Saltmarsh Restoration Project Toolkit (Version 1)

Rachel Langley, Living Seas Coordinator, Essex Wildlife Trust

Based on 2021 research

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Executive summary:

This Toolkit is for practitioners and for those considering different options for saltmarsh restoration including coir roll structures installed across channels within the marsh to encourage sediment accretion. The simplicity and clarity of this restoration approach is a strength of the project, in terms of ease of delivery, scalability and engagement. The approach could be delivered by a wide range of land managers with limited support.

This is the *first* version of this Toolkit and is designed to provide specific considerations and learnings on how projects using coir roll structures can be scoped out, delivered, and monitored for success. It should not be considered a definitive guide but more *a resource to support the evolution of this approach*; any future projects and restoration locations must be considered on a project-by-project and site-by-site basis.

This document is split into two sections. First, the Toolkit covers how each aspect of this method can be approached, what we have learned from developing the project so far and outlines our learning and recommendations. The second part is a more detailed report examining our delivery of Phase 3 of the Saltmarsh Restoration Project, including more detailed information about the data we have collected, how this was analysed, and the results. This section should be used as a supporting document to the Toolkit.

We are in a nature and climate emergency. Saltmarshes provide a number of ecosystem services and are considered important nature-based solutions and blue carbon habitats. Saltmarsh restoration can support nature's recovery - contributing to restoring 30% of land and sea by 2030; and restoring at least 15% of our priority habitats along the English coast by 2043, in line with the 25 Year Environment Plan. The restoration of existing saltmarsh habitats is key to our race to net zero and fighting the climate crisis, alongside ambitious saltmarsh creation projects and a significant reduction in emissions. Building on momentum from COP 26 will be essential.

The Saltmarsh Restoration Project was established in 2018 in Essex as an experimental, low-cost restoration technique by the Environment Agency (EA) and Essex Wildlife Trust (EWT). This Toolkit is part of our long term, multi-phase work to restore saltmarshes in Essex and beyond. Phase 1 and 2 were the installation and initial monitoring phases. Coir roll structures were installed in low energy saltmarsh to encourage sediment to build up behind and around them, encouraging vegetation to establish. Carbon is captured by the plants growing in the saltmarsh through photosynthesis and is stored both in the plant and the sediment beneath. The University of Essex joined as a project partner in 2020. Phase 3 started in 2021 and builds on Phases 1 and 2 to develop our monitoring and deliver this Toolkit. It is a vital development step that will ultimately kickstart our aspiration to roll-out this restoration approach on a landscape scale (Phase 4).

Key measurables were agreed to enable the success of the structures to be measured – sediment accretion, vegetation establishment and carbon storage potential. A combination of fieldwork, mapping and data analysis has enabled completion of the first set of quantitative results for the project. The main findings include that vegetation has successfully established on all the saltmarsh structures, sediment has accreted (as shown through photography but not drone or satellite-based information), and carbon is present in the sediment by the coir roll structures.

Several recommendations and learnings are captured throughout the Toolkit to support practitioners and those considering this restoration approach. It is important to highlight that although we still need more data to definitively measure the success of the structures, our initial findings provide a solid baseline to springboard future research and data collection and could be used to establish future targets. Furthermore, consideration should be made as to whether specific targets are needed or whether a certain number/area of structures in a marsh could be inferred to be successfully restoring and/or protecting the marsh. To combat the nature and climate emergency, we need actions now that restore nature and make both nature and people more resilient to climate change, whilst helping us to adapt; giving us time to plan bigger, transformational projects with a changing coastline. This restoration approach should be considered one of a suite of tools that could help us to achieve this.

The Toolkit

1. Why restore saltmarshes?

1.1. We are in a nature and climate emergency

We are in a climate and nature emergency, and the two are inextricably linked. Climate change is driving nature's decline, and the loss of wildlife and wild places leaves us ill-equipped to reduce carbon emissions and adapt to change. One cannot be solved without the other.

Recent global net zero pledges and commitments to reduce emissions by 2030 have improved the prospect of limiting global warming to 2ºC by 2100, but they must be delivered in full and extended further. However, even if warming is limited to 2ºC, significant alterations to the UK's climate will still take place (Climate Change Committee, 2021); the UK must adapt to a minimum average global temperature rise of between 1.5 and 2°C for the period 2050 – 2100 and consider the risks up to a 4ºC warming scenario (Climate Change Committee, 2021).

We know from experience that restoring nature can help. When healthy, our natural habitats can reduce the risk of flooding, help prevent coastal erosion, improve people's health and wellbeing, and maintain healthy soils, clean water and the pollinators needed for our crops.

Nature itself is at risk from climate change, but if helped to recover, its potential to store carbon and provide additional benefits means it can help us to turn the tide on the climate catastrophe. We must kick start nature's recovery and make nature-based solutions a priority.

The saltmarsh at Essex Wildlife Trust's Abbotts Hall nature reserve, Blackwater estuary, Essex. Photo credit: Terry Whittaker / 2020 Vision

1.2. What are saltmarshes and why are they important?

A distinctive feature of estuaries, saltmarshes are regularly flooded by the tide and are comprised of unique, salt-tolerant plants. Saltmarsh habitats in the UK have seen loss and damage over the years (in the UK we have lost 85% of our saltmarshes (The Wildlife Trusts, 2020). The most recent estimates for saltmarsh extent in England is between 32,162 ha and 37,953 ha (refs within Gregg, et al., 2021)and it is estimated that 57% of the

UK's remaining saltmarshes are in unfavourable condition (RPA, 2020).With this decline we have lost the ecosystem services (see Figure 1) and functions provided by the habitat.

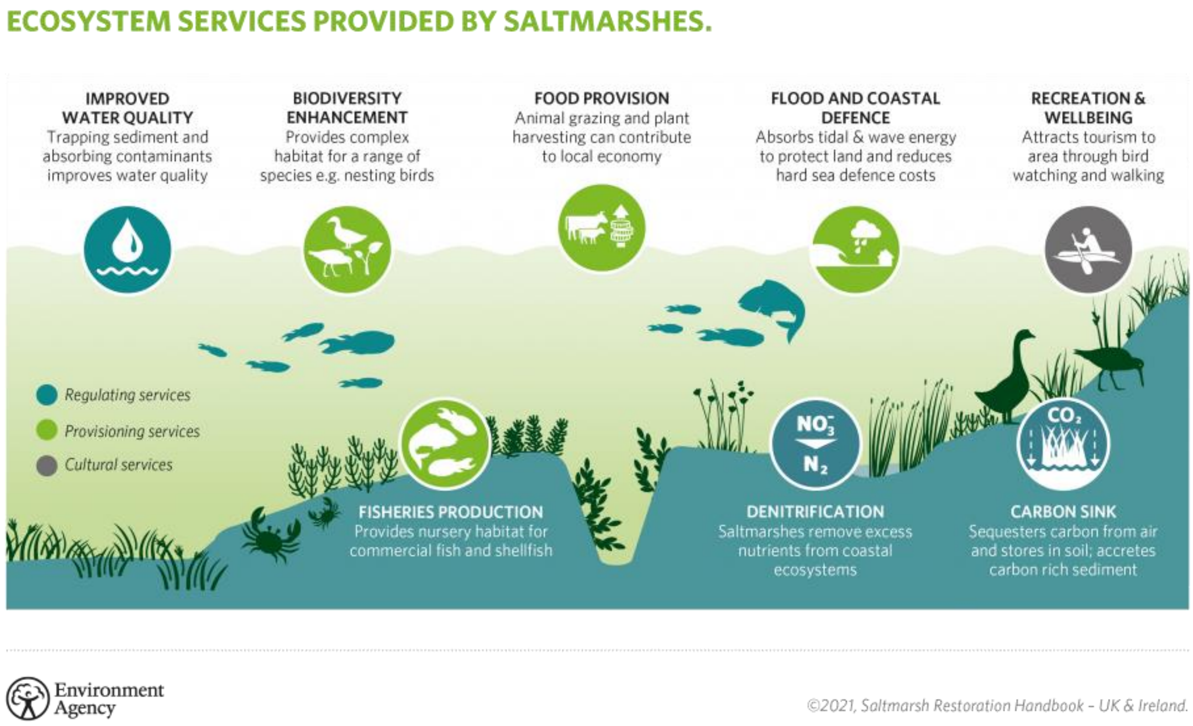

Figure 1 The ecosystem services provided by saltmarshes (taken from (Hudson, Kenworthy, & Best, 2021)

Active intervention is required to reverse the decline of saltmarsh habitats, and to successfully restore resilient and well-functioning ecosystems. Saltmarsh restoration is a prime example of a 'nature-based solution'. Nature-based solutions seek to protect or enhance nature in a way that helps tackle climate change and other challenges, while benefitting biodiversity and improving human wellbeing (Stafford, et al., 2021). As an example, Shepherd, et al. (2007) estimated that fronting saltmarsh provided a net saving of (in 2019 prices) just under £7,000/km yr-1 in flood defence expenditure on the Blackwater Estuary (Essex, England) (Hudson, Kenworthy, & Best, 2021).

1.3. Blue carbon

'Blue carbon' refers to the carbon accumulated in marine habitats. Saltmarsh is considered as one of the most important blue carbon habitats due to its ability to accumulate carbon and store it in plant biomass (saltmarsh plants can fix atmospheric carbon directly through photosynthesis where it is stored in the vegetation, roots and rhizomes of the plants in relatively short timescales) and the surrounding sediments (Swale, et al., 2022). Healthy saltmarshes can store carbon in similar amounts to many peatlands, with UK marshes have a typical sequestration rate of 4.40-5.50 t.CO2/ha/yr (Stafford, et al., 2021), although they are subject to erosion and accretion with natural coastal processes and are affected by changing sea levels) (Gregg, et al., 2021).

Coastal change and sea level rise is inevitable, and predictions suggested a nearly inevitable loss of saltmarshes (and other coastal landforms) in the twenty-first century and beyond for rapid relative sea level rise scenarios (Horton, et al., 2018). However, it is critical that the carbon stored in existing saltmarshes is locked up for as long as possible, while new saltmarsh is being created and ambitious, landscape-scape scale opportunities for marsh protection, restoration and expansion are explored and implemented.

In addition, human activities can disturb and reduce the quality and extent of marine habitats, limiting their ability to accumulate and store carbon, and can even result in elevated carbon emissions (Swale, et al., 2022). The UK Government has put in place ambitious targets around climate change, including achieving net zero greenhouse gas (GHG) emissions by 2050. The UK Climate Change Committee (2021) identified 'risks to natural carbon stores and sequestration from multiple hazards leading to increased emissions' as one of the highest priorities for further adaptation over the next two years. Therefore, maintaining our carbon stores and the restoration of existing saltmarsh habitats is key to our race to net zero (Marine Conservation Society & Rewilding Britain, 2021), even though blue carbon habitats are currently excluded from net zero reporting (Swale, et al., 2022). By protecting and restoring existing marshes, the carbon locked up in the sediments is prevented from being transported to other habitats, or mineralised and released to the atmosphere as CO2 as the saltmarshes erode and degrade. (Gregg, et al., 2021). It is important to note here that there are naturally high carbon turnover rates in lower elevation marshes which are subject to natural coastal processes, such as erosion and accretion. What is key is that human activities are not exacerbating this natural process further.

The restoration of existing marshes is needed alongside ambitious saltmarsh creation projects and a significant reduction in emissions.

In many cases, actions to increase carbon storage will also achieve other ecosystem service objectives such as enhancing biodiversity, climate change adaptation and resilience of marine habitats, increasing fish stocks, providing nature-based experiences for people, and improving the overall health and productivity of our seas (Swale, et al., 2022). This will benefit both wildlife, local coastal communities, and contribute to wider-scale benefits.

1.4. Saltmarsh restoration approaches

In 2021, as part of the Restoring Meadow, Marsh and Reef (ReMeMaRe) programme the Saltmarsh Restoration Handbook (Hudson, Kenworthy, & Best, 2021) was published to provide practical guidance on restoring and creating saltmarsh habitat across the UK and Ireland. It brings together advice on planning and implementing such schemes with case studies (including this project – case study 5.1.) and lessons from previous examples. This Toolkit does not look to replicate this but provide the context for how this project can be implemented and complement other restoration techniques. It is advised that the Saltmarsh Restoration Toolkit is consulted in tandem with this Toolkit.

There are three main ways that the extent and quality of blue carbon habitats such as saltmarshes can be enhanced: 1) the creation of new habitat (for example, mudflat and saltmarsh in managed realignment sites); 2) active restoration (inventions to re-establish a habitat that has been lost, or improve the quality of existing degraded habitat); and 3) natural recovery (removal of pressures) (Swale, et al., 2022).

While in no way designed to replace or compete with managed realignment projects, which are often the best approach for large-scale saltmarsh restoration and creation, this project offers a low-cost and quicker alternative that builds resilience in natural (and restored) marshes by providing a stabilisation technique which also protects sea walls, establishes vegetation and looks to store carbon. The approach could also be used as part of managed realignment and beneficial use project designs.

Saltmarsh at Abbotts Hall nature reserve Blackwater estuary, Essex. Photo credit: Terry Whittaker 2020 Vision

2. Background to the Saltmarsh Restoration Project

Each of the sections below outlines important considerations for setting up a similar project; it covers what approach was taken for this project and captures learnings and recommendations for future phases and new projects.

2.1. Rationale for project

Developing a range of innovative and flexible approaches to saltmarsh restoration is key to enabling us to combat the twin biodiversity and nature crises. Active intervention is required to reverse the decline of saltmarsh habitats, and to successfully restore resilient and well-functioning ecosystems.

Saltmarshes are an iconic feature of the Essex coastline, and Essex contains a significant proportion of the UK's saltmarsh resource. Protecting and restoring this habitat is a key strategic focus of Essex Wildlife Trust's (EWT) coastal and marine work, as well as that of local organisations and Partnerships.

2.2. Setting project goals, objectives and measurables of success/success criteria

2.2.1. What we have done:

At its inception, the goal of Phase 1 (installation) and Phase 2 (initial monitoring) was to restore saltmarsh habitat (which in turn would help protect sea walls). See Appendix 1 for the 2020 project report. This ultimate goal has remained, and Phase 3 objectives have focused on quantifying the success of the saltmarsh restoration approach (using coir roll structures); developing our student offering and developing and raising the profile of saltmarsh restoration, nature-based solutions and blue carbon. To help measure the success of the project to date, and in agreement with the Environment Agency (EA) and the University of Essex (UoE), the following measurable categories were agreed:

1. **Sediment accretion** – in its simplest form, we want to explore if/how the coir roll structures (see section 2.5) are encouraging sediment to accumulate.
2. **Vegetation establishment** – in its simplest form, we want to explore if/how vegetation establishes on the coir roll structures.
3. **Carbon storage potential** – in its simplest form, we want to explore if/how the coir roll structures are contributing to the storage of carbon in any accumulated sediment

The data collected in Phase 3 and presented in this Toolkit and Report will provide an important snapshot of how the restoration approach is faring. With any snapshot, it will be important to build on this information.

2.2.2. Learnings and recommendations:

- Early agreement of goals, objectives and measurables is recommended.
- Agreement of goals, objectives and measurables with project partners is advised, and is beneficial
- Any monitoring should inform future restoration (design, locations, approach, monitoring, scalability).
- Consideration of the monitoring methodology is important.
- This project provides an opportunity to measure/evidence the nature-based solution benefits provided by saltmarshes. The emphasis of overarching nature-based solutions objectives should be on the health, diversity, integrity and intactness and resilience of ecosystems, rather than simplistic standalone targets. Metrics used to help inform this can include area, condition, and connectivity, and abundance and diversity of species (Chausson, Smith, Sneddon, Coath, & Matheson, 2020).

2.3. Partners, stakeholders and specialists

2.3.1. What we have done:

Working in partnership increases the knowledge, expertise and resources available to deliver a project and reach a greater audience. It may also encourage ‘buy-in’ from other stakeholders. Partnership working has been key to this project’s success so far. In 2018, this project started out as a Partnership between the EA and EWT. The UoE were involved as Partners from 2020. One of the project sites, Moverons Farm, is owned by a coastal landowner. The Blackwater Partnership (a local Partnership made up of eNGOs, government organisations, oystermen, water companies and more) has been provided with regular updates on the project and to get local organisation support.

2.3.2. Learnings and recommendations:

- Having the Environment Agency as a project partner has been beneficial
- Having a university involved has helped develop the project and bring specialist expertise
- Consideration of landowners and access should be considered at an early stage. Landowner support is key.
- Natural England representatives should be engaged with throughout the project, and from an early a stage as possible.
- It may be necessary to engage with Marine Management Organisation representatives and others.
- Engagement with and input from specialists is also key. Discussions with specialists throughout the project is also important.

2.4. Site selection

2.4.1. What we have done:

The two project sites at EWT’s Abbotts Hall nature reserve, Blackwater estuary and Moverons Farm, Colne estuary (see Figure 2) were chosen by the EA and EWT as suitable sites to trial this experimental approach to restoration for several reasons, including: saltmarsh in the area is eroding, the Moverons site was part of an EA focus area at the time, and the sites are suitable for manual installation and semi-regular monitoring.

Both sites were ground-truthed before installation, which informed on the practicalities of structure installation and future monitoring, and importantly, to observe the sites throughout the tidal cycle.

The Blackwater estuary area has and continues to benefit from several studies that help with the selection of possible sites for expansion. This includes a natural capital assessment of the Blackwater estuary (Natural Capital Solutions, 2021), an evaluation of saltmarsh change in the Blackwater (ABPMer, 2016) and a planned assessment of opportunities for the beneficial use of dredged sediment for restoration projects.

The Blackwater Partnership (of which EWT, EA and UoE are Partners) has and will continue to be updated about the project. When appropriate, local landowners and stakeholders will also be approached.

2.4.2. Learnings and recommendations:

- It is important to understand relevant past and present research in the area
- Partnership working is key
- The *Saltmarsh Restoration Handbook* (Hudson, Kenworthy, & Best, 2021)and the *Saltmarsh Management Manual* (Environment Agency, 2007) are good sources to get an oversight of the available considerations and information (including what influences saltmarsh change).
- More focused, local studies may be available for the area that will help inform suitable sites.
- Any potential sites should be ground-truthed and relevant stakeholders and partners consulted as appropriate.
- Consideration should be given as to how this restoration approach would fit in relation to other saltmarsh restoration approaches, such as managed realignments and the creation of intertidal habitat through the beneficial use of dredged sediment. This restoration approach should not be considered an alternative to these but cheaper, potentially more flexible approach that complements them, and could be integrated into the designs of larger-scale projects.

Figure 2 The project location and sites

2.5. Materials and installation:

2.5.1. The material: coir rolls:

Coir is made from the husk of coconut shells. Coir rolls (see Figure 3 for six rolls being installed) are biodegradable structures that are widely used in wetland restoration, but less so in intertidal restoration projects. Along the coast, coir roll structures act as wave protection and sediment retention features and can be used within realignment schemes, or when restoring existing saltmarshes, to provide conditions that encourage sediment deposition and subsequent accretion (Hudson, Kenworthy, & Best, 2021). Small-scale trials are a good way to investigate whether biodegradable structures, like coir rolls are appropriate options to facilitate or speed up restoration at a particular site.

Figure 3 Coir rolls being installed as a 6-roll structure at Abbotts Hall by an EWT staff member and volunteer, November 2018

2.5.2. What we did:

In our project, 3m x 0.3m unvegetated coir rolls were purchased from Salix River & Wetland Services Ltd, Thetford (river restoration and erosion control specialists). The coir roll structures were installed in November 2018 to take advantage of the saltmarsh seed bank, so species could colonise the structures in the spring

In November 2018, all coir rolls were manufactured with a UV stabilised polypropylene multi filament net. At the time of publishing this Toolkit, fully biodegradable coir cased coir rolls are available and would be the preferred option for any future project.

The coir rolls were delivered by HIAB to each site. The rolls were then transported to the seawall by 4x4 and tractor and trailer. They were stored on a hard standing and covered before installation. Both project sites were relatively easy to access from the sea walls.

The coir rolls were strategically placed and secured with chestnut stakes and hessian rope in low-energy channels within the saltmarsh (see Figure 4 for a schematic).

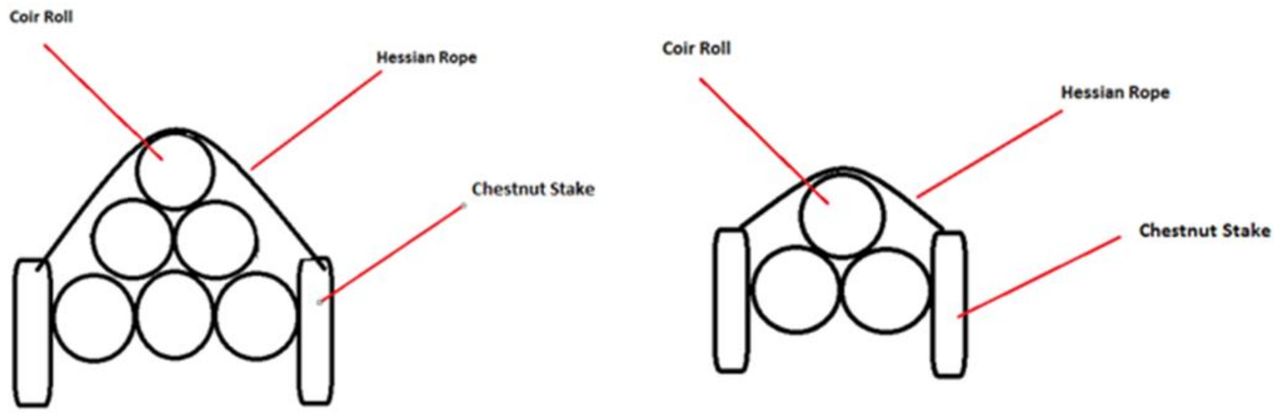

Figure 4 Schematic of the coir roll structures (3- and 6-roll options)

The coir rolls were installed manually by a combination of a EWT volunteers and staff and EA staff (Figure 3 and 5). It was hard, physical work. They are heavy and require at least two people to carry them. A total of 34 structures (each made up of 3- or 6- coir rolls) over two sites were installed in 3 working days.

Figure 5 Environment Agency and Essex Wildlife Trust installing the Moverons structures (left); Essex Wildlife Trust volunteers installing structure at Abbotts Hall nature reserve (right). Both in November 2018.

The structures were installed in three different layout types – U-shaped, aligned and single. All the structures at AHF are in a single layout and Moverons has a combination of all three (two singles, one aligned and the rest U-shaped). See Figure 6 for an example of a U-shaped layout.

Figure 6 An example of a U-shaped layout (one structure to the left, to the right and one placed centrally, to form a U-shape) at the Moverons Farm site (structure 6, 7 and 8)

Table 1 outlines the pros and cons/considerations of using coir rolls, which includes learning from this project.

Table 1 An overview of the pros and cons/considerations of using coir rolls

Pros	Cons/considerations
Relatively cheap	Avoid polypropylene netting and substitute with a biodegradable material
Relatively easy to install (can be installed by hand)	A hard standing is needed to store the coir rolls before installation
Coir is biodegradable	How accessible is the restoration site? How close can vehicles get?
Suited to small-scale projects	Can (will) sink into the sediment. Is this desirable?
	Potential barrier to fish and invertebrate movements

2.5.3. Learnings and recommendations:

- Choosing suitable sites will require an assessment of how the structures will be physically installed (is it practicable?) and monitored. Any future project installation sites that are hard to access would have to assess whether installation by hand is practicable, or whether alternative options need to be considered.
- It is recommended that structures are installed between September and November. It is important to have a good knowledge of the sites prior to installation.
- Installation must take place around low tide.
- The structure layout should be considered.
- Many sites are likely to fall within protected sites and so are likely to require consents/permits. It should not be assumed that a project can take place within a protected site. Any projects taking place within protected sites will need to consider when installation and any monitoring can take place.
- It is important to consider the furthest a HIAB (or similar) vehicle may be able to gain access to a seawall, and where the rolls can be stored in advance of installation.
- Coir rolls should be installed as soon as possible after delivery. If this is not immediately possible, they should be on a hard standing and be covered to protect them.
- Installation by hand is hard, physical work. Multiple individuals in good physical health will be required.
- A thorough Health & Safety Risk Assessment is essential.
- Consideration of the saltmarsh channel hardness is necessary. Is it possible to secure the chestnut stakes into the channel?
- Biodegradable materials should be used in any future installations.

- It is recommended that biodegradable coir cased coir rolls are trialled and installed in any future restoration projects.
- There are other products available that may be suitable for saltmarsh restoration but reviewing this is outside the scope of this version of the Toolkit.

2.6. Licencing and permitting

2.6.1. What we did:

In November 2018, the original coir roll structures were installed under article 19 of the Exempted Activities Order: Maintenance of coast protection, drainage and defence works.

However, conditions and requirements are likely to be different from site to site, so not all advice will be appropriate for each project/site. This could mean a Marine Management Organisation (MMO) marine licence would be required. If a marine licence is required, this has potential to add significant cost and time to the project but it does not mean future projects are unviable.

In addition to initial installation licence and permit requirements, all projects must consider the requirements for undertaking field work and research. Many coastal restoration sites are likely to fall within designated sites and thus will require a consent from Natural England to undertake the work on a Site of Special Scientific Interest (SSSI) (or other Protected Site). During Phase 3, the Natural England Responsible Officers for the relevant SSSIs were updated about the project and proposed activities. They were extremely helpful with assessing the impact of the field work and signing off the consents. A SSSI consent is issued to the landowner, rather than the individual/group undertaking the work. The project would not be possible at Moverons Farm without their support for the work, permitting access to their land and supporting getting the necessary consents.

Undertaking drone surveys to monitor the success of the coir roll structures in terms of sediment accretion and vegetation establishment, requires detailed paperwork to be completed before a flight. A drone pilot licence is also required.

2.6.2. Learnings and recommendations:

- Early exploration of which licences and permits are required is key. It is down to applicants/project managers to assess their works against the conditions of any possible exemptions, which can be assisted by the use of the MMOs' online interactive marine licencing tool. It is suggested that project managers use the interactive tool and then speak to their local Environment Agency Coastal Partnership & Strategic Overview team to see whether they believe the project could fit in with the exemption. If not, the next stage would be to request formal pre-application advice from the MMO about a licence. This is done by submitting an online enquiry requesting pre-application advice and engagement.
- If a MMO licence is required, consideration of the lead time of securing licences should be considered. Additional funding will also likely be needed if an MMO licence is required.
- Build positive relationships with and get 'buy in' from with Natural England Responsible Officers. These individuals have a detailed knowledge of their area and are of great benefit to the project.
- Build positive relationships with landowners, keep them informed about the project and feedback results when available. Landowner involvement and support is key to the project, and they are a great asset.
- A licenced drone pilot should be part of the project and detailed pre-flight paperwork must be completed.
- Consider opportunities for multi-activity permits and licences.

2.7. Funding

2.7.1. What we did:

At its inception, this project was funded by an Environment Agency Water Environment Improvement Fund (WEIF) grant at a cost of under £10,000 (excluding staff time). The current Phase (3) has been kindly funded by players of People's Postcode Lottery. At its current scale, the project has a low capital cost, with the majority of costs being in staff time. Any scaling of this project will require more significant financial investment in both.

A key appeal of this approach to saltmarsh restoration, which has the potential to be delivered across many sites nationally, is the low capital cost of the coir roll structures, costing as little as around £125 per structure (2018 prices).

Funding strategies for future installations of structures would need to be assessed on a project-by-project basis, depending on the specifics of the site in question, the delivery team and local funding landscape. But it is anticipated that likely sources of funding would be grant making trusts, eNGOs, or corporate bodies looking to meet CSR targets. There is likely to be an up-front cost in securing licenses and permits ahead of work.

2.7.2. Learnings and recommendations:

- Early understanding and securing of any required licences and permits is vital and may have an up-front cost on the part of the delivery team. It is almost certain that grant making trusts or corporate supporters will not fund the process of securing these permissions. Many will require these to be in place at an early stage, before funding is agreed or before bids are submitted. Undertake this process early, and use the permissions to strengthen the case for support.
- Funding bids are greatly strengthened by partnership work and a range of supportive, engaged stakeholders in the local community.
- Identify any relevant policy agendas that support individual projects and funding bids
- Monitoring of impact is essential

3. Monitoring and measurables

The next section provides an overview of the data the project has collected to date. Each section includes an overview of what we did, what we found and provides learnings and recommendations. Detailed methodologies and results can be found in the Phase 3 Project Report.

3.1. Mapping and photography of the structures

3.1.1. What we did and what we found:

Phase 3 of the project enabled us to focus on mapping the locations using a variety of techniques and software. This was achieved by a combination of smartphone GPS, handheld GPS units, drone work – using a Phantom 4 Advanced (DJI, Shenzen) (Figure 7)), Pix4D Mapper 4.6.4 for image processing, and ArcGIS Pro 2.8.2 for mapping structure locations and creation of maps. All maps were created using ArcGIS® software by Esri unless stated otherwise. ArcGIS® and ArcPro™ are the intellectual property of Esri and are used herein under license. The mapping and drone elements provided the foundation from which other data collection and analysis took place.

Specialist skills and licences are needed for undertaking the drone work and the data/image analysis, and training of project staff was required for both. Planning drone flights requires pre-planning and paperwork to be completed, and the pilot requires a drone licence. The UoE is developing their in-house drone survey skills, and this project provided an ideal opportunity to test approaches and kit.

Taking photographs remains a simple and effective way to monitor the structures. Time lapse footage provides some extra insights to how the structures interact with the tide and are a useful 'extra' piece of monitoring.

3.1.2. Learnings and recommendations:

- Specialist GIS and drone pilot skills are invested in (in-house or outsourced). This requires regular updating of training and skills.
- Project partners enable the pooling of shared expertise and resources, which may enable specialist skills to be shared.
- Appropriate software and hardware are available to enable speedy processing times and high-quality mapping and analysis. Appropriate licences must also be obtained and kept up to date.
- Natural England Consent must be gained before flying a drone over a SSSI/SPA (Special Protection Area).
- Potential to use a GIS mobile app such as ArcGIS Field Maps in future data collection. This would allow the user to view the map and their own location on a mobile device such as smart phone or field tablet. Field Maps has built-in accuracy reporting for the device's built in GPS which adapts to the current conditions, therefore mapping of structure locations and any other attributes required could be efficiently and confidently completed on site at any point from the planning stage to post-installation.
- It is recommended that fixed-point photography takes place at 6-month intervals, with one monitoring day taking place when the vegetation is at its peak in June-July.

Figure 7 The University of Essex drone pilot and drone preparing for flight (right photo credit Natalie Hicks)

3.2. Sediment accretion and assessment of channels:

Rationale: in its simplest form, we want to demonstrate that the structures are encouraging sediment to accumulate.

3.2.1. What we did and what we found:

In summary, three years after installation of the structures, there is visual sediment accretion on and around the structures (shown from fixed point photography) but it has not yet been possible to measure the accretion and any erosion (although this should be possible in future years); this provides a solid basis for future monitoring. Vegetation will only establish where sediment has accreted, so Section 3.3 should be considered further evidence for the coir roll structures accreting sediment, at the very least on the coir roll structures themselves.

Drone surveys were undertaken to offer a detailed but larger-scale assessment of the structures within the saltmarsh. The drone footage provided context for the location of the coir roll structures within the saltmarsh channels. It is possible to zoom in on the structures in some detail (see Figure 8) and this offers a way to monitor how the structures are faring without the need for an on-the-ground assessment.

Digital surface models (DSMs) were created through processing sets of photographs taken by the drone in 2020 and 2021. Photographs were processed in Pix4D Mapper 4.6.4 into 3D maps. Change maps were created in QGIS 3.16.9. The DSMs created from the drone imagery are shown in *Appendix 2*. It was not possible to calculate a valid elevation change map based on comparisons of the imagery collected. However, there is promise for the detection of accretion associated with the structures over longer-term intervals and with well-aligned imagery.

LiDAR analysis was undertaken to infer whether the structures have caused a change in elevation within the channels. Change maps were created in QGIS 3.16.9. The LiDAR analysis is shown in *Appendix 3*. At this point in time the LiDAR imagery does not detect sediment accretion on and around the structures.

Figure 8 Close-up view of structures 6, 2 and 3 at Abbotts Hall nature reserve Shiplock area 3D orthomosaic created in Pix4D Mapper.

Photographs were taken of each of the structures during 2021 (3 years after installation) to provide on-the-ground observations and opportunities for comparison. Photographs from previous years were also reviewed. On-the-ground photography of the structures is show in Appendices 4a-d and Figure 9 shows an example of changes over time. There were visual signs of accretion. The time lapse camera footage showed the interaction between the coir roll structures and the tide.

3.2.2. Learnings and recommendations:

- Depending on the nature of the marsh channels, some structures have the potential to reach the level of the existing marsh and may in time create vegetation 'bridges' over the channels. Structures that are installed in deeper channels will likely never reach the height of the natural marsh; although these still have the potential to slow the flow and encourage accretion.
- A combination of on-the-ground photography and drone footage and DSMs are used to continue to monitor the structures and the surrounding marsh.
- Longer-term, repeatable drone footage is advised. This is likely to become more important as the structures further 'bed in' to the channels and in some cases, are no longer visible. It also provides the opportunity to monitor changes over the marsh on a larger scale over time, and has the potential to make comparisons between channels with and without structures.
- Consideration is taken for the benefits of using drone imagery over LiDAR, including greater spatial resolution (therefore likely greater sensitivity to small amounts of accretion/erosion); ability to control the

time of year of the imagery (i.e. ability to choose same season and therefore similar stage of plant maturity); ability to control the time of day of the imagery (i.e. ability to choose similar tide heights).

- Drone footage is taken on an annual/semi-annual basis around low tide during June – July when the saltmarsh vegetation is at its most verdant. This should be reviewed five years after installation and provides a method to obtain detailed imagery of saltmarshes when considering other sites that may be suitable for this restoration technique in the future.
- Drone imagery is taken at sites being considered for coir roll structures a number of years before installation in order to make a detailed assessment of the existing sediment accretion/erosion dynamics of the marsh.
- Drone footage is taken of the wider marsh so any wider changes can be detected over time.
- LiDAR analysis should take place pre- and post-installation, with post-installation taking place immediately (or as soon as possible after) installation and 5 years after installation
- Pre-installation imagery could be used to help identify future sites that may be suitable for this restoration approach, especially if there are time and resource limitations to collecting drone imagery.
- Fixed-point photography takes place on an annual basis at low tide between June – July (in line with drone imagery recommendations).
- Where possible, time lapse cameras are deployed at sites being considered for coir roll structures in the future. The footage is also a valuable engagement tool.
- The ability of photographs and maps as an aid to engage and inspire audiences should not be underestimated.

Figure 9 Moverons structure 5 in June 2020 (left) and June 2021 showing how the structure has 'bedded in' to the channel.

3.3. Vegetation establishment:

Rationale: In its simplest form, we want to show that vegetation can establish on the structures.

3.3.1. What we did and what we found:

The overall take away message from our monitoring is that saltmarsh vegetation can successfully establish on the coir roll structures three years after installation. Saltmarsh vegetation established on the coir roll structures in the first summer after installation.

The first quantitative vegetation survey took place three years after installation, so although it is not possible to quantify the change over time, visual changes shown in the photographs are clear. The quantitative investigations show that most of the vegetation is made up of pioneer species such as *Salicornia.* There is a large percentage cover of *Vaucheria spp* algae for most of the structures (see Figure 10), and some structures only have *Vaucheria* present. Although this is an alga rather than a saltmarsh plant species, *Vaucheria* can strengthen sediment by creating stable and elevated surfaces, which can in turn promote marsh establishment (van de Vijsel, van Belzen, Bouma, van de Wal, & van de Koppel, 2021).

Figure 10 Example of structure with Vaucheria establishment - Moverons Structure 3

Various statistical tests and investigations were undertaken to explore vegetation establishment. Despite the project sites being on different estuaries and on marshes with different characteristics, the total percentage cover of vegetation on the structures did not significantly differ between them. This is positive as it indicates that the site does not wholly influence the success of the establishment. However, the study had a small sample size.

U-shaped layouts (rather than aligned/side-by-side and single) are currently the most successful structure layout (compared to aligned and single structures) for both total vegetation percentage cover and total number of species, although this is based on a small sample size. Some of the most successful structures in terms of vegetation establishment are shown in Figure 11 and are all part of U-shaped layouts.

The distance of the coir roll structures from the seaward saltmarsh edge looks to potentially affect the number of species established, with a general (but not significant) trend for a greater vegetation percentage cover the further from the marsh edge.

There is a low saltmarsh plant species richness established on the coir roll structures compared to the natural marsh at Abbotts Hall nature reserve. This is to be expected as the coir roll structures are within relatively deep channels within the marsh, so offer habitat most suitable for pioneer species rather than mid- and upper-marsh species. The majority of species present are pioneer species, including the alga, *Vaucheria*.

Figure 11 From top left clockwise, Moverons Structures 14, 15, 17, 18 (all photographs taken in June 2021) demonstrating the higher vegetation cover possible on the structures. Note that is was not possible to estimate the percentage cover for structure 17 from the photographs.

3.3.2. Learnings and recommendations:

- Quantitative vegetation monitoring continues to assess if/how the vegetation species and percentage cover changes over time.
- *Vaucheria* continues to be recorded in future monitoring. It will be important to see whether structures with only or predominately *Vaucheria* present become established by saltmarsh species in future years.
- Consideration of the depth of the channels and height of the natural marsh vegetation. Some structures have the potential to reach the level of the existing marsh and may in time create vegetation 'bridges' over the channels. Structures that are installed in deeper channels will likely never reach the height of the existing marsh.
- Further monitoring is undertaken at existing sites, and structures are installed at new sites to further test this and increase the sample size.
- U-shaped layouts are considered as the optimum layout (of the three tested layouts) when identifying future restoration sites. However, having examples of each layout within each site would better test this.
- To better understand the effect of the distances and layout, a better spread of distances amongst the different layouts would be available.
- The vegetation of the coir roll structures and the natural marsh is compared at Moverons Farm.
- It is recommended that a standard monitoring methodology is adopted for both (and any future sites)
- Additional structures are installed as part of this investigatory Phase to increase the sample size.
- NDVI options continue to be explored and for any future NDVI surveys, the same camera is used under the same conditions and that ground control points are used
- A multi-method approach is adopted for future monitoring
- Expert surveyors are available to advise/carry out future surveys to minimise the chance of misidentification.
- A data analysis expert/researcher is available to lead on bringing together future survey results and comparing results between years. This may be suitable as a discrete MSc/PhD project.

3.4. Carbon storage potential:

Rationale: in its simplest form, we want to demonstrate how/if the structures are contributing to the storage of carbon in any sediment accumulated.

3.4.1. What we did and what we found:

Sediment cores were taken from around the coir structure (one sample on each side of the structure – Figure 12). Cores were also taken from the natural marsh and channels with no coir roll structures, to act as 'control' samples. The total carbon content (mg/g) was calculated.

The project found no significant difference between the carbon stored in the sediment directly by the structures vs the natural marsh and creeks without structures. While these sediment carbon content results are useful as a starting point, the results are based on a small sample size. This also means that it makes sense to combine carbon content results for the whole site, rather than looking at the carbon content for individual structures; with more data, individual analysis of structures may be possible, with replicates around each structure.

It is not possible to ascertain how much the structures are directly contributing to carbon storage at this point in time. However, all samples contained some level of carbon and the carbon storage benefits of saltmarshes are widely acknowledged.

Figure 12 Taking a sediment core from one of the coir roll structures

3.4.2. Learnings and recommendations:

- That future carbon calculations are standardised for comparison with other studies
- That the data collection approach is reviewed and refined in future years, to include enough replicates to analyse trends without compromising the stability of the structures and the marsh.
- That the carbon stored in the saltmarsh plants that have established on and around the coir roll structures is considered for future studies, or at least highlighted when analysing the vegetation communities present.
- That sediment samples are analysed for carbon content for all project sites at the same/similar time.
- If there is a small sample size, combine different site results where possible. With more data, individual analysis of structures may be possible.
- Future project monitoring could include not only measuring the amount of carbon around these structures, but also to age the carbon (e.g. using chlorophyll as a proxy provides an indication of how recent the carbon is) and identify the source of the carbon (is it terrestrial e.g. from salt marsh plants, or is it marine e.g. diatoms, *Vaucheria*). A seasonal study of the carbon dynamics would also determine how this changes over an annual timescale, and if the salt marsh is accreting this carbon for sequestration (carbon sink) or losing it.
- That longer term carbon monitoring of the sites is undertaken to determine and assess the carbon storage benefits provided by this restoration technique, and to contribute to blue carbon research of saltmarshes.

- That some form of student research is included in future monitoring to provide a valuable engagement and learning opportunity for students.
- The project has the potential to demonstrate the additional nature-based solutions provided by saltmarshes in the future. It also provides a useful engagement tool, raising awareness of nature-based solutions and blue carbon and providing important practical experience for students.
- A Natural England Consent would normally be required for sediment sampling in Protected Sites (this was gained for this project for both sites).

3.5. Other considerations:

3.5.1. Potential barriers to fish migration

Although there are obvious benefits to installing coir roll structures, impacts on all aspects of wildlife must be considered. The issue of the structures potentially impeding fish movements within the marsh was considered in the early stages and photography taken since installation in 2018. Following fish ecology specialists raising concerns about the potential for these structures to impede fish passage, an estuarine fish specialist visually reviewed a handful the structures at AHF in 2021. As the structures were within deeper channels and had bedded into the channels, with the saltmarsh creating new smaller runnels around and under the structures in places, it was felt that the structures would not be causing a significant barrier for estuarine fish movements. Since installation, there have been no visible fish mortalities on or around the structures. This will be kept under review.

3.5.1.1. Learnings and recommendations:

- The potential of coir roll structures acting as barriers to fish migration must be considered in the early stages of the project, especially at sites with shallow channels.
- Engaging with estuarine fish specialist during the design, installation and monitoring phases would be beneficial.

3.5.2. Other pressures

As well as actively restoring and recreating functioning blue carbon habitats, removing other pressures and activities hindering this process should be considered; this includes elevated nutrients and anthropogenic activities that have a potential of causing direct physical habitat disturbance (Swale, et al., 2022). Although currently outside the scope of this project, a holistic approach to coastal restoration should be considered.

3.5.2.1. Learnings and recommendations:

- A holistic approach to coastal restoration should be adopted where possible, where projects like this are delivered alongside others that combat key pressures in each location, including elevated nutrients.

3.6. Adding impact: communications and engagement

3.6.1. What we did and what we found

A communications plan was developed for the project which identified relevant activities to undertake throughout the year to help achieve the project outcomes. This included creating a project webpage, featuring in EWT's Wild Essex magazine and The Wildlife Explorer podcast, creating social media posts and creating a project video. Throughout the year, the project was pitched to press and media outlets and received positive coverage from print and online press and the Project Lead was involved in several interviews. Raising awareness of the project and getting information out in the public domain meant that several organisations directly contacted EWT about featuring the project. The project helps demonstrate how saltmarshes provide nature-based solutions to the climate crisis; it helps feed into important conversations and campaigns and demonstrates on-the-ground action.

Working with the UoE has enabled the project to utilise invaluable specialist expertise and skills. It has also enabled the project to offer UoE students practical field work experience of a topical and current coastal conservation project. BSc Marine and Freshwater Biology students completed field work at EWT's Abbotts Hall nature reserve over two days as part of their Estuarine and Coastal Ecology Field Module (Figure 13). The students undertook vegetation surveys and sediment samples and made a valuable data collection contribution to the project. The students' completed a survey before and after undertaking the field work. Overall, students' self-rated knowledge of saltmarshes, saltmarsh restoration, nature-based solutions, using coir rolls for saltmarsh restoration, and the carbon sequestration and storage abilities of saltmarshes increased after undertaking the field work.

3.6.2. Learning and recommendations:

- A thorough communications plan is created for similar projects to get the maximum engagement and to support future nature-based solutions focused campaigns.
- Local Partnerships and relevant stakeholders are engaged where possible.
- Opportunities for engagement and Partnership working with universities is explored.

Figure 13 UoE students receiving a talk by EWT and EA representatives before starting their field work (left); UoE students receiving a sediment core methodology briefing (right)

4. Overall conclusions and next steps:

We are in a nature and climate emergency. Saltmarshes provide a number of ecosystem services and are considered important nature-based solutions and blue carbon habitats. The restoration of existing saltmarsh habitats is key to our race to net zero and fighting the climate crisis, alongside ambitious saltmarsh creation projects and a significant reduction in emissions.

This Toolkit has outlined the approach this project has taken to date. It captures key learnings and recommendations. Key findings from the monitoring include that vegetation has successfully established on all the saltmarsh structures, sediment has accreted (as shown through photography but not drone or satellite-based information yet), and carbon is present in the sediment by the coir roll structures. This is an important stage for the project and the methods and approaches outlined form the basis for ongoing monitoring and future projects.

Due to a small sample size, structures were assessed as a group rather than individual structures. More data points (i.e. more structures or replicates) would be needed for this. Although we still need more data to be able to definitively measure the success of the structures, our initial findings provide a solid baseline to springboard future research and data collection and could be used to establish future targets. Furthermore, consideration should be made as to whether specific targets are needed or whether a certain number/area of structures in a marsh could be inferred to be successfully restoring and/or protecting the marsh.

In terms of carbon storage and sequestration benefits, protecting existing habitats should be prioritised over restoration efforts, as the carbon stocks within natural habitats tend to be larger (per unit area) than those for restored habitats (Swale, et al., 2022). Therefore, these structures should be considered for both what they directly deliver in terms of establishing vegetation and accreting sediment, but also in the secondary benefits they provide in protecting the existing marshes – keeping the carbon locked up.

This Toolkit has presented several options for monitoring key variables. However, it may not be necessary for all these approaches to be adopted for future phase or new projects. A balance between resourcing and outputs should always be considered. Software is constantly evolving and improving and upskilling staff will be necessary.

This Toolkit provides guidance on some of the key considerations and approaches of how locations for additional structures could be decided. Each project and site will need to be considered on its own merits. It is also important to note that this project is only three years old; the potential long-term impacts and benefits will not be clear for several years (as is the case for many restoration efforts).

While in no way designed to replace or compete with managed realignment projects, which are often the best approach for large-scale saltmarsh restoration and creation, this project offers a low-cost and quicker alternative that builds resilience in natural (and restored) marshes by providing a stabilisation technique which establishes vegetation, encourages sediment accretion and has the ability to store carbon. The approach could also be used as part of managed realignment and beneficial use project designs.

There are several key **next steps** for this project:

- Use this Toolkit and report to inform the creation of a monitoring plan for 2022 and 2023, taking the project up to 5 years since installation. It is felt that more data and refinement of monitoring approaches is needed before this approach is rolled out on a large-scale.
- Share this Toolkit and Report with practitioners, relevant organisations and interested stakeholders
- Work with relevant organisations to resolve any licencing issues for future installations.
- Continue the student field work with the University of Essex, further refining the data collection approach and analysis
- Start to scope out areas in Essex with eroding marshes that might be suitable for project expansion.
- Aim to incorporate coir roll structures into future managed realignment and BuDS saltmarsh restoration projects where appropriate. Note this would be a new stream of work looking at their potential for created rather than natural marshes.
- Build on positive communication and engagement activities and general public interest.
- Explore opportunities to further promote the work done to date
- Continue to consider potential fish migration impacts
- Continue to upskill project staff.
- Consider how other pressures and activities hindering saltmarsh restoration, such as elevated nutrients and anthropogenic activities that have a potential of causing direct physical habitat disturbance can be managed.

Phase 3 Report

1. Introduction:

This report captures the data collected and analysed during Phase 3 of this project to date. It is split into the following measurable categories, as defined by the Project Partners – Essex Wildlife Trust (EWT), the Environment Agency (EA) and the University of Essex (UoE).

- **Sediment accretion** – in its simplest form, we want to explore if/how the structures are encouraging sediment to accumulate.
- **Vegetation establishment** – in its simplest form, we want to explore if/how vegetation establishes on the structures.
- **Carbon storage potential** – in its simplest form, we want to explore if/how the structures are contributing to the storage of carbon in any accumulated sediment

This report is designed to be used as a supplementary document to the Toolkit. This report provides more detailed information about each of the approaches used, so there is some overlap between the two.

2. Mapping and photography of the structures:

2.1. Method:

Phase 3 of the project enabled us to focus on mapping the locations of the coir roll structures, quadrats and surrounding saltmarsh using a variety of techniques and software. This was achieved by a combination of smartphone GPS, handheld GPS units, drone work – using a Phantom 4 Advanced (DJI, Shenzen), Pix4D Mapper 4.6.4 for image processing, and ArcGIS Pro 2.8.2 for mapping structure locations and creation of maps. Maps throughout this document were created using ArcGIS® software by Esri unless stated otherwise. ArcGIS® and ArcPro™ are the intellectual property of Esri and are used herein under license. The mapping and drone elements provided the foundation from which other data collection and analysis took place.

GPS co-ordinates and grid references collected in the field were used to create a point vector layer of the coir roll structure locations. Accuracy of these locations was then improved by referring to the georeferenced orthomosaic created in Pix4D Mapper from the drone images, where the structures could be visualised directly. The Near geoprocessing tool in ArcGIS Pro was used to measure the distances from each coir roll structure to the nearest coir roll structure to it. The position of the sea wall and the saltmarsh edge from the Imagery basemap were digitised as line features in the study areas, and the Near geoprocessing tool used to measure the shortest distance from each coir roll structure to these features.

It is recommended that a minimum of 16GB of RAM is available for Pix4D Mapper. In addition, based on CPU usage during this project, estimated minimum CPU requirement for processing sets of images is Intel i7 (or AMD equivalent) processor - 4 core, 8 threads minimum (8 core, 16 threads preferable). Image processing took on average approximately an hour per image set, though this was variable according to number of images.

Photos were also taken of the structures, building on the photo database that has been developed since the installation of the structures in 2018. (see Appendices 4a-d). Time lapse footage was taken of two structures.

2.2. Results:

The coir roll distances can be found in Appendix 5 and are used within Section 4.

The location of each coir roll structure at Abbotts Hall nature reserve and Moverons are shown in Figures 1 and 2. They provide a detailed overview of where each structure sits in each channel.

Appendix 3a-d has photos of the structures in 2021 and pre-2021. The photos show the variety of structures and will be analysed in more detail in the next sections.

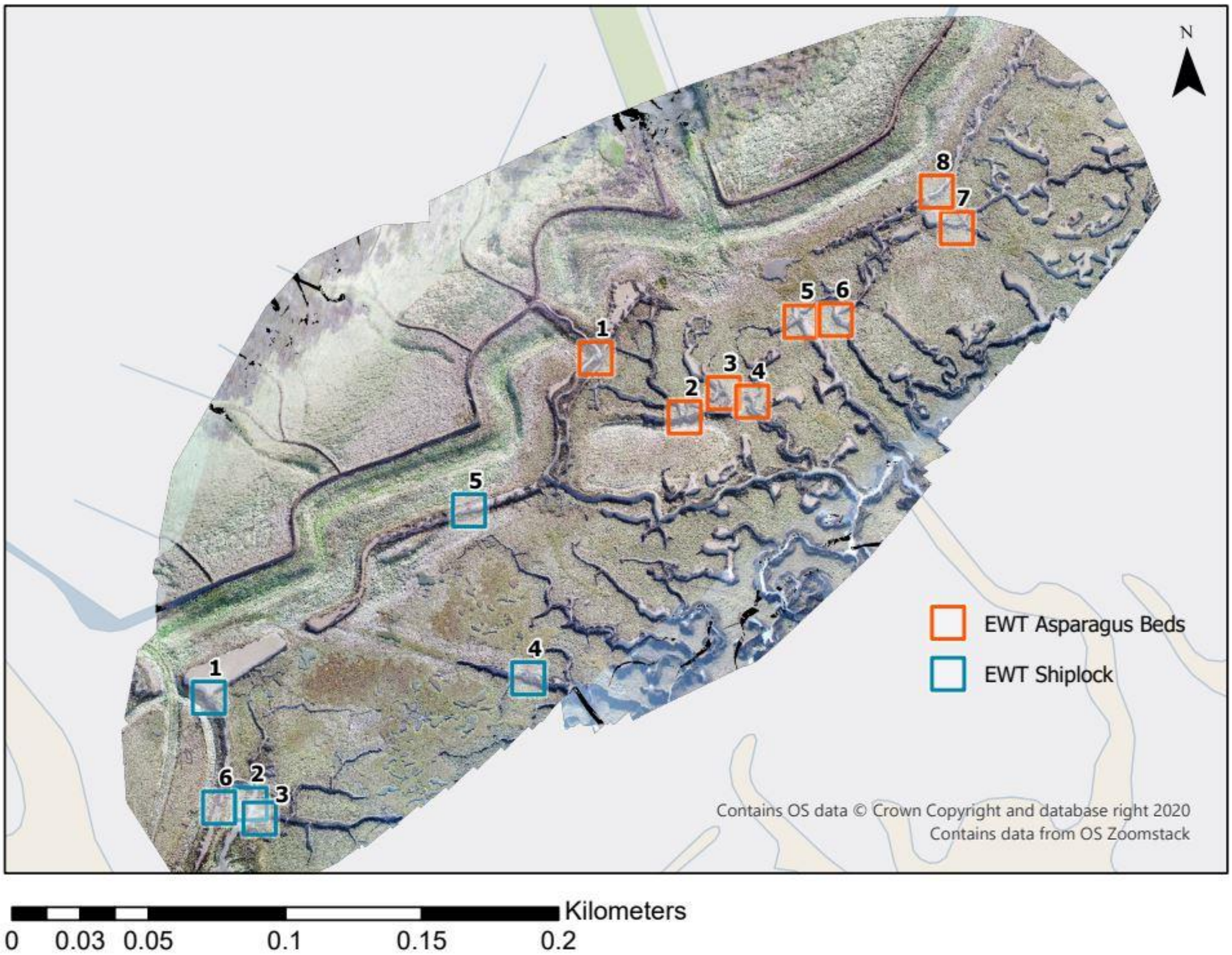

Figure 1 EWT's Abbotts Hall nature reserve coir roll structure locations, highlighting the two project areas within the site – Asparagus Beds and Shiplock. All coir rolls at this site have a single structure layout.

Figure 2 Moverons Farm coir roll structure locations with associated structure layout.

3. Sediment accretion and assessment of channels:

3.1. Method:

Drone surveys were undertaken to offer a detailed but larger-scale assessment of the structures within the saltmarsh. The method for drone surveys and drone survey analysis is outlined in Section 2.1.

Digital surface models (DSMs) were created through processing sets of photographs taken by drone in 2020 and 2021. Photographs were processed in Pix4D Mapper 4.6.4 into 3D maps. Change maps were created in QGIS 3.16.9, using the raster calculator to subtract the earlier DSM from the later.

LiDAR analysis was undertaken to infer whether the structures have caused a change in elevation within the channels. Change maps were created in QGIS 3.16.9, using the raster calculator to subtract the earlier LiDAR imagery from the later. Negative, unchanged (+/- 0.15 to account for margin of error) and positive values were classified into different colours to indicate decreased, unchanged and increased elevation. To investigate the elevation change pre installation (2018) and post installation, the following time-intervals were investigated: 2001-2020 (Abbotts only); 1999-2020 (Moverons only); 2015-2018; 2018-2020.

Photographs were taken of each of the structures during 2021 (3 years after installation) to provide on-the-ground observations and opportunities for comparison. Photographs from previous years were also reviewed and sorted into updated documents.

3.2. Results:

The drone footage provided context for the location of the coir roll structures within the saltmarsh channels. A detailed, 3-D, bird's eye view of each of the structures was created. It is possible to zoom in on the structures in some detail (see Figure 3) and offers a way to monitor how the structures are faring without the need for an on-the-ground assessment. The ability to take distance measurements from the footage gives flexibility for analysis over time.

Figure 3 Close-up view of structures 6, 2 and 3 at EWT's Abbotts Hall nature reserve Shiplock area 3D orthomosaic created in Pix4D Mapper.

The DSMs created from drone imagery from 2020 and 2021 are shown in *Appendix 2* and an example DSM shown in Figure 4. Although accurate geolocation through use of ground control points was attempted in this project, and good geolocation accuracy was achieved, it was not of a high enough accuracy to directly compare DSMs without prior co-registration. However, some structures were faintly visible in the Moverons change map despite the misalignment. This is promising for the detection of accretion associated with the structures over longer-term intervals and with well-aligned imagery.

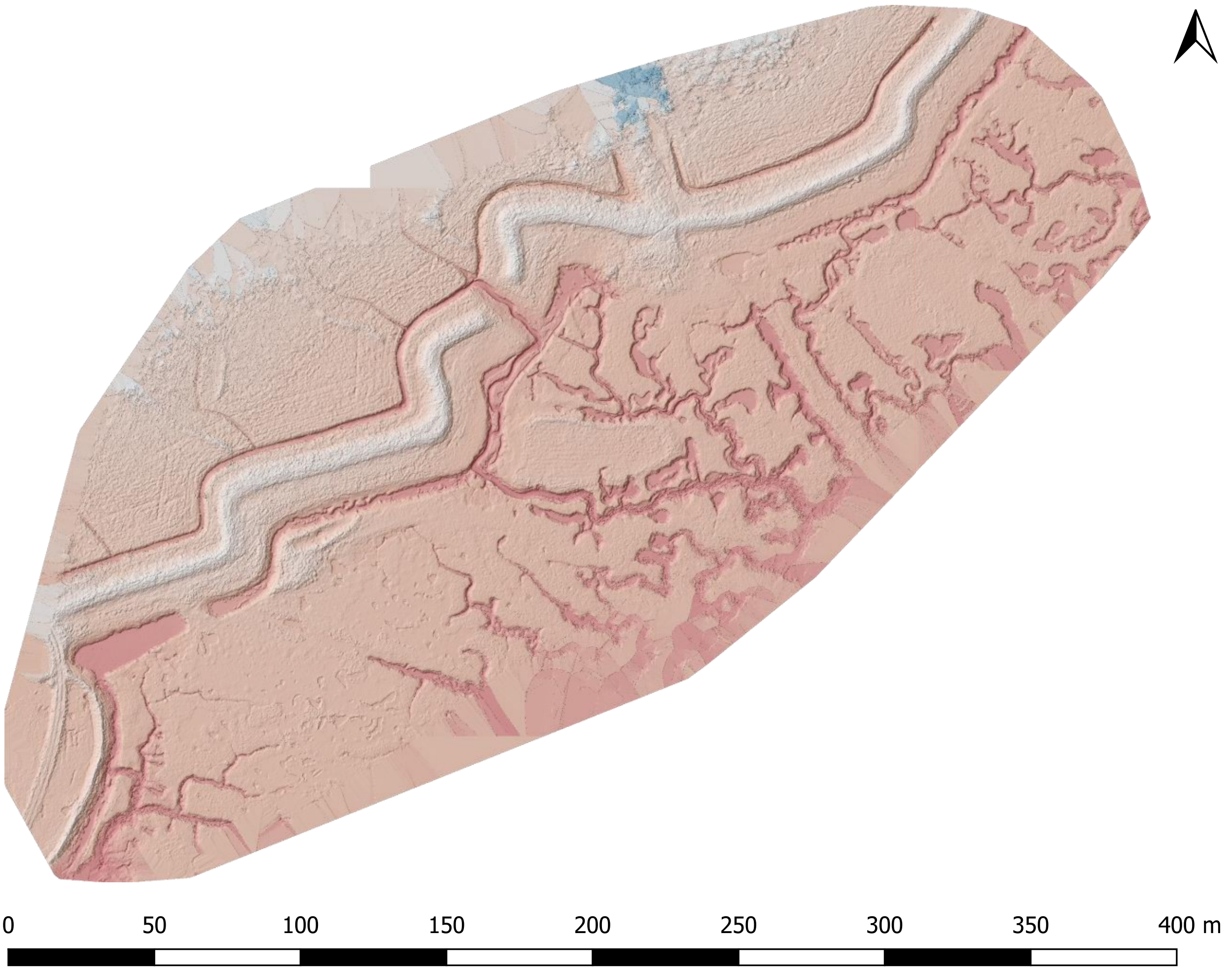

Figure 4 DSM from Abbotts Hall drone footage in 2020. Elevation is represented as red (lowest elevation) to blue (highest elevation). DSM created in Pix4D Mapper and map created in QGIS.

Because change-maps could not be calculated, localised changes were investigated by manually digitising polygons around the structures, immediately adjacent to the structures, and further away from the structures but within the same/adjoining creek (control). A markedly higher elevation difference was not detected between either the structure or adjacent to the structure polygons compared to the control areas (for both individual or grouped structures).

Although there were some issues with creating valid change maps from the DSMs, this could be remedied for future flights and data collection and is valuable learning for the project in terms of upskilling staff and building expertise. The fact that some of the Moverons structures are visible despite some imagery misalignment is promising for the detection of accretion associated with the structures over longer term intervals.

The LiDAR analysis is shown in *Appendix 3* and one of the elevation change maps is shown in Figure 5 as an example. The 1999/2001 to 2020 maps show a clear decrease in elevation along the edge of the saltmarsh. This linear decrease in elevation is a potential indication of lateral retreat due to erosion over the past ~20 years. Extensive increases in elevation were detected across the saltmarsh, potentially due to increased height of dense vegetation such as *Halimione portulacoides* (sea purslane). In the main channels and throughout smaller channels there are increases/decreases in elevation in many of the change maps which, due to their location, can be attributed to differing tide heights. This means that any changes in ground elevation along the channels themselves are difficult to detect. No clear changes in elevation associated with the structures have been detected in these change maps. Ongoing comparisons of pre- and post- installation imagery may be possible with similar tidal heights, acquired in the same season (to minimise tidal and vegetation differences). As the spatial resolution of the LiDAR tiles currently available and used for these change maps is 1m, it may require comparisons over several years to detect the sediment build up or movement around the structures.

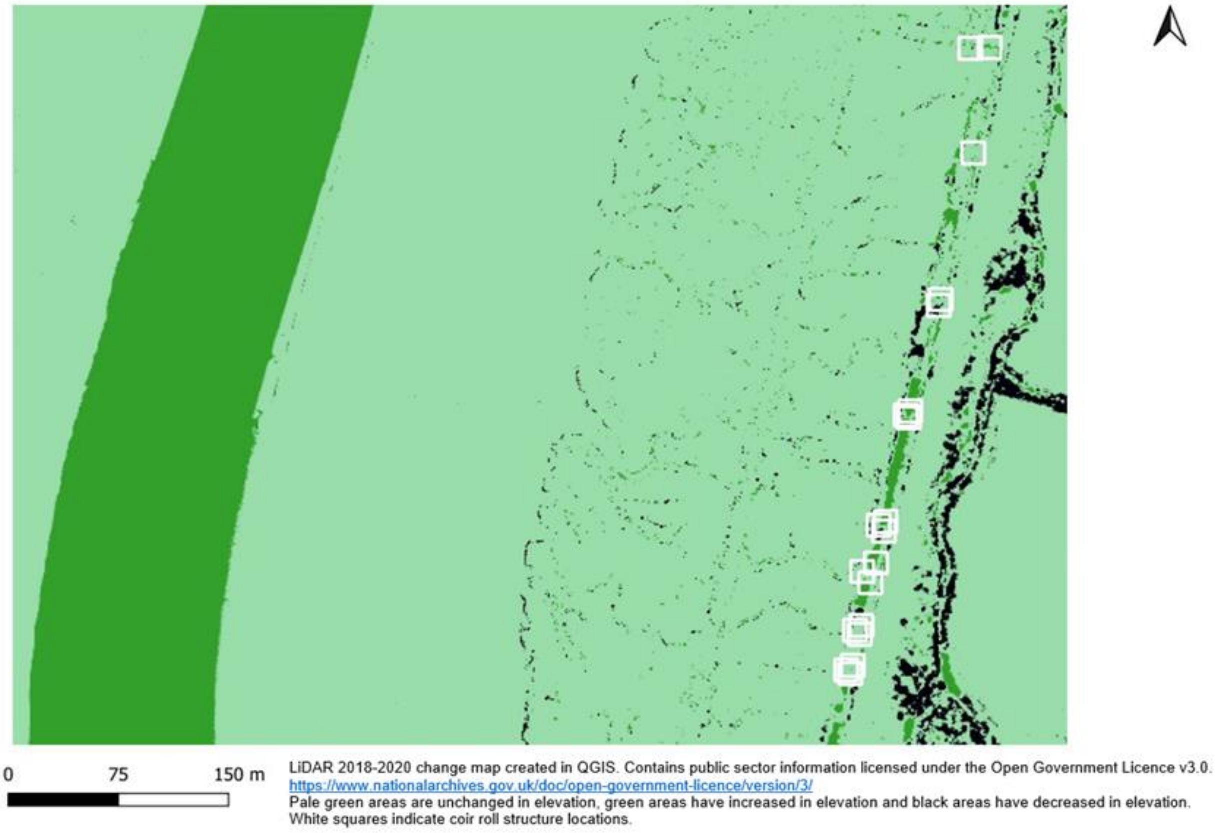

Figure 5 LiDAR 2018-2020 change map of Moverons Farm created in QGIS. Pale green areas are unchanged in elevation, green areas have increased in elevation and black areas have decreased in elevation. White squares indicate coir roll structure locations.

On-the-ground photography of the structures is show in Appendices 4a-d. Comparing photos from 2018 to 2021 shows visual signs of accretion, with structures at Moverons in particular, becoming level with the height of the existing marsh. On-the-ground, fixed point photography continues to offer a simple and effective way to monitor these structures. The time lapse camera footage provides opportunities to monitor how the tide interacts with the structures

4. Vegetation establishment:

4.1. Method:

UoE students undertook vegetation surveys of the coir roll structures at Abbotts Hall nature reserve. The number of species and the percentage cover of vegetation was recorded for each coir roll structure. Vegetation surveys were also completed of the natural saltmarsh using quadrats; the number of species and percentage cover of vegetation were recorded. Saltmarsh vegetation specialists were present to support the students and to ensure consistency and accuracy of the data. The GPS coordinates of the quadrats were taken using smartphone GPS. A different approach to vegetation surveys was adopted for Moverons Farm, with species and percentage cover of vegetation being estimated from photos taken of the coir roll structures (which can be found in Appendix 4c and 4d). Quadrats were not undertaken. Figure 6 show the locations of the quadrats at Abbotts Hall nature reserve. The vegetation data was analysed using R software (v4.1.0; (R Core Team, 2001)).

Normalised difference vegetation index (NDVI) imagery was collected by staff from the UoE on 05/11/2020 at Abbotts Hall nature reserve and 06/11/2020 at Moverons Farm, using a Sentera Single High-Precision sensor mounted onto a DJI Phantom 4 Advanced drone. Sentera Field Agent and Drone Deploy was used to plan the flight, UAV Forecast for weather forecasting and Airmap for the flight plan. Image overlap was 75% with an altitude of 60m. The images collected during these flights were analysed in 2021. Orthomosaics were created through processing the resulting sets of images using Pix4D Mapper 4.6.4 software.

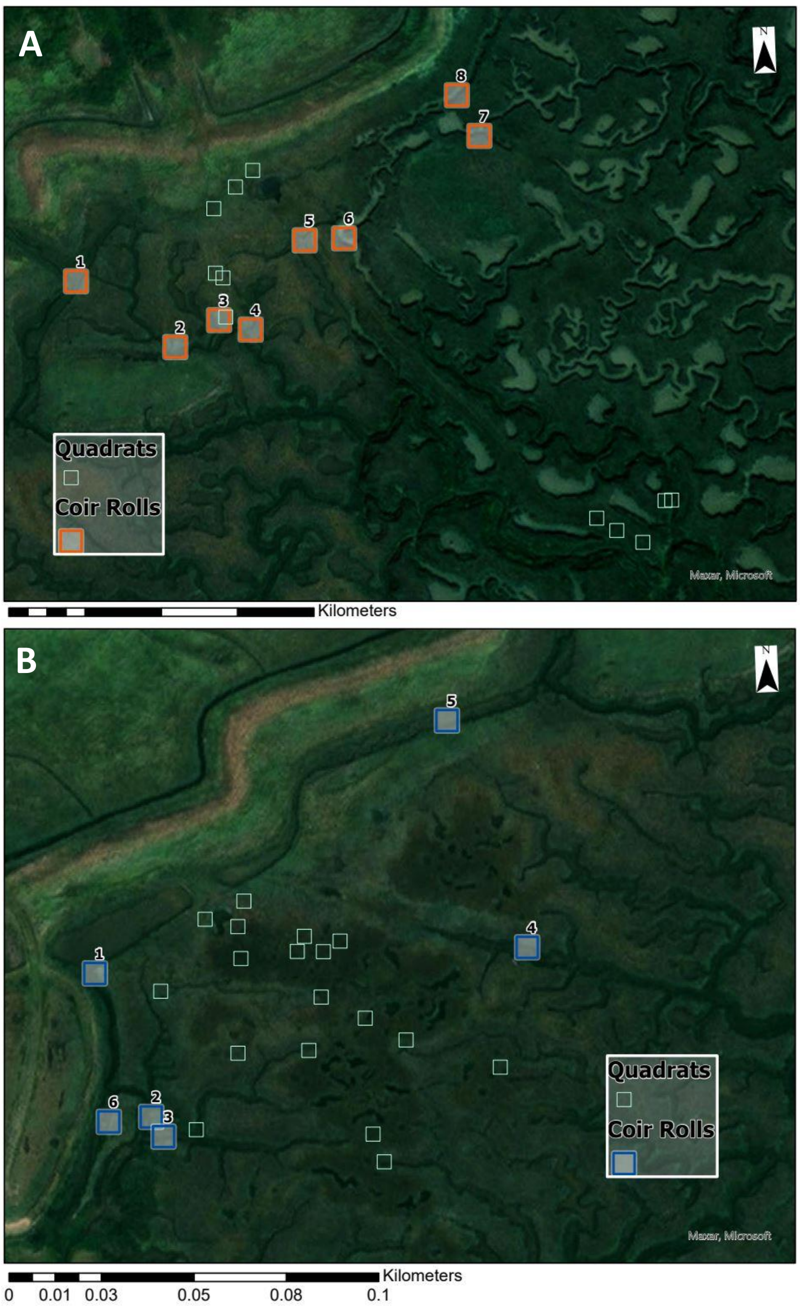

Figure 6 (A) Locations of EWT's Abbotts Hall nature reserve Asparagus Beds coir roll structure and quadrats. There are some unmapped quadrats due to missing location data and anomalous GPS co-ordinates which, when mapped, appeared outside the study area. These were Groups 3, 6, 7 and 8 (B) Locations of EWT's Abbotts Hall nature reserve Shiplock quadrats. There is one unmapped quadrat due to anomalous GPS co-ordinates which, when mapped, appeared outside the study area.

4.2. Results:

4.2.1. Vegetation percentage cover and species on coir roll structures:

Vegetation (including *Vaucheria*) was established on all the coir roll structures (see Figure 7). Most were pioneer species typically found on mudflats, including *Salicornia spp* and *Spartina spp*. *Vaucheria spp* algae was also present; found on 100% of the structures at Abbotts Hall nature reserve and making up a large percentage cover of most structures. However, when excluding the algae *Vaucheria*, the overall percentage cover of vegetation is much reduced. The two sites have the same species richness of four, and structures at both are characterised by pioneer and low marsh species. When including *Vaucheria*, the maximum number of species established on any one structure is three (although note Moverons species richness was measured from photos rather than an on-the-ground survey).

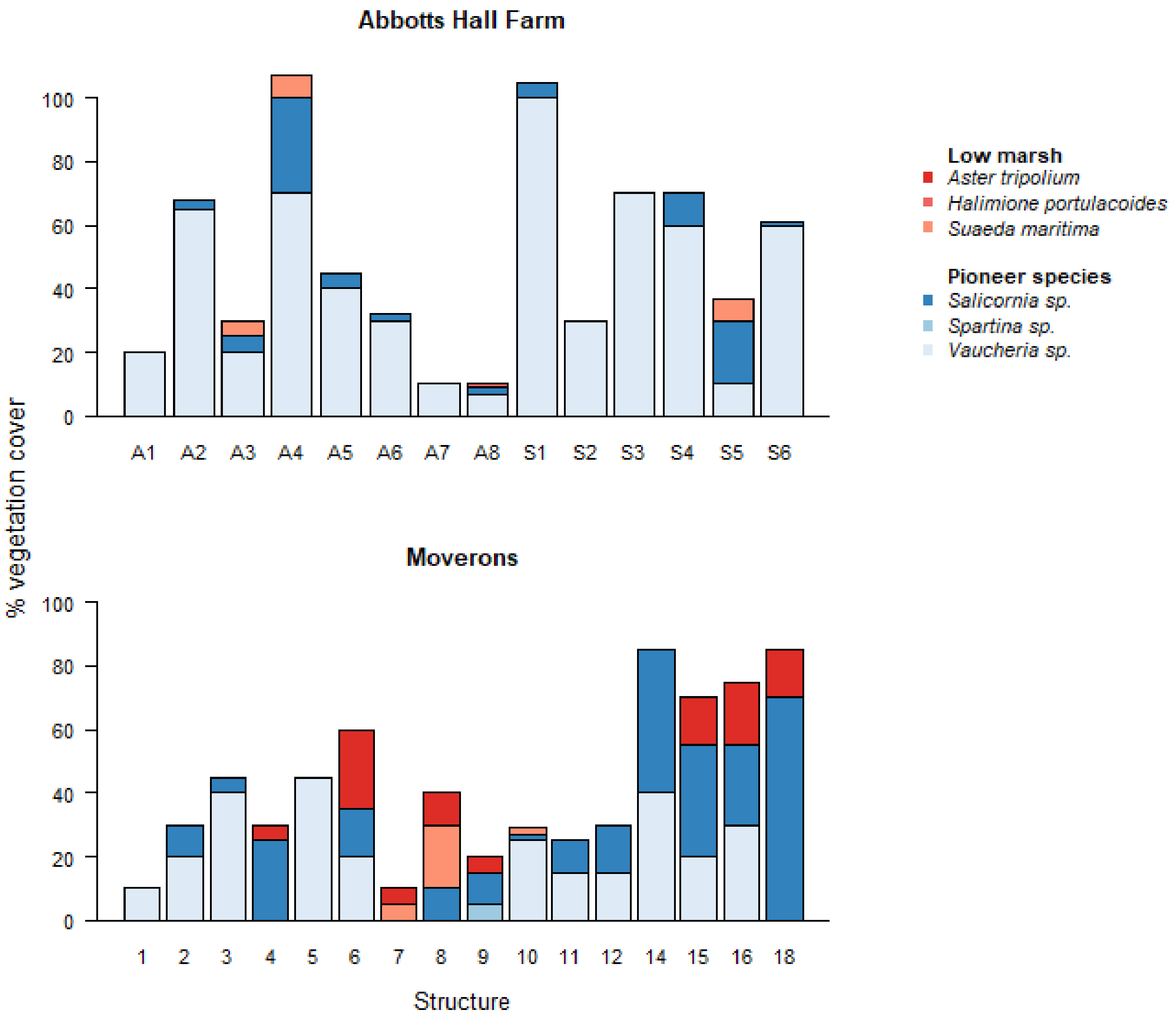

Figure 7 Percentage cover of saltmarsh vegetation species and Vaucheria spp. algae established on coir roll structures at our two sites in June 2021. Structures at Abbotts Hall nature reserve with prefix 'A'= Asparagus Beds, and 'S'= Shiplock. Moverons vegetation data were estimated from photographs of the structures and not from direct observation in the field. Photographs for Moverons structures 13, 17, 19 and 20 were either unavailable for June 2021, or were of insufficient quality. Does not include cover of dead vegetation due to difficulty in identification.

4.2.2. Vegetation establishment and site:

When all established vegetation is considered (including dead growth), a Wilcoxon Signed-rank Test shows there is no significant difference in the total percentage cover of vegetation on the structures between the sites (W=101.5, p=0.677), and see Figure 8. However, when excluding the alga *Vaucheria* from the analysis, leaving only saltmarsh plant species, there is a significant difference between the vegetation cover at Abbotts Hall nature reserve and Moverons (W=18.5, p=0.003**), with Moverons being greater – see Figure 8. However, the differences in survey methodology and the small sample size mean these results should be noted with caution.

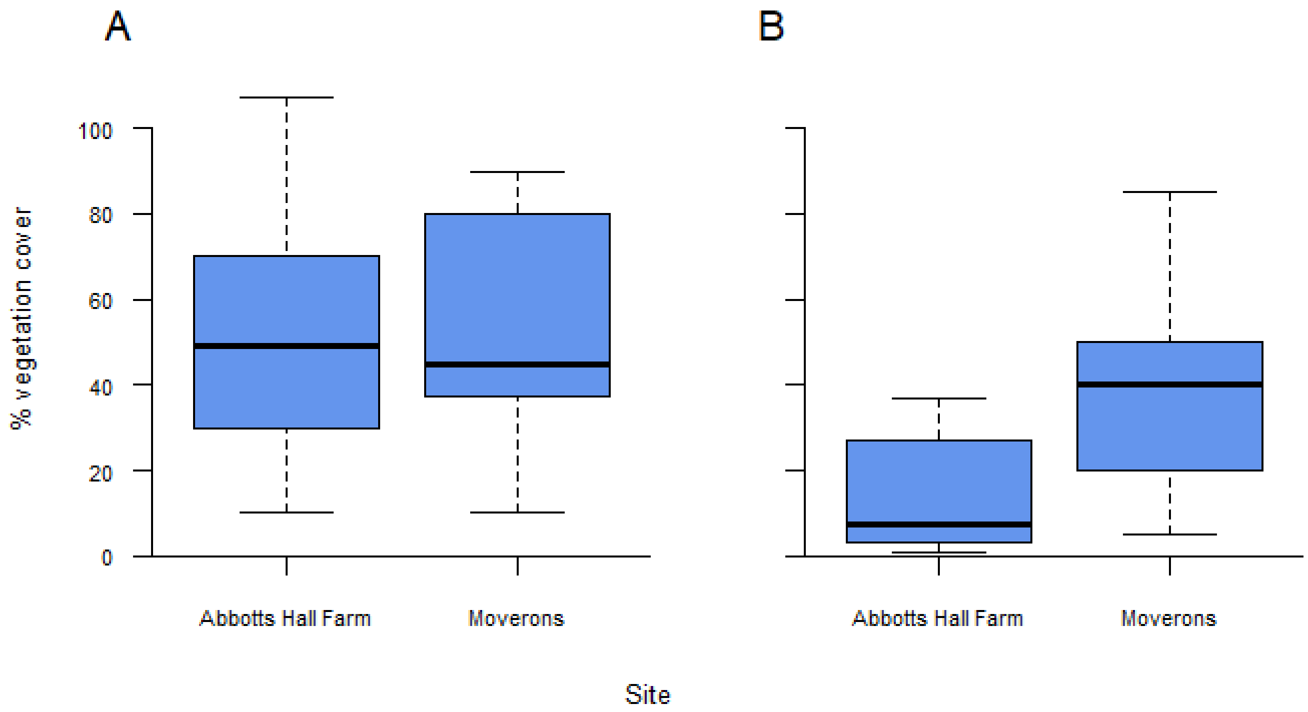

*Figure 8 (A)The percentage cover of saltmarsh and pioneer vegetation (**including** Vaucheria sp and unidentified dead vascular species) established on coir roll structures at Abbotts Hall nature reserve (n=14) and Moverons (n=16). **(B)** The percentage cover of saltmarsh and pioneer vegetation (inc unidentified dead vascular species but **excluding** Vaucheria sp) established on coir roll structures at Abbotts Hall nature reserve (n=10) and Moverons (n=14). Black bars= median values; boxes= interquartile ranges (IQR); dashed bars= lower and upper extremes. Note: Moverons vegetation data were estimated from photographs of the structures and not from direct observation in the field, and the mean for this site does not include estimates for structures 13, 17, 19 and 20 as photographs were either not available or were of insufficient quality.*

Visual observations and photographs concur with the statistics and show that several of the structures at Moverons have had particularly successful vegetation establishment. Figure 9 shows a selection of the structures with the highest percentage cover and a large visual biomass. Figure 10 shows structures with lower percentage cover across both project sites. The Abbotts Hall nature reserve structures have a high percentage cover of *Vaucheria*, which is not as evident/more difficult to see on the Moverons structures. In addition, it was not possible to estimate a vegetation percentage cover and species for all the Moverons structures, so some with significant cover have not been included in the calculations in this report.

Photographs taken in previous years (see Appendices 4b and 4d) mean that is possible to monitor changes in vegetation over time, even if this is not directly quantifiable. For example, Figure 11 shows how the vegetation establishing on Moverons structures has developed.

Figure 9 From top left clockwise, Moverons Structures 14, 15, 17, 18 (all photographs taken in June 2021) demonstrating the higher vegetation cover possible on the structures. Note that is was not possible to estimate the percentage cover for structure 17 from the photographs, so this is not included in Figure 6 or the calculations.

Figure 10 Structures with lower veg percentage cover. From top left clockwise, Moverons 1; Asparagus 1, 7 and 8 (all photographs taken in June 2021)

Figure 11 Moverons structures 6, 7 and 8 in (A) August 2019; (B) June 2020; (C) June 2021 showing how vegetation has established on the structures . NB the palettes have been erected to prevent sheep traversing onto the marsh via the structures.

4.2.3. Vegetation establishment and structure layout:

Structures were installed in three layout types – singles, aligned (side-by-side) and in a U-shape. All the structures at AHF are in a single layout and Moverons has a combination of all three (two singles, one aligned and the rest U-shaped). As the U-shaped layout only occurs at Moverons, the effect of site and layout was investigated.

Overall, greater percentage vegetation cover (including *Vaucheria* algae) was recorded on coir roll structures in U-shaped layouts (Figure 12 A). We know that there was no difference in percentage vegetation cover between the sites (Figure 8A). However, when considered alongside site, there appears to be some effect of structure layout at Moverons (Figure 12A), although a Two-way ANOVA controlling for the effect of site, showed this not to be statistically significant ($p=0.199$). When the alga *Vaucheria* is excluded from the analysis, a Two-way ANOVA shows that percentage vegetation cover is significantly different between the layout types ($p<0.001$***).

Overall, U-shaped layouts also yield a greater **number of species** (Figure 11 B). A Two-way ANOVA showed that the layout of structures significantly affects the number of species ($p=0.014$*), but there was no effect of site (ANOVA, $p=0.471$). TukeyHSD post-hoc tests revealed that structures set in a U-shape layout have significantly more species than Single structures ($p=0.023$*). When *Vaucheria* is excluded from the analysis, the layout significantly affects the number of species ($p=0.018$*) but the site itself does not ($p=0.403$). This is the same results as when *Vaucheria* is included. However, the small sample size when both including and excluding *Vaucheria* should be noted.

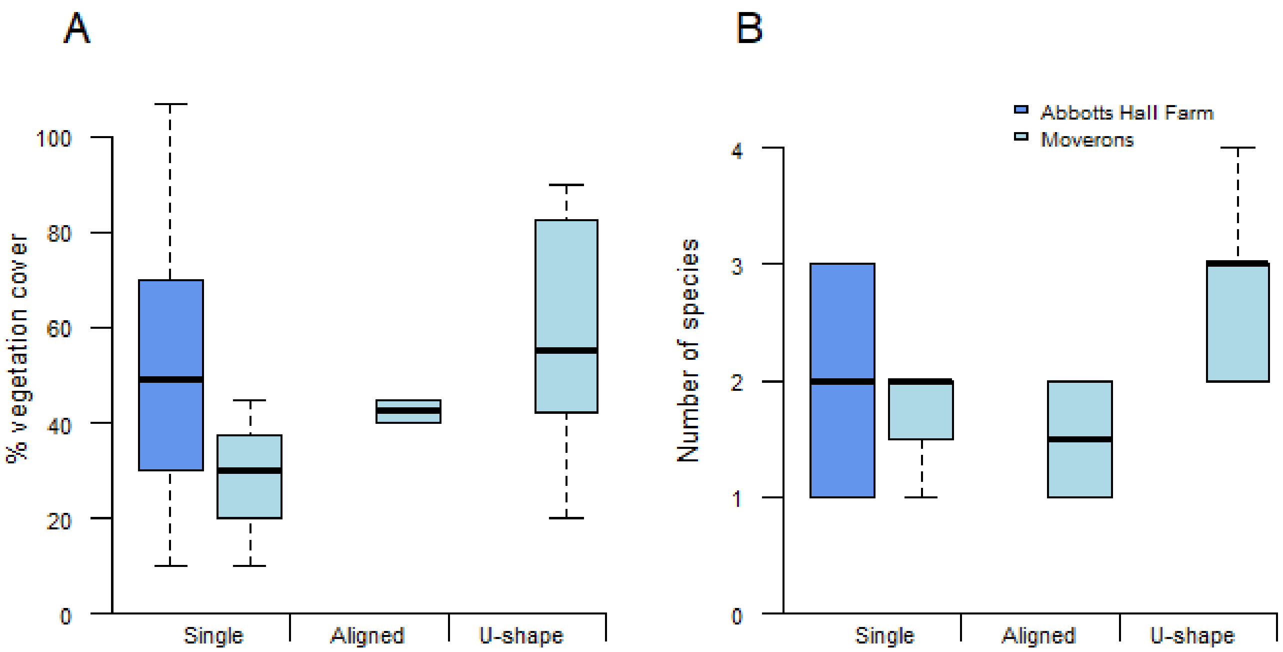

Figure 12 (A) Percentage cover of saltmarsh and pioneer vegetation (incl. Vaucheria sp. and unidentified dead vascular species) established on coir roll structures set in different layouts, separated by site. (B) The number of saltmarsh and pioneer vegetation species (incl. Vaucheria sp.) established on coir roll structures set in different layouts, separated by site. Samples sizes: AHF single n=14; Moverons single n=3; Moverons aligned n=2, Moverons U-shape n=11. Black bars= median values; boxes= interquartile ranges (IQR); dashed bars= lower and upper extremes.

4.2.4. Vegetation establishment and distance/position on the marsh relationships:

The relationship between vegetation percentage cover and number of species on coir roll structures was investigated for 1) distance to seawall; 2) distance to saltmarsh edge, 3) distance to nearest coir roll structure. There is no significant relationship between any of these distances and vegetation percentage cover or number of species, although vegetation percentage cover and the distance to the saltmarsh edge has the closest relationship ($p=0.065$), with a general trend for a greater vegetation percentage cover the further from the marsh edge.

When *Vaucheria* is excluded from calculations, there is no significant relationship between the distance variables and percentage vegetation cover or number of species. A linear model confirmed that layout is the overriding factor affecting both of these, which has already been implicated in previous sections.

4.2.5. Comparison of vegetation of the coir roll structures and the natural marsh (Abbotts Hall nature reserve only):

At Abbotts Hall nature reserve vegetation surveys of the natural marsh were undertaken using quadrats. Figure 13 shows a comparison of the species recorded on the natural marsh and the coir roll structures for the whole site (Shiplock and Asparagus Beds combined). As the structures at Abbotts Hall nature reserve are within the channels rather than at a similar height to the marsh, this difference in species is to be expected, with the natural marsh having a greater species richness.

4.2.6. NDVI analysis:

Appendix 6 shows the NDVI maps created. NDVI imagery indicates the relative spectral reflectance in the red and near-infrared wavelength bands, which in turn indicates the presence of healthy green vegetation (which absorbs red and reflects near-infrared radiation). Repeated collections of imagery using the same camera and under the same conditions – e.g. same season, similar weather conditions at time of image collection – will assist monitoring of vegetation development on the coir roll structures. For comparison of repeated sets of images, the most accurate geolocation possible will be required and therefore use of ground control points is recommended. With ground-truthing surveys, this imagery can be used to detect individual plant species, which may allow the development of plant communities to be monitored, and the similarity of vegetation developing on the structures to be compared to the vegetation on the natural saltmarsh. At Moverons Farm, there was insufficient image overlap in some areas for all coir roll structures to be covered in the orthomosaics during processing. Pix4D's recommended image overlap for processing images in Pix4D Mapper is 75% front overlap and 60% side overlap.

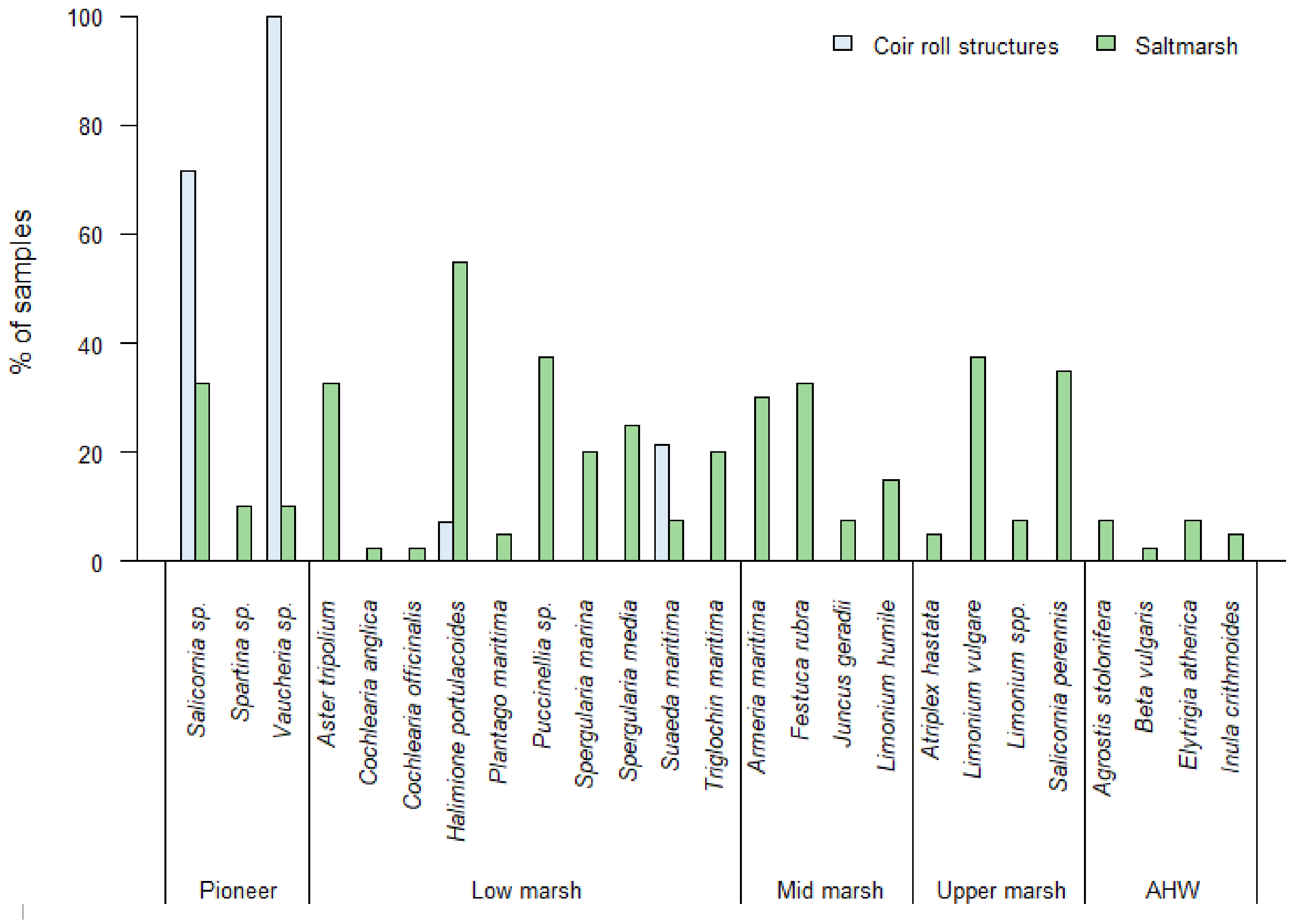

Figure 13 The percentage of coir roll structures upon which vegetation species were recorded, and the percentage of 1×1m quadrats within which vegetation species were recorded on the established saltmarsh surrounding the coir roll structures at Abbotts Hall nature reserve. Vegetation species data on the established saltmarsh were unavailable for Moverons. AHW= above high water.

5. Carbon storage potential

Rationale: in its simplest form, we want to demonstrate how/if the structures are contributing to the storage of carbon in any sediment accumulated.

5.1. **Method:**

A mini-core (~1cm diameter, 10cm depth) was used to extract a sediment sample from the sediment around the coir structure (one sample on each side of the structure). Cores were also taken from the natural vegetated marsh and sediment in channels with no coir roll structures, to act as 'control' samples. The core was labelled and sealed, and the top 2cm of each core was extruded and used for analysis. The wet and dry weight of the sample were calculated, as well as the percentage water content. The sediment was then freeze dried overnight, and total carbon content (mg/g) was measured using a Skalar MSC Primacs^{MSC} analyser, and each sample was weighed out into a crucible for analysis. The machine was standardised using glucose standards, and individual measurements for each sample were standardised by weight to give mgC / gram of sediment.

Students from the UoE collected sediment samples from Abbotts Hall nature reserve, with close supervision from supervisor academic staff. UoE researchers used the same methodology to collect sediment samples from Moverons Farm. Please note that due to unforeseen circumstances, it was not possible to process the Moverons sediment samples before the release of this Toolkit.

5.2. Results:

A Wilcoxon Signed-rank Test showed that there was no significant difference between the mean total carbon content of soil samples taken from coir roll structures and from control plots (locations within channels and on natural saltmarsh with no coir roll structure present) at the two Abbotts Hall nature reserve sites combined ($W=155$, $p=0.463$); Figure 14 A. The mean carbon content for the coir roll structures is 0.2mg/g soil and the mean carbon content for the control samples is 0.19 mg/g soil. When the control samples are split into those known to have been taken from the natural saltmarsh and those taken from the channels, the mean carbon content of the saltmarsh controls is 0.14 mg/g soil and 0.21 mg/g soil for the channels. A Kruskal-Wallis Test showed that there is no significant difference in carbon content between coir roll structures, saltmarsh controls and channel controls($\chi^2(2)=1.27$, $P=0.529$), although, as shown in Figure 14 B, the median carbon content of the control samples taken from the channels is notably higher.

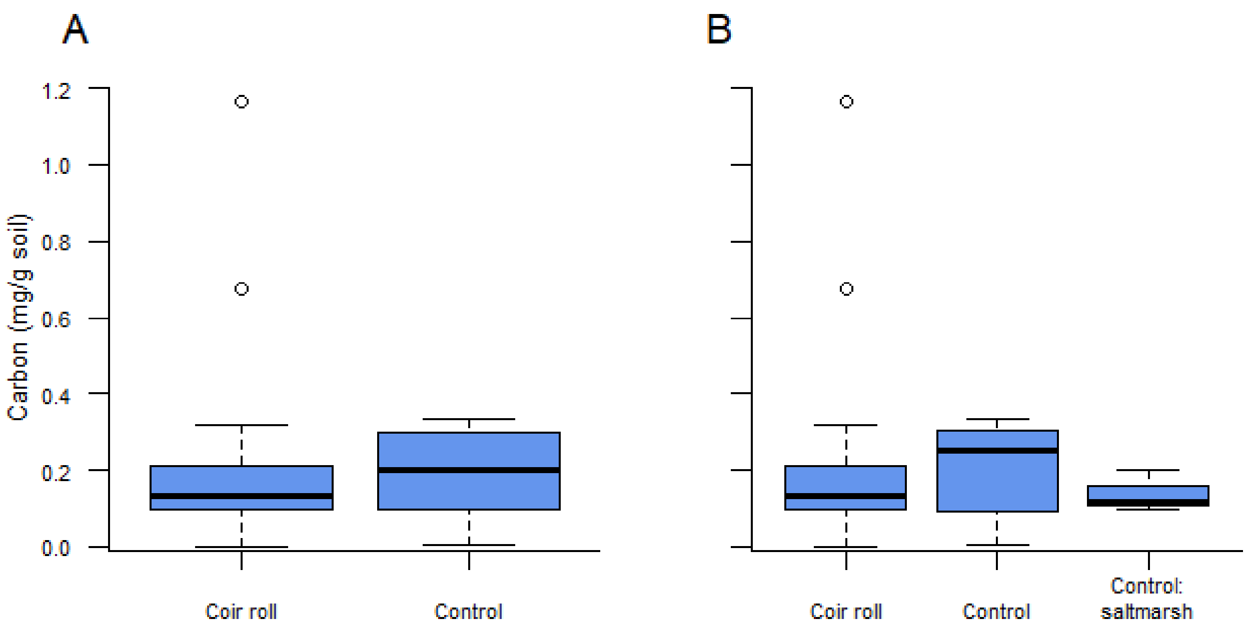

Figure 14 (A) The carbon content of soil samples taken from coir roll structures (n=28) and control plots (locations within creeks and on established saltmarsh with no coir roll structures present) (n=13) at Abbotts Hall nature reserve. (B) The carbon C content of soil samples taken from coir roll structures (n=28) and control plots (locations within creeks and on established saltmarsh with no coir roll structures present (n=10)) at Abbotts Hall nature reserve. Control samples known to be taken from established saltmarsh (n=3) are shown separate from control samples taken from within creeks. Black bars=median value; boxes=interquartile ranges (IQR); dashed bars=lower and upper extremes.

There were no significant relationships between the total carbon content (mg/g) and the distance from the saltmarsh edge, seawall or to the nearest coir roll structure.

References, Appendices and Acknowledgements
(for Toolkit and Phase 3 Project Report)

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Appendices

1. Saltmarsh Restoration Project Report and Review 2020
2. Drone DSM change maps
3. LiDAR change maps
4. A) Abbotts Hall nature reserve photos 2021; B) Abbotts Hall nature reserve photos Pre-2021; c) Moverons photos 2021; d) Moverons photos Pre-2021
5. Coir roll distances table
6. NDVI maps