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W Austin[1,2], C Smeaton[1], S Riegel[1], P Ruranska[1] and L Miller[1]

[1]School of Geography and Sustainable Development, University of St Andrews, St Andrews, United Kingdom

[2]Scottish Association for Marine Science, Scottish Marine Institute, Oban, United Kingdom

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Keywords

Blue carbon; saltmarsh; coastal; intertidal; organic carbon; storage; soil; Scotland

Executive summary

Coastal saltmarsh occupies the interface between land and sea and is one of the most common soft-sediment habitats of Scottish coastlines. Saltmarsh comprises a highly adapted and unique species assemblage protected by national and international regulation. Coastal saltmarsh is included in the EU Habitats Directive (EU, 1992) of which four Annex 1 habitats are recognized (*Salicornia* and other annuals; *Spartina* swards; Atlantic Salt Meadows; Mediterranean and thermo-Atlantic halophilous scrubs)). The majority of saltmarsh is also designated under the Site of Special Scientific Interest (SSSI) framework (Rees et al. 2019) which gives protection under law from development and other damage.

Given the high-level protection saltmarshes are afforded, there have been considerable efforts to restore and create new habitat to make up for historic and on-going losses through land reclamation or a changing climate. Such initiatives increasingly recognize that carbon-rich sediments are trapped and buried in the process of saltmarsh restoration and creation. Saltmarsh therefore constitutes a high priority Blue Carbon habitat, with scope for climate mitigation tied to its protection, restoration and even the creation of new habitat.

Greenhouse gas (GHG) emissions and removals resulting from changes in saltmarsh management (such as habitat restoration) can be included in national emission accounting under the Land Use, Land Use Change and Forestry (LULUCF) sector. However, they are not included in the UK or Scottish GHG inventories (GHGI) at this time, neither are they specifically identified in the UK Nationally Determined Contributions (NDC).

However, 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 saltmarsh management activities in the UK GHGI is 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 as well as for climate change adaptation and resilience by increasing biodiversity and coastal protection. The UK has set a precedent for their inclusion by electing to report emissions from peatlands in its national inventory for the second commitment period of the Kyoto Protocol, and by 2022 at the latest, under the obligations of the UN Framework Convention on Climate Change (UNFCCC). By implementing restoration of saltmarsh (mostly via managed realignment) as a nature-based solution to capture

carbon and therefore remove GHG from the atmosphere, saltmarsh can contribute to the UK government's commitment (by law under the UK's Climate Change Act) to reduce GHG emissions and achieve net zero by 2050, and the Scottish Government's commitment to reach net zero by 2045.

In this study, we provide an estimate of the quantity of organic carbon (OC) held within the surficial soils (top 10 cm and 15 cm) of Scotland's extensive saltmarsh habitats. This work builds upon the Scottish Saltmarsh Survey (Haynes, 2016) by integrating the mapped extent of saltmarsh vegetation types with field-derived measurements of soil dry bulk density and OC obtained from a diverse range of saltmarsh soils across Scotland (Ruranska *et al*., 2020). This approach has enabled a new surficial OC stock estimation to be made for the soils within Scotland's saltmarshes, the first such national assessment of its kind.

Key findings

1. Scottish saltmarsh soils (top 10cm) hold 367,888 ± 102,278 tonnes of OC.

2. The average OC density found in Scottish saltmarsh soils (top 10 cm) is 6.0 ± 1.8 kg m^{-2} and is higher than most other terrestrial land covers to the equivalent depth of sampling within Scotland; the upper marsh zone holds the greatest OC density.

3. Scotland's 10 largest saltmarshes hold >50 % of the total Scottish surficial saltmarsh soil OC stock.

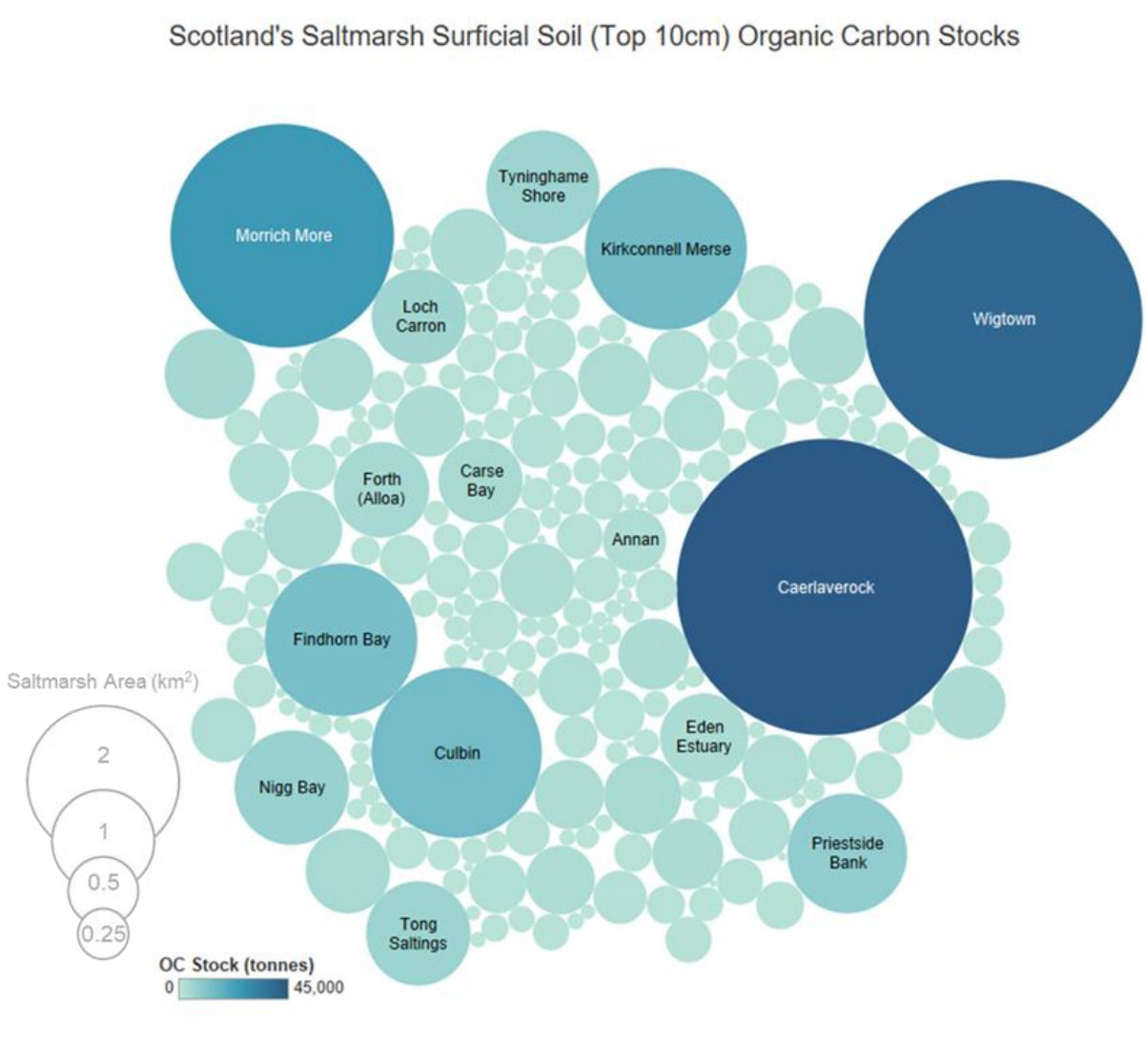
4. Scotland's large estuarine saltmarshes hold the greatest quantity of OC within their soils (41.8% of the total Scottish surficial saltmarsh soil OC stock).

5. The saltmarshes of Dumfries and Galloway hold the largest quantity of OC of any of Scotland's local authorities (41.2% of total Scottish surficial saltmarsh soil OC stock).

GIS layers

Alongside this report, a new GIS project with layers mapping the surficial (top 10 cm and 15 cm) soil organic carbon density (kg m^{-2}) across Scotland have been produced. These new layers are built upon the digital outputs from the Scottish

Saltmarsh Survey (Haynes, 2016). The data layers can be found at: https://doi.org/10.7489/12389-1



Summary Figure: Scotland's saltmarsh surficial soil (top 10 cm) organic carbon stocks. Circle size represents area (km^2) and colour indicates organic carbon stock (tonnes).

1. Introduction

Blue Carbon habitats (Nellemann and Corcoran, 2009) such as saltmarsh, seagrass and mangroves are recognised as important sites for the burial and storage of carbon (C) (Duarte *et al*., 2005). Occupying only 2% of the ocean surface area , these coastal vegetated habitats) are estimated to contribute 50% of global organic carbon (OC) burial in marine sediments (Duarte *et al*., 2013). Outside the tropics, saltmarsh is the most widespread of the intertidal habitats (Mcleod *et al*., 2011) therefore potentially providing a globally significant climate regulation service through the burial and long-term storage of C within their soil (Duarte *et al*., 2013).

Intertidal saltmarsh habitats bury OC at a greater rate and store more C per unit area than some of their subtidal and terrestrial counterparts (Mcleod *et al*., 2011). The enhanced storage capabilities of saltmarshes are linked to:

(i) High primary productivity on the marsh surface.
(ii) Depositional environments that trap C from both autochthonous (e.g. plant material) and allochthonous (terrestrial and/or marine) material; and
(iii) Organic matter (OM) preservation conditions, such as low oxygen and high sulphur concentrations in the sediments, which promote the preservation of OM.

Saltmarshes are under threat; an estimated 25 % of global saltmarsh habitat has been lost since the 1800's (Mcleod *et al*., 2011), with assessments predicting that a further 50% of the world's saltmarshes may permanently disappear by the end of this century from erosion and coastal squeeze (Kirwan *et al*., 2016; Spencer *et al*., 2016). The quantity of the saltmarsh OC stocks lost due to this widespread habitat disturbance is unknown but global C burial and storage capacity has undoubtedly been diminished with the loss of saltmarsh habitat.

The first step to protecting and managing these important C resources is understanding the current quantity of OC held within saltmarshes. Blue carbon stock estimates at regional and national scales are becoming more common in the southern hemisphere and in the tropics (Kelleway *et al*., 2017; Thorhaug *et al*., 2019). Yet within NW Europe, such OC stock estimates either don't exist or are built upon minimal data (Legge et al., 2020; Luisetti et al., 2019). Currently, the only available soil OC stock estimate for Scottish saltmarshes is 552,900 tonnes of OC (Beaumont et al., 2014). This estimate is based on a relatively small quantity of data which also highlights the difficulty of upscaling data from single or small numbers of marshes to achieve a national OC inventory.

Recently, it has become clear that vegetation type and diversity is a primary driver of OC accumulation in saltmarsh soils *(Burden et al., 2019; Chen et al., 2018; Ford et al*., 2019). This relationship has been used to estimate saltmarsh soil OC stocks in selected saltmarshes across Wales (Ford *et al*., 2019). Here, using nationwide saltmarsh vegetation mapping (Haynes, 2016) and extensive saltmarsh soil property data (Ruranska *et al*., 2020) we seek to develop and exploit the relationship between vegetation and soil OC content to estimate the OC stock of surficial soils within Scotland's saltmarsh.

