Small-scale Saltmarsh Restoration Methods Review

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Executive Summary

The UK Saltmarsh Code is a developing, voluntary standard designed to certify and facilitate the sale of carbon credits derived from saltmarsh restoration projects. It aims to incentivize saltmarsh restoration by creating a financial stream for projects and contributing to national Net Zero goals. The code will provide a framework for saltmarsh restoration projects, allowing them to generate revenue by selling carbon credits to buyers seeking to offset their emissions. This will help accelerate saltmarsh restoration and deliver other benefits such as biodiversity gains, flood alleviation, and nutrient remediation.

At present, the Saltmarsh Code focusses on managed realignment, the deliberate breaching of coastal flood defences, inundating agricultural land and subsequent creation of saltmarsh habitat. This is because managed realignment is a well-established technique with a significant body of research quantifying the storage and sequestration of carbon that allows for accurate monetisation. There are, however, several other methods for saltmarsh creation that have the potential for inclusion into the Saltmarsh Code. These methods are generally less costly than managed realignment and at a small scale having quicker timelines for delivery.

The aim of this project is:

- to set out the steps needed to include small scale saltmarsh restoration methods into the Saltmarsh Code to provide delivery agencies and investors with confidence and options for ‘quick wins’ for saltmarsh restoration and start to overcome the lack of ‘shovel ready’ projects,
- a review of saltmarsh restoration methods across the UK and NW Europe, highlighting successful projects, success criteria and drivers of saltmarsh restoration, and
- a comprehensive field survey of small-scale saltmarsh restoration sites in the UK to quantify relative success of different saltmarsh creation methods and the goods and benefits they deliver.

Reviewing the Saltmarsh Code framework identified four main steps that need to be taken to assess whether a new method of restoration could be included: 1) defining the restoration activity; 2) an estimation of likely carbon credits resulting from projects; 3) an estimation of the monetary cost to perform the restoration, and 4) an estimation of potential supply of projects. This report is the first attempt to define and assess potential restoration activities required for step 1.

The review of saltmarsh restoration methods in northwest Europe found 31 sites concentrated in Germany and in the Netherlands, with one additional site located in Belgium. There were no small-scale restoration projects identified along the North Frisian coast of Germany, in Denmark and in France. Methods included construction

of breakwaters or dams to reduce wave-generated erosion, sediment enhancement devices to accelerate marsh expansion, seeding and planting, and use of removed topsoil to create the right conditions for saltmarsh plant growth. Restoration success varied between methods and there was a general lack of rigorously designed experiments to enable accurate assessment or quantification of findings required for any potential Saltmarsh Code development.

Small-scale restoration projects have been carried out in all of the devolved nations in the UK with the exception of Northern Ireland. A total of 63 sites were identified of which the majority were in England with only two sites in Wales and seven sites in Scotland. Within England most sites are concentrated in the southeast. Restoration methods included the ‘drag box’ which drags dredged sediment deposited near the receiver site to a level where saltmarsh plants can grow, polders using brushwood fencing, beneficial use of dredged sediment (BUDS) pumped onto high mudflat or eroding saltmarsh, and a variety of sediment retention methods. As with northwest Europe, restoration success varied and there was a lack of the robust experimental design needed to generate data on environmental benefits or costs for delivery.

Field surveys were carried out in 2024 at 14 different saltmarsh locations in Suffolk, Essex and Hampshire in England to assess the relative merits of different restoration methods. The time span of these interventions varied from one to 20 years. At each site, areas of marsh directly impacted by the interventions were surveyed, as well as an adjacent existing marsh used as a reference site. At each site, data on plant community, soil properties (water content, loss on ignition, bulk density, total organic, inorganic carbon) and structural characteristics (elevation, creek profile) of the saltmarsh were assessed.

Both the desk-based review and the fieldwork highlighted the importance of marsh height and sediment characteristics for plant establishment and diversity. High water content, the right sediment shear strength combined with low wave exposure are likely to create the right conditions for saltmarsh establishment. At the same time, lack of scientific trials with controls and the unique background to each restoration site, made it difficult to truly compare restoration outcomes across sites.

Based on the fieldwork assessment, BUDS is a method which has the potential to successfully restore or create saltmarsh at a scale that might be investable. Whilst other methods might also be beneficial (e.g. BESE mats to trap sediment and provide structure for roots; SREDs to trap sediment), they are more difficult to scale up spatially and are likely to take longer because they rely on sediment to accumulate naturally. On the other hand, BUDS is only feasible where local dredging provides the required sediment; therefore other methods should still be considered for areas where BUDS cannot take place.

Although the initial assessment identified BUDS as a candidate for inclusion in the Saltmarsh Code subject to further comprehensive assessment, other restoration methods demonstrated a strong community involvement and health and wellbeing element which should be recognised. Many of the interventions visited as part of the field survey were installed by hand, either by local communities, NGO working groups or individual efforts. While there were no data available on numbers of participants involved, there was general consensus that installing sediment traps and other innervations by hand gave participants a greater understanding of what was previously an underappreciated and undervalued habitat.

In order to progress the potential inclusion of restoration methods other than managed realignment into the UK Saltmarsh Code, we propose further work as follows:

- A detailed assessment of BUDS to include 1) scoping BUDS in relation to the Saltmarsh Code in more detail (e.g. defining activities, estimating carbon emissions, market assessment), 2) long-term monitoring of selected BUDS sites to understand carbon gain over time, and 3) how BUDS sediments differ across the UK and whether their properties are related to plant establishment and plant diversity,
- A long-term robust trial to determine which restoration methods are best suited for saltmarsh restoration and creation at scale in areas where BUDS is not feasible. This should include 1) comparing different methods within one site and across several sites, 2) a cost-benefit analysis and carbon footprint analysis of methods, and 3) long-term monitoring to understand the carbon gain over time
- A structured, regional assessment of how different marsh types respond to small-scale interventions given variation in plant community type, sediment particle size, land use and sea level rise scenarios. This should consider changing climate conditions by 2050 and 2100 and how restoration targets for such “future” marshes may be different to the concept of restoring back to current or past ‘reference’ conditions.

Contents

Glossary

Term	Definition
BESE mats	Biodegradable EcoSystem restoration Elements (**BESE mats)** BESE mats provide plants with structural improvement for rooting and depending on how many sets are locked together can raise the height for plants growth by several centimetres. BESE mat is their commercial name and also referred to as potato mats or potato lattices because they are made out of potato starch – a potato waste product. Because they are biodegradable, they will naturally decompose over time.
BUDS	**Beneficial use of dredge sediment**. Sediment is placed / pumped either onto the marsh to increase elevation or placed in front of the seaward edge to stop erosion and allow tide to distribute the sediment across the marsh
Bulk Density	**Bulk density** is defined as the mass of the material divided by its bulk volume. It is indication of soil compaction.
Bunds	**Clay** or **gravel bunds** are substantial sediment retention structures often used in conjunction with sediment deposition when the nature or volume of the material require solid support to stay in place.
Coir rolls / matts	Biodegradable structure made from coconut fibre. **Coir rolls** are often placed within creeks in triangular prisms to trap sediment on either side. **Coir matts** are placed on bare marsh to trap sediment and provide solid structures for plant seedlings.
Drag box	The drag box is part of a novel technique to move previously deposited, consolidated sediment higher on to the marsh.
Dyke	An embankment that acts as a barrier to prevent tidal inundation of saltmarsh areas. Summer dykes allow inundation by high spring tides.
Fascine	**Fascines** or **faggots** are fences commonly made with **brushwood bundles** from a variety of material such as ash, hazel and willow but can also be made with **straw bundles**. These bundles are placed in between a double row of wooden stakes and then fastened onto the stakes with wire. They can run either perpendicular to the shore, parallel to the shore, in both directions combined (this would create polders), but also in a curved way around the saltmarsh edge.
Loss on ignition	A method to determine the soil organic matter (SOM) content by measuring weight loss after heating to a specified temperature.
Managed Realignment	Deliberate breaching of coastal defences and subsequent tidal inundation to restore intertidal habitat. This is the predominant method of saltmarsh restoration in the UK.

Polders	A saltmarsh or mudflat area enclosed by defences such as dykes and fascines, which generally prevent the area from being inundated by the tide.
Redox potential	The soil redox potential indicates the balance between oxidized and reduced forms of substances in the soil. A high redox potential is found in an oxidizing environment and a low redox potential suggests a reducing environment. This is measured in millivolt.
Riprap groynes	A breakwater made out of large stones or boulders.
Rock rolls	**Rock rolls** are made up of medium-sized rocks held in place by a metal mesh and wooden stakes.
Rock sills	**Rock sills** are rock mounds much larger than rock rolls and are held in place by the weight of the rocks without additional structure.
Shear vane	A device used to measure soil strength.
SREDs	Sediment retention enhancement devices. A range of **SREDs** are used to retain sediment, such as **coir rolls**, **brushwood fascines**, **rock rolls** and **rock sills**. Some of these are often used in conjunction with **BUDS**.

1. Introduction

Currently managed realignment (MR) is the focus of the Saltmarsh Code and is the best way to recreate saltmarsh at scale. The downside is that implementation can take years to deliver due to the planning and consent process, and the costs involved can be extremely high when there is a need for major new sea defence construction further inland (average of £69,000 per ha compared to £15,000 without, Hudson et al., 2015). As such, case study analysis as part of the Code has shown that, in some cases, carbon credits alone will not generate enough revenue to make MR investable without including other sources of finance. There are, however, a number of other small-scale interventions and quick wins (for carbon, biodiversity and other services) that could be used to upscale restoration efforts of existing but degrading saltmarsh over significantly shorter timescales. The longer-term vision for the Saltmarsh Code is to include these smaller-scale, quicker to implement, restoration techniques, which would also open up the Code to private landowners or in smaller areas, rather than just larger landowners or organisations who have the means to deliver expensive MR projects. Incorporating and having a means to encourage and incentivise these smaller, quicker 'wins' is essential to unlocking greater potential for saltmarsh to contribute to climate change mitigation.

The Saltmarsh Restoration Handbook catalogued these other (non-managed realignment) restoration techniques but did not provide a systematic review of success criteria (i.e., what worked / did not work, where and why) or assessment of the benefits each method would deliver (Hudson et al., 2021). The evidence behind carbon, biodiversity, and other ecosystem service gains (or potential losses) from these restoration methods have not been collated and reviewed, which is the first step needed in a roadmap to inclusion in the Saltmarsh Code, and also essential for our ability to recommend restoration actions.

This project will review saltmarsh restoration methods (other than MR) across the UK and NW Europe, their relative merits for climate mitigation and biodiversity, and timescales for delivery. The aim being to provide delivery agencies and investors' confidence and options for 'quick wins' for saltmarsh restoration and start to overcome the lack of 'shovel ready' projects.

Objectives:

- To review saltmarsh restoration options (other than MR) in the UK and NW Europe.
- Describe the relative merits of different techniques to deliver climate mitigation, biodiversity gain and other ecosystem services.
- Provide a critical assessment of restoration options in the UK and relative confidence in successful delivery of saltmarsh goods and services.

2. Inclusion of small-scale restoration into the Saltmarsh Code

2.1 Introduction to the Saltmarsh Code

The Saltmarsh Code is a voluntary standard enabling the verification and sale of carbon sequestered through saltmarsh restoration, as part of the voluntary carbon market. Saltmarsh carbon can be sold to buyers seeking to voluntarily compensate for their emissions, generating additional revenues to accelerate saltmarsh restoration in the UK, beyond what would be achievable through the public purse alone. This potential to increase restoration effort is the motivation behind developing the Code, not the sale of carbon per se. Restoration to deliver all social and environmental benefits – such as biodiversity gains, flood alleviation and nutrient remediation – is the end goal.

The voluntary carbon market is the most developed at present and therefore presents this opportunity. However, there is an expectation that the Saltmarsh Code will, in time and given increased scientific understanding, include other types of high-integrity 'credits' reflecting these multiple benefits. Within UK nature markets as a whole, there is a general movement and interest towards being able to issue more than one type of credit concurrently on the same piece of land (called Stacking), making it easier to leverage the finance needed for more ambitious and multifunctional projects.

At present, the Saltmarsh Code only focusses on restoration through MR, but there is an appetite to include other restoration activities – as described within this report – once knowledge on the benefits and success rate of these are better understood. Incorporating these smaller-scale and quicker to implement restoration techniques is essential to realising the full potential of the Saltmarsh Code, and to enable private finance to be directed towards restoration projects.

2.2 Principles of the Saltmarsh Code

The Saltmarsh Code is a high-integrity, evidence-based, and evidence-led approach to quantifying the carbon gain of restoration activities. This transparent and rigorous standard provides assurances to buyers that the climate benefits are real, quantifiable, additional, and long lasting. Only companies/corporates who have done everything they can to reduce their emissions can purchase credits to voluntarily offset remaining emissions, i.e. only the residual emissions after following a mitigation hierarchy, thus reducing the danger of greenwashing. The Saltmarsh Code has clear procedures and rules to follow, defining strict criteria by which a project can be included in the Code, and how the number of credits to be sold is calculated.

2.3 Inclusion of new restoration activities

The boxes below outline the steps and information needed to include a new restoration activity – a few important questions/decisions considerations for the inclusion of BUDS as an example are given – in the Saltmarsh Code for the purposes of realising carbon credits. However, it is worth noting, the steps would be the same (or in the least, very similar) when considering other types of credits. The boxes use BUDS as an example for the restoration activity to be included into the Code and highlight some important questions and considerations, which would need to be considered.

In the early stages, there are four main steps that need to be taken – defining the restoration activity to be included, an estimation of likely carbon credits resulting from projects, an estimation of the monetary cost to perform the restoration, and an estimation of potential supply of projects. It is generally considered that the net increase in carbon (or other credit type) should be able to be demonstrated through publicly available evidence including empirical studies, and preferably peer-reviewed. These four steps combined will provide a steer as to whether it is worthwhile developing the Code for a particular restoration activity. For example, if an activity results in large carbon gains for very little financial outlay, but is very niche, the cost and effort of developing the procedures to accommodate it within the Code could be better directed elsewhere.

That said, theoretically anything can be included in the Code, but without the information or ability to predict likely carbon gain, the estimated return on investment cannot be calculated. If this is the case, the ability to leverage up-front investment to allow the restoration to go ahead would inevitably be more difficult, as a target audience would likely be restricted to concessionary buyers, those purchasing due to corporate social responsibility, or philanthropic funders.

1. **Define restoration activity to be included, including its scope**

   BUDS considerations: does this include the delivery of material, or do the project activities start after this? Where does the dredging activity end, and BUDS start?

2. **Gather data/knowledge to estimate likely carbon credits resulting from projects**

- Estimate and predict carbon gain from the restoration activity over a 'permanence period', typically 100-year timescales.
- Can the actual carbon gain be monitored effectively?
- What are the likely embodied and operational carbon emissions

  BUDS consideration: can we discount against the carbon savings from less fuel use resulting from needing to move the sediment a shorter distance?
- Estimate the baseline (current) land-use carbon content/rate of change, including how this was likely to change in the future in the absence of the project.

  BUDS consideration: likely to be eroding marsh with the ability to estimate rate of change difficult (due to lack of monitoring data).

3. Estimate monetary cost of restoration
BUDS consideration: which costs are associated with dredging and which with BUDS? This would need to align with the agreed scope (defined in step 1).

Steps 2 and 3 combined will give an idea as to the extent in which the sale of carbon credits could fund a project, bearing in mind carbon income does not need to be able to cover all costs (as blended finance approaches are workable).

4. Market Assessment
Assess the likely supply of projects, both currently and in the future taking into account likely change to policy and practise.

If steps 2, 3, and 4 combined look favourable, the process of including the new restoration activity into the Code can then be continued. This stage can be grouped under four headings (Figure 1) and, in the most part, developed concurrently.

Science
Design Monitoring, Reporting, and Verification (MRV) protocols for the:
- Restoration activity
- Baseline scenario
- Embodied & operational emissions

Business Plan and Financial Model
Gather robust costings for:
- The restoration activities
- Maintenance costs
- MRV
- Additional operational costs for the Code

Update the current financial model of the Saltmarsh Code to include the implications of an additional restoration activity.
Create project based financial projections to estimate return on investment.

Code Design
Establish criteria for assessing:
- Additionality
- Permanence
- Leakage

Develop tools for:
- Risk – to enable quantification of buffer credits
- Financial additionality
- Carbon credit calculation

Establish Validation and Verification process (regularity, and procedure)

Ownership and Management
Consider the impact (positive and/or negative) on the structure/agreements/ procedures already in place.
Amend and agree new ways of working if appropriate (which may include further training and/or resource to run the Saltmarsh Code).

Figure 1: Individual headings of Code development to include a new restoration activity. These can take place concurrently once the initial steps have demonstrated that the inclusion of a restoration activity into the Code would be favourable.

3. Saltmarsh Restoration Review

Following the Earth Summit held in Rio de Janeiro, Brazil in 1992 where world leaders adopted the Convention on Biological Diversity, including no net loss in extent of priority habitats, saltmarsh restoration and expansion has been gathering momentum across northwest Europe. The majority of schemes have been large scale realignment of coastal flood defences either to mitigate on-going losses, or compensatory habitat. There have been a number of smaller scale schemes which have created saltmarsh which are described below.

3.1 Northwest Europe

3.1.1 Restoration methods applied

Small-scale saltmarsh restoration efforts in northwest Europe are concentrated in Germany and in the Netherlands, with one additional site located in Belgium. An overview of types of restoration strategies and associated major approaches are presented in Table 1 for these three countries for which project details were available. A map highlighting the locations for each of the projects is given in Figure 2. The individual restoration approaches are then explained in more detail and put into context. A full list of all the project sites is provided in Table A1 (Appendix 1).

A total of 31 sites were identified, which are restricted to Belgium, Germany and the Netherlands with no small-scale restoration projects identified along the North Frisian coast of Germany, in Denmark and in France. The majority of these (18) are located in Germany and represent the efforts of the Lower Saxony Wadden Sea National park to restore saltmarshes (Rupprecht et al., 2023). Another big scheme comprising two sites is the Marconi Delfzijl project in the Netherlands, which combines saltmarsh restoration for public benefits with research trials to identify best methods for successful saltmarsh creation (de Vries et al., 2021). Transplanting for research purposes is another large theme which took place across ten sites (Silinski et al., 2016; van den Ven et al., 2024). The research approaches applied are rather regional specific with no overarching method – apart from transplanting for research – apparent across these countries.

Table 1: Summary of saltmarsh restoration approaches in northwest Europe.

Country	Restoration Strategy	Number of sites	Major approaches	Sources
Belgium	Assisted biotic restoration	1	Transplanting	Silinski et al. (2016)
Germany	Assisted abiotic restoration	18	Topsoil removal, removal of summer dyke, sediment deposition into channels / creeks / ditches, creation of tidal creeks, SREDs (one site only)	Rupprecht et al. (2023)
Netherlands	Assisted abiotic restoration	1	Construction of dam, sediment deposition onto marsh, SREDs	de Vries et al. (2021)
Netherlands	Assisted abiotic restoration and biotic restoration	2	SREDs, sediment deposition onto marsh, seeding (Salicornia)	Temmink et al. (2020), Fivash et al. (2021), de Vries et al. (2021)
Netherlands	Assisted biotic restoration	9	Transplanting	Silinski et al. (2016), van den Ven et al. (2024)

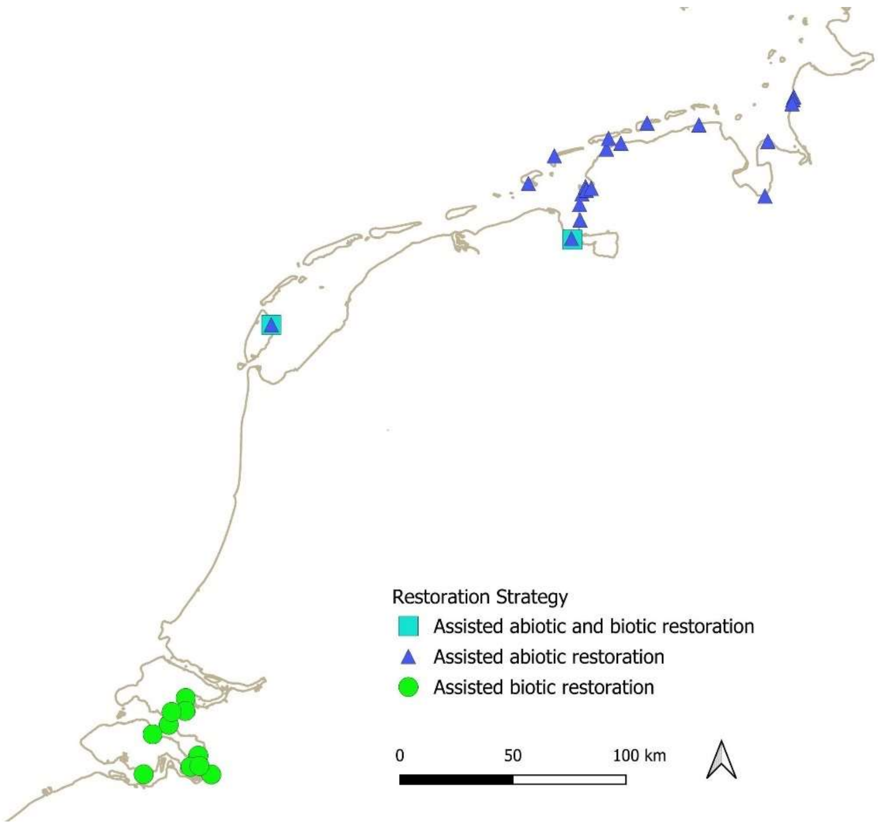


Figure 2: Locations of saltmarsh restoration sites in northwest Europe.

Abiotic Restoration Strategies

Breach of summer dyke

In northwest Europe the primary sea defences often have an additional smaller sea wall in front referred to as summer dyke. These mostly cut off the marsh from tidal inundation but do allow inundation during higher winter spring tides which bring in nutrient rich sediments to fertilise the grasses ready for summer livestock grazing. The area protected by the summer dykes are referred to as polders (from the Dutch) or "koog" in northwest Germany. Breaching or removal of summer dykes is used to reconnect the polders with the natural tidal dynamics to increase inundation frequency and duration (Rupprecht et al., 2023). Although this approach is outside of the scope of this report, it is still included here because it is often carried out in conjunction with other methods.

Creation of tidal creeks

Creation of tidal creeks can take place in several forms for different purposes. Some creeks are artificially created to direct the tidal water into particular areas of the marsh, some are created to reconnect marsh to the tides, whilst old creeks are also reactivated. In some instances, work is carried out to allow the initiation of natural tidal creek formation by flattening target areas (Rupprecht et al., 2023).

Construction of dam

As part of the Marconi Delfzijl project two riprap groynes or dams – a breakwater made out of large stones or boulders – were built. One was erected to protect the saltmarsh creation pilot site against waves and currents. The other dam was built around the saltmarsh park; it extends much further than the first dam and shields the area almost completely from tidal currents and waves.

Sediment deposition

Where appropriate sediment from topsoil removal (see below) is used to fill artificial drainage ditches to rewet the ground and to encourage natural hydrological processes. At one site the sediment retention in the creek was supported by brushwood fascines (Rupprecht et al., 2023). The Marconi saltmarsh pilot project included a trial in which different percentages of mud (defined as fraction < 63 µm) were added to the top 1 m of the subsurface. The mud was locally dredged material which had been stored on land. The saltmarsh park also had mud added but this was only harrowed into the top layer and not mixed into the top 1 m.

Sediment retention enhancement devices (SREDs)

SREDs were included at three locations, two of which in the Netherlands and one in Germany. Temmink et al. (2020) used **BESE mats**, which were installed aboveground and belowground to test whether these structures would increase transplant survival by reducing sediment mobility. Three BESE sheets were combined to create a 6 cm thick structure. Two sets of sheets were combined to create a 91 x 91 cm structure with a hole in the centre (10 cm), into which the transplant was planted. These were either installed aboveground or buried 6 cm into the sediment for the belowground application. A similar approach at the de Schorren site in the Netherlands was also described by Fivash et al. (2021) but without the belowground burial.

As part of the Marconi pilot project **brushwood fascines** were used to create seven individual compartments in which saltmarsh development was encouraged and monitored. The fascines were used to provide a barrier towards the seaward side but also to divide the compartments. One of the projects listed by Rupprecht et al. (2023) used brushwood fascines to help retain the sediment deposited into creeks.

Topsoil removal

A commonly applied method in Germany is “Oberbodenabtrag” or topsoil removal. This approach reinstates natural terrain height, increases tidal inundation and encourages sedimentation and natural creek development. The material is either used within the project, e.g. for filling drainage ditches, or used nearby for coastal protection. Immediately after the removal of the topsoil, mudflats and pioneer marsh are created but within three to five years lower marsh starts to develop. Most projects including topsoil removal are relatively recent without any long-term monitoring data. Project areas for topsoil removal are usually between 10 ha and 40 ha in size with one site as large as 70 ha. (Rupprecht et al., 2023).

Biotic Restoration Strategies

Seeding

To investigate whether seeding accelerates saltmarsh development, de Vries et al. (2021) conducted an experimental trial as part of their Marconi pilot saltmarsh creation project and seeded some of their plots with glasswort *Salicornia procumbens* seeds. This required about 1.5 years of preparation which included climate chamber trials to identify the best method for highest germination success rate. They first collected glasswort plants in autumn, which were stored for vernalization – exposure to prolonged cold which enables germination in the following spring. Plants were then chopped into small fragments, mixed with sawdust and added to freshwater for three days to initiate germination. The latter method was identified as the best approach during the trials. The wet plant fragments mixed with the sawdust were then applied to the trial plots at a density of 50 m^{-2} (de Vries et al., 2021).

Transplanting

Several transplanting trials for research have been conducted in Belgium and the Netherlands. This involved planting of sea club-rush *Scirpus maritimus* (Silinski et al., 2016) and cordgrass *Sporobolus anglicus* (syn. *Spartina anglica*) (Temmink et al. 2020; van den Ven et al., 2024). The sea club-rush plants were grown from both seeds and tubers and planted at different elevations on tidal mudflats and within marsh vegetation at an average shoot density of 121.5 shoots m^{-2} (Silinski et al., 2016). Cordgrass transplants were collected as plugs (10 x 15 cm) with 17.6 shoots per plug which corresponds to 1,133 shoots m^{-2}. These were planted into BESE mats, which were installed either aboveground or belowground (Temmink et al., 2020). Van den Ven et al. (2024) also collected cordgrass transplants from donor populations, which were reduced to eight shoots per transplant. These were planted into eight different locations and the characteristics of the different field locations (e.g. elevation, sediment properties) were related to transplant survival.

3.1.2 Restoration success

The success criteria given can be broadly classified into abiotic and biotic processes. The most commonly listed abiotic success criterium is sediment accretion. Others include soil moisture, condition of ditches and SREDs, tidal dynamic, inundation and general geomorphological development; however, these additional criteria were only applied for projects in northwest Germany (Rupprecht et al., 2023).

The most common biotic success criteria all relate to plant survival, plant establishment and the spread and growth of plants (e.g. number of shoots and biomass) but all of these are only applied in research studies and not in actual restoration projects. Instead, restoration projects focus on the wider picture in relation to plant establishment such as vegetation diversity, extent of saltmarsh area and number of saltmarsh zones.

Additionally, two projects in northwest Germany also assessed the success of habitat use for both target breeding and migrating birds. Selected indicator species for breeding birds were redshank *Tringa totanus*, oystercatcher *Haematopus ostralegus*, avocet *Recurvirostra avosetta* and meadow pipit *Anthus pratensis* (Rupprecht et al., 2023). Other monitoring parameters which were not linked to any success criteria were fish, benthos, ground beetles and orthoptera. These were monitored as part of one project in northwest Germany (Rupprecht et al., 2023).

Success evaluations are mainly carried out by research trials and relate to plant establishment or survival. Transplanting has mixed success depending on species and environmental conditions. The sea-club rush trial by Silinski et al. (2016) failed with no plants surviving seven months after planting, possibly due to transplants not reaching the biomass threshold required for survival. Initial plant survival was better in the sheltered site on bare mud areas, but on existing marsh there was no difference in plant survival between sheltered and exposed site because the marsh plants provided sheltering conditions themselves.

For cordgrass *S. anglicus* transplanting success and plant survival ranged from 0% to 80% for van de Ven et al. (2024) and depended mainly on site conditions (low-nutrient and muddy sites yielded best survival) but was also linked to donor plant origin with donor plants from sheltered sites showing better survival. Survival of cordgrass plants can be further improved with the provision of additional aboveground structures in the form of BESE mats, which increased the plant survival from 0% to 100% (Temmink et al. 2020). This is further supported by Fivash et al. (2021), who recorded more natural colonisation of plants (higher species number and biomass) on raised structures compared to control areas.

Seeding with glasswort *S. procumbens* seeds as described above was successful at the Delfzijl saltmarsh pilot improved. Best vegetation development was achieved when mud was harrowed into the top 1 m of the soil to create either 20% or 50% of mud content. The added mud most likely reduced erosion and increased soil cohesion, soil moisture and nutrient availability. Whilst seeding of glasswort enhanced plant establishment in the first year, glasswort also established naturally and in the second year the advantage of seeding compared to natural establishment was no longer apparent (de Vries et al., 2021).

An example for a successful restoration project in northwest Germany is Ostheller on Norderney. Fascines and faggots sealing the ditches remained intact and sediment accretion was taking place. Topsoil removal reduced the extent of upper marsh and created mudflats and pioneer marsh, and the breeding bird target was achieved. A further example for a successful project is Langwarder Groden at Butjadingen. The tidal dynamic was re-established by the removal of the summer dyke and creation of tidal creeks. Removal of topsoil reduced the marsh height and created pioneer and lower marsh, which subsequently increased vegetation diversity. Sediment accretion was evident at nine out of 10 sediment erosion bars (Rupprecht et al., 2023).

In contrast, Mittelplate at Leybucht was only a partial success. High elevation prevented reversal of high marsh to low-mid marsh, and efforts to increase flooding were only partially successful. This highlights that marsh elevation is key to restoration success.

3.1.3 Drivers of saltmarsh restoration

Not all restoration works state the main reasons behind the projects and it is likely that when no reason is explicitly stated, the overall driver is habitat restoration or enhancement. Among the sites in northwest Europe four drivers of saltmarsh restoration were identified:

Creation of compensatory habitat
Examples include compensatory habitat for the construction of network connections for offshore windparks (Mittelplate, Leybucht, and Ostheller, Norderney, both in northwest Germany) and for the construction of a port and dyke reinforcements (Langwarder Groden, Butjadingen, northwest Germany) (Rupprecht et al., 2023).

Research trials
Twelve out of the 31 sites had restoration work carried out with research trials as the main goal to better understand plant establishment in relation to environmental conditions (Silinski et al. (2016), Temmink et al. (2020), Fivash et al. (2021), de Vries et al. (2021), van den Ven et al. (2024).

Habitat restoration
None of the projects included in this review of northwest Europe explicitly lists habitat restoration as the main driver, even though this is probably the case for many of them. The summary of saltmarsh restoration in northwest Germany highlights that the overlying goal of saltmarsh management within the Wadden Sea Nationalpark is the protection, encouragement and restoration of natural processes; it is therefore likely that this is also the main driver behind many of their restoration projects even though this may not be mentioned explicitly (Rupprecht et al., 2023).

Public benefits and engagement
Of interest is the Marconi Delfzijl project, which specifically intended to connect the city of Delfzijl with the Ems-Dollard estuary for the enjoyment and benefit of local residents. As such, the project background considered the poor quality of life and lack of recreational opportunities of its local resident and created a saltmarsh park accessible to the public. Additionally, a saltmarsh pilot project was created for research purposes.

Public interests such as recreational needs and the opportunity to experience nature are rarely the main drivers behind saltmarsh creation but can be secondary considerations and incorporated into the overall project designs. Examples of this are board walks through the marshes with interpretation signs. These were incorporated at two sites in northwest Germany at Ronde Plate and Langwarder Groden (Rupprecht et al., 2023). The latter site is particularly promoting its recreational infrastructure with a 4 km hiking trail with signposts and information boards and a 2 km nature discovery trail (Tourismus-Service Butjadingen, no date) and was voted ‘nature wonder’ of the year 2024 by the German Hiking Association (Deutscher Wanderverband, 2024).

Of interest is that Langwarder Groden was a compensatory habitat project for the construction of a port and this raises the question whether public benefits are more likely to be incorporated into compensatory habitat projects compared to projects carried out just for habitat restoration.

3.2 UK

3.2.1 Restoration methods applied

Small-scale restoration projects have been carried out in all of the devolved nations in the UK with the exception of Northern Ireland as far as we know. A total of 63 sites were identified of which the majority is in England with only two sites in Wales and four sites in Scotland. Within England most sites are concentrated in the southeast. Figure 3 highlights all small-scale restoration schemes within the UK.

Most projects focussed on abiotic restoration with biotic restoration only included in 11 of all of the sites (Table 2). The major approaches applied across the UK are further outlined below.

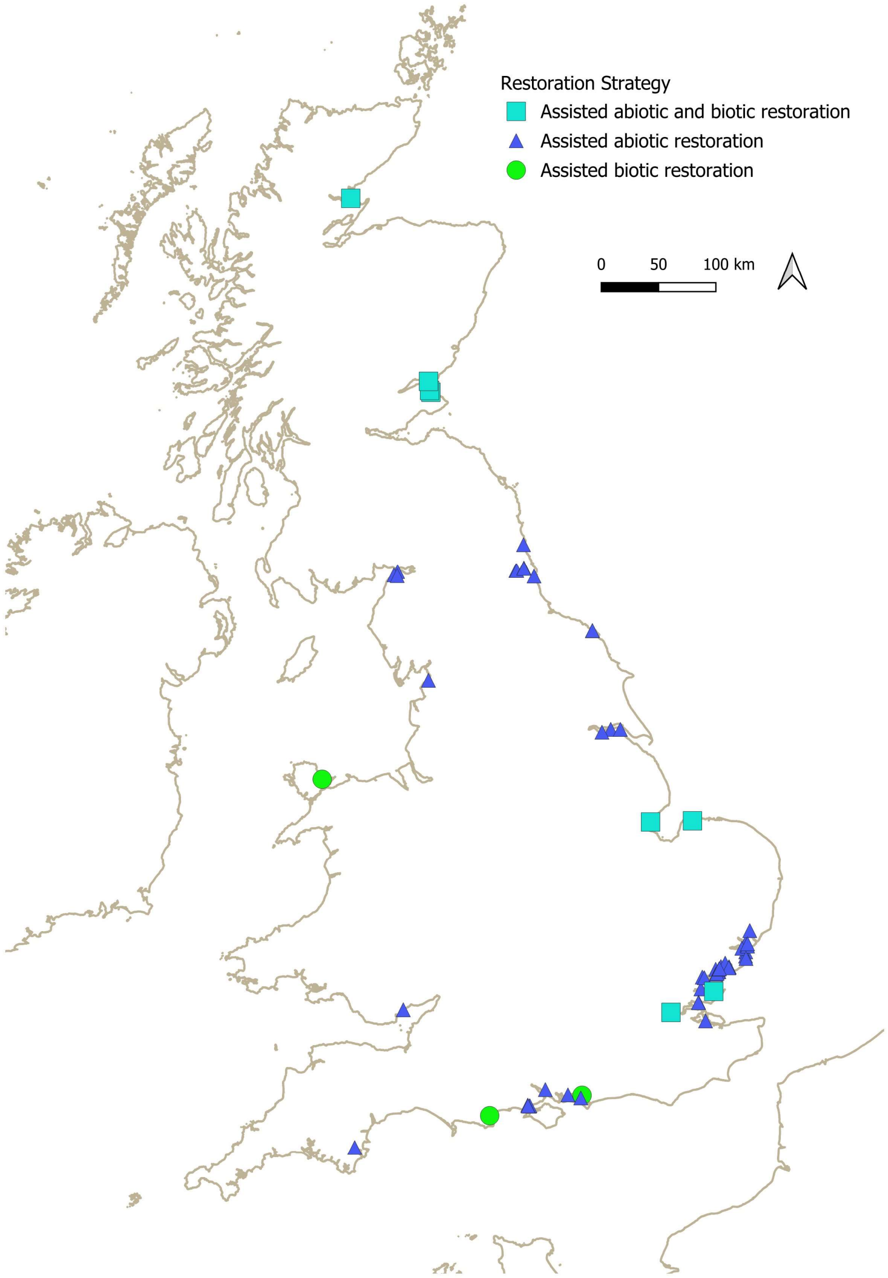


Figure 3: Locations of saltmarsh restoration sites in the UK.

Table 2: Summary of saltmarsh restoration approaches in the UK.

Restoration Strategy	Number of sites	Major approaches	Sources
Assisted abiotic restoration	52	Sediment deposition, SREDs, dragbox	OMReg Database, Defra and Environment Agency (2004), ABPmer (2016), Langley (2021), Alford (2017), Groundworks NE & Cumbria (no date), Catchment to Coast (no date), Solent Seascape Project (no date), Reeder et al. (2021), Slee et al. (2023), Dart Harbour (no date), Solway Firth Partnership (2025), Natural Dales Wool Products (no date)
Assisted abiotic restoration and biotic restoration	8	Transplanting, SREDs	Mossman et al. (2019), Maynard (2020), Salix (no date)
Assisted biotic restoration	3	Transplanting, Seeding	Defra and Environment Agency (2004), Duggan-Edwards et al. (2019)

Abiotic Restoration Strategies

Drag box

The drag box is a novel technique trialled by Land & Water in South England. One site (West Itchenor) was completed in 2023 (section 2.2.2 case study 11) and work at a second site (Boiler Marsh) commenced in 2024 (section 2.2.2 case study 12).

Polders

Whilst polders are commonly established in northwest Europe to claim land from the sea, in the UK they are generally constructed with saltmarsh creation for coastal protection in mind. A large polder project at Rhymney Great Wharf in South Wales created a 13 ha polder area between the late 20th century and 2005 with brushwood fascines to stop saltmarsh erosion and protect sea defences. Additional work at the site involved reinforcement of the sea defences (Alford, 2017). The polders were erected around existing marsh but also included bare mud areas. The existing polders were reinforced and extended by Natural Resources Wales in 2024/25 (NRW, 2025).

At Well House on Mersea Island (Essex) brushwood fascines were erected in 1986 in an area of 5.6 ha and some of this was enclosed to create polders. The project aimed to stop saltmarsh erosion through sediment accretion within the polders to protect adjacent farmland (Defra and Environment Agency, 2004).

Sediment deposition

Beneficial use of dredged sediment (BUDS) is the most commonly used application for sediment deposition, and this is usually placed on top of marshes to raise marsh height. When necessary, SREDs (e.g. clay or gravel bunds, brushwood fascines, coir rolls) are installed to hold the material in place. Less commonly, the sediment material is also placed in front of marsh edges to provide stabilisation and some of this is expected to be washed on top of the marsh by the tide (Bedlam's Bottom, Medway Estuary, Kent; OMReg Database). At Brightlingsea Creek (Essex) BUDS was used to fill borrow pits, which had been dug after the 1953 storms to excavate material for the sea walls (OMReg Database).

Sediment retention enhancement devices (SREDs)

A large variety of SREDs are applied throughout the UK; most common are **fascines** and **coir logs** across numerous locations. An example is Hackett's Marsh (Hamble River, Solent Estuary), where the Solent Seascape Project deployed **coir rolls** as creek barriers in 2024 as part of their first phase (University of Portsmouth, 2024). Also relatively common are clay and gravel bunds; these are usually applied in conjunction with sediment deposition.

Less frequent and more specialised techniques include **BESE mats**, which have only recently been applied in the UK as techniques to aid saltmarsh plants with establishment. They are being trialled by Groundwork NE & Cumbria (2023 set-up, section 2.2.2 case study 5) and the Environment Agency's Catchment to Coast project at Southend-on-Sea (2024 set-up, section 2.2.2 case study 8). **Coir mats** are also trialled as part of the Environment Agency's Catchment to Coast project at Southend-on-Sea and compared against BESE mats in terms of plant establishment, and a similar trial is being run (2024) by ExoEnvironmental Ltd in the Pyefleet channel of the Colne Estuary, England (pers. comm.). The second phase of the Solent Seascape Project at Hackett's Marsh will involve **coir mats** and planting these with plug plants (University of Portsmouth, 2024). **Rock rolls** were set up by Groundworks NE & Cumbria at one site along the River Tyne (section 2.2.2 case study 4). For their research project Mossman et al. (2019) created **sediment retaining wooden frames** which measured 1 m x 1 m and were 15 cm tall. These were filled with sediment from plots which had their height lowered by 15 cm. There are also three documented examples of the use of **rock sills** in the UK (all on the Humber in Lincolnshire) from the late 1980s and early 1990s (Defra and Environment Agency, 2004). **Corrugated plastic sheeting** was used at one site (Yacht Haven Lymington, Hampshire) to reduce drainage and enhance retention of dredged sediment (OMReg Database).

On much smaller scales, private landowners on the river Esk have also used less conventional materials to stabilise eroding saltmarsh such as **tyres** or **parts of**

shipwrecks (pers. comm. landowner; section 2.2.2 case study 6). Other material and devices were deployed at Hest Bank (Morecambe Bay) in 2024 and include **pallets** filled with chestnut stakes, **hessian sacks** filled with sheep wool and straw, **willow baskets** weaved into the shape of turtles and spider webs made out of **rope** (section 2.2.2 case study 1).

Rock-filled gabions with sediment backfill were used in Essex by the Environment Agency to repair fringing saltmarsh protecting sea walls as risk of structural collapse (Slee et al., 2023). Over a 10-year period, saltmarsh successfully established on 7 out of 15 structures, with tidal height and sediment shear strength being key drivers of success (Slee et al. 2023).

Biotic Restoration Strategies

Seeding
One occurrence of using seeds to establish saltmarsh plants is documented from Cleavel Point (Dorset) which took place in 1997/98. Seeds were collected with a large vacuum cleaner, dried, stored and then hand sown (Defra and Environment Agency, 2004).

Transplanting
Transplanting mainly takes place as part of research trials. At Red Wharf Bay on Anglesey Duggan-Edwards et al. (2019) planted cordgrass at three different sites (low, medium and high wave exposure) at three different densities. Plants were dug up from nearby marsh and planted in 80 cm x 80 cm plots. This is further outlined in section 2.2.2 case study 2.

Mossmann et al. (2019) planted five saltmarsh plant species (sea thrift *Armeria maritima*, sea purslane *Atriplex portulacoides*, sea lavender *Limonium vulgare*, sea plantain *Plantago maritima* and sea arrowgrass *Triglochin maritima*) at three different sites at manipulated heights and recorded their survival over 4 years. Seeds were collected from several natural marshes and mixed. A commercial company germinated the seeds and grew plugs. Initially, these were watered with tap water but then received artificial seawater two weeks prior to planting.

Clare Maynard started planting sprigs at the Eden Estuary as early as in 1999 and 2000 with three different species initially (sea club-rush, common reed *Phragmites australis* and common saltmarsh grass *Puccinellia maritima*). This was extended to other sites in the Tay Estuary and Dornoch Firth from 2010 onwards and also included planting of red fescue *Festuca rubra*, sea plantain, sea aster *Tripolium pannonicum*, glasswort *Salicornia europaea* agg. and sea arrowgrass. As the project expanded, she also included coir rolls at the sites to reduce wave action. What started out as a research trial has become an on-going project with increasing interest from various landowners across northeast Scotland (Maynard et al., 2011; Maynard, 2014; Maynard, 2020; pers. comm C. Maynard).

Transplanting has also been used as part of restoration projects but with limited application. The commercial company Salix, specialising on river restoration and erosion control, have planted sea aster and arrowgrass at West Thurrock lagoon and marshes (Essex) in conjunction with brushwood fascines along a 600 m edge of eroding saltmarsh (Salix, no date). Planting with cordgrass assisted with restoration on a former onshore car park at Bosham (West Sussex) and with restoration after pipe excavation at Cleavel (Dorset). The former project used locally harvested sprigs planted at 0.3 m to 0.6 m intervals, whereas the latter project used 0.15 m^2 locally harvested squares (Defra and Environment Agency, 2004).

3.2.2 Case Studies

We have selected thirteen sites to illustrate the wide range of saltmarsh restoration techniques applied in the UK (Table 3), which are presented on the following pages.

Table 3: Overview of the case studies presented on the following pages. SRED = sediment retention enhancement devices.

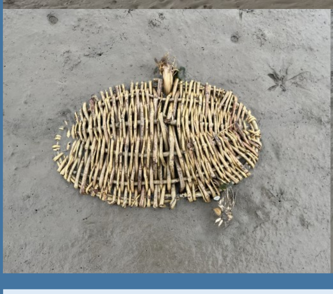
Case Study Number	Site	Restoration Year	Restoration Strategy
1	Hest Bank, Morecambe	2024	SRED
2	Red Wharf Bay, Anglesey	2016	Transplanting
3	Sandy Beck, Wansbeck	2023	SRED
4	Hebburn, Tyne	2021 & 2023	SRED
5	Gateshead, Tyne	2023	SRED
6	Esk, Whitby	2022 to 2024	SRED
7	Moverons Farm, Colne	2018	SRED
8	Two Tree Island, Thames	On-going	SRED
9	Suffolk Yacht Harbour, Orwell	Since 2014	BUDS & SRED
10	Cobmarsh Island, Mersea Harbour	2022	BUDS
11	West Itchenor, Solent	2023	BUDS & Drag box
12	Boiler Marsh, Solent	2012/2013 & 2024	BUDS & Drag box & SRED
13	Dart Estuary	2024	SRED

Hest Bank, Morecambe Bay

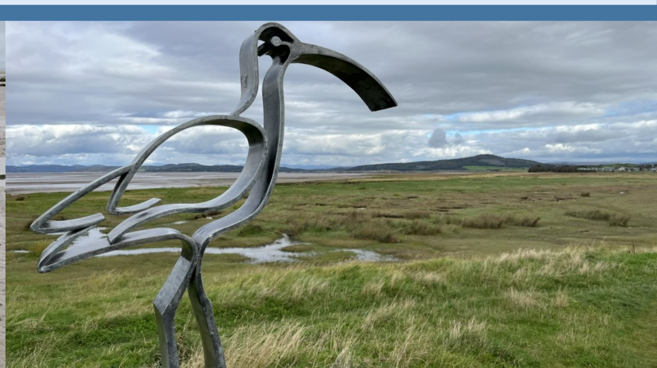
Sediment Retention Enhancement Devices

2024

[Our Future Coast](#) is an initiative funded by Defra's Flood and Coastal Resilience & Innovation Programme operating across 14 sites in the northwest of England. The overall project's aim is to work with nature and local communities to make coastlines more resilient to future change.




One of the 14 sites is Hest Bank, where an almost 2 km long stretch of saltmarsh covering approximately 28 ha has disappeared in the last 20 years. Lancaster City Council alongside Morecambe Bay Partnership and Lancaster University have raised awareness of saltmarsh within the local communities and have organised workshops to create sediment retention enhancement devices (SREDs) made with local material by local people. These were subsequently deployed by volunteers in September 2024 where the saltmarsh once existed (top). The project is testing different devices including willow turtles (centre left), pallets filled with chestnut stakes (bottom left), and sheep wool and straw filled hessian sacks (centre), and spider webs made out of rope (centre right). The effectiveness of the different devices in terms of sediment accretion and plant establishment will be reviewed in 2025 and compared to the same devices deployed in front of persisting but eroding saltmarsh at Bolton-le-Sands (bottom right). If successful, the deployment of these SREDs can be upscaled in 2025.

Red Wharf Bay, Anglesey

Transplanting

2016

A research project set up by Duggan-Edwards et al. (2020) at Red Wharf Bay on Anglesey (top left) investigated transplanting success of cordgrass *Sporobolus anglicus* at different wave forcing levels combined with different planting densities. One year after planting, the project concluded that high density planting was beneficial at the high exposure site, whereas medium density planting fared better at the sheltered site, where densely planted clumps had high mortality.

A site visit nine years after planting to the sheltered site (bottom left) and the medium wave forcing site (bottom right) only found surviving plants at the sheltered site. The original experimental plot design was still visible, and plants had not spread much into neighbouring areas. Sediment had accumulated between plots and created slightly elevated mounds, on which glasswort *Salicornia* sp. was colonizing (top right).

Sandy Bay, Wansbeck

Sediment Retention Enhancement Devices

2023

Groundwork NE & Cumbria are delivering the 'Revitalising our Estuaries' program, which implements nature-based solutions to restore a variety of ecosystems around six estuaries in the northeast of England. This includes works such as the creation of pools, bird nesting habitat, control of invasive species, but also saltmarsh restoration with different methods.

Sandy Bay contains a sandy saltmarsh approximately 0.32 ha in size. The marsh is dominated by saltmarsh grass *Puccinellia maritima* with abundant scurvy grass *Cochlearia* sp., sea plantain *Plantago maritima* present. The eastern side of the marsh shows signs of erosion and fragmentation with losses of saltmarsh in recent years. Groundwork NE & Cumbria have installed two lines of brushwood fascines to increase sedimentation and allow expansion of the existing marsh.

Hebburn, Tyne

Sediment Retention Enhancement Devices

2021 & 2023

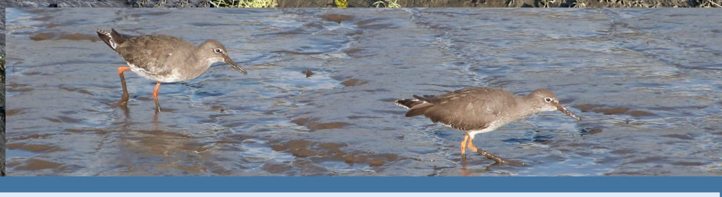
At two locations in Hebburn on the eastern side of the river Tyne, Groundwork NE & Cumbria have installed sediment retention enhancement devices to encourage sediment build up and expansion of the existing saltmarsh area. Both sites host similar marshes mostly consisting of *Salicornia* sp. pioneer marsh growing on a substrate made out of stones and coarse gravel with little mud present. A very narrow mid-marsh community dominated by sea plantain *Plantago maritima* and sea aster *Aster tripolium* is wedged in between the pioneer marsh and the sea defence.

At one of these sites (above) lines of brushwood fascine have been placed parallel to the shore with smaller sections arranged perpendicular to the shore. At the other site (below) rock rolls were installed parallel to the shore to trap sediment.

Gateshead, Tyne

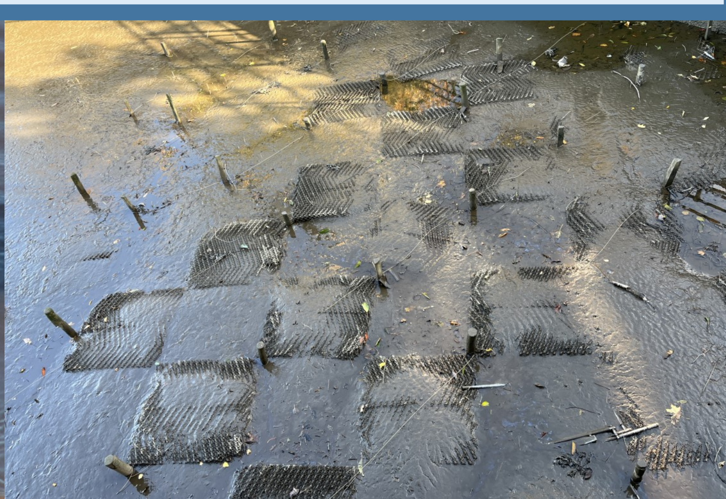
Sediment Retention Enhancement Devices

2023



At two locations in Gateshead on the southern side of the river Tyne, Groundwork NE & Cumbria have installed sediment retention enhancement devices to encourage saltmarsh plant establishment. The areas mainly consist of very soft mudflats, which provide feeding sites for wading birds such as redshank *Tringa totanus* (above) and curlew *Numenius arquata* (below). At one of these sites a very small pocket of remnant saltmarsh dominated by saltmarsh grass *Puccinellia maritima* persists .

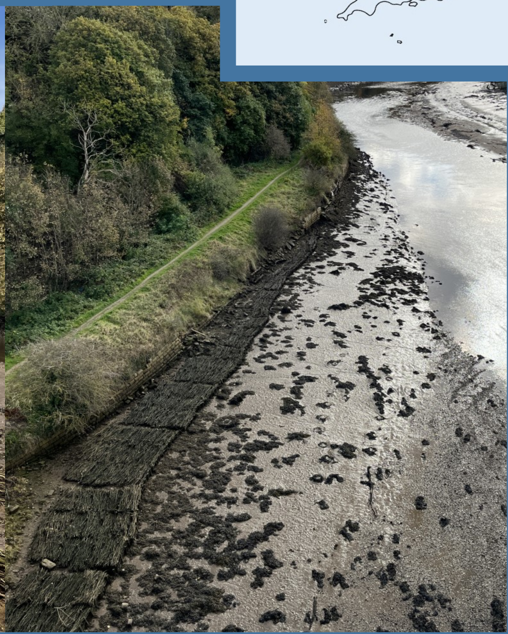
Groundwork NE & Cumbria installed a total of approximately 160 m2 of potato lattices also known as Biodegradable EcoSystem restoration Elements (BESE mats) directly onto the soft mud. These will provide temporary structures to encourage saltmarsh plant establishment and will biodegrade over 5 to 10 years' time.



Esk, Whitby

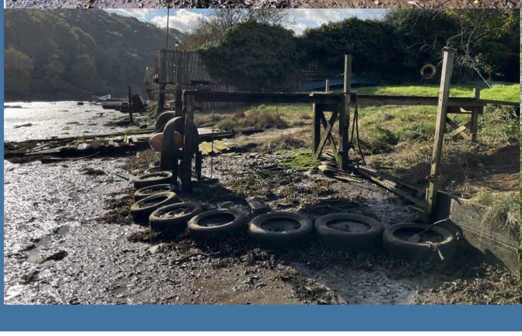
Sediment Retention Enhancement Devices

2022 to 2024



The most southerly of the 'Revitalising our Estuaries' sites is the river Esk. Small pockets of saltmarsh persist at Whitby Marina and further inland along the intertidal stretches of the river but the constraints of the river banks prohibit the marsh from migrating further. Some remnant marsh backs directly onto gardens and landowners have tried to halt the loss of saltmarsh themselves (wooden reinforcement and tyres below left).

To aid with stabilisation of the existing marsh and to trap sediment and encourage saltmarsh expansion Groundwork NE & Cumbria have installed two and three rows of brushwood fascines (top left and bottom right). At a nearby site without any existing saltmarsh they have installed up to five rows of brushwood fascines immediately adjacent to one another, which at their widest are 3 m wide (top right).



Moverons Farm, Colne

Sediment Retention Enhancement Devices

2018

A saltmarsh restoration project initiated in 2018 by the Environment Agency and Essex Wildlife Trust (EWC) installed coir rolls within creeks at two sites, one of which was Moverons Farm (top). The aim of the project was to explore the effectiveness of coir rolls to build up sediment and to contribute to carbon storage as well as to determine whether vegetation would establish on the coir rolls. A range of coir roll set ups were trialled: three and six rolls as triangular prisms, single structures, double structures and U-shape structures.

A site visit six years after installation showed that most coir rolls had trapped sufficient sediment to become buried themselves and were only visible through their support stakes and the vegetation growing on top. Vegetation species were a mixture of pioneer (glasswort *Salicornia* sp. and cordgrass *Sporobolus anglicus*) and low marsh (sea aster *Aster tripolium*) plants.

Two Tree Island, Thames

Sediment Retention Enhancement Devices

On-going

[Two Tree Island](#) is a nature reserve on the Thames Estuary managed by Essex Wildlife Trust. Its saltmarsh extent on the eastern side is also part of Leigh National Nature Reserve as the best surviving saltmarsh within the estuary. The site has a long history of channel blocking and channel stabilisation with brushwood fascines (below), which is thought to have been carried out by volunteers for at least 20 years.

The island is now also part of the Environment Agency's Flood and Coastal Resilience Innovation Programme (FCRIP) *Catchment to Coast*, which aims to improve coastal resilience to erosion and flooding with nature-based solutions across different sections of the catchment. To establish saltmarsh along the eroding seaward edge on Two Tree Island (bottom left), BESE mats (biodegradable 3D structures made out of potato starch, bottom centre) and coir mats (biodegradable mats made from coconut fibre, bottom right) are trialled to test their effectiveness for sediment accumulation and plant establishment.

Catchment to Coast

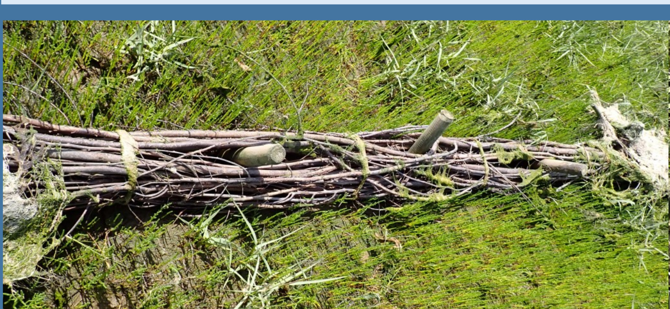
Suffolk Yacht Harbour, Orwell

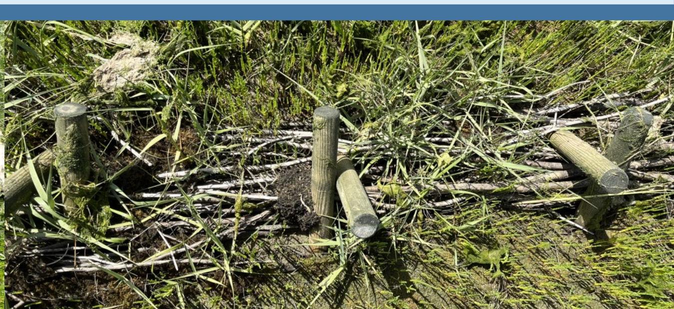
BUDS & Sediment Retention Enhancement Devices

Since 2014, on-going

Restoration work at two marshes to the east and to the west (left) of Levington Suffolk Yacht Harbour (Orwell Estuary, Suffolk) began in 2014 when a partnership between Suffolk Yacht Harbour and Stour & Orwell Estuaries Management Group and support from a range of organisations (incl. EA, MMO, Suffolk Wildlife Trust) enabled pipe installations (below) in order to pump sediment from the yacht harbour directly onto the marshes.

Initially, coir logs were used to retain the sediment. After several winters of sediment deposition and height gain of the saltmarsh from the pumped sediment, it became too difficult to carry coir logs further onto the marsh, and brushwood fascines were used instead to trap the sediment. These are supported by stakes which are installed in the shape of an 'X' (below), which prevents the brushwood from floating and being washed away. The switch from coir logs to local brushwood also significantly reduced the carbon footprint of the material used. Pumping of sediment onto the marshes is repeated annually during the winter months, alternated between both sites and sediment accretion is monitored by the Suffolk Wildlife Trust.





Cobmarsh Island, Mersea Harbour

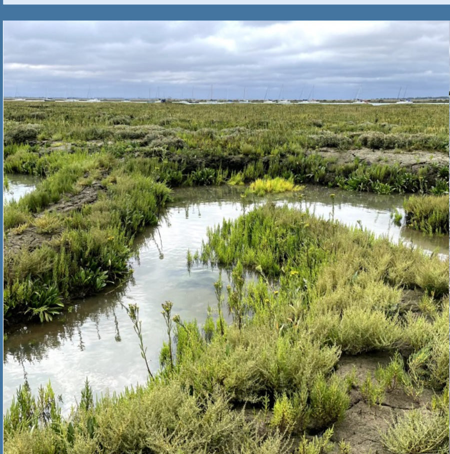
BUDS

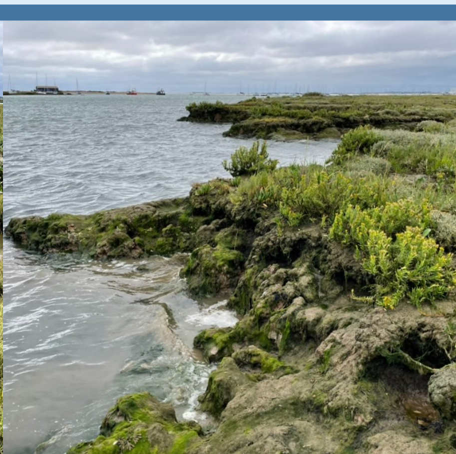
2022

10

Cobmarsh Island (left and below) is located at the entrance of Mersea Harbour and along with neighbouring island forms part of the natural protection of the harbour through wave attenuation. However, the saltmarsh extent on Cobmarsh Island declined from 12.94 ha in 1888 to 6.33 ha in 2014.

To prevent further marsh erosion, encourage marsh recovery and to create additional valuable coastal habitat such as gravel nesting sites for little terns *Sterna albifrons*, a project with beneficial use of dredged sediment from Harwich harbour was completed by the Mersea Harbour Protection Trust in 2022. Two years after completion the saltmarsh on Cobmarsh Island is characterised by a diverse sward, whereas neighbouring Sunken Island (below) – without any intervention – shows many signs of erosion.





West Itchenor, Solent

BUDS & Drag Box

2023

11

The Solent Seascape Project is restoring and reconnecting four key habitats including saltmarsh and is working with communities and stakeholders to build local capacity to improve understanding and management of seascape processes.

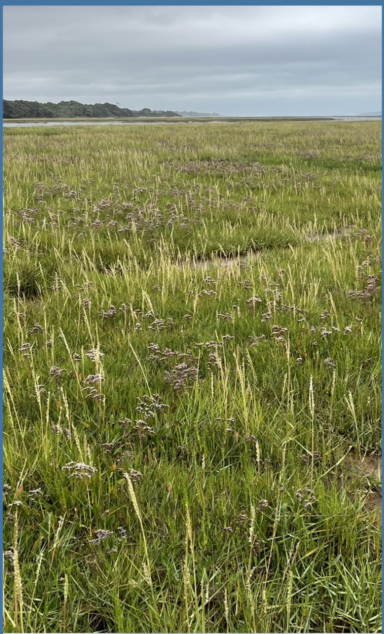
Chichester Harbour has lost more than half of its historic saltmarsh extent since 1946. To reverse some of this decline Chichester Harbour Protection and Recovery of Nature worked in partnership with Land & Water / Earth Change as part of the Solent Seascape Project to trial a new restoration technique. To apply this approach dredge sediment is deposited on the lower shore directly from a split hopper barge and it is then moved to the upper shore by a dragbox without having to introduce fences or other structures to keep the sediment in place. This was trialled at West Itchenor in 2023 for an area of about 0.1 ha (top). The site is situated between a uniform cord grass *Sporobolus* spp. marsh to the west (bottom left) and a mature and diverse marsh to the east (bottom right). A year later the first saltmarsh plants had colonised the site, mainly consisting of perennial glasswort *Sarcocornia perennis* (centre left), annual seablite *Suaeda maritima* (centre right) and some saltmarsh grass *Puccinellia maritima (*centre), but the overall plant cover across the site was below 1%.

Boiler Marsh, Solent

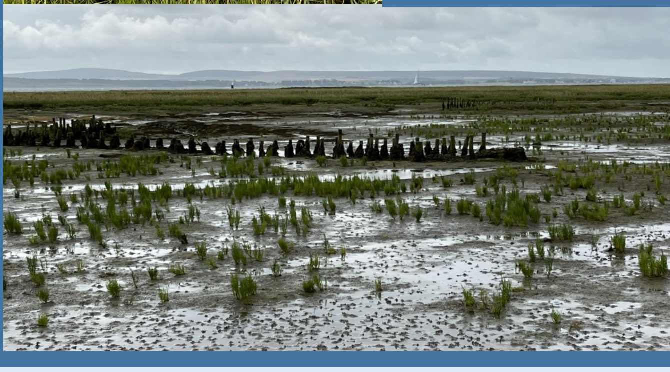
BUDS & Dragbox & Sediment Retention Enhancement Devices

2012/ 2013 & 2024

12



Boiler Marsh (left) is a saltmarsh island in the west Solent near Lymington. Prior to restoration, a channel was extending inland across the eastern side of the island, which was going to divide the island in two and accelerate the rate of marsh erosion. To halt the channel's progression, locally-dredged sediment was pumped into an area of poor quality habitat at the end of the channel in the northeast corner of the island and retained with straw-filled wooden fences (below). These campaigns (in 2012 and 2013 winters) were completed by Wightlink Ltd. and Land & Water Ltd to mitigate for any possible impacts from new ferries on intertidal habitat. This campaign used around 4,000 m3 sediment, successfully stalled the channel progression and improved habitat quality at the placement site.



Since 2014 novel restoration approaches have been applied. Every winter, the Lymington Harbour Commissioners have 'bottom-placed' locally-dredged sediment from barges into Boiler Marsh's southern bay. This material is placed as high as possible on a spring high water to help feed the marsh and form a temporary barrier to prevent marsh erosion. In 2024, a trial project was undertaken to move this placed material (now consolidated over several year) higher up using a saltmarsh restoration drag box (SRDB) (below) to increase marsh elevation and encourage plant establishment. ABPmer and others have been monitoring this site to describe how these measures perform and possibly achieve biodiversity and nutrient improvements.

Dart Estuary

Sediment Retention Enhancement Devices & Community Engagement

2024

13

The Saltmarsh Project along the Dart Estuary is led by the Bioregional Learning Centre and combines saltmarsh restoration with art integration and community engagement over a three-year period. As part of the project, volunteers are offered the opportunity to join in with hands-on saltmarsh restoration and awareness of saltmarshes and their threats are raised through talks, boat trips and art events.

UKCEH surveyed the marshes in the Dart estuary in 2024 and advised the project on appropriate saltmarsh restoration methods tailored to the requirements of each marsh. This included the installation of a boardwalk to reduce soil erosion and improve access (right), erection of brushwood fascines to enhance sediment accumulation and reduce erosion (below), and repairing a collapsed stone wall, which had resulted in marsh erosion. The project has gained local momentum and saltmarsh restoration is rolled out to other local estuaries as part of the South Devon National Landscape Estuaries Management Plan.

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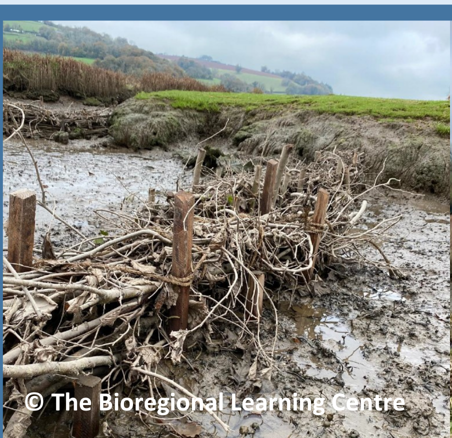

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3.2.3 Restoration success

As previously discussed, success criteria can be split into abiotic and biotic processes. The most common abiotic criteria in the UK were sediment accretion and retention with the latter criterium directly linked to BUDS. Less common were erosion progression (determined by distance of marsh retreat) and effectiveness of coastal defence, although it is unclear how the latter would be assessed.

Amongst the biotic success criteria, plant colonisation, vegetation succession, plant survival and plant biomass were the most commonly listed ones. Whilst these were largely applied by research projects – similarly to northwest European projects – many restoration projects also applied these criteria in their success evaluation. Examples include Loder's Cut Island (Deben Estuary, Suffolk; OMReg Database), Moverons (Colne Estuary, Essex) and Abbotts Hall (Blackwater Estuary, Essex (Langley, 2021) and Northey Island (Blackwater Estuary, Essex; OMReg Database). Less commonly mentioned were saltmarsh area, a diverse benthic community, ragworm abundance and the presence of feeding birds.

Additionally, a range of monitoring parameters not necessarily linked to success evaluation were also covered in monitoring programs: redox potential, sediment composition, presence of birds and marine mammals, insects, carbon captured and marsh condition.

Success in research trials

Mossman et al. (2019) had better plant colonisation and survival at raised plots (by 15 cm), which was linked to better redox potential. Raised plots were almost fully vegetated after four years through natural colonization, whereas half of the lowered plots were still unvegetated. The most successful natural coloniser was sea purslane. Sea lavender naturally colonised in a few plots but only through vegetative growth from nearby plants. On average about 35% of planted individuals survived but planting success was highly species dependent: 13% of sea thrift, 28% of sea plantain, 33% arrowgrass, 49% sea lavender and 53% sea purslane.

Maynard's (2020) transplanting success and washout rates in Scotland were site dependent but it is unclear why some sites fared better than others. Transplanting success ranged from around 15% to just over 40%. Coir rolls generally increased plant survival, but this effect was also site dependent.

Planting of cordgrass at Red Wharf Bay on Anglesey (Duggan-Edwards et al., 2020) had the best survival one year after planting at medium density (240 to 320 shoots per 80 cm x 80 cm plot) in sheltered conditions. At more exposed sites planting at a higher density improved plant survival and sediment capture. This is more detailed in section 2.2.2 case study 2.

Restoration success

Planting of cordgrass at the former car park at Bosham (Chichester Harbour, West Sussex) was successful with 100% plant survival two months after planting; additionally, the plants stabilised the substrata and prevented further erosion (Defra and Environment Agency, 2004). Planted cordgrass squares also survived well at Cleavel Point (Poole Harbour, Dorset) but did not colonise bare patches between the squares. Seeding at Cleavel Point was successful and with saltmarsh grass, glasswort *Salicornia* spp. and sea aster germinating (Defra and Environment Agency, 2004).

Vegetation also established naturally at several sites. At South Ferriby (Humber, Lincolnshire), saltmarsh plants colonised after a total marsh elevation gain of 55 cm within two years through the placement of rock sills (Defra and Environment Agency, 2004). At Point Clear - St Osyth (Brightlingsea, Essex) vegetation developed after oyster pits were filled with sediment to bring it to the same level of the natural marsh, although not every single pit was vegetated (Reeder et al. 2021).

The Essex saltmarsh restoration project initiated in 2018 by the Environment Agency and Essex Wildlife Trust installed coir rolls into creeks at Moverons Farm (section 2.2.2. case study 7) and Abbotts Hall. This was considered a successful project because sediment accreted around the coir rolls and vegetation established on top of the structures.

Success in respect to BUDS tends to refer to the amount of sediment retained at the site. Retainment of half of the material was considered a success for Bedlam's Bottom (Lymington, Hampshire) and bottom-placed sediment at Boiler Marsh (Lymington, Hampshire). Other projects report that most of the material was retained (e.g. pumped sediment at Boiler Marsh and Loder's Cut Island, Deben Estuary, Suffolk). Even when a large amount of material is washed back into the estuary, a smaller amount may be sufficient to achieve the restoration aims. This was the case for Levington Suffolk Yacht Harbour (Orwell Estuary, Essex) (OMReg Database).

The drag box pilot project at West Itchenor (Chichester Harbour, West Sussex), raised the height of the foreshore with the first vegetation emerging after the project was carried out (section 2.2.2 case study 11).

Northey North West sediment deposition and old sea wall reinforcement were successful in retaining the deposited sediment and the area also accreted additional sediment. This led to expansion of the saltmarsh area (OMReg Database).

Sediment accretion can also be a success indicator, but this will be site dependent. Examples include a total gain of 55 cm at South Ferriby (Humber, Lincolnshire) and a gain of 80 cm at Goxhill, Humber, Lincolnshire (Defra and Environment Agency, 2004).

A different example of a successful project with benthic invertebrates as the main criteria was Parkeston Marshes (Stour Estuary, Suffolk), where sediment was deposited onto the marsh to enhance the habitat. A diverse benthic community had colonised the sediment but the material was coarser than in neighbouring natural marsh, which meant that the benthic community also differed (OMReg Database).

Unsuccessful restoration projects

Unsuccessful projects unable to halt erosion include Lymington River (Lymington, Hampshire), where the marsh continued to retreat at 1 m per year even after coir rolls were installed. The reason behind this was three-fold: wave action caused gaps in coir rolls, wave reflection between cliff edge and coir rolls exacerbated erosion and scour and subsidence caused coir rolls to sink (Defra and Environment Agency, 2004). At Well House (Mersea Island, Essex) even though the polder accreted erosion, the marsh behind the polders further retreated (Defra and Environment Agency, 2004). This highlights that accretion alone may not be a sufficient success criterium if the project has additional aims.
A further example of an unsuccessful saltmarsh restoration project is Shotley Marina (Orwell Estuary, Suffolk). Even though the tidal flat was raised through sediment deposition, which increased sediment invertebrate diversity and feeding wading bird abundance, the increase in height was not sufficient to encourage saltmarsh plant establishment (Defra and Environment Agency, 2004).

At Shotley Foreshore (Orwell Estuary, Suffolk) mobile clay bunds led to mass loss of deposited material. Combined with consolidation this reduced the backfill level by 60 cm (Defra and Environment Agency, 2004). The sister scheme at Trimley Foreshore (Orwell Estuary, Suffolk) was more successful with stable sediment one month after scheme completion but the benthic community was still poor (Defra and Environment Agency, 2004).

Rhymney Great Wharf is an example of mixed success. Further retreat of the wharf was prevented by the installation of brushwood fascines to create polders and the sea defences were maintained; however, the mud flats in front of the Wharf did not accrete any sediment and therefore did not develop into saltmarsh (Alford, 2017).

3.2.4 Drivers of saltmarsh restoration

Drivers of small-scale saltmarsh restoration are quite variable in the UK and include the following:

Creation of compensatory habitat
There are two examples of saltmarsh restoration as compensatory habitat for major construction work including Allfleet's Marsh MR site, which included BUDS and the construction of clay bunds. This site was created to make up for losses on intertidal habitat to port development at Lappel Bank (Medway Estuary) and Fagbury Flats (Orwell Estuary) (OMReg Database). The Boiler Marsh (Lymington Estuary, Hampshire) was carried out by Wightlink Ltd. to mitigate for possible effects from new passenger ferries operating in the Solent Estuary European Marine Site (OMReg Database).

Research trials
At nine sites research trials were the main purpose for saltmarsh restoration projects. At eight of these, research projects looked into understanding plant survival after transplanting in relation to environmental conditions (Duggan-Edwards et al., 2019; Mossman et al., 2019; Maynard, 2020) and one study compared the efficiency of two different SREDs in relation to saltmarsh plant colonisation (Two Tree Island, Catchment to Coast, currently underway).

Habitat restoration
The umbrella term 'habitat restoration' covers many different facets such as saltmarsh restoration, enhancement, creation and halting of erosion. Examples of these include habitat creation at Allfleet's Marsh (Wallasea Island, Essex) through bunds and BUDS, habitat enhancement by filling borrow pits at Brightlingsea Creek (Essex) with BUDS, habitat restoration at Moverons (Essex) by blocking creeks with coir rolls and saltmarsh restoration work, the range of saltmarsh restoration and creation by Groundworks NE & Cumbria, and the attempt to halt saltmarsh erosion at several sites such as Lymington River (Hampshire) with coir rolls or polders at Well House, Mersea Island (Essex).

Demonstration or pilot project
The Bedlam's Bottom (Medway, Kent) BUDS project in 1996 was a demonstration project for bottom dumping and trickle feeding of sediment without any retention devices (OMReg database). There are also two drag box pilot projects to date: The Boiler Marsh (Lymington Estuary, Hampshire) drag box project in 2024 and the first small project at West Itchenor.

Coastal protection and flood risk management
The Horsey Island recharge project has been on-going since 1988 to protect the deteriorating seawalls. This first involved creating barriers as wave energy breaks and then using BUDS over several years to stabilise the barriers and create marsh habitat. The polders made with brushwood fascines at Well House on Mersea Island were also intended as coastal protection for the farmland immediately behind the narrow strip of eroding saltmarsh. The polders at Rhymney Marsh (Severn Estuary, South Wales) also aim to protect the sea defences.

Not all flood risk management and coastal protection projects aim to protect man-made structure but can also be directed at protecting natural features. This was one of the aims behind the 'Mersea Harbour and Tollesbury Wick Climate Change Adaptation Recharge Project' in the Blackwater Estuary (Essex), the bottom dumping of dredged sediment onto Boiler Marsh (Lymington Estuary, Hampshire), and the Northey Island (Blackwater Estuary, Essex) BUDS projects.

Public benefits and engagement

It appears that no project has public benefits incorporated as the main aim of saltmarsh restoration and only two projects integrated this element into project delivery. One of the key aims for the Our Future Coast initiative in northwest England is working with local communities and consequently the saltmarsh restoration project at Hest Bank (Morecambe Bay) has integrated public engagement into their project delivery. This included workshops to make and deploy SREDs. This is further outlined in section 2.2.2. case study 1. Groundworks NE & Cumbria also include public benefits into their project delivery. This involves school and scout group visits, workshops to make restoration features and supporting corporate volunteer days. Additionally, 36 young people were employed to work on their restoration projects across a range of habitats, including saltmarsh (pers. comm. H. Hornby).

4. Fieldwork at selected UK sites

4.1 Fieldwork methods

Between July and September 2024, fieldwork surveys were carried out at 14 different saltmarsh locations in Suffolk, Essex and Hampshire in England (Table 4, Figure 4). Sites were chosen where different types of saltmarsh restoration interventions had been undertaken. The time span of these interventions varied from one to 20 years. Within each intervention site, areas of marsh directly impacted by the interventions were surveyed, as well as areas of "reference" marsh away from the site of intervention, but within the same marsh area. In addition, a number of further reference sites were also surveyed, to provide additional baseline data for relatively well-established saltmarshes or at locations where interventions are currently being considered. The reference sites were either high-quality saltmarsh that could possibly the target for restoration work or a control marsh where intervention may be necessary but had not taken place.

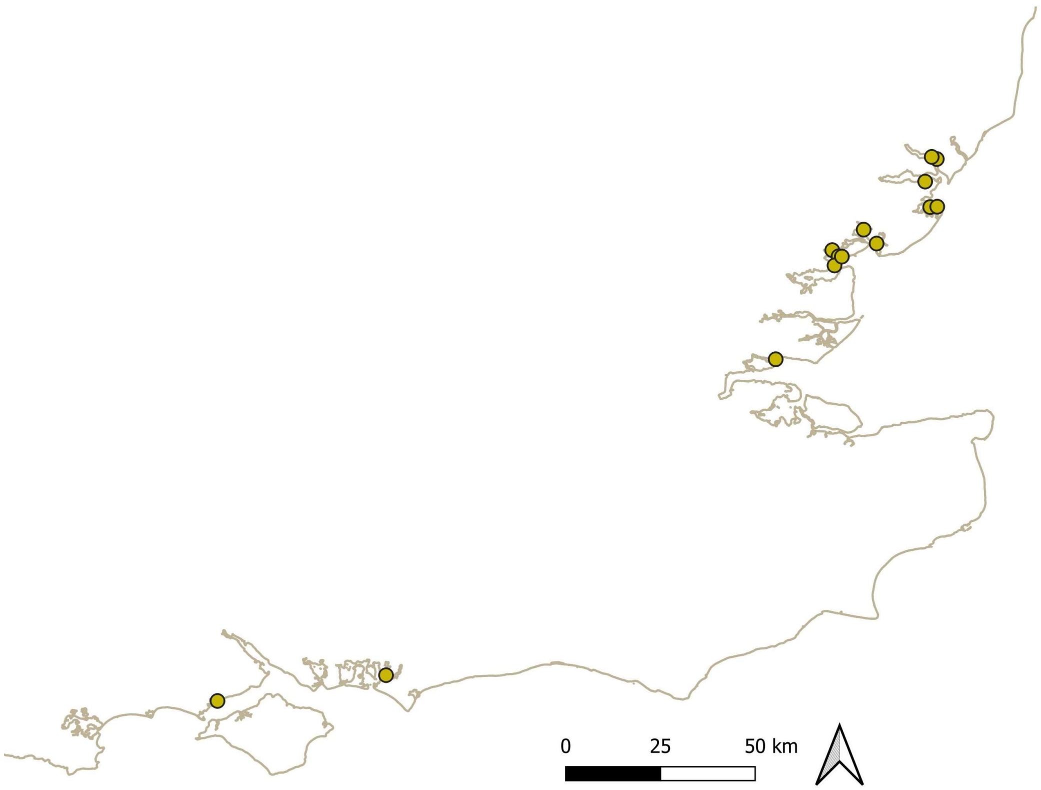

Figure 4: Locations of fieldwork sites along the UK southeast and south coast visited in 2024.

Table 4: Overview of fieldwork sites and interventions.

Site Names	Intervention Year	Intervention	Number of transects	Number of quadrats
Abbotts Hall	2018	Coir rolls (within-creek)	2	10
Boiler Marsh - Lymington	2013	Creek blocking (fascines) and BUDS (sediment pumped)	2	10
Copperas Bay - Harwich	Future work	Reference, pre-restoration	3	15
Horsey Island	Early 1990s to 2006	Creek blocking and BUDS (sediment pumped)	2	10
Itchenor	2023	Drag box and BUDS (previously deposited)	3	15
Levington East	Since 2014	BUDS (sediment pumped)	2	10
Levington West	Since 2014	BUDS (sediment pumped)	2	10
Moverons - Brightlingsea	2018	Coir rolls (within-creek)	2	10
Old Hall	2021/22	BUDS Shingle bank	2	10
Point Clear - St Osyth	October 2016 to March 2017	Creek blocking (wooden sluice boxes placed across internal marsh creeks) and BUDS (sediment pumped)	2	10
Stone Marsh - Walton	Future work	Reference, pre-restoration	1	8
Tollesbury	2021/22	BUDS	2	10
Two-Tree Island - Southend	Creek blocking: on-going since at least 2005, BESE mats and coir mats: 2024	BESE mats and coir mats; creek blocking (fascines)	2	10
West Mersea (Cobmarsh, Sunken Island)	1997-1998 and 2022 (Cobmarsh only, Sunken Island is reference site	Cobmarsh: BUDS, Sunken Island: no intervention	2	10

4.1.1 Site Walkovers

The first phase of data collection at each site involved conducting a detailed site walkover survey per area (non-intervention and intervention) to document baseline conditions and identify key features of the marsh system. Data collection was guided by a structured site walkover sheet, which captured parameters including: site identification, general characteristics and restoration method. Sites were categorised based on their creek system (e.g., dendritic creek systems with extensive salt pans) and any other notable features. Approximate dimensions and characteristics of the marsh zones (pioneer, low, mid and high) were documented. Any additional distinct areas were noted, if present.

Observations were made of key geomorphic and sedimentary features such as erosion and sediment build-up. Additionally, an assessment of the marsh boundary conditions at the seaward edge and the landward edge were performed and included cliffing, clay seawalls and alternative transitions to terrestrial environments.

Vegetation was surveyed and categorised based on the relative abundance of halophytes and algae within the marsh system. Observations were grouped using the DAFOR technique: Dominant (>50%), Abundant (31-50%), Frequent (16-30%), Occasional (6-15%), Rare (1-5%).

4.1.2. In-field quadrat data collection

To evaluate plant species composition, soil properties, and structural characteristics of the marsh, a transect survey was conducted per area (non-intervention and intervention) following a standardised protocol. Transects lines were placed to capture the variation within the areas of intervention, and in the “reference” area. There were five quadrats (2 x 2 m) per transect, placed roughly equidistant between the seaward marsh edge (Q1) to the landward edge of the (Q5) marsh. The transect surveys captured data on species presence, vegetation cover, soil parameters, and other relevant attributes.

GPS waypoints were documented to allow for precise relocation. Within each quadrat, the percentage cover of each plant species and ground cover was estimated visually using the Domin scale, including algal cover, bare mud, tidal litter, water, cyanobacteria. Five random vegetation height measurements were taken within each quadrat to assess structural variability. Six random soil strength measurements were taken using a shear vane at two depths: three measurements at the soil surface (0 cm) and three at 10 cm depth. No Shear vane measurements were made at the Tollesbury and Old Hall sites due to loss of equipment.

Soil Moisture was measured by the TMS-4 (TOMST) data logger, which was moved around the quadrat to account for variability. The soil moisture data is stored as raw counts with counts around 3,600 representing full saturation in most soils (TOMST, no date) but full saturation in saltmarshes is consistently around 4,000. To assess

salinity levels, five random measurements of soil electrical conductivity were taken in each quadrat. Results were recorded in millisiemens per centimeter (mS/cm). Conductivity was not measured at every site due to equipment faults.
Two random soil samples were taken within each quadrat using an auger. When collected, the cores were split into the top (0 – 5 cm) and 5 – 10 cm depth for further analysis in the lab for water content, loss on ignition (LOI) and total organic and inorganic carbon. Additionally, two random soil samples were taken using a bulk density core for further analysis in the lab for water content and bulk density.

4.1.3. In-field topography data collection

A theodolite and levelling rod were used to accurately assess the elevation profiles and creeks within each marsh system. The instrument was used to understand the relationship between the marsh surface and its adjacent creek systems. At each area (non-intervention and intervention), 20 paired measurements were collected. Each pair included the marsh surface elevation next to a creek and the corresponding creek's depth. Some larger areas included 40 pairs of measurements to account for a larger variability. At some sites another set of elevation measurements were collected to assess the marsh/creek elevation immediately where coir rolls/creek blocking were present.

4.1.4. Laboratory data collection

Water content
To quantify the water content in marsh sediment, soil samples from each depth (0–5 cm and 5–10 cm, n = 2) and from the bulk density corer were weighed to record the wet weight. Samples were then dried in an oven at 60°C for 48 hours or until a constant weight was achieved. The dry weight of each sample was recorded and the water content (%) was calculated.

Loss on ignition (LOI) to determine Soil Organic Matter content (SOM)
To determine the organic matter content through LOI, subsamples (dry sediment) from each depth (0–5 cm and 5–10 cm, n = 2) were finely ground and placed in a pre-weighed crucible. Samples were weighed and then placed in a muffle furnace and heated at 550°C for 3 hours to combust organic material. After cooling, the samples were weighed again and LOI (%) was calculated. This is also referred to as soil organic matter (SOM) content.

Bulk Density
To measure sediment bulk density, soil samples from the bulk density corer (volume of 251.33 m^3, corer 8 cm diameter and 5 cm tall) were weighed to record the wet weight. Samples were then dried in an oven at 80°C for 48 hours or until a constant weight was achieved. The dry weight of each sample was recorded, and the bulk density (g/cm^3) was calculated.

Total organic carbon (TOC)

To determine the total organic carbon content, 100 mg of finely ground dry sediment from each core subsample (0–5 cm and 5–10 cm, n = 2) was weighed into individual crucibles. TOC (%) was measured using a solid sample TOC combustion analyser that oxidizes organic carbon into CO_2 , which was quantified.

Inorganic Carbon (IC)
To quantify inorganic carbon (IC) content, 50 mg of finely ground dry sediment from each subsample was weighed into a test tube. IC was measured by acidifying the sample by adding phosphoric acid and Milli-Q water to release CO_2 from carbonate minerals. The released CO_2 was quantified to determine IC content. For both TOC and IC, a standard curve was prepared using carbon standards at 12% and 19% concentrations to ensure calibration accuracy.

4.1.5 Data Analysis

Aerial images of each field site were obtained from Google.Earth and locations of quadrats, intervention locations plotted (using latitude and longitude measured in the field using GPS). Using the Environment Agency publicly available LIDAR database (© Environment Agency copyright and/or database right 2022. All rights reserved), the elevation (relative to ordnance datum) was determined for each quadrat and location. LIDAR height measurements were also extracted from this data source for the location used as the baseline for the theodolite measurements taken at each site. All theodolite measurements of sediment and creek heights were then converted into Ordnance Data (m).
The unit of replication for data analysis was the individual quadrat. Sample sizes were generally n = 5 for each intervention and corresponding reference site. Multiple data measurements taken within quadrats (see above) were averaged to provide a single quadrat data value. This was then paired with other quadrat data, such as community plant cover, species composition, elevation etc. Box plots, scatter plots and statistical analysis (non-parametric Kruskall-Wallis and post-hoc Wilcoxon rank sum exact tests, Peason’s correlations) were conducted in R, using the package R-Studio (RStudio 2024.09.1+394 "Cranberry Hibiscus" Release). Statistically significant differences, correlations or relationships were determined using a probability value of $p < 0.05$ or less.

4.2 Results and discussions

4.2.1 Case Studies

Moverons Farm (section 2.2.2, case study 7): coir rolls and creek blocking

The saltmarsh quadrats at Moverons farm in the Colne Estuary, Essex, were mainly positioned around 3 m ODN. The non-intervention site is relatively flat, at 2.77m ODN, with a classic mid-low marsh flora approaching 100% cover, dominated by common saltmarsh grass, and sea purslane with some sea aster (Figure 5). Towards the sea, there was an increased abundance of the annual halophyte sea blite *Suaeda maritima*. The intervention site, where Essex Wildlife Trust (EWT) installed coir rolls in 2018 had been historically reclaimed, but the seawalls breached naturally many years ago (sometime between 1896 and 1921 (English Nature, 1992). The site is now also dominated by common saltmarsh grass and sea purslane (Figure 5) and is set back and protected by some natural saltmarsh at the seaward edge. This site was slightly lower in the tidal frame (2.65 m ODN), and contains greater areas of sea blite, algal cover, and bare mud. Despite this different history, there was no difference in sediment water content (Figure 6), SOM (Figure 7), TOC (Figure 8) or sediment shear strength (Figure 9) between the intervention and non-intervention areas. Both areas were criss-crossed with relatively deep creeks 0.5-0.7m deeper than the surface of the marsh (Figure 10). Where coir rolls had been deployed across the back of the intervention area, the difference between marsh surface and creek bottom was slightly less (-0.4 m),and the bottom of the infilled creeks was about 30 cm higher than the creek bottoms in the main marsh of both areas (Figure 11).

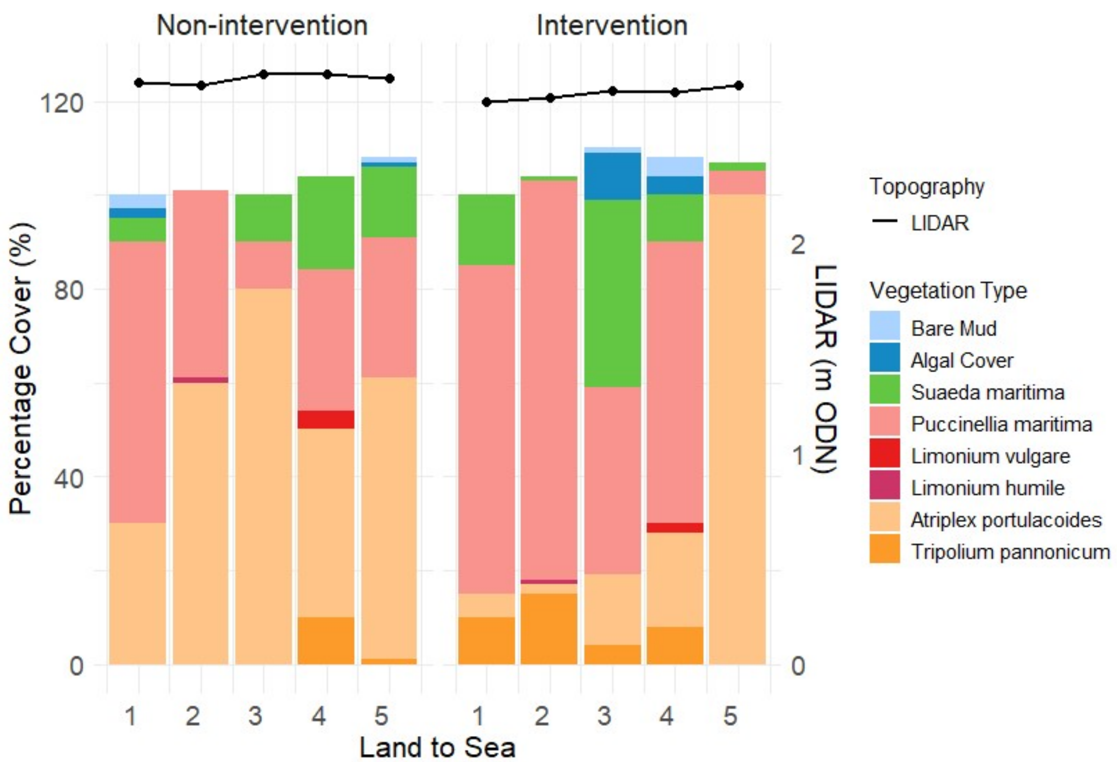

Figure 5: Vegetation percentage covers and site elevation in meters (based on LiDAR) at Moverons Farm. Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

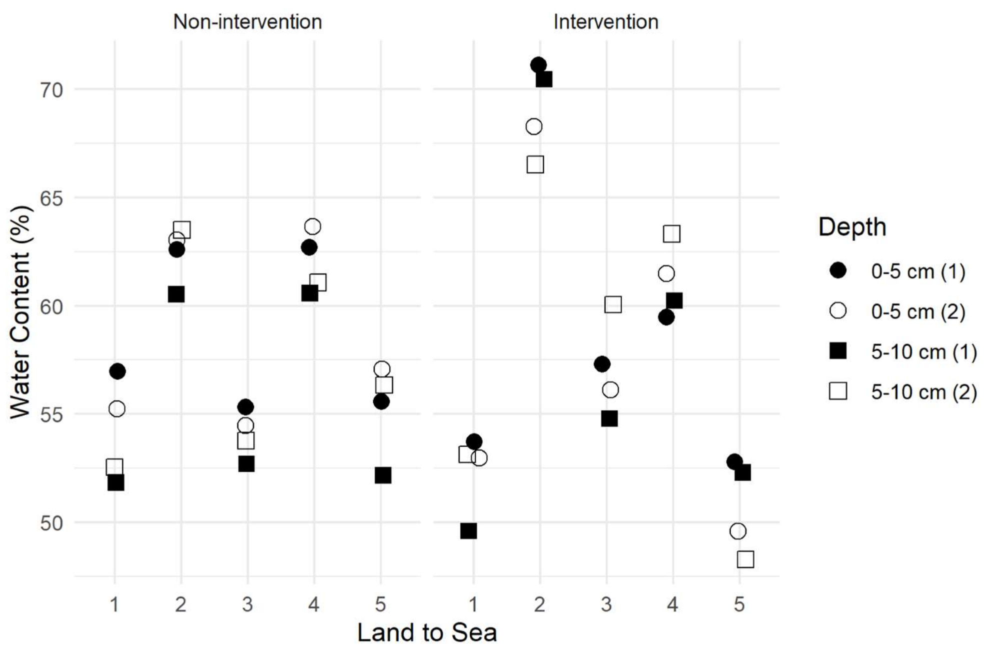

Figure 6: Water content from soil core samples (quadrat n = 2) at Moverons Farm. Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

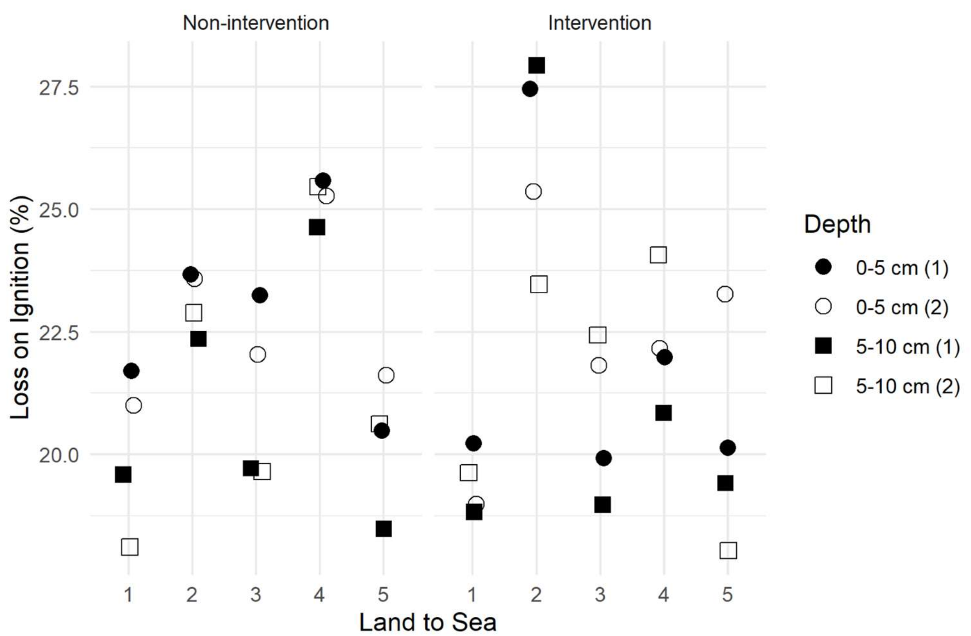

Figure 7: Soil organic matter content (loss on ignition (%)) from soil core samples (quadrat n = 2) at Moverons Farm. Numbers 1 to 5 represent the

position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

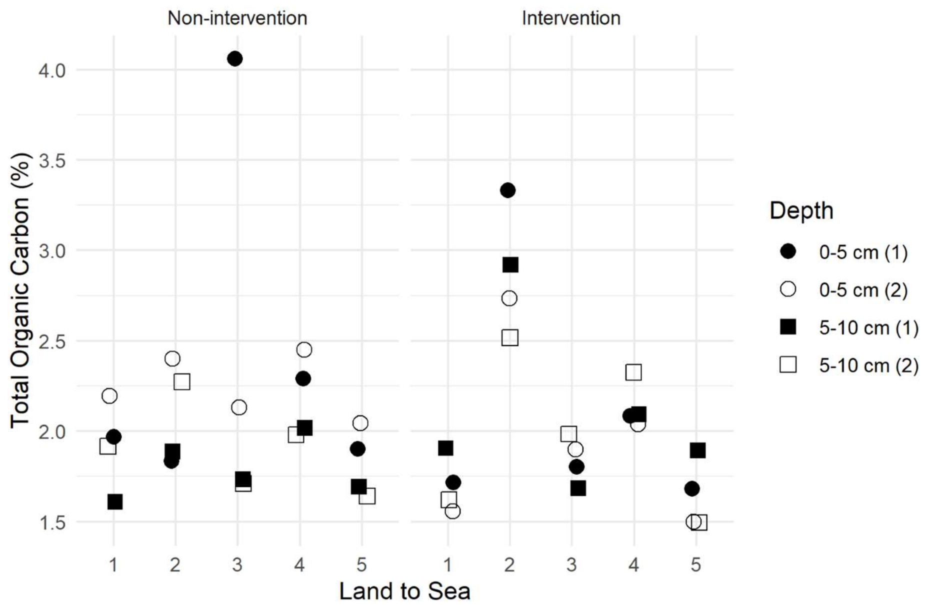

Figure 8: Total organic carbon (%) from soil core samples (quadrat n = 2) at Moverons Farm. Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

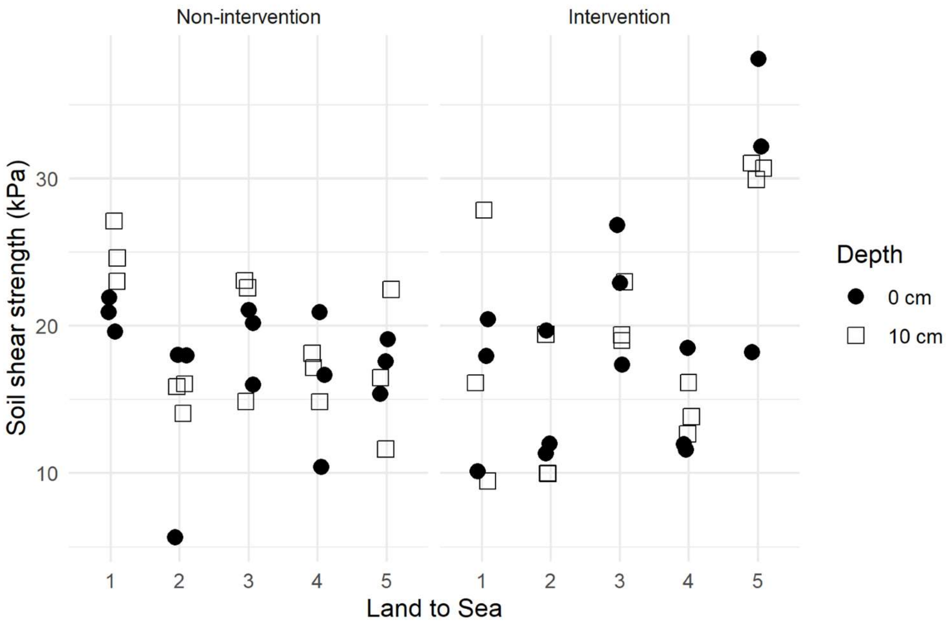

Figure 9: Soil shear strength (kPa) at Moverons Farm (quadrat n = 3). Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

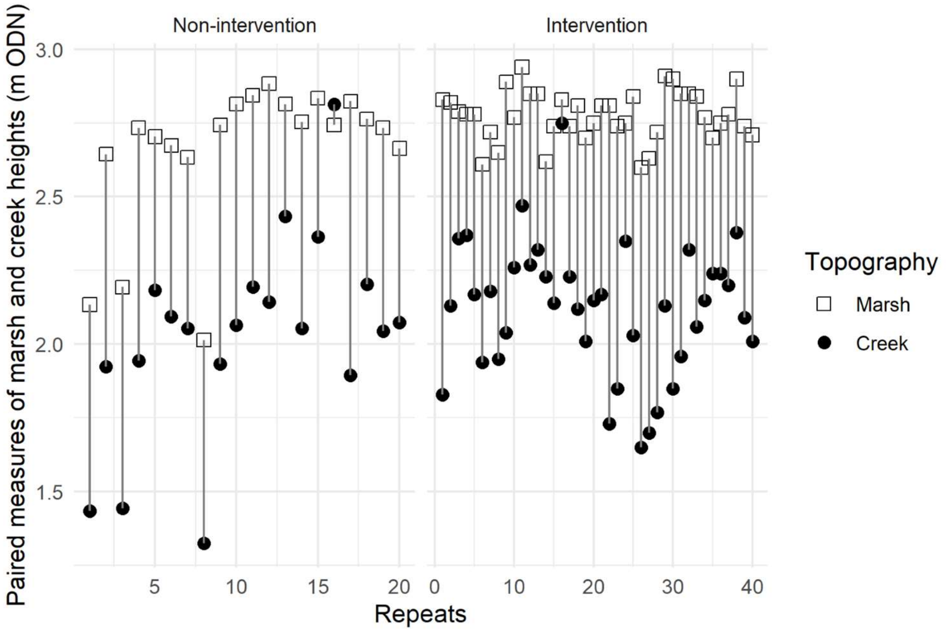

Figure 10: Paired theodolite and levelling rod measurements of marsh surface height and creek bed height at Moverons Farm. Non-intervention n = 20, intervention n = 40.

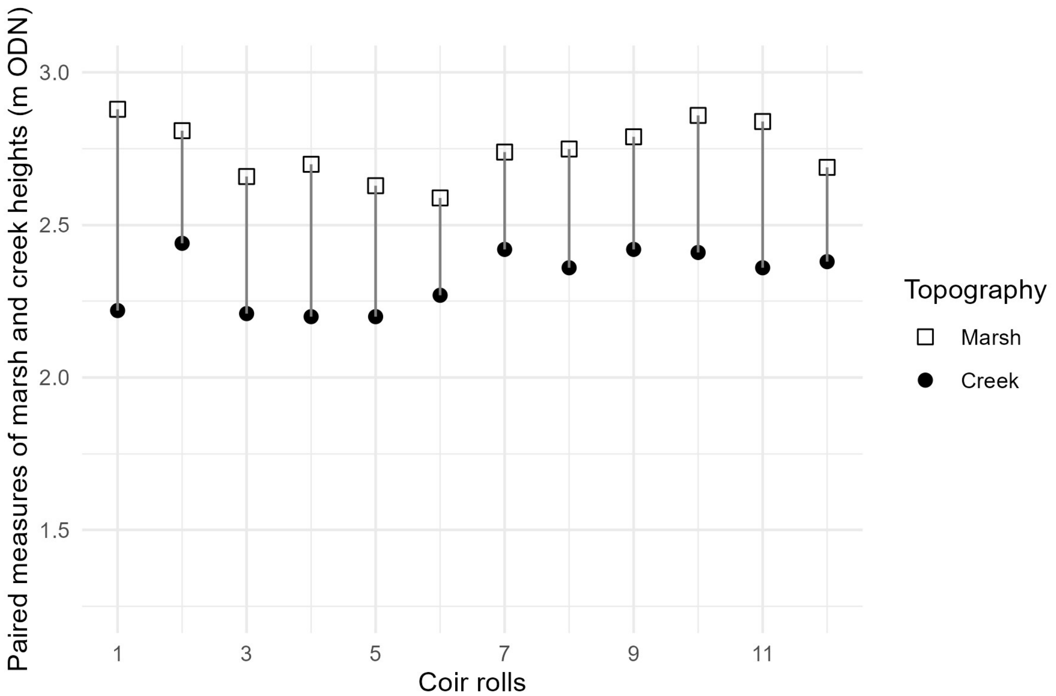

Figure 11: Paired theodolite and levelling rod measurements of marsh surface height and creek bed height at Moverons Farm immediately where coir rolls had been installed, n = 12.

Two Tree Island (section 2.2.2, case study 8): creek blocking, and BESE matting

In comparison to Moverons, Two Tree Island in the Thames estuary, is a site that has been subject to significant erosion over the last decades (University of Essex unpublished data) and is a focus site for restoration in the EA-funded Catchment to Coast project (case study 7). Both the non-intervention and intervention transect lines were around 3 m ODN, with 100% cover of vegetation (mainly saltmarsh grass and sea purslane) but with greater coverage of sea aster and cordgrass. The seaward region was characterized by lower marsh halophytes, glasswort *Salicornia* agg., perennial glasswort *Sarcocornia perennis*, bare mud and tidal litter (Figure 12). The marsh surface in the intervention region was 10 cm lower than the non-intervention area, with higher sediment water content (Figure 13), extensive cordgrass in Q5, and generally lower SOM content (Figure 14). Creek bottoms were deeper (15 cm) in the intervention area than in the non-intervention area, with marsh-creek differences around 40 cm (Figure 15). Where brushwood fascines had been used across the back of the intervention area of the marsh, the sediment height in the creeks was higher (+15 cm) than in creeks in the adjacent marsh (Figure 16). The BESE matting and coir rolls were placed below Q5, but only during 2024, and have not yet had time to be colonised.

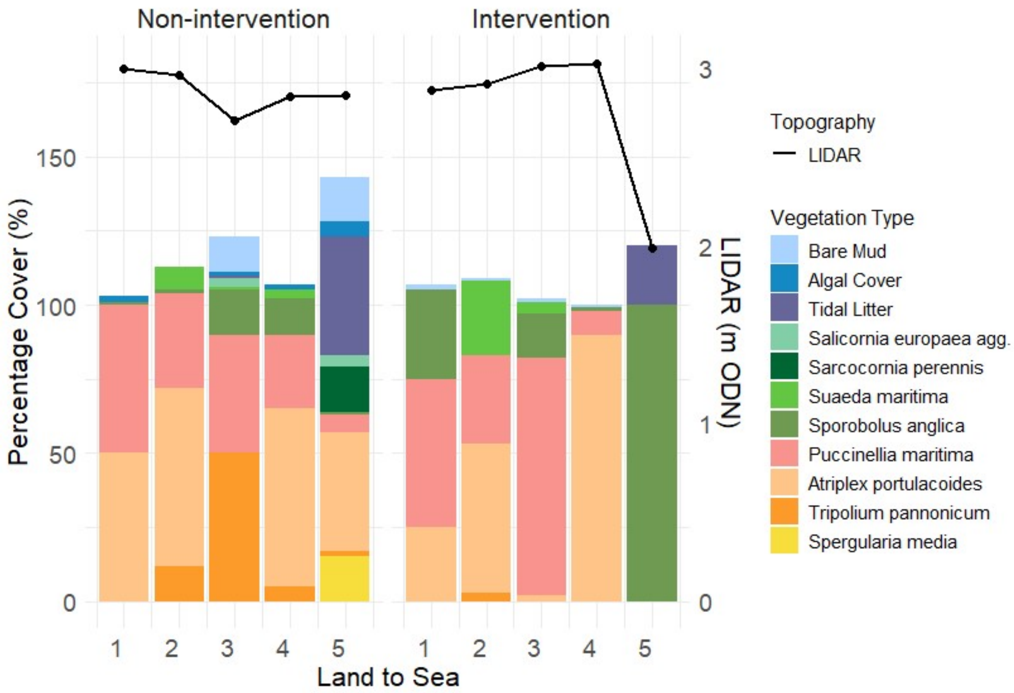

Figure 12: Vegetation percentage covers and site elevation in meters (based on LiDAR) at Two Tree Island. Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

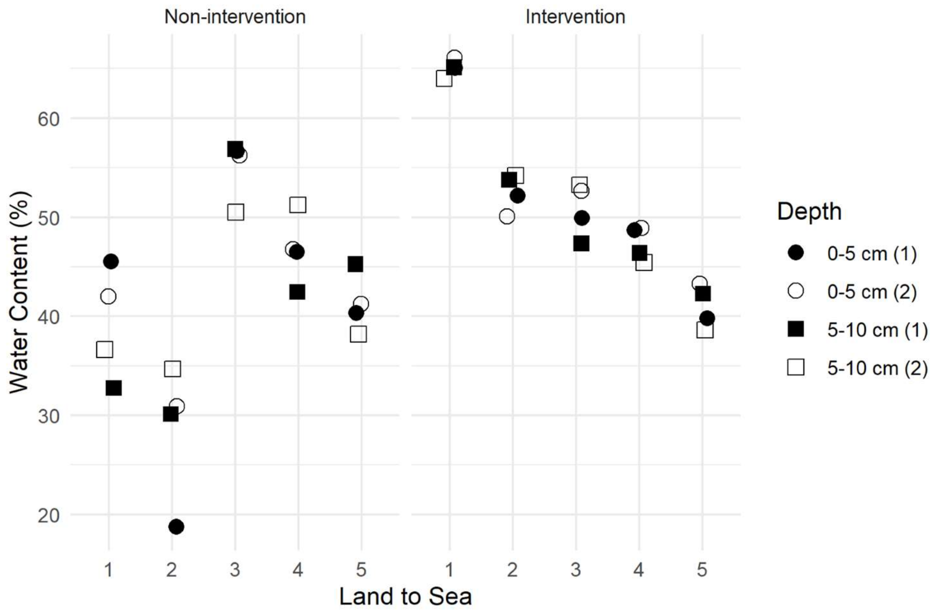

Figure 13: Water content from soil core samples (quadrat n = 2) at Two Tree Island. Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

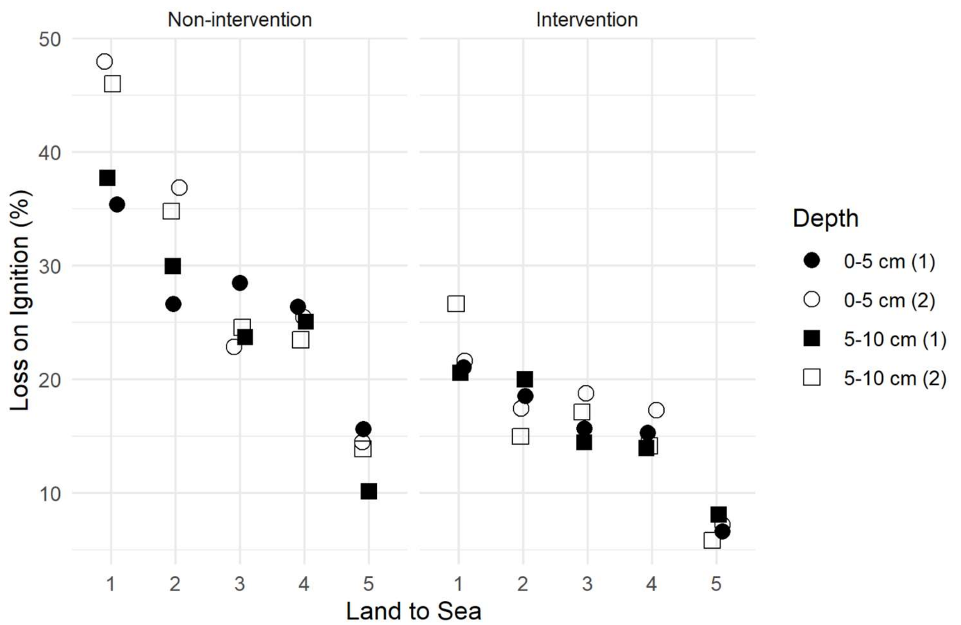

Figure 14: Soil organic matter content (loss on ignition (%)) from soil core samples (quadrat n = 2) at Two Tree Island. Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

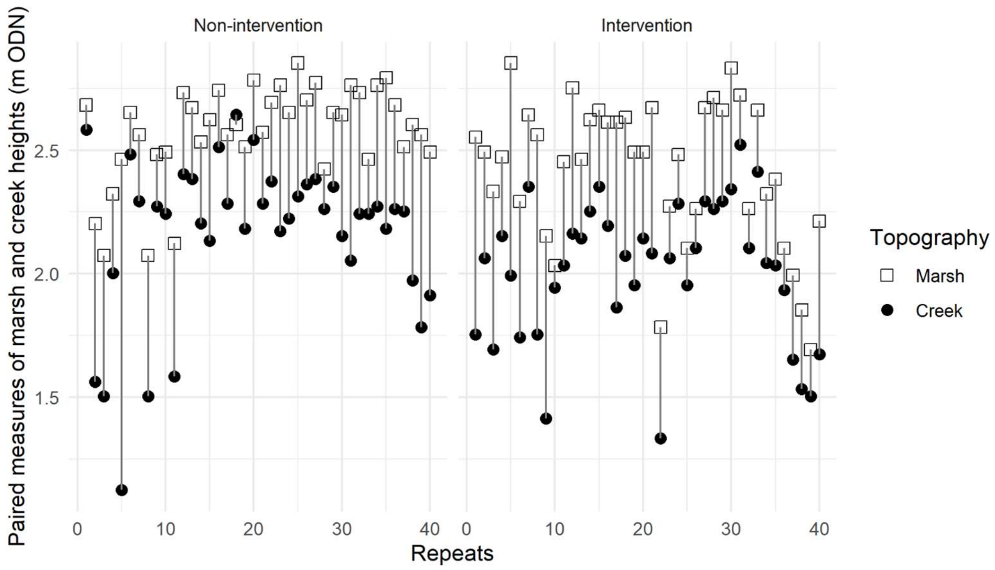

Figure 15: Paired theodolite and levelling rod measurements of marsh surface height and creek bed height at Two Tree Island. Non-intervention n = 40, intervention n = 40.

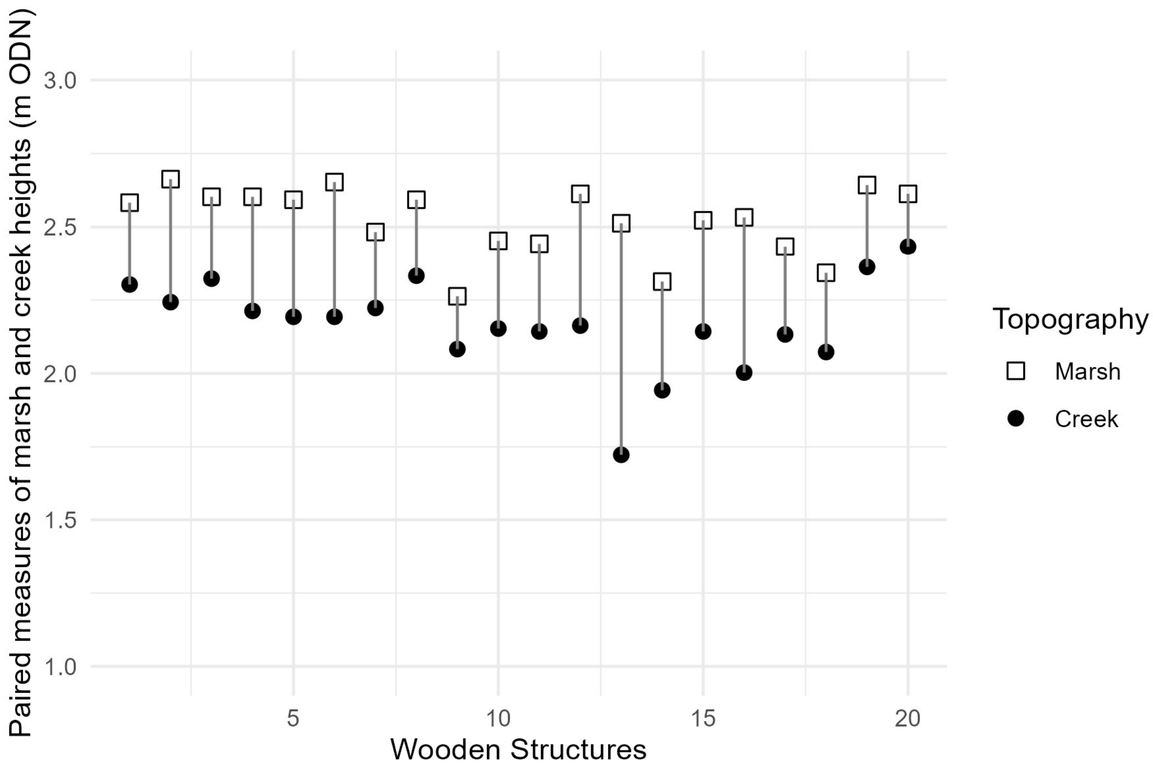

Figure 16: Paired theodolite and levelling rod measurements of marsh surface height and creek bed height at Two Tree Island immediately where wooden structures had been installed, n = 20.

