 2100 (Fig. A4.16) reducing the surficial soil organic carbon stock to **808 tonnes.**

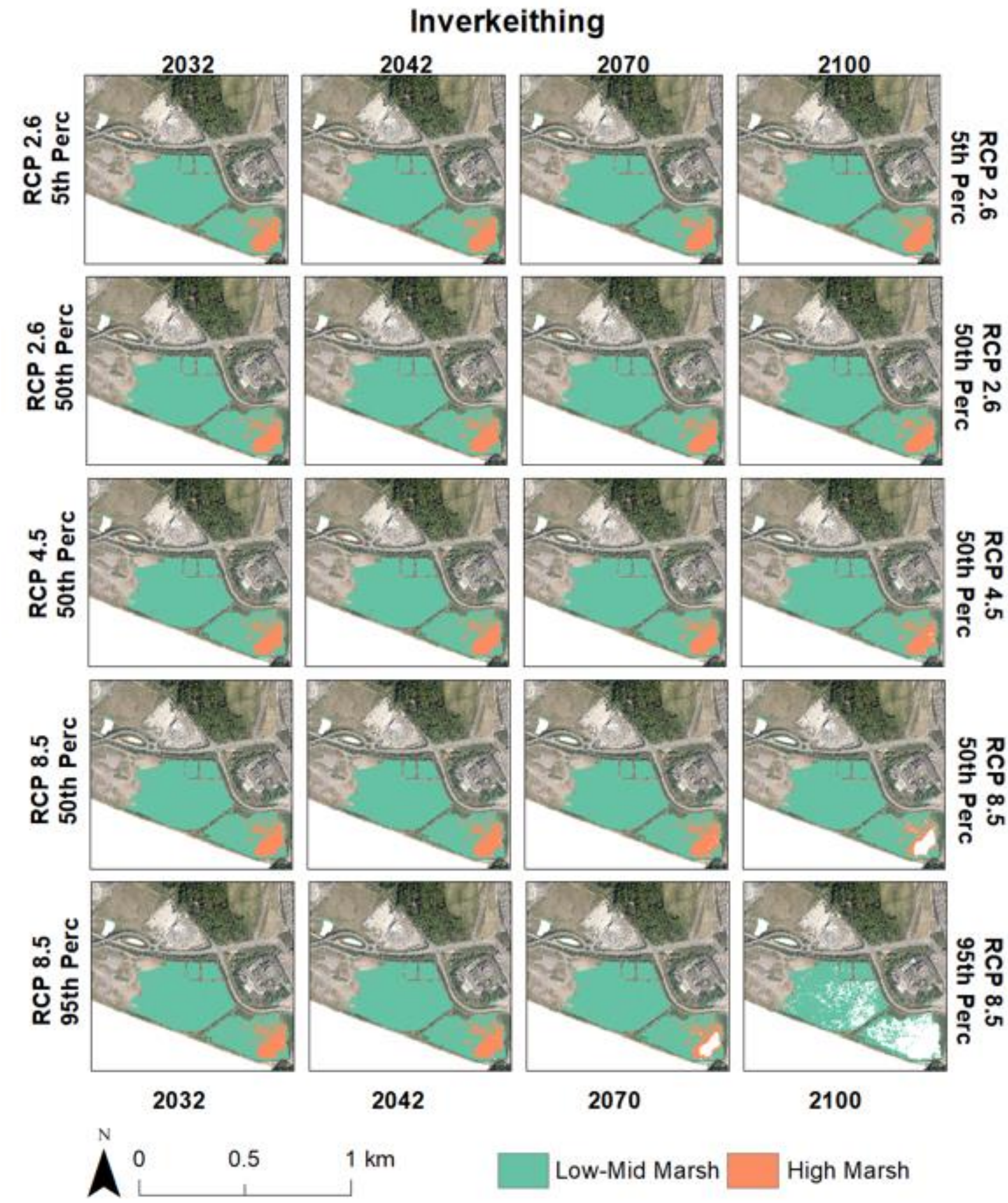

Figure A4.16. Saltmarsh extent following a hypothetical managed realignment at Inverkeithing, Scotland and including subsequent habitat loss (assuming no landward migration of the coastline nor any vertical accretion of the marsh surface as sea-level rise occurs) from a simple drowning of the saltmarsh surface. Sea-level change projections under different emissions scenarios are shown for the 50th and 95th percentiles for RCP 2.6 (low emissions), RCP 4.5 (medium emissions) and RCP 8.5 (high emissions) for 2032, 2045, 2070 and 2100.

11.9 Carron Pools

The site at Carron Pools is found in the inner reaches of the Firth of Forth (Fig. A4.17). The site is currently occupied by arable agriculture. The site is found at next to Grangemouth petrochemical plant. It is envisaged that it would be difficult to undertake realignment activities at this site without a significant engineering involvement. Review of historic maps suggest this site was reclaimed prior to 1846.

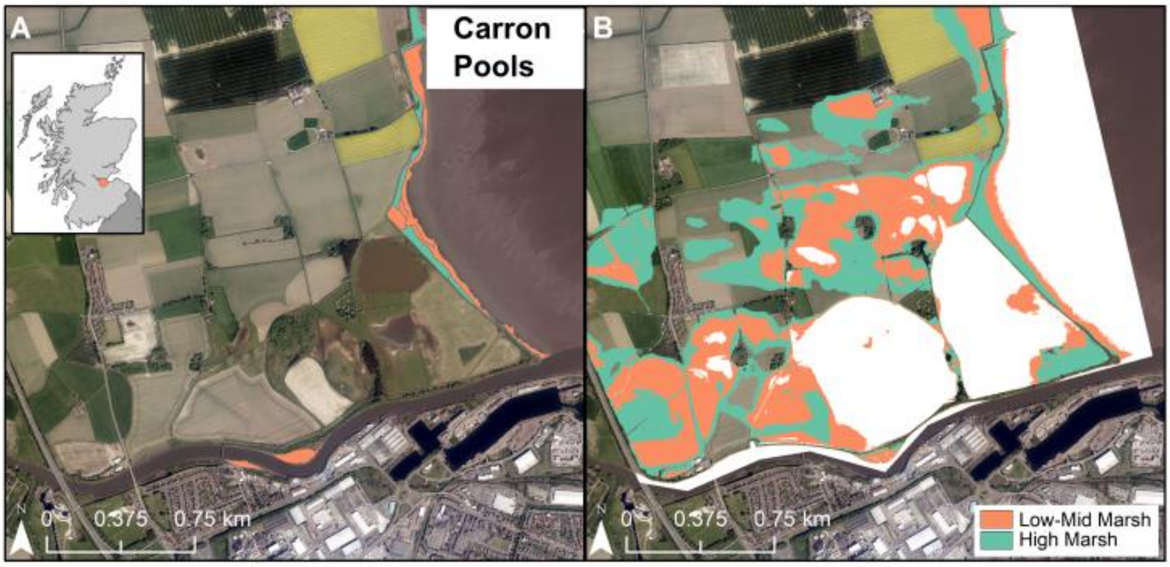

Figure A4.17. Spatial model for Carron Pools (**A**) the extent of present saltmarsh at Carron Pools (Haynes. 2016) - inset map of Scotland shows site location; (**B**) the potential extent of saltmarsh created by managed realignment at this site. High Marsh (green); Low-Mid Marsh (orange).

Realignment of the site could potentially create **0.1.78 km^2** of saltmarsh comprised of **0.85 km^2** of low-mid marsh and **0.93 km^2** of high marsh. Aerial photography and current mapping (Fig. A4.17) confirms the presence of saltmarsh increasing the likelihood of successful saltmarsh establishment at the site after realignment activities. These factors have resulted is the site being categorised as **suitable** for realignment.

If saltmarsh was successfully established at the site and reached a point where its carbon burial and storage capacity mirrored natural sites the surficial (top 10cm) soils in the low-mid marsh could potential hold **4,950 ± 3,593 tonnes OC**, while the high marsh could hold **6,343 ± 4,575 tonnes OC**. In total the surficial saltmarsh soil (top 10cm) stock at this site **11,293 ± 5,806 tonnes OC** which would represent a **3.07%** increase in Scotland's current saltmarsh surficial soil OC stock (Austin *et al*., 2021).

Under future median (50th Percentile) predications of relative sea level rise the extent of the realigned saltmarsh area will reduce by between **3.29 – 4.11% by 2032**, **4.91 – 6.87% by 2045**, **7.83 – 15.33% by 2070** and **11.04 – 32.88% by 2100**. Under the worst (RCP 8.5 95th percentile) future relative sea level predications the realigned marsh will be reduced in size by **63.65%** by 2100 (Fig. A4.18) reducing the surficial soil organic carbon stock to **4,105 tonnes.**

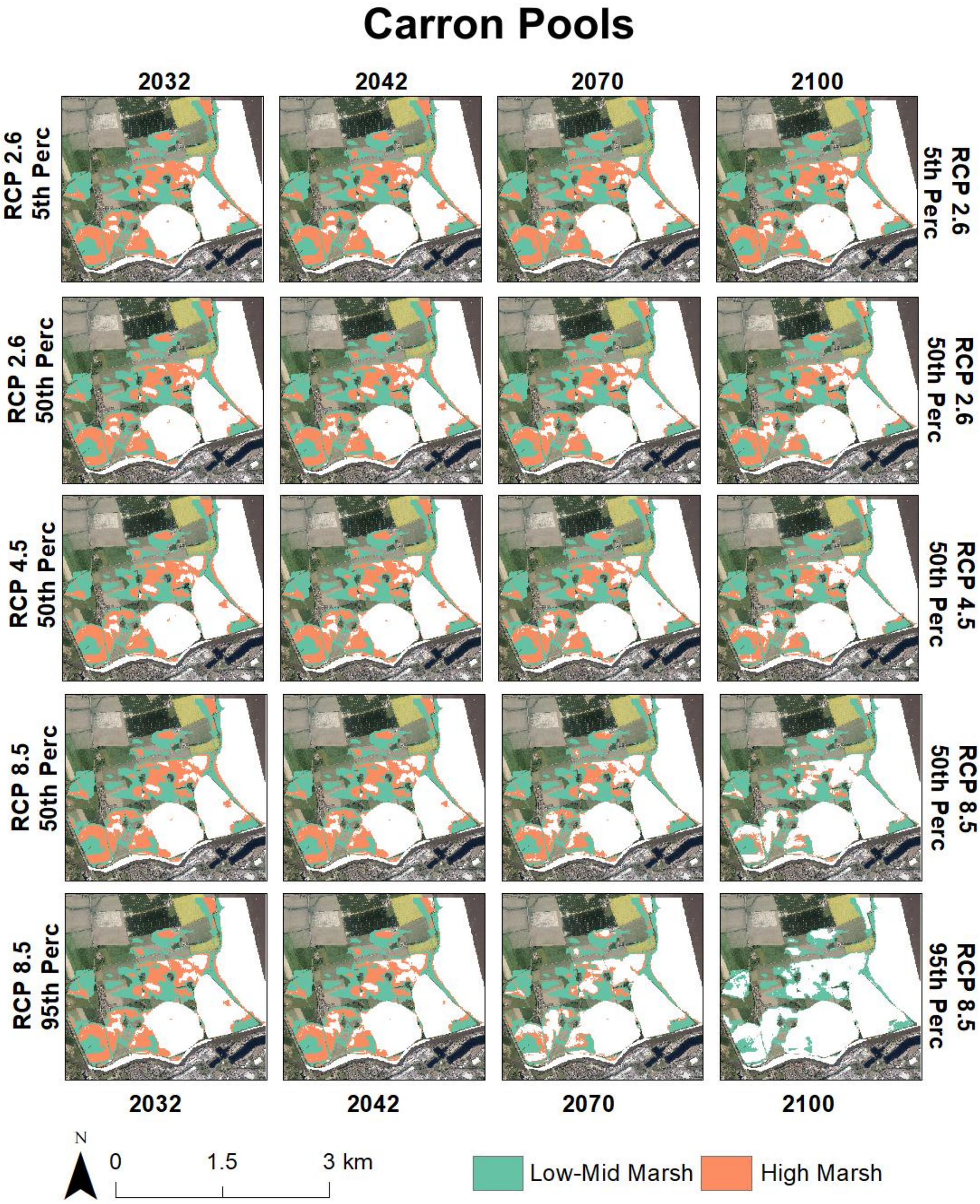

Figure A4.18. Saltmarsh extent following a hypothetical managed realignment at Carron Pools, Scotland and including subsequent habitat loss (assuming no landward migration of the coastline nor any vertical accretion of the marsh surface as sea-level rise occurs) from a simple drowning of the saltmarsh surface. Sea-level change projections under different emissions scenarios are shown for the 50th and 95th percentiles for RCP 2.6 (low emissions), RCP 4.5 (medium emissions) and RCP 8.5 (high emissions) for 2032, 2045, 2070 and 2100.

11.10 Longannet

The site in the Longannet is found in the inner reaches of the Firth of Forth (Fig. A4.19). The site is currently occupied by arable agriculture waste ground. The east of the site is situated on the former coal storage area for Longannet power station. It is envisaged remediation (contaminated land) would have to take place prior to any realignment activities Review of historic maps suggest this site was reclaimed prior to 1856

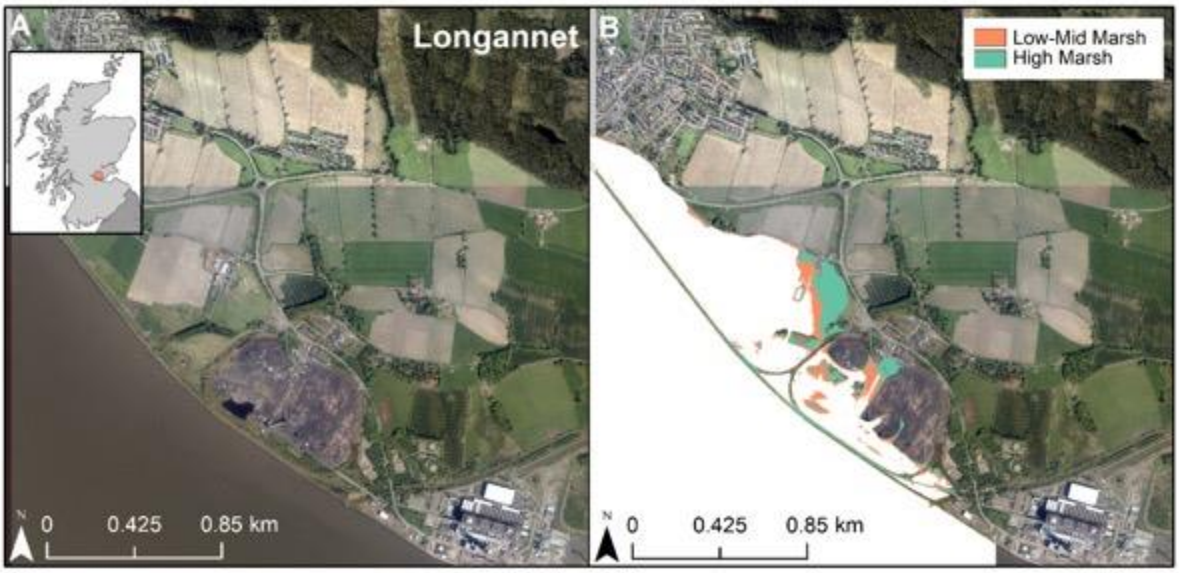

Figure A4.19. Spatial model for Longannet (**A**) the extent of present saltmarsh at Longannet (Haynes. 2016) - inset map of Scotland shows site location; (**B**) the potential extent of saltmarsh created by managed realignment at this site. High Marsh (green); Low-Mid Marsh (orange).

Realignment of the site could potentially create **0.22 km^2** of saltmarsh comprised of **0.10 km^2** of low-mid marsh and **0.12 km^2** of high marsh. Aerial photography and current mapping efforts (Haynes, 2016)) confirm that saltmarsh is not present at the site (Fig. A4.19) decreasing the likelihood of successful saltmarsh establishment at the site after realignment activities. These factors have resulted is the site being categorised as **less suitable** for realignment.

If saltmarsh was successfully established at the site and reached a point where its carbon burial and storage capacity mirrored natural sites the surficial (top 10cm) soils in the low-mid marsh could potential hold **577 ± 419 tonnes OC**, while the high marsh could hold **819 ± 591 tonnes OC**. In total the surficial saltmarsh soil (top 10cm) stock at this site **1,396 ± 723 tonnes OC** which would represent a **0.38%** increase in Scotland's current saltmarsh surficial soil OC stock (Austin *et al*., 2021).

Under future median (50th Percentile) predications of relative sea level rise the extent of the realigned saltmarsh area will reduce by between **5.18 – 6.48% by 2032**, **6.04 – 10.74% by 2045**, **12.04 – 20.54% by 2070** and **16.50 – 34.52% by 2100**. Under the worst (RCP 8.5 95th percentile) future relative sea level predications the realigned marsh will be reduced in size by **62.11%** by 2100 (Fig. A4.20) reducing the surficial soil organic carbon stock to **529 tonnes.**

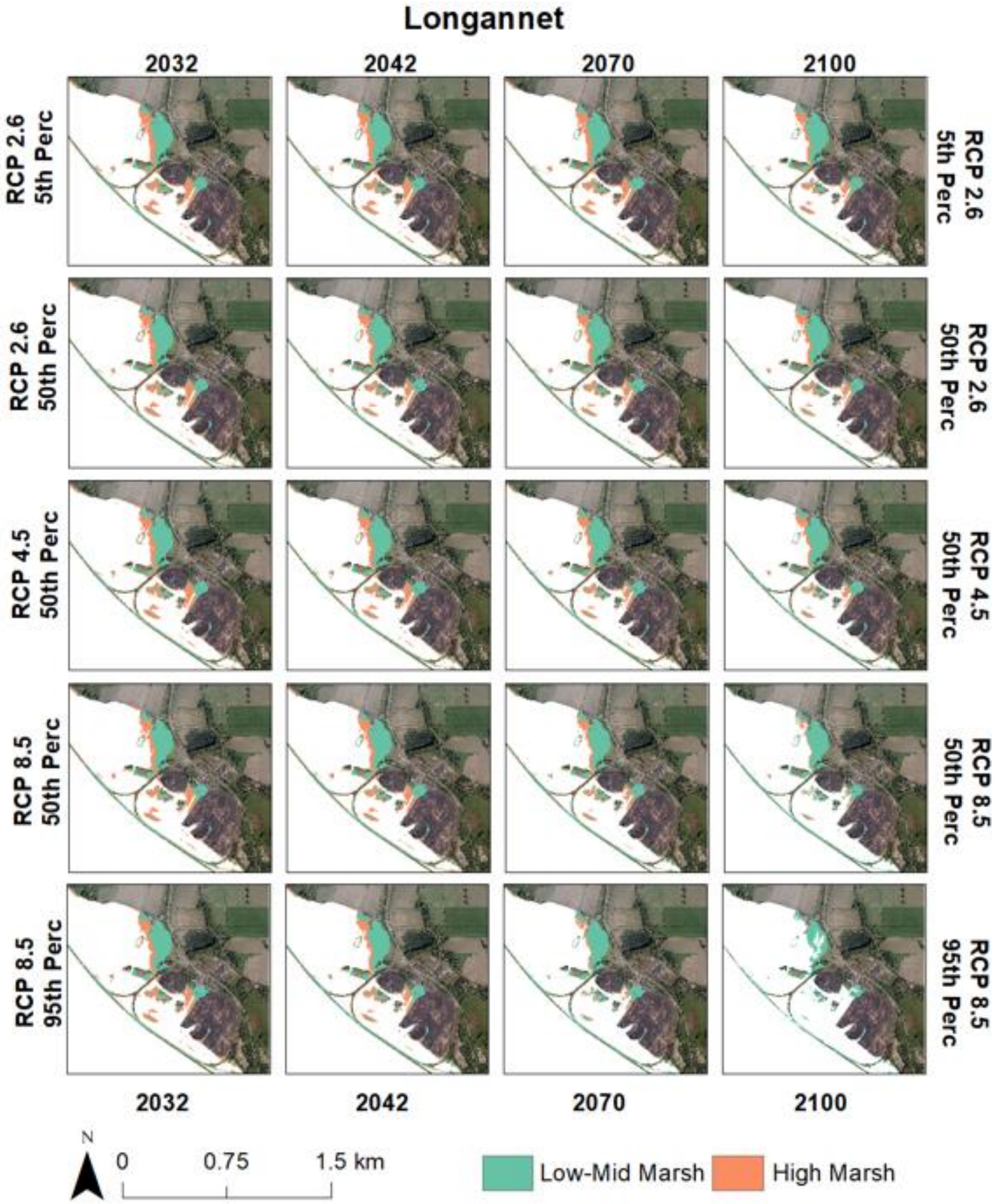

Figure A4.20. Saltmarsh extent following a hypothetical managed realignment at Longannet, Scotland and including subsequent habitat loss (assuming no landward migration of the coastline nor any vertical accretion of the marsh surface as sea-level rise occurs) from a simple drowning of the saltmarsh surface. Sea-level change projections under different emissions scenarios are shown for the 50th and 95th percentiles for RCP 2.6 (low emissions), RCP 4.5 (medium emissions) and RCP 8.5 (high emissions) for 2032, 2045, 2070 and 2100.

11.11 Hawkhill

The site in the Hawkill is found in the inner reaches of the Firth of Forth (Fig. A4.21). The site is currently occupied by power grid infrastructure. Realignment activities is currently impossible at this site sue to the presence of this infrastructure. Review of historic maps suggest this site was reclaimed prior to 1856.

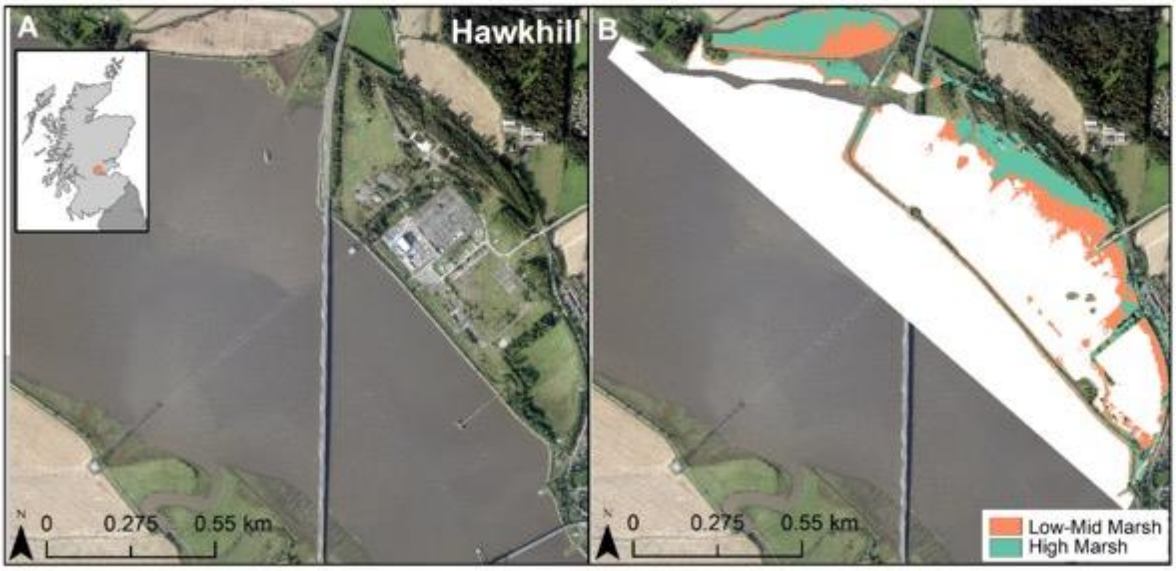

Figure A4.21. Spatial model for Hawkhill (**A**) the extent of present saltmarsh at Hawkhill(Haynes. 2016) - inset map of Scotland shows site location; (**B**) the potential extent of saltmarsh created by managed realignment at this site. High Marsh (green); Low-Mid Marsh (orange).

Realignment of the site could potentially create **0.26 km^2** of saltmarsh comprised of **0.12 km^2** of low-mid marsh and **0.13 km^2** of high marsh. Aerial photography (Fig. A4.21) confirms the presence of saltmarsh (<0.03 km2, and therefore not mapped as part of current mapping efforts (Haynes, 2016)) increasing the likelihood of successful saltmarsh establishment at the site after realignment activities. These factors have resulted is the site being categorised as **not suitable** for realignment.

If saltmarsh was successfully established at the site and reached a point where its carbon burial and storage capacity mirrored natural sites the surficial (top 10cm) soils in the low-mid marsh could potential hold **716 ± 519 tonnes OC**, while the high marsh could hold **901 ± 650 tonnes OC**. In total the surficial saltmarsh soil (top 10cm) stock at this site **1,618 ± 831 tonnes OC** which would represent a **0.44%** increase in Scotland's current saltmarsh surficial soil OC stock (Austin *et al*., 2021).

Under future median (50th Percentile) predications of relative sea level rise the extent of the realigned saltmarsh area will reduce by between **5.82 – 7.13% by 2032**, **8.35 – 11.08% by 2045**, **12.34 – 21.06% by 2070** and **16.40 – 34.76% by 2100**. Under the worst (RCP 8.5 95th percentile) future relative sea level predications the realigned marsh will be reduced in size by **72.23%** by 2100 (Fig. A4.22) reducing the surficial soil organic carbon stock to **46.5 tonnes.**

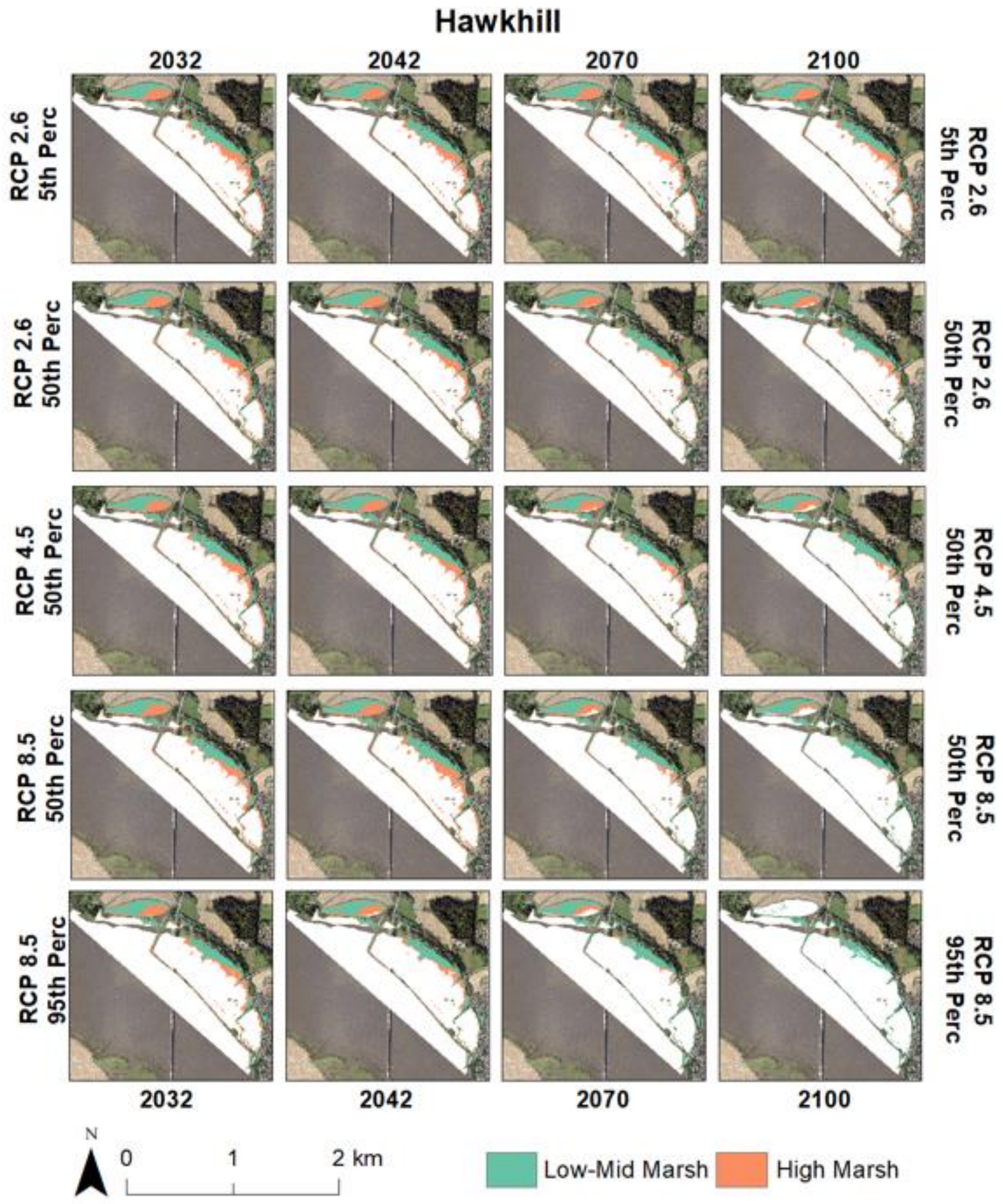

Figure A4.22. Saltmarsh extent following a hypothetical managed realignment at Hawkhill, Scotland and including subsequent habitat loss (assuming no landward migration of the coastline nor any vertical accretion of the marsh surface as sea-level rise occurs) from a simple drowning of the saltmarsh surface. Sea-level change projections under different emissions scenarios are shown for the 50th and 95th percentiles for RCP 2.6 (low emissions), RCP 4.5 (medium emissions) and RCP 8.5 (high emissions) for 2032, 2045, 2070 and 2100.

11.12 Skinflats

The site at Skinflats is found in the upper reaches of the Firth of Forth (Fig. A4.23). The site is currently occupied by arable agriculture and is free from infrastructure. Review of historic maps suggest this site was reclaimed prior to 1846.

Figure A4.23. Spatial model for Skinflats (**A**) the extent of present saltmarsh at Skinflats (Haynes. 2016) - inset map of Scotland shows site location; (**B**) the potential extent of saltmarsh created by managed realignment at this site. High Marsh (green); Low-Mid Marsh (orange).

Realignment of the site could potentially create **0.44 km^2** of saltmarsh comprised of **0.22 km^2** of low-mid marsh and **0.22 km^2** of high marsh. Aerial photography and current mapping (Fig. A4.23) confirms the presence of saltmarsh increasing the likelihood of successful saltmarsh establishment at the site after realignment activities. These factors have resulted is the site being categorised as **highly suitable** for realignment.

If saltmarsh was successfully established at the site and reached a point where its carbon burial and storage capacity mirrored natural sites the surficial (top 10cm) soils in the low-mid marsh could potential hold **1,281 ± 930 tonnes OC**, while the high marsh could hold **1,495 ± 1,079 tonnes OC**. In total the surficial saltmarsh soil (top 10cm) stock at this site **2,776 ± 1,421 tonnes OC** which would represent a **0.75%** increase in Scotland's current saltmarsh surficial soil OC stock (Austin *et al*., 2021).

Under future median (50th Percentile) predications of relative sea level rise the extent of the realigned saltmarsh area will reduce by between **6.73 – 8.10% by 2032**, **9.41 – 10.74% by 2045**, **14.13 – 24.71% by 2070** and **18.92 – 39.35% by 2100**. Under the worst (RCP 8.5 95th percentile) future relative sea level predications the realigned marsh will be reduced in size by **60.81%** by 2100 (Fig. A4.24) reducing the surficial soil organic carbon stock to **1088 tonnes.**

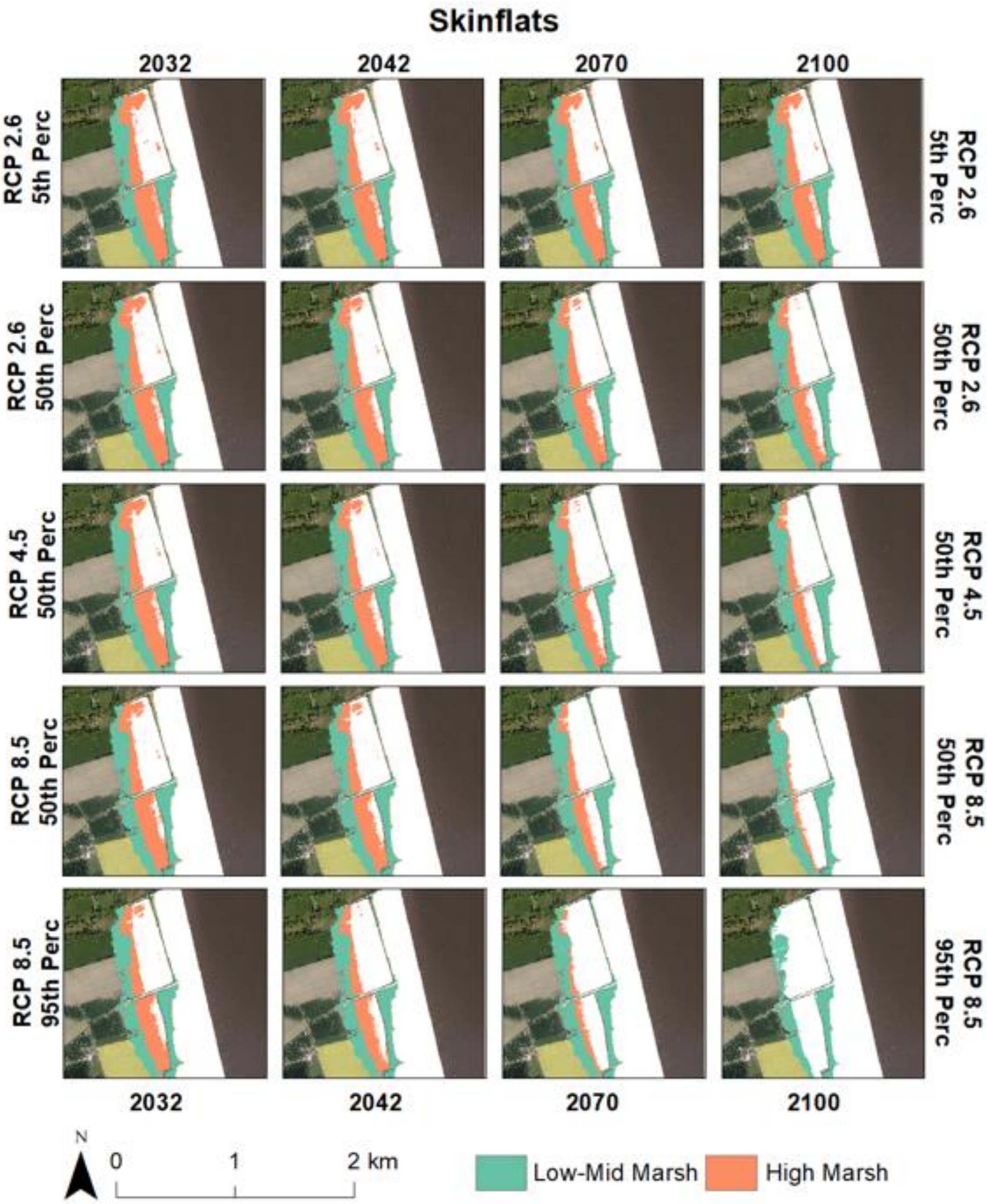

Figure A4.24. Saltmarsh extent following a hypothetical managed realignment at Skinflats, Scotland and including subsequent habitat loss (assuming no landward migration of the coastline nor any vertical accretion of the marsh surface as sea-level rise occurs) from a simple drowning of the saltmarsh surface. Sea-level change projections under different emissions scenarios are shown for the 50th and 95th percentiles for RCP 2.6 (low emissions), RCP 4.5 (medium emissions) and RCP 8.5 (high emissions) for 2032, 2045, 2070 and 2100.

11.13 Dunmore

The site at Dunmore is found in the upper reaches of the Firth of Forth (Fig. A4.25). The site is currently occupied by arable agriculture and is free from infrastructure but does back onto the town of Airth. It is envisage that the realignment project could proceed while maintaining the protection afford to the town. Review of historic maps suggest this site was reclaimed prior to 1856.

Figure A4.25. Spatial model for Dunmore (**A**) the extent of present saltmarsh at Dunmore (Haynes. 2016) - inset map of Scotland shows site location; (**B**) the potential extent of saltmarsh created by managed realignment at this site. High Marsh (green); Low-Mid Marsh (orange).

Realignment of the site could potentially create **0.73 km^2** of saltmarsh comprised of **0.47 km^2** of low-mid marsh and **0.26 km^2** of high marsh. Aerial photography and current mapping (Fig. A4.25) confirms the presence of saltmarsh increasing the likelihood of successful saltmarsh establishment at the site after realignment activities. These factors have resulted is the site being categorised as **highly suitable** for realignment.

If saltmarsh was successfully established at the site and reached a point where its carbon burial and storage capacity mirrored natural sites the surficial (top 10cm) soils in the low-mid marsh could potential hold **2,743 ± 1,991 tonnes OC**, while the high marsh could hold **1,755 ± 1,267 tonnes OC**. In total the surficial saltmarsh soil (top 10cm) stock at this site **4,498 ± 2,355 tonnes OC** which would represent a **1.22%** increase in Scotland's current saltmarsh surficial soil OC stock (Austin *et al*., 2021).

Under future median (50th Percentile) predications of relative sea level rise the extent of the realigned saltmarsh area will reduce by between **9.40 – 11.41% by 2032**, **13.27 – 17.30% by 2045**, **19.01 – 30.09% by 2070** and **24.33 – 50.32% by 2100**. Under the worst (RCP 8.5 95th percentile) future relative sea level predications the realigned marsh will be reduced in size by **77.26%** by 2100 (Fig. A4.26) reducing the surficial soil organic carbon stock to **1023 tonnes.**

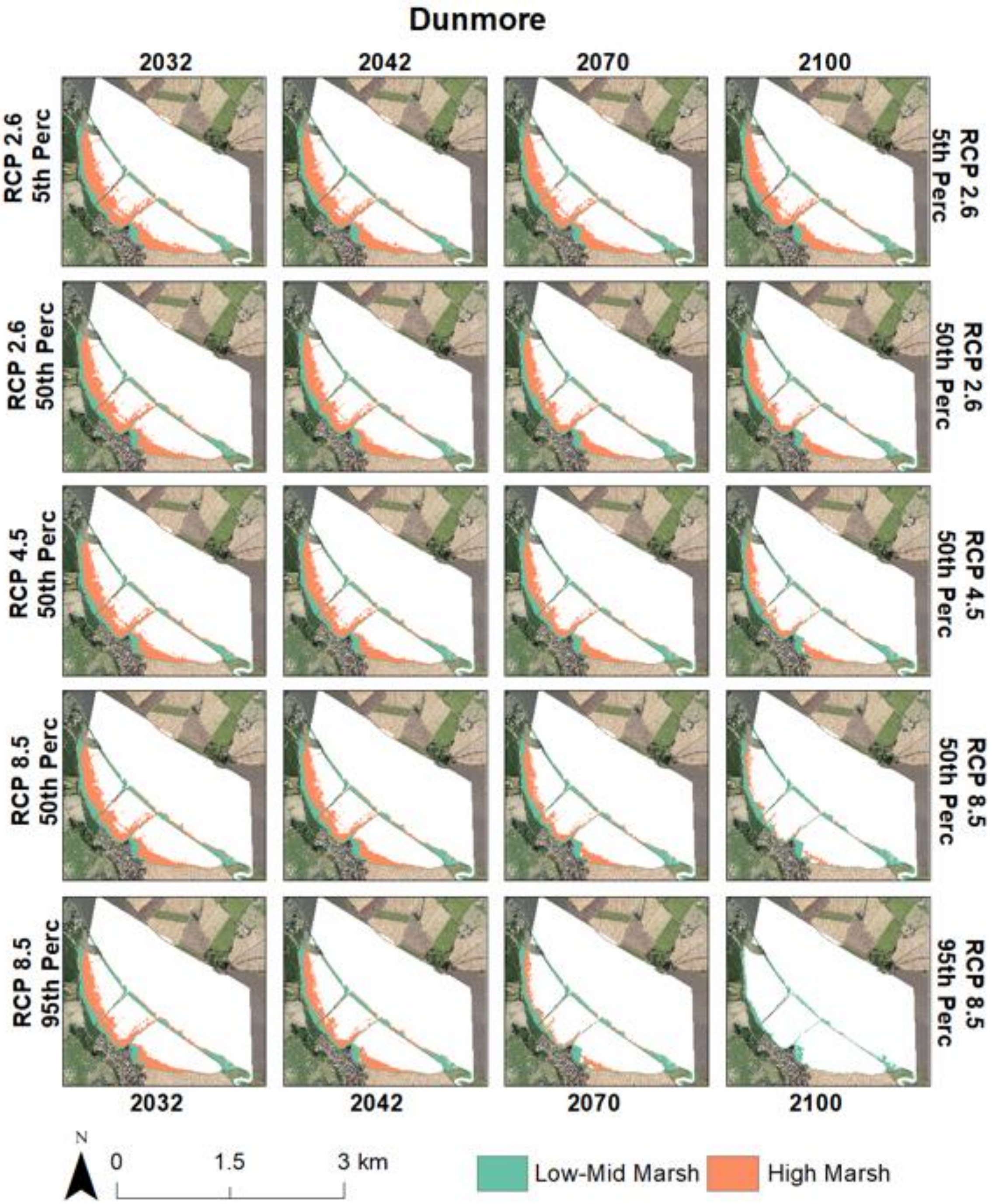

Figure A4.26. Saltmarsh extent following a hypothetical managed realignment at Dunmore, Scotland and including subsequent habitat loss (assuming no landward migration of the coastline nor any vertical accretion of the marsh surface as sea-level rise occurs) from a simple drowning of the saltmarsh surface. Sea-level change projections under different emissions scenarios are shown for the 50th and 95th percentiles for RCP 2.6 (low emissions), RCP 4.5 (medium emissions) and RCP 8.5 (high emissions) for 2032, 2045, 2070 and 2100

11.14 Inch of Ferryton

The site at Inch of Ferryton is found in the upper reaches of the Firth of Forth (Fig. A4.27). The site is currently occupied by arable agriculture and is free from infrastructure. Review of historic maps suggest this site was reclaimed prior to 1856.

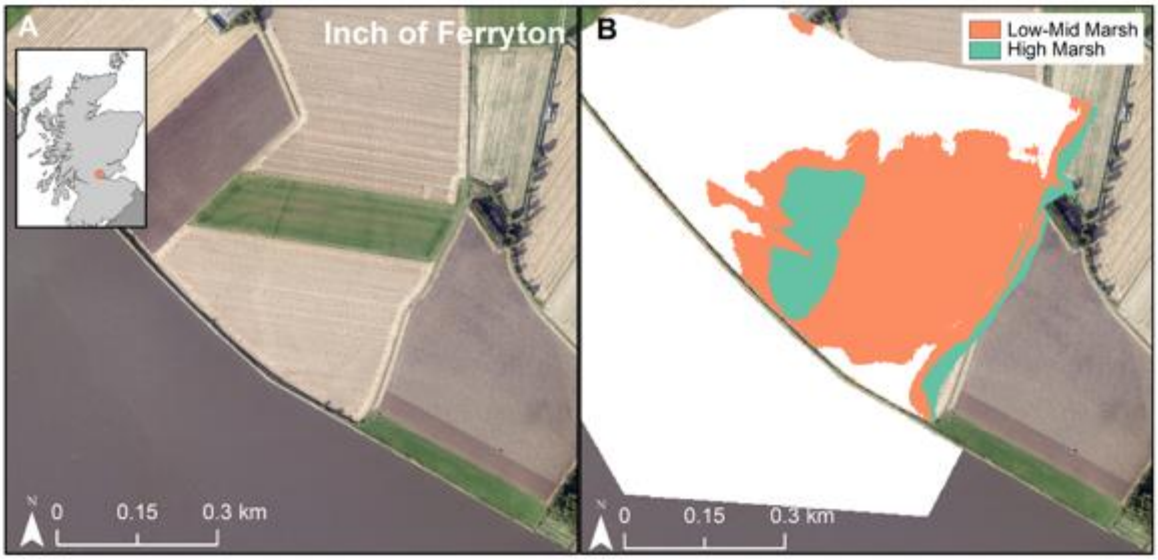

Figure A4.27. Spatial model for Inch of Ferryton (**A**) the extent of present saltmarsh at Inch of Ferryton (Haynes. 2016) - inset map of Scotland shows site location; (**B**) the potential extent of saltmarsh created by managed realignment at this site. High Marsh (green); Low-Mid Marsh (orange).

Realignment of the site could potentially create **0.22 km^2** of saltmarsh comprised of **0.17 km^2** of low-mid marsh and **0.05 km^2** of high marsh. Aerial photography (Fig. A4.27) confirms the presence of saltmarsh (<0.03 km2, and therefore not mapped as part of current mapping efforts (Haynes, 2016)) increasing the likelihood of successful saltmarsh establishment at the site after realignment activities. These factors have resulted is the site being categorised as **highly suitable** for realignment.

If saltmarsh was successfully established at the site and reached a point where its carbon burial and storage capacity mirrored natural sites the surficial (top 10cm) soils in the low-mid marsh could potential hold **990 ± 719 tonnes OC**, while the high marsh could hold **321 ± 232 tonnes OC**. In total the surficial saltmarsh soil (top 10cm) stock at this site **1,311 ± 754 tonnes OC** which would represent a **0.36%** increase in Scotland's current saltmarsh surficial soil OC stock (Austin *et al*., 2021).

Under future median (50th Percentile) predications of relative sea level rise the extent of the realigned saltmarsh area will reduce by between **4.41 – 5.81% by 2032**, **7.20 – 11.12% by 2045**, **13.03 – 26.18% by 2070** and **18.87 – 65.11% by 2100**. Under the worst (RCP 8.5 95th percentile) future relative sea level predications the realigned marsh will be reduced in size by **85.31%** by 2100 (Fig. A4.28) reducing the surficial soil organic carbon stock to **192.6 tonnes.**

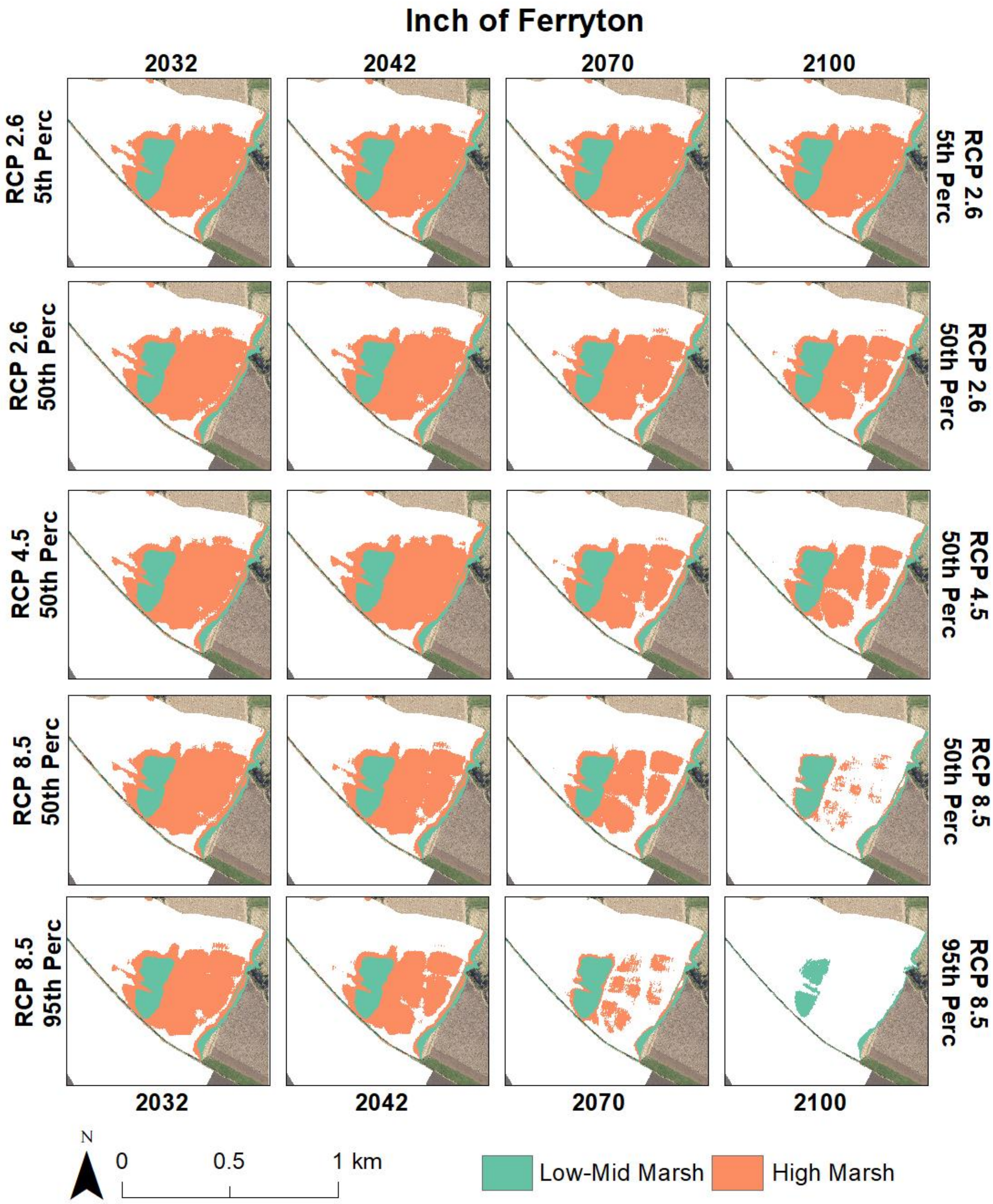

Figure A4.28. Saltmarsh extent following a hypothetical managed realignment at Inch of Ferryton, Scotland and including subsequent habitat loss (assuming no landward migration of the coastline nor any vertical accretion of the marsh surface as sea-level rise occurs) from a simple drowning of the saltmarsh surface. Sea-level change projections under different emissions scenarios are shown for the 50th and 95th percentiles for RCP 2.6 (low emissions), RCP 4.5 (medium emissions) and RCP 8.5 (high emissions) for 2032, 2045, 2070 and 2100.

11.15 Tyninghame

The site at Tyninghame is found in the outer reach of the estuary (Fig. A4.29). The site is currently occupied by arable agriculture and is free from infrastructure. Review of historic maps suggest this site was reclaimed prior to 1894.

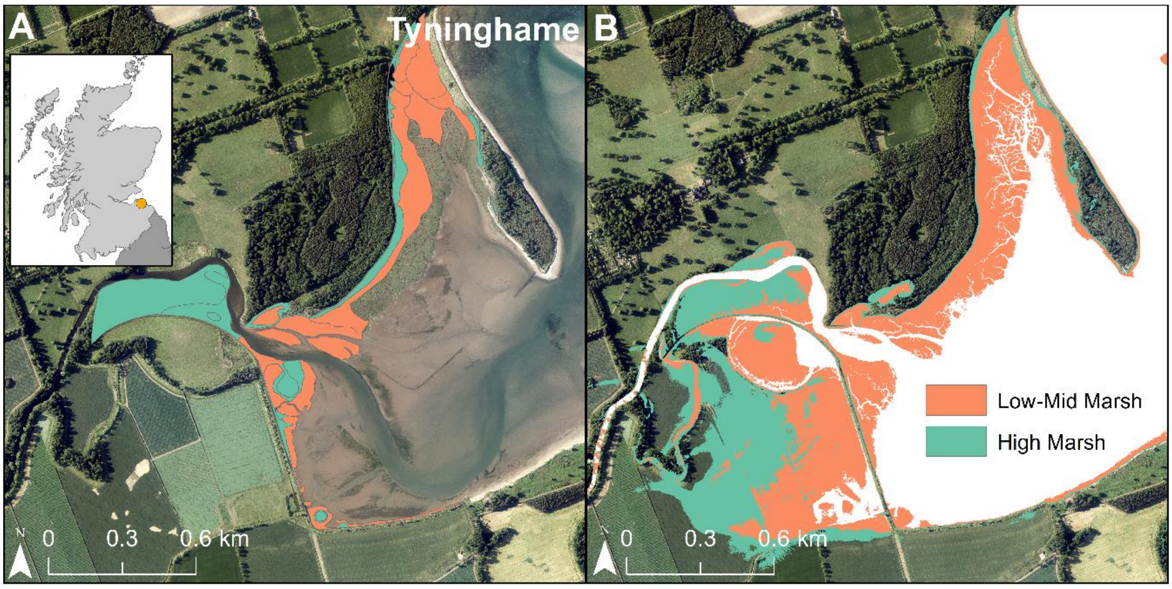

Figure A4.29. Spatial model for Tyninghame (**A**) the extent of present saltmarsh at Tyninghame (Haynes. 2016) - inset map of Scotland shows site location; (**B**) the potential extent of saltmarsh created by managed realignment at this site. High Marsh (green); Low-Mid Marsh (orange).

Realignment of the site could potentially create **1.13 km^2** of saltmarsh comprised of **0.69 km^2** of low-mid marsh and **0.44 km^2** of high marsh. Aerial photography and current mapping (Fig. A4.29) confirms the presence of saltmarsh increasing the likelihood of successful saltmarsh establishment at the site after realignment activities. These factors have resulted is the site being categorised as **highly suitable** for realignment.

If saltmarsh was successfully established at the site and reached a point where its carbon burial and storage capacity mirrored natural sites the surficial (top 10cm) soils in the low-mid marsh could potential hold **4,018 ± 2,917 tonnes OC**, while the high marsh could hold **2,984 ± 2,152 tonnes OC**. In total the surficial saltmarsh soil (top 10cm) stock at this site **7,002 ± 3,618 tonnes OC** which would represent a **1.90%** increase in Scotland's current saltmarsh surficial soil OC stock (Austin *et al*., 2021).

Under future median (50th Percentile) predications of relative sea level rise the extent of the realigned saltmarsh area will reduce by between **4.30 – 5.82% by 2032**, **7.45 – 11.07% by 2045**, **14.05 – 26.12% by 2070** and **21.42 – 43.34% by 2100**. Under the worst (RCP 8.5 95th percentile) future relative sea level predications the realigned marsh will be reduced in size by **72.63%** by 2100 (Fig. A4.30) reducing the surficial soil organic carbon stock to **1,916 tonnes.**

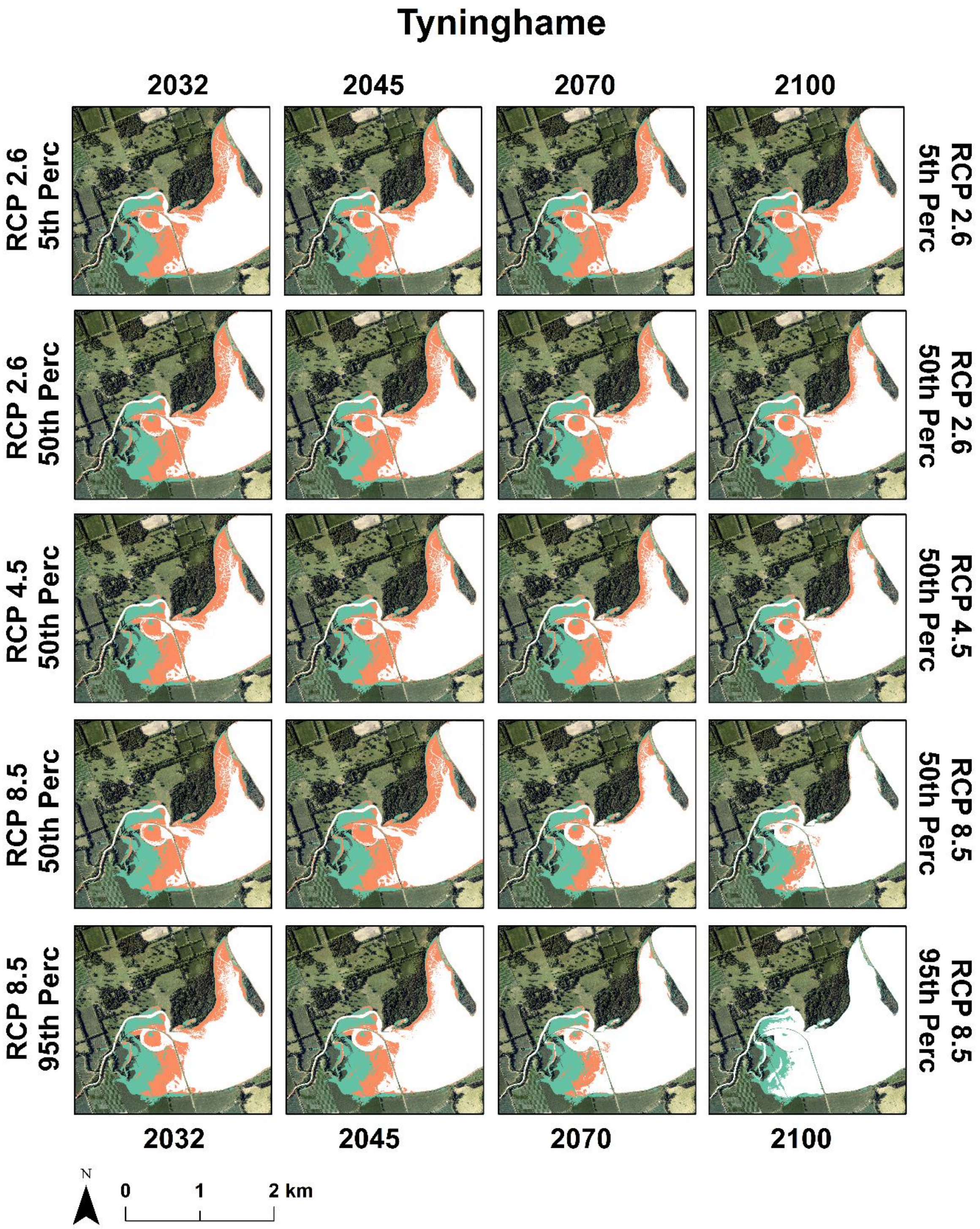

Figure A4.30. Saltmarsh extent following a hypothetical managed realignment 1Scotland and including subsequent habitat loss (assuming no landward migration of the coastline nor any vertical accretion of the marsh surface as sea-level rise occurs) from a simple drowning of the saltmarsh surface. Sea-level change projections under different emissions scenarios are shown for the 50th and 95th percentiles for RCP 2.6 (low emissions), RCP 4.5 (medium emissions) and RCP 8.5 (high emissions) for 2032, 2045, 2070 and 2100.

climateXchange
Scotland's centre of expertise connecting
climate change research and policy

info@climatexchange.org.uk
+44(0)131 651 4783
@climatexchange_
www.climatexchange.org.uk

ClimateXChange, Edinburgh Climate Change Institute, High School Yard, Edinburgh EH1 1LZ