2. Scottish saltmarsh

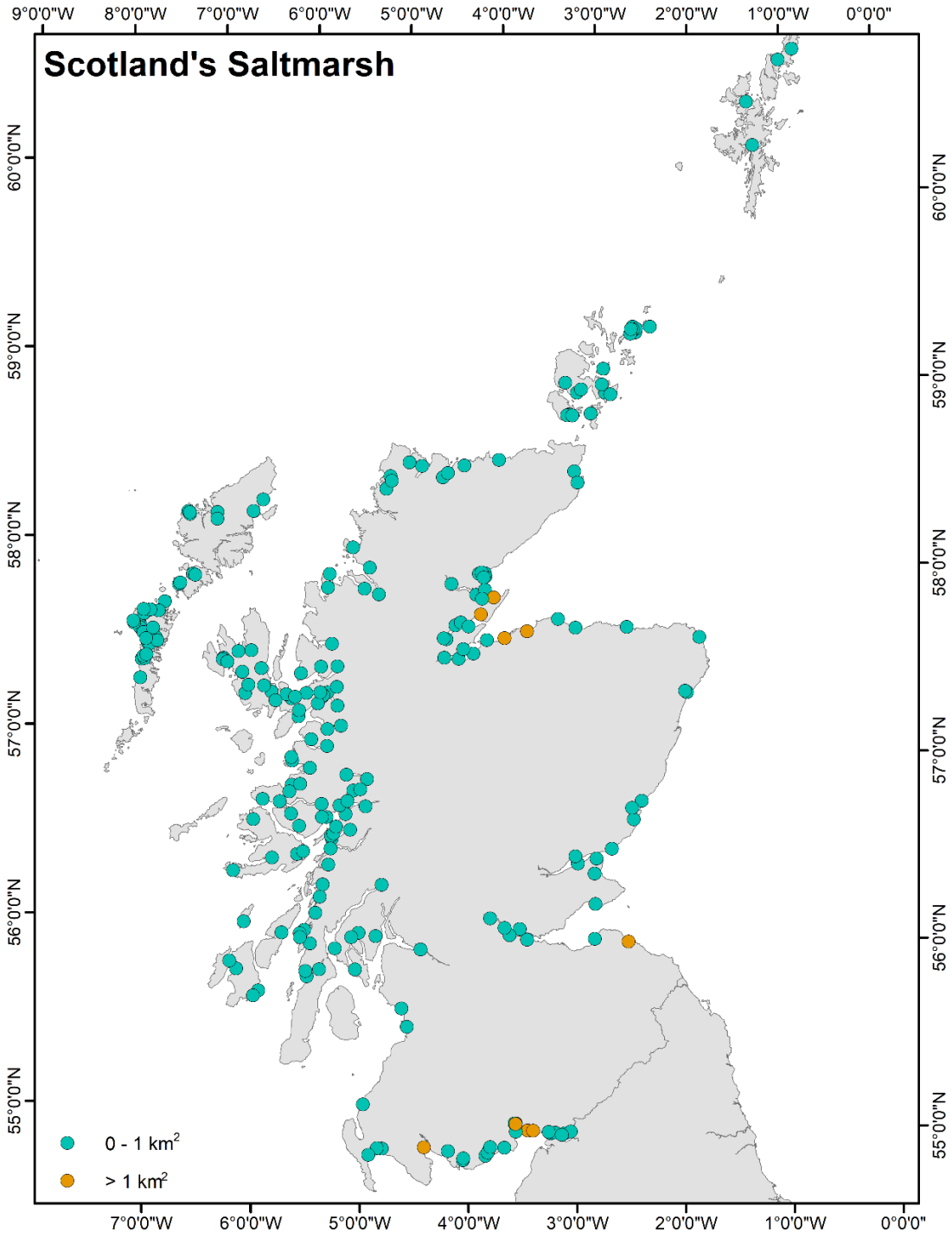


Figure 1: Location of Saltmarshes across Scotland, saltmarsh areas >1 km^2 are highlighted in orange. Derived from Haynes (2016).

Scotland's mapped saltmarshes are estimated to cover an area of 58.4 km^2 (Figure 1) which represents ~13% of all saltmarsh in the United Kingdom (Haynes, 2016). The geomorphology of the Scottish coastline results in a high number (240 surveyed) of small (mean size: 0.25 km^2) saltmarshes; only nine Scottish

saltmarshes extend beyond 1 km^2 in size (Figure1). Scottish saltmarshes can be classified into six types: estuarine, embayment, back-barrier, fringing, loch-head and perched (Fig.2), as defined by Haynes (2016).

Estuarine saltmarshes: are found in the wide mouths of estuaries, normally behind a sheltered headland. The movement of sediment and regular influxes of saline water allow expansive saltmarshes to form in these settings. The largest saltmarshes in Scotland are all estuarine in nature. **(19 saltmarshes; 24.62 km^2; 41.70% of Scottish saltmarsh areal coverage)**

Embayment saltmarshes: are saltmarshes developing in a bay where surrounding geomorphology protects the saltmarsh from wave action. This is the most common type of saltmarsh in Scotland. Embayment marshes are often crescent-shaped formations and often include a full range of saltmarsh zones. Embayment marshes are similar to estuarine saltmarshes but embayment saltmarshes are generally smaller. **(133 saltmarshes; 17.41 km^2; 29.49% of Scottish saltmarsh areal coverage)**

Back-barrier saltmarshes: form in the shelter of sand dune and shingle structures, which shelter the marsh from direct wave action. They are also found behind shingle spits and bars on the west coast. **(8 saltmarshes; 6.96 km^2; 11.79% of Scottish saltmarsh areal coverage)**

Fringing saltmarshes: can be found in most regions of Scotland and are often associated with rivers and channels. They are often narrow in width with larger areas developing in kinks or bays. Fringing marsh is often found where estuarine systems narrow into river valleys. **(16 saltmarshes; 2.79 km2; 4.73% of Scottish saltmarsh areal coverage)**

Loch-head saltmarshes: are the main type found on the west and north coasts of Scotland. These are similar to embayment marshes but are found at the landward terminus of sea lochs and other sheltered areas. **(61 saltmarshes; 7.05 km^2; 11.94% of Scottish saltmarsh areal coverage)**

Perched saltmarshes: are a rare habitat type in Scotland and across the UK. Perched saltmarshes form on sea cliffs and in the shelter of raised rocky outcrops, where shallow sediments tend to develop in the wave splash-zone. **(6 saltmarshes; 0.21 km^2; 0.36% of Scottish saltmarsh areal coverage)**

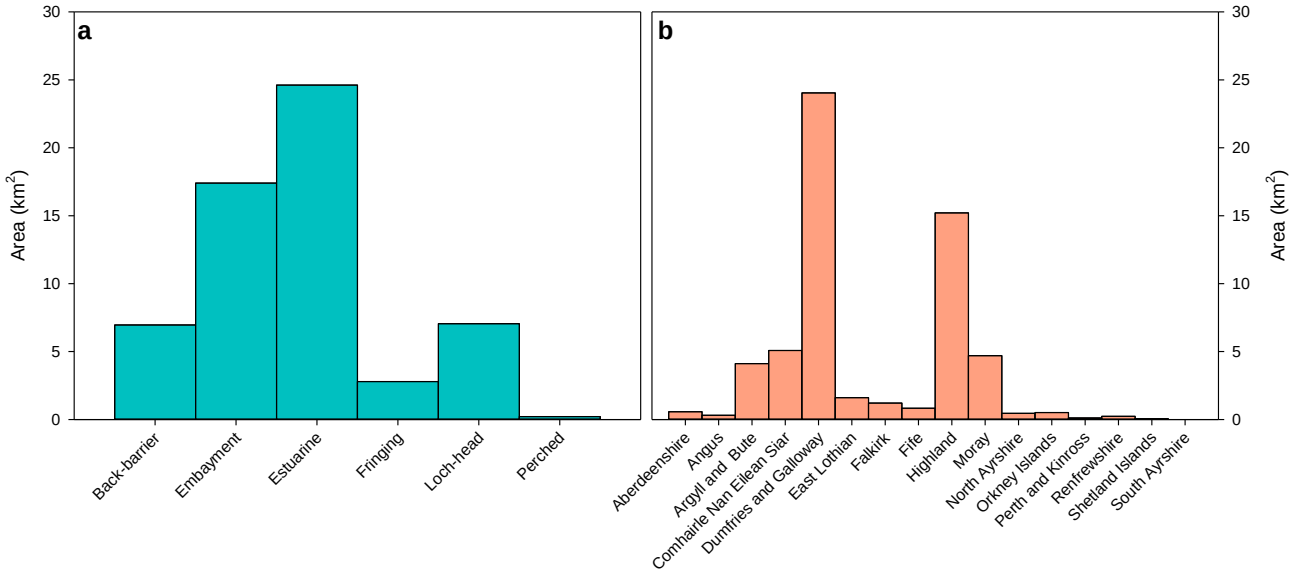


Figure 2: (**a**) Areal extent (km^2) of Scottish saltmarsh, classified by saltmarsh type (types are defined according to Haynes, 2016). (**b**) The areal extent (km^2) of saltmarsh within each of Scotland's local authority regions.

2.1 Saltmarsh vegetation

Saltmarshes can be divided into four zones (pioneer, low, middle and high marsh) which are generally defined by tidal level and inundation (Figure 3).

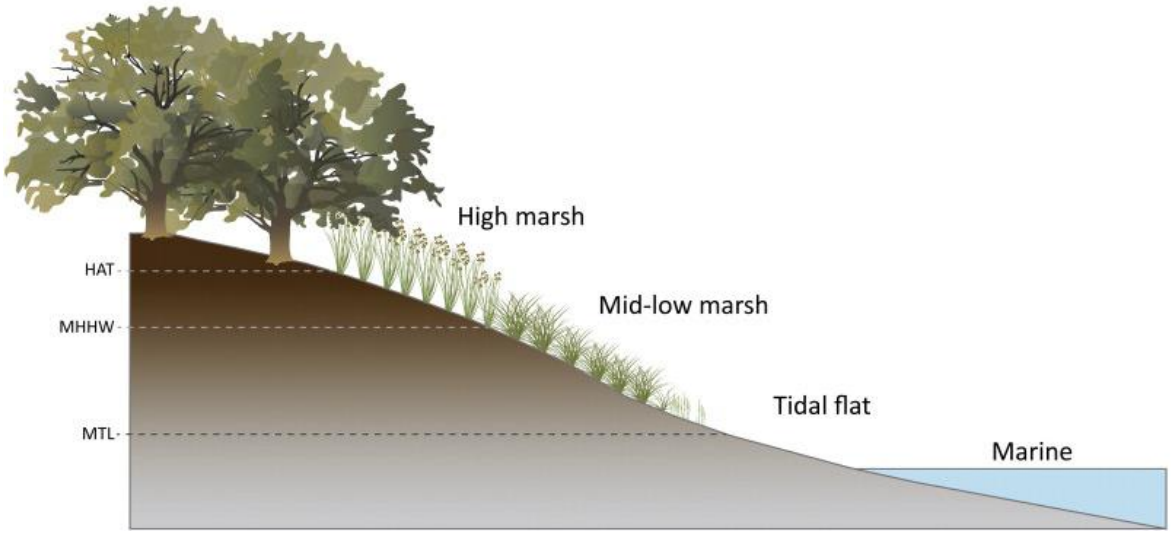


Figure 3: Conceptual model of saltmarsh zonation in relation to tidal inundation. (Adapted from Barlow *et al*. (2013)).

Pioneer marsh: can be found at the marine bordering edge to the main saltmarsh surface and in isolated patches on adjacent tidal flats. **(0.08 km^2; 0.13% of Scottish saltmarsh areal coverage)**

Lower marsh: is a zone often found as a very narrow border at the seaward edge of the main saltmarsh surface, which is often eroded and fragmented. Lower marsh vegetation is denser than pioneer marsh and is normally dominated by *Puccinellia maritima* vegetation. **(4.83 km^2; 8.23% of Scottish saltmarsh areal coverage)**

Middle marsh: is not always present on Scottish saltmarshes; this zone was missing on many of the marshes surveyed by Haynes (2016). The common identifying feature of the middle marsh is often the presence of pans (small pools) across a relatively flat area of saltmarsh. **(16.96 km^2; 28.90% of Scottish saltmarsh areal coverage)**

Upper marsh: covers the largest area of saltmarsh in Scotland. These areas grade into transitional communities such as coastal grassland, swamp, mire and sometimes heath and are generally dominated by *Festuca rubra* vegetation. **(36.81 km^2; 62.74% of Scottish saltmarsh areal coverage)**

The main identifying feature of these saltmarsh zones is their vegetation type and coverage (Burd, 1989). Saltmarsh vegetation in the UK can be classified according to the National Vegetation Classification (NVC) scheme (Rodwell *et al*., 2000). All saltmarsh vegetation classes are found within the Scottish systems (Fig.4) but generally the marshes are dominated by NVC 13 (*Puccinellia maritima*) and NVC 16 (*Festuca rubra*); these NVC types represent 28.60 % and 55.56 % of the mapped saltmarsh vegetation coverage of Scotland (Figure3).

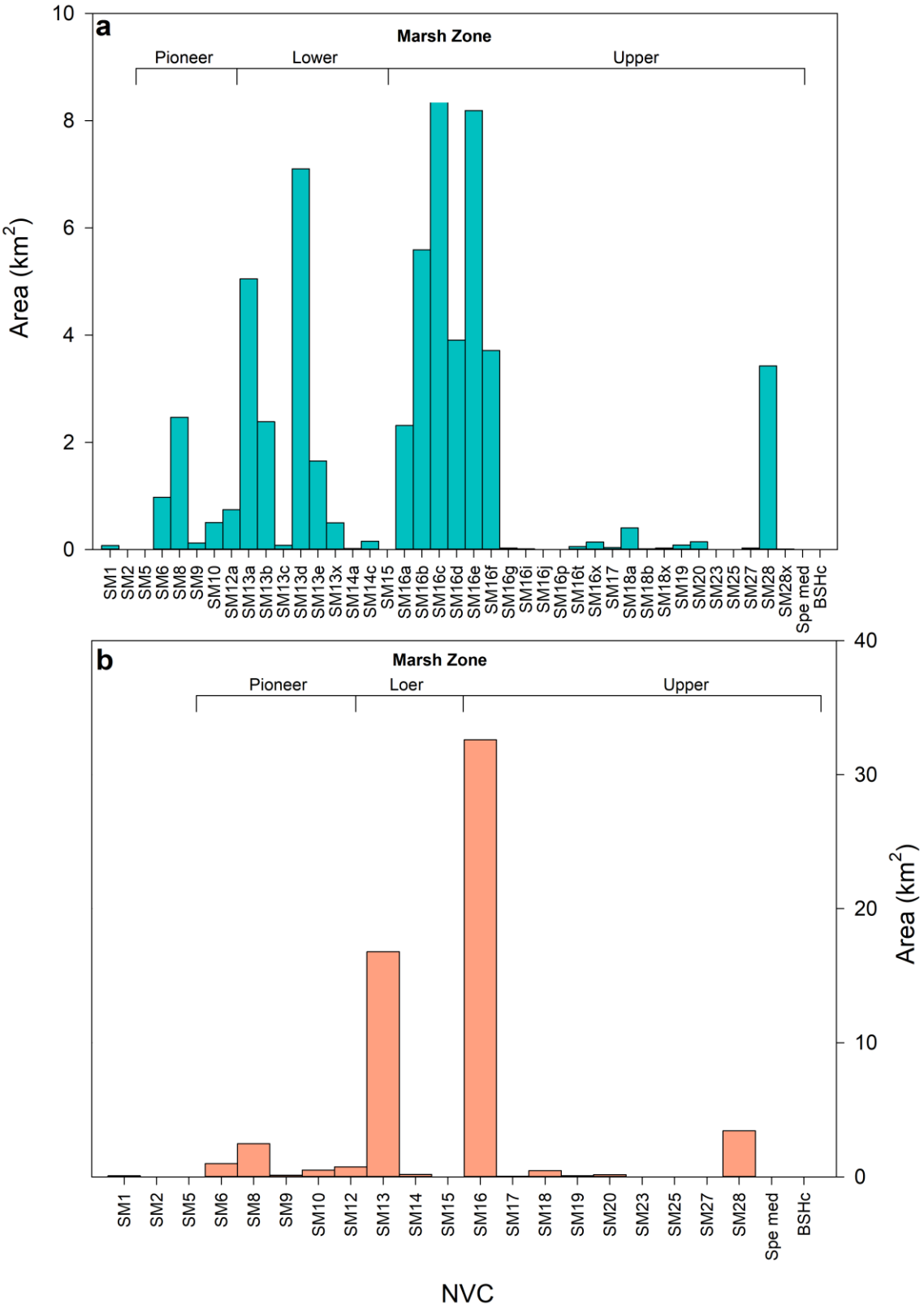


Figure 4: Areal extent (km²) of mapped saltmarsh in Scotland, categorised using the (**a**) National Vegetation Classification (NVC) scheme; and (**b**) Simplified NVC scheme. Detail of the NVC scheme can be found in Supplementary Table 1.

3. Methodology

3.1 Saltmarsh areal coverage

The Scottish saltmarsh survey (SSS) was a national survey which was completed in 2016 and details the areal extent of NVC classes across all saltmarshes greater than >0.03 km^2 in area (Haynes, 2016) (Figure 5).

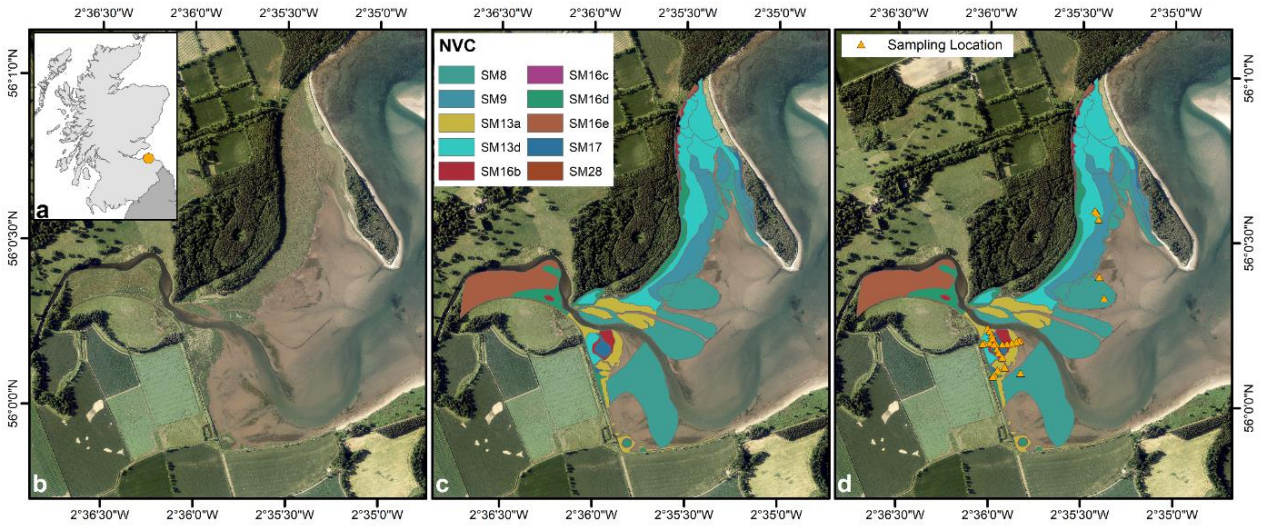


Figure 5: Example of data and mapping products used within this assessment of Scottish saltmarshes (Tyninghame Shore marsh, Dunbar). (**a**) Aerial photograph (*Digimap*). (**b**) NVC classification (Haynes, 2016). (**c**) Soil sampling locations – yellow symbols (Ruranska *et al*., 2020).

Field surveys for the SSS were undertaken between 2010-2012 by Nature Scotland (formerly known as Scottish Natural Heritage) on all saltmarshes > 0.03 km^2 in size, with an additional 10 perched and 25 small marshes (<0.003km^2) also included in the survey (Haynes, 2016). In recognition that the SSS took place some time ago, a ± 5% error has been applied to the areal extent of each NVC class and to the area of each saltmarsh as a whole, potentially accounting for possible erosion or accretion in the last decade (Ladd *et al*., 2019). By applying this error term, the uncertainties in marsh extent will be better represented in the calculations and propagated into the final soil OC stock estimates.

The perched saltmarshes are generally found on cliffs where salt spray from the ocean sustains the salt tolerant vegetation (Figure6). While saltmarsh vegetation is present, these habitats are largely devoid of any significant underlying OM-rich soil and are therefore excluded from this analysis (Haynes, 2016; Porter *et al*., 2020).

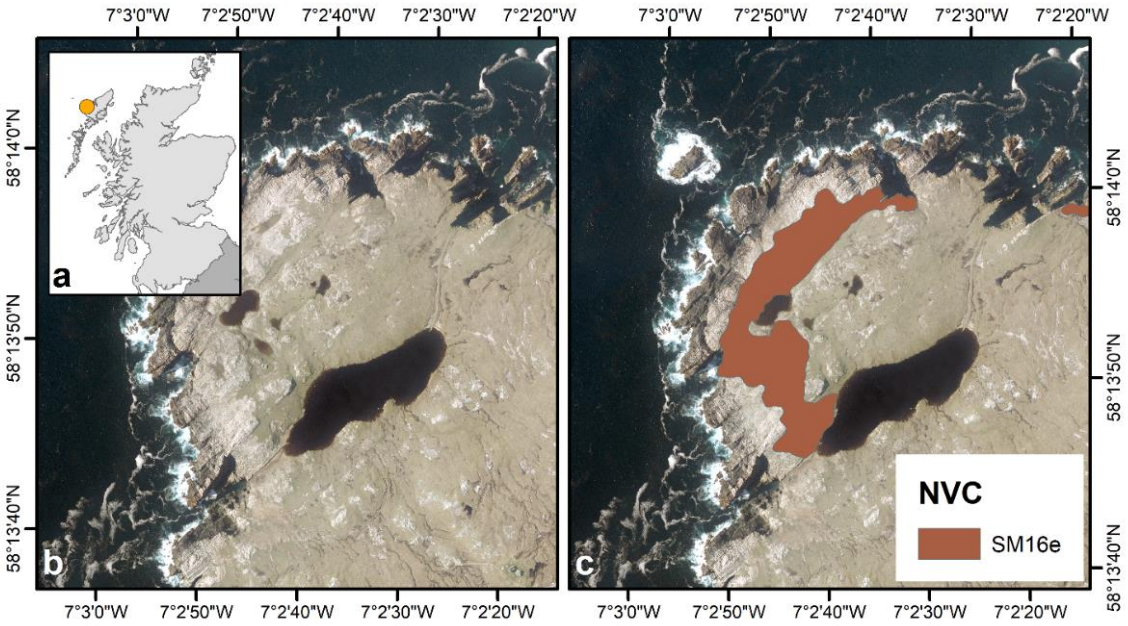


Figure 6: Example of a perched clifftop saltmarsh at Gallen Head on the Isle of Lewis.

The SSS identified 226 saltmarshes under 0.03 km^2 across Scotland (Haynes, 2016). In total, 25 of these small saltmarshes (<0.03 km^2) were surveyed; these ranged between 0.001km^2 and 0.03 km^2 in size. To best estimate the OC stored in the soil of the 201 unmapped small saltmarshes, three approaches were taken.

(1) Use of an idealised (i.e. normal) distribution across the 0 - 0.03 km^2 range.
(2) Utilise the distribution of the areal extent of the 25 surveyed small saltmarshes.
(3) Assume that all the saltmarshes were 0.03 km^2 in size.

The mean, standard deviation, min, max area values were determined from each distribution. While NVC data for the majority of these small area saltmarshes are unavailable, the approach adopted provides a range of estimates that will be useful in constraining the total soil OC stock of all Scottish saltmarshes and avoids an inevitable sampling bias towards Scotland's larger saltmarshes (>0.03 km^2).

3.2 Ground-truthing the vegetation vs soil OC relationship

To quantify the soil OC stock of Scottish saltmarshes, it was necessary to establish a new quantitative relationship between vegetation (NVC) class and the physical properties and OC content of the soil in a Scottish context; the exisiting methodological approach was developed for a relatively small number of Welsh

saltmarshes with significantly sandier soils than their Scottish counterparts (Ford *et al*., 2019).

3.2.1 Saltmarsh soil physical property and OC content data

The Carbon Storage in Intertidal Environment (C-SIDE) project has produced bulk density (g.cm^{-3}) and OC content (%) data (Ruranska *et al*., 2020) as part of the C-SIDE Citizen Science programme, where individuals and groups across the UK collected saltmarsh soil samples and returned these to a national soil archive at the University of St Andrews. The C-SIDE dataset (Ruranska *et al*., 2020) alongside other published data (Marley *et al*., 2019; Smeaton *et al*., 2021) from Scotland have been utilised to determine the relationship between NVC class and soil OC in Scottish saltmarshes.

The Citizen Science sampling programme facilitated the collection of five samples from saltmarshes across the UK using a modified 50 ml syringe, which was pushed into the saltmarsh soil, twisted and removed with a pug of soil. A full syringe represents 10 cm of soil; this soil sampling depth is comparable to many other blue carbon audits in the UK (Burrows *et al*., 2017; Porter *et al*., 2020) and by focusing on the surficial soils (i.e. top 10 cm) the chances of compaction and disturbance during the sample collection process is also reduced (Smeaton *et al*., 2020). All sampling locations were recorded using GPS.

Upon arrival at the University of St Andrews, the soil samples were dried at 60°C for 72 hours and weighed. Using the dry mass (g) and the sample volume (before drying) the dry bulk density was calculated following the approach of (Dadey *et al*. (1992)) as described below.

Dry Bulk Density (g.cm^{-3}) = *Dry Mass* (g) / *Volume before drying* (cm^3) (*Eq.1*)

The dry samples were then milled to a fine powder with 10 mg of sample being placed in silver capsules. The samples were acidified with HCl (10%) to remove carbonate ($CaCO_3$). The acidified samples were dried overnight at 50°C and sealed. The OC contents of the sealed samples were measured using an Elemental Analyser (Elementar Vario EL Cube) following the methodology of (Nieuwenhuize *et al*., 1994; Verardo *et al*., 1990).

The underpinning data are accessible from the Environmental Information Data Centre (https://eidc.ac.uk/) which details all quality control measures that were applied to the data to assure it is fit for purpose. The C-SIDE dataset consist over

471 samples from 47 saltmarshes across Scotland (Figure 5 and Supplementary Table 2).

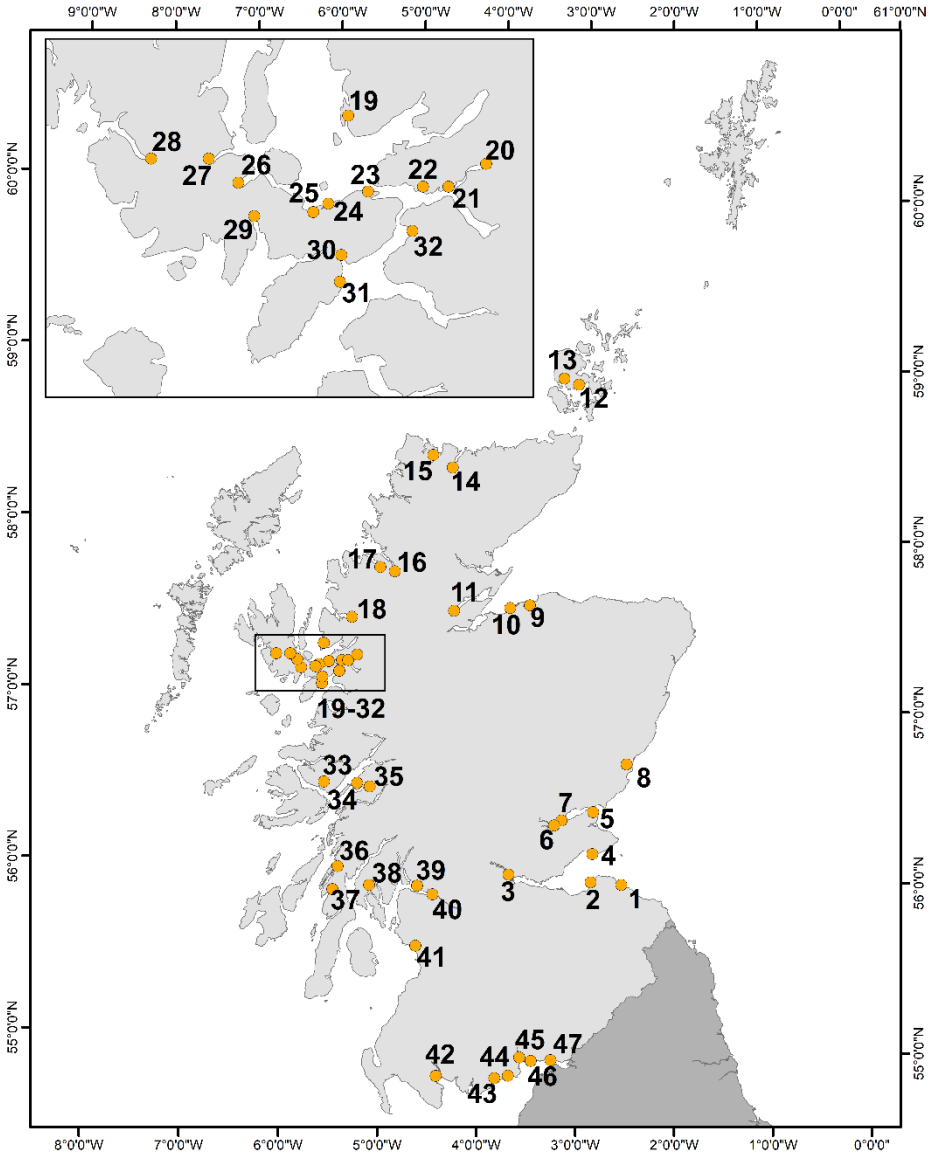


Figure 7: C-SIDE soil sampling locations across 47 Scottish saltmarshes. For the corresponding site identification information, please refer to Supplementary Table 2.

3.2.2 Vegetation classification

The identification and classification of saltmarsh vegetation is a specialist skill that the C-SIDE Citizen Science participants could not have been expected to have. Therefore, the vegetation (NVC class) at each sampling site were determined from the SSS mapping (Haynes, 2016). NVC classes were extracted from the SSS digital data at the GPS coordinate of each soil sample. It is recognised that this approach could have potentially resulted in some samples being incorrectly assigned to an

NVC class, particularly if changes in vegetation composition had occurred since the original survey was completed. While this is possible, the impact is more likely to be minor and within NVC sub-classes (e.g. NVC 16a to NVC 16b) rather than due to shifts to a different saltmarsh zone (and NVC class).

The combination of the C-SIDE data and vegetation classification (Haynes, 2006) allows the dry bulk density and OC content for each NVC class to be estimated. Mean and standard deviations were calculated for the simplified NVC classes. Additionally, mean values for bulk density and OC content were calculated for each saltmarsh zone. Where data was not available for a specific NVC class (e.g. NVC25), the mean values for the marsh zone (i.e. upper marsh in this case) were applied as a surrogate. Supplementary Table 1 details the relationship between NVC, simplified NVC and saltmarsh zone.

3.3 Quantifying saltmarsh soil OC stocks

The soil OC stocks were calculated following the standard methodology (Eq.2-5) where the NVC areal extent is combined with the NVC specific dry bulk density and OC content to determine the OC stock of the soil.

To improve the calculation and reporting of uncertainties, the OC stocks were calculated 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 (area, dry bulk density, OC content) to populate Equations (2-5). 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.

Volume (m^3) = *Area* (m^2) x *Soil Depth* (m) (*Eq.2*)
Mass (kg) = *Volume* (m^3) x *Dry Bulk Density* ($kg.m^{-3}$) (*Eq.3*)
OC Stock (kg) = *Mass* (kg) x *OC Content* (%) (*Eq.4*)
OC Density ($kg.m^{-2}$) = *OC Stock* (kg) / *Area* (m^2) (*Eq.5*)

The calculations were undertaken for both the top 10 cm and the top 15 cm of soil to allow comparisons with other terrestrial soils/land uses across Scotland (Henrys *et al*., 2012). It should be noted that the sample material from which the dry bulk density and OC data are derived only represents the top 10 cm of soil that were sampled; the 15 cm OC stocks are extrapolated to this depth. It is well-known that

OC degrades and generally decreases with soil depth (Arndt et al., 2013; Marley et al., 2019) and we note that extrapolation to 15 cm may result in an overestimation of the soil OC stocks.

The outputs from these calculations were combined with the geospatial data from the SSS to create new bespoke geospatial (GIS) layers illustrating the soil OC density across Scottish saltmarshes.

4. Results

4.1 Vegetation vs soil properties

A total of 805 data points from the top 10 cm of Scottish saltmarsh soil were made available by the C-SIDE project (Ruranska *et al*., 2020). This dataset consisted of 378 dry bulk density measurements and 427 soil OC contents (Figure 8). The mean dry bulk density value for the top 10 cm of saltmarsh soil is 0.49 ± 0.29 g.cm^{-3} with values ranging between 0.1 g.cm^{-3} in the fibrous/porous soils to 1.54 g.cm^{-3} in the much sandier systems. The mean OC content of Scottish saltmarsh soil is 13.19 ± 7.59 % with values ranging from 0.39 % in sands and 41.56% in organic-rich soils. Both the dry bulk density and organic carbon values are comparable to published data from UK saltmarshes (Beaumont *et al*., 2014; Burden *et al*., 2019, 2013; Ford *et al*., 2019; Harvey *et al*., 2019; Marley *et al*., 2019; Smeaton *et al*., 2020).

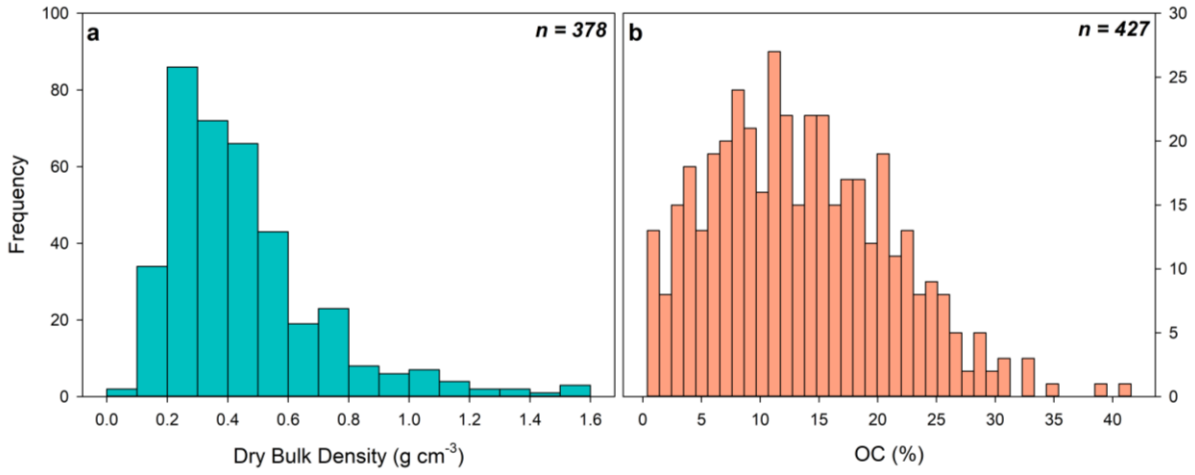


Figure 8. Assessment of soil property data (Ruranska *et al*., 2020). Frequency distributions of (**a**) dry bulk density (g.cm^{-3}); and (**b**) OC content (%).

The combination of these data points and the soil sample-specific NVC class attributed from the SSS mapping (Haynes, 2016) made it possible to calculate NVC-specific dry bulk density values and OC contents for 10 out of the 18 simplified

saltmarsh NVC classes (Table 1). A significant percentage of the dry bulk density (93%) and OC (87%) data relate to NVC classes 13 and 16. These classes are the most common in Scotland (Fig.4) and represent 84.16% of all saltmarsh vegetation; the new and well-constrained dry bulk density and OC values for these NVC classes are therefore highly advantageous for the overall Scottish saltmarsh soil OC stock calculations. For the eight NVC classes without dry bulk density nor OC data, the mean values calculated for the appropriate saltmarsh zone (e.g. pioneer, lower and upper) have been used to calculate soil OC stocks (Table 1).

Table 1

Scottish saltmarsh soil dry bulk density ($g.cm^{-3}$) and OC content (%) for the different vegetation (NVC) classes and marsh zones.

NVC	Number of Samples	Dry Bulk Density ($g\ cm^{-3}$)	Number of Samples	OC (%)
SM6	4	0.66 ± 0.33	4	6.49 ± 1.77
SM8	6	0.44 ± 0.13	6	8.80 ± 3.44
SM9	1	0.23	1	11.52
SM10	7	0.43 ± 0.30	7	10.83 ± 3.93
SM12	2	0.16 ± 0.01	2	22.74 ± 9.36
SM13	123	0.46 ± 0.30	106	11.27 ± 7.11
SM14	1	0.46	1	8.50
SM16	229	0.45 ± 0.23	267	14.60 ± 7.75
SM17	—	—	19	13.21 ± 7.92
SM28	5	0.47 ± 0.09	14	13.77 ± 1.71
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

Dry bulk density values vary across NVC classes and marsh zone (Table 1; Figure 9), with some of the largest variation in dry bulk density in the pioneer marsh, potentially due to the low sample number from this zone (*n=18)*. There is greater variability in the observed soil OC values, particularly in the upper marsh zones and towards the terrestrial environment (Figure 9); this same pattern has been reported in UK saltmarshes (Ford *et al*., 2019; Marley *et al*., 2019) and elsewhere around the world (Mueller *et al*., 2019; Owers *et al*., 2020; van Ardenne *et al*., 2018).

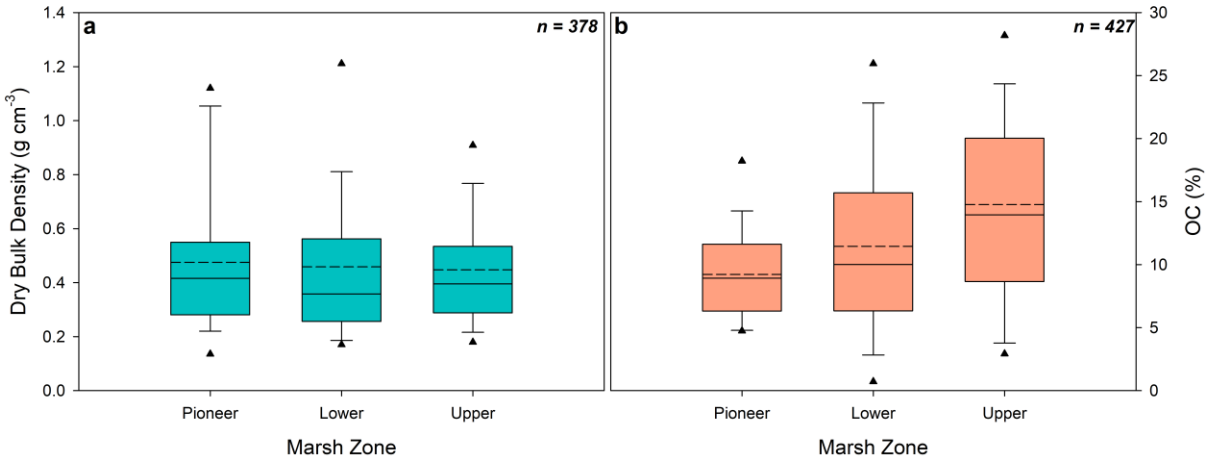


Figure 9: Scottish saltmarsh zones and observed soil properties (**a**) dry bulk density (g.cm^{-3}), and (**b**) OC content (%). The solid line indicates the median and the dashed line indicates the mean value. The whiskers indicate 1.5 times the range of between the first and third quantile for both extremes; the points represent the 5th and 95th percentile values.

4.1.2 Small Saltmarshes (<0.03 km^2)

The areal extent of the 201 unmapped small (<0.03 km^2) saltmarshes were estimated using the three approaches outlined in Section 3.1. Using an idealised size distribution (Figure 10a), the mean saltmarsh size is estimated to be 0.015 ± 0.005 km^2 which, in turn, results in the 201 unmapped systems occupying an area of 3.015 ± km^2. Utilising the size distribution from the 25 surveyed marshes (Figure 10b), the mean saltmarsh size is estimated to be 0.014 ± 0.009 km^2 which, in turn, results in the same 201 small saltmarshes covering an area of 2.814 ± 1.809 km^2. The final approach, in which all the unmapped saltmarshes are assumed to be 0.03 km^2 (i.e. the maximum size possible), the total areal extent of the 201 unmapped saltmarshes would be equivalent to 6.03 km^2.

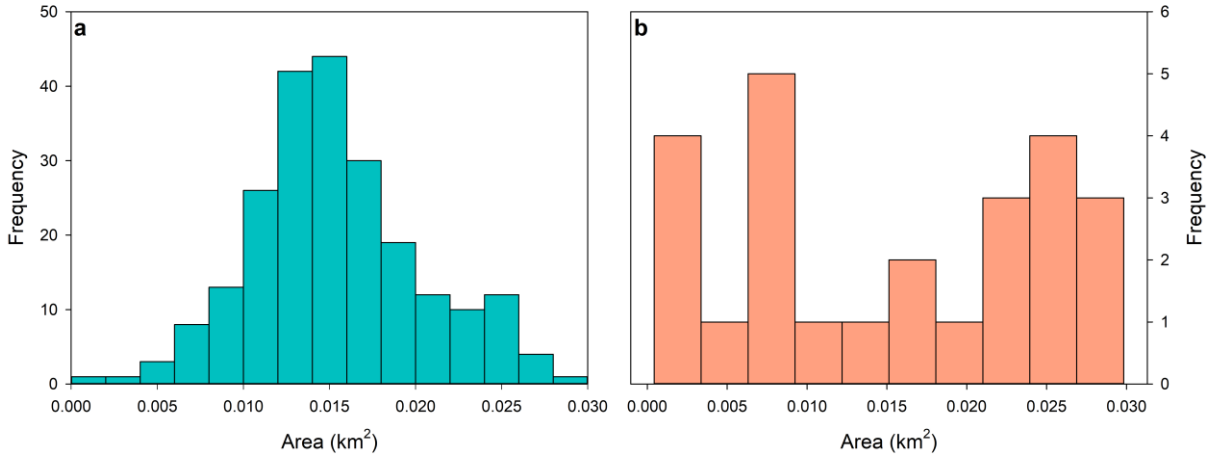


Figure 10. Frequency distribution of the areal extent (km^2) of small Scottish saltmarshes (<0.03 km^2). **(a)** Idealized distribution of 171 small unmapped saltmarshes, and (**b**) Frequency distribution of the mapped areal extent of 25 small saltmarshes. Mapped and unmapped saltmarshes are defined by Haynes (2016).

The small (<0.03 km^2) saltmarshes were largely unmapped by Haynes (2016) and therefore lack NVC data from which the NVC-specific dry bulk density and OC contents can be used in upscaling soil OC stock calculations. For these 201 small unmapped systems, the mean dry bulk density (0.49 ± 0.29 $g.cm^{-3}$) and OC (13.19 ± 7.59 %) values were utilised to estimate the soil OC stock.

4.2 Scottish saltmarsh soil OC stock

The calculated NVC-specific soil OC density values for Scottish saltmarshes range between 3.64-6.57 kg OC m^{-2} in the top 10 cm and 5.46-9.86 kg OC m^{-2} for the top 15 cm of the soil profile. When compiled to the spatial mapping of NVC classes from the SSS classes, it is possible to understand the spatial distribution of OC across individual saltmarshes (Figure 11). In-turn, these approaches allows the soil OC stock to be calculated for specific marshes, NVC classes and Scotland's entire saltmarsh area. Using this approach, it is estimated that the saltmarsh mapped as part of the SSS hold 349,052 ± 98,729 tonnes of OC in the top 10 cm of soil and potentially 523,578 ± 158,089 tonnes of OC in the top 15 cm of the soil profile across Scotland.

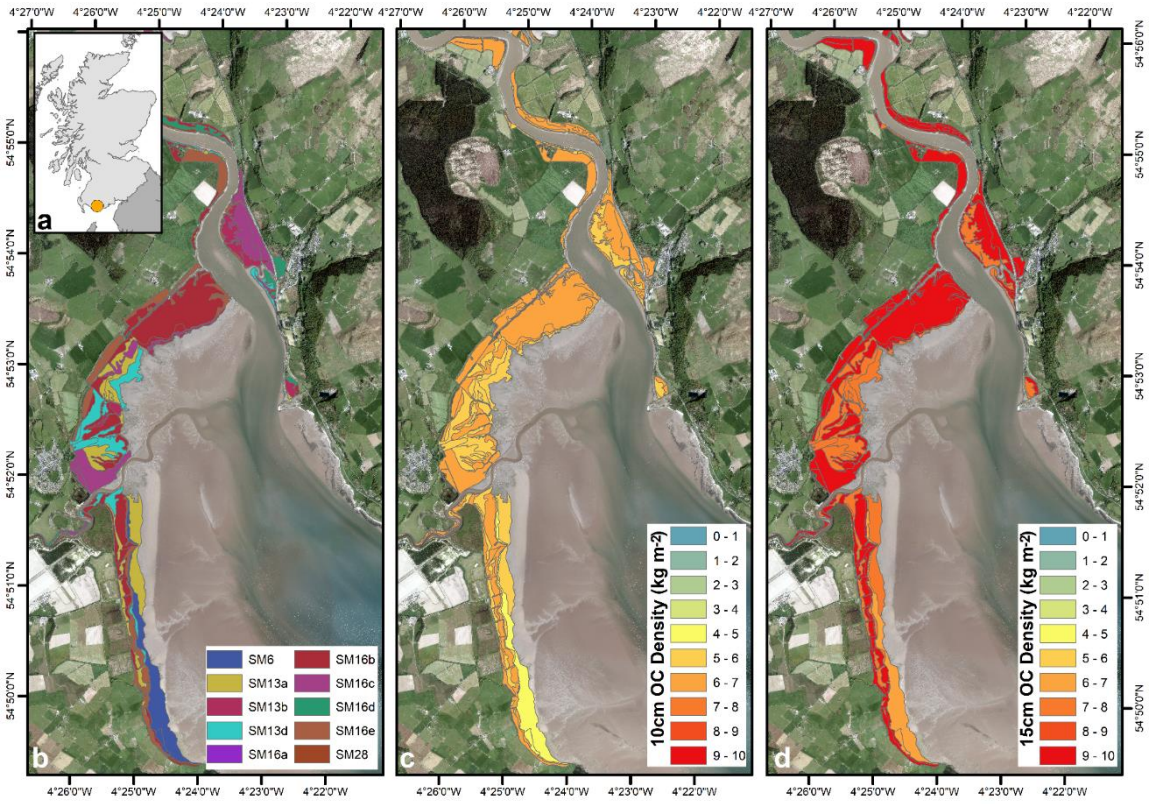


Figure 11. Example of mapped OC density (kg.m^{-2}) across Wigtown Bay (Solway Firth) saltmarsh. (**a**) NVC (Haynes, 2016). (**b**) Soil OC density for the top 10 cm of soil. (**c**) Soil OC density for the top 15 cm of soil.

The largest OC stocks are associated with NVC classes 13 and 16 (Figure 12), unsurprising given that these are the dominant saltmarsh vegetation classes in Scotland. The upper marsh zone of Scotland's saltmarshes are the most OC rich, followed by the lower and pioneer marsh zones (Table. 2).

Table 2

OC stock (Mt) and density (kg OC m^{-2}) estimated for the top 10 and 15 cm of soil across the different saltmarsh zones and Scotland's saltmarsh as a whole.

Marsh Zone	OC Stock (Mt)				OC Density (kg m^{-2})			
	Mean	Std. Dev	5th Percentile	95th Percentile	Mean	Std. Dev	5th Percentile	95th Percentile
Top 10 cm of Soil								
Pioneer	0.02	0.00	0.01	0.02	4.4	0.9	1.6	6.1
Lower	0.09	0.04	0.01	0.14	5.3	2.2	0.8	8.4
Upper	0.24	0.07	0.08	0.53	6.5	1.8	2.0	14.5
Scottish Saltmarsh	**0.35**	**0.10**	**0.16**	**0.65**	**6.0**	**1.8**	**2.6**	**11.1**
Top 15 cm of Soil								
Pioneer	0.03	0.01	0.01	0.03	6.6	1.4	2.1	8.6
Lower	0.13	0.06	0.03	0.34	7.9	3.3	1.6	20.0
Upper	0.36	0.10	0.10	0.56	9.7	2.8	2.6	15.2
Scottish Saltmarsh	**0.52**	**0.16**	**0.23**	**0.79**	**8.9**	**2.7**	**4.0**	**13.5**

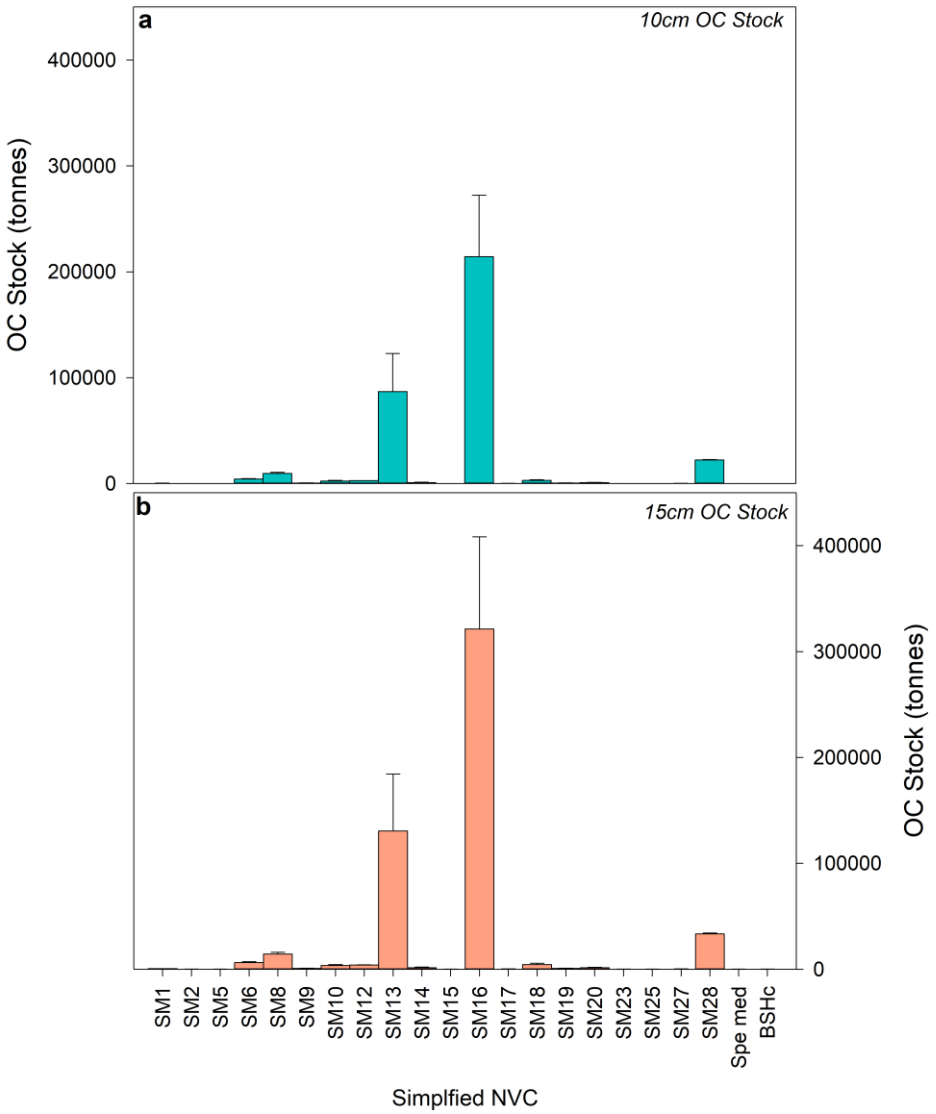


Figure 12: OC stock (tonnes) estimated for (**a**) top 10 cm of soil, and (**b**) top 15 cm of soil for each of the vegetation classes found within Scotland's saltmarshes. See Supplementary Table 3 for further details.

The three methods used to estimate the surficial soil OC stock of the 201 small, unmapped saltmarshes (<0.003 km^2) identified by the SSS result in estimates ranging between 18,187 to 38,972 tonnes OC (top 10 cm; Table 3). The third approach (see Section 3.1) estimates the maximum quantity of OC that could be stored in these small systems and is unlikely to be accurate; estimates from the other two methodological approaches result in similar OC stocks and the average from these outputs has been used to represent the total soil OC stock. The small saltmarshes (<0.03 km^2) of Scotland are estimated to hold 18,837 ± 3,549 tonnes of OC in the top 10 cm with 28,255 ± 5,324 tonnes of OC estimated to be in the top 15 cm of soil.

Table 3

Modelled OC soil stocks for Scottish saltmarshes (unmapped by the SSS) and < 0.03 km^2 in area. The estimates are presented for the top 10 and 15 cm of saltmarsh soil. Differences in the methodological approaches are outlined in Section 3.1.

		Top 10 cm of Soil OC Stock (tonnes)		Top 15 cm of Soil OC Stock (tonnes)	
Method	**Area (km^2)**	**Mean**	**Std. Dev**	**Mean**	**Std. Dev**
1	3.02 ± 1.01	19,486.25	2,135.83	29,299.37	3,203.74
2	2.81 ± 1.81	18,187.16	3844.49	27,280.75	5,766.73
3	3.02	38,972	—	58,458.74	—
Mean (1+2)	**2.91 ± 1.68**	**18,836.7**	**3549.08**	**28,255.06**	**5323.63**

In total, it is estimated that the soils within the saltmarshes of Scotland hold 367,888 ± 102,278 tonnes of OC in the top 10 cm and potentially 551,833 ± 163,412 tonnes of OC in the top 15 cm.

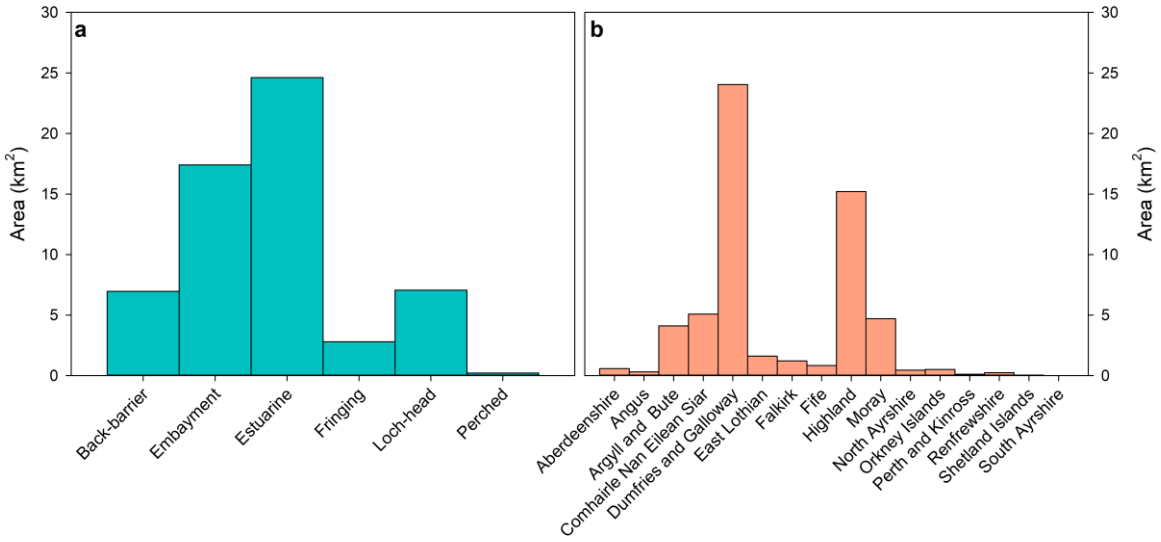


Figure 13: Soil (top 10 cm) OC stock (tonnes) estimated for (**a**) saltmarsh type, and (**b**) saltmarsh occurrence within Scotland's local authority areas. Further details are provided in Supplementary Tables 4 and 5.

The majority of the OC in the soils of Scotland's saltmarshes can be found in estuarine and embayment saltmarsh types, followed by the loch-head, back barrier and fringing saltmarshes (Figure 13a). The estuarine saltmarshes that dominate Dumfries and Galloway hold the greatest amount of OC (41.20% of total OC stock) (Figure 13b). The saltmarshes within the Highland Council area have the second largest OC stock (25.93% of total OC stock). Unlike Dumfries and Galloway, where there are a small number of very large saltmarshes, within the Highland Council area there are also a high number of small loch-head and embayment saltmarshes. At the national scale, the OC held within Scotland's saltmarsh soils is concentrated within a few large saltmarshes. For example, three saltmarshes - Caerlaverock (Solway

Firth), Wigtown Bay (Solway Firth) and Morrich More (Dornoch Firth) hold 31.51% of the total OC within the surface (10 cm) soils across all of Scotland's saltmarshes (Table 4). Furthermore, ten of Scotland's largest saltmarshes hold >50 % of the total saltmarsh soil OC stocks (Table 4).

Table 4

Ranked soil OC stocks for individual saltmarshes across Scotland (Full list in supplementary data). The estimates are presented for the top 10 and 15 cm of soil and as a percentage of the national saltmarsh OC stock.

Rank	Marsh	Top 10cm OC Stock (tonnes)	Top 15 cm OC Stock (tonnes)	% of National Saltmarsh OC Stock
1	Caerlaverock	44,541.92	66,812.88	12.74
2	Wigtown	40258.85	60,388.28	11.51
3	Morrich More	25,397.75	38,096.62	7.26
4	Kirkconnell Merse	14,502.69	21,754.03	4.15
5	Culbin	13,981.01	20,971.52	4.00
6	Findhorn Bay	12,870.44	19,305.67	3.68
7	Priestside Bank	7,924.69	11,887.03	2.27
8	Nigg Bay	6,592.16	9,888.24	1.88
9	Tyninghame Shore	5,770.29	8,655.43	1.65
10	Tong Saltings SSSI	5,667.46	8,501.18	1.62
11	Loch Carron	5,032.86	7,549.29	1.44
12	Whiteness Head	4,072.91	6,109.37	1.16
13	Forth (Alloa)	3,943.20	5,914.80	1.13
14	Southwick	3,788.21	5,682.31	1.08
15	Carse Bay	3,549.42	5,324.12	1.01
16	Greenmerse	3,371.19	5,056.78	0.96
17	Gruinart Flats	3,258.75	4,888.13	0.93
18	Milnfield Merse	3,032.81	4,549.21	0.87
19	Orchardton Bay	2,900.87	4,351.30	0.83
20	Beauly Firth	2,886.04	4,329.05	0.83
21	Rough Firth	2,874.95	4,312.42	0.82
22	Eden Estuary	2,859.35	4,289.02	0.82
23	Garnock Estuary	2,817.25	4,225.88	0.81
24	Loch Crinan	2,802.76	4,204.14	0.80
25	Luce Bay	2,744.54	4,116.82	0.78
26	Loch Beg	2,545.75	3,818.63	0.73
27	Dornoch Point	2,528.76	3,793.15	0.72
28	Aberlady Bay	2,518.55	3,777.82	0.72
29	Gretna to Redkirk	2,455.31	3,682.97	0.70
30	Bridgend Flats	2,310.21	3,465.32	0.66
31	Kentra Bay	2,309.44	3,464.17	0.66
32	Annan	2,238.01	3,357.02	0.64
33	Glencaple & Kelton	2,196.13	3,294.19	0.63
34	Skinflats	2,194.74	3,292.11	0.63
35	Nonach	2,162.38	3,243.57	0.62
36	Illeray 1	2,133.62	3,200.43	0.61
37	River Dee	2,036.30	3,054.45	0.58
38	Ulva Islands & Loch na Cille	1,835.30	2,752.95	0.52
39	Sleek of Tarty	1,804.75	2,707.12	0.52
40	Montrose Basin	1,643.79	2,465.68	0.47
41	Loch Duich	1,583.19	2,374.79	0.45
42	Inverscaddle Bay	1,542.81	2,314.21	0.44
43	Inner Clyde	1,491.91	2,237.86	0.43
44	Munlochy Bay	1,468.47	2,202.70	0.42
45	Dalmore	1,398.90	2,098.35	0.40
46	Ceann a' Baigh	1,381.99	2,072.98	0.40
47	Gress Saltings SSSI	1,332.47	1,998.70	0.38
48	Loch Eil	1,317.32	1,975.98	0.38
49	Loch Moidart	1,268.77	1,903.15	0.36
50	Luskentyre Banks and Saltings SSSI 2	1,226.02	1,839.03	0.35

5. Scotland's saltmarsh soil OC stocks

It is estimated that 367,888 ± 102,278 tonnes of OC are stored in the top 10 cm of soil within Scottish saltmarshes. Beaumont *et al*. (2014) estimated that Scottish saltmarsh soils hold 552,900 tonnes of OC. However, the data utilised in the Beaumont *et al*. (2014) study was limited to a few study sites and additionally took into consideration soil profiles between 50-100 cm in depth instead of the surface (10 cm and 15 cm) assessments of this study.

No reliable saltmarsh soil OC stock estimates exist for the UK at the present time, primarily because of a lack of constraining field data, which have resulted in highly variable estimates. Luisetti *et al*., (2019) estimated that UK saltmarsh soils hold 13 million tonnes of OC. However, when we consider that Scottish saltmarshes represent ~13% of the UK saltmarsh area, a simple up-scale would imply Scottish saltmarshes hold approximately 1.72 million tonnes of OC. These estimates are significantly higher than those of Beaumont *et al*., (2014), who estimated that UK and Scottish saltmarsh soils hold 5.87 and 0.55 million tonnes of OC, respectively. The high estimates of Luisetti *et al*. (2019) are based upon a single data set from the Humber estuary (Rees *et al*., 2000) that has been up-scaled to the entire extent of the UK saltmarsh habitat; these estimates cannot be considered as reliable. Finally, Legge *et al*., (2020) estimated that saltmarsh soils (top 10 cm) bordering the NW European shelf hold between 2.8 and 7.6 million tonnes of OC. Using the methodology set out by Legge *et al*. (2020), it is calculated that the soils of Scottish saltmarshes hold between 131,873 and 251,114 tonnes of OC, nearly an order of magnitude less than the OC stocks estimated by Luisetti *et al*., (2019) and lower, albeit within error, of the estimates made in this study. Legge *et al*. (2020) utilised data from the Coastal Biodiversity and Ecosystem Services Sustainability (CBESS) project, which focused on the saltmarshes of Morecambe Bay and Essex, neither of which are directly comparable to the saltmarshes of Scotland. The saltmarshes of Morecambe Bay are sandy systems, while the Essex saltmarshes are clay-rich (Burden *et al*., 2019; Wood *et al*., 2015) resulting in OC-poor systems in comparison to Scottish saltmarshes *(Marley et al*., 2019; Ruranska *et al*., 2020; Smeaton *et al*., 2020); these differences most likely explain the very different OC stocks estimates obtained.

The OC stock estimates within this study are built upon 805 data points from across Scotland, representing a significant improvement on data constraints in previously published estimates (Beaumont *et al*., 2014; Legge *et al*., 2020; Luisetti *et al*., 2020). The combination of an extensive soil dry bulk density and OC dataset, well mapped saltmarsh vegetation across Scotland (Haynes, 2016) and the methodological

approach (i.e. MCMC), gives us confidence that the 10 cm soil OC stock and the associated uncertainties are the most accurate and robust assessment available for the UK.

Alongside the soil OC stock estimates for the top 10 cm of Scotland's saltmarshes we extrapolate to a depth of 15 cm to allow the OC densities to be compared to those of other known terrestrial soil systems (Henrys *et al*., 2012). Soil OC density ($kg.m^{-2}$) for different land cover types were extracted from the countryside survey 2007 data (Henrys *et al*., 2012). This data is derived from a soil sampling programme across the UK, which collected a soil sample every 1 km^2.

When compared to the Scotland-specific OC density values from the countryside survey 2007 dataset (Henrys *et al*., 2012), saltmarsh soils are observed to contain higher OC densities than nearly all other terrestrial environments with only heather habitats (largely peaty environments) matching the OC densities found in saltmarshes (Fig. 14). When broken down into the different saltmarsh zones, the highest observed OC densities are found, as expected, in the upper saltmarsh with lower values observed in both the lower and pioneer saltmarsh zones (Figure 14).

While useful for comparison with their terrestrial counterparts, is important to highlight that the 15 cm saltmarsh OC stocks are likely to have been overestimated. Additionally, as part of the countryside survey (Henrys *et al*., 2012) root material was removed from the soil before the OC content of the soil was quantified. Root material (referred to as below ground carbon) is rarely removed from intertidal soils in blue carbon studies and this material is often considered a fundamental competent of the OC that is locked in these coastal soils.

