Saltmarsh Creation for Natural Flood Defence in the Tay & Eden Estuaries & the Dornoch Firth

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Summary

This report details the findings of the Green Shores project, a collaboration between coastal landowners and community organisations between 2017 and 2020. Green Shores was a local and evidence-based natural flood management project that created fringe saltmarsh habitat in key sections of degraded shoreline.

The development of natural solutions to reduce coastal erosion and flood-risk in flood-prone, low-lying coastal areas within Scottish estuaries is urgent. Nature-based solutions (NBS) are being increasingly recommended by government agencies and projects such as Dynamic Coast (1 & 2), Scottish Natural Heritage and the Scottish Environment Protection Agency.

This project investigated soft engineering materials combined with direct saltmarsh planting as a natural and cost-effective alternative to traditional coastal defences. More than 300 community volunteers were engaged, helping to grow, plant and enhance estuarine fringe saltmarsh. The work was carried out in the economically important Eden Estuary (Fife), Tay Estuary and Dornoch Firth (Special Areas of Conservation and Specially Protected Areas).

The findings were variable, as saltmarsh transplants that successfully established ranged from 32 – 74%. However, the majority of bio-degradable wave breaks survived storm high tides in three of the four sites over three consecutive years, and sediment accumulation was clearly visible behind the wave breaks at all the sites.

Overall, these mixed results suggest that fringe saltmarsh communities in low-lying estuarine settings may benefit from NBS, but these measures require further exploration. This report for landowners, local authorities and statutory conservation bodies, contains key results and recommendations.

Introduction

a. Project background

Scotland's National Biodiversity Strategy (NBS) recognises estuarine fringe saltmarsh as a relatively rare, key habitat for conservation and restoration. Saltmarsh restoration strategies in other parts of the world can range from managed realignment (i.e., the deliberate flooding of coastal land), to precise techniques such as laboratory-based tissue culturing to propagate pre-adapted varieties of coastal plants. Fringe saltmarsh restoration practices by direct planting, however, remain largely unexplored here in the UK.

Preliminary studies into this strategy began in the Eden Estuary in 1999, by transplanting a range of saltmarsh species dug from local, healthy marshes in field trials around the estuary's shoreline. It was found that restoring saltmarshes can be a slow process, with the transplants taking a few years to establish as a functioning marsh. Monitoring of these original transplant sites found that a) transplants can be washed away immediately post-planting, b) they are vulnerable to wave stress during the first two to three years of establishment, and c) the relatively small donor marshes around the estuary can sustain only a limited amount of harvesting.

The objective of this project was to restore and enhance this habitat by the direct planting of native and locally provident saltmarsh species. A further objective was to provide transplant protection by the installation of bio-degradable soft engineering materials called bio-rolls and bio-mats. The vulnerable shorelines that were targeted included the seaward margins of historic seawalls, eroded soft embankments and degraded natural saltmarsh habitat. Additionally, a coastal plant hub was also developed as an outreach facility and in order to grow saltmarsh transplants with the help of volunteers from the local community and school pupils.

b. Evidence base

Saltmarsh restoration research has been ongoing in the Eden Estuary (Fig. 1). Sea Club Rush (*Bolboschoenus maritimus*) plots planted during a PhD study between 1999 and 2003, expanded over a seventeen-year period from 10 m^2 to a minimum of 100 m^2 and a maximum of 800 m^2 (Fig. 2). This expansion was coupled with increased sediment strength and accumulation in the upper mudflats, an increase in biodiversity and carbon storage, as well as recovery of adjacent eroded saltmarsh (see further reading for reports and theses).

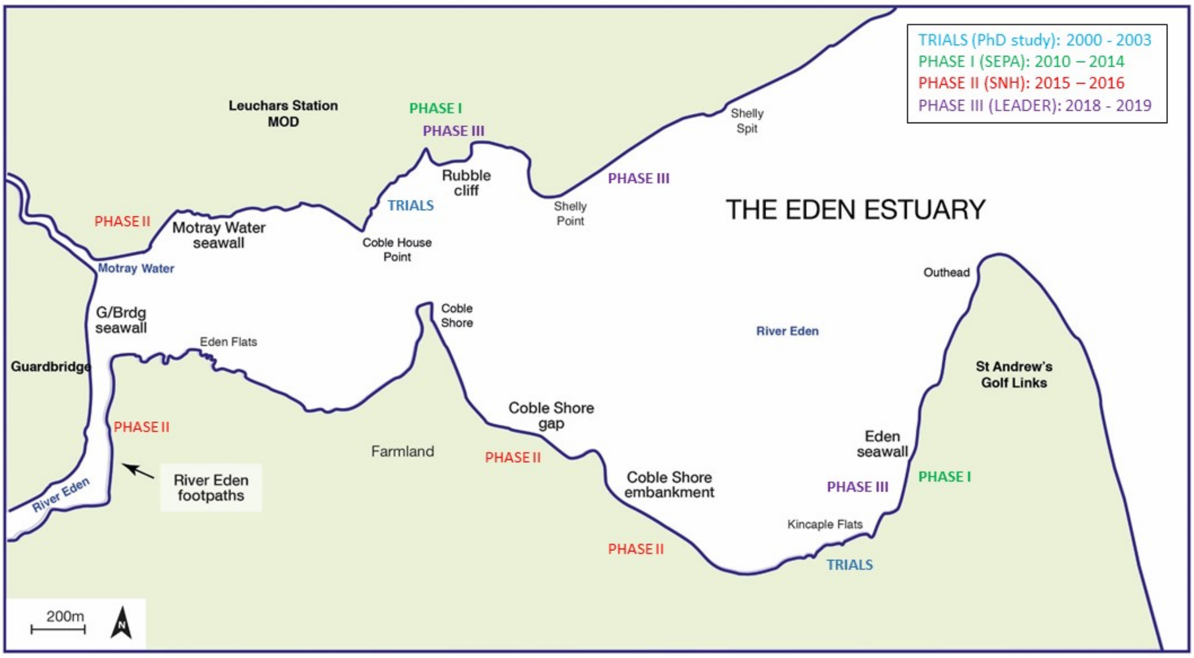

Figure 1. The Eden Estuary with saltmarsh restoration trial locations (2000 – 2019).

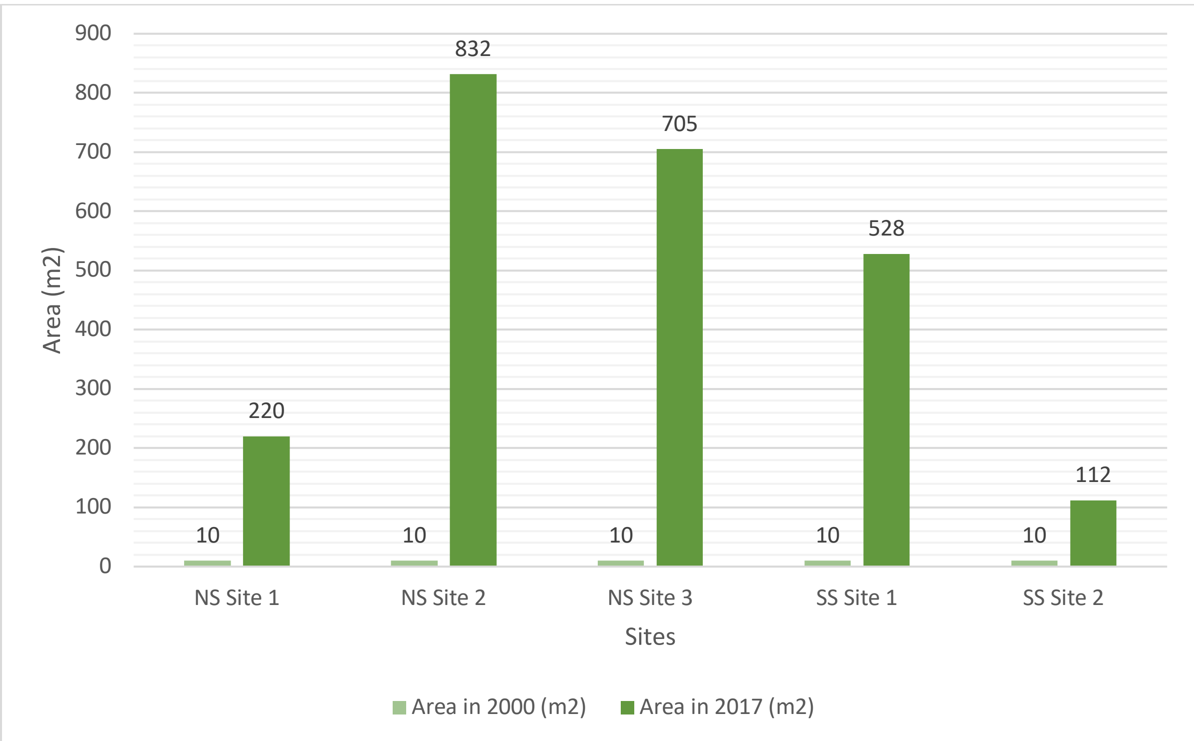

Figure 2. Transplant site expansion (m^2) in the Eden Estuary, north (NS) & south (SS) shores.

The success of these plots led to greater interest and further research in the practice to help develop better methods for the strategy. Coir filled bio-rolls and mats, originally developed for riverbank restoration schemes, were pioneered in shoreline settings by researchers from Florida State University in the Guana Tolomato Matanzas Reserve in Florida, with many positive results (*pers. comm*. Cheryl Mannel,). Closer to home, the Alde and Ore Enterprise Partnership (Sudbourne, Suffolk, England), also investigated saltmarsh improvements using a variety of soft engineering materials (*pers. comm*. David McGinity, AOEP). Technical help from UK companies specialising in bio-engineering products, also encouraged the implementation of bio-roll trials in shoreline settings in Scotland.

Methods

a. *Restoration sites*

Four sites were selected in three estuaries; one each on the north and south shores of the Eden Estuary, and one site each in the Tay and Dornoch Firths (Fig. 3 & Table 1). The targeted areas in each of these sites measured approximately 200m shore parallel and 15m shore perpendicular.

Table 1. Site names and locations selected for saltmarsh restoration and wave-protection trials.

Estuary	**Site name**	**Grid Refs**
Eden Estuary	Shelly Shore	NO 477 201
Eden Estuary	Eden Course	NO 489 185
Tay Estuary	Tayport Common	NO 467 280
Dornoch Firth	Dornoch Sands	NH 789 882

Figure 3. UK map with Eden and Tay Estuaries and Dornoch Firth locations.

Eden Course

Globally renowned and high value golf courses managed by the St Andrews Links Trust bound almost a kilometre of the south shore of the Eden Estuary (Fig. 4). The majority of these links' courses are protected from the worst effects of coastal flooding by 5 to 6-metre-high gabion basket seawalls. However, sections of the seawall require maintenance periodically, and as such, the St Andrews Links Trust invited saltmarsh restoration trials at the base of the seawall to help protect it from being undermined by wave action. These trials were conducted between 2010 to 2014 and although initially successful, the wash out rate proved to be unacceptably high (>70%). This high wash out rate was most likely due to tide and wave energy being rebounded off the seawall. With flooding and erosion set to increase in the future, and higher and more robust hard defence measures cost prohibitive, further restoration using wave-protection devices was recommended.

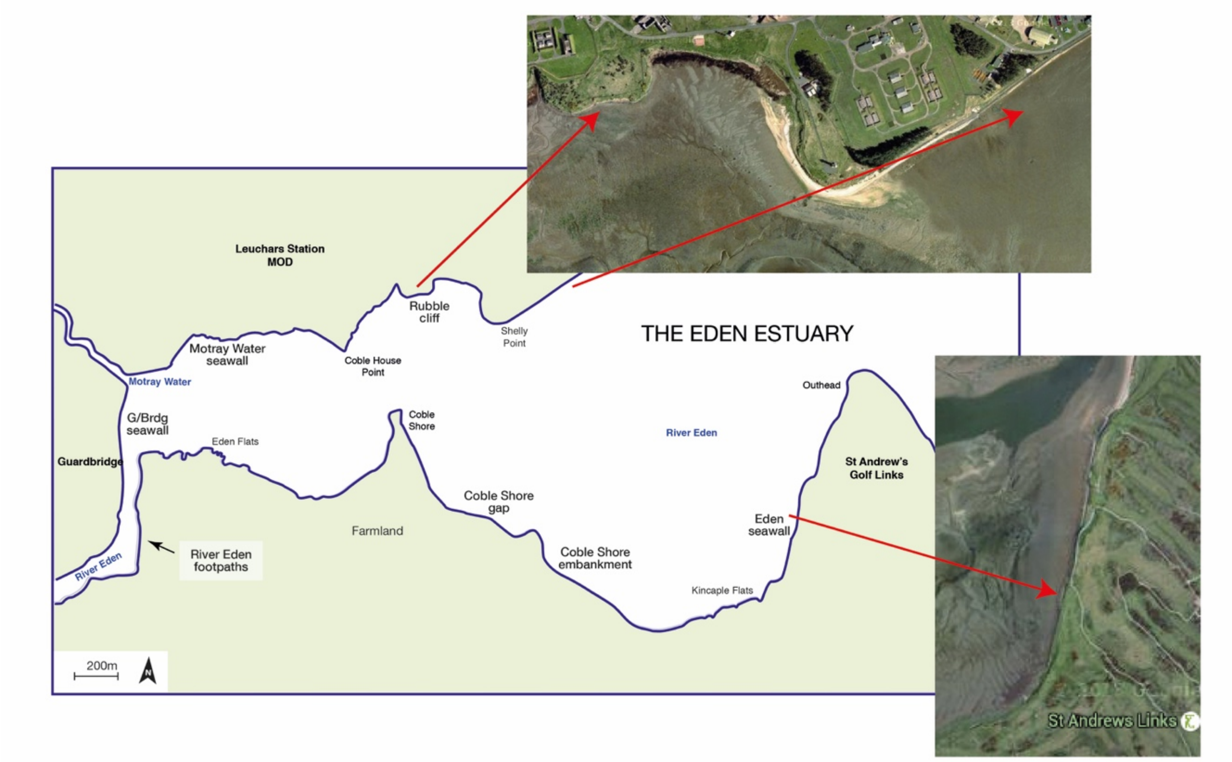

Figure 4. The Eden Estuary Shelly Shore and Eden Course sites on the north and south shores respectively.

Shelly Shore

The northern shore of the Eden Estuary borders Leuchars Station, a former airbase for more than 100 years and recently becoming a military station for army units. A variety of measures are already in place to protect the station from coastal flooding from the estuary, which include 6m-high soft embankments and 5m-high vertical gabion seawalls (Fig. 4). One particular section, between Shelly Point and Shelly Spit, was targeted for restoration trials as substantial natural stands of Sea Club Rush thrive near the target site. Using those stands as a donor marsh, it was considered that encouraging saltmarsh growth at the base of the gabions would prolong their lifespan and reduce maintenance costs in the longer term.

Tayport Common

This is a popular recreational park in Tayport on the south shore of the Tay Estuary, created during the mid-20th century to bury a historic municipal waste site (Fig. 5). During the latter half of the century, erosion has exposed the inert waste and to rectify the issue the local authority placed a rip rap barrier (boulders) at the base of its seaward edge. In recent decades however, flooding and erosion are becoming ever more problematic, and further hard defence measures will be limited by costs. Over the same time period, a narrow fringe of Saltmarsh Grass (*Puccinellia maritima*) in front of the rip rap defence has dwindled to fragments, although a large stand of Sea Club Rush thrives nearby. The presence of this marsh, and the wish to halt the erosion of the old marsh, encouraged soft engineering trials by the local authority.

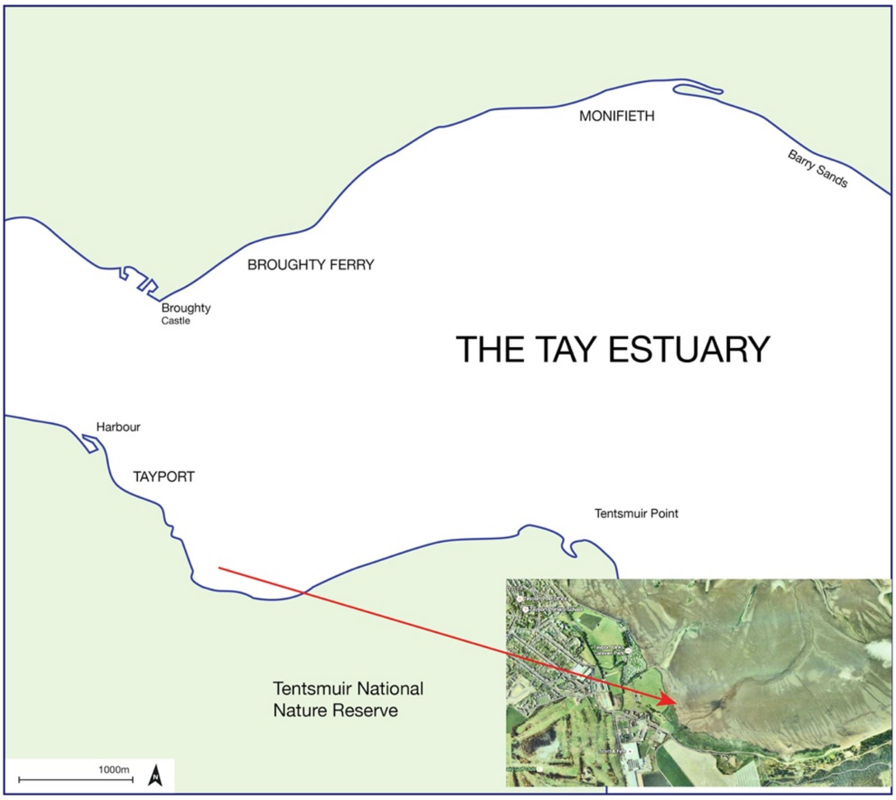

Figure 5. The Tay Estuary and the inset image showing approximate site location.

Dornoch Sands

Flooding and erosion incidents have been increasing on the low-lying land on the northern shore of the Dornoch Firth, a popular Highland tourist destination and home to the award-winning Royal Dornoch Golf Club (Fig. 6). The natural fringe of Saltmarsh Grass habitat along the length of the Firth's shore has increasingly fragmented in recent years. In particular, a large gap in the marsh front effectively creates a funnel for inrushing tidal waters during high tides. The tidal force has created a severe erosion scarp and flooding events are becoming more problematic along the low-lying seaward edge of the Struie Course. Soft engineering trials and saltmarsh planting were recommended to try to repair the natural marsh and help prevent further collapse of the seaward edge of the Struie Course.

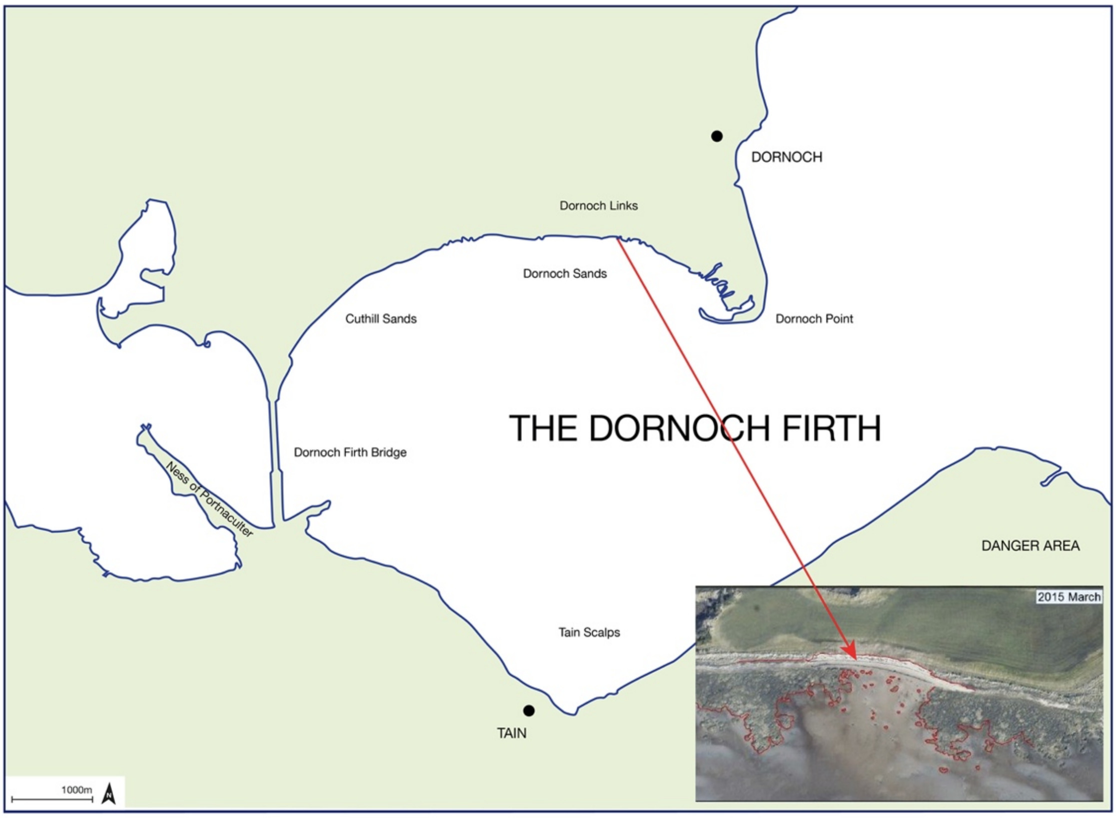

Figure 6. The Dornoch Firth with inset of the Dornoch Sands restoration site. Inset image courtesy of A. Rennie, Dynamic Coast.

b. <u>Plant collection from natural saltmarsh stands</u>

Saltmarshes in northern Britain are classed as typical Western Atlantic salt meadow (JNCC, 2015), but the saltmarshes in the firths and estuaries in Eastern Scotland have strong regional variations, composed of a mixed community of Saltmarsh Grass (*Puccinellia maritima*) and Red Fescue (*Festuca rubra*), with various common saltmarsh herb species scattered throughout (Fig. 7). Organic-rich, swamp saltmarsh (reed types) are also frequent transitional communities in Scottish estuaries, and in brackish inlets especially, often tend to dominate over salt meadows (Fig. 8).

The restoration and propagation transplants collected from the field sites included Saltmarsh Grass (*Puccinellia maritima*), Red Fescue (*Festuca rubra*), Sea Plantain (*Plantago maritima*), Sea Aster (*Aster tripolium*), Sea Club Rush (*Bolboschoenus *maritimus*), Annual Glasswort (*Salicornia europaea* agg.) and Sea Arrowgrass (*Triglochin maritima*). These species were collected as vegetative plugs or turfs for two purposes. Most were used for direct planting in field trials, but some were taken to a polytunnel for further division in order to oversee their growth in a more controlled environment. This strategy was intended to develop the potential for stronger, more robust transplants in future planting seasons.

The removal of vegetation from small, fragmented saltmarsh to supply a relatively high transplant demand, for direct planting or polytunnel growth, can be a destructive process. The hollows created in natural saltmarsh during this harvesting therefore must be carefully filled in with sediment removed from various locations in outer mudflats. This helps to avoid pits as trip hazards for the general public, but also speeds up colonisation from adjacent plants and reduces the danger that the pits may become focal points for further erosion. Monitoring these hollows is advised for several weeks initially, followed by monthly during winter, to ensure the infilling process was successful.

Figure 7. Western Atlantic Salt Meadow and the resulting pit backfilled with estuarine sand.

The optimal harvesting window avoids late winter and equinoctial onshore storms, and thus occurs between March and April on the East coast of Scotland, and before plants emerge from dormancy to resume full growth, to reduce the risk of 'transplant shock'. Admittedly, this window is inconsistent and therefore hard to predict.

Figure 8. Natural stand of Sea Club Rush (Bolboscheonus maritimus) *in the Tay Estuary.*

c. <u>Coastal plant hub</u>

The harvested transplants that were not directly planted in the field trials were transported to the Green Shores' coastal plant hub to allow for further growth. Earlier studies demonstrated that greenhouse propagation can increase the transplant supply by at least tenfold, which not only reduces the quantity harvested from natural populations but provides the transplants with time to develop substantial root growth, ensuring rapid root anchorage when planted out in the field. The greater development of the transplants that can be obtained by growing the plants in the controlled conditions of a greenhouse or polytunnel also extends the field planting window into early summer.

The coastal hub (Fig. 9), a 14 x 4 metre semi-commercial polytunnel, was built at the end of 2017, with St Andrews Links Trust staff kindly helping to prepare the tunnel for transplant growth. The size and quality of the tunnel was based on the number of transplants to be grown, some several thousand, and being large enough to hold small groups of volunteers to provide shelter during poor weather.

Figure 9. Coastal plant hub growing Sea Club Rush transplants in wetland plant tubs.

Sustainable growing mediums were locally sourced to provide a 50:50 mix of a sandy estuarine sediment and an organic peat-free compost, the latter provided by the Links Trust's composting scheme.

d. Planting

The harvested transplant plugs and turfs that were to be directly planted were first split into several smaller sections (allowing a few plant stems per transplant). Approximately 300 volunteers, including school parties and from a variety of other organisations, helped to plant the sites over the project's lifetime (Fig. 10 a, b & c).

Figure 10. Outreach and community involvement: a) Dornoch Academy pupils dividing and potting transplants, b) St Leonards pupils planting Shelly Shore & c) community gardeners at the Tayport site.

The created planting areas were too large for the high-density planting (10 per m^2) trialled during previous work, and instead transplants of the selected species were planted in groups of ten, ten times in each plot, i.e., 100 transplants of turfs or plugs per plot. These random groupings avoided row planting, a method that has been shown to allow the incoming tide a direct channel through the saltmarsh, which can increase the transplant wash out rate. Volunteers were instructed to plant in random formations such as circles and swirls, which were more likely to ensure transplant success. However, high tides and storms can wash away transplants until they have fully established, even when planted in random formations. To reduce this likelihood, soft engineering methods were trialled.

e. *Soft engineering trials*

Coir-filled bio-rolls are increasingly used in riverbank restoration schemes in the UK and have met with some success in fringe saltmarsh restoration projects in the United States. The bio-rolls can help to reduce wave energy and tidal currents whilst also allowing water and sediment through the biodegradable material. These trials were to protect the transplants until roots have established, effectively creating a sheltered area for the deposition and consolidation of sediment, which in turn should aid more rapid transplant establishment and expansion, and the natural colonisation by other marsh species.

Bio-rolls were procured from Salix Rivers & Wetlands Services Ltd., a leading company in the UK specialising in a wide range of bioengineering products. The rolls (3m by 0.3m) were heavy, at approximately 9kg dry weight, and becoming two to three times heavier when wet. Installation was undertaken prior to planting and mostly by greenkeepers and statutory authority personnel (Fig.11 a & b).

Figure 11. Respectively, Royal Dornoch Golf Club and St Andrews Links Trust staff installing bio-rolls.

f. *Experimental design*

In the spring of 2018, the bio-rolls were placed on the mudflat surface at approximately 15 m seaward of the shoreline and these were held in place with chestnut stakes driven into the sediment. Polypropylene cord was weaved around the stakes and through the bio-roll netting to secure them to the mudflats and prevent flotation during high tides.

Three bio-roll units were required to make one large, curved bio-roll formation, as advised (*pers. comm* Cheryl Mannel). Six of these formations were installed per site, requiring two to three days for installation.

Two hypotheses were tested: a) the effectiveness of transplanted saltmarsh without soft-engineering, and b) the effectiveness of transplanted saltmarsh with soft-engineering (in the form of bio-roll formations). Thus, three plots were planted without bio-rolls, and three were planted with bio-rolls. As a control for the first hypothesis, plots were left completely bare of plants or soft engineering, leaving only upper unvegetated mudflat. The control for the second hypothesis was installed bio-rolls, but with no transplants.

For statistical analysis, these plots were replicated three times at each site. Each site therefore had twelve plots: - three with bio-rolls and transplants, three with just bio-rolls, three with just transplants and three with bare mudflat (Fig. 12).

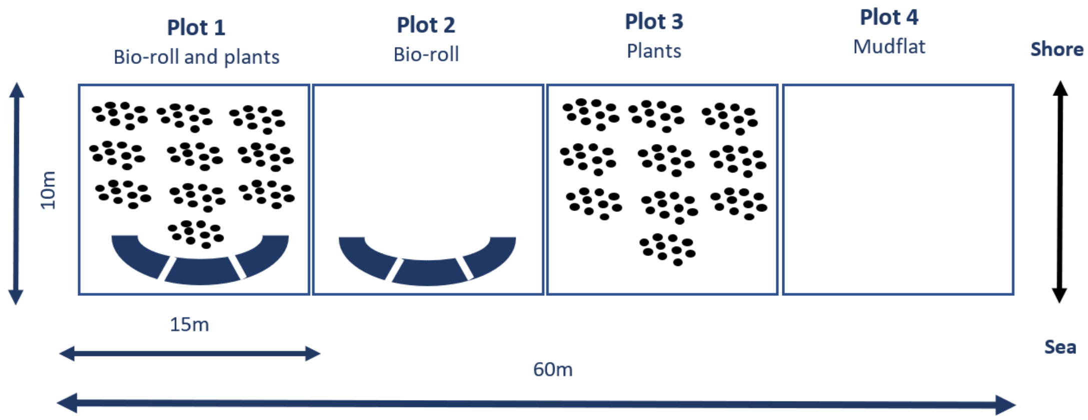

Figure 12. Experimental design (app. scale): plot 1 = transplants & bio-rolls; plot 2 = just bio-rolls; plot 3 = just transplants; plot 4 = bare mudflat.

Results

Initial planting took place between April and May 2018, and the monitoring process began shortly after. The results illustrated in this report are a combination of the results of summer monitoring in 2018 and 2019, (please note, monitoring and further work was cut short by the outbreak of COVID-19 in 2020).

One of the main issues regarding the direct planting of saltmarsh transplants is the efficiency of the practice, i.e. the number of those transplants planted in total at each site that were actively growing post-planting, regardless of any form of protection (Fig. 13). In this case, the Tayport Common site was highly successful (74%) compared with much lower values for the sites at Dornoch Sands (36%), the Eden Course (32%) and Shelly Shore (35%). However, bio-roll protection overall increased the rate of success of those transplants actively growing at each site.

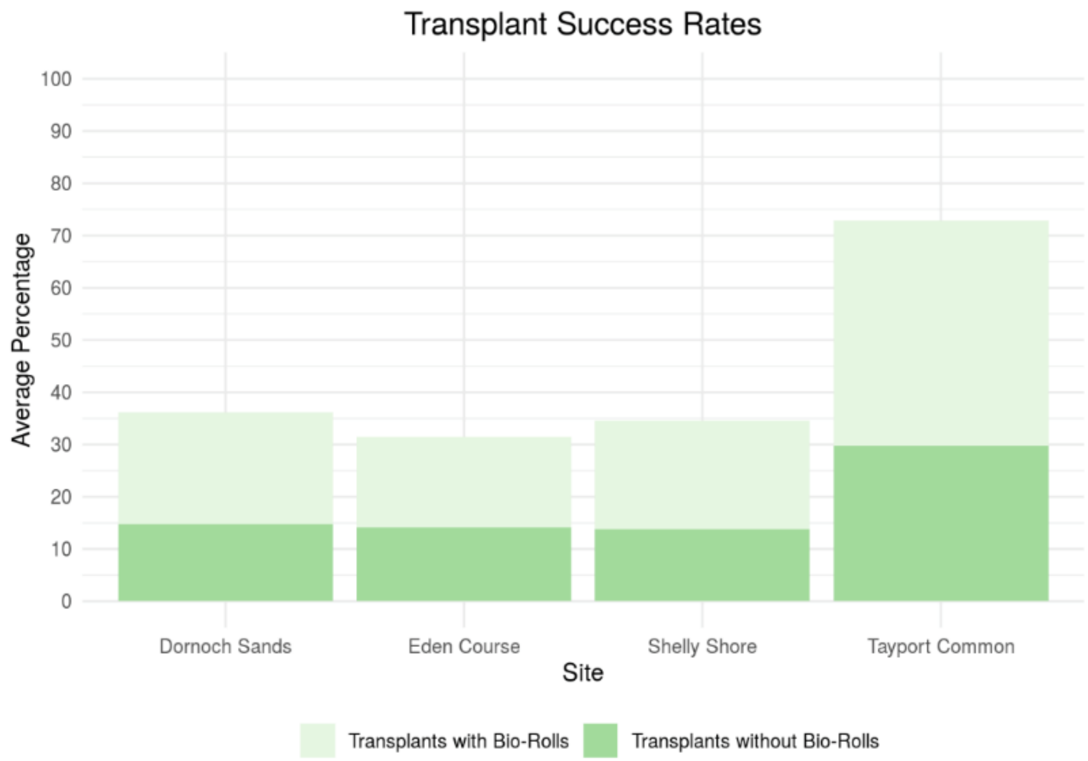

Figure 13. Transplant success rates as the percentage of transplants that were actively growing after two growing seasons.

Site comparisons also show that the Tayport Common site was the most successful regarding those transplants (growing or not) that were washed away by the tides, having a very low wash-out rate (10.84%). Although the overall transplant success rate was low for the Dornoch site, this site produced the clearest wash-out rate results, with transplants behind bio-rolls faring better than those without protection (22% and 34% respectively). The bio-rolls at the Eden Course and Shelley Shore appeared to have little effect on the wash out rate (Fig. 14).

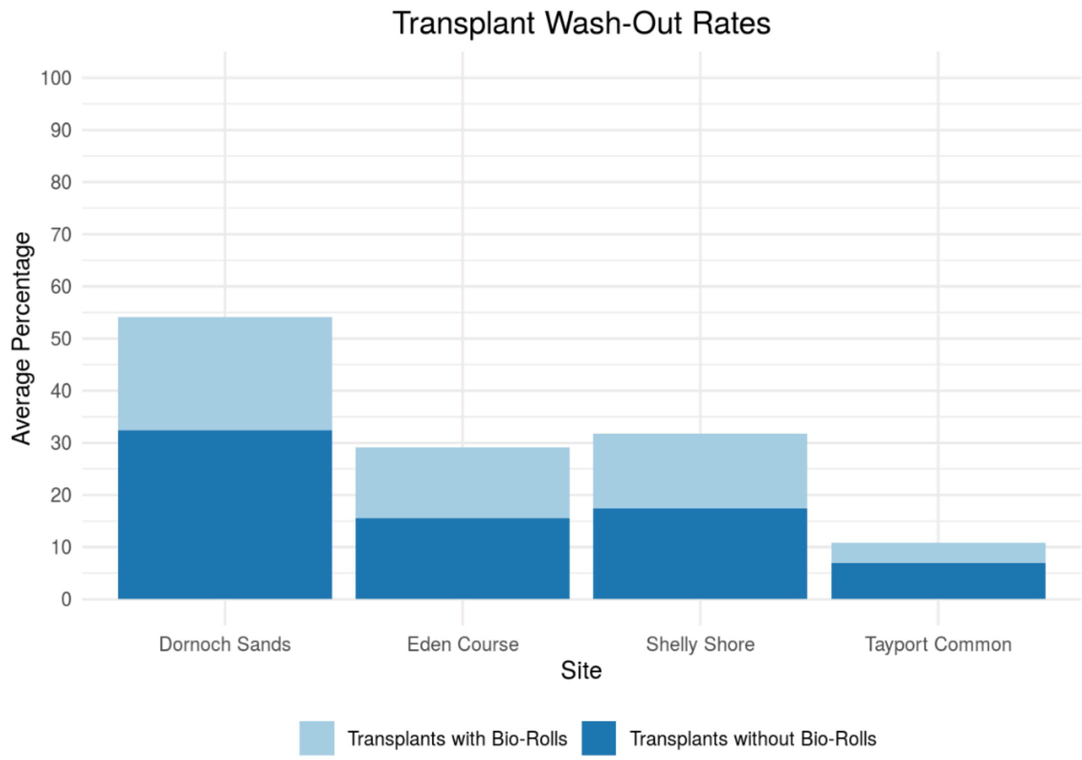

Figure 14. Transplant wash-out rates as a percentage of the total number planted at each site, behind bio-rolls or without bio-rolls.

Except for the Tayport Common site, success rates regarding growth or washout of the transplants were lower than hoped, although this in itself is not surprising given the experience of previous work in the Eden Estuary, that showed fringe saltmarsh restoration to be a slow process.

Despite low rates, the following images (Figs. 15 to 18) highlight that sediment accumulation behind the bio-rolls was a common theme for all the sites. This indicates that whilst bio-rolls did not consistently increase the rate of transplant success, they performed well in a process known to be a precursor to natural saltmarsh colonisation and development. Further monitoring and comparison of the sedimentation rates at each site will help to understand this function better.

Figure 15. Bio-rolls have assisted the process of sedimentation on the mudflats, Eden Course, 2018.

Figure 16. A low rate of transplant success at Shelly Shore, 2018, note sedimentation behind the bio-rolls.

Figure 17. A high rate of transplant success behind bio-rolls at Tayport, 2018.

Figure 18. Irreparable storm damage to bio-rolls at Dornoch Sands, 2018.

Recommendations

In general, the early establishment of restored saltmarsh requires various active interventions which need to be learnt from trial and error. Given decadal variations in weather patterns and estuary dynamics, a longer-term approach will be required to measure saltmarsh restoration success.

a. Site maintenance

The project helped to establish the need for maintenance of planted saltmarsh sites in several categories, which included:

- After-planting care to re-establish transplants uprooted by marine action and/or human error
- Repairs due to accidental trampling damage from members of the public
- Summer growth care such as manual removal of algae
- Winter care to remove flotsam - storm damage can be unpredictable but especially important after equinoctial high tides
- Bio-roll storm damage repairs, especially if they need to be immediately removed to prevent marine debris accumulation, vandalism (bio-rolls are particularly visible from a distance) and accidental damage

b. Planting

Firstly, for greater transplant success, improvements must be made regarding planting techniques, and secondly, improvements could be made to increase the speed of marsh expansion. These strategies will be possible through further development of the use of native species. This could be through selective breeding of varieties with enhanced salt and flood tolerance, or through developing varieties that can tolerate greater wave impact. Longer seasons for transplants growing in polytunnels to allow greater 'hardening off' would also help to better prepare transplants for field growth. Another possibility is to utilise seed production from the polytunnel transplants. Seed use was precluded for use in this project because previous studies showed that seeds collected in the field had a seedling success rate of lower than 10%. However, transplants grown in a polytunnel that can be encouraged to seed, may help to produce higher rates of 'seed vigour'. Other methods that deserve further exploration are the use of larger blocks or turfs planted out in the field, in addition to mixing species and varieties during field planting.

c. Soft engineering products

The use of bio-rolls, whilst somewhat effective, presented a few challenges. These structures are large and unwieldy, and as such time and care must be taken with transport and installation at work sites. Being heavy, especially when wet, also meant that scouring at the base of the rolls was high, despite a high rate of sedimentation in the lee of the roll. Additionally, chestnut fencing stakes proved hard to hammer into place, and the work suited to a fencing company with experience and resources.

As a follow up to the bio-rolls in the spring of 2019, bio-mats (flattened versions of the bio-rolls) were also tested on site. These results have been left out of the final report, because unfortunately few survived the first few tides at any site, and thus failed at too fast a rate to collect meaningful results. Shorter, less than sturdy pegs were provided with the mats, which although easier to install, was considered to be one of the main reasons for the quick failure of the mats. To improve the effectiveness of these kind of structures overall, it may be possible to combine the use of bio-mats and bio-rolls. Placing mates directly underneath bio-rolls would considerably reduce scouring. These combined devices would also be better held *in situ* with tree stakes, as an intermediate between heavy chestnut stakes and insubstantial pegs.

Another option would be to plant the transplants directly into the bio-rolls before being anchored on site. This pre-planting service is offered by some bio-engineering companies, but locally provident (and site-ready) transplants and/or seedlings would have to be provided. Adopting this technique in-house was a possibility considered at the start of Green Shores, but holes would have had to have been drilled through the dense fibre to enable transplant insertion, which was considered time-consuming and potentially difficult for local volunteers.

Commercially available bio-engineering products have rapidly developed since the onset of this project, and the number of companies that offer technical expertise and bespoke solutions has been increasing. For example, 'Aqua-logs' are a much heavier version of bio-rolls (composed of Xylit, a chemically inert by-product of the brown coal industry) and as a result, scouring issues would be problematic. They would also require more time, effort and skill to have them transported and installed on site but more positively, they would be more likely to withstand potential storm damage and therefore to provide a more stable and sheltered area for direct planting efforts.

d. Volunteers

This project combined practical on-site estuary work and restoration research, which required a considerable voluntary effort. The volunteer help during the Green Shores project amounted to approximately 9,000-person hours (no. volunteers x planting hours) over the course of three years but note this does not account for polytunnel or outreach preparatory work or monitoring and maintenance of field sites.

Working with school parties and the public along various shorelines brought challenges. Extreme weather (winter or summer), muddy, tidal environments and often difficult access over rough terrain in rural locations required careful consideration and planning. The co-ordination of volunteers and various local groups throughout multiple locations was also found to be time-consuming and for future efforts, consideration should be given to engaging a dedicated volunteer co-ordinator.

Conclusions

The Green Shores project provided a rare example in Scotland of a nature-based solution that offers genuine potential to be successfully deployed around vulnerable, low-lying, soft coastal environments. Fringe saltmarsh restoration by direct planting can be a slow process, but this project has shown that a greater rate of success is possible through the use of low-impact and soft bio-engineered products. Since the inception of Green Shores, the variety and range of these products has increased and as such these require further investigation to help find bespoke solutions for individual sites. Given that the effects of climate change and the impact of rising sea levels on coastal assets are chronic conditions that are rapidly becoming acute, time is of the essence to further develop these soft coastal defence options.

Further Reading

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d. Spin off research projects

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Taylor, B. (2018) *Saltmarsh restoration influence on sediment dynamics and carbon sequestration.* PhD thesis, University of St Andrews.

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Wade, K. (2017) *Biodiversity, ecosystem functioning & services of restored saltmarsh areas.* PhD thesis, University of St Andrews.

Cirou, J. (2015) *Donor populations & germination conditions for seed use in saltmarsh restoration.* Master's thesis, University of St Andrews.

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