Levington West (Suffolk Yacht Harbour, section 2.2.2, case study 9): creek blocking and BUDS

The saltmarshes at Levington are suffering from significant erosion, with marsh heights below 2 m ODN, and at the eroding front edge of the marsh, as low as 1 m ODN. In the non-intervention area, the back of the marsh was dominated by low marsh halophyte species (Figure 17), with high water content (> 50%, Figure 18) with the seaward quadrats mainly algal biofilms, and some cordgrass (tidal heights < 1.5 m ODN). Within saltmarsh subject to creek blocking and regular sediment recharge from the adjacent marina, there was a gradient of sediment bed height. At the point of discharge, sediment height had been raised to 2.0 m ODN (Figure 21), with a lower water content (20-30%, Figure 18), firm sediment bed (Shear strength between 24-40 kPa, Figure 19) and very low soil organic matter content (Figure 20), with some sea purslane and sea spurrey *Spergularia* sp. colonization. Away from the discharge site, both the marsh surface (+20 cm) and the height of the creek base were higher (+30 cm) than the adjacent non-intervention area, due to the infilling by sediment (Figure 21). Cordgrass and glasswort *Salicornia* agg. were the dominant halophytes.

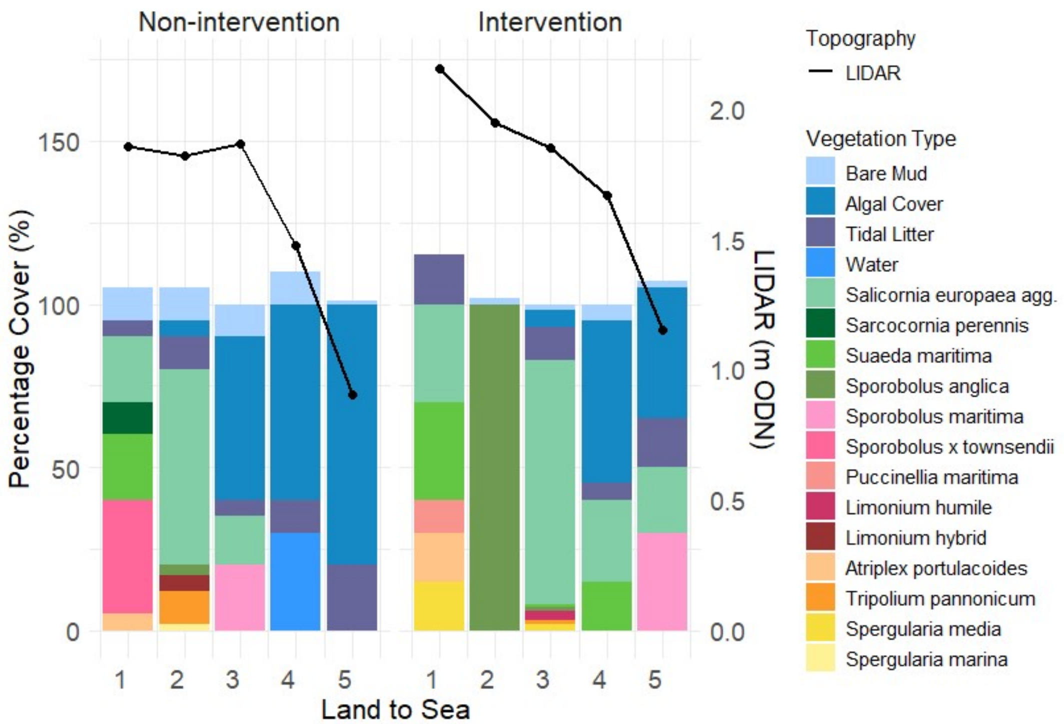

Figure 17: Vegetation percentage covers and site elevation in meters (based on LiDAR) at Levington West. Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

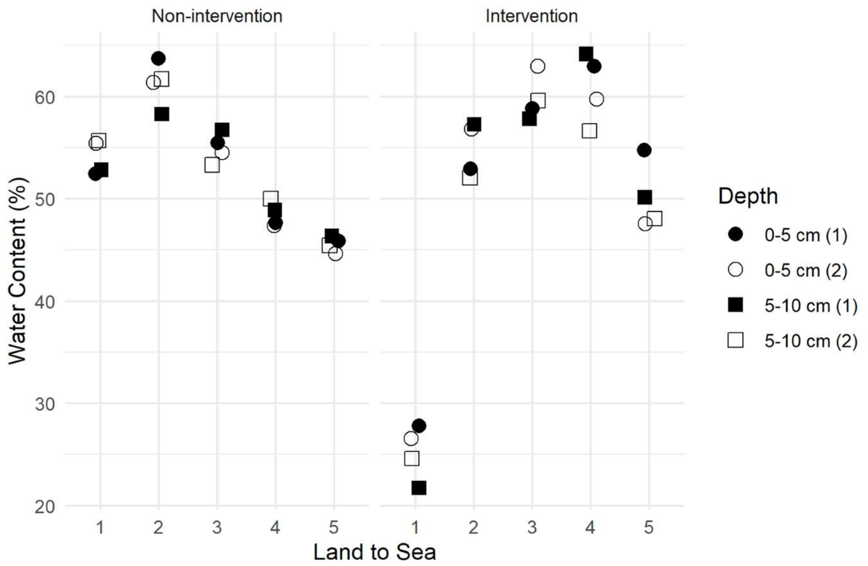

Figure 18: Water content from soil core samples (quadrat n = 2) at Levington West. Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

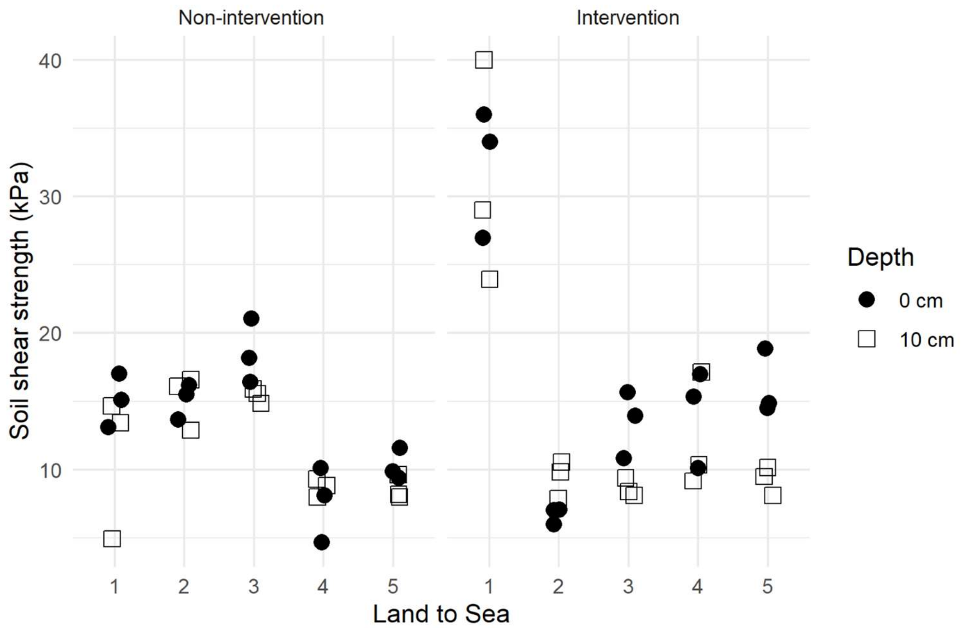

Figure 19: Soil shear strength (kPa) at Levington West (quadrat n = 3). Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

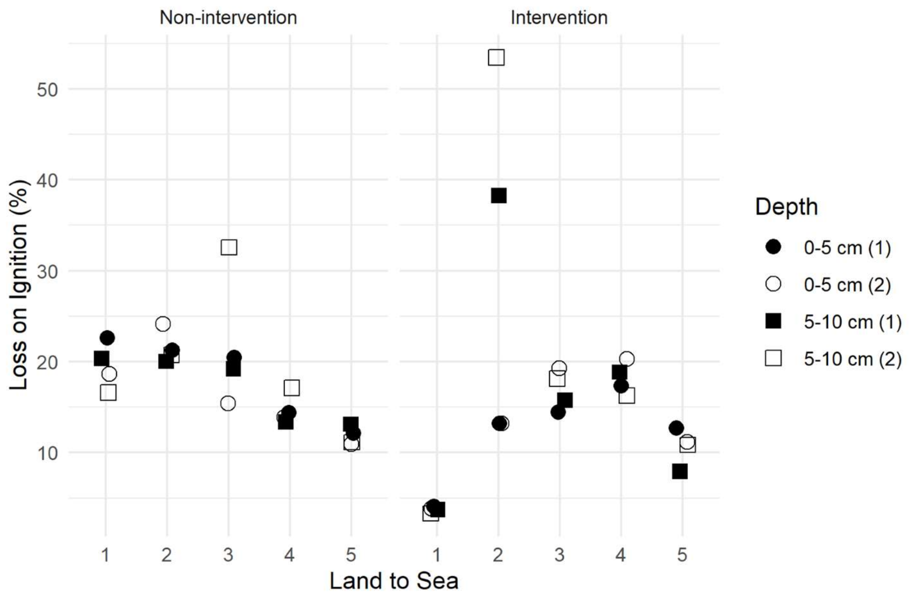

Figure 20: Soil organic matter content (loss on ignition (%)) from soil core samples (quadrat n = 2) at Levington West. Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

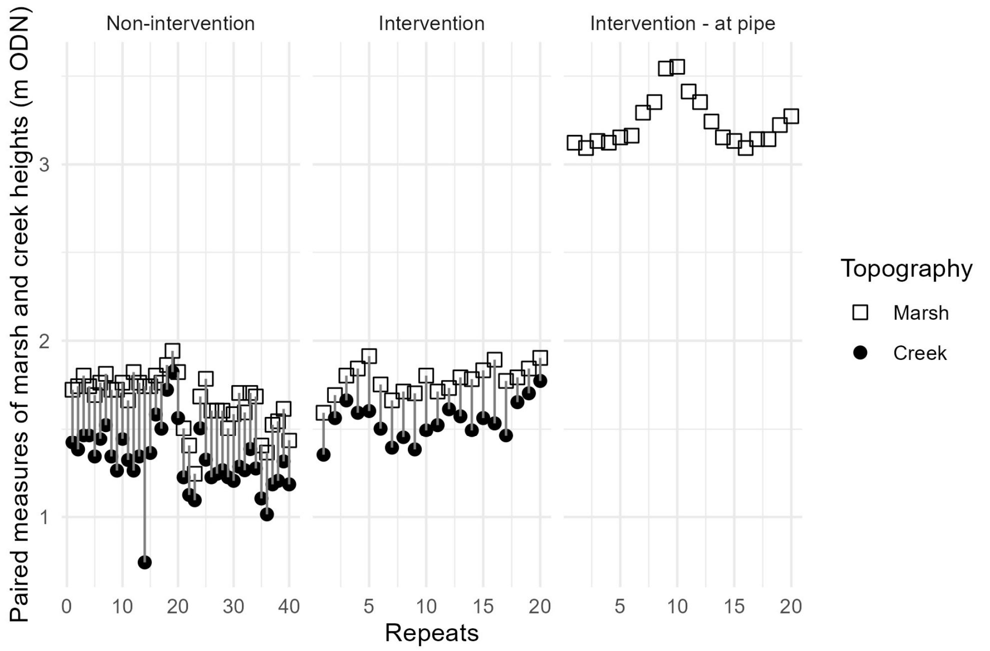

Figure 21: Paired theodolite and levelling rod measurements of marsh surface height and creek bed height at Levington West. Non-intervention n = 40, intervention n = 20, intervention at pipe, additional n = 20

Mersea Harbour: Sunken and Cobmarsh Islands (section 2.2.2, case study 10): BUDS

The saltmarsh islands in the vicinity of West Mersea Harbour have suffered significant erosion, which threatens the integrity of the harbour. Sunken Island has had no interventions and shows erosion features of hard sediment ridges interspersed with deep furrows, with an average height difference of 65 cm between marsh surface and creek bottom (Figure 26). Sunken Island sits between 1 – 2 m ODN, and the flora was dominated by a patchy cover of glasswort *Salicornia* agg., cordgrass with some sea aster, sea blite cyanobacteria mats and bare mud (Figure 22). Water content was around 50% (Figure 23), but sediment shear strength and TOC were low (Figures 24 and 25). In contrast, the surface height of Cobmarsh Island was 2.5-2.7 m ODN, with the marsh supporting a diverse halophyte community, dominated by saltmarsh grass, sea purslane, sea lavender *Limonium* spp. and sea blite *Suaeda* species, with over 100% cover at Q1-Q4 (Figure 22). Despite higher sediment water content than Sunken Island (Figure 23), sediment shear strength was higher (30 kPa, Figure 24), with soil total organic content around 2% (Figure 25). Though many areas of the marsh surface around creeks were at a similar tidal height to Sunken Island, creek depth was on average 35 cm (Figure 26).

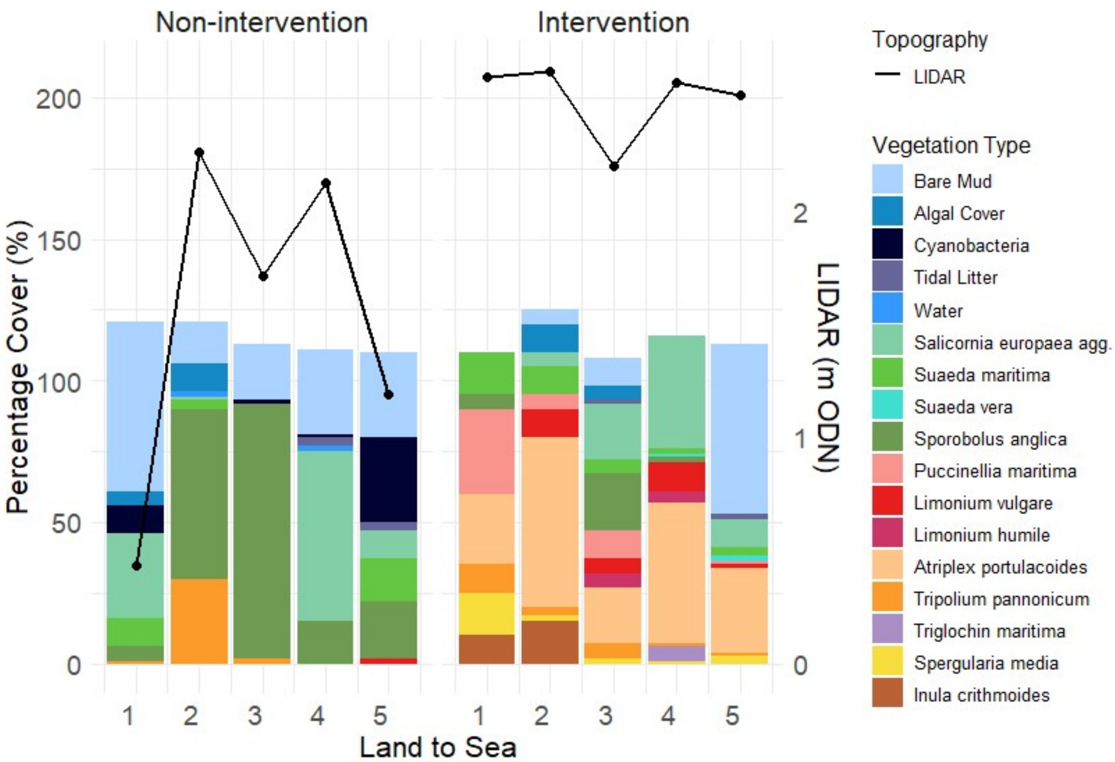

Figure 22: Vegetation percentage covers and site elevation in meters (based on LiDAR) at Sunken Island (non-intervention) and Cobmarsh Island (intervention). Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

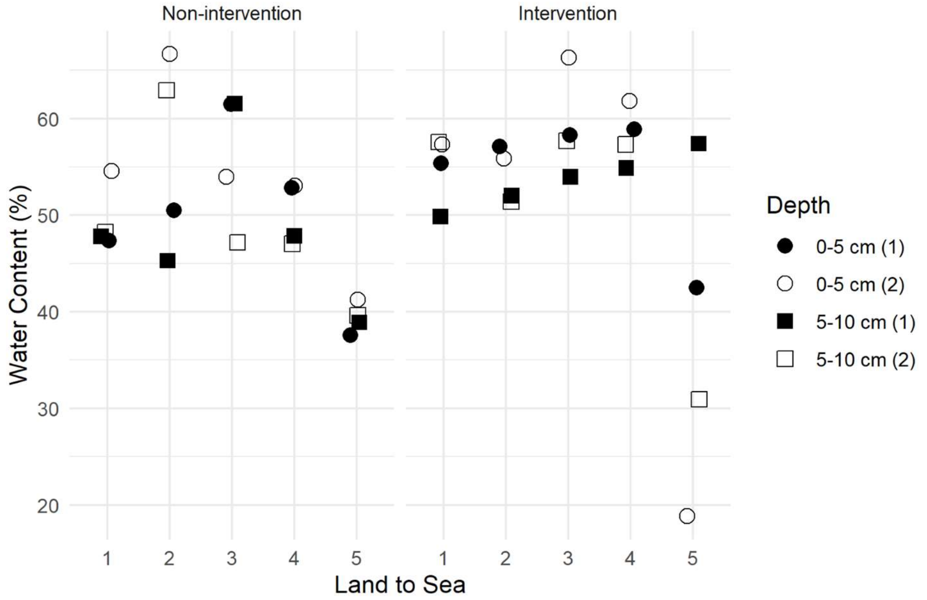

Figure 23: Water content from soil core samples (quadrat n = 2) at Sunken Island (non-intervention) and Cobmarsh Island (intervention). Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

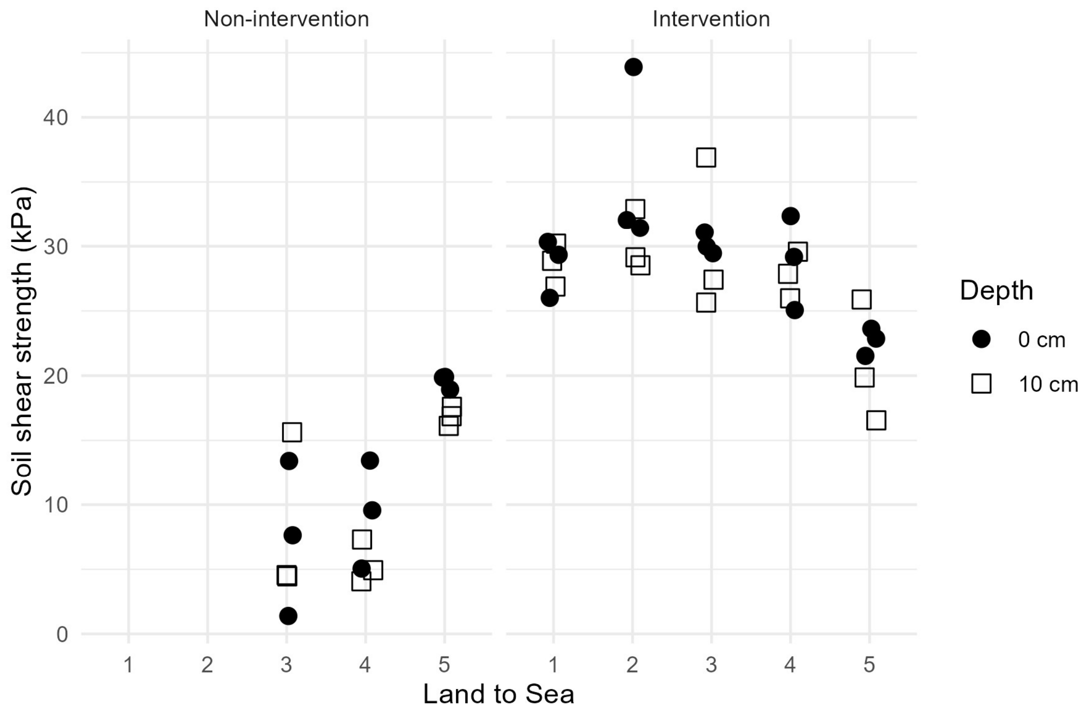

Figure 24: Soil shear strength (kPa) at Sunken Island (non-intervention) and Cobmarsh Island (intervention). (quadrat n = 3). Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side. There are no data points for quadrats 1 and 2 at the non-intervention site.

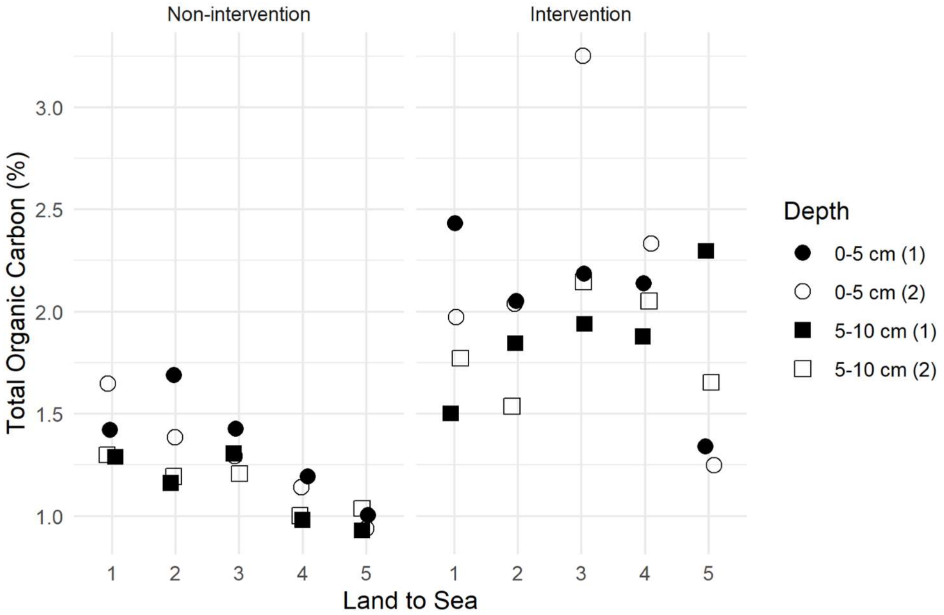

Figure 25: Total organic carbon (%) from soil core samples (quadrat n = 2) at Sunken Island (non-intervention) and Cobmarsh Island (intervention). Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

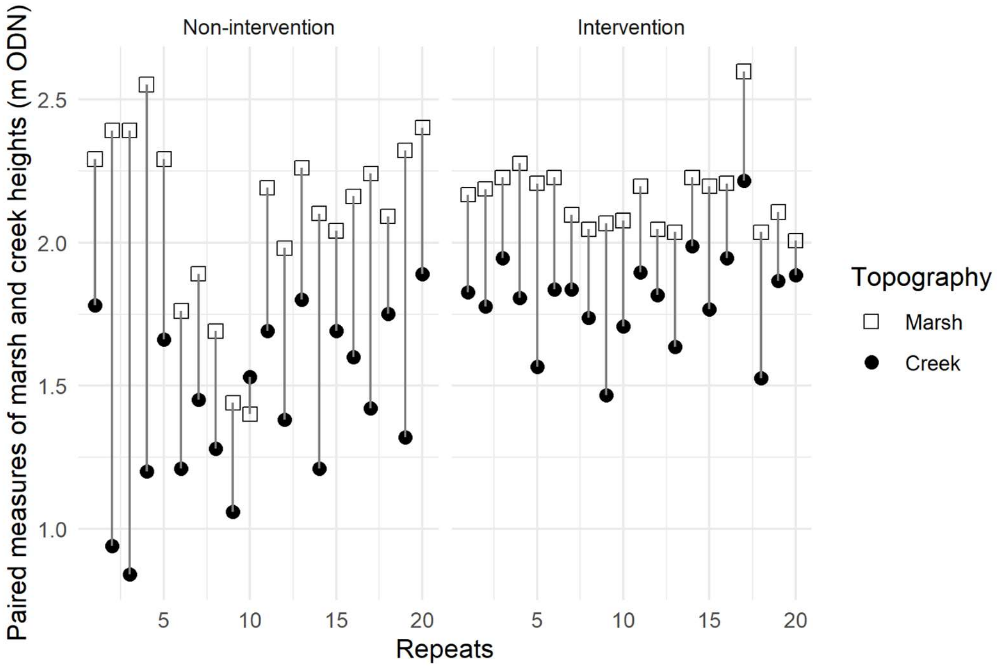

Figure 26: Paired theodolite and levelling rod measurements of marsh surface height and creek bed height at Sunken Island (non-intervention) and Cobmarsh Island (intervention). Non-intervention n = 20, intervention n = 20.

Itchenor (section 2.2.2, case study 11): Drag box

The non-intervention marsh at Itchenor supported a diverse halophyte flora, with 100% cover, at tidal heights about 2.5 m ODN. Dominant species were saltmarsh grass, sea purslane, sea plantain and sea arrowgrass (Figure 27), with the marsh sediment high in water content (70%, Figure 28), but high shear strength (Figure 29), probably due to plant roots. Soil organic carbon was high in this area, > 4% TOC (Figure 30). Sediment at the most seaward quadrat was lower (2.0 m ODN, Figure 31), had lower shear strength (Figure 29), and was dominated by perennial glasswort and cordgrass (Figure 27). The second non-intervention marsh was in stark contrast to the first one. The marsh sediment was lower in the tidal frame (1.5 m ODN, Figure 31) and supported 100% cover of cordgrass (Figure 27), with lower organic carbon content (<1.5 % TOC, Figure 30). The drag box intervention had raised the sediment height to this level, but was drier and firmer, with TOC < 1%. Itchenor demonstrates well the potential ecological gain that would be achieved if halophyte colonization could lead to continuing sediment accretion and the establishment of a diverse saltmarsh flora.

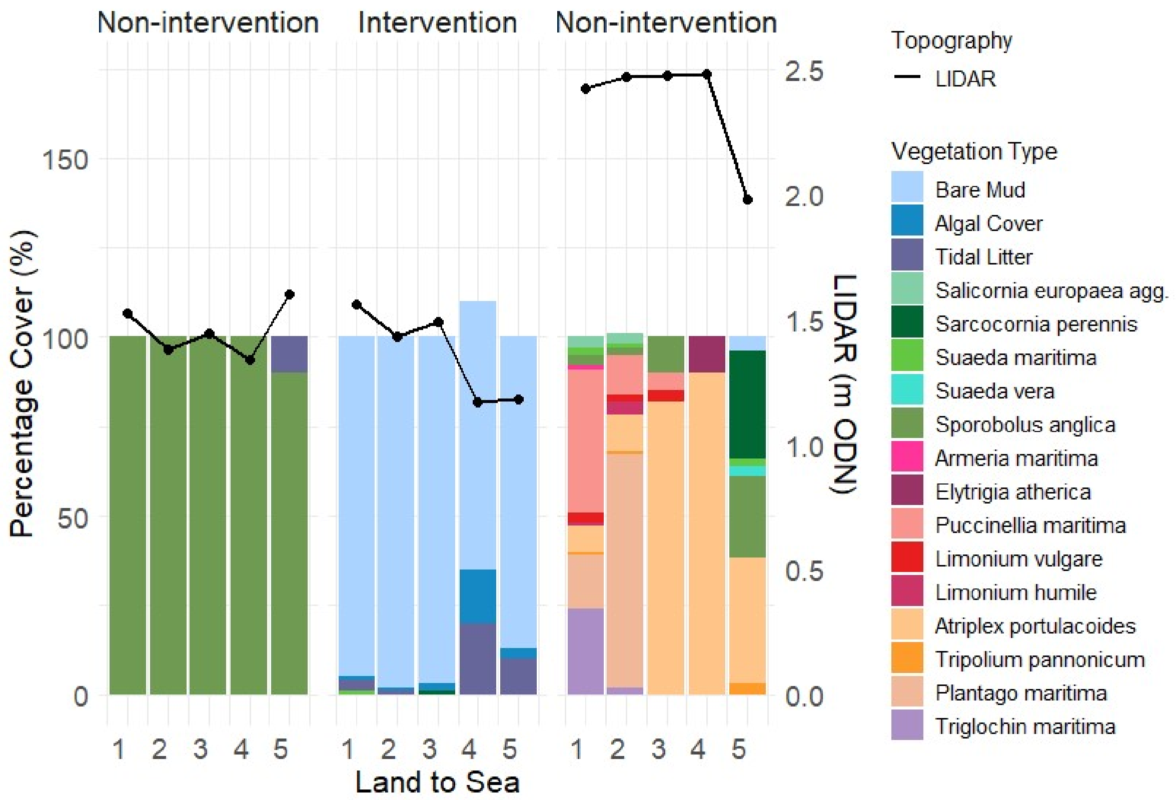

Figure 27: Vegetation percentage covers and site elevation in meters (based on LiDAR) at Itchenor. Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

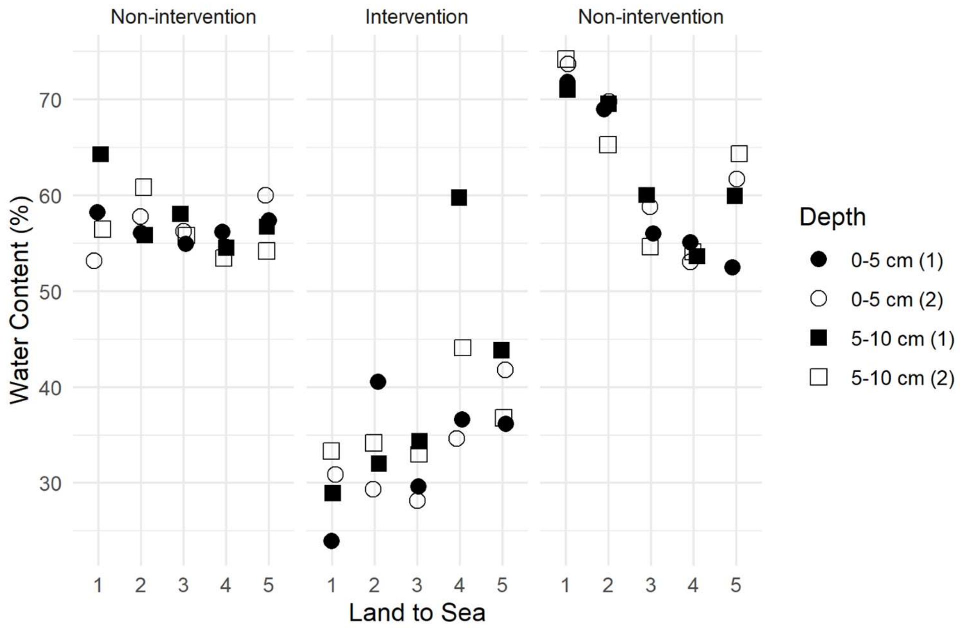

Figure 28: Water content from soil core samples (quadrat n = 2) at Itchenor (non-intervention left = cordgrass dominated, non-intervention right = diverse marsh). Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

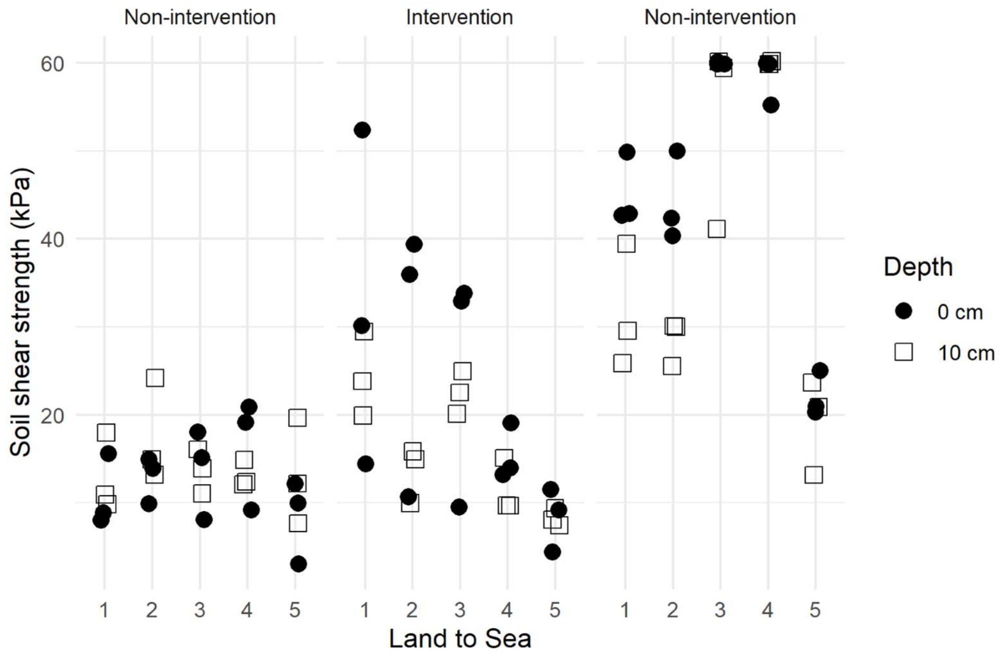

Figure 29: Soil shear strength (kPa) at Itchenor (non-intervention left = cordgrass dominated, non-intervention right = diverse marsh). (quadrat n = 3). Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

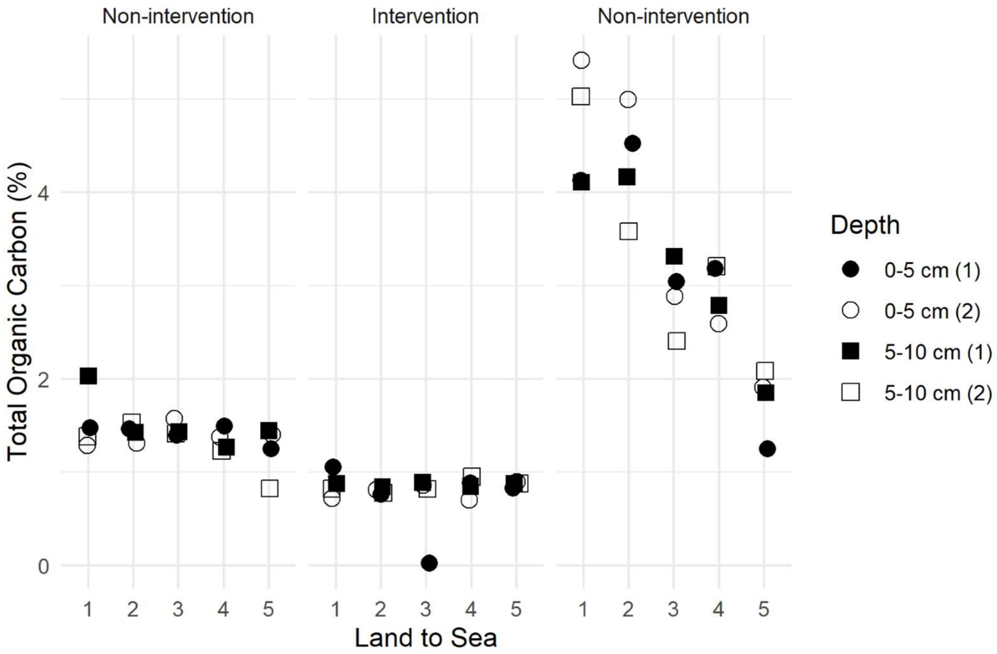

Figure 30: Total organic carbon (%) from soil core samples (quadrat n = 2) at Itchenor (non-intervention left = cordgrass dominated, non-intervention right = diverse marsh). Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

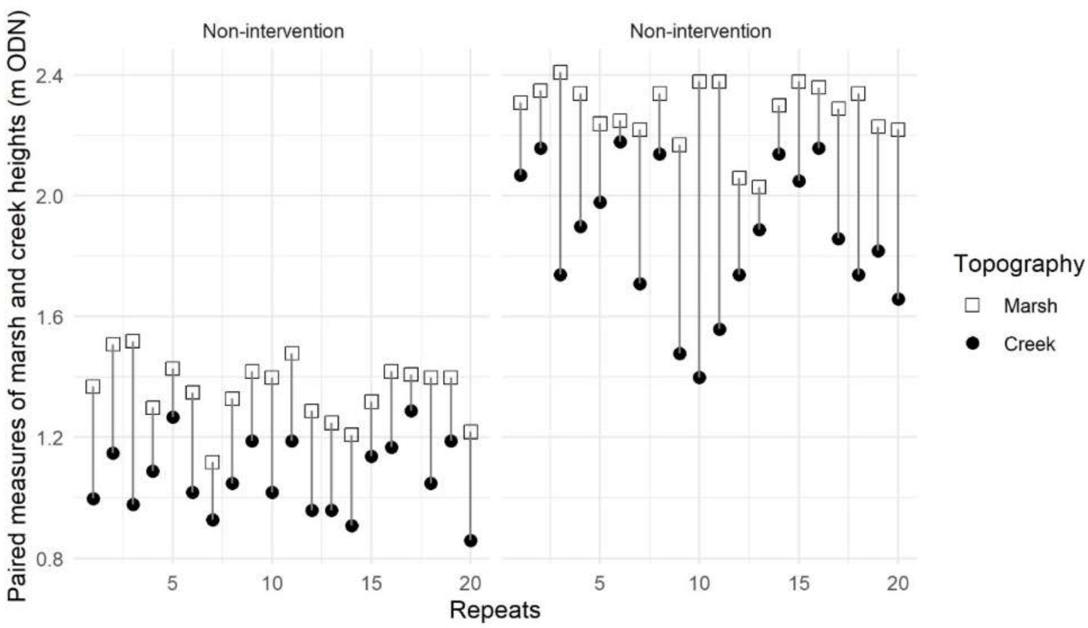

Figure 31: Paired theodolite and levelling rod measurements of marsh surface height and creek bed height at Itchenor (non-intervention left = cordgrass dominated, non-intervention right = diverse marsh). Non-intervention n = 20, intervention n = 20.

Boiler Marsh (section 2.2.2, case study 12): BUDS, sediment recharge

The saltmarsh at Boiler Marsh, is also low in the tidal prism (around 1.0 m ODN). On the non-intervention site a mix of glasswort *Salicornia agg.*, saltmarsh grass and some sea purslane and sea lavender *Limonium vulgare* present (Figure 32). Quadrats 4 and 5 were predominantly very soft, bare mud, with some relict patches of sea lavender *L. vulgare*. Sediment organic content was high, around 4% TOC (Figure 35). In the intervention area, halophyte cover was more extensive, mainly lower shore species, such as glasswort *Salicornia* agg. and cordgrass (apart from Q1 and Q5 (which was bare mud) Figure 32). The highest point on the intervention (Q1) was dominated by *Atriplex portulacoides* but the sediments had a much lower organic carbon content (1-2% TOC, Figure 35), and were drier (Figure 33) and firmer (Figure 34).

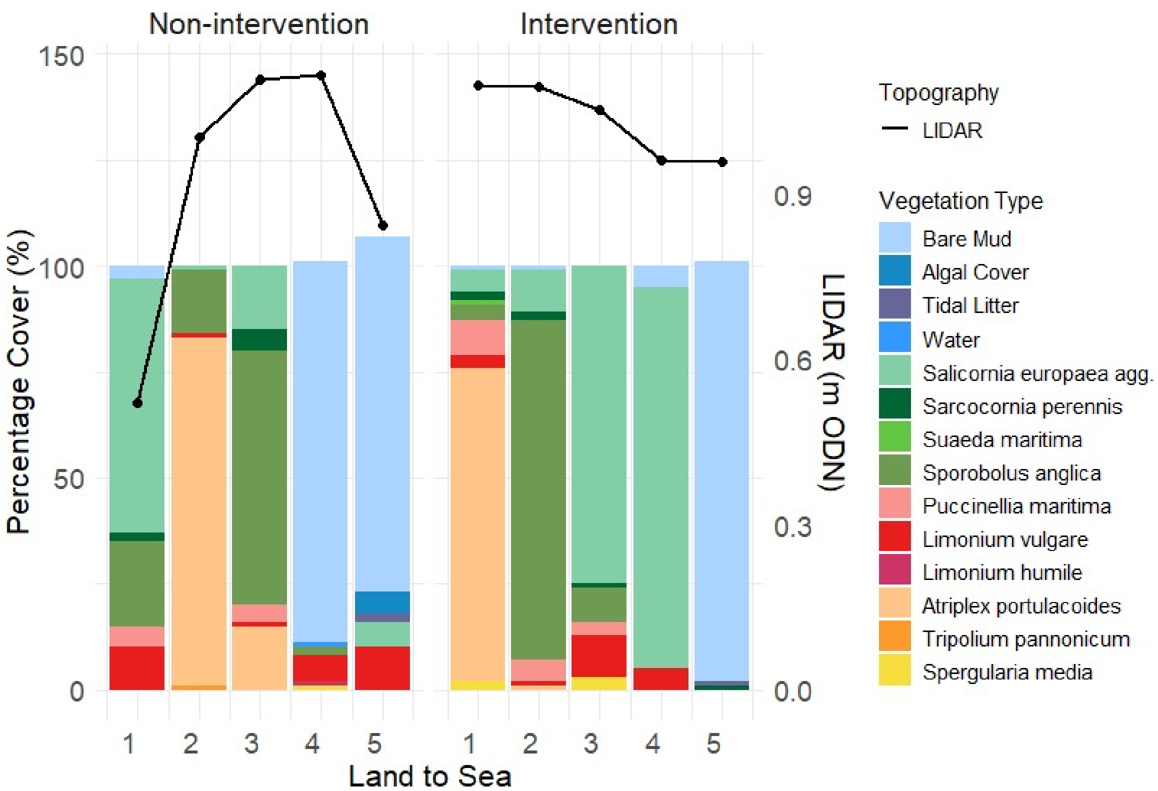

Figure 32: Vegetation percentage covers and site elevation in meters (based on LiDAR) at Boiler Marsh. Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

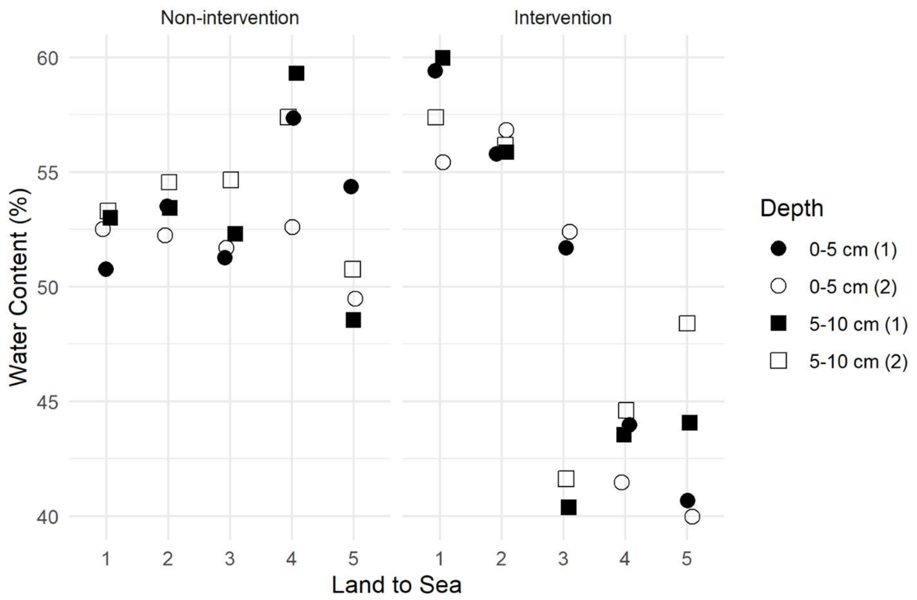

Figure 33: Water content from soil core samples (quadrat n = 2) at Boiler Marsh. Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

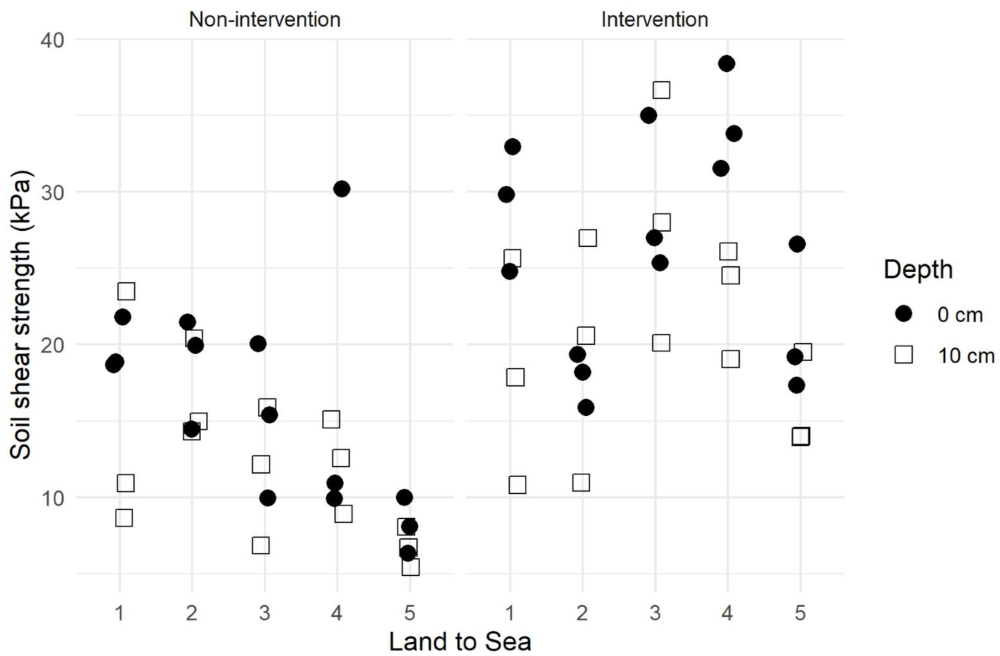

Figure 34: Soil shear strength (kPa) at Boiler Marsh. (quadrat n = 3). Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

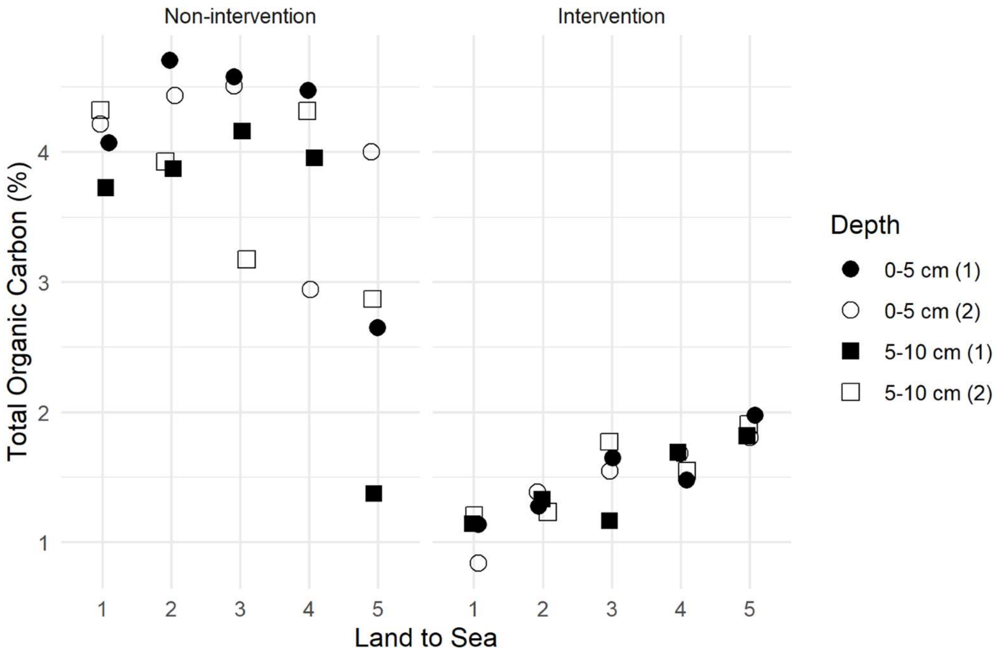

Figure 35: Total organic carbon (%) from soil core samples (quadrat n = 2) at Boiler Marsh. Numbers 1 to 5 represent the position of the quadrats along the transects: 1 = seaward side, 5 = landward side.

4.2.2 All field sites

Tidal height and species composition

The elevation of a site is a strong determinant of the percent cover of saltmarsh vegetation and the species composition of the saltmarsh community in non-intervention sites (Fig. 36). Sites higher in the tidal frame are dominated by saltmarsh grass and sea purslane. Sea aster, sea plantain and sea lavender Limonium spp. were common in mid-height sites, with pioneer species, glasswort *Salicornia* agg., sea blite, cordgrass, bare ground and algal mats at lower elevations. Where interventions have been conducted, site elevation is still a strong determinant of the corresponding plant community present (Figure 36), though there is greater variability in the relationships between species composition and tidal height, and a greater relative abundance of pioneer species or lower shore specialists such as cordgrass. Generally, the restoration sites have a greater abundance of pioneer or annual halophyte taxa. This is due to the different history of the different intervention sites. Some represent sites that are in declining condition but still hold some of the original species present, while others have been recently colonised from bare mud.

On the south coast, there is a similar gradient (Figure 37). Saltmarsh plant communities on the mature marsh at Itchenor correspond to those found in established marshes on the east coast. However, at Boiler Marsh the non-intervention sites still have some perennial halophytes. This site is eroded now and at a lower tidal height with extensive bare ground and pioneer species (glasswort *Salicornia* agg. and sea blite) The recently restored and currently sparingly-colonized drag box site at Itchenor is at a tidal height that should support growth of cordgrass (*Sporobolus* spp).

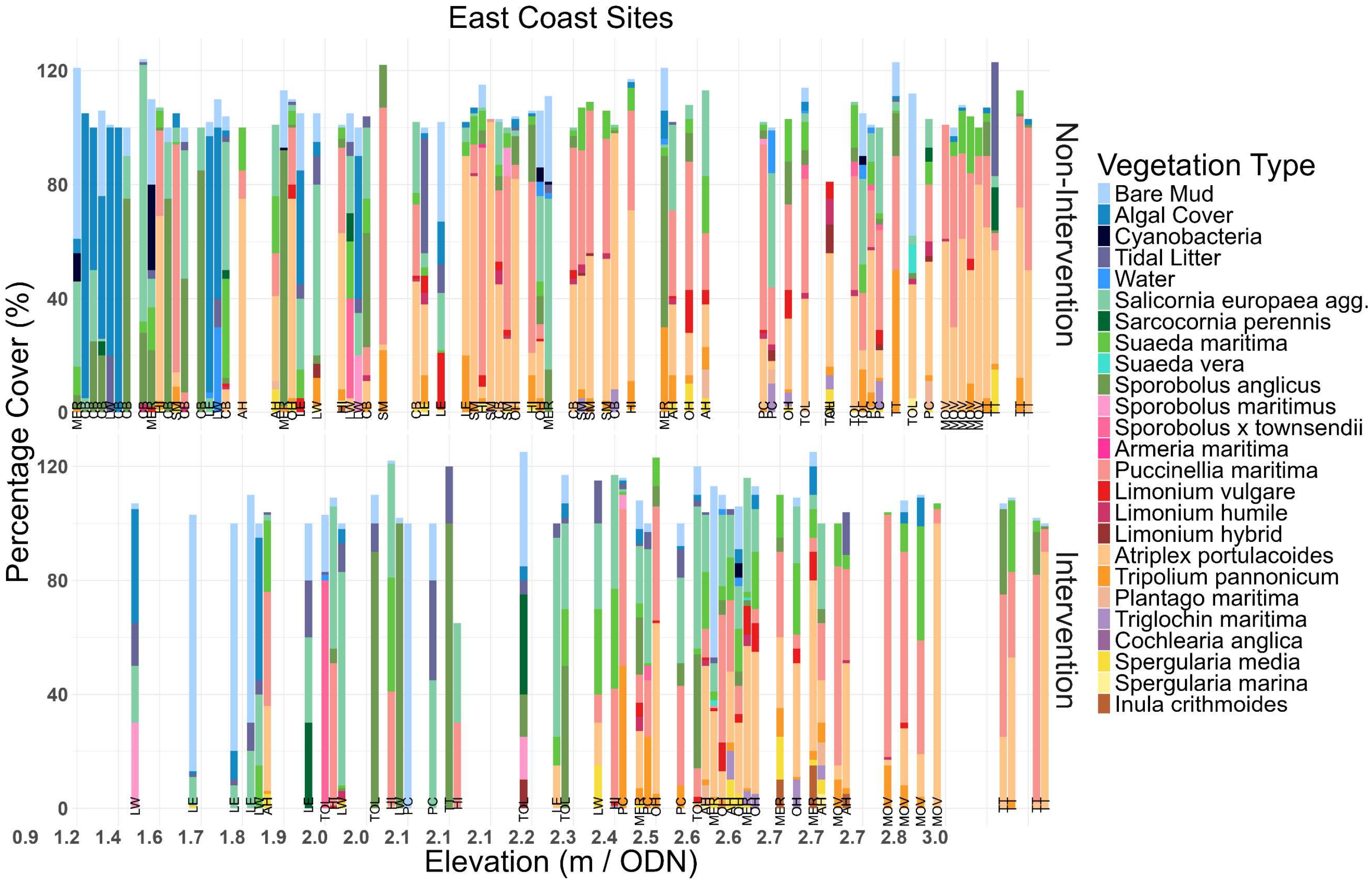

Figure 36: Saltmarsh plant community composition (% cover of a 2 x 2 m quadrat) in relation to tidal height (elevation in metres, Ordnance datum) in non- intervention and intervention sites in eastern England in 2024. AH = Abbotts Hall, CB = Copperas Bay, HI = Horsey Island, LE = Levington East, LW = Levington West, MER = Sunken and Cobmarsh Island, MOV = Moverons, OH = Old Hall, PC = Point Clear, SM = Stone Marsh, TOL = Tollesbury, TT = Two Tree Island.

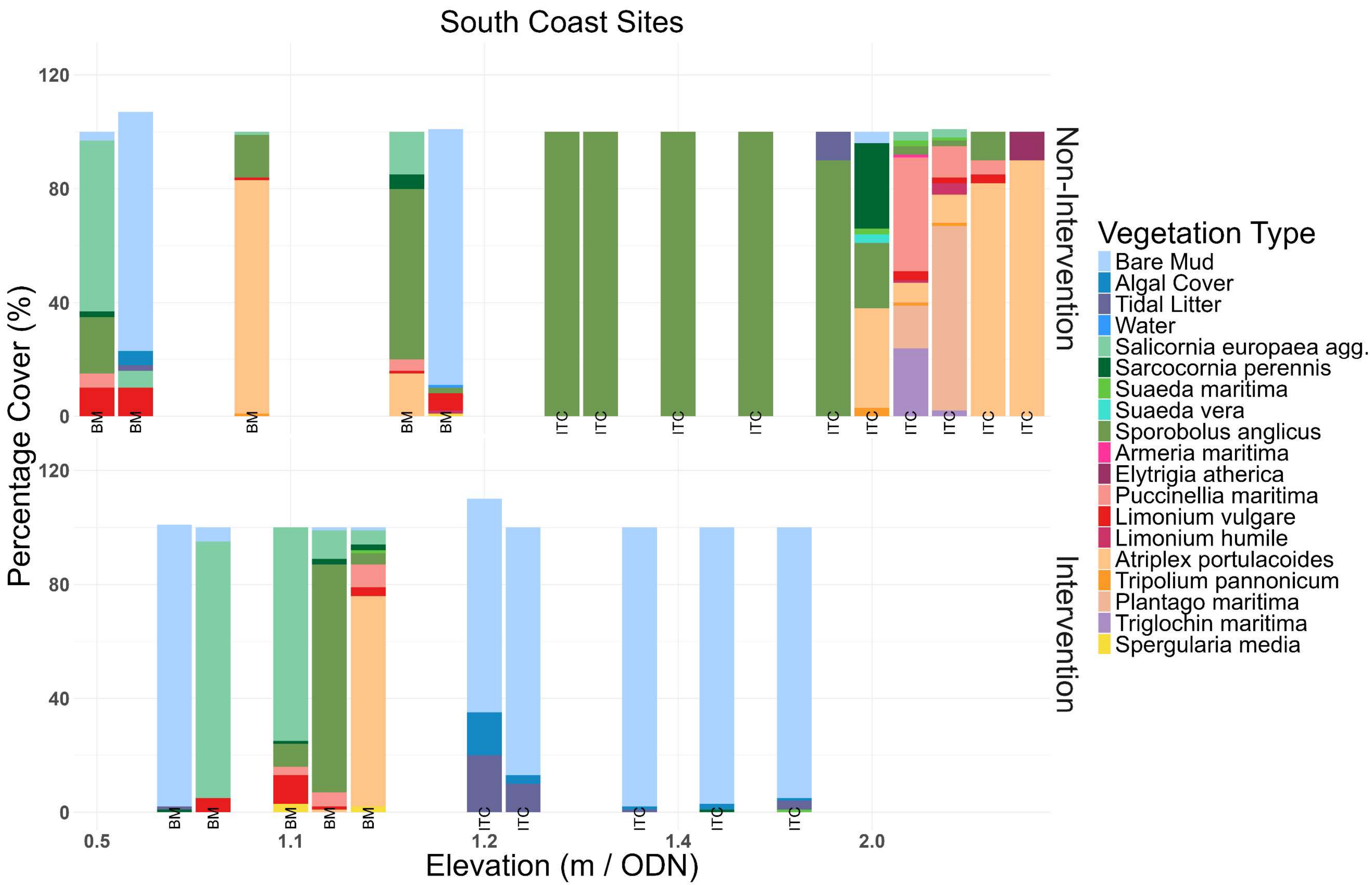

Figure 37: Saltmarsh plant community composition (% cover of a 2 x 2 m quadrat) in relation to tidal height (elevation in metres, Ordnance datum) in non-intervention and intervention sites in southern England in 2024. BM = Boiler Marsh, ITC = Itchenor.

Species Richness and sediment water content

Sediment water content was showed a positive relationship with halophyte species richness across all the sites sampled (Figure 38). This relationship was similar for non-intervention sites and sites where either BUDS, coir/creek blocking or both interventions had been used.

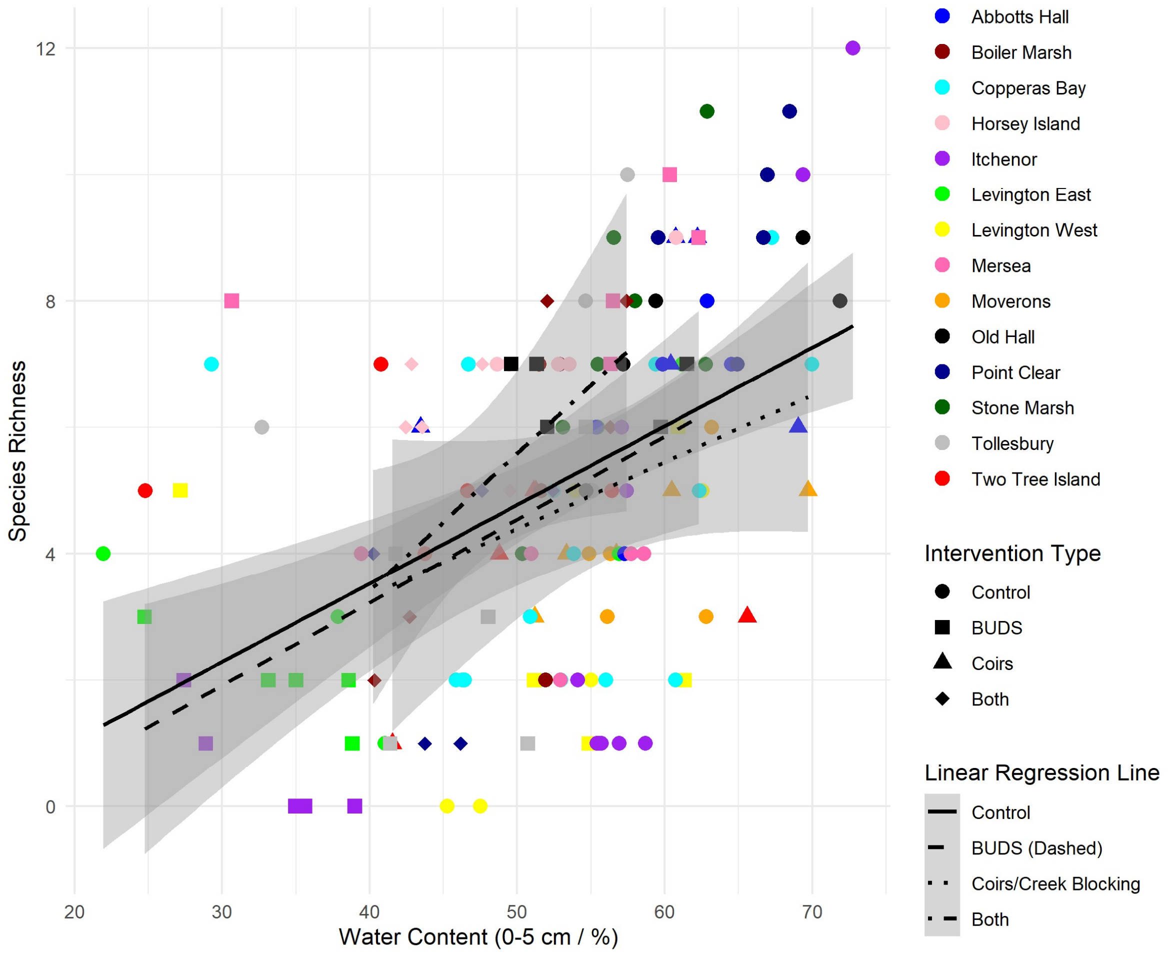

Figure 38: Relationship between saltmarsh community species richness and sediment water content (%, top 5 cm) at control and intervention locations across eastern and southern England in 2024. 'Both' refers to coirs/creek blocking and BUDS, n per intervention: control = 88, BUDS = 30, coirs / creek blocking = 15, both = 15.

Sediment water content was different between control marsh sites and the three different interventions investigated. BUDS sites had lower sediment water content, and this was also found where BUDS was used in association with creek blocking ('both' treatment in Fig. 39). Coir rolls/ creek blocking on its own did not result in a significant difference compared to control sites (Figure 39).

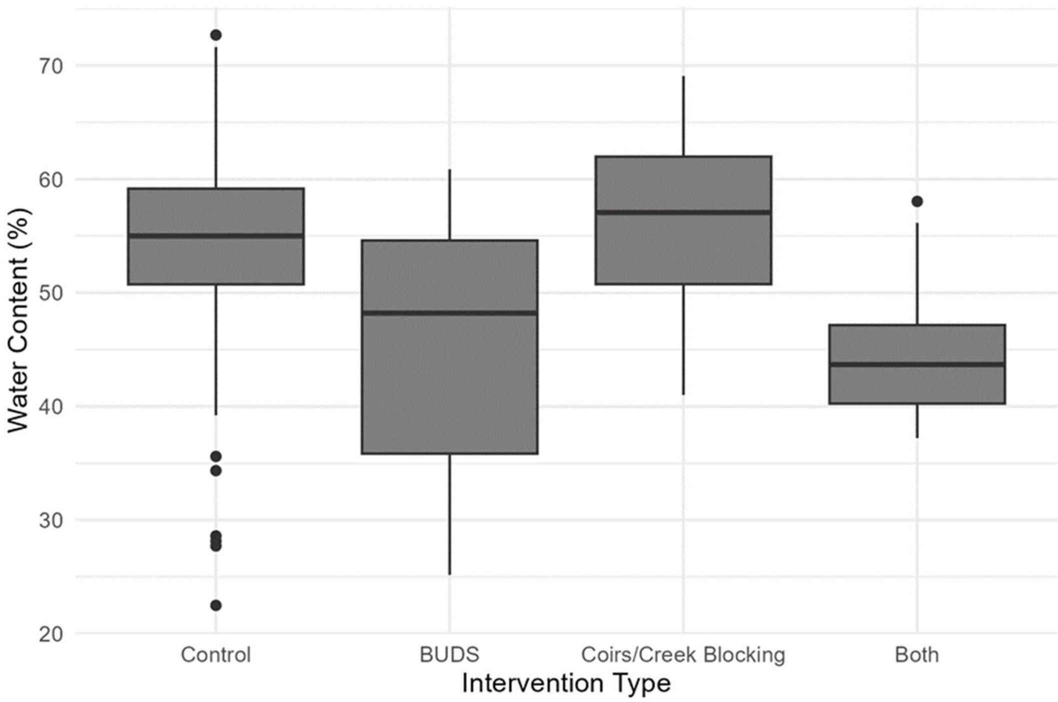

Figure 39: Comparison of sediment water content (median values and 25-75 percentiles) by restoration intervention method and non-intervention sites across eastern and southern England in 2024, n per intervention: control = 88, BUDS = 30, coirs / creek blocking = 15, both = 15.

Plant species richness and sediment shear strength

The shear strength of a sediment reflects the ability of the sediment bed to resist erosion though bulk failure (rather than incremental surface erosion). Wetter sediments have lower shear strength, and dry sediments have higher shear strength. However, the presence of plant roots can enhance the shear strength of otherwise wet sediments (Evans et al., 2022; Brooks et al. 2023). Previous research (Slee et al. 2023) has found that a sediment shear strength of around 30-40 kPa is optimal to maximise saltmarsh plant richness and diversity. In the present study, the highest values of sediment shear strength were in this optimal range (30-40 kPa), and shear strength was correlated with species richness (Figure 40). Intervention type did not result in any deviation from the pattern observed in non-intervention locations.

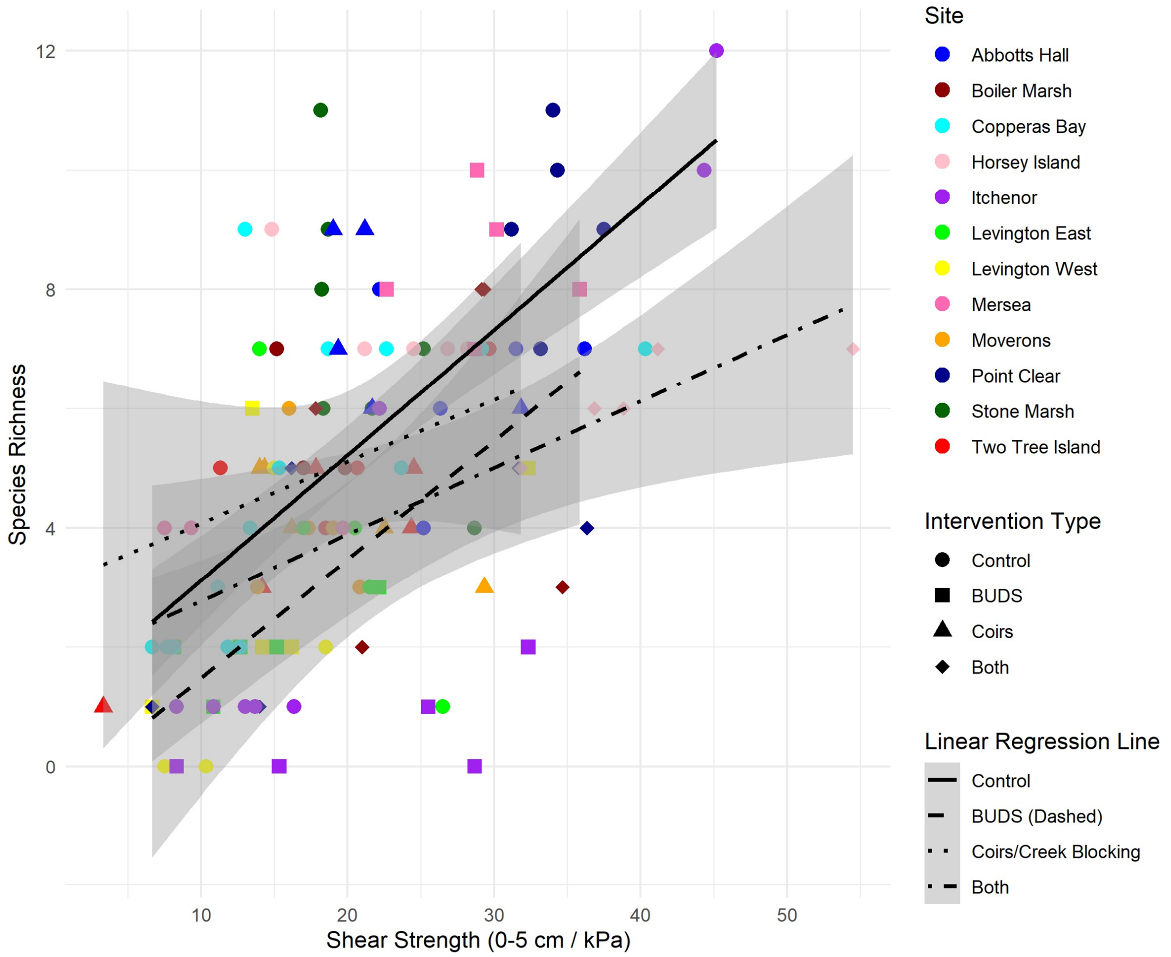

Figure 40: Relationship between saltmarsh community species richness and shear strength (kPa, top 5 cm) at control and intervention locations across eastern and southern England in 2024. 'Both' refers to coirs/creek blocking and BUDS, n per intervention: control = 74, BUDS = 20, coirs / creek blocking = 15, both = 15.

Sediment organic matter and organic carbon content

The fraction of organic matter present in saltmarsh sediments is important for considering saltmarshes as "blue carbon" sinks or sources. SOM content is usually measured by high temperature combustion or loss on ignition (%LOI). SOM content values ranged from less than 5% to in excess of 40% across the 14 different marshes investigated (Figure 41).

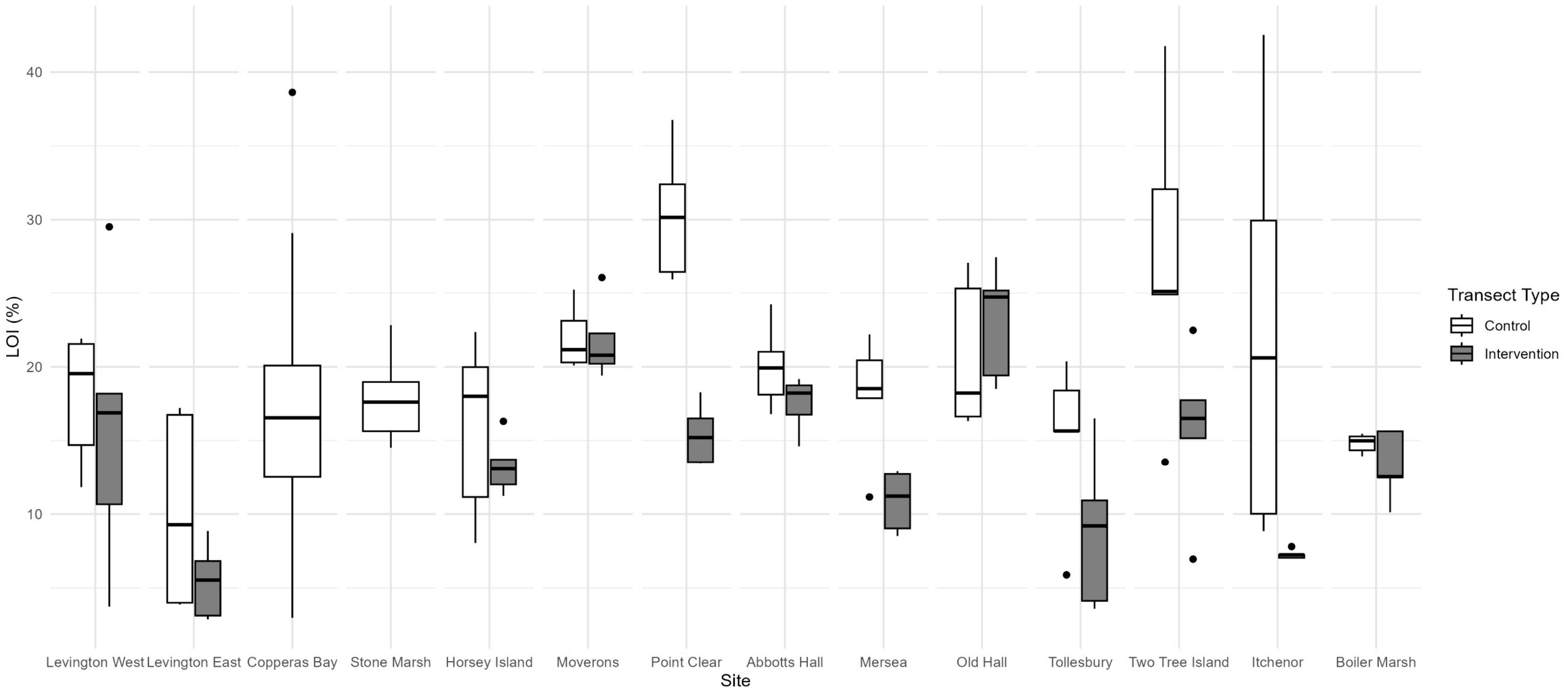

Figure 41: Comparison of soil organic matter content (LOI (%)) by saltmarsh site (14 sites) across eastern and southern England in summer 2024. At 12 of these sites, areas subject to saltmarsh restoration interventions were compared with control areas, location sample n = 10.

Sediment organic content was lower in sites where BUDS had been deployed, but not with creek blocking (Figure 42). This was probably due to deposition of lower organic matter sediment onto sites through the BUDS process, with lower water content, which also reduces the richness of saltmarsh plants.

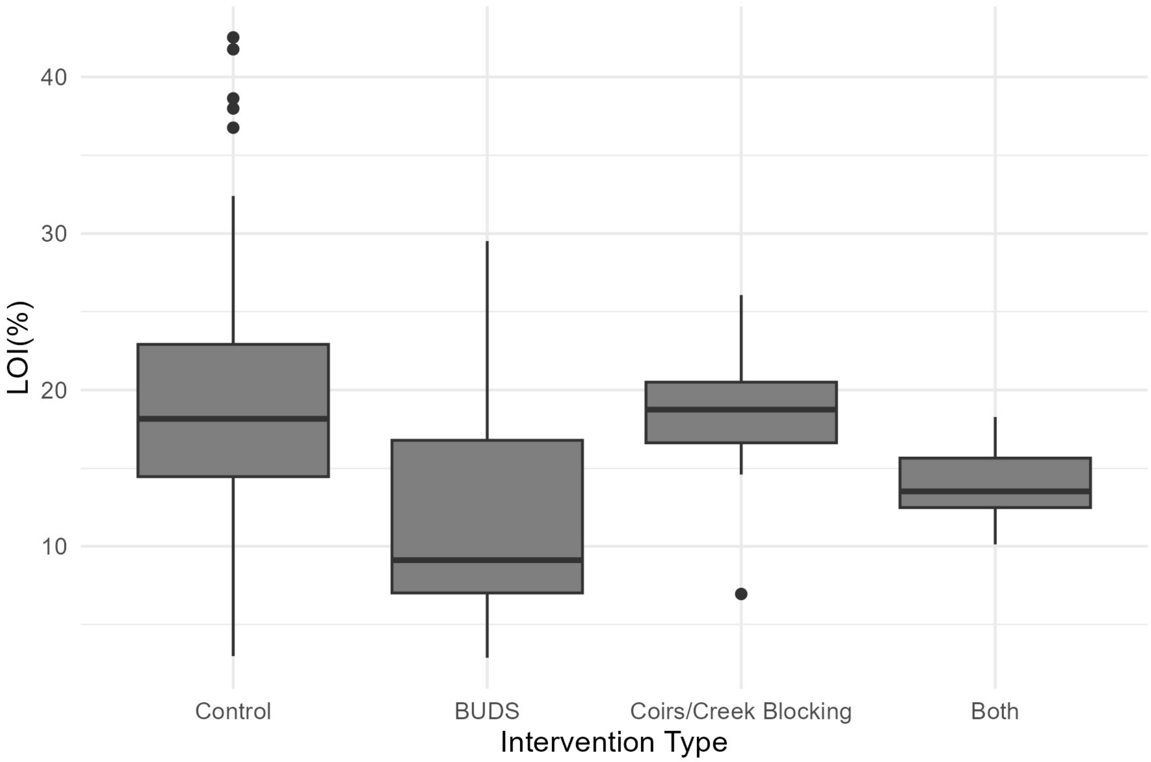

Figure 42: Comparison of quadrat soil organic matter content (average LOI (%)) by restoration intervention method and non-intervention sites across eastern and southern England in 2024, n per intervention: control = 88, BUDS = 30, coirs / creek blocking = 15, both = 15.

Total organic carbon represents a fraction of the organic matter measured by loss on ignition. Both TOC and SOM content were measured at a number of sites in this study. TOC was positively related with SOM when considering all the marshes, at which both had been measured, with TOC representing about 10% of the sediment organic matter. The relationship between TOC and SOM did not differ between intervention and non-intervention sites (Figure 43).

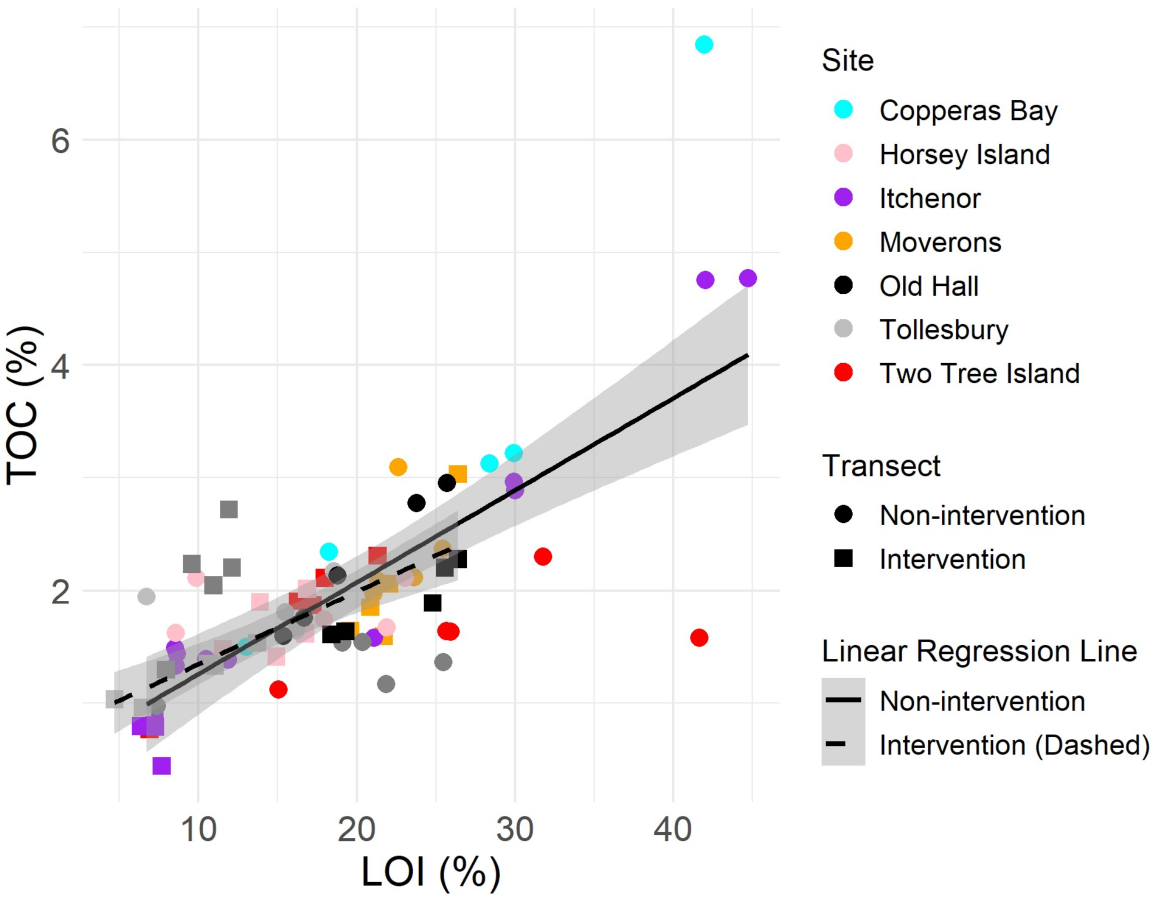

Figure 43: Relationship between soil organic matter (LOI %) and total organic carbon (TOC %) in the top 5 cm of sediment in intervention and control areas of eight different saltmarshes in eastern and southern England in summer 2024, non-intervention n = 45, intervention n = 35.

Sediment TOC was lower in intervention areas at six of the eight study sites with TOC data, mostly at sites where BUDS had been used (Figure 44). Comparing restoration approaches found that BUDS approaches had lower %TOC compared to control locations, with coir rolls / creek blocking not showing any real difference to control marshes (Figure 45).

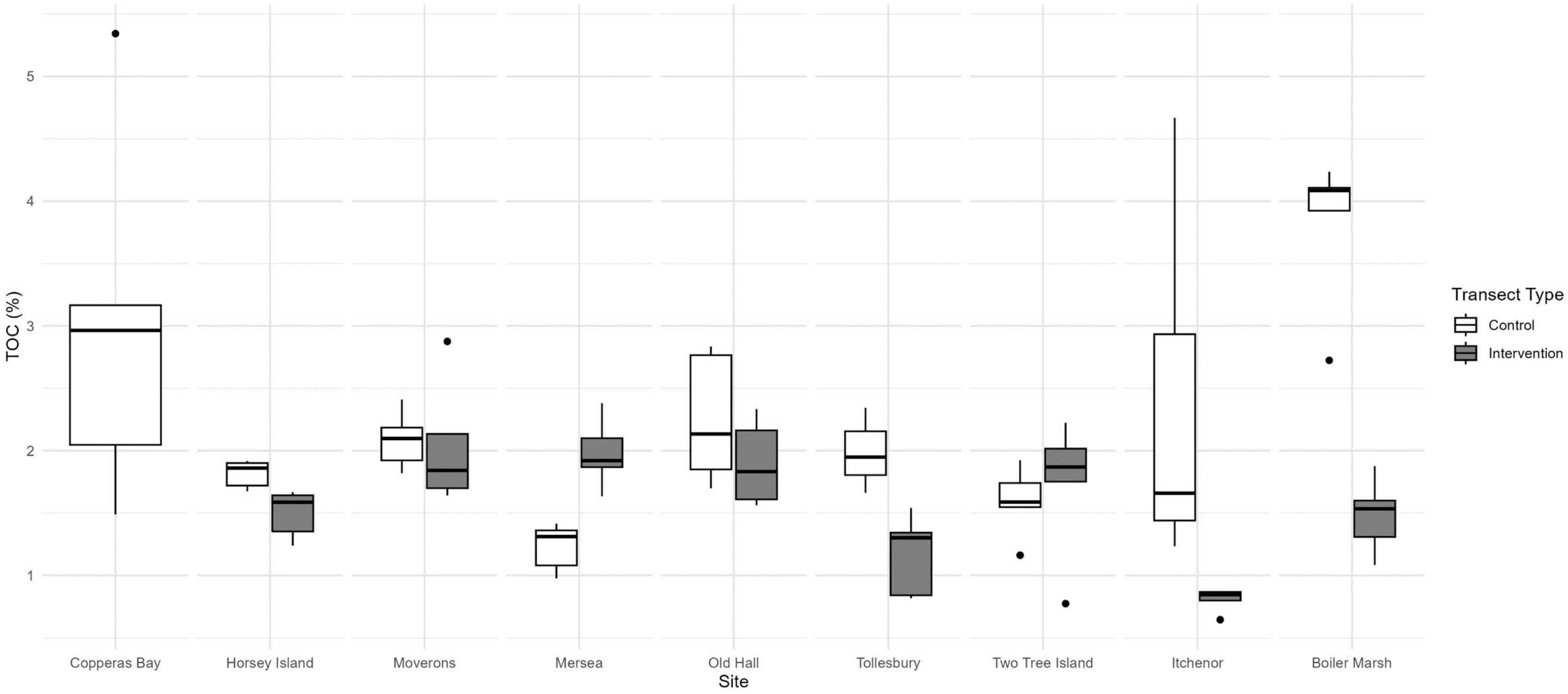

Figure 44: Comparison of total organic carbon (%TOC) in the top 5 cm of sediment in intervention and control areas of nine different saltmarshes in eastern and southern England in summer 2024 (note, no restoration interventions at Copperas Bay site), location sample n = 10.

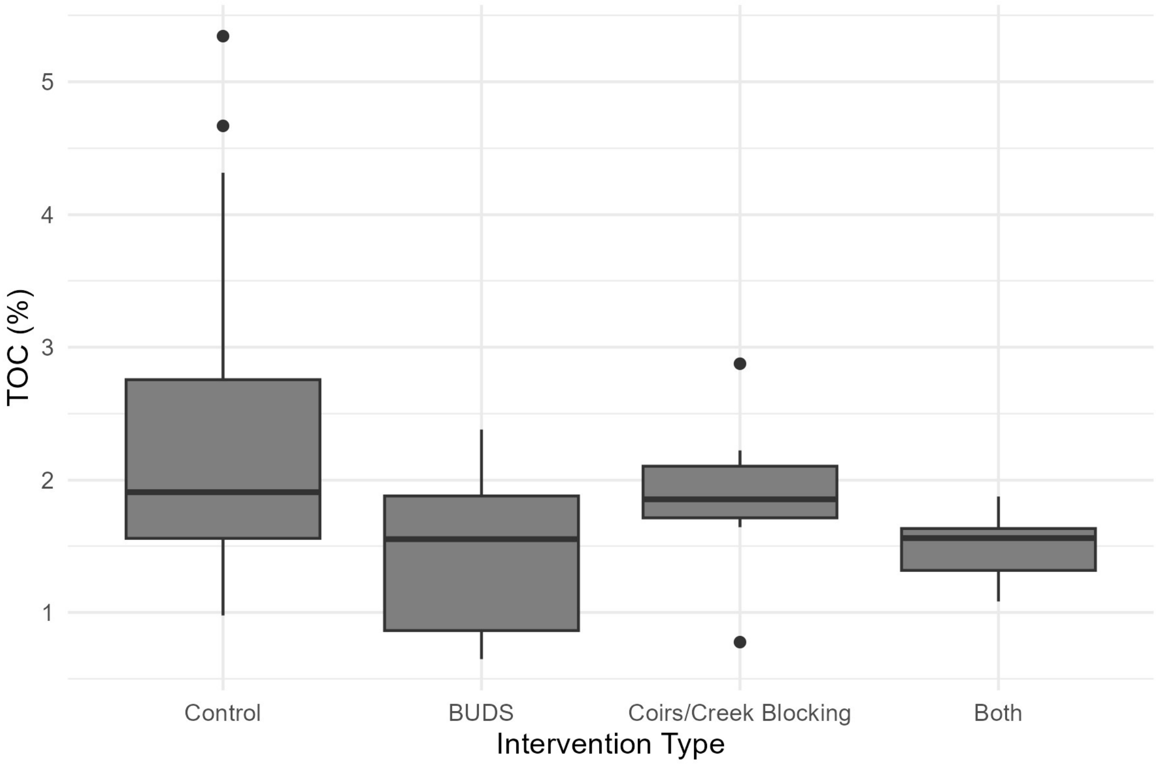

Figure 45: Comparison of total organic carbon (%TOC) in the top 5 cm of sediment between control and three restoration approaches in saltmarshes in eastern and southern England in summer 2024, n per intervention: control = 50, BUDS = 20, coirs / creek blocking = 10, both = 10.

Height differences

The height of a site within the tidal frame is a key determinant to successful plant colonisation and the development of a healthy marsh (see Figures 35 and 36 above). Creeks cutting through saltmarshes provide a route for sediment to be brought into a marsh on incoming tides, but in eroding situations, also serve to carry sediment out of a marsh (Green & Coco 2014). By providing new sediment into a site, BUDS and BUDS in combination with creek blocking reduced the depth of creeks relative to saltmarsh surfaces (Figure 46), but this pattern is quite site dependant (Figure 47).

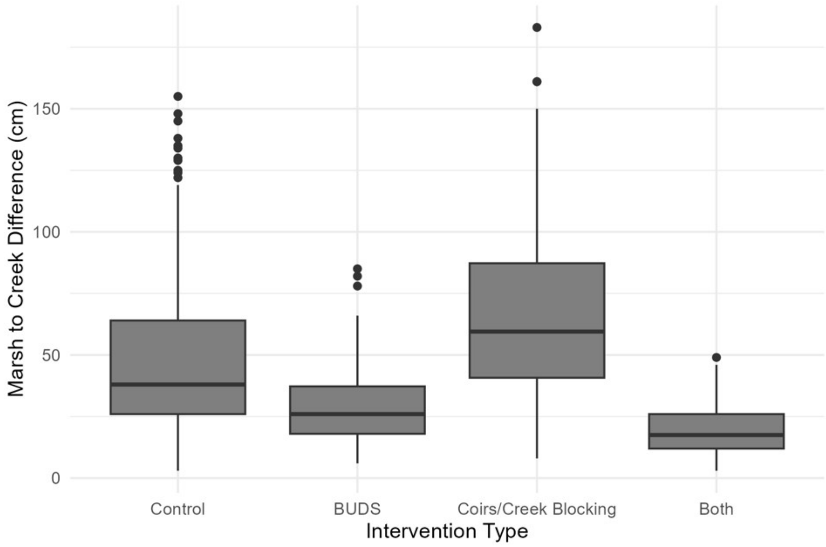

Figure 46: Comparison of the height difference between the vegeated marsh surface compared to the bed height of creeks, between control and three restoration approaches in saltmarshes in eastern and southern England in summer 2024, n per intervention: control = 281, BUDS = 120, coirs / creek blocking = 100, both = 40.

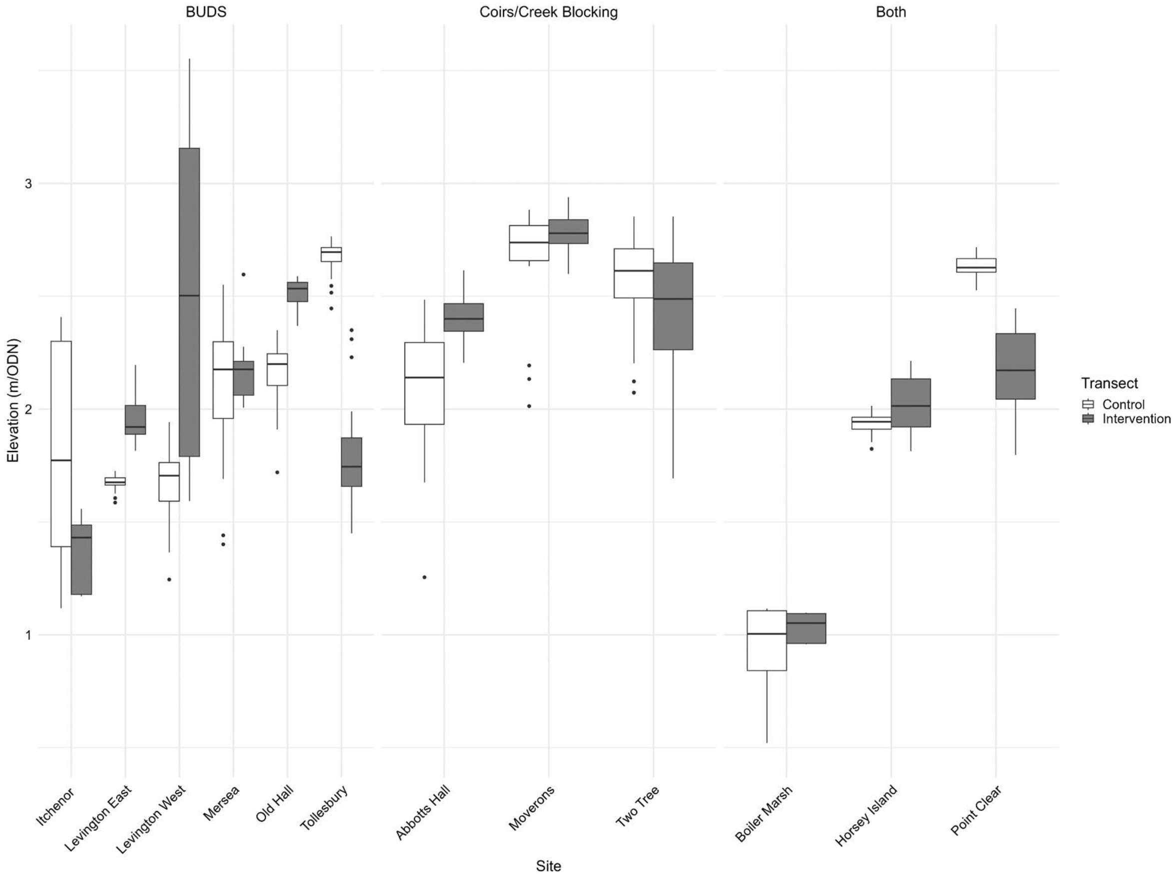

Figure 47: Tidal height (mODN) of each site (with controls and interventions). Intervention site may be lower that controls, or exceed controls locations, depending on the individual characteristics of the site, location sample n = 10.

4.2.3 Discussion and summary

The survey of sites in 2024 reinforced the importance of tidal elevation within the tidal frame as the key variable related to salt marsh vegetation cover, species composition and species richness. The classical zonation of salt marsh species along a gradient of tidal elevation (which directly related to periods of seawater cover) is well described for northwest Europe (Adam, 1990; Mossman et al., 2019). Pioneer species, like glasswort *Salicornia* spp. and sea blite *Suaeda maritima*, and the cordgrass *Sporobolus anglicus* can survive lower on the shore, but the recognisable 'mid-marsh' community of sea lavender *Limonium* spp., sea aster, sea purslane and saltmarsh grass, and other plant species is strongly height dependant. In some of the intervention sites (Boiler Marsh), and control sites that are eroding (e.g. Sunken Island, Copperas Bay), some remnants of this mid-marsh flora persist. Successful salt marsh restoration needs to provide conditions to either prevent sediment loss, promote sediment accumulation, or provide a source of sediment (Pontee et al. 2021, Ladd et al. 2019).

BUDS approaches provide the sediment and can raise tidal elevation necessary to repair a damaged salt marsh, but it is important to consider the properties of the sediment placed within a particular site. Compacted sediment with a low water content is deleterious to salt marsh plant growth, and prevents successful colonisation (Boorman, 2003; Slee et al., 2023). Conversely, very wet, unconsolidated sediments also do not support pioneer plant colonisation. However, over time unconsolidated sediment will become stabilised, first by microalgal biofilms and then by salt marsh plants, provided sediment is not physically wash away (Mossman et al., 2019; Slee et al., 2023). Salt marsh plant roots contribute to increased sediment shear strength, while maintaining water content, and contributing to increased sediment organic matter (Evan et al., 2022; Brooks et al., 2023; Slee et al., 2023). In reviewing the different approaches investigated, BUDS appears the most successful approach, followed by BUDS with creek-blocking.

Creek blocking on its own, can result in creek infilling (Figs. 9, 10), but there was limited evidence that this has a significant positive impact on the main marsh plant community. Creek blocking at Levington West may have led to increased water logging on that site (Q2), and increased dominance of cordgrass *Sporobolus anglicus*. Some important halophyte species, for example, sea purslane, which is a key target species to establish mid-marsh plant assemblages, require aerated and draining saltmarsh soils, and may be negatively affected by a higher water table. Saltmarsh is in dynamic equilibrium with the adjacent mudflats and offshore sediment stores (Green and Coco, 2014; Ladd et al., 2019), and movement of sediments on and off a marsh over the annual cycle of erosion and deposition is an important natural aspect of a healthy salt marsh (Callaghan et al., 2010; Redzuan & Underwood, 2020). Creek blocking runs a risk of disturbing these processes, as well as potentially trapping juvenile fish that move into and out of marshes over the tidal cycle to feed. These factors need to be considered in any restoration design.

Saltmarsh restoration has the potential to establish a virtuous cycle, where if the elevation is suitable and there are propagules available in the local species pool plant and animal communities will reassemble, unaided. This is important, as salt marshes can hold significant stocks of organic carbon, and therefore play a role in climate mitigation (McMahon et al., 2023). On almost all the ‘restoration’ locations studied, there is ‘vertical space’ available to bring the damaged or repaired site up to a tidal level that will support a functioning salt marsh (based on the ‘reference’ non-intervention sites in the immediate vicinity). Knowing the vertical space available, provides an opportunity to estimate the potential future carbon storage if restoration is successful. BUDS sediments when newly deployed were recorded to be low in organic matter and organic carbon (section 3.2.2), but over a process of biological development, organic carbon content is likely to increase. Utilising interventions to prevent further salt marsh loss will also preserve organic carbon *in situ*, that may otherwise become biologically available in the surrounding seascape and be degraded (Preston et al., 2025). Preserving existing carbon stocks does not attract carbon credits, but is an important consideration, given the stocks of organic carbon held within existing UK salt marshes (Burden & Clilverd, 2021), and in understanding the overall national ‘blue carbon’ inventory.

One challenge identified in this study is that each site had specific features defined by the local context. Each BUDS and channel-blocking scheme is different, sometimes in quite significant ways. Local designs specific to particular sites, tailored to either funding options, availability of materials, volunteers, or consents, create additional variability. It is not always clear what the success criteria of any particular scheme were intended to be. This site-species variation makes determining an ‘average’ treatment effect difficult, though differences between BUDS, channel blocking, and BUDS + blocking have been identified. We had to identify ‘control’ locations within sites to establish a baseline, or target for restoration to reach. Many schemes do not have baseline or time-course data, so understanding the temporal dynamics of restoration is a challenge, and further work on time frames for restoration is needed. A well-designed set of trial restorations, with appropriate controls, could significantly provide a stronger evidence-base for small-scale restoration approaches.

5. Conclusion

Both the restoration methods review and fieldwork data have highlighted that position of the marsh surface within the tidal frame is the key for plant establishment and development of a diverse marsh (Mossman et al., 2019; section 3.2.2.). McMahon et al. (2023) also demonstrated that this was true for several MR sites with consequently higher soil organic carbon content at more elevated sites.

Increasing the elevation of the marsh surface can be achieved naturally over time as tidal waters deliver sediment, which becomes trapped by plants. However, this is dependent on whether sediment load is sufficiently high to keep up with relative sea-level rise (SLR). BUDS can aid with raising marsh height for saltmarsh establishment or keeping marsh height in line with SLR, but the use of BUDS appears unique to the UK. The only examples of sediment deposition in northwest Europe occur when locally removed sediment is redistributed across the marsh (Rupprecht et al., 2023). In the UK, however, BUDS is commonly used with many examples of successful projects (section 2.2.3). The fieldwork data demonstrated that BUDS works best combined with creek blocking to hold the sediment in place and allow dewatering and consolidation. This, for example, results in the small difference between marsh height and creek bed height where BUDS has been deployed. BUDS material tends to be very wet and liquid when deposited or pumped and is therefore easily washed away by the tides. SREDs are therefore beneficial to reduce material loss. The novel technique of moving already consolidated material onto the upper shore with the drag box is able to achieve this without the need for SREDs. The dragbox trials have only been in place a couple of years, so the long-term colonisation rates of this material are unknown.

In addition to marsh elevation, having sediment with suitable characteristics in place will aid the establishment of plants. This includes 20% to 50% mud content (fraction < 63 µm; de Vries et al., 2021) and low-nutrient and muddy sites (van de Ven et al., 2024). The fieldwork data showed that to optimise halophyte colonisation, sediment shear strength should not be higher than 40 kPa and have a water content above 50%.

The review of restoration methods also highlights that additionally to marsh height and sediment properties, wave exposure is also an important factor with lower wave exposure leading to better plant survival. This can be achieved by placing coir rolls to break the waves (Maynard, 2020) or by selecting sites with lower wave exposure (Duggan-Edwards et al., 2020).

Several planting trials have also shown that saltmarsh creation can be aided by transplanting or seeding. However, this is very labour-intensive and can therefore only be carried out on very small scales. When the marsh conditions are right and seed material is locally present within the system, then plant establishment is likely to take place naturally (de Vries et al., 2021; Mossman et al., 2019).

Both the restoration methods review and the fieldwork assessments have also highlighted, that – apart from scientific research trials – restoration projects do not include controls and usually only include one restoration approach. The evaluation of restoration success is therefore often limited. The right conditions required for saltmarsh establishment and development of diverse marshes are clear; however, which of the discussed methods are likely to deliver these most efficiently is less evident.

Another factor to consider is that restoration efforts in the UK and the fieldwork completed as part of this project are focussed on the south and south-east of England. Saltmarshes across the UK are subject to biological variation – divided by the so-called 'Solway line', running from the Firth of Forth to the Solway (Dijkema, 1987) – and climatic and physical gradients (e.g. precipitation, sediment characteristics, different impacts of sea-level rise). This makes it likely that response to particular restoration methods may not be uniform across the UK.

Based on the fieldwork assessment, BUDS is a method which has the potential to successfully restore or create saltmarsh at a scale that is potentially investable. Whilst other methods might also be beneficial (e.g. BESE mats to trap sediment and provide structure for roots; SREDs to trap sediment), they are more difficult to scale up spatially and are likely to take longer because they rely on sediment to accumulate naturally. On the other hand, BUDS is only feasible where local dredging provides the required sediment; therefore, other methods should still be considered for areas where BUDS cannot take place.

Although the initial assessment identified BUDS as a candidate for inclusion in the Saltmarsh Code subject to further comprehensive assessment, other restoration methods demonstrated a strong community involvement and health and wellbeing element which should be recognised. Managed Realignment and BUDS are engineering projects requiring heavy machinery and dredging boats to breach sea walls and transport large quantities of sediment from the donor to receiver sites. Many of the interventions visited as part of the field survey were installed by hand, either by local communities, NGO working groups or individual efforts. While there were no data available on numbers of participants involved, there was general consensus that installing sediment traps by hand gave participants a greater understanding of what was previously an underappreciated and undervalued habitat.

To include potentially promising saltmarsh restoration techniques such as BUDS or the use of SREDs into the Saltmarsh Code, several steps need to be followed initially to determine whether the inclusion of these would be viable. This includes an estimation of the carbon credits likely to be gained by a particular restoration activity. The Saltmarsh Code is currently limited to managed realignment because this is the focus of the existing scientific state of knowledge. Carbon gain over time from other restoration methods is currently not predictable and this would also need to be assessed against the carbon footprint of carrying out the restoration. In order to progress the potential inclusion of restoration methods other than MR into the Saltmarsh Code, we propose further work as follows:

- A detailed assessment of BUDS to include 1) scoping BUDS in relation to the Saltmarsh Code in more detail (e.g. defining activities, estimating carbon emissions, market assessment) 2) long-term monitoring of selected BUDS sites to understand carbon gain over time, and 3) how BUDS sediments differ across the UK and whether their properties are related to plant establishment and plant diversity,
- A long-term robust trial to determine which restoration methods are best suited for saltmarsh restoration and creation at scale in areas where BUDS is not feasible. This should include 1) comparing different methods within one site and across several sites, 2) a cost-benefit analysis and carbon footprint analysis of methods, and 3) long-term monitoring to understand the carbon gain over time
- A structured, regional assessment of how different marsh types respond to small-scale interventions given variation in plant community type, sediment particle size, land use and sea level rise scenarios. This should consider changing climate conditions by 2050 and 2100 and how restoration targets for such “future” marshes may be different to the concept of restoring back to current or past ‘reference’ conditions.

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7. Appendix

Table A1: List of all the sites mentioned and summarised in this report.

Site Name	Region	Estuary	Country	Latitude	Longitude	Restoration Year	Source
Groot Buitenschoor		Scheldt	Belgium	51.363	4.248	2011	Silinski et al. (2016)
Borkum, Ronde Plate	Lower Saxony		Germany	53.570669	6.7016126	2018	Rupprecht et al. (2023)
Butjadingen, Langwarder Groden	Lower Saxony		Germany	53.609745	8.3239061	2014	Rupprecht et al. (2023)
Jadebusen, Neuwapeler-Außengroden	Lower Saxony		Germany	53.396536	8.251676	2016	Rupprecht et al. (2023)
Juist, Billheller	Lower Saxony		Germany	53.666797	6.8966112	2017	Rupprecht et al. (2023)
Krummhörn, Campen	Lower Saxony		Germany	53.401399	7.0128386	2018	Rupprecht et al. (2023)
Krummhörn, Dyksterkruger Heller Süd	Lower Saxony		Germany	53.462409	7.0229411	2021	Rupprecht et al. (2023)
Krummhörn, Pilsumer Heller	Lower Saxony		Germany	53.502636	7.0477463	2005	Rupprecht et al. (2023)

Langeoog, Sommerpolder	Lower Saxony		Germany	53.747773	7.540954	2004	Rupprecht et al. (2023)
Leybucht, Hauener Hooge	Lower Saxony		Germany	53.530549	7.077461	2023	Rupprecht et al. (2023)
Leybucht, Hauener Hooge	Lower Saxony		Germany	53.516022	7.0787614	1994	Rupprecht et al. (2023)
Leybucht, Mittelplate	Lower Saxony		Germany	53.52078	7.1136616	2013	Rupprecht et al. (2023)
Norderland, Lütetsburger Sommerpolder-West	Lower Saxony		Germany	53.667512	7.2485814	1986	Rupprecht et al. (2023)
Norderland, Westernessmerheller	Lower Saxony		Germany	53.682617	7.3490061	2022	Rupprecht et al. (2023)
Norderney, Ostheller	Lower Saxony		Germany	53.708335	7.2713161	2008, 2015	Rupprecht et al. (2023)
Wangerland, Elisabeth Außengroden	Lower Saxony		Germany	53.713011	7.8830936	2012-2015	Rupprecht et al. (2023)
Wurster Küste, Cappel-Nord	Lower Saxony		Germany	53.769307	8.5383415	2008	Rupprecht et al. (2023)
Wurster Küste, Cappel-Süd	Lower Saxony		Germany	53.758399	8.5295483	2008	Rupprecht et al. (2023)
Wurster Küste, Dorum Neufeld	Lower Saxony		Germany	53.743103	8.5201316	2018	Rupprecht et al. (2023)

De Schorren	Texel (Westfrisian Islands)		Netherlands	53.123817	4.900338	2016-2017	Temmink et al. (2020)
De Schorren	Texel (Westfrisian Islands)		Netherlands	53.123817	4.900338	2016-2018	Fivash et al. (2021)
Delfzijl Pilot Saltmarsh	Northeast Netherlands	Ems	Netherlands	53.327589	6.945745	2018	de Vries et al. (2021)
Delfzijl Saltmarsh Park	Northeast Netherlands	Ems	Netherlands	53.332055	6.940539	2018	de Vries et al. (2021)
Dortsman	Southern Dutch Delta	Eastern Scheldt	Netherlands	51.62375	4.11729	2020	van den Ven et al. (2024)
Oude Tonge	Southern Dutch Delta	Eastern Scheldt	Netherlands	51.57449	4.00379	2020	van den Ven et al. (2024)
Rattekaai	Southern Dutch Delta	Eastern Scheldt	Netherlands	51.62431	4.02903	2020	van den Ven et al. (2024)
Rilland		Scheldt	Netherlands	51.40083	4.1775	2011	Silinski et al. (2016)
Schor van Waarde	Southern Dutch Delta	Western Scheldt	Netherlands	51.5418	3.89652	2020	van den Ven et al. (2024)
Sint Philipsland	Southern Dutch Delta	Eastern Scheldt	Netherlands	51.44229	4.17573	2020	van den Ven et al. (2024)
Viane	Southern Dutch Delta	Eastern Scheldt	Netherlands	51.67517	4.12691	2020	van den Ven et al. (2024)

Zandkreek	Southern Dutch Delta	Eastern Scheldt	Netherlands	51.40072	4.11985	2020	van den Ven et al. (2024)
Zuigors	Southern Dutch Delta	Western Scheldt	Netherlands	51.38587	3.81937	2020	van den Ven et al. (2024)
Abbotts Hall	Essex	Blackwater	UK	51.787869	0.863655	2018	Langley (2021)
Allfleet's Marsh (Wallasea)	Essex	Crouch	UK	51.6152	0.8371	2006	OMReg Database
Anthorn	Cumbria	Solway Firth	UK	54.911652	-3.257592	2024	Solway Firth Partnership
Barrow Haven	Lincolnshire	Humber	UK	53.699599	-0.396854	1991	Defra and Environment Agency, 2004
Bedlam's Bottom	Kent	Medway	UK	51.3867	0.7115	1996	OMReg Database
Black Shed	North Yorkshire	Esk	UK	54.476568	-0.614537	2024	Groundworks NE & Cumbria
Boiler Marsh (Bottom Placed)	Hampshire	Lymington	UK	50.748649	-1.5056473	2014 to 2024	OMReg Database, Colin Scott
Boiler Marsh (pumped)	Hampshire	Lymington	UK	50.7516	-1.5011	2013	OMReg Database, Colin Scott
Bosham	West Sussex	Chichester Harbour	UK	50.828931	-0.852226	1998	Defra and Environment Agency, 2004

Brancaster	Norfolk		UK	52.96244	0.63889	2010 to 2013	Mossman et al. (2019)
Brightlingsea Creek (Borrow Pits)	Essex		UK	51.800176	1.0361695	2017	OMReg Database
Campfield	Cumbria	Solway Firth	UK	54.94395	-3.25299	2024	Solway Firth Partnership
Cardurnock	Cumbria	Solway Firth	UK	54.917472	-3.257592	2024	Solway Firth Partnership
Cindery Island	Essex	Colne	UK	51.8035	1.0329	2010	OMReg Database
Cleavel Point	Dorset	Poole Harbour	UK	50.674575	-1.998049	1997/1998	Defra and Environment Agency, 2004
Dart Estuary Saltmarshes	Devon	Dart	UK	50.411523	-3.657044	2024	Dart Harbour (no date)
Dornoch Sands	Scotland	Dornoch	UK	57.86681	-4.042977	2018	Maynard (2020)
Dunston Staiths inlet, Gateshead, South Tyneside	Tyne and Wear	Tyne	UK	54.958019	-1.640417	2023	Groundworks NE & Cumbria
Eden Course	Scotland	Eden	UK	56.356058	-2.8285344	2000 - 2018	Maynard (2020)
Fambridge (Westwick Marina)	Essex	Crouch	UK	51.6389	0.6677	2001	OMReg Database
Farlington Marshes	Hampshire		UK	50.834075	-1.027572	2024 (?)	Natural Dales Wool Products

Foulton Hall and Stone Point	Essex	Hamford Water	UK	51.9149	1.2535	1998	OMReg Database
Freiston Shore	Lincolnshire		UK	52.96443	0.09364	2010 to 2013	Mossman et al. (2019)
Goxhill	Lincolnshire	Humber	UK	53.697625	-0.269574	1988	Defra and the Environment Agency, 2004
Hackett's Marsh, Hamble River		Solent	UK	50.877362	-1.307171	2024	University of Portsmouth (2024)
Hest Bank	North England	Morecambe Bay	UK	54.092819	-2.815348	2024	Morecambe Bay Partnership, pers. comm.
Horsey Island Recharge	Essex	Hamford Water	UK	51.8819	1.2486	Early 1990s to 2006	OMReg Database, Defra and Environment Agency (2004), ABPmer (2016)
Kingfisher Court, Gateshead	Tyne and Wear	Tyne	UK	54.958117	-1.628912	2023	Groundworks NE & Cumbria
Langenhoe	Essex	Blackwater	UK	51.808119	0.930896	2012	Slee et al. (2023)
Levington (Suffolk Yacht Harbour)	Essex	Orwell	UK	51.9956	1.2664	2003 and on-going	OMReg Database, S. Read pers. comm.
Liebherr Slipway, Sunderland	Tyne and Wear	Wear	UK	54.913514	-1.393443	2021-22	Groundworks NE & Cumbria

Loder's Cut Island	Suffolk	Deben	UK	52.080065	1.3168131	2015, 2017, 2018	OMReg Database
Lymington River	Hampshire	Lymington	UK	50.756426	-1.526673	1994	Defra and Environment Agency, 2004
Maldon (Hythe Quay)	Essex	Blackwater	UK	51.731	0.6904	1993, since 2001 annually	OMReg Database
Mersea Harbour Adaptation	Essex	Blackwater	UK	51.769327	0.9027243	2022 (main project, but also some deposition in 1997-1998)	OMReg Database
Moverons Farm	Essex	Colne	UK	51.83334	0.986963	2018	Langley (2021)
Northey Island North West	Essex	Blackwater	UK	51.725793	0.7161972	2016	OMReg Database
Old Hall	Essex	Blackwater	UK	51.766877	0.8915703	2022	RSPB
Parkeston Marshes	Suffolk	Stour	UK	51.9445	1.2061	1994	OMReg Database
Point Clear - St Osyth	Essex	Brightlingsea	UK	51.795725	1.0297898	Oct 2016-March 2017	Reeder et al., (2021)
Prince Consort Road, Hebburn	Tyne and Wear	Tyne	UK	54.978987	-1.531008	2021	Groundworks NE & Cumbria

Red Wharf Bay	Northwest Wales		UK	53.297986	-4.193169	2016	Duggan-Edwards et al. (2019)
Rhymney Great Wharf	South Wales	Severn	UK	51.500472	-3.08479	1988, 2005, 2024	Alford, 2017
Riverside Park, Hebburn, South Tyneside	Tyne and Wear	Tyne	UK	54.974342	-1.532442	2023	Groundworks NE & Cumbria
Sandy Bay	Northumberland	Wansbeck	UK	55.162935	-1.534354	2023	Groundworks NE & Cumbria
Shelly Shore	Scotland	Eden	UK	56.370299	-2.8482706	2000 - 2018	Maynard (2020)
Shotley Foreshoe	Suffolk	Orwell	UK	51.9672	1.2742	2003	OMReg, Defra and Evironment Agency (2004)
Shotley Marina	Suffolk	Orwell	UK	51.9595	1.2795	1998	OMReg, Defra and Evironment Agency (2004)
South Ferriby	Lincolnshire	Humber	UK	53.678732	-0.513565	1986	Defra and Environment Agency (2004)
Tayport Common	Scotland	Tay	UK	56.441314	-2.864266	2018	Maynard (2020)
Titchmarsh Marina	Essex	Hamford Water	UK	51.8631	1.2526	1998 to 2007	OMReg Database
Tollesbury	Essex	Blackwater	UK	51.749759	0.865631	2012	Slee et al. (2023)

Tollesbury	Essex	Blackwater	UK	51.755837	0.8788891	2022	RSPB and Essex Wildlife Trust
Trimley Foreshore	Suffolk	Orwell	UK	51.97739	1.2809	2003	OMReg, Defra and Evironment Agency (2004)
TwoTree Island	Essex	Thames	UK	51.534186	0.632385	n/a	this report
TwoTree Island	Essex	Thames	UK	51.53192	0.62978	2024	Catchment to Coast (no date)
Wallasea	Essex	Crouch	UK	51.61532	0.82833	2010 to 2013	Mossman et al. (2019)
Wellhouse	Essex	Blackwater	UK	51.789529	0.906161	1986	Defra and Environment Agency, 2004
Wellhouse	Essex	Blackwater	UK	51.79189	0.91125	2012	Slee et al. (2023)
West Itchenor	West Sussex	Chichester Harbour	UK	50.808488	0.8690065	2023	OMReg Database, pers. comm. T. Godfrey
West Thurrock Lagoons and Marshes		Thames	UK	51.462557	0.281197	2021	Salix (no date)
Whitehall Landing, Whitby	North Yorkshire	Esk	UK	54.478454	-0.613506	2022-23	Groundworks NE & Cumbria
Yacht Haven Lymington	Hampshire	Lymington	UK	50.7502	-1.5241	2013	OMReg Database

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