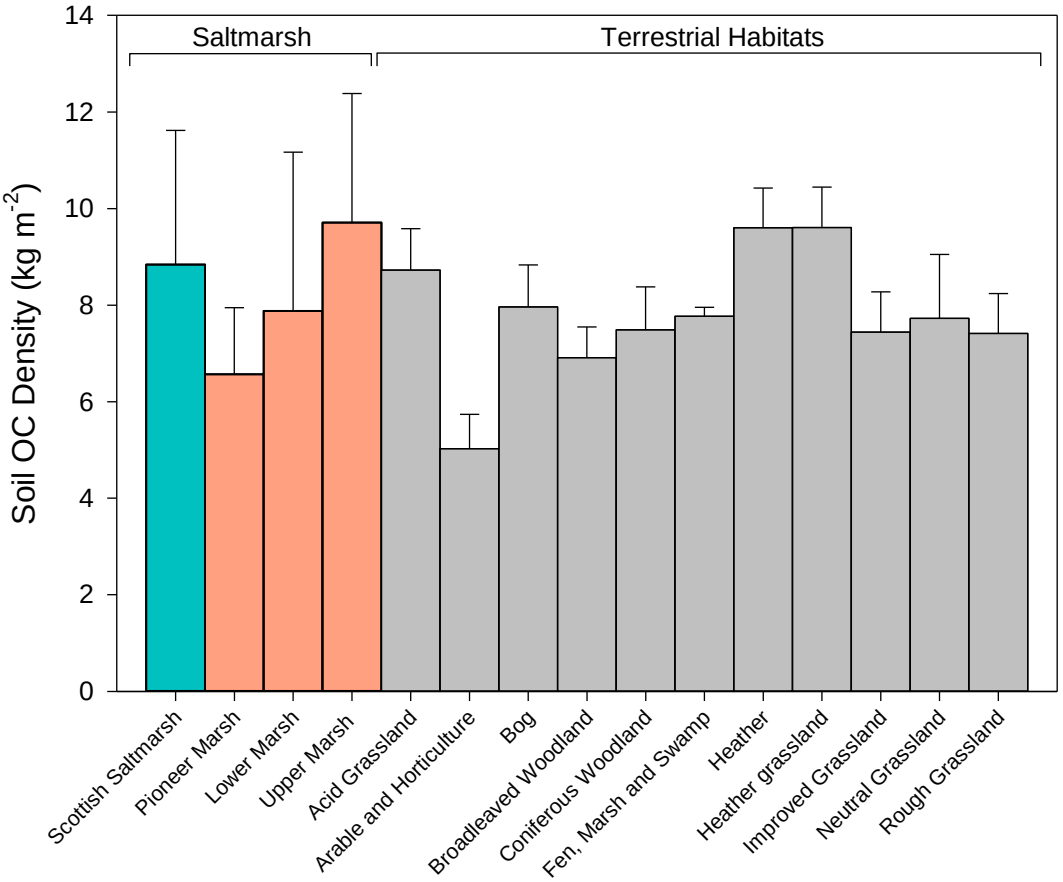


Figure 14: Scottish saltmarsh soil (top 15 cm) OC density (kg.m^{-2}) in comparison to different terrestrial environments (grey bars) across Scotland derived from the Countryside Survey data (Henrys *et al*., 2012).

The soil OC stock estimates made in this study may be considered surficial (top 10 and 15 cm of soil). Yet the variability in UK relative sea level change throughout the Holocene (Shennan *et al*., 2018) provides a powerful reminder that saltmarshes are continuously in a state of dynamic change, both eroding and accreting. Currently, there are very few fully depth-integrated (full depth of saltmarsh deposits) saltmarsh soil OC stocks available for Scotland or elsewhere in the UK. The marshes at Waulkmill Bay and Bridge of Waithe, both located on the Orkney islands, have fully depth-integrated soil OC stocks reported; it was estimated that they hold 645 ± 135 and 417 ± 66 tonnes of OC, respectively (Porter *et al*., 2020). In this study, the top 10 and 15 cm of the saltmarsh soil at Waulkmill Bay, for example, are estimated to hold 362 and 543 tonnes OC respectively. While it is clear that the 10 and 15 cm soil OC stock estimates do not fully encompass the full depth, and in-turn the total OC stored, in saltmarsh soils, the data currently available suggest that the surficial OC stock estimates represent a significant fraction (>50%) of the total OC that may be

stored in many Scottish saltmarshes. It is therefore likely that surficial OC stock estimates would form a robust foundation to inform potential policy and management intervention options for continued sequestration and storage of OC in Scottish saltmarsh soils.

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Appendix A: Supplementary Tables

Supplementary Table 1

Vegetation types found within Scottish saltmarshes categorised using the National Vegetation Classification (NVC) scheme (Rodwell et al., 2000).

Description	Marsh Zone	NVC (Detailed)	NVC (Simplified)
Zostera communities	Littoral	SM1	SM1
Ruppia maritima salt-marsh community	Littoral	SM2	SM2
Spartina alterniflora saltmarsh	Pioneer	SM5	SM5
Spartina anglica saltmarsh	Pioneer	SM6	SM6
Annual Salicornia saltmarsh	Pioneer	SM8	SM8
Suaeda maritima saltmarsh	Pioneer	SM9	SM9
Transitional low-marsh vegetation with Puccinellia maritima, annual Salicornia species and Suaeda maritima	Pioneer	SM10	SM10
Coastal stands of rayed Aster tripolium	Pioneer	SM12a	SM12
Puccinellia maritima saltmarsh - Puccinellia maritima	Lower	SM13a	SM13
Puccinellia maritima saltmarsh - Glaux maritima	Lower	SM13b	SM13
Puccinellia maritima saltmarsh - Limonium vulgare-Armeria maritima	Lower	SM13c	SM13
Puccinellia maritima saltmarsh - Plantago maritima-Armeria maritima	Lower	SM13d	SM13
Puccinellia maritima saltmarsh - Puccinellia maritima-turf fucoid	Lower	SM13e	SM13
Puccinellia maritima saltmarsh - Puccinellia maritima-Spartina anglica	Lower	SM13x	SM13
Halimione portulacoides saltmarsh - Halimione portulacoides	Lower	SM14a	SM14
Halimione portulacoides saltmarsh - Puccinellia maritima	Lower	SM14c	SM14
Juncus maritimus-Triglochin maritima saltmarsh	Lower	SM15	SM15
Festuca rubra saltmarsh - Puccinellia maritima	Upper	SM16a	SM16
Festuca rubra saltmarsh - Juncus gerardii	Upper	SM16b	SM16
Festuca rubra saltmarsh - Agrostis stolonifera/Festuca rubra-Glaux maritima	Upper	SM16c	SM16
Festuca rubra saltmarsh - Tall Festuca rubra	Upper	SM16d	SM16
Festuca rubra saltmarsh - Leontodon autumnalis	Upper	SM16e	SM16
Festuca rubra saltmarsh - Carex flacca	Upper	SM16f	SM16
Festuca rubra saltmarsh - Juncus gerardii, Agrostis stolonifera, Glaux maritima & Triglochin maritimum pioneer	Upper	SM16g	SM16
Festuca rubra saltmarsh - Agrostis stolonifera/Triglochin maritimum	Upper	SM16i	SM16
Festuca rubra saltmarsh - Festuca rubra and Juncus balticus	Upper	SM16j	SM16
Festuca rubra saltmarsh - Eleocharis palustris variant	Upper	SM16p	SM16
Festuca rubra saltmarsh - Transitional saltmarsh	Upper	SM16t	SM16
Festuca rubra saltmarsh - Festuca rubra and Molinia caerulea	Upper	SM16x	SM16
Artemisia maritima saltmarsh	Upper	SM17	SM17
Juncus maritimus saltmarsh community - Plantago maritima	Upper	SM18a	SM18
Juncus maritimus saltmarsh community - Oenanthe lachenalii	Upper	SM18b	SM18
Juncus maritimus saltmarsh community - proposed Molinia caerulea	Upper	SM18x	SM18
Blysmus rufus saltmarsh	Upper	SM19	SM19
Eleocharis uniglumis saltmarsh	Upper	SM20	SM20
Spergularia marina-Puccinellia distans saltmarsh	Upper	SM23	SM23
Suaeda vera saltmarsh	Upper	SM25	SM25
Ephemeral saltmarsh vegetation with Sagina maritima	Upper	SM27	SM27
Elymus repens	Upper	SM28	SM28
Festuca rubra	Upper	SM28x	SM28
Spergularia media	Upper	Spe med	Spe med
Cochlearia officinalis pioneer community (dense-sparse) on shingle	Upper	BSHc	BSHc

Supplementary Table 2

Soil sampling locations across Scottish saltmarshes. Site ID corresponds to Figure 7.

Site ID	Name	Site ID	Name
1	Tyninghame Shore	25	Broadford Bay
2	Aberlady Bay	26	Loch Ainort
3	Skinflats	27	Loch Sligachan
4	Cocklemill Bay	28	Loch Harport
5	Tayport	29	Loch Slapin
6	Magdrum Island (river Tay)	30	Loch na Dal
7	Carthagena Bank (River Tay)	31	Isleornsay
8	Montrose	22	Glenelg
9	Findhorn Bay	33	Loch Aline
10	Culbin	34	Loch Laich
11	Dingwall	35	Loch Creran
12	Waulkmill Bay	36	Loch Crinan
13	Bridge of Waithe and Cummi Ness	37	Loch Caolisport
14	Kyle of Tongue	38	Ruel Estuary/Loch Riddon
15	Eilean Dubh (Loch Eriboll)	39	Inner Clyde
16	Loch Broom	40	Inner Clyde
17	Little Loch Broom	41	Garnock Estuary
18	Loch Torridon	42	Wigtown
19	Toscaig	43	Orchardton Bay
20	Nonach	44	Southwick
21	Ardelve (Loch Alsh)	45	Kinkconnell Merse
22	Kirkton (Loch Alsh)	46	Caerlaverock
23	Kyle	47	Annan
24	Rubha Ardnish		

Supplementary Table 3

OC stock (tonnes) and density (kg OC m^{-2}) estimated for each vegetation class found within Scotland's saltmarshes. The estimates are presented for the top 10 and 15 cm of soil.

	Top 10 cm of Soil				Top 15 cm of Soil			
	OC Stock (tonnes)		OC Density (kg m^{-2})		OC Stock (tonnes)		OC Density (kg m^{-2})	
NVC	**Mean**	**Std. Dev**	**Mean**	**Std. Dev**	**Mean**	**Std. Dev**	**Mean**	**Std. Dev**
SM1	339.8	71.6	4.38	0.92	509.7	107.4	6.57	1.38
SM2	3.7	0.8	4.38	0.92	5.6	1.2	6.57	1.38
SM5	46.6	9.8	4.38	0.92	70.0	14.7	6.57	1.38
SM6	4,194.5	572.0	4.28	0.58	6,291.7	858.0	6.43	0.88
SM8	9,554.1	1,103.5	3.87	0.45	14,331.1	1,655.2	5.81	0.67
SM9	539.0	113.6	4.38	0.92	808.5	170.3	6.57	1.38
SM10	2,355.7	596.4	4.66	1.18	3,533.5	894.6	6.99	1.77
SM12	2,701.0	69.5	3.64	0.09	4,051.5	104.2	5.46	0.14
SM13	86,992.8	35,792.5	5.18	2.13	130,489.2	53,688.8	7.78	3.20
SM14	926.1	386.2	5.25	2.19	1,389.1	579.3	7.88	3.29
SM15	1.7	0.7	5.25	2.19	2.5	1.1	7.88	3.29
SM16	214,176.0	58,107.9	6.57	1.78	321,264.0	87,161.8	9.86	2.67
SM17	224.0	69.3	5.91	1.83	336.0	103.9	8.87	2.74
SM18	2,930.1	804.9	6.48	1.78	4,395.2	1,207.3	9.71	2.67
SM19	563.6	154.8	6.48	1.78	845.4	232.2	9.71	2.67
SM20	968.1	265.9	6.48	1.78	1,452.2	398.9	9.71	2.67
SM23	43.4	11.9	6.48	1.78	65.1	17.9	9.71	2.67
SM25	23.3	6.4	6.48	1.78	34.9	9.6	9.71	2.67
SM27	205.8	56.5	6.48	1.78	308.7	84.8	9.71	2.67
SM28	2,2253.8	529.2	6.47	0.15	33,380.8	793.8	9.71	0.23
Spe med	1.2	0.3	6.48	1.78	1.7	0.5	9.71	2.67
BSHc	7.5	2.1	6.48	1.78	11.2	3.1	9.71	2.67
Total	**349,051.7**	**98,728.8**	**5.95**	**1.68**	**523,577.6**	**158,088.6**	**8.92**	**2.52**

Supplementary Table 4

OC stock (tonnes) estimated for each saltmarsh type found within Scotland's. The estimates are presented for the top 10 and 15 cm of soil and as a percentage of the national saltmarsh OC stock.

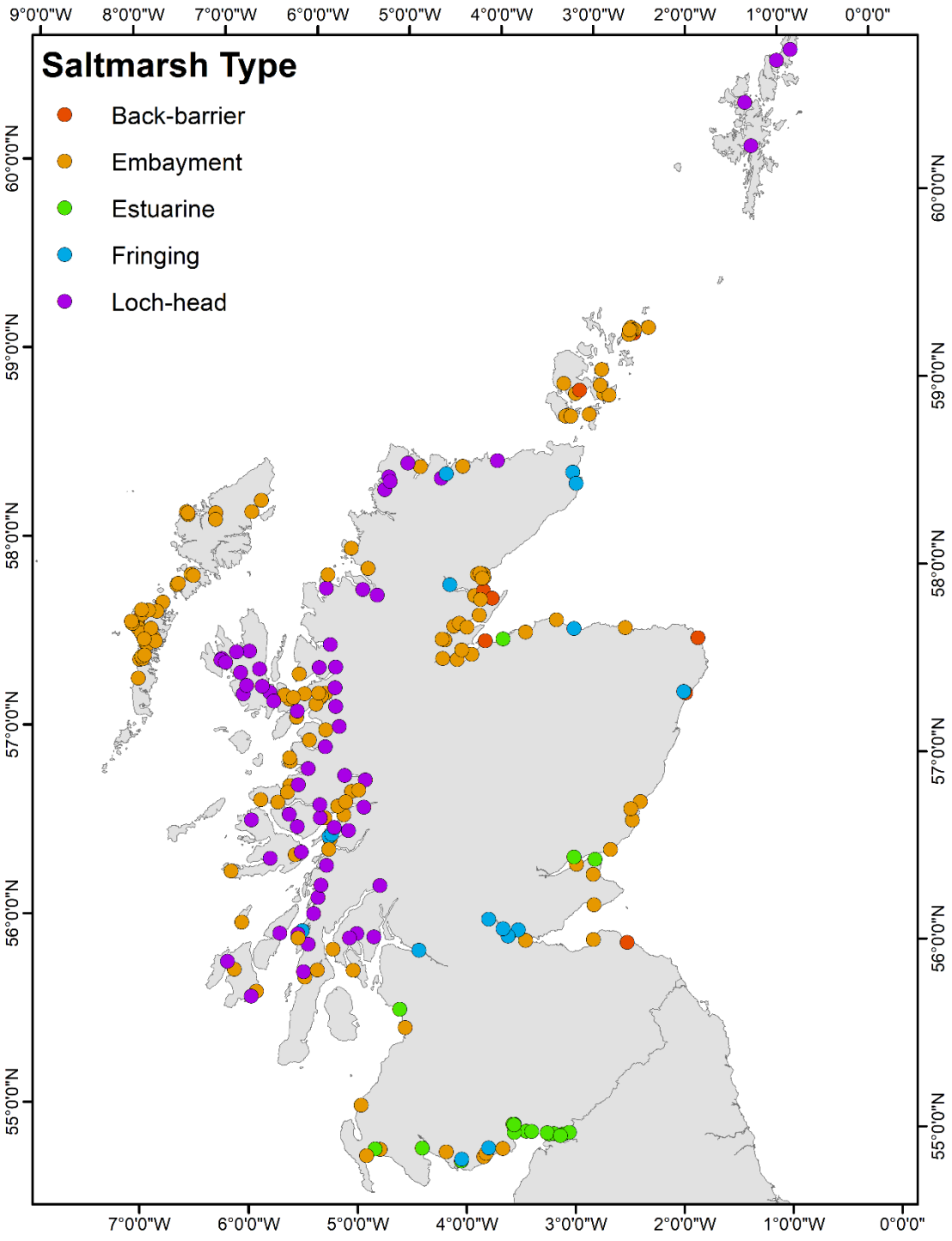
Marsh Type	Area (km^2)	Top 10 cm OC Stock (tonnes)	Top 15 cm OC Stock (tonnes)	% of National Saltmarsh OC Stock
Back-barrier	6.96	40,026.38	60,039.56	11.40
Embayment	17.41	102,580.28	153,870.42	29.21
Estuarine	24.62	147,058.40	220,587.60	41.88
Fringing	2.79	15,974.31	23961.47	4.55
Loch-head	7.05	44,119.62	66,179.43	12.56
Perched	0.21	—	—	—

Supplementary Table 5

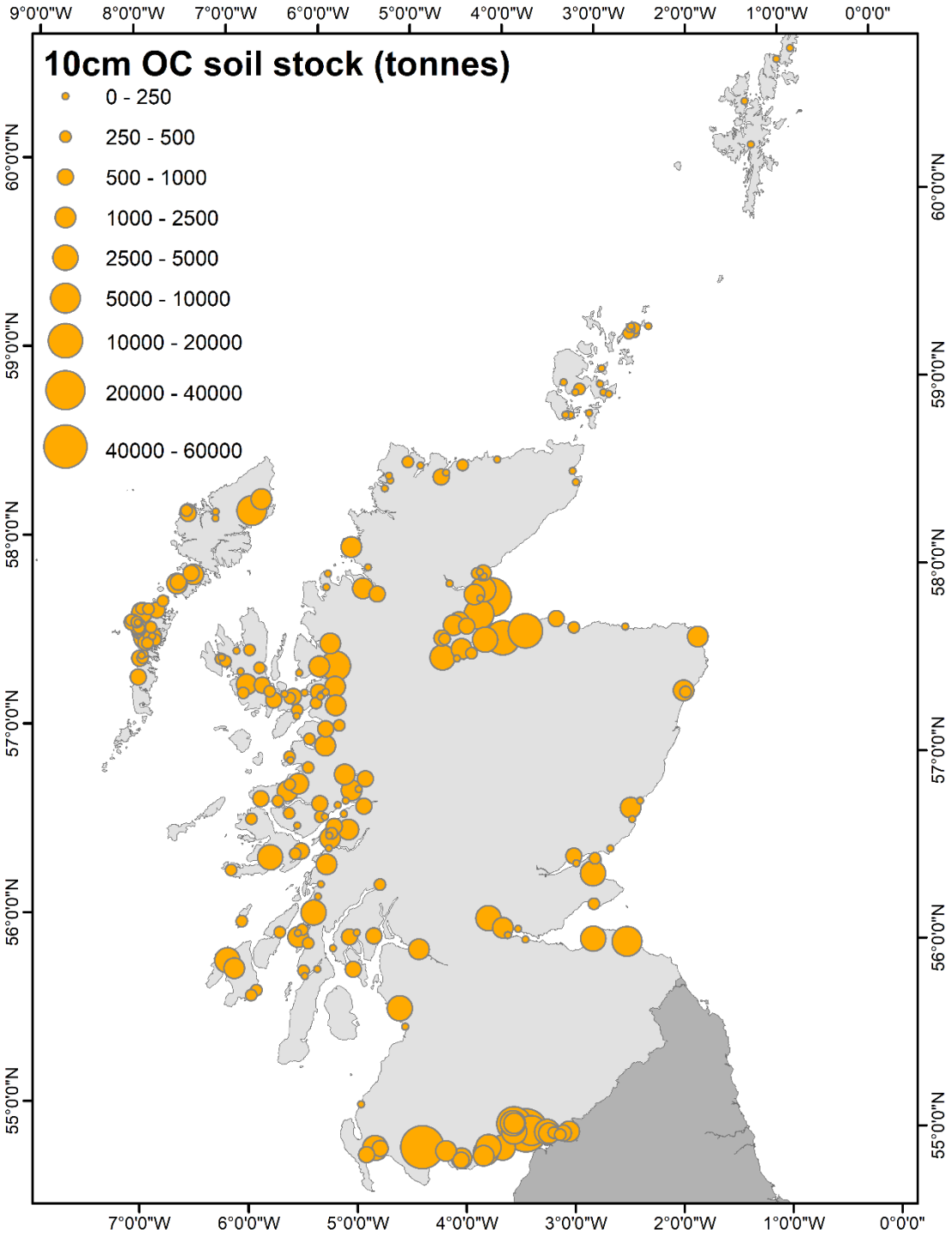
Estimated soil OC stock (tonnes) held with saltmarsh within each of Scotland's Local Authorities. The estimates are presented for the top 10 and 15 cm of soil and as a percentage of the national saltmarsh OC stock.

Local Authority	Area (km^2)	Top 10 cm OC Stock (tonnes)	Top 15 cm OC Stock (tonnes)	% of National Saltmarsh OC Stock
Aberdeenshire	0.57	3,562.96	5,344.44	1.02
Angus	0.30	1,715.86	2,573.78	0.49
Argyll and Bute	4.11	25,533.31	38,299.96	7.30
Comhairle Nan Eilean Siar	4.88	29,631.82	44,447.73	8.47
Dumfries and Galloway	24.04	144,106.06	216,159.10	41.20
East Lothian	1.60	8,288.83	12,433.25	2.37
Falkirk	1.21	6,322.68	9,484.02	1.81
Fife	0.83	3,769.95	5,654.92	1.08
Highland	15.21	90,681.28	136,021.92	25.93
Moray	4.69	27,561.50	41,342.25	7.88
North Ayrshire	0.45	2,817.25	4,225.88	0.81
Orkney Islands	0.50	3,061.33	4,592.00	0.88
Perth and Kinross	0.12	764.19	1,146.29	0.22
Renfrewshire	0.23	1,491.91	2,237.86	0.43
Shetland Islands	0.05	295.07	442.60	0.08
South Ayrshire	0.03	154.99	232.49	0.04

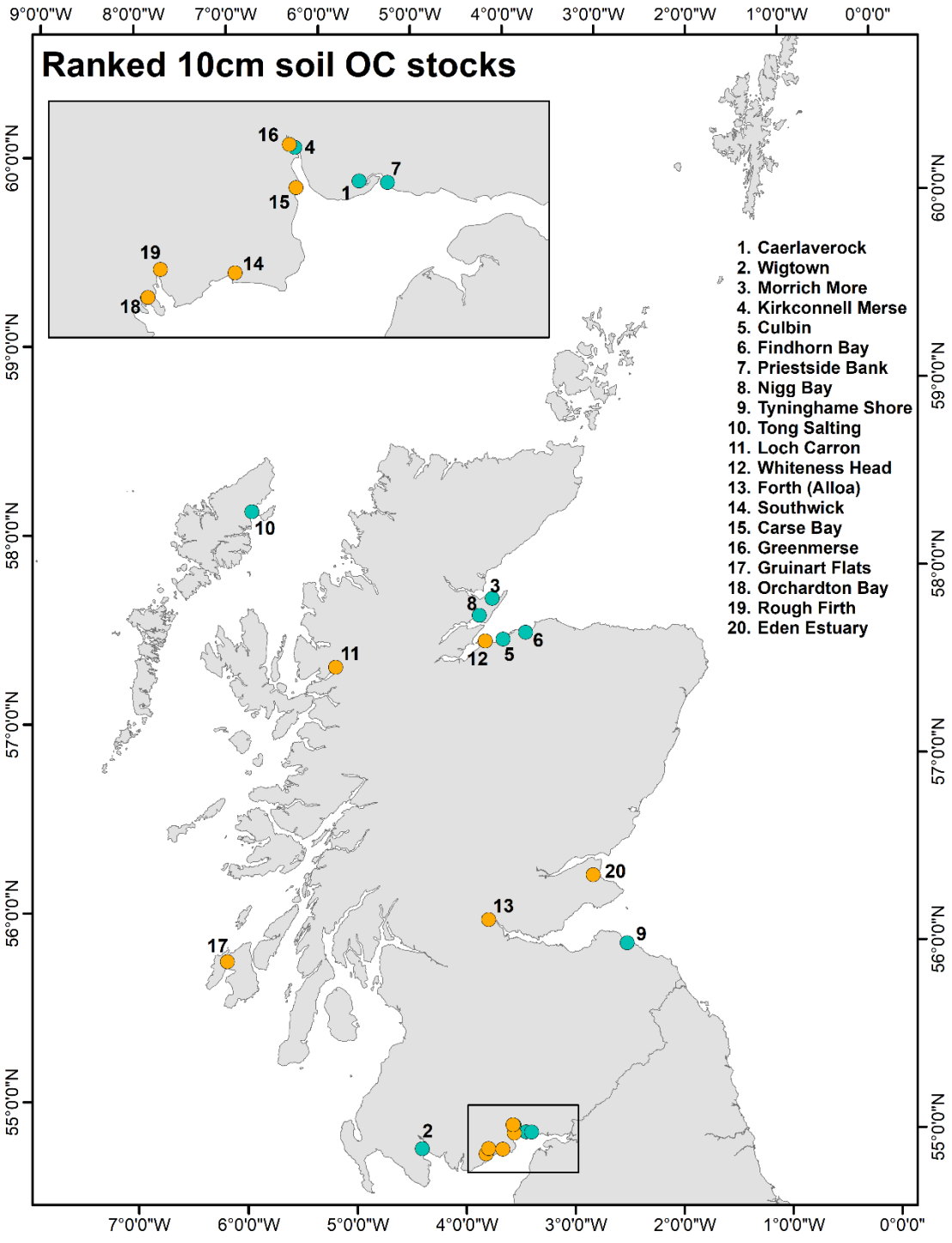
Appendix B: Supplementary Figures



Supplementary Figure 1: Scotland's saltmarsh grouped by type. Derived from Haynes (2016).



Supplementary Figure 2: Scotland's saltmarsh soil (top 10 cm) OC stock.



Supplementary Figure 3: The top 20 largest saltmarsh OC stores in Scotland.

Marine Scotland Science
Marine Laboratory
375 Victoria Road
Aberdeen
AB11 9DB

Copies of this report are available from the Marine Scotland website at www.gov.scot/marinescotland