The Restoration of Vegetation on Saltmarshes

R&D Technical Report W208

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Statement of use
This R&D Technical Report provides guidance and practical support to the Environment Agency and coastal managers in assessing the need for assisted saltmarsh establishment or enhancement, and where necessary, the selection of the most suitable plant species and appropriate procedures, in association with flood defence managed realignment schemes or maintenance works.

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CONTENTS

Page

CONTENTS Page

CONTENTS Page

CONTENTS Page

LIST OF TABLES

LIST OF FIGURES

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EXECUTIVE SUMMARY

When flood defence engineering work is carried out on or immediately adjacent to a saltmarsh, some damage to the existing vegetation is likely to occur. The extent of damage will depend on whether a major scheme is being carried out (where vegetation will need to be reinstated or enhanced as part of the project) or whether minor maintenance works are being undertaken, such as a repair to an outfall structure. In other cases, where the engineering works involve the setting back of the flood defence, it may be desirable to promote the development of a new saltmarsh or the restoration of a degraded or former saltmarsh.

Saltmarsh vegetation has both a flood defence role (wave attenuation; erosion prevention; promoting accretion) and a nature conservation role (providing a habitat for wildlife). It is therefore important to ensure that the marsh vegetation cover is properly established and functioning effectively following any engineering works.

This report reviews a number of saltmarsh seeding, planting and natural regeneration initiatives in the UK and elsewhere, notably in North America where there is extensive experience spanning many decades. North American experience is particularly relevant to the UK because there are many species which are common to the countries in question, the climate in the northern USA and southern Canada is similar to that in the UK and, whilst the differences between tidal ranges are acknowledged, harvesting, planting and site preparation techniques are essentially the same once the tidal range exceeds 0.3m.

The report goes on to assess the physical, chemical and biological conditions required for successful saltmarsh vegetation establishment, and to determine which saltmarsh species might be potentially useful in respect of flood defence engineering works. Possible sources of seeds and/or plants are then discussed, and seeding and planting methods are reviewed. A guidance section summarises the decision making process in respect of saltmarsh creation or restoration projects, reminds the reader of the necessary physical conditions for effective vegetation establishment (whether for natural colonisation or a planted/seeded site), and indicates the suitability of the various saltmarsh species for use in different scenarios. The final section of the report sets out the key findings and recommendations.

The key findings of this piece of research can be summarised as follows:

1. Saltmarsh vegetation can only be established successfully if the physical as well as biological conditions are satisfactory. Chemical conditions, unless there is reason to believe that the site is contaminated, are of lesser importance. The critical importance of the physical conditions such as exposure and elevation means that a saltmarsh creation or restoration initiative may need to include engineering works designed to ensure conditions which are suitable for vegetation establishment.
2. Assuming that satisfactory physical conditions are achieved, and that there are existing saltmarshes within the general area of the proposed creation or restoration site, there is a high likelihood that colonisation by saltmarsh species will occur naturally. Natural colonisation should be considered as the preferred option for saltmarsh vegetation establishment: it is likely to be both more sustainable and less expensive than managed colonisation. Planting or seeding initiatives may nonetheless be useful in situations where there are no existing saltmarshes in the area and/or where natural colonisation is deemed to be undesirable from either a flood defence or a nature conservation perspective (for

example, where natural colonisation would not produce vegetation cover quickly enough to meet flood defence objectives, or in environmentally sensitive sites where potentially undesirable species might establish if natural colonisation is permitted). A specific example of the potential application of such planting and seeding techniques would be to ensure rapid establishment of vegetation along the toe of counterwalls or similar earth structures constructed on managed realignment sites.

3. The various saltmarsh species have different biological characteristics. These characteristics, in turn, govern the suitability of different species for seeding, transplanting, turfing, etc., and hence for their use in flood defence projects.
4. There are inherent difficulties in establishing saltmarsh vegetation from seed in low zone saltmarsh areas due to wave energy and inundation as well as the presence of fine-grained sediments which may smother germinating seeds and young seedlings. Seeding is only recommended in mid to high zone sites, or as part of a mixture including vegetative propagules where the latter provide protection (eg. as a nurse crop) while seeds are germinating and establishing.
5. Transplants are more likely than seeds to succeed in low zone saltmarsh sites, particularly sites of low to moderate wave energies. Moderate wave energy conditions on a site are likely to cause some washout of propagules, and could result in a need for protection. High wave energy sites will require some protection if transplants are to grow and survive. Ensuring such protection might involve the provision of a breakwater, for example a breached embankment or a specially designed structure which still allows intertidal connection.
6. Either seeding or transplanting techniques or both may be used in the mid and high zone saltmarshes given the more protected conditions.
7. One or more of the following techniques for saltmarsh vegetation establishment may be appropriate for saltmarsh creation or restoration initiatives depending on the prevailing (or modified) physical conditions at the site:
   - natural colonisation
   - seeding alone
   - planting with seeding
   - planting alone
   - provision of protection via the breaching of an existing embankment, combined with natural colonisation, seeding, and/or planting (managed landward realignment)
   - provision of protection via the placement of a temporary or permanent breakwater(s), combined with natural colonisation, seeding and/or planting (managed seaward realignment)
   - any combination of the above, for example at different parts of the site
8. In situations where the existing elevation is too low for effective vegetation establishment (eg. where managed realignment is proposed), the placement of suitable fill or dredged material may be required in order to raise eroded or degraded areas to a suitable intertidal elevation.
9. There is a significant amount of relevant existing information on saltmarsh creation and restoration, both from UK experience and, particularly, from North America. Future planting and seeding initiatives need to draw on the lessons already learned.
10. It is essential that all saltmarsh creation and restoration initiatives (existing and future schemes) are properly monitored. Changes can thus be recorded and responses properly planned and implemented. Monitoring also allows potentially valuable information to be gathered, thus assisting in the design of future schemes.

KEYWORDS

Saltmarshes, creation, restoration, seeding, planting, flood defence.

1 INTRODUCTION

1.1 Background

When flood defence engineering work is carried out on or immediately adjacent to a saltmarsh, some damage to the existing vegetation is likely to occur. The extent of damage will depend on whether a major scheme is being carried out (where vegetation will need to be reinstated or enhanced as part of the project) or whether minor maintenance works are being undertaken, such as a repair to an outfall structure. In other cases, where the engineering works involve the setting back of the flood defence, it may be desirable to promote the development of a new saltmarsh or the restoration of a degraded or former saltmarsh.

Saltmarsh vegetation has both a flood defence role (wave attenuation and associated protection of the flood defence structure; preventing erosion of the saltmarsh surface; and promoting accretion) and a conservation role (providing a habitat for wildlife). It is therefore important to ensure that the marsh vegetation cover is properly established and functioning effectively following any engineering works. The degree to which regeneration will occur naturally, and its likely success, depends on such factors as soil type and elevation, hydrology and wave climate, drainage and the proximity of existing appropriate species (Landin, 1993).

In most situations natural colonisation by saltmarsh plants is to be preferred, but there are some locations where natural regeneration will not occur, will not occur quickly enough, or cannot be allowed to occur (for example because there is a danger of pest or exotic species becoming established in place of desirable species). In these situations, seeding or planting may be necessary to enhance the process and prevent possible erosion of material. However, neither the techniques of restoration nor the most suitable seed and plant types have previously been adequately identified and documented for Great Britain.

1.2 Aim of Project

According to the terms of reference, the aim of this project is to provide practical support and guidance to the Environment Agency to enable them to maintain and enhance saltmarshes, to design schemes, and to provide advice to other agencies and organisations. In doing so, the project will help to ensure that saltmarshes support vigorous vegetation, therefore providing a better sea defence.

For the purposes of this report, saltmarsh has been defined as any vegetated area within the soft sediment intertidal zone, which can tolerate fully saline or brackish conditions, low zone saltmarsh is defined as the area around and below mean high water (MHW); high zone saltmarsh as the area around or above mean high water springs (MHWS); and the mid zone saltmarsh as the area between MHW and MHWS. Other definitions pertinent to this report are contained in the glossary (see Appendix A).

1.3 Objectives

The overall objective of the research project is:

"To produce recommendations for operational engineers to restore or create vegetation growth on new or existing saltmarshes, when natural regeneration is not considered appropriate or possible."

The specific objectives are:

i. To define the type of site where seeding or re-planting may be appropriate.
ii. To review past success in saltmarsh regeneration both natural and by seeding or planting.
iii. To recommend appropriate species for seeding and planting on saltmarsh where restoration is to be undertaken.
iv. To recommend suitable seed mixes and plant sources for both seeding and planting.
v. To investigate the potential for harvesting seed locally or commercially for saltmarshes.
vi. To provide guidelines and recommendations on seeding and planting techniques and the appropriate levels at which success is most likely.
vii. To produce a R&D Technical Report, a brief chapter for inclusion in the Agency's *"Guide to the Understanding and Management of Saltmarshes"* and a one page executive summary.
viii. To identify potential areas for further research.

In preparing this report, the authors have been aware of the Environment Agency's duties under the Environment Act 1995 (Sections 6 and 7) and the Land Drainage Act 1991 (Section 12) to take into account the environmental impacts of its actions and through its actions to further the conservation and enhancement of the environment (Environment Agency, 1998).

1.4 Approach and Report Structure

As set out in the terms of reference for this research project, there are two main scenarios in which the Environment Agency may wish to establish saltmarsh vegetation by planting and/or seeding. The first scenario involves projects in which the new or restored marsh is an integral part of the flood defence scheme - for example a set back scheme where a newly created or restored marsh is required to act as a mechanism for wave attenuation, or in the situation where an existing marsh is deteriorating to the point where it can no longer provide an effective flood defence function. Another, more specific example would be in the situation where it is necessary to establish vegetation along the toe of counterwalls constructed on managed realignment sites. The second scenario is one in which flood defence engineering works have caused damage which requires repair to an existing saltmarsh, irrespective of whether or not that marsh has a flood defence role.

Where vegetation cover is required in order to attenuate wave energy, it will be necessary to establish species which are potentially "useful" for front line flood defence purposes. These are species which help to promote accretion, resist wave energy, withstand storms, and/or prevent erosion. In a situation where an existing saltmarsh of nature conservation importance is damaged by flood defence works, however, it may be necessary to try to re-establish local, native species, possibly in conjunction with front line defence species.

In either of the above cases, the type of site at which an initiative to vegetate or re-vegetate with saltmarsh species is likely to be successful will be dictated by the conditions needed for effective establishment. After an initial review of past experience with seeding, planting and natural regeneration initiatives (Section 2), the report therefore goes on to assess the physical, chemical and biological conditions required by saltmarshes (Section 3), and to determine which particular species might be potentially useful in respect of flood defence engineering works (Section 4). Section 5 then discusses possible sources of seeds and/or plants. Section 6 provides guidance on saltmarsh seeding or planting, and Section 7 sets out the findings and recommendations of the report.

Throughout the process of preparing the report, the study team has been mindful of a number of important factors. In the first instance, although British experience with saltmarsh restoration, specifically seeding and planting, is limited, there is a wealth of experience and data available from North America as well as some relevant information from elsewhere in Europe. The project therefore draws extensively on relevant North American experience in particular. Secondly, it is apparent from existing experience that the physical, chemical and biological conditions at a site where vegetation is required will be of fundamental importance (Hayes *et al.*, 1998; Landin, 1993; National Research Council, 1994; US Army Corps of Engineers, 1986). This is acknowledged and explained throughout the report. Finally, the study team was conscious of the need to ensure that the report is both practical and objective in order to maximise its usefulness to operational engineers and saltmarsh managers. Reference is made, where appropriate, to selected scientific/biological reports and publications rather than reproduce such information in this report. Other relevant documents are listed in the bibliography.

2 PRIOR EXPERIENCE AND COMPLETED PROJECTS

2.1 Background

There are a number of sites in the UK where saltmarshes have either been planted or seeded, or where vegetation has established or re-established naturally. Not all such initiatives, however, have been documented. A series of site visits to representative sites therefore comprised an essential component of this research effort, and discussions were also held with some of the scientists responsible for experimental schemes. These visits and discussions took place alongside a review of other documented projects designed to establish saltmarsh vegetation.

In addition to the British experiences, lessons can also be learned from selected examples of both natural regeneration and seeding/planting initiatives elsewhere. In North America in particular, thousands of marshes have been built for the restoration, creation, protection and/or management of habitats as well as for shoreline protection, sediment management, hydrology management and numerous other marsh functions and values.

The following sub-sections discuss the sites visited and other British/European initiatives, and provide examples of both sites where saltmarsh vegetation has established naturally (following, for example, physical intervention at the site), and sites where planting, seeding, turfing, etc. have been undertaken. These sub-sections are followed by a discussion of relevant North American experience.

2.2 British Examples of Sites Where Saltmarsh Vegetation has Established by Natural Recolonisation

2.2.1 Managed realignment scheme at Tollesbury, Essex

Tollesbury managed realignment site is located at the upper end of the Blackwater Estuary, Essex. Saltmarsh and mud flat was developed by breaching (in 1995) an embankment that had previously provided protection against saline inundation enabling the site to be maintained as a wheat field. Areas of wheat stubble were left standing in the field with the expectation that this would provide a little roughness to help with colonisation by marsh plants. Other areas were left bare, ploughed or covered in grass to determine whether the state of the land surface at the time of inundation would affect the rate of natural recolonisation. The existing hedgerows and trees were left standing to serve as baffles (see Figure 2.1, Appendix B). As tidewater inundated the site, the hedgerows and trees died from the effects of saltwater, but nevertheless slowed the water velocity and caused the sediment to accumulate. Sedimentation is occurring at a rate of 200mm (8 inches) annually, and should increase as marsh plants colonise the very low elevation site.

Although several vegetation planting and sowing trials were undertaken at this site (see details in Section 2.3.1), the majority of the site was left for recolonisation to occur naturally. Currently (approximately 3 years after the breach), the elevation of the entire site is still too low for much colonisation to occur. However, along most of the area of the hedgerow, sufficient sediment has accreted to enable a dense stand of glasswort (*Salicornia* spp.) to grow. Several small clumps of common cordgrass (*Spartina anglica*) have also colonised within the glasswort (*Salicornia* spp.) stands. The rest of the site remains as unvegetated mud flat. Ploughing parts of the site prior to inundation had no effect with regard to the survival of plantings or the success of natural colonisation.

2.2.2 Managed realignment at Pawlett Hams, Bridgwater Bay

In 1994, 4.8ha of saltmarsh was created following the realignment of a sea wall at Pawlett Hams. This managed realignment scheme formed part of an Environment Agency (then the National Rivers Authority) scheme to improve flood defences along the eastern bank of the River Parrett. Within the three years following the breach common saltmarsh grass (*Puccinellia maritima*) and annual sea blite (*Suaeda maritima*) had colonised throughout the area. Colonisation had also taken place by lesser sea-spurrey (*Spergularia marina*), greater sea-spurrey (*S. media*) and hard grass (*Parapholis strigosa*) in the high zone saltmarsh (6.2-6.7m AOD) and common glasswort (*Salicornia europea*) grew mainly in the low zone saltmarsh (5.7-6.0m AOD). The most rapid colonisation was along the toe of the new sea wall where, by 1997, there was a 3-6m strip of saltmarsh dominated by common saltmarsh grass (*Puccinellia maritima*). Several relatively uncommon species have also become established along the sea wall, including sea wormwood (*Seriphidium maritimum*), sea barley (*Hordeum marinum*), sea clover (*Trifolium squamosum*) and rock sea lavender (*Limonium procerum*) (high zone saltmarsh).

Several important observations were noted from the subsequent monitoring of this site and were recorded in Leach *et al.*, (1997). Colonisation by the vegetation tended to be more rapid at high elevations (>6.3m AOD), than at lower elevations (<6.3m AOD) and vegetation cover was greatest at the top of the shoreline, adjoining the new sea wall (>6.1m AOD). The distribution of the species appeared to be strongly influenced by elevation. Common glasswort (*Salicornia europea*) was most frequent at the lower elevation (≤6.0m AOD). Common saltmarsh grass (*Puccinellia maritima*) and lesser sea-spurrey (*Spergularia marina*), on the other hand, occurred in the region of 6.3-6.4 AOD, which is a similar elevation to neighbouring areas of long established common saltmarsh grass (*Puccinellia maritima*) saltmarsh. Greater sea-spurrey (*Spergularia media*) and hard grass (*Parapholis strigosa*) were found abundantly above 6.5m AOD. Several other saltmarsh colonists, including sea barley (*Hordeum marinum*), rock sea lavendar (*Limonium procerum*), sea wormwood (*Seriphidium maritimum*) and sea clover (*Trifolium squamosum*) occurred mainly on areas of high elevation adjoining the sea wall (Boorman, 1996).

2.2.3 Managed realignment at Orplands, Essex

Orplands is a managed realignment site located in St Lawrence Bay on the south shore of the Blackwater estuary in mid Essex. The site at Orplands was breached in 1993 and is by far the largest of the managed realignment sites in the area.

The site was prepared for inundation by constructing an earth embankment to the limit of the landward extent for flooding, and by cutting creeks. An old farm embankment was breached in two locations, one of which is now widening. The material from the two breaches was placed inside the embanked area to serve as a wave buffer at the entrance of each breach. These two mounds of material have colonised with high marsh and appear to be relatively stable considering where they are located. In one location on the site, ponds were excavated to provide some diversity and manage water flowing from a nearby hillside.

At the time of the site visit in July 1998, Orplands was almost completely colonised with a very diverse community of saltmarsh species. Almost every saltmarsh species occurring in southern England was found on this site (see Figure 2.2, Appendix B). Glasswort (*Salicornia* spp.) and stands of seablite (*Suaeda* spp.), sea spurry (*Spergularia* spp.), common saltmarsh grass *(Puccinellia maritima)*, common sea lavender *(Limonium vulgare)*, and sea purslane *(Atriplex portulacoides)* are common. However, this site is accumulating trapped sediment at approximately the same rate as Tollesbury (approximately 200mm per year). It is therefore likely to evolve into high zone saltmarsh to very dry high zone saltmarsh, and may change over time into dry land due to sediment entrapment.

2.2.4 Managed realignment at Thornham Bay, Chichester Harbour, West Sussex

This site is a 6.9ha managed realignment project in Chichester Harbour. The site was originally an area of rough ground covered with scrap cars and other rubbish and was protected by an embankment. The rubbish was removed, and the embankment was breached to provide intertidal conditions. A tidal channel of approximately 1.5-3.0m wide was excavated and the site was smoothed and cleaned. Restoration work commenced approximately two years ago (1996) and was continuing until mid-1998. The saltmarsh is used for recreation by people walking, running, dog-walking, and bird watching. A bridge was constructed over the breach so that the area could be used by visitors (Figure 2.3, Appendix B).

The site is entirely high zone saltmarsh, and approximately 20-30 percent of the area floods at high tide. Plant species growing on the relatively lower elevations of the site include sea couch (*Elytrigia atherica*), glasswort (*Salicornia* spp.), sea plantain *(Plantago maritima)*, sea aster *(Aster tripolium)*, common reed (*Phragmites australis*), and common saltmarsh grass *(Puccinellia maritima)*. Non-salt tolerant species such as wild carrot (*Daucus carota*), clovers (*Trifolium* spp.), fescues (*Festuca* spp.), and bent grasses (*Agrostis* spp.), together with limited sedges (*Carex* spp.) occuring at higher site elevations (see Figure 2.3, Appendix B). It is fronted outside the embankment by a mixed stand of common cordgrass (*Spartina anglica*) and glasswort (*Salicornia* spp.).

2.2.5 Managed realignment at Northey Island, Essex

In 1991, Northey Island was the first recorded site in the UK to undergo managed realignment. The existing sea wall was lowered and a 20m wide spillway was created at the lowest part of the experimental area. This site is very small (0.8ha), and of a higher elevation than the Tollesbury managed realignment site (see above). When the embankment was breached, a cliff formed and high marsh is now growing to landward of the cliff, with a good transition zone exhibited. Glassworts (*Salicornia* spp.) and annual sea-blite (*Suaeda maritima*) were the main colonists in the first two years of tidal inundation, together with common saltmarsh grass (*Puccinellia maritima*) on higher ground (Turner and Dagley, 1993; Dagley, 1995). The most rapid colonisation and greatest species richness was at relatively high elevations, particularly along the toe of the new sea wall.

Seven years after the breach of the sea wall, the lower reaches of the marsh outside and just inside the embankment comprise mainly sea purslane *(Atriplex portulacoides)*, common sea lavender *(Limonium vulgare)*, thrift *(Armeria maritima)*, and sea aster *(Aster tripolium)*, with some glassworts (*Salicornia* spp.). There are small stands of common cordgrass (*Spartina anglica*) at the very lowest elevations.

2.2.6 Managed realignment at Saltram, Devon

A spillway 5-10m wide was constructed with four flap valves at a site at Saltram, near Plymouth, Devon in order to allow water onto a new saltmarsh area. The flaps were regularly vandalised, however, allowing too much water to enter the site, which proved to have insufficient drainage (partly due to the spillway being constructed at too high a level to allow water to exit the site). The standing water which accumulated as a result of the flaps being vandalised killed off that saltmarsh vegetation which had initially established. Once the drainage problems had been resolved, however, a dozen or so species colonised the site: these include sea aster (*Aster tripolium*), sea-spurrey (*Spergularia* spp.), and glasswort (*Salicornia* spp.). This site is interesting in that there is very little other saltmarsh in the surrounding area to act as a seed source: the seeds which colonised the area must therefore have had to travel a considerable distance.

2.2.7 Beneficial use of dredgings scheme at Horsey Island, Essex

On the north side of Horsey Island, Essex, an area of degraded saltmarsh has been the recipient of dredged material from channel deepening works at nearby Harwich. At this site, a line of detached lighters (small barges) had previously been sunk along the north-east shoreline of the island. These lighters act as a wavebreak. Landward of the lighters, a gravel bund was constructed using dredged material. This was then backfilled with fine-grained dredged material to an intertidal elevation. A sandbag wall held the sediment while it stabilised, maintaining the elevation of the site.

This project was completed in May 1998, and was already rapidly colonising with glasswort (*Salicornia* spp.) in lush, dark green stands of vegetation in July 1998 (see Figure 2.4, Appendix B). The nutrient level in the dredged material appears to have contributed significantly to the development of the site by hastening colonisation and enhancing survival. In comparison, at a nearby site that received no dredged material, the glasswort (*Salicornia* spp.) are the more common red-light green colour and only about a quarter of the height of the glasswort (*Salicornia* spp.) growing on the dredged material deposits. Based on prior experience with dredged material projects in the USA, Landin predicted that the site which received the dredged material will be completely vegetated in less than three years barring unforeseen storm events or grazing pressures.

2.2.8 Vegetation restoration following pipeline installation at Horsey Island, Essex

This site comprises an area of agricultural land landward of an embankment which has been fenced off and a pipeline system constructed through the embankment to allow saline water to enter via the far end of the site (see Figure 2.5, Appendix B). The fenced area was designed to flood with each tide. Saltmarsh vegetation rapidly colonised the area (within the first growing season) with many different species including glasswort (*Salicornia* spp.), common cordgrass (*Spartina anglica*), sea aster *(Aster tripolium)*, sea purslane *(Atriplex portulacoides)*, lesser sea-spurrey *(Spergularia marina)*, saltmarsh grass *(Puccinellia maritima)* and common sea lavender *(Limonium vulgare)*. Three years after the first tidal inundation, the site is still showing a rich floristic diversity with species such as red fescue *(Festuca rubra)* becoming apparent. The site was successful because it continued to be protected from the full force of the sea by the embankment, while still providing access for intertidal water exchange.

The marsh surrounding Horsey Island comprised areas of grazed and ungrazed marsh. Areas of saltmarsh that had been grazed were showing signs of stress and consisted mainly of glasswort (*Salicornia* spp.) and annual seablite (*Suaeda maritima*) with little species diversity. An area of saltmarsh, which had been fenced and protected from grazing sheep and horses for about 18 months, however, was being allowed to recover naturally. At the time of the site visit, this area was still under stress to some extent but species consisted of glasswort (*Salicornia* spp.), common saltmarsh grass (*Puccinellia maritima*), sea lavender (*Limonium vulgare*), and a few other species. Another area of saltmarsh which had been fenced and protected from grazing for approximately 30 months was a "flower garden" of common sea lavender and was highly diverse (see Figure 2.6, Appendix B). Since sea lavender is a perennial and blooms on its second year growth (first year is a rosette), it is probable that sea lavender is also more abundant than was apparent on the 18-month-old site and will show better in the next growing season.

2.2.9 New area of saltmarsh at Holkham Bay, Wells Next The Sea, Norfolk

This site is located on the beach to the west of Wells, Norfolk. It comprises a dune system with common cordgrass (*Spartina anglica*) and glasswort (*Salicornia* spp.) growing behind it between the beach and the dune (see Figure 2.7, Appendix B). Anecdotal observations by local people suggest that the common cordgrass (*Spartina anglica*) and glasswort (*Salicornia* spp.) have been present for at least 3-5 years.

The dune is colonised by marram grass (*Ammophila arenaria*). The glassworts (S*alicornia* spp., probably common glasswort (*Salicornia europaea*)) and cordgrass (*Spartina anglica*) appear to be thriving and spreading. The cordgrass (*Spartina anglica*) was starting to flower at the time of the site visit in July 1998. There were also numerous mud snails (*Hydrobia* sp.) all over the saltmarsh plants and soil. The substrate was firm sand and shingle/gravel, with very little trapped fines. Almost no other saltmarsh plant species were found in this small area of saltmarsh because the elevation was too low for them to colonise.

2.3 British Examples of Saltmarsh Vegetation Establishment by Planting or Seeding

2.3.1 Planting and sowing experiments, Tollesbury, Essex

Experimental work investigating the viability of planting and sowing saltmarsh vegetation was undertaken at Tollesbury, Essex in 1995 (before, during and after the managed realignment scheme discussed in the previous section). The research was divided into two phases: Phase I commenced before the embankment breach and main inundation of the managed realignment site and was concerned with the pre-establishment of saltmarsh species. Phase II was the main experimental phase and it followed the breaching of the sea wall and the opening of the site to regular tidal inundation.

During Phase I, the formerly agricultural plots were planted with specially raised plants of common saltmarsh grass (*Puccinellia maritima*) and sea aster (*Aster tripolium*), these being considered the species most likely to survive the relatively low elevation. The elevation of the planting area was -3.0m msl and although accretion rates are very high over the majority of the site the planting area remains at that elevation since it is near the breach of the embankment and below the survival range of even common cordgrass (*Spartina anglica*) and (*Salicornia* spp.). The plants did not survive in this area and the planting area remains a mud flat.

Specially raised plants were planted in the lowest parts of the site which had previously been flooded with saline water to kill the terrestrial vegetation. Replicate plots were established nearby but at a sufficiently high elevation to avoid the flooding and therefore the terrestrial vegetation remained until the main flooding of the site when the embankment was breached. Three months later, the plants in the lower area were surviving better than those in the higher area (the area that had not been pre-cleared of terrestrial vegetation). This indicated that, in the short term, the removal of the existing vegetation may be beneficial to the establishment of transplants. Following the breaching of the seawall, however, the survival of the remaining higher plants was greater than those planted at the lower level. The plots in the pre-flooded lower area suffered considerably from their lower elevation and from the persistence of standing water (Boorman, 1996). All of the plants at the lower level subsequently died (see Figure 2.8, Appendix B).

Nonetheless, this trial demonstrated that the high zone saltmarsh species tested were unable to survive in this low zone, and that the most tolerant species tested only survived until they were smothered by accretion or by the growth of algal mats. This latter result was anticipated, however, since the transplant zones (a creek base and foreshore mud flat) were within the intertidal elevations at which algal mats occur.

Phase II involved the propagation of 25,000 plants which were used for seed collection. Nine different saltmarsh species were used: sea aster (*Aster tripolium*), sea pink (*Armeria maritima*), sea puslane (*Atriplex portulacoides*), golden samphire (*Inula crithmoides*), sea lavender (*Limonium vulgare*), sea plantain (*Plantago maritima*), common saltmarsh grass (*Puccinellia maritima*), sea arrow grass (*Triglochin maritima*), annual sea blite (*Suaeda maritima*), and greater sea spurrey (*Spergularia media*). Plots were seeded at densities of 5000 and 500 seeds per m^2 for high and low density plots respectively.

Further randomised plots were planted with circular cores (plugs), taken from the existing higher marsh, each core being 0.01 m^2 in area with a mixture of growing vegetation. The cores were planted at a density of 1 per m^2 and it was hoped that the transplanted plant material would act as a focus for plant colonisation of the adjoining areas. Unlike the planting or sowing, this method has the advantage of not requiring special preparation (plant propagation or seed collection) beforehand. According to English Nature, this method was the most successful of the techniques used.

2.3.2 *Spartina anglica* planting at Bosham, Chichester Harbour, West Sussex

Bosham is located in a relatively sheltered area within Chichester Harbour. The saltmarsh at this location in the harbour is generally dominated by common cordgrass (*Spartina anglica*). The area is very low in elevation and has a very low wave energy. Sediment is accreting throughout the upper bay area. Common cordgrass (*Spartina anglica*) has colonised in this area naturally, and is mixed at the lowest elevations with glasswort (*Salicornia* spp.) on the west side of the bay. On the east side of the bay, elevations are higher, with one metre deep tidal rivulets: the saltmarsh community here is mixed, consisting of sea purslane (*Atriplex portulacoides*), common sea lavender (*Limonium vulgare*), common saltmarsh grass (*Puccinellia maritima*), sea aster (*Aster tripolium*), cordgrass (*Spartina* spp.), and some glasswort (*Salicornia* spp.). At the highest elevations sea couch (*Elytrigia atherica*) and some common reed (*Phragmites australis*) dominate.

The Chichester Harbour Conservancy planted common cordgrass (*Spartina anglica*) in May 1998 in a small area approximately 15 x 30 metres, which was previously the site of a car park, at Bosham. The surrounding area of existing saltmarsh is almost entirely restricted to dense stands of common cordgrass (*Spartina anglica*). Sprigs were taken from wild stands of common cordgrass (*Spartina anglica*) growing in ditches around Bosham and transplanted at approximately 0.3-0.6m centres. To prevent continued car parking, large stones were placed along the road edge and the area was planted between the stones and the water. The sprigs are growing and spreading, and are already developing seed heads. This is a very low wave energy site, but is inundated at high tides in excess of one metre depth. Two months after planting one hundred percent survival of the plants was evident (see Figure 2.9, Appendix B).

This site is a good example of how common cordgrass (*Spartina anglica*) can be planted and utilised for multiple purposes (ie. stabilising substrate/preventing erosion, and making an area more aesthetically pleasing to visitors to the area).

2.3.3 *Spartina anglica* planting at Wytch Farm Gathering Station, Dorset

This site was planted with common cordgrass (*Spartina anglica*) for stabilisation and aesthetic purposes several years ago. At one time the entire harbour area had broad extensive stands of cordgrass (*Spartina* spp.) but they are now suffering from die-back. At the planted area, the marsh front is eroding and a short cliff has already formed where the common cordgrass (*Spartina anglica*) root systems are being undercut. The site has almost no other species growing on it and has no room for transition into higher marsh before reaching pasture and other land uses (see Figure 2.10, Appendix B). Although the initial planting of the *Spartina anglica* in this area appeared to be successful, general die-back of the species in the area has resulted in panne formation at this site.

2.3.4 Vegetation transplants using turfs at Shotover Moor Marsh, Dorset

The 70m wide marsh at this site underwent restoration when a pipeline was constructed across the high marsh area. Restoration was carried out by removing a deep turf of vegetation (approximately 0.4m deep) from the surface of the trench where the pipeline was to be placed, to a holding area alongside the trench. Care was taken not to stack the turfs, which were then reinstated to the exact position from which they had been removed, and with the same orientation, as soon as possible after pipeline construction. The turfs were stored for as short a time as possible and were not allowed to dry out (they were watered from an adjacent stream). This technique of saltmarsh restoration has been carried out in the US on several pipeline project sites in North Carolina, Mississippi, and Louisiana, and is encouraged by US federal pipeline and energy regulatory agencies.

The project appears to have been very successful, with a great deal of diversity of species. This is a protected, intertidal high marsh, growing with brackish to fresh marsh species common reed (*Phragmites australis*), rushes (*Juncus* spp.), sedges (*Carex* spp.), cattails

(*Phleum* spp.), and an assortment of less dominant species (see Figure 2.11, Appendix B). The species used in this restoration project are not suitable for flood defence protection as front line plants, but are excellent plants to consider for high marsh elevations.

2.3.5 *Spartina anglica* planting using turfs at Cleaval Point, Poole Harbour, Dorset

This saltmarsh site was restored after excavation to lay a 0.15m backwash pipeline. The pipeline was smaller than that described in the Shotover Moor Marsh site above, and the site was partially planted in recent months (1997/1998). Common cordgrass (*Spartina anglica*) was transplanted using turfs of approximately 0.15m square taken from the nearby marsh. Care was taken to ensure that the common cordgrass (*Spartina anglica*) squares were removed from random locations so that the production of large bare patches was avoided. The turfs were replanted firmly to prevent them from being washed away at the next tide and pegged in a 1m intersecting grid. It was important to plant the turfs at the same soil depth and tidal location as that at which they were originally growing.

The planted area is growing well (see Figure 2.12, Appendix B), but the area where natural colonisation is being allowed is still bare in a number of places. This site is expected to completely cover with vegetation and, considering the availability of propagules of various marsh plants, this should occur with little difficulty. The pipeline crossing location comprises only a very small part of the overall natural marsh which occurs at this site.

A nearby area that had also suffered damage from the pipeline installation also underwent restoration work. Seeds were obtained for this project using a large vacuum cleaner (Devax): it was considered important to obtain seeds from a nearby marsh in order to ensure that they were genetically adapted to local conditions. The seeds were then dried and stored in a shed prior to being hand sown on the affected area of saltmarsh. This remedial work proved successful, with species such as common saltmarsh grass (*Puccinellia maritima*), glasswort (*Salicornia* spp.) and sea aster (*Aster tripolium*) germinating well.

2.3.6 Experimental realignment site at Abbotts Hall, Essex

The National Rivers Authority (now the Environment Agency) identified an experimental saltmarsh regeneration area at Abbotts Hall, Essex which was built in 1995. The objectives of the experiment were to rectify the low land level differential and to re-create dormant, previously claimed saltmarsh. The experimental site is 20 hectares in area. Existing levels range from +1 metres OD to +25 metres OD and the site fronts onto the north bank of Salcott Creek, a tributary of the Blackwater Estuary. The area was drained by a 450mm concrete piped sluice which was modified to allow tidal water to enter and flood the site.
Due to the narrow bore of the sluice, relatively few seeds from the adjacent saltmarshes were reaching the recently flooded area. In order to provide a seed source, drift materials from the strandline of nearby marshes were collected and spread around the site. This drift material was collected by hand, transported in large sacks and liberally distributed around the newly created intertidal area. Despite the relatively crude methods involved, this seeding method proved to be relatively cheap and effective, and used a nearby seed source which meant that the plants were adapted to the local conditions.

Within the first year after the "seeding" there was some initial growth of saltmarsh vegetation. Glasswort (*Salicornia* spp.) and sea purslane (*Atriplex portulacoides*) were the first species to colonise, providing a good vegetation cover over the marsh. Other vegetation such as sea-blite (*Suaeda* spp.) colonised as the salt levels in the soil increased. These plants were largely killed off due to poor drainage and standing water, and were succeeded by grass leaved orache (*Atriplex littoralis*). Grassed leaved orache (*Atriplex littoralis*) is a plant that can stand 1.5m tall and is therefore able to tolerate the ponded water much better. It is also able to ensure a good supply of oxygen. Some patches of sea purslane (*Atriplex portulacoides*) remain in areas which are not permanently flooded (personal communication, I. Dyack, 1998). Overall, however, the site was found to be at too high an elevation for optimum saltmarsh establishment and this affected the species establishment, survival and community. Researchers on this site are also experimenting with a controlled amount of inundation in line with English Nature's recommendations (personal communication, D. Weight, Environment Agency, 1998).

2.3.7 Saltmarsh restoration programme for pollution control and *Spartina anglica* transplanting, Southampton Water

Past oil contamination from a refinery and other shipping movements in Southampton Water resulted in damage to the saltmarsh adjacent to Fawley refinery. In an attempt to conserve the saltmarsh habitat, Esso took the initiative to reduce the amount of oil contained in its effluent discharges, which led to the regeneration of the dominant plant common cordgrass (*Spartina anglica*) in denuded areas. In order to further improve the rate of recovery, common cordgrass (*Spartina anglica*) transplanting was undertaken. Firstly, however, any adverse environmental conditions that may have hindered vegetation growth were addressed to ensure that optimum conditions were available for successful saltmarsh establishment.

The transplanting was carried out in late spring. Plugs of healthy *Spartina anglica* were removed from the adjacent healthy area of saltmarsh using a simple coring device. The plugs were 100mm in diameter and 200mm long. The plugs were transported to the denuded areas by hovercraft and replanted in holes dug out in the denuded area.

To illustrate the scale of the project, it is worth noting that 4,000 plugs were transplanted in 1983, and a further three or four phases of transplanting have been carried out since. The scheme is continuous (monitoring and transplanting occurs every 2-3 years) and has proved to be successful. There has not only been a recovery in vegetation, but also in invertebrate and bird populations.

2.3.8 Establishment of *Phragmites* by aerial seeding on the Flevoland Polder in the Netherlands

Large quantities of common reed (*Phragmites australis*) seeds were harvested from selected stocks and sown by air on newly reclaimed mud flats with the aim of preventing weed establishment on the south-east Flevoland polder in the Netherlands. Subsequently when drainage had been improved by common reed (*Phragmites austrailis*), an excellent de-waterer of saturated soils, and salt water had leached from the soil, the reeds were ploughed in and weed free land was produced for agricultural crop production. A total of 35,000 ha of common reed (*Phragmites australis*) were established during this operation (Ranwell, 1975).

This method of seeding was designed to be used for the dewatering and reclamation of mud flats prior to agricultural use, however, the principle might also be applicable to areas of saltmarsh in certain circumstances where water could not be excluded (ie. with adequate high zone intertidal connections).

2.3.9 *Zostera* spp. planting trials in North Norfolk

Although not a saltmarsh species, it is nonetheless useful to mention the planting trials which have taken place using eelgrass (*Zostera* spp.) because the establishment of eelgrass beds could act to stabilise sediment in front of, or prior to, a saltmarsh regeneration project.

Eelgrass (*Zostera* spp.) planting trials in the early 1970s were described by Ranwell (1975). The aim of these trials was to provide information on the feasibility of promoting eelgrass (*Zostera* spp.) growth. Greater areas of eelgrass (*Zostera* spp.) were required to provide food resources in protected areas to offset the losses, through reclamation, of natural feeding areas for Brent geese.

The area selected for the trials was Breydon Water in Norfolk. Narrow leaved eelgrass (*Zostera angustifolia*) already existed and dwarf eelgrass (*Zostera noltii*) was beginning to establish. Because of the natural colonisation of these species, it was considered that the conditions were suitable for *Zostera* planting and growth.

In March 1972, twenty (220 x 150 x 100 mm depth) clumps of dwarf eelgrass (*Zostera noltii*) were dug with an iron frame and transplanted into wet plastic boxes lined with muslin. These clumps were then lifted out by the muslin and set into holes in the mud, flush with the surface. By September of the same year all the plants were living, and several had increased in area by a factor of 10, and 95% of the plants were flowering. The following winter was mild and, although unprotected, the plants did not suffer from overgrazing by the geese. This experiment appears to have been successful and resulted in the establishment of healthy dwarf eelgrass (*Zostera noltii*) beds, however, subsequent trials revealed that careful planting of the turfs flush with the soil surface (roots well buried but stems above soil) is critical for successful establishment (Ranwell, 1975).

2.3.10 *Zostera marina* transplants using turfs in Essex

Eelgrass (*Zostera marina*) beds suffered extensive die back in the British Isles in the 1930s leading to only a few beds remaining by the 1950s. These remaining beds included several sites along the Essex coast, including Two Tree Island, Foulness Island and Osea Island. Because of the ability of this subtidal and intertidal species to dissipate wave energy and stabilise mud flats, it was decided to attempt to transplant eelgrass (*Zostera marina*) from one of these remaining beds, to several nearby experimental sites. The aim of this experiment was to see if the eelgrass (*Zostera marina*) could help to stabilise an eroding shoreline.

In April 1982, the Anglian Water Authority transplanted eelgrass (*Zostera marina*) from a donor site to the west of Osea Island on the River Blackwater, onto three transplant sites: Tollesbury, West Mersea and Dengie in Essex. The transplanting was carried out by cutting turfs at both the donor site and within the area of plant receipt at the transplant site, using an iron cutting frame (200mm x 200mm x 100mm deep). A spade slid under the turf enabled easy lifting of each eelgrass sample. Four turfs were placed in plastic trays, each wrapped in polythene to prevent moisture loss. A total of 20 plastic trays (ie. 80 turfs) were taken to each transplant site. The donor site was surveyed and a level taken one week before the transplants were taken. The turfs were placed in the receiving sites at the appropriate level and at 1m spacings to give the plants a good chance to hold together on a relatively unstable foreshore.

The eelgrass (*Zostera marina*) plants had a low survival rate and these experiments were deemed to be unsuccessful. This was largely because the transplant sites were too exposed and at the wrong elevation, and the plants could not withstand the higher energy environment (personal communication, English Nature, 1998).

2.4 Relevant North American Experience

2.4.1 Background

There is a great deal of potentially relevant information about saltmarsh planting and seeding available from North America. The following sub-sections discuss examples of this North American experience, whilst Box 2.1 provides a general background. This experience is pertinent to the UK in so far as:

- the climate in the northern United States and in parts of southern Canada is comparable to that in the British Isles
- many of the species are common to both the UK and North America
- although tidal ranges in the UK are typically greater than those in North America, harvesting, planting and site preparation techniques are generally the same irrespective of tidal range once the latter exceeds 0.3m (ie. they are carried out according to the low, mid and high marsh zones).

Box 2.1 History and current situation with respect to saltmarsh seeding and planting in North America

North America has extensive saltmarshes along its coasts within the intertidal zone (it also has saltmarshes in the interior US). In the past 75 years, an increasing number of marshes have been restored, enhanced, or protected, particularly since the passage of the Clean Water Act of 1972 which set out requirements for mitigation for any damage caused to, *inter alia*, marsh habitats. There are several thousands of restored and/or created coastal sites throughout the US, including more than 200,000 hectares of saltmarshes. In the United States, a saltmarsh is defined as one which receives only saline waters. Brackish and coastal freshwater marshes are referred to as intertidal marshes.

Saltmarsh communities in the US have very different compositions from coast to coast, with different genera and species making up the intertidal zone vegetation. However, a number of US genera and species are also common to the British Isles, and relevant information from the US can therefore be extrapolated to the UK. In addition, the US short form of smooth cordgrass (*Spartina alterniflora*) (occurs north of New York harbour) is a parent of *Spartina townsendii* and a double parent of common cordgrass (*Spartina anglica*), which occur in the British Isles. The areas with conditions which are most similar to the British Isles are those of Oregon and Washington in the Pacific north-west, and on the Atlantic coast from Chesapeake Bay northwards.

Most older saltmarshes in the US formed by natural colonisation but most of the more recent saltmarshes have been planted. Few are left to chance, because the exposure and harsh conditions found within the intertidal zone require rather intensive technology for initial establishment and restoration. Wetland engineering and biology has progressed to such levels in the US that "how-to" manuals exist to provide wetland managers with the information needed to carry out this work. Most of the more recent sites have had monitoring and documentation in the form of annual or final technical reports detailing techniques and results. Some selected examples of published documents are listed in the bibliography.

In general, where there are high wave energy intertidal zones, irrespective of the level of salinity, experience in the US indicates that saltmarsh planting rather than seeding is required and that the plantings must be protected from wave energy by a permanent breakwater. In moderate wave energy intertidal zones of all salinities, saltmarsh planting is required and must be initially protected from wave energy by a temporary breakwater capable of survival for at least three years. In low wave energy or less saline intertidal zones, saltmarsh planting is optional and does not require breakwater protection. Planting is most commonly carried out at 1 metre centres, with more dense planting where rapid cover is needed. At 1 metre centres, complete vegetation cover of a site can be expected within 3-5 years, and usually occurs with 3 years on low wave energy, brackish to fresh water intertidal sites.

Most of the US experience and expertise has been gained by many years of field trials and studies. Much of this information is beginning to be published in international journals, and has been published in government reports and US "national/regional" journals for the past 20-30 years. Prior to that time, marsh restoration/establishment was considered akin to farming: it largely occurred on public fish and wildlife refuges, and was not published in peer-reviewed documents. This trial and error approach has resulted in failed sites as well as successful ones, but all have been considered lessons learned. Without proper engineering and environmental planning, design, construction, monitoring, and management, marsh establishment is rarely successful (Knutson and Woodhouse, 1983; Landin, 1992; Landin, 1993; National Research Council, 1994; Gill *et al.*, 1995; LaSalle, 1996; Hayes *et al.*, 1998; Soil Conservation Service, 1992; Kusler and Kentula, 1990; Thunhorst, 1993; Roberts, 1991; Landin, 1998; Landin *et al.*, 1998; Yozzo and Titre, 1997).

2.4.2 Atlantic Coast examples of North America saltmarsh restoration

Barren Island, Chesapeake Bay, Maryland

Restoration at this site included extensive smooth cordgrass (*Spartina alterniflora*) and saltmeadow cordgrass (*Spartina patens*) plantings carried out by hand on an old eroding dredged material island. The first project, of approximately 5ha, was undertaken in 1980. It comprised plantings on unprotected shorelines, and included some bare ground sandy areas for nesting Least Terns. The second project built in 1995, was more extensive. The eroding shoreline of the island was protected by the in-situ filling of 31m long geotextile custom-made tubes with dredged sand. Sand dredged material was then pumped behind the tubes to an intertidal elevation. The tubes were placed in 1-2m water approximately 125m from shore at a height to break waves up to the high tide level (the highest waves broke over the top of the tubes). The site has 20-30 ppt salinity, and a 1.5m tidal range. The project was funded by the Baltimore District, US Army Corps of Engineers. The site is being monitored, and compared to natural saltmarshes in the vicinity (Blama *et al.*, 1995).

Windmill Point, James River, Chesapeake Bay, Virginia

This was the first intertidal marsh purposely built by the US Army Corps of Engineers on the Atlantic Coast, in 1973. Although plantings were intended, the site colonised naturally within the first growing season - so rapidly that no plantings were carried out in the marsh area. Colonising species included arrow arum (*Peltandra* spp.), arrowhead (*Sagittaria* spp.), bulrush (*Typha latifolia*), wood club rush (*Scirpus* spp.) and other fresh to brackish species. Although the site was protected by a berm, it was an island, fully exposed to current and tides. Salinity was normally below 10 ppt, and the tidal range was 1-1.5m. In 1983 during a major long-duration "El Nino" event, the island broke in half, and many plants either drowned or were eroded away. The site currently remains as two smaller islands which provide fish spawning areas and bird feeding areas, but it no longer meets all the original project goals, especially the engineering goals. The project was funded by the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi. This site has been monitored for over 26 years (Lunz *et al.*, 1978; Landin and Newling, 1988; Landin *et al.*, 1989; Landin, 1997).

Buttermilk Sound, at the Altamaha River juncture with the Atlantic Intercoastal Waterway, Georgia

This saltmarsh was built on a high sand island in 1974. Salinity was normally 20 ppt, and there was a 1-1.5m tidal range. This site was hand planted and seeded in trials which included fertilisers and controls with smooth cordgrass (*Spartina alterniflora*), saltmeadow cordgrass (*Spartina patens*), big cordgrass (*Spartina cynosuroides*), marsh elder (*Iva frutescens*), sea ox-eye (*Borrichia* spp.) and several other minor marsh species. The site trapped fines immediately, and is now covered with more than 0.3m of mud. It is currently dominated by smooth cordgrass (*Spartina alterniflora*) and big cordgrass (*Spartina cynsuroides*) and is thriving. The project was funded by the Waterways Experiment Station. The site has been monitored for more than 26 years, and compared to three natural saltmarshes in the vicinity (Reimold *et al.*, 1978; Newling *et al.*, 1985; Landin *et al.*, 1989; 1998).

2.4.3 North Carolina examples of saltmarsh restoration

Atlantic Intercoastal Waterway, North Carolina
In the late 1960s and early 1970s, Seneca, Woodhouse and Broome of North Carolina State University, in an effort to determine if smooth cordgrass (*Spartina alterniflora*) could be grown in order to restore saltmarsh, mechanically planted (with a wheeled tractor pulling a drill-seeder) seeds in the intertidal zone on the sand. The seedings were very successful, but these results can only be achieved on firm sand in a protected area. They have not been duplicated in other parts of the United States due to differences in tidal, climatic and, most importantly, substrate conditions. Salinity at the restoration site was 35 ppt, with a 1.5m tidal range, but with almost no wind fetch or wave problems. The project was funded by NC State University.

Wells Island, North Carolina
This site was built and planted in 1979. It was constructed of sandy dredged material in an area without seagrasses or other benthic values or nesting habitat for sea and wading birds, and was approximately 5ha. The crown of the island was left bare for terns, skimmers, and other bird species. The fringes were hand planted (not seeded) with smooth cordgrass (*Spartina alterniflora*) and saltmeadow cordgrass (*Spartina patens*) by a North Carolina university consortium to protect the island shorelines and stabilise the sandy sediment. The site is very successful. Salinities are 35 ppt, and the tidal range is 1.5m. The site has been monitored for approximately 19 years. It was funded by the Wilmington District, US Army Corps of Engineers (Ms. Trudy Wilder, US Army Corps of Engineers, Wilmington, NC, personal communication, 1998).

Atlantic Intercoastal Waterway near Beaufort, NC
Three sites were graded to an intertidal elevation in 1990, and hand planted on sandy dredged material with smooth cordgrass (*Spartina alterniflora*). In the subtidal zone the site was hand-planted with eelgrass (*Zostera marina*). The cordgrass (*Spartina alterniflora*) plantings were very successful, but the eelgrass plantings were not. No reasons were specifically identified for the failure and partial failure of the eelgrass, but most such plantings attempted on the Atlantic coast that have failed have been shown to have light, turbulence, and/or wave exposure causes. This was a joint project of the US Army Corps of Engineers and the National Marine Fisheries Service, and funded by the Corps. Salinities were up to 35 ppt, and the tidal range is 1.5m. The site was monitored from 1990-1994.

2.4.4 Gulf of Mexico examples

Apalachicola Bay, Florida
In 1975, a manmade island located in the Panhandle Region of Gulf Florida, was embanked with sand and filled with fine-grained dredged material and then hand-planted with smooth cordgrass (*Spartina alterniflora*) and saltmeadow cordgrass (*Spartina patens*). Tests included different spacings but there were no plantings as a control. The site has been very successful and the plantings served as a nurse crop, allowing subsequent colonisation by a wide range of saline, brackish, and fresh marshes species in zones within the site. The protective berm was breached in 1975, and over time has eroded away completely (partially due to direct hits by

three major hurricanes over the years - saltmarshes survive hurricanes well). The project was funded by the Waterways Experiment Station, and has been used as a teaching site for Corps coastal wetland restoration training courses for many years. There are over 26 years of site monitoring data. Salinities at the site are normally 10-20 ppt, and the tidal range is approximately 0.3m (Kruczynski *et al.*, 1978; Newling *et al.*, 1984; 1985; Landin *et al.*, 1989; Landin, 1997).

Gaillard Island, Mobile Bay, Alabama

This is a 542ha island constructed in 1980-1981 at the juncture of two major shipping channels, over 2 miles from shore. It was the site of a number of field trials for bioengineering techniques and planting, and was both hand and mechanically planted with smooth cordgrass (*Spartina alterniflora*) and saltmeadow cordgrass (*Spartina patens*) on one of its three sides (a triangular shaped island) from 1983-1988. The other two sides of the island are armoured in stone. The plantings trapped huge quantities of sediment each year, and during winter months were smothered, but the vegetation would grow through the mostly sandy substrate and colonise further out into Mobile Bay. Behind each new area created by this effect, brackish to saline minor marsh species colonised and continue to thrive. The growth of cordgrass has now reached the point where, due to water depth and exposure, it is no longer able to expand outward and is beginning to recede. The most important utilisation of Gaillard Island is by more than 30,000 sea and wading birds (28 species) which nest on this island each year, and feed in the more than 300ha intertidally-connected containment pond in the island's interior. The project was funded by Mobile District, US Army Corps of Engineers, and tests were conducted by the Waterways Experiment Station. Salinities normally are 10-20 ppt, with a 0.3m tidal range, and storm tide surges up to 4m. The site has been monitored since 1980, and compared to natural saltmarshes in the vicinity (Landin, 1986; Landin *et al.*, 1989; Landin, 1997).

Southwest Pass, Lower Mississippi River, Louisiana

This pass has been the site of almost year-round maintenance of the shipping channel of the Mississippi River for many decades. In prior years, dredged material was side-cast underwater. In 1974, however, the material began to be pumped over the natural river berms west of the river into subsided areas in Barataria Basin. No plantings of any sort were made; the goal was simply to bring the subsiding delta back to intertidal elevations. Approximately 8000ha of these placement sites have naturally colonised with smooth cordgrass (*Spartina alterniflora*), saltmeadow cordgrass (*Spartina patens*), big cordgrass (*Spartina cynsuroides*), saltgrass (*Distichlis spicata*), sharp club rush (*Scirpus americanus*), saltmarsh bulrush (*Scirpus robustus*) and other species. The area has a 0.3m tidal range, and 0-15 ppt salinity. The work was funded by New Orleans District, US Army Corps of Engineers, and monitoring has been carried out by the Louisiana Universities Consortium (LUMCON), the US Fish and Wildlife Service, and the Waterways Experiment Station (WES). WES monitoring compared the site to nearby saltmarshes, and found that the area is still subject to massive subsidence: for every 2 hectares of marsh constructed, one will have subsided and drowned within ten years. Flooding of the Mississippi River, and storm tide surges of up to 4m have an influence on all work in this area (Landin *et al.*, 1989; Landin, 1997).

Bolivar Peninsula, Galveston Bay, Texas

In 1974, on an island separated from the Peninsula by the Gulf Intercoastal Waterway, 5ha of saltmarsh hand-plantings were carried out in field trials. Plantings in the saltmarsh zone included smooth cordgrass (*Spartina alterniflora*), saltmeadow cordgrass (*Spartina patens*), and saltgrass (*Distichlis sipicata*). In higher zones, native shrubs and trees were planted. The trials included spacing, seeding, fertilisers, and an area of no plantings as a control. This site has a 44km wind and wave fetch exposure, and was protected by geotextile tubes which, at that time, were considered temporary due to lack of information on their durability. The tubes colonised with oysters, and currently remain as an intertidal oyster bed. Less protected parts of the site eroded away. The site has been monitored for more than 26 years, and compared to six natural saltmarsh sites and three manmade sites in the vicinity. The original plantings have spread east and west on the island. The site has a 0.3m tidal range, 35 ppt salinity, and storm tides which can exceed 4m. It has survived two direct hits by Gulf Coast hurricanes with no damage. Funding for the project was provided by the WES and by Galveston District, US Army Corps of Engineers. The site has been the model for numerous other saltmarsh projects within Galveston Bay, a number of which are currently under construction as part of the Houston, TX, Ship Channel deepening and widening project. (Allen *et al.*, 1978; Newling *et al.*, 1985; Landin *et al.*, 1989; Landin, 1997).

Aransas National Wildlife Refuge, Gulf Intercoastal Waterway, Texas
In 1995-96, three eroding saltmarsh sites totalling about 15ha were protected in field trials with several types of bioengineering materials: geotextile tubing, geowebbing, erosion control fabrics, and salt-tolerant concrete bags. The sites were planted with smooth cordgrass (*Spartina alterniflora*) to serve as nurse crops. To date, the sites are growing well and are considered successful. They are being monitored by the WES and by Texas A&M University-Corpus Christi. The geotextile tubes have already colonised with dense growths of algae and benthic organisms; waves at high tide can break over the tops of the tubes. The least successful test was of geowebbing, which was undercut and is subject to erosion. Funding for these projects came from mitigation efforts by private developers, the WES, and the Galveston District, US Army Corps of Engineers. The sites have a 0.3m tidal range, 35 ppt salinity, in some spots more than a 60km wind and wave fetch, and storm tide surges exceeding 4m (Davis and Landin, 1996; McClellan and Maurer, 1997).

2.4.5 Pacific Northwest examples of coastal marsh restoration

Miller Sands, Columbia River, Oregon
This manmade island in the middle of the large Columbia River was constructed in 1935. Three locations on it were used for field trials in 1974, one of which was intertidal saltmarsh. Hand-plantings of Pacific sedge (*Carex obnupta*), Lyngbye's sedge (*Carex lungbyeii*), tufted hair-grass (*Deschampsia cespitosa*), and sea arrow grass (*Triglochin maritima*) were conducted with different spacings and fertiliser applications, and with no plantings as a control. The site has been monitored for more than 26 years, and compared to three natural marsh sites in the vicinity. The plantings have been highly successful and have spread from the original small planting of approximately 3ha to an area approximately 4km in length. Sand at a higher elevation than the marsh was planted with marram grass (*Ammophila arenaria*), (known in America as European beachgrass). The site receives very high and diverse fish and wildlife use, and has been declared habitat for endangered fish by the National Marine Fisheries Service. Funding was provided by the Portland District, US Army Corps of Engineers, and the WES. There is a 2-3m tidal range, and salinities are normally 20-30 ppt (Clairain *et al.*, 1978; Landin *et al.*, 1987; 1989; Newling *et al.*, 1985; Landin, 1997).

Jetty Island, Puget Sound, Port of Everett, Washington
This 41ha sandy manmade island was built in 1895, and has been the site of additions and constructions for many years. The most recent effort was a 3ha addition in 1990, which was hand-planted with Pacific sedge (*Carex obnupta),* Lyngbye's sedge (*Carex lyngbyeii*), tufted hair-grass (*Deschampsia cespitosa*), marram grass (*Ammophila*), and other species, including eelgrass (*Zostera marina*). Eelgrass (*Zostera marina*) is intertidal in Washington State, although it is subtidal on the Atlantic, Gulf, and southern California coasts). The island has been monitored since 1976 for seabird nesting, and since 1990 for saltmarsh vegetation. Funding has been varied, and provided at different times by the Seattle District, US Army Corps of Engineers, the Port of Everett, the WES, and the US Environmental Protection Agency. It has 35 ppt salinity and a 3m tidal range (Soots and Landin, 1978; Houghton and Gregoire, 1997).

2.4.6 Southern California examples of saltmarsh restoration

Salt Pond 3, Southeast San Francisco Bay, California
In 1972, an abandoned and subsided 15ha salt pond was filled with fine-grained dredged material from the adjacent flood control channel. The site was hand and machine planted (with a tracked bulldozer pulling a modified tree planter) with pacific cordgrass (*Spartina foliosa*) and pacific glasswort (*Salicornia pacifica*). Plantings were very successful, but the salt pond embankment was breached in 1973 and has continued to erode since that time. It currently is only a remnant of its former size, and will be gone completely in a few more years. Intertidal channels were cut into the site to provide better access. The site has been monitored since 1972, and compared to three natural saltmarshes in the vicinity. It is now dominated by glasswort (*Salicornia*), the natural progression of saltmarshes in that part of California. The site has also trapped up to 1.5m of sediment in parts. Salinity is 35 ppt, with a 3m tidal range, and storm tide surges at high tide of over 5-6m. Salt Pond 3 has been used as a model for present and future sites in subsidence zones in California (Morris *et al.*, 1978; Newling *et al.*, 1985; Landin *et al.*, 1989; Landin, 1990).

Muzzi Marsh, Marin County, San Francisco Bay, California
In 1977, the State of California restored this degraded 5ha saltmarsh by raising the elevations using dredged material. It colonised naturally with a large number of species at and above the high zone marsh line, and is dominated in low zones by pacific glasswort (*Salicornia pacifica*) with a fringe of pacific cordgrass (*Spartina foliosa*). A tidal creek was excavated into the site. Monitoring has been conducted by the State, and the site is part of a county park with high natural resource recreational use (bird watching, walking). Salinities are 35 ppt, with a 3m tidal range. The site is protected from most storms in the area, and is located on the protected north-west side of the Bay.

Sonoma Baylands, Petaluma River, North San Francisco Bay, California
In 1996, a subsided former agricultural field was filled with nearly 3m of dredged material to bring it back to an intertidal elevation. The embankment was not breached (a lesson learned from Salt Pond 3), but had culverts installed. The site is therefore protected but has adequate intertidal connections. It was planted with pacific cordgrass (*Spartina foliosa*) and glasswort (*Salicornia* spp.). It is a new project, highly visible to the public, that is being compared to other sites within the Bay. It has 35 ppt salinity, and a 3m tidal range even with the culverts. The project was funded by the San Francisco District, US Army Corps of Engineers, and the Sonoma Baylands Trust. To date, it is considered highly successful, and will become a model

itself for future projects (Scott Miner, Project Manager, US Army Corps of Engineers, San Francisco, personal communication, 1998).

Donlin Island and Venice Cut, San Joaquin River, California Delta, California
These two sites were formerly subsided farmland adjacent to the river and protected by farm embankments which failed, flooding about 30ha of land. They were restored in 1983 by the placement of maintenance dredged material from the navigation channel, and allowing natural colonisation to occur. Species dominating the sites include big cordgrass (*Scirpus californicus*), tule or Californian bulrush (*Scirpus californicus*), two species of bulrush (*Typha* spp.) and sedges (*Carex* spp.). Woody plants have colonised the high marsh zones. Donlin Island is fresh water (zero ppt), and Venice Cut is brackish (15 ppt), with 2-3m tides. The sites are subjected to annual flooding from the river. The sites were compared to intertidal marshes in the vicinity by the University of California at Davis. The projects were designed by the WES, and funded by Sacramento District, US Army Corps of Engineers and the Port of Stockton, California.

2.4.7 *Zostera marina* planting in the US

Eelgrass (*Zostera marina*) planting in the US has not been very successful on the Atlantic or Gulf of Mexico coasts, although limited success has occurred in Tampa Bay, Florida and in Chesapeake Bay. In the Caribbean, such planting has tended to be more successful because of the relatively higher water quality (Mr Roy R. Lewis III, Key Largo, Florida, personal communications, 1978-98). Eelgrass plantings on the Pacific coast, primarily in southern California, have been very successful and have all taken place on dredged sand subtidal deposits (Dr. Keith Merkle, San Diego, California, personal communications, 1990-98). Several hundred hectares have been planted and have survived for many years. Problems with the failure of eelgrass plantings in the US usually arise because of problems with increased turbidity and/or contaminants in the water.

3 SITE EVALUATION AND SPECIES SELECTION CRITERIA

3.1. Introduction

Experience both from the UK and elsewhere suggests that the most important factor in establishing saltmarsh vegetation is to achieve satisfactory physical and biological conditions at the selected site. Chemical conditions, unless there is reason to believe that the site is contaminated, are of lesser importance. Furthermore, saltmarsh species will vary in their biological characteristics and thus in their suitability for seeding or planting.

Four primary factors will usually determine the success or otherwise of initiatives to establish saltmarsh vegetation (Landin, 1993; National Research Council, 1994). These are:

1. Appropriate physical conditions and intertidal elevations;
2. Appropriate geological and substrate (soil/sediment) conditions conducive for vegetation establishment and survival;
3. Site engineering (if required) to deal with wave and wind energy, boat and ship wash, and land subsidence; and
4. The introduction of appropriate halophytic (salt tolerant) vegetation adapted to the previous factors.

There are, however, a number of contributory components to each of these four primary factors and this chapter therefore reviews the various physical, chemical and biological characteristics of saltmarshes and saltmarsh plants. It also provides specific guidance (where this is available) on the type of conditions which need to be present at a site if the chance of a successful seeding or planting initiative is to be maximised.

3.2 Site Evaluation: Physical Conditions

Different saltmarsh species have individual requirements and tolerance thresholds with respect to the physical and chemical conditions at a site. These are often region-specific and can vary with species between locations. Meeting such conditions will be fundamental to the likely success of any scheme designed to establish saltmarsh vegetation: the key parameters which will require assessment are therefore discussed below.

3.2.1 Waves and currents

Exposure to wave action is a major factor in determining the feasibility of marsh vegetation establishment along any exposed shoreline. Many marsh species can withstand low to moderate levels of wave energy (ie. those characteristic of many sites in bays and estuaries) but most species cannot grow and persist in higher energy conditions. Protection is therefore essential.

Sub-surface wave run-up (ie. bed currents associated with wave run-up), especially in shallow estuaries, undercuts saltmarshes at their roots and causes bank slumping and shoreline erosion. Research has shown that if the sub-surface waves moving in-shore can be tripped, eroding saltmarsh can survive and even regenerate in relatively higher wave energy conditions, because most of the surface waves are attenuated by marsh vegetation after a short distance (Davis and Landin, 1997).

The upper and lower limits of some species tend to be higher than expected in situations where they are directly exposed to waves and wind that have travelled longer distances. This may be because the greater fetch and exposure leads to more turbulence and substrate erosion.

Saltmarshes do not generally occur in areas of high currents. High currents will make it harder for seedlings to establish and maintain a root hold. High currents also make the plant stems gyrate and thus encourage erosion, or break off stems at the surface leaving the roots intact in the soil but unable to generate any new shoots. Good tidal circulation is nonetheless essential in all saltmarsh restoration and creation projects in order to ensure, *inter alia*, an adequate supply of sediment.

The tolerance of marsh plants to the type of conditions discussed above also varies with the alignment of a site in relationship to the direction of the strong winds, wind velocities, and the seasonal timing of the winds, as well as the nearshore topography, tidal currents and type of substrate. In general, unprotected sites exposed to long wind fetches should not be seeded. UK literature suggests that fetch should be less than 2000m for successful initial colonisation of saltmarsh (Boorman, 1987). In the United States, however, extensive research has been conducted on wind fetch and wave run-up in coastal marshes, and saltmarshes have been restored and/or created in areas with as much as 42km of open water and wind fetch across estuaries (Landin *et al.*, 1989). The engineering of such sites is critical, but may not involve more than a simple breakwater to trip the long sub-surface waves which cause the scour and undercutting (Davis and Landin, 1997).

Saltmarshes generally occur naturally along protected or semi-protected intertidal soft sediment shores. They also persist when tidal inundation is dampened or blocked by tide gates, sand bars, berms, islands or embankments. In order to develop to its natural potential, saltmarsh vegetation at flood defence restoration sites should therefore be provided with tidal influence similar to that of a natural marsh system. In more exposed sites, this will mean a requirement for artificial protection from wave action and strong currents. Protection during the early stages of colonisation and development may be achieved by constructing brushwood fences or other bio-engineering structures in more protected areas. In more exposed areas, the provision of a permanent breakwater with the marsh located behind the structure but still having an intertidal connection will be required (Davis and Landin, 1997; National Research Council, 1994).

3.2.2 Tidal prism

The amount of water entering and leaving a saltmarsh site, and the speed with which it does so (ie. the tidal prism) is similarly important because most saltmarsh species will be more difficult to establish and maintain in areas of high velocity and scour. This could be a particular problem around the point of water entry and discharge, and may require careful engineering design of any manmade tidal connections (Hayes *et al.*, 1998).

3.2.3 Tolerance of tidal range

The upper and lower limits of all saltmarsh species are highly correlated with the heights of both normal mean high water, and spring tide levels and the mean spring tidal range. However, individual features of larger estuaries may cause species limits to be higher or lower for their tidal regime than in small estuaries. It may be difficult to establish vegetation on deeper water sites or those with a very large tidal range (except at their upper elevations) because the stored supply of oxygen for respiration may be insufficient to ensure survival during submergence. That said, however, a number of British saltmarsh species (eg. *Spartina* spp.) have adapted to complete inundation for several hours at a time, and these are therefore the species being considered for flood defence works.

3.2.4 Elevation relative to tide

The most important biological benchmark in intertidal conditions with regard to vegetation establishment is the depth of flooding via tide and run-off from the land - in other words, the elevation relative to tide at which plants can no longer survive and reproduce. Elevation, depth of flooding and the tidal regime determine the degree, duration, and timing of submergence and thus the type of species which will survive. Natural patterns of intertidal vegetation are readily referenced to elevation "benchmarks". These can be observed in the vicinity of each individual site prior to final design and implementation in order to determine exactly where planting should take place for each species (Hayes *et al.*, 1998). Most species occur over a limited range of intertidal elevations, and each has a peak abundance in different parts of the saltmarsh. In saltmarshes with more gentle slopes, this range may seem extensive. However, in saltmarshes with steeper slopes, a fringe or distinct narrow zone may be obvious for each species.

Elevation relative to tide must be adequate in order to achieve success in establishing the desired saltmarsh plant cover: contouring the topography to include mean sea level to extreme high water will generally provide suitable elevations for many saltmarsh species. In the United States, in order to ensure that the right zone has been identified when benchmarks are indistinct, planting may also take place above and below the zone of optimum conditions for the species (US Army Corps of Engineers, 1986).

3.2.5 Tolerance of slope

The width of the intertidal zone and its slope determines the area suitable for marsh growth. Productive marshes are found over a wide range of slopes: however, either an excessive or insufficient slope can have important effects on marsh establishment and growth. Steep slopes facilitate drainage and aeration but are more difficult to plant, relatively resistant to natural colonisation by marsh species, and limit the area that can support marsh. More importantly, steep slopes can be undercut by sub-surface wave run-up more readily, and will not attenuate wave energy as efficiently. Waves cannot dissipate their energy over a short distance on a steeply sloping foreshore.

Very gradual slopes impede circulation and drainage and are usually less productive due to the formation of hypersaline pannes. In earlier studies in the United States, Woodhouse (1979) suggested slopes of 1-3% as the preferred range, provided that surface drainage is not impeded. Subsequent research, however, indicates that slopes of 3-5% may be best unless the design of the site also calls for shallow intertidal ponds (eg. to accommodate juvenile fish). Appropriate drainage is similarly important as the impoundment of water may prevent vegetation growth, but it is worth noting that shallow water areas serve other purposes such as providing feeding areas for wading birds and a refuge for small fish.

3.2.6 Sediment regime (eroding or accreting)

An eroding saltmarsh will be largely unstable and sediment may be lost from around the plant stems causing further erosion of the marsh. In a highly erosive environment, it may be difficult to establish any vegetation cover and engineering solutions will be required to artificially stabilise the area prior to attempting any vegetation planting or seeding. Sufficient sediment should be in suspension within the estuary or water body to allow accretion to occur at a rate of between 3-10mm per annum (Beeftink, 1977). Too much accretion (in excess of 25mm per annum) could lead to the smothering of some plants, particularly pioneer species, over time. It is acknowledged that both the Tollesbury and Orplands sites (see Section 2) are accreting at a rate in excess of 150mm per annum and are thriving. However, both sites were initially too low in elevation when the breaching of the embankments took place and they are still working towards an intertidal equilibrium.

3.2.7 Preferred sediment grain size

The sediment grain size at a marsh site is important for several reasons. Firstly, the grain size affects the drainage of the marsh. Some species prefer sandy, well drained soils (eg. some oraches (*Atriplex*) species), whereas others are more able to withstand finer grained muddy soils which retain moisture more easily (eg. glasswort (*Salicornia*) and most other lower zone saltmarsh species). Secondly, although coarser grained sands tend to contain less nutrients and organic matter than finer grained muds, successful marsh establishment on sandier soils does not require any fertilisation providing there are sufficient nutrients in the tidal water (see Section 3.3.3). Finally, the physical process of planting is easiest in sandy soils, whereas silts and clays can present problems in terms of anchorage and support.

Most new coastal marshes in the United States (natural and man-made) occur on sandy substrates. There are good reasons for this: sandy soils provide a better oxygenated, firmer foundation for root establishment, and do not scour out as badly as silts and clays. Once plants become established, fines accrete in the stands of marsh plants and cover the original sandy substrate. This is the natural process of many coastal wetlands and is seen where older marshes have peat beds overlying the original sand. In addition, where sand is the underlying substrate, sub-surface wave run-up is not so damaging to the establishing saltmarsh (Landin *et al.*, 1989; National Research Council, 1994).

3.2.8 Preferred sediment depth

Saltmarsh plants, like most plants, require a sufficient depth of sediment to accommodate their root structure. Some existing saltmarsh sites, particularly eroding ones, have a very narrow band of surface sediment, or the sediment may be completely absent and the underlying clay may be exposed. The underlying clay is largely impermeable to root structures and may cause the plant material to break apart and wash out to sea. An absent or thin layer of surface sediment, unless accretion is occurring, will prevent saltmarsh growth. It may, therefore, be necessary to import sediment, for example (sandy) dredged material, to some sites where saltmarsh establishment is desired. However, such an addition of material will only be a temporary measure unless something is also done to alter the erosion pattern, for example through the establishment of a wave break.

3.2.9 Degree of soil compaction

Soils and sediments contain small spaces or pores within their structure. These spaces may be filled with either air or water (interstitial water), depending on the degree of tidal inundation and the soil texture. Such spaces are important as they provide oxygen and nutrients to the roots of the plants. A heavily compacted soil will inhibit root growth. The movement of heavy vehicles used in sea wall construction, for example, may therefore have a detrimental effect on the establishment of saltmarsh plants. The use of low ground pressure equipment and innovative technology will relieve this effect, but where such damage has already been caused, loosening/aeration and/or backfilling will be required to return the level of the affected area to the level of the surrounding marsh. This is especially important in areas where there is a sea wall because the waves which are turned back will drop into the lowered surface area and cause scour. Once started, this process is difficult to stop.

3.2.10 Creek density, drainage and soil water content

Adequate drainage is important at a saltmarsh site as the impoundment of water may prevent vegetation growth. Species composition and vigour is controlled by the residence time of the pore water in the sediment and the duration of surface water cover at the site. This, in turn, is governed by the degree of flushing and drainage. If the creek network does not allow an adequate rate of seawater flushing and drainage, there is a high probability that this will have an adverse effect on the flora. Most saltmarsh species grow in anaerobic soils (ie. soils with an absence of oxygen). They can do this because they take in oxygen through their leaves and stems and transport it to their roots. Cordgrass (*Spartina*) species are particularly adept at this: it is one of their adaptations which allow them to grow in the very lowest intertidal zones (ie. those which exclude other species). Species which do better in well drained soils (higher zone species in particular) cannot perform this process as efficiently. This is just one of the factors responsible for natural saltmarsh community zonation (Reimold and Queen, 1973; National Research Council, 1993; 1994).

If sediment is not flushed with sufficient seawater, oxygen is quickly stripped from the sediment and the bacteria present will resort to anaerobic respiration, thereby producing toxins which are detrimental to the vegetation.

3.2.11 Tolerance to oxic or anoxic conditions

Marsh soils are, by nature, chronically or periodically flooded and are, therefore, usually poorly to very poorly aerated. The severity and duration of this varies with such factors as topographic position, soil texture, and water regime as well as the biological activity in the soil. Oxygen is supplied to these soils by oxygen-bearing water and plants growing on them. Parts of the intertidal marsh soils may be drained and aerated at each ebb tide if the internal drainage allows appreciable emptying of pores during these brief intervals of exposure. Similarly, parts of high marsh soils may become aerated during periods of dry weather and low water tables.

Most sediments will be highly anaerobic or low in oxygen. As noted in the previous section, however, plants have various adaptations to this environment such as anatomical features that enable their leaves and stems to supply oxygen to their roots. Furthermore, some intertidal species contribute to the aeration of soils by releasing oxygen from their roots (eg. cordgrass (*Spartina*) and glasswort (*Salicornia* spp.)).

3.2.12 Geographical location

Geographical location is important in that it represents *inter alia* the effects of climate on the competitive abilities of the various saltmarsh species and hence their influence on each other's realised tidal niche. Climatic factors which affect saltmarsh plant behaviour and performance include seawater temperatures, the length of the growing season, the directness of sunlight, the moisture regime, exposure, and precipitation seasonality. Certain species are characteristic of different locations and may be limited geographically. Research (Burd, 1989) has shown that plants can have different regional adaptations (ie. plants in one location may not tolerate conditions in another region so well). This has been researched particularly in relation to the planting of marram grass where significant differences in genotypes of marram from around the coast have been identified. It is also graphically demonstrated in the saltmarsh genera and species that are common to the British Isles, Europe and North America. Those genera and species common to the UK growing in North America may be found to have different adaptations and sometimes grow in different conditions, especially with regard to tidal regimes, water temperature, competition, community associations, and their ability to withstand erosive conditions.

Temperature is similarly important to successful marsh establishment and this in turn is related to climate and geographical location. Certain plants are geographically distributed based on climatic conditions. Plants at the extremes of their geographical tolerance may not be so vigorous as they could be in other locations. It is therefore important to establish the natural geographical coverage of a species before determining its suitability for planting in a certain area: this is most easily accomplished by examining nearby saltmarshes to determine the species present. Biological benchmarks can be determined by simple surveying to establish which species are growing at which elevations (Hayes *et al.*, 1998)

3.3 Site Evaluation: Chemical Conditions

3.3.1 Water and sediment quality

Saltmarsh sediments, because of their generally high organic matter and surface area, have substantial adsorptive capacities for many kinds of pollutants such as excess nitrogen, phosphorus, organic pollutants and heavy metals. Saltmarsh vegetation is, however, able to tolerate relatively high levels of these pollutants, exhibiting very little, if any stress in some cases, although this will depend on the pollutant type, concentration and cumulative effect of other pollutants. Transient high levels of herbicides (for example, those washed from adjacent land into a saltmarsh during the first rainfall after spring application) may, however, be harmful to saltmarsh plants and seedlings may be particularly vulnerable.

In the United States, both intertidal marshes and interior marshes continue to be studied to determine their role in pollutant uptake and removal, and possible mechanisms to enhance this process. A number of the plant species discussed in Section 4 have the capacity to act as pollutant "sinks", and are used for this purpose in North America.

It is also worth noting that, because of the high adsorptive capacity of saltmarsh sediments, it is possible that contaminants may be retained and become buried in the sediment layer as the saltmarsh accretes, even if the overlying water is free from contamination. Where there is reason to believe that potentially harmful historic contaminants might exist, sediment quality as well as water quality should be assessed when considering a seeding or planting initiative.

A problem associated with water quality is that of increased nutrient content. Nutrients are required for healthy vegetation establishment and survival (see Section 3.3.3 below, on nutrient status). However, an excess of nutrients will lead to eutrophication, and may result in the formation of dense algal mats which will wash onto the marsh surface with incoming tides and lodge there. These algal mats could smother existing saltmarsh vegetation, create anoxic conditions and prevent healthy saltmarsh growth.

3.3.2 Tolerance to salinity

Saltmarsh plants must clearly have some degree of salt tolerance. Some of the most salt tolerant species have the capacity to excrete salt through special structures (salt glands) in their leaves. Others possess another mechanism in their roots for screening toxic ions and slowing adsorption (Reimold and Queen, 1973).

Plants of the regularly flooded, low zone marshes are well equipped to live and grow in salinities up to 35ppt (sea strength). However, these plants are usually quicker to establish and are more productive in salinities below sea strength. Soils that are fresh to slightly brackish will allow natural invasion of species from fresh water marsh and brackish water marsh habitats. In North America, salinities in excess of 50ppt may lead to high mortality of pacific cordgrass (*Spartina foliosa*) (Zedler, 1984), but glasswort (*Salicornia*) species have been found to thrive at up to 100ppt in the same region of southern California (Landin *et al.*, 1989).

Seeds and young seedlings are usually more sensitive to salt concentrations than established plants. Saltmarsh seeds germinate best in freshwater, and the young seedlings grow best in freshwater. They can be transplanted out of a marsh nursery by gradually introducing a level of salinity equivalent to that to be found at the transplanting site, over several weeks prior to transplanting (Landin, 1978).

3.3.3 Nutrient status

According to Zedler (1984), nitrogen may be limiting to plant growth in the proposed marsh substrates, although not all scientists agree with this view. Phosphorus is rarely limiting to saltmarsh growth, although it can enhance productivity if nitrogen is also added. Saltmarsh seeding initiatives involving sandy substrates and/or those which require the rapid establishment of vegetation may seem initially to benefit from the application of fertilisers (Bache and Macaskill, 1981). This may be important if rapid cover of vegetation is deemed to be important. However, saltmarsh fertiliser studies in the United States using both slow release fertilisers and fertiliser packets placed in the hole of each transplant indicate that there is no effect, positive or negative, of fertilisation in the medium to long term success (Landin *et al.*, 1989).

As dredged materials are frequently rich in organic matter, a thin layer of dredged material might be spread over the site prior to planting or seeding to provide an initial "shot in the arm" to young saltmarsh plants, but the North American research would indicate that this is not necessary where the tidal waters are rich in nutrients. Such an application of dredged material would, however, be of benefit in providing a less compacted surface for young roots to grow in and allow much more rapid growth.

3.4 Summary of Biological Considerations and Influences

Different saltmarsh species have unique biological characteristics. Understanding these characteristics and the mechanisms and adaptations which allow a species to survive and reproduce, is essential in selecting species that might be appropriate for use in a particular situation at a saltmarsh restoration or creation site. The biological characteristics of and influences on saltmarsh species, and a brief approach to biological techniques likely to be of importance in respect of creation or restoration initiatives, are discussed below.

3.4.1 Characteristic: reproduction

Most saltmarsh plant species reproduce by two mechanisms, by seed production or by vegetative means (ie. rhizomes, stolons, tubers, tillars, nodes and root mats that can be separated into individual plants). Many saltmarsh species use both reproductive methods to varying extents, depending on their adaptations and survival strategies for dealing with stress or disturbance. Man has also added several other methods of vegetative plant propagation, including the taking of woody stem cuttings, grafting, layering, and tissue culture.

There are three widely used techniques of propagation appropriate for saltmarshes, direct sowing of seeds in mixes or in monostands, planting nursery-raised potted or bare-root plants, and transplanting sprigs from donor saltmarshes (Landin, 1978; Thunhorst, 1993 and Hayes *et al.,* 1998). Two innovative techniques recently tried include spreading of material from strandlines, and temporary removal of top soil (turf) with rooted plant material, storage of same, and replanting the same top soil with plants back onto the site after the source disturbance is past. In each of these five techniques, the establishment period is critical because the individual plant and the entire planted/seeded stand are at risk from factors such as drought (in high zone saltmarshes), predation from grazing wildlife and domestic animals, wind and wave energy, and other types of damage.

3.4.2 Characteristic: flowering and seeding

Most UK vascular saltmarsh species flower from June through to September, with common cordgrass (*Spartina anglica*) flowering well into November. Townsend's cordgrass (*Spartina townsendii*) produces sterile seeds. Seeds are generally set and mature enough for harvest by August-October. Each species' seed heads weather and shatter at different rates, so it is important to understand each species' life cycle well enough to know exactly when (and how) to collect seeds. Flowering and seeding occurrence and timing are important to know, as well as types of seeds and their ease of harvest, so that seed collection and harvest can be planned well in advance of actual flowering and seeding.

3.4.3 Characteristic: growth habit and longevity

Part of a species' survival strategy is its growth, reproduction, and death as an annual, a biennial, or a perennial species. Often, saltmarsh species within genera will vary, with all three growth strategies occurring within a genus. The life cycle of the plant species is important in determining which species to plant and/or the best method(s) of reproduction. An annual species completes its life cycle in one year, germinating in autumn or spring, flowering, fruiting and dying by the following autumn; examples are common glasswort (*Salicornia europea*) and spear leaved orache (*Atriplex prostrata*). A biennial species germinates and grows slowly the first year, then flowers, seeds, and dies the second year; an example is sea aster (*Aster tripolium*). A perennial species germinates the first year, and flowers and seeds in following years, often living for a number of years; examples are perennial glasswort (*Salicornia perennis*), sea plantain (*Plantago maritima*), sea arrow grass (*Triglochin maritima*), common saltmarsh grass (*Puccinellia maritima*), and most of the common saltmarsh species in the British Isles. The majority of saltmarsh species are either herbaceous or woody perennials, which means that they are able to reproduce vegetatively as well as by seeds.

3.4.4 Characteristic: growth rate

The rate of growth of a saltmarsh species is one of the adaptations these plants have to enable rapid colonisation and establishment under harsh conditions. Most germinate and/or develop young root systems within a matter of weeks to hold the plant in place except under storm conditions. By the end of the first growing season, the most competitive species will have developed root systems that will sustain them through winter months without protection from storms. Examples of these are common cordgrass (*Spartina anglica*), perennial glasswort (*Salicornia perennis*), common reed (*Phragmites australis*), and sea aster (*Aster tripolium*). Woody stemmed species such as shrubby sea-blite (*Suaeda vera*), once established, will endure for many years. UK saltmarsh species which are slow growing are not considered hardy enough to recommend for front line flood defence purposes.

3.4.5 Characteristic: vigour /plant cover and density

The rapid speed of establishment and growth of saltmarsh species gives some predictability not only to how the species will establish, but how it will grow, survive, and provide ground and marsh cover. The speed with which vegetation becomes established and the density of that vegetation will both be important factors in selecting appropriate species if a dense cover and/or rapid establishment are required for flood defence purposes.

In the United States, research has developed to a level in which knowing the growth habits of a species (eg. common reed (*Phragmites australis*)) allows one to safely make predictions for design, implementation, and management. It is known that this species, for example, will not tolerate above 15-20 ppt salinity, will tolerate partial inundation, will not tolerate pounding by wave energy, will colonise and grow rapidly or can be planted with the same result, and is an extremely hardy aggressive species. It is also expected to completely vegetate a site within one to two growing seasons. In the US, marsh species are not selected for planting on a new site unless they can provide at least 75-85 % ground cover within three growing seasons, even in colder climates and higher tidal regimes. Understanding such characteristics is vital to the success of marsh restoration and creation projects.

3.4.6 Characteristic: above-ground form

The above-ground form of a plant (ie. shrub form, woody stems, herbaceous form, height, density of stems, location of reproductive structures on stems, growth from leaves on stems or basal leaves from roots, and other unique adaptations) are some of the important characteristics that allow a saltmarsh species to tolerate and survive harsh coastal conditions. The aerial parts of saltmarsh plants are important for flood defence in that they often form a flexible mass which dissipates wave energy. As wave energy is diminished, both the offshore transport and the longshore transport of sediment are reduced, and sediment loads will drop out, settling in the marsh. Dense stands of vegetation then create a depositional environment, causing accretion rather than erosion of the shore, a major goal of flood defence using plant materials.

Box 3.1 explains the results of US observations and experiments in respect of wave energy dissipation by vegetation.

Box 3.1 North America experience of the use of smooth cordgrass (*Spartina alterniflora*) to attenuate wave energy

In the US, smooth cordgrass (*Spartina alterniflora*) was found in both Virginia and Maryland to attenuate moderate wave energy at high tide with a saltmarsh depth/width of 5-7m. Waves were attenuated within 2-3m in low wave energy conditions. High wave energy could not be dissipated with saltmarsh vegetation alone, and to sustain a marsh over time required a protective structure. This was verified with several field and wave-model studies at the US Army Engineer Waterways Experiment Station from 1973-1990.

3.4.7 Characteristic: below-ground form

The below-ground form (ie. root depth, density, underground vegetative reproductive strategies, and structure) of saltmarsh species is critically important because plants that form dense root and rhizome mats add stability to the shore sediment and can withstand pounding by waves over a longer period of time. This protective mat is of particular importance during severe winter storms when the aerial stems (which may break off at soil level when dormant) only provide limited resistance to the impact of waves. It is well known that a dense root structure significantly increases soil stability under conditions influenced by water movement. Shear strength of vegetated soils is as much as two or three times greater than unvegetated soils: this is especially so for fine-grained sediments (Gray, 1974; US Army Corps of Engineers, 1986). In addition, the shear strength of soils is higher when the volume fraction or weight density of the root system is greater under normal saltmarsh conditions.

3.4.8 Characteristic: competition/dominance

Salinity

In the coastal environment only plants adapted to varying saline conditions will survive. As soon as the conditions become more brackish, other more adaptable species will outcompete the saltmarsh species. A US example is provided by the very competitive cordgrass

(*Spartina*) species which occur in North America. Three cordgrass (*Spartina* spp.) smooth cordgrass (*S. alterniflora*), pacific cordgrass (*S. foliosa*), and Texas cordgrass (*S. spartinae*) grow and thrive in the low zone saltmarshes, and can survive at 35-50 ppt salinity. If salinity changes to 20 ppt, however, saltmeadow cordgrass (*S. patens*) and big cordgrass (*S. cynosuroides*) will hold their own with the other cordgrass (*Spartina*) species. If salinity changes to fresher than 20 ppt, common reed (*Phragmites australis*) will out-compete all cordgrass (*Spartina* spp.). An ecologically equivalent selection process occurs in Great Britain with other genera and species, and is shown by categorising the species into defined groups (i), (ii) and (iii); (see Section 4).

Holding ground
Several marsh species, especially common reed (*Phragmites australis*), are so aggressive and so fast growing that, once colonised or planted, their root mats and ground cover are sufficiently dense to exclude almost all other species. This is true regardless of soil texture. To change plant communities, or introduce new species, under such conditions requires drastic controls and management.

Inundation
Certain saltmarsh species are able to colonise and survive in the low zone saltmarsh, where inundation may occur for several hours with each tidal ebb and flow. Other saltmarsh species cannot tolerate this length of inundation, but can colonise mid zone saltmarshes, where neither the depth nor length of inundation is as great. Still other species can tolerate saturated and standing or slow moving water conditions, and occasional inundation, resulting in their occurrence only in high zone saltmarsh. Competition is fierce in the mid to high zone saltmarshes, whereas only a few species can withstand conditions at low zone. These are listed in group (i) in Section 4.

Inhibitory conditions
In general, UK saltmarsh species are not known to have alleopathic strategies (ie. where a certain plant species, through soil and fallen leaf chemistry, can provide a hostile environment for other species and exclude them from a certain area around it). In North America, there are both wetland and desert plant species that exhibit this competitive strategy, and these are not used in planting schemes because of this problem (unless the project goal is a monostand of that particular species). In the UK, one example of this may relate to one of the theories potentially explaining the observed die-back of cordgrass (*Spartina* spp.). That is, that the high organic levels which result from initial decay of cordgrass (*Spartina* spp.) may increase the rate of die-back by increasing the water retaining ability of the substrate, thus also rendering it an unsuitable substrate for future colonisation by other species.

3.4.9 Influence: effect of benthos and wildlife

It has been established that certain benthic species eg. ragworm (*Hediste diversicolor*) and mud snail (*Hydrobia ulvae*) may inhibit the growth of various saltmarsh plants by grazing on their seedlings (West, 1997). This being the case, measures may need to be taken to prevent the damage caused to the seedlings and thus promote more successful saltmarsh growth. The deliberate scraping of the marsh surface to create a ridge and furrow profile, with the drier ridges providing a refuge from such herbivore pressure where glasswort (*Salicornia*) saltmarsh can develop, may provide one technique to encourage pioneer saltmarsh development in such circumstances.

A far greater problem in both Europe and North America is predation and grazing on new seeds, seedlings, and tender plant growth by geese and other omnivores. On all coasts in North America, new plantings and seedings in coastal marshes have been totally destroyed by overnight raids by flocks of geese, or persistent grazing by fur-bearer species. This problem is aggravated by the use of fertiliser on newly planted sites, which temporarily increases the nutrient content of plant material and makes it more attractive to wildlife. In the UK, where wildlife and domestic grazing may be a factor, consideration of a species rapid growth and hardiness is therefore essential.

3.4.10 Influence: proximity to existing saltmarsh

The proximity of a new site to an established marsh is very important in that the existing marsh will provide a seed base and source of vegetative propagules for the colonisation of the new site. Such a local source of plant materials (both seeds and vegetation) will be genetically adapted to the regional conditions of the potential new saltmarsh site. If there is no nearby existing saltmarsh, it may be necessary to artificially provide a seed and propagule source to the new site to encourage a more rapid saltmarsh growth. This is discussed further in Section 3.1. If a saltmarsh is nearby it shows that conditions are likely to be, or previously were, generally acceptable. In the US, a rule of thumb for siting or locating a new marsh is that if the site is not already supporting a marsh, there is usually a good reason why it is not: the question is why is there no marsh there, or why did an existing one degrade on that location? To consider creating a marsh in that location means that one or more of the four factors discussed in Section 3.1 above will have to be re-established (all four for created saltmarshes, the first three of the critical factors for restored saltmarshes).

3.4.11 Influence: tolerance of wave, wind, and boat wake energy

As indicated above, tolerance of the species to wave, wind, and wake energy is critical to the success of a new site. The plant species selected must be able to withstand the forces of wind and water if they are to be used for flood defence, and those species which have adapted to survival in such harsh conditions are identified in this report. That said, some species are more resistant than others: three groups of genera and species are therefore identified in Section 4.2.

3.4.12 Influence: adaptations to inundation and elevation

Coastal plant community zonations, while greatly influenced by salinity and water/wind actions, are also sorted in terms of competition for space by the ability of the different species to adapt to varying periods of inundation and elevations in relation to mean sea level (msl). The same species native to both North America and Great Britain cannot survive at the same periods and depths of inundation. This is a continental adaptation that is also a survival strategy, and is especially obvious for *Spartina alterniflora*, *S. anglica*, *Salicornia* spp., *Atriplex portulacoides* and *Limonium vulgare*.

4 REVIEW OF SPECIES

4.1 Flood defence objectives

As discussed earlier, in order to be of value for flood defence, a saltmarsh will need to contain species which, *inter alia*, promote accretion, resist wave energy, withstand storms, and help to prevent erosion. Certain saltmarsh species might be effective in this capacity either alone or as part of a mix. This research project therefore carried out a review of the key British saltmarsh species in order to collect information for each species in relation to the characteristics discussed in Section 3 above. Relevant information was gathered for each species from published and unpublished information (European and North American). This was supplemented by field observations and the knowledge and experience of the authors. The inclusion of field observations was felt to be important because a great deal of potentially valuable unpublished information exists for many of the species reviewed.

4.2 Screening of Species

A screening exercise was also carried out to establish which species might be potentially useful in flood defence terms. This comprised a consideration of the following factors based on published information and the experience of the study team:

- which species are sufficiently robust (ie. able to withstand storm conditions; help prevent erosion of the seawall or cliff face without encouraging macro- or micro-level erosion within the saltmarsh)?
- which species help to reduce wave energy and promote accretion?
- which species are characteristic of the various tidal zones?
- which species appear at sites which are (re-)colonising naturally, both initially and within a 2-3 year period?

This screening exercise identified three groups of species:

(i) species which appear to be potentially useful for seeding and/or planting either to establish and maintain a marsh, or as pioneer planting to encourage natural regeneration (ie. pending the establishment of species which are deemed to be "more desirable"; see Section 4.3 below). These are typically a few species characteristic of the lower saltmarsh zone which colonise quickly, grow in stands rather than as individuals and provide relatively dense cover. These species are the most important to consider for flood defence initiatives;

(ii) species which could form part of a mix with species from (i) above in order to increase the diversity of the (re-)vegetated site or which might be suitable for introduction as a more enduring saltmarsh successional stage following on from marsh establishment using species from (i) above;

(iii) species which may require planting or seeding either if upper marsh vegetation is required or if damage involving these species needs to be repaired. Such species would not, however, withstand the physical conditions at the front of the marsh. Whilst they may be highly desirable from a diversity and/or habitat standpoint, these are "minor marsh species" when considered from a flood defence perspective because they grow in the highest marsh elevations, in fresh to brackish water, and/or in highly protected conditions.

The following table shows the species reviewed as part of the screening exercise, grouped according to the above categories. These species are not prioritised within the category. Please note that some species appear in more than one category where they are versatile or relatively adaptable to higher marsh conditions.

Table 4.1: Saltmarsh species categorised according to suitability

Group (I) Low zone saltmarsh	Common cordgrass (*Spartina anglica);* Glasswort (*Salicornia/Sarcocornia* spp.); Common saltmarsh grass (*Puccinellia maritima);* Sea purslane (*Atriplex portulacoides*) (formerly *Halomione portulacoides);* Sea-blite *Suaeda* spp.
Group (ii) Mid zone saltmarsh	Common sea lavender (*Limonium vulgare);* Common saltmarsh grass (*Puccinellia maritima);* Sea purslane (*Atriplex portulacoides);* Sea aster (*Aster tripolium);* Shrubby sea-blite (*Suaeda vera);* Sea arrow grass (*Triglochin martima);* Sea plantain (*Plantago maritima);* Spear leaved orache (*Atriplex prostrata);* Sea wormwood (*Seriphidium maritimum);* Thrift (*Armeria maritima);* Red fescue (*Festuca rubra);* Sea-spurrey (*Spergularia* spp.); Scurvy Grass (*Cochlearia* spp.); Spear leaved orache (*Atriplex prostata);* Creeping bent (*Agrostis stolonifera*).
Group (iii) High zone saltmarsh	Common sea lavender (*Limonium vulgare);* Oraches (*Atriplex* spp.); Common reed (*Phragmites australis);* Rushes (*Juncus* spp.); Sedges (*Carex* spp.); Lesser bulrush (*Typha angustifolia);* Bulrush (*Typha latifolia);* Sea plantain (*Plantago maritima);* Sea wormwood (*Seriphidium maritimum);* Sea-blite (*Suaeda* spp.); Couch (*Elytrigia* spp.); Thrift (*Armeria maritima);* Red fescue (*Festuca rubra);* Scurvy Grass (*Cochlearia* spp.); Sea arrow grass (*Triglochin maritima*).

Most species are characteristic of one or more of the saltmarsh zones. For the purpose of this report, low zone saltmarsh is defined as the area around and below mean high water (MHW); high zone saltmarsh as the area around or above mean high water springs (MHWS); and the mid zone saltmarsh as the area between MHW and MHWS.

A number of the species shown in the table, and all of the genera, are common to North American intertidal marshes - for which a great deal of information already exists. However, in some cases, even the same species does not behave in the same way in the UK as it does in North America. As discussed elsewhere in this report, not all species will be useful in all situations or locations, and care will need to be taken to ensure that geographical, morphological and/or other site conditions are suitable for each species (or mix of species) before using them on a site. It is also important to note that many of these species will colonise naturally on a saltmarsh site if conditions are suitable, and therefore will not require planting or seeding. Site design and engineering will need to ensure appropriate physical conditions.

4.3 Potentially Conflicting Engineering and Environmental Goals

The review of species was undertaken primarily to establish which species potentially meet the flood defence requirements discussed above. It is acknowledged, however, that there may be some conflicts between some of the species identified as being of value in flood defence terms and those which might be more valuable in terms of nature conservation interests. Specifically, cordgrass (*Spartina* spp.), whilst providing dense early cover in many coastal restoration situations, is not perceived by many of those in the UK conservation sector as being of nature conservation value because of this genus' tendency to outcompete more desirable native species in the UK. That said, however, there may be cases where it is appropriate to establish *Spartina anglica* for pioneer planting (ie. as a nurse crop) in order to create the conditions required for the subsequent establishment of other marsh species (eg. to encourage accretion of sediment to a level suitable for the colonisation/planting of other, more desirable, species). It is also worth noting that, in North America, the five native coastal cordgrass species (*Spartina* spp.) are considered the most valuable low zone saltmarsh species for finfish and shellfish nursery and cover uses, and are the major producers and exporters of beneficial detritus that contributes greatly to the food chain in North American estuaries.

Should work be necessary within a designated site it will always be essential to consult with the relevant statutory countryside agency (eg. English Nature, Countryside Council for Wales or Scottish Natural Heritage) as well as those responsible for site management if different, prior to any decision being made. If the site is within or close to a European designated site, it may also be necessary to undertake an "Appropriate Assessment" under the terms of Regulation 48 of the Habitats Regulations 1994 implementing Article 6(3) of the Habitats Directive (92/43/EEC).

4.4 Species Descriptions

The following paragraphs give brief summaries of life requirements and suitability information for restoration for flood defence for each of the species identified in Groups (i), (ii) and (iii). A matrix summarising their tolerances to salinity, wave and wind energy, tidal range and propagation potential is provided in Section 6.

The general information and guidelines on saltmarsh species were developed, and the following descriptions were obtained, through a combination of field work, experience and expertise of the research team, and from the following publications: Coppin and Richards (1990); Environmental Laboratory (1978); Falco and Cali (1977); Faulkner and Poach (1996); Fitter *et al.*, (1984); Hayes *et al.*, (1998); Landin (1978); Landin *et al.*, (1989; 1998);

Reimold and Queen (1973); Reimold *et al.,* (1978); Stace (1997); Taft and Maddrell (undated); Thunhorst (1993); US Army Corps of Engineers (1986; 1998).

4.4.1 *Spartina anglica*, European cordgrass

Common cordgrass (*Spartina anglica*) is a perennial grass that occurs throughout the British Isles, most commonly in southern and southeast England and in some areas of Wales and Scotland. It tolerates complete inundation and relatively high wave energies, and has been transplanted extensively for shoreline protection and flood defence for a number of decades in the UK. Its counterpart in the United States is smooth cordgrass (*Spartina alterniflora*), which is also its parent, and which has been extensively transplanted, and in some cases seeded, for decades in the US. In some British estuaries, common cordgrass (*Spartina anglica*) appears to be the only saltmarsh species that can withstand and survive harsh conditions. Parts of the north Humber estuary provide an example of this where, in particular locations, common cordgrass (*Spartina anglica*) is the only vascular species in the intertidal zone (see Figure 4.1, Appendix B). The species also tends to colonise and survive at a lower intertidal zone than other species, thus exhibiting a higher tolerance of inundation for long periods of time.

Common cordgrass (*Spartina anglica*) grows in all sediment textures, shingles, sand, silt, or clay. It is tolerant of turbid and moderately contaminated conditions, and will survive and help negate oily conditions in the tidal zone. Under some conditions, however, individual plants may cause “micro-scouring” in the immediate area around stems, creating "holes" in the mud flats. This is due to stems being whipped about by waves and winds and loosening sediment where this occurs. This condition seems to occur on an eroding saltmarsh rather than an accreting saltmarsh: the established root systems of the species tend to be undercut in an eroding marsh thus allowing the creation of a tidal "shelf" that shows at low tide and is covered by inundating tidal waters at higher tides. It is also possible that accretion rates under small clumps of common cordgrass (*Spartina anglica*) are lower than the surrounding mud flats (Pethick, Leggett and Husain, 1990). Gray *et al.,* (1991) have studied the historical colonisation, hybridization, and evolution of cordgrass (*Spartina* spp.) in the British Isles, and are a key source of information on British cordgrass behaviour and tolerance.

Common cordgrass (*Spartina anglica*) is a highly persistent and competitive hybrid species, and as such occupies niches that could not be tolerated by other species. The species can be planted from the lowest tidal zones at -0.3m to -1.6m msl, and tolerates sea strength salinity (35 ppt). At this elevation, glasswort (*Salicornia* spp.) will occur with the common cordgrass (*Spartina anglica*). Common cordgrass (*Spartina anglica*) lends itself well to vegetative propagation, and in fact is best propagated in this manner. Material can be selectively taken from a donor marsh and each clump divided into a number of smaller transplants. Although it has potentially viable seeds, common cordgrass (*Spartina anglica*) plantings achieve optimum growth and density faster with single or multiple stem plantings. Depending on conditions and project goals, these plantings can be at anywhere from 1 metre centres to 0.25 metre centres. Further, plant material can be combined with bioengineering techniques to enable plantings to better withstand wave and tidal conditions.

Common cordgrass (*Spartina anglica*) will also colonise a site naturally if physical conditions are suitable. A good example of this was found at Wells Next the Sea in Norfolk, behind a manmade dune constructed on shingle, where both common cordgrass (*Spartina anglica*) and glasswort (*Salicornia* spp.) were growing and spreading under more protected conditions than the rest of the beach exhibited (see Section 2.2.9). Common cordgrass (*Spartina anglica*) seeds can be harvested in late summer and autumn, and should be stored in salt water under refrigerated conditions for 60-90 days to break dormancy. They will not germinate well until placed in fresh water. Since many of the seeds are not viable, germination tests should be conducted prior to planting if seeding is the method chosen for restoration. It should also be noted that, even in the USA, smooth cordgrass (*Spartina alterniflora*) seeds have only been shown to work at one locality on clean sand (North Carolina) and that this success has not been repeated in other parts of the US.

As indicated elsewhere, any planting of cordgrass needs to be considered carefully because of its ability to outcomplete other species and its potential to create unsuitable areas for subsequent colonisation. This aspect has been discussed further in Section 4.3. Certain characteristics of the existing environment should also be considered when determining when to use the species, including whether or not this species is present on the site already, whether control measures have been used previously to eradicate the species and what habitats and/or sensitive species/communities are present in adjacent areas.

4.4.2 *Salicornia/Sacrocornia* spp., glassworts

Glassworts (*Salicornia* spp.) in the United Kingdom are highly adaptable species, and were classed into one genus, whether annuals or perennials. Perennial glassworts have now been reclassified to the genus perennial glasswort (*Sarcocornia*) from glasswort (*Salicornia*), while annual glassworts remain in their same genus.

There are several species that occur, the most common and probably the most likely to propagate well being common glasswort (*Salicornia europaea*), European glasswort, which is an annual, and perennial glasswort (*Sarcocornia perennis*), which is a perennial. Glasswort (*Salicornia* spp) are often found growing at the lowest intertidal zones, in monostands or with common cordgrass (*Spartina anglica*), sometimes at an even lower elevation than the latter (see Figure 4.2, Appendix B). They tolerate complete and long inundations. They tend to colonise slopes, flats, and shelves at approximately -1.0m below mean sea level (msl) where they can get a toe-hold, but they are not great sediment builders.

Glasswort (*Salicornia* spp.) tolerate sea-strength salinities, high wave energies, and low-nutrient conditions. In North America, the genus has also been found to be tolerant of turbid and moderately contaminated conditions, as well as hyper-saline conditions of up to 100 ppt salinity. For example, they may be the only plants to survive in salt pannes (sea strength is usually considered to be 35 ppt). Since they are found growing in marinas and ports (ie. areas in which pollution might be anticipated), their tolerance of adverse conditions in the United Kingdom is probably similar. Glasswort (*Salicornia* spp.) grow in all sediment textures, shingles, sand, silt, and clay.

Glasswort (*Salicornia* spp.) will colonise a site readily if physical conditions are suitable. They are generally not propagated by seeds: a means of propagation is to cut and harvest an existing stand of glasswort (*Salicornia* spp.) around 40-60mm above the ground surface with a hand-cutter, or harvest mechanically with a cutter, and rake up the broken or cut pieces into receptacles for transfer to a restoration site. There, the pieces can be spread over bare areas, and hand-tilled or disked into the substrate, where they will sprout roots from nodes on the cut pieces and grow readily. If seeds can be obtained from a source such as a drift or debris strandline in the marsh in autumn (see the example for Abbotts Hall, Section 2.3.6), they can be broadcast over a site, but this can be more labour intensive than vegetative propagation. The cut and harvested donor site will recover rapidly. Seeds can be harvested and immediately broadcast on a site, where they will germinate the following spring, or can be refrigerated and held prior to broadcasting to prevent winter washout by storms.

4.4.3 *Puccinellia maritima*, common saltmarsh grass

There are at least eleven subspecies and hybrids of annual and perennial *Puccinellia* spp. found in the British Isles. The one most likely to be of any value from a restoration standpoint is common saltmarsh grass (*P. maritima*), which is a perennial. Common saltmarsh grass (*Puccinellia maritima*) grows landward and at slightly higher elevations than glasswort (*Salicornia* spp.) and cordgrass (*Spartina* spp.), at approximately -0.3m to -0.6m msl. It is not as hardy an invader as these latter species, but has potential for providing flood defence assistance either as a species in a mixed stand, or as a coloniser of the zone immediately higher than the lowest intertidal zone.

The species will tolerate salinity at and above sea strength. Its roots hold the sediment together and, when ungrazed, it can grow up to 200mm in height. It is therefore likely to have some value in flood defence terms. However, it is not known to provide protection against wave energy in monostands. Little is known about its tolerance of contaminants, or of its ability to improve water quality. It is generally found growing on fine-textured sediments, but may occur on coarser-grained material.

Common saltmarsh grass (*P. maritima*), produces above-ground stolons from which shoots develop. New plants can grow from these shoots. It can therefore be propagated either by seeds or vegetatively. Its seeds can be harvested either by hand or machine, if stand sizes are sufficient, in the autumn, but at present time little is known about storage, dormancy, and germination requirements. Vegetative sprigs can be obtained from existing donor stands if sufficient plant material is available. One means of plant collection for transplanting may be to only gather rooted stolons (shoots), leaving the parent plant to continue to grow. Another is to selectively harvest parent plants from a site, and break them apart into a number of smaller rooted pieces for transplanting. Any existing saltmarsh seed bank or debris/strandline pile in the UK will probably contain some common saltmarsh grass seeds which could be spread on a restoration site.

4.4.4 *Atriplex portulacoides*, sea purslane

There are at least 20 species of the genus oraches (*Atriplex*) occurring in the British Isles. They may be perennial shrubs, such as sea purslane, or annual herbs, such as spear-leaved orache, both of which are salt tolerant and occur in the coastal saltmarsh zone. Sea purslane is a low growing shrub at approximately -0.3m to -0.6m below msl, sometimes to -1.0m below msl, able to tolerate sea strength water and sediment. Once it colonises a mud flat, mounds or humps slowly begin to form until the sea purslane is "perched" on mounds or high platforms between the mud flat area and other saltmarsh species.

Sea purslane (*Atriplex portulacoides*) forms extensive saltmarshes along the southern coast estuaries. It appears to grow well in fine-textured sediment, and although not tested for levels, occurs in estuaries known to have contaminated conditions. The species prefers well-drained soils. The flood defence value of sea purslane is likely to be quite high because it forms dense "pillows" of ground cover (see Figure 4.3, Appendix B).

Because sea purslane (*Atriplex portulacoides*) is an excellent seed producer, it should be propagated by seeds, rather than vegetative propagules. Seeds can be gathered by sweeping stands of sea purslane with fine nets in autumn (August to September), then broadcasting seeds immediately onto restoration sites, or, holding them in refrigerated conditions over winter for broadcasting in the spring of the year. Seeds could also be collected by gathering material from the strandline. The seeds of each *Atriplex* are different in shape and size, and can be used to identify species prior to harvest. However, sea purslane is very distinctive, and there should be little doubt about which seeds to harvest.

Sea purslane is not able to tolerate such high wave energies as common cordgrass (*Spartina anglica*). However, it does occur in areas of complete daily inundation by the sea. Stands of sea purslane will occur from individual clumps to dense monostands, and the closer to wave energy conditions the plants grow, the denser the stands tend to be, although there is some colonisation by a few other species such as common sea lavender and sea aster within sea purslane stands. In more protected areas, it is just one of a number of species which occur.

4.4.5 *Suaeda maritima*, annual sea-blite

Annual sea-blite, occurs in the low to mid- zones of saltmarshes, and often occurs with glasswort (*Salicornia* spp.). Shrubby sea-blite (*Suaeda vera*), is an evergreen shrub that grows up to 1.5 metres high, and occurs on sand and shingle and the mid- to upper-zones of saltmarshes. It grows on fine-textured soils. This species has been observed just behind the front line defence colonisers in saltmarshes, and grows at 0 to -0.3m below msl. Annual sea-blite is not tolerant of high wave energies, but is a good species to use in a seed or plant mixture for a saltmarsh plant community established just behind glasswort (*Salicornia* spp.), sea purslane (*Atriplex portulacoides*) and common cordgrass (*Spartina anglica*). Its tolerance of contamination and turbidity is not known.

Annual sea-blite (*Suaeda maritima*) and shrubby sea-blite (*Suaeda vera*) do not occur in monostands in natural or manmade saltmarshes, or in saltmarshes which have re-vegetated by natural colonisation. These species are only suggested in this report as a genus to consider due to its salt tolerance and its ability to provide diversity in a saltmarsh community.

Sea-blites are propagated by seeds, regardless of whether the desired species is shrubby sea-blite, a woody shrub, or annual sea-blite, an annual herb. Seeds can be gathered in early autumn by sweeping with a fine-woven net, then storing dry in refrigerated conditions so that they can be sown the following spring, or by immediately broadcasting seeds among a nurse crop within a site to be restored (see Section 5.2).

4.4.6 *Limonium vulgare*, common sea lavender

There are approximately 42 species and subspecies of sea lavenders occurring in the British Isles, only one of which is common and likely to have potential as a saltmarsh restoration species, common sea lavender (*Limonium vulgare*). The species is a perennial herb with a reproductive stem and flowers growing from a cluster of basal leaves. This species occurs in muddy, fine-grained saltmarshes, at approximately -0.3m to -0.6m below msl. It occurs in and slightly above sea purslane stands, and higher than common cordgrass (*Spartina anglica*) and glasswort (*Salicornia* spp.). Common sea lavender tolerates complete inundation and sea strength salinity, but not high wave energies as a monostand. It commonly occurs with other species, which together as mixtures, can withstand wave energy. Sea lavender occurs in turbid waters, but little is known about its toleration of contaminants.

Sea lavender blooms on second year growth (ie. it grows from seeds the first year as a "rosette", then blooms the following year). However, it is not a true biennial species, which dies after the second year bloom, but will continue to live and flower in other years. In a natural setting, there are some of the plants blooming every year so that this growth pattern typical of perennial herbs is not immediately obvious. Figure 2.6 (Appendix B) shows an Essex marsh with sea lavender in full bloom.

Common sea lavender is an important saltmarsh species in mixed stands, and thus should be considered a component of any restoration mixture of seeds, or encouraged in colonisation. Seeds are the best means of propagation, and should be harvested by sweeping with a fine net in autumn, then sown immediately on the new site in an existing nurse crop or stored dry in refrigeration until spring before sowing.

4.4.7 *Aster tripolium*, sea aster

Sea aster (*Aster tripolium*) is a biennial (sometimes annual) that occurs in saltmarshes throughout the British Isles. It tolerates complete inundation and moderate wave energies, and can tolerate full sea strength salinity. Sea aster (*Aster tripolium*) is common in saltmarshes but little noticed until it blooms in late summer and early autumn with numerous small lavender-blue, sometimes whitish, flowers. In certain locations such as Essex the flowers will be a bright yellow colour as shown in Figure 4.4 (Appendix B). It grows to 1.0m on an upright stem from a basal florette. Sea aster has small fleshy leaves with rounded tips.

Sea aster grows in all sediment textures, silt, clay, and sand. It is tolerant of turbid and low-nutrient conditions, but almost always grows in mixed stands with other saltmarsh species. Occasionally, it will be found as single plants growing on rocks or cliffs. Sea aster can be propagated by harvesting seeds in autumn, either by sweeping or by harvesting seed heads, storing dry through winter months, then sowing onto the new site in a seed mixture the following spring. If necessary, seeds can be sown in autumn on the new site if they are protected from scour from winter storms as part of a drift pile or strandline.

4.4.8 *Triglochin maritima*, sea arrowgrass

Sea arrowgrass (*Triglochin maritima*) is a perennial with rhizomes as well as erect flowering stems up to 0.6m. Its leaves are fleshy, linear, and flat on the upperside near the base and at the tip. Sea arrowgrass is native to the British Isles, but is also native to the North America

Pacific north-west coast, where it grows at the lowest intertidal zones adjacent to subtidal mud flats and is considered a primary coloniser. In the British Isles, it does not tolerate as much inundation nor wave energy as it does in North America, and it grows in mixed stands with other saltmarsh species.

Sea arrowgrass (*Triglochin maritima*) grows in all soil types: silts, clays, and sands. It can grow in turbid water, but little is known about its tolerance to pollutants, although it has been a test subject on dredged material studies in the United States where salinity was the limiting factor in its survival. It can be propagated by harvesting rhizomes. However, it is a slow growing species, and this method of propagation will not yield many propagules. It is best to harvest seeds in autumn after flowering. Sea arrowgrass will always be considered a "minor" species in the British Isles for saltmarsh restoration due to the general unavailability of adequate plant material, but if included in a planting scheme will add diversity to a site.

4.4.9 *Plantago maritima*, sea plantain

Sea plantain (*Plantago maritima*) is a perennial which may have from one to many basal rosettes in a clump (see Figure 4.5, Appendix B). Leaves are linear and may grow to 0.3m. Flowering stems grow as upright spikes and may be 0.1m high. This is a common native species on all coasts of the British Isles, and can grow in mixed stands in saltmarshes, or on rocky cliff and mountain areas as isolated plants. It can tolerate moderate wave and wind energy and complete inundation, as well as fully saline conditions. It is therefore considered a highly adaptable plant. However, it cannot survive as a monostand saltmarsh and it will not serve in any way as a wave break species. It must therefore be planted as part of a plant mix.

Sea plantain (*Plantago maritima*) grows in all soil types, including shingle and rocky areas, and in turbid waters. In North America, where it is also native, it tolerates moderately contaminated water well. The species can be propagated by harvesting seeds in the autumn after flowering by sweeping or vacuuming, or by harvesting the entire seed head. Seeds can be stored dry in a cool moist area until planting in the spring, or, they can be sown or broadcast directly onto the new site in the autumn as long as adequate protection is provided from winter storms that will wash out seeds. Sea plantain is a "minor" saltmarsh species with regard to flood defence or shoreline protection, but is important for its contribution to site diversity. It can sometimes be found growing with sea purslane and sea lavender in mixed stands, in exposed areas which do not appear to be suitable for its growth, so its tolerance to wave energy may be underestimated.

4.4.10 *Atriplex prostrata*, spear-leaved orache

Spear-leaved orache (*Atriplex prostrata*), formerly known as *Atriplex hastata*, is an annual orache that can grow to 1.0m high. It is native throughout the British Isles, and grows in saline locations as well as in waste areas and field edges. It has hybridised with other *Atriplex* species, and the hybrids are also found growing on coasts, in saline areas, and field edges. Leaves are triangular and toothy, and grow at right angles to the stem. Spear-leaved orache grows in all soil types, and depending on where it is located, can become reddish in appearance.

Spear leaved orache (*Atriplex prostrata*) is tolerant of partial inundation, moderate wave and wind energy, and brackish to sea strength conditions, but it is not able to survive in a monostand in a saltmarsh, rather, it grows in mixed stands. It can be propagated by harvest of its numerous seed heads which are produced on every stem in autumn. Seeds can either by swept or vacuumed from plants, or entire seed heads can be removed and stored dry, then broadcast on the new site in the spring. This is such a common weed species throughout the British Isles that it would probably never be considered a candidate for commercial nursery cultivation.

4.4.11 *Seriphidium maritimum*, sea wormwood

Sea wormwood (*Seriphidium maritimum*), formerly known as *Artemisia maritima*, is an aromatic shrubby perennial, with woody erect stems. It is native to England and Ireland, and grows in the drier parts of saltmarshes (high zone marsh) or on salty roadsides. It produces numerous flowering heads with yellow to orange flowers. Flowers are bisexual. Stems and leaves are silvery grey and downy, producing a very distinctive plant in a saltmarsh.

Sea wormwood can grow in all soil types, but is not tolerant of wave energy or frequent inundation. It is thus considered a "minor" marsh species for flood defence purposes, but can be used in seed mixes to provide saltmarsh diversity in the mid to high marsh zones directly behind species listed in Group (i). It grows best in more protected areas.

4.4.12 *Armeria maritima*, thrift

Thrift (*Armeria maritima*) is a perennial herb, a member of the same family as sea lavenders with many similar characteristics, and it flowers from basal rosettes on second year growth. It has pink, rarely white, flowers, and grows to 0.3m in height. It is native throughout the British Isles, most common to saltmarshes and saline turf, and will grow on rocks and cliffs by the sea. Thrift has been observed growing in mixed stands with sea purslane (*Atriplex portulacoides*), sea lavender (*Limonium vulgare*), and glassworts (*Salicornia* spp.), so it is fairly tolerant of inundation and wave energies.

Thrift grows in all soil types. Its tolerance of contaminants is not known, but it is a "minor" marsh species growing in mixed stands. It can be propagated by collecting seeds in autumn after flowering is completed. Seeds can be swept or vacuumed, or entire seed heads can be collected and stored dry for broadcasting in spring on a new site. This is a species that may grow from the collection and broadcasting of strandline material. However, it is only recommended as part of a plant/seed mix.

4.4.13 *Festuca rubra*, red fescue

Red fescue (*Festuca rubra*) is a bright green, tufted perennial grass with a purplish tinged flower and seed head which gives it its name of red fescue. The flowering stems grow to 0.6m. The species is common throughout the British Isles. Although not a native, it has naturalised and is used so extensively throughout that most people are unaware it is not one of the native fescues. This species is commercially available from seed houses. It grows in high marshes, on road verges, and similar places, as well as being cultivated for lawns, meadows, and fields. It is also common throughout eastern North America and the Pacific Northwest.

Red fescue (*Festuca rubra*) grows in all soil types, and is tolerant of salinity and moderate contaminants in its environment. It is a highly adaptable grass that is recommended as part of a seed mix for high to mid saltmarsh zones because it provides good cover and is a reliable seed producer. It is propagated by collecting seeds in autumn, but as noted earlier, is also readily available from commercial seed houses. This is not, however, a species of benefit for front line flood defence.

4.4.14 *Spergularia* spp., sea-spurreys

The sea-spurreys (*Spergularia*) species, are annual, sometimes perennial, herbs common throughout muddy and sandy areas in the British Isles. They are natives, and are part of mixed stands in high to mid zone saltmarshes. There are nine species within a subfamily, and distinguishing amongst them is difficult. The genus has opposite leaves, white to pink flowers, and grows to 0.35m. Lesser sea-spurrey (*S. marina*) and hybrids are perennial and woody-stemmed. This genus and several species within it also grow in North America, where they are also considered to be high marsh species.

Sea-spurreys are tolerant of all soil types. Their ability to tolerate contaminants is not known. They should be considered as a "minor" marsh species, and included in seed mixes for high to mid zone saltmarshes. All species of this genus are propagated primarily by seeds, which may be harvested in autumn, stored dry, and sown or broadcast in the following spring.

4.4.15 *Cochlearia* spp., scurvy-grasses

Scurvy-grasses (*Cochlearia*) species can be perennial, annual, or biennial herbs. Although called "grasses" they are not true grasses at all. Some species are native, but several are introduced to the British Isles; they apparently hybridise readily as well. They flower on single stems that may be 1.5m high, and have rounded or heart-shaped fleshy leaves. White flowers produce spherical or heart-shaped seed pods. Scurvy-grasses grow in waste ground, along road verges, in high to mid zone saltmarshes, and in field edges.

Scurvy-grasses (*Cochlearia*) species grow in all soil types, and are probably highly tolerant of contaminants. They are salt-tolerant, and are present in mixed stands in mid to high zone saltmarsh (see Figure 4.6, Appendix B). Seeds can be collected in autumn after flowering by sweeping or vacuuming the marsh, or by removing entire seed stalks with pods intact, storing them dry over winter, and broadcasting them in spring. These species' seed pods could be part of a strandline assortment, but it depends on location and proximity to high marsh and other places the species commonly grow.

4.4.16 *Agrostis stolonifera*, creeping bent

Creeping bent (*Agrostis stolonifera*) is a native stoloniferous grass which grows to 0.75m in moist dune slacks, marshes, along stream margins and shorelines. It is abundant throughout the British Isles, and can be found in high to mid zone saltmarshes as long as the salinity levels are very low. Creeping bent (*Agrostis stolonifera*) produces abundant seeds on panicled branches, and hybridises with other bent grass species.

Creeping bent (*Agrostis stolonifera*) grows in all soil types, and is tolerant of a wide range of conditions as long as salinity levels are low. Its value to flood defence is minor, but it is an important species for soil cover and diversity behind the front line saltmarsh area. It is therefore recommended as part of a seed/plant mixture. It is propagated by collecting seeds in autumn, storing dry, and broadcasting the following spring. It may also be commercially available as a pasture grass, or could easily lend itself to commercial harvest where it grows in stands beyond the marsh zone.

4.4.17 *Phragmites australis*, common reed

Common reed (*Phragmites australis*) is a cosmopolitan species, now considered native throughout the world. It occurs on all continents with temperate to tropical shorelines and marshes. Common reed is abundant in wet places, prefers freshwater marshes but can grow in brackish conditions not exceeding about 20 ppt of salinity. It is a prolific, aggressive coloniser of disturbed soils such as dredged material deposits, mud flats, and wet fields. In Europe and Britain, it is commercially grown and harvested for roof thatch, especially in parts of Great Britain and in the Netherlands. In coastal France and in eastern North America, it is considered a pest species, and considerable efforts are made to control its spread and dominance in marshes and mud flats.

Common reed (*Phragmites australis*) is a perennial, can grow to 4.0m in height, and produces long rhizomes that in warmer climates can grow as much as 0.3-0.4m in 24 hours. Common reed flowers on a large branched head, and produces abundant seeds.

Common reed (*Phragmites australis*) grows in all soil types except rock faces, and is tolerant of contaminants and pollutants. It has been studied in the United States for its ability to de-water highly saturated soils, and to uptake contaminants to remove them from the food chain. It can be propagated by harvest and burial of its rhizomes, which will root in wet conditions. However, it is probably more easily propagated by harvesting its seeds in autumn, storing in cool moist conditions, then broadcasting on a new site in the spring. Since common reed roots from the nodes on its long rhizomes, it could lend itself to commercial harvest. However, it already grows in most places it can reach, and is an early aggressive coloniser that will exclude all other species when it occurs in dense stands. It is an excellent flood defence species if salinities are not high: other than herbicides, its only other known control is salt.

4.4.18 *Juncus* spp., rushes

The rush family, (*Juncaceae*), is very large and prolific. In the British Isles, there are numerous species in the genus rush (*Juncus* spp.) and other genera in the family. Rushes (*Juncus* spp.) can be annuals or herbaceous perennials, and are usually aquatic or marsh species. They have long, grass-like stems which produce flowers at their tips. The two species most likely to be found in British saltmarshes are saltmarsh rush (*J. gerardii*) and sea rush (*J. maritimus*), both native species which are also native to North America. They can grow to 2.0m high, and grow in dense stands under optimum conditions.

Rushes (*Juncus* spp.) grow in all soil types, silt, clay, and sand, and trap fines after they become established to form layers of silt and clay at their roots. Although most species of the genus are not salt tolerant, several in Britain are, including saltmarsh rush (*J. gerardii*) and sea rush (*J. maritimus*). They tolerate moderate wave and wind action, and contaminated and turbid conditions. In the United States, several *Juncus* species are used to filter wastewater for purification purposes. Rushes (*Juncus*) species produce rhizomes, which can be used for vegetative propagules for transplanting to new sites. However, seeds can easily be harvested using sweeps or vacuums, or by removing entire seed heads. Seeds should be stored in cool, wet conditions using fresh water. This is important, because rushes (*Juncus*) seed coats are hard and tough, and require acid scarification for germination to take place if seeds are not stored under proper conditions. In Canada, rushes (*Juncus* spp.) and wood club rush (*Scirpus*) species seeds are stored in porous bags over winter, suspended in marsh water, where the acidity of the water breaks down the tough seed coat and allows good germination to occur in the spring.

4.4.19 *Carex* spp., sedges

The sedge family (*Carex* spp.), is also a very large family, with numerous genera. These occur throughout the world, with a number of species native and naturalised to the British Isles. Most sedges (*Carex*) species are only freshwater tolerant, but several grow in high zone saltmarsh and in dune slacks. Individual species can vary greatly, but in general most of the genera do not exceed 0.3m in height. Seeds are produced on single to multiple stems, and these plants are best propagated by seed collection in early autumn. Since most plants flower early, they may lose their seeds before other species planned for harvest, so collectors need to be aware of this fact. Seeds should be stored in cool, moist conditions over winter, then broadcast on a new site in the spring.

4.4.20 *Typha angustifolia*, lesser bulrush / lesser reedmace / saltmarsh cattail

Lesser bulrush (*Typha angustifolia*) is native to Europe, Britain, and North America. It is tolerant of brackish conditions, unlike most other species within this genus. Lesser bulrush (*T. angustifolia*) may grow to 2.0m in height, and has narrow blade-like basal leaves. It occurs in mixed stands with other brackish to fresh marsh species, and can occur with bulrush / common reedmace / broad-leafed cattail (*Typha latifolia*), which is not salt-tolerant but is native and abundant throughout the northern hemisphere. Lesser bulrush (*Typha angustifolia*) provides good cover, wildlife habitat, and stability to sites where it can grow.

The species grows in all types of soils, and both are tolerant of contaminants. It is best propagated by seed head harvest, stored cool and moist over winter in plastic bags, then the seed head shredded to release seeds over a new site in the spring. It will tolerate some inundation as well as all but standing water conditions, and will tolerate moderate wave energy. Like common reed (*Phragmites australis*), salinity is its limiting factor. It is an excellent addition to a flood defence intertidal marsh mix, as long as salinities are not above 15 ppt.

4.4.21 *Elytrigia* spp., sea couch and common couch

Couch (*Elytrigia*) species, formerly of the genus *Elymus*, are native and abundant throughout the British Isles. Sea couch (*Elytrigia atherica*) are often considered as pest species due to their prolific growth in all sorts of locations, and it has been suggested by several scientists interviewed during this research that it, like common cordgrass (*Spartina anglica*), should not be recommended for planting. Sea and common couches (*Elytrigia atherica and Elytrigia repens*) are perennial grasses, growing up to 1.5m high. Seeds are produced on single stems. Sea couch (*Elytrigia atherica*) is capable of production of long rhizomes, which may be used for transplanting.

Couch (*Elytrigia*) species grow in all soil types, and are tolerant of a wide range of conditions. They may grow in dense stands, and all but "take over" high zone saltmarsh. If a decision is made to include couch in a seed mix for mid to high zone marsh for purposes of soil cover and sediment stabilisation, it can more easily be propagated by sweeping or vacuuming seeds in autumn, or collecting entire seed heads, for storage in a dry cool place, then broadcasting on a new site the following spring.

4.4.22 *Scirpus maritimus*, sea club-rush

The family which includes the genus sea club-rush (*Scirpus*) is very large, and occurs throughout the world. There are a number of species native to the British Isles. The one most likely to grow in saltmarsh conditions here is sea club-rush rush (*Scirpus maritimus*). Sea club rush (*Scirpus maritimus*) is a native, rhizome producing perennial, growing to 1.0m high, with long basal leaves. It occurs in wet muddy places in brackish, moderate wave energy conditions. It can occur in dense stands under favourable conditions, which are near fresh water and little to no wave energy.

Sea club rush (*Scirpus maritimus*) grows in all soil types, and is tolerant of contaminants and turbidity. Species of this genus are also commonly used for purification in wastewater wetlands in the United States. Although strong rhizome producers, the easiest means of propagation would be by collection of seed heads in autumn, storage under cool, wet conditions (see recommendations and cautions for *Juncus*) to scarify seed coats, then broadcast on a new site in spring. In the United States, this genus is generally always propagated by digging new plants growing from rhizomes around parent plants, but this is highly labour intensive. If seed germination becomes a problem, however, vegetative propagules can and should be used. The species most common to intertidal marshes in North America are saltmarsh bulrush (*Scirpus robustis*), which tolerates 15 ppt salinity and produces tubers as well as rhizomes, softstem bulrush (*Scirpus validus*), strictly a freshwater species, and sharp club rush (*Scirpus americanus*), an abundant species (known as American three-square due to its triangular-shaped stems) which tolerates up to 10 ppt salinity. Sharp club rush (*S. americanus*) also occurs in the British Isles as an introduced species.

5 SELECTING APPROPRIATE SPECIES AND IDENTIFYING SOURCES OF MATERIALS

5.1 Introduction

In situations where natural recolonisation is neither possible nor appropriate, the success of any initiative designed to establish saltmarsh vegetation will be heavily dependent on ensuring suitable physical conditions (see Section 3.2). Given suitable conditions, however, and depending on the characteristics of the required species (see Section 3.4), there are essentially three possibilities: seeding, planting and turfing (using existing marsh soils and seedbanks). Experience both from the US and the UK (although the latter is limited) suggests that seeding in particular is difficult in low zone saltmarshes and is likely to fail in all but firm sandy soils. Seeding has a much greater likelihood of success in mid zone and high zone saltmarshes under suitable conditions (ie. lower wave energy, better drained soils and shorter duration of high tides).

Seeding has not been found to work in the US. Woodhouse *et al.*, at North Carolina State University in the late 1960s and early 1970s, were able to successfully seed *Spartina alterniflora* on clean sand dredged material, but this success has not been duplicated anywhere else in the United States. Seeding was given up as a viable method within the lower intertidal zone by the late 1970s after numerous tests resulted in failures. However, seeding is still a viable option, and is sometimes used, in mid- to higher saltmarsh zones. Natural colonisation is, however, the preferred method of plant establishment. The philosophy in the US is that saltmarsh (low zone and intertidal) and seagrass sites require planting, whilst more protected brackish to fresh water sites do not. In order to meet specific goals, for mitigation for example, or in order to achieve more rapid shoreline protection, these latter sites might be planted as well. Seeds are sometimes used, especially to establish a nurse crop or similar to protect other plantings, but most often it is commercially or publicly grown nursery stock that is used. Seeding is, however, usually less expensive than transplanting.

In the UK, there are no examples of successful traditional seeding, but seed banks have been used in at least two cases to re-establish marshes (Abbotts Hall, Essex and Cleaval Point, Dorset). That does not mean that seeds cannot be used and, in fact, seeds are recommended for a number of selected species in mid to high zone saltmarshes. Seeds can be collected from the species that occur in mid to high zone saltmarshes: vegetative propagules would require either using sprigs taken from donor marshes or the commercial harvest and growing of nursery stock, a long and laborious process.

Seeding, planting and turfing techniques are all discussed below in order that the possible options can be thoroughly examined.

5.2 Species Selection

Having identified and selected those species which appear to be suitable for planting or seeding and which could serve a useful purpose from a flood defence perspective, realistic seed and vegetative propagule mixes and sources of these materials (plants and seeds) need to be identified. Firstly, however, potentially suitable species are summarised according to the site conditions encountered and the relevant marsh zone (see Figure 5.1). A few of the species identified are also suitable for damage repair on sites where disturbance is expected to be minimal but where natural re-vegetation is not expected to occur on its own. Most of these species mixes will not be all seeds, or all vegetative propagules, but combinations thereof. This is due to ease of propagation for each species.

In some cases it may be advisable to consider planting a nurse crop. A nurse crop can be comprised of one or more of glasswort (*Salicornia* spp.), common cordgrass (*Spartina anglica*), and/or sea purslane (*Atriplex portulacoides*). It is designed to provide cover to help hold seed in place while they are germinating and growing. In some cases, such a mix of species might be used to begin the process of marsh restoration by encouraging accretion and hence creating conditions suitable for the subsequent natural colonisation or seeding/planting of other species.

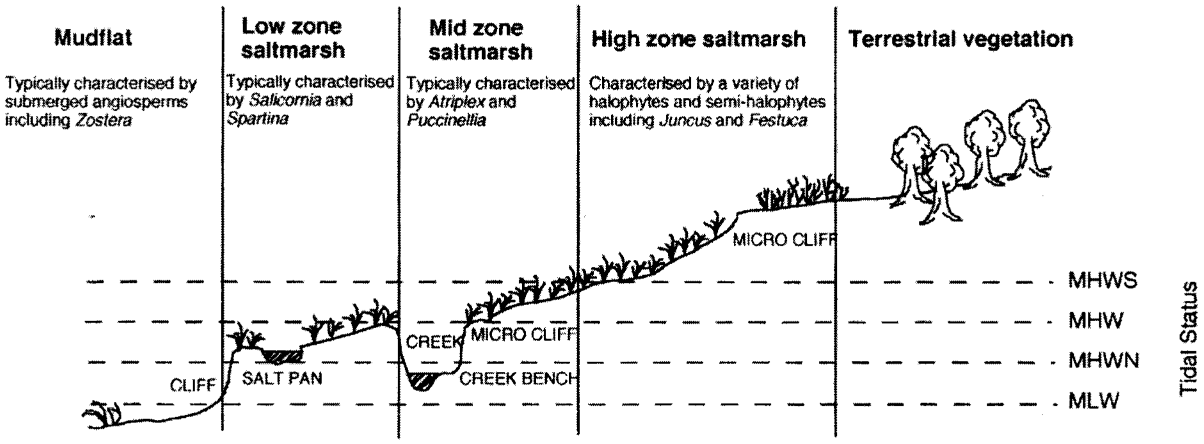

Figure 5.1: Profile of a saltmarsh and mudflat illustrating the main physiological features

5.2.1 Low zone intertidal saltmarsh, complete inundation

Where wave energy conditions are low to moderate, vegetative propagules of glasswort (*Salicornia* spp.) would be suitable to act as a protector and nurse crop for a seed mixture. Young plants would be intermixed with seeds of sea purslane (*Atriplex portulacoides*), common saltmarsh grass (*Puccinellia maritima)* and annual sea-blite (*Suaeda maritima*). This combination of species should be able to survive in the lowest intertidal zones. Under moderate to high wave energy conditions, the likelihood of survival will be increased if the mix is entirely of vegetative propagules (ie. seedlings and transplants). However, whilst all of these species produce viable seeds, glasswort (*Salicornia* spp.) lend themselves particularly well to transplanting. To obtain vegetative propagules of the other species listed, cores taken from a donor marsh or the growth of seedlings in peat pots from harvested seeds will be required.

Since there is opposition to planting common cordgrass (*Spartina anglica*) on environmental grounds (see Sections 4.3 and 4.4.1), this species is not explicitly recommended, but it may well colonise a new site anyway if conditions are suitable for glasswort (*Salicornia*). From a technical standpoint, common cordgrass (*Spartina anglica*) would be likely to serve as a better nurse crop than glasswort (*Salicornia*) because it provides a better wave buffer. That said, however, it is not clear whether or not common cordgrass (*Spartina anglica*) die-back might in turn create adverse conditions for the subsequent establishment of other species (see Section 3.4.8).

The most difficult aspects of the recommended plant/seed mixture for this environment will be the mechanical or hand harvest of *Salicornia* sprigs, and the timely seed harvest of one or more of the other four species recommended. Sweeping existing mixed stands of low saltmarsh in the late summer and autumn (August to October) will result in some seed collection. However, it will be difficult to harvest an adequate supply of seeds for large sites using such methods. For large sites, it would be necessary to find and germinate seeds in a plant nursery (commercial or public/university) in order to grow plants for seed harvest in years to come, or to grow seedlings for transplant onto a site. Alternatively a scheduled "seed harvest" could be set up each year to be sure of having a supply of viable seeds when needed. However, as discussed further in Section 5.3.1 it may be necessary to designate a number of sites for such a venture because of the potential problems associated with poor seeding years.

5.2.2 Mid-zone intertidal saltmarsh, complete to partial inundation

There are several ways to group species for use within the mid zone, and many of the species in question can be grown from seeds if a source of seeds can be identified. Groupings should be based on observations of existing nearby saltmarshes, to note what is growing in them at equivalent elevations or biological benchmarks. The following are three possible mixtures to consider, although it should be remembered that there is great flexibility in mixtures in the mid-zone due to less stressful conditions and greater numbers of species from which to choose. Selection may be based, for example, on availability of propagules rather than on the mandatory decision on what species will tolerate the harshest of conditions.

(1) Low mid-zone: seeds of common saltmarsh grass (*Puccinellia maritima*), sea purslane (*Atriplex portulacoides*), and shrubby sea-blite (*Suaeda vera*); vegetative propagules of sea arrowgrass (*Triglochin maritima*) and glasswort (*Salicornia* spp.).

(2) Mid mid-zone: seeds of common saltmarsh grass (*Puccinellia maritima*), common sea lavender (*Limonium vulgare*), sea aster (*Aster tripolium*), sea wormwood (*Seriphidium maritimum*), sea plantain (*Plantago maritima*), and/or spear leaved orache (*Atriplex prostrata*).

(3) High mid-zone: seeds of sea wormwood (*Seriphidium maritimum*), thrift (*Armeria maritima*), red fescue (*Festuca rubra*), sea-spurrey (*Spergularia* spp.), scurvy grasses (*Cochlearia* spp.), creeping bent (*Agrostis stolonifera*), and/or spear leaved orache (*Atriplex prostrata*).

5.2.3 High zone intertidal saltmarsh, limited inundation, brackish to fresh water conditions

This zone has many species from which to select, but perhaps more importantly it is the zone and the tolerance levels of salinity and inundation where almost all species will readily colonise a new site naturally assuming that it is not too exposed, and will require little or no planting or seeding. However, two examples of high marsh sites that required planting and seed banks (turfing) to ensure rapid recovery are Shotover Moor Marsh and Cleaval Point, both in Poole Harbour (see Sections 2.3.4 and 2.3.5).

As with mid-zone species, groupings should be based on observations of existing nearby saltmarshes, to note what is growing in them at the same elevations and biological benchmarks. The following are possible seed/plant mixtures suitable for high zone intertidal saltmarshes.

(1) Saline to brackish conditions, some wave energy: seeds of common sea lavender (*Limonium vulgare*), oraches (*Atriplex* spp.), lesser bulrush (*Typha angustifolia*); vegetative propagules of sea arrow grass *Triglochin maritima*.

(2) Saline to brackish conditions, no wave energy: vegetative propagules and/or seeds of wood club rush (*Scirpus* spp.) and rushes (*Juncus* spp.); seeds of common sea lavender (*Limonium vulgare*), oraches (*Atriplex* spp.), sea-blite (*Suaeda* spp.), sea wormwood (*Seriphidium maritimum*), thift (*Armeria maritima*), sea couch (*Elytrigia* spp.), red fescue (*Festuca rubra*), sea-spurrey (*Spergularia* spp.), scurvy grass (*Cochlearia* spp.) and/or lesser bulrush (*Typha angustifolia*).

(3) Near fresh to freshwater conditions, some wave energy: seeds of common reed (*Phragmites australis*), sedges (*Carex* spp.), rushes (*Juncus* spp.), wood club rush (*Scirpus* spp.), sea plantain (*Plantago maritima*), creeping bent (*Agrostis stolonifera*), red fescue (*Festuca rubra*), and/or sea couch (*Elytrigia* spp.).

5.3 Materials Sources and Planting Techniques

5.3.1 Collection of seeds and plants from wild sources

Certain sites and species of plants are protected by law under various Acts and Directives. When considering the collection of plants or seeds it is essential to determine the status of the site and the species involved, prior to collection. The relevant countryside agency (English Nature, Countryside Council for Wales) should be consulted and permissions sought and obtained from both the relevant agency and the landowner, whenever seeds or plants are obtained from a wild source.

Further potentially useful information on the procedures which apply when working on or close to designated sites is contained in the Environment Agency report "Managed Realignment: A Guide to Consents and Licences" (HR Wallingford, 1999).

5.3.2 Seed sources: commercial suppliers

Almost no seed sources of potentially useful species are currently available from commercial suppliers. The seeds that are available are primarily grass seeds as relatively more is known about the seeding and germination of grass seeds. Some small quantities of other species (such as sea aster (*Aster tripolium*)) are sometimes available from North European sources. The two main grass species for which seeds are available are reflexed saltmarsh grass (*Puccinellia distans*) (not actually a saltmarsh species) and Dawson creeping red fescue (Johnson Seeds, Boston, personal communication, 1998). Reflexed saltmarsh grass (*Puccinellia distans*) originated in North American high marshes. The species does occur in

Britain, and is widely used in areas where salt tolerance is required, such as for roadside verges. Dawson creeping red fescue has also been used in Britain, for example on a coastal golf course. This latter species has been tested and found to withstand up to 10ppt salinity.

Broad leaved plants (eg. sea aster (*Aster tripolium*)) are not so readily used in construction projects and, as such, are generally not available in significant quantities. A wild flower project carried out by Johnsons Seeds (personal communication, 1998) grows certain broad-leaved species which are tolerant of salt conditions. Such species include three dune species (yellow horned poppy (*Glaucium flavum*), sea holly (*Eryngium marititimum*) and sea pea (*Lathyrus japonicus*)) and sea aster (*Aster tripolium*). Sea aster has been harvested from and used in mid to high zone estuarine locations around the Lincolnshire coast. Although it has been found growing in the low zone, it grows best at the upper range of low zone and into mid zone saltmarshes. Commercial nurseries, however, are also using it to plant in high marsh conditions.

In the UK, if an appropriate commercial supplier knows the details of a client's requirements the supplier would potentially be able to produce seeds and plants to order on a consistent basis. The details required by the supplier would need to include the species and the geographic location of the proposed seeding site because, as discussed earlier, research has shown that plants can have different regional varieties which would not tolerate conditions in another region (inundation, salinity, exposure, soil type, etc., see Section 3.2.12). Any seeds which are produced in this way would have a good genetic base, providing they are restricted in multiplication to two generations from the wild source. While it is not strictly necessary to continue collections from wild sources for seed germination, it is recommended in order to ensure continued adaptability to the prevailing site specific conditions. In the US, seeds continue to be collected from the wild on a regular basis, but care is taken to ensure that donor sites are not damaged in the process.

If a commercial supplier had previous knowledge of the (group of) species then the process would be easier as they would have a greater background knowledge of seeding times, seed dormancy, methods of collection, etc. and would not have to carry out so much initial research. Johnsons Seeds at Boston, for example, have a great deal of background data on reflexed saltmarsh grass (*Puccinellia distans*) and so would be more confident to carry out seeding trials with other common saltmarsh grass (*Puccinellia*) species (eg. common saltmarsh grass (*P. maritima*). Common saltmarsh grass (*Puccinellia maritima*) is one of the species which is likely to prove successful for seeding in the UK as it is a native species and is often one of the pioneer species in saltmarsh development. To develop and produce the seeds for seeding purposes for other species is likely to take about two seasons (two years) if propagation knowledge of the species already exists. Success would also depend on the conditions during the growing seasons which can influence the yield.

If a commercial nursery was advised of the quantity of seed required for a particular project site well in advance of the planting need, they would be able to collect sufficient seeds to generate the correct yield. As noted earlier, however, there may be problems in obtaining seeds given the protected status of many existing marsh areas.

Combined seeding and planting

Another option which might involve a commercial nursery would be combined seeding and planting. This technique would enable the provision of rapid cover from the planted species and allow for the further coverage of the area with different species to increase the vigour and diversity of the area. Transplanting of plants grown in nursery conditions is further discussed in Section 5.3.6. An appropriate supplier would probably be prepared to produce plants as well as seeds: Johnsons Seeds, for example, have produced plants for amenity areas which required coverage quicker than seeding would allow. An experienced company could also make recommendations for flexibility in seed/plant mixtures, and the required management of the seeded or planted site, when providing mixes.

One potentially significant problem which may be experienced with producing seeds or plants is the need to gather seeds and grow plants when climatic conditions are not suitable for rapid growth. In the United States, this problem has been resolved by the use of greenhouses or hothouses. Another potential problem relates to the natural production of seeds in the wild, especially if success depends in any way on a predictable harvest: in the United States, most wild plants do not have predictable seed years, making seed harvest very unreliable from the same locations year after year. If saltmarsh restoration in the UK is to proceed on anything other than a small scale, it would be imperative that commercial suppliers and nurseries become involved in the operations to ensure adequate and appropriate stocks of the required species.

5.3.3 Seed sources: collection from an existing marsh

Seeds could be collected from an existing natural marsh, either by hand or by machine (eg. by vacuuming seeds from the seed heads of wild plants, see Section 2.3.5). Such seed collection is possible and has been carried out in the UK albeit on a limited basis. As discussed earlier, a potential difficulty with techniques of this type would be obtaining permission to collect seeds within existing saltmarsh areas, most of which are protected by designation as Sites of Special Scientific Interest or similar. However, areas of existing marsh could be designated as official donor sites in different regions, or new saltmarshes could be created and "cultivated", in both cases the site being managed specifically to provide seeds. A further possibility which has been tried in Essex, is the collection and spreading of material from the strandline in an existing (or nearby) marsh: this is discussed further in Section 2.3.6.

5.3.4 Establishing saltmarsh vegetation from seeds

Saltmarsh could potentially be established from seeds in one of the following ways:

- hand seeding directly onto the marsh
- tractor seeding or drilling directly onto the marsh, depending on the nature and moisture content of the substrate
- aerial seeding directly onto the marsh, depending on nature aid moisture covert of the substrate
- cultivation of seeds in nurseries and planting-on at the marsh site (see Section 5.3.2 below)
- spreading material collected from the strandline onto the marsh (see Section 2.3.6).

Each of these techniques has advantages and disadvantages as summarised below.

Table 5.1: Advantages and disadvantages of different seeding methods

Technique	Advantages	Disadvantages
Hand seeding	• Accurate positioning of seeds in firm sandy soils • Seeds can be pushed into the sediment therefore protecting them from washing away, but hoes and rakes must be used.	• Not suitable in other than firm sandy soils • Labour intensive • Relatively slow method.
Tractor seeding/drilling	• Quick method of covering a large area • Tracked vehicles can be used in muddy sediments, but have to plant seedlings using modified tree planters because seeds will not germinate in muds • Seeds are drilled into sandy sediment therefore protecting them from washing away • Not labour intensive.	• Need a firm substrate for machinery • Seeds are confined to rows in the first year of growing • Tracked vehicles may cause compaction of soft sediments, requiring remedial measures in some situations.
Aerial seeding	• Sites of 2 ha and larger can be seeded by helicopter, but is expensive • Small planes are less expensive and can cover a large area quickly, but are not as accurate.	• Not easy to accurately position the seeds • Seeds are placed on the surface of the sediment and therefore may be washed away the next tide • Relatively expensive, particularly helicopters.
Cultivation of seeds	• Can select healthiest of plants • Opportunity to involve local conservation groups with the growing and/or planting of the plants • Opportunity to involve commercial seed houses • No need to use donor marsh for the planting of established vegetation.	• Long process: requires wild seed harvest, sorting, storage, viability testing, germination and propagation, growth of seedlings to reproductive size, harvest of nursery seed crop • Expensive • Need to ensure plants are adapted to local environmental conditions.
Spreading of material collected from strandline	• Inexpensive • Ensures use of a local seed mix with genetic adaptations for local conditions • Opportunity to get local people involved with the project.	• Very labour intensive • Not necessarily an efficient way of distributing seeds • Handling difficulties due to weight and bulkiness of material.

5.3.5 Transplanting from a donor natural marsh site

If young plants are to be used to establish saltmarsh vegetation, there are a limited number of options. The protected status of most British saltmarshes means that wholesale removal of plants from an existing marsh is unlikely to be acceptable. However, with negotiation and permissions from the relevant authorities, it may be possible to use techniques such as taking cores of 80-150mm in diameter and not more than 150mm deep from a number of different locations within a site: on a limited scale, this would be possible without causing damage even at a protected site. The technique has been used on part of the Tollesbury experimental site (personal communication, English Nature, 1998; see also Section 2.3.1) where it proved to be the most successful of the methods tested in terms of establishing vegetation cover.

Removing plant materials from donor marshes was the technique most widely used in the United States until marsh restoration and creation reached such a scale that collection from donor marshes became impractical (and even illegal in some States). However, for very small projects where only limited plant material is required natural donor marshes are still utilised, especially if the site is on an island or difficult to access by road.

Notwithstanding the potential problems of identifying an appropriate donor site, Section 2 discusses a number of British examples involving the use of plants from donor sites for transplanting. Examples of donor sites which are possibly less controversial include areas where saltmarsh plants are growing outside of designated or protected areas (for example, at Chichester Harbour, *Spartina anglica* growing in a ditch behind a seawall was removed and used for planting at a newly restored saltmarsh site (see Section 2.3.2)). Providing the donor site is not seriously or irreversibly damaged, or the resource significantly depleted, this method of transplanting is likely to be acceptable.

5.3.6 Transplanting of plants grown in nursery conditions

An alternative to the use of donor sites is to grow young plants in nursery conditions for transplanting. There are many examples of the use of this technique in the United States: as indicated above, the reason that commercial and public nurseries have become so important is that donor marshes cannot be used as the sole source of materials because of the sheer scale of the development of new sites.

If this procedure is to be used, it is important to note (as discussed earlier) that seeds and young seedlings are usually more sensitive to salt concentrations than established plants. Saltmarsh seeds germinate best in freshwater, and the young seedlings grow best in freshwater. They can be transplanted out of a marsh nursery by gradually introducing a level of salinity equivalent to that to be found at the transplanting site, over several weeks prior to transplanting (Landin, 1978).

Costs of commercial saltmarsh herbaceous plant stock in the US range from $0.25 to $1.00 per small transplant or seedling. These are usually grown in a small decomposable peat pot or peat bag that can be inserted directly into the soil without removal of the plant from the pot.

5.3.7 Turfing, or use of seed banks contained in marsh soils

The sites at Cleaval Point and Shotover Moor Marsh (see Sections 2.3.4 and 2.3.5) are examples of turfing, in which top soil is removed from the site which is to be impacted, stored, then returned to the site with an intact seed bank and other propagules in place. In the US, this is a common wetland restoration technique using a seed bank. Mitigation projects often require a developer to remove top soil from the wetland that is to be destroyed, stockpile it under strict conditions, then return it to a mitigation site. Such a site may be either the impacted site after work is finished (eg. a pipeline or utility line project, or strip-mining operation), or a newly prepared site which has been excavated to be at the proper wetland elevation once the top soil is placed on it and has settled/consolidated. The new site may be some distance from the site to be destroyed, but will be within the same region and as near to the destroyed site as possible. Such projects require innovation, but are usually highly successful.

The removal of turf from a site to be impacted in the UK can result in similarly successful schemes, as demonstrated by the two small projects at Poole Harbour. However, the use of the technique becomes more difficult away from mid to high zone saltmarshes and into the low zone: this is due to wave and wind energy and inundation duration where disturbed soils with their seed banks and plant materials may erode before re-establishing well rooted systems.

5.3.8 Timing of seeding and/or transplanting

The timing and techniques used for seeding and transplanting are crucial to the success of establishment. The optimum time for seeding (and turfing) is from mid-spring to early summer, during a period of warm, moist conditions, sufficient for plants to become well established. The drier summer months should generally be avoided. Unless seeding and turfing are carried out in highest zone saltmarshes, planting should be governed by temperature, not by water because tide water and inundation occurs year-round. There is also a need for a certain amount of freshwater (eg. riverine, rain water) in order to maintain a healthy marsh.

Deciduous species are usually planted when they are dormant, and evergreens are usually planted in cool weather to lessen the shock of transplant. This period can be considerably extended by using container grown plants. The planting season is usually defined as the period when average temperatures are below five degrees centigrade but above freezing, but this can be extended for marsh plantings. Generally in the UK, this is considered to be from October until April, but excluding January and February. Planting during the first part of this season (autumn and early winter) may be more successful than in early spring if planting occurs in mid to high zone saltmarshes. Low zone planting initiatives should always be carried out after winter storms have past.

Root activity can persist for longer periods than the normal growing season for shoots, and in most saltmarsh species the below-ground biomass seldom goes completely dormant. Root systems can regenerate during the early spring, before the accepted start of the growing season when leaves appear. Therefore, vegetation planted at the very end of the planting season (early summer) has a reduced chance of good root establishment before the shoots grow, and usually suffers a higher failure rate. Such plantings also have less time over a growing season to establish sufficient roots to withstand winter storms the following winter. Planting in the spring should take place sufficiently early to enable root establishment before shoot activity begins.

5.3.9 Plant spacing

Plant spacing will strictly depend on the type of vegetation cover required, project goals, availability of plant material, and growth form and characteristics of the species selected. For quick cover, spacing may need to be quite close together. If rapid cover is not so urgent and funding is a constraint, spacing can be further apart and the plants will eventually grow together to provide full ground cover. In the US, depending on the above factors, marsh plantings will range from planting on 0.25 to 1.0m centres for herbaceous plant material. US researchers have also found that, although there are a number of generalities that can be applied to marsh restoration and creation sites, each marsh has site-specific influences that will vary from others, thereby affecting a wide range of selection criteria.

5.3.10 Planting techniques

In the UK, only mid to high zone saltmarsh areas can be considered "terrestrial" in their planting techniques and site preparation methodologies, whereby standard agricultural equipment and planters can be used to sow and plant the saltmarsh at low tide. In the low zone saltmarshes, where substrate is firm sand or cobble, it may also be possible to use agricultural equipment at low tide to plant such sites. However, in low zone softer sediments or in higher zones with very soft sediments (ie. silts and clays) this will not be possible. Planting on such sites must be undertaken by hand or light-foot-pressures tracked vehicles that will be able to "float" on the soft sediment. Alternatively, it may be worth investigating the techniques practised in North America for the planting such sites: these include the use of sleds and marsh walkers to carry plant material onto soft sediment, the use of surf boards on ebb and flow of tide to float over the site and plant in a few centimetres of water, and numerous other field-tested techniques.

5.3.11 Monitoring

Once a saltmarsh site has been established using any of the above methods it is important that the site is monitored in order to record the success or otherwise of the methodology used. The results of such monitoring will not only provide useful data for the actual site, but will also provide comparisons for future sites with similar conditions. The duration and frequency of the monitoring which is necessary will depend on the objectives of the scheme and on the resources available. Monitoring for less than 5 years is considered in the US to be short-term: indeed, in certain cases, monitoring is still on-going 30 years after the completion of a scheme (Landin *et al.,* 1989; Landin, 1992).

It is necessary to establish a baseline situation prior to any works in order to record changes during subsequent monitoring. A control site is also important to establish any changes which may affect a site as a result of natural or anthropogenic changes outside the influence of the scheme to be monitored.

The type of monitoring which is required will be site specific but could include aspects of the following:

- engineering monitoring usually consists of physical and chemical soil and water aspects, and geomorphological studies which may include examination of site-specific factors.
- environmental monitoring usually consists of biological soil and water aspects, fish, wildlife, benthos, plants and ecological changes.
- post-project monitoring would also include examination of plant materials for survival of plants, natural colonisation or invasion by other species, percent cover of a site, stem heights, reproductive success, and other parameters (Landin *et al.,* 1989; Landin 1992).

The methods to be used for monitoring will depend on the objectives of the scheme, and will be site specific to the particular location.

In order to set targets for the development of saltmarsh vegetation communities it may be appropriate to utilise the National Vegetation Classification which describes relevant saltmarsh communities or the Habitats and Species Directive (Directive 92/43/EEC) which details relevant saltmarsh communities (eg. *Salicornia* and other annuals). These classifications could be used either to define the desired species/communities from a nature conservation perspective and/or to monitor the transition from successful vegetation cover to a desirable community.

5.4 Economics of Saltmarsh Vegetation Establishment

Most of the techniques discussed above (collecting seeds, growing plants, storage of seeds and vegetative propagules, transplanting and turfing) are likely to be labour-intensive and therefore potentially costly. This could in turn lead to a number of problems in promoting a flood defence scheme in which the establishment of saltmarsh vegetation comprises a significant component of the total works. Specifically, the organisation promoting the scheme should consider:

- the total cost of the work, including capital and maintenance costs, and ways in which these costs might be reduced, and
- the need to consider how to quantify the (marginal) economic benefits of the saltmarsh creation or restoration (if an application for grant-aid is to be submitted to the Ministry of Agriculture, Fisheries and Food (MAFF)).

5.4.1 Involvement of volunteer groups

Depending on the location and objective of a particular saltmarsh creation or restoration initiative, one way of reducing the labour cost component of the scheme may be to try to involve voluntary groups such as wildlife trusts and the British Trust for Conservation Volunteers (BTCV). In particular, such groups might get involved in the transplanting of seedlings/plants either from a nursery area or from a donor site. BTCV have a long history of such participation in projects designed to restore vegetation to sand dune areas, and the representatives contacted as part of this study see no reason why they should not become involved in saltmarsh projects. The "conditions" governing such participation include a specific conservation objective to the work, and the payment of a fee to cover the volunteers' expenses.

The American experience of using volunteers in this way is summarised in Box 5.1.

Box 5.1 The involvement of volunteer groups in North America

In the United States, volunteer groups such as Americorps, Boy Scouts of America, school classes, and adults from environmental organisations have been involved with such initiatives. However, the involvement of volunteers has not been as widespread as it might have been in the US due to concerns about legal liability, expenses, and other institutional considerations. At the present time, such issues are not as prominent in respect of the involvement of volunteers in the UK.

5.4.2 Alternative sources of funding

Another option is to investigate alternative sources of funding for the saltmarsh creation or restoration component of a scheme. In this respect, it may be worth investigating further the possibility of carrying out such work under an initiative such as the Countryside Stewardship scheme. Managing saltmarshes can attract an annual payment to the landowner under this scheme of £20-£40/ha. Until the necessary techniques are proven in the UK, and the creation and management costs can be quantified, this payment is likely to be regarded as being insufficient to meet the associated costs and it may therefore be necessary to seek land belonging to an owner with conservation sympathies (eg. a Wildlife Trust), or to seek a top-up payment from another funding agency/initiative. It is worth noting, however, that a similar Government-run initiative in the US has been hugely successful. The US Department of Agriculture is responsible for the Wetland Reserve Programme, with a goal of restoring one million acres of degraded wetlands by the year 2000. That goal has nearly been reached. Long term funding comes from federal taxpayers and can be as much as $50.00 per acre per year (around £75.00 per hectare).

5.4.3 Benefit cost assessment

If a saltmarsh restoration scheme is to be undertaken as part of a flood defence scheme, it will be necessary to consider the economic costs and benefits. If the planting or seeding initiative is deemed to be essential (either as part of the wave attenuation mechanism and/or in order that the Agency can meet its conservation duties (see Section 1.3)), the costs of restoration will not be separated from the overall scheme costs (capital and maintenance). However, if saltmarsh restoration is (part of) one of a number of options, or an addition to the basic scheme, it may be necessary to evaluate the associated costs and benefits separately (ie. as marginal costs and benefits).

As indicated above, the costs of a restoration scheme will include planning, baseline data collection, design, implementation and construction, monitoring and management. Costs will also need to include any engineering works required to create suitable physical conditions (slope grading and attaining the correct intertidal elevation, and the construction of temporary or permanent breakwaters, etc.); the plants and/or seeds; and the associated labour. There will also be ongoing management costs. On the benefits side of the equation there will be both the flood defence benefits and the conservation benefits. In cases where the saltmarsh is an integral part of the scheme, the flood defence benefits will be assessed in the usual manner (MAFF, 1993). In cases where the saltmarsh vegetation is required as a conservation benefit (ie. where marginal costs and benefits have to be considered), the evaluation of benefits is potentially more complex.

There are examples of the economic assessment of the functions and values of saltmarshes and wetlands, notably in North America. Such valuations generally include one or more of a number of functions and values - for saltmarshes, these include storm attenuation, sediment stabilisation, shoreline and infrastructure protection, fish abundance and diversity, wildlife abundance and diversity, recreation, historical and cultural values, aesthetics, water quality and turbidity management, and contaminants abatement and clean-up (Landin, 1993; National Research Council, 1994; Hayes *et al.*, 1998). Assessments of these benefits have been carried out using a number of economic valuation methods including the contingent valuation method and contingent ranking techniques. Whilst such valuations are undoubtedly useful in attempting to evaluate environmental benefits in money terms and thus contribute to the economic equation, it is also important to note that some of the techniques remain controversial and the results of such analyses must be applied with caution.

A further potential difficulty in justifying expenditure on the establishment of saltmarsh vegetation lies with the British requirement to apply discounting techniques to the benefit cost analysis. Conservation values arguably increase over time, particularly where a species or habitat is becoming increasingly rare, and/or where a habitat is maturing to achieve its full potential. Discounting, however, assumes that the value of an asset decreases over time. This problem is compounded by the fact that the costs of restoration will be incurred early on in the life of a particular initiative (ie. they will remain largely unaffected by discounting), but the full benefits may not come on line for some time (ie. the time taken for the marsh to establish). Obviously, the more rapidly it is possible to establish the marsh - also a flood defence objective - the less of a problem this will be. The issue is, however, highlighted simply as being a problem which engineers and others may face in terms of justifying saltmarsh restoration as part of a flood defence scheme. In this respect it is interesting that, in the US, discounting is only applied to manmade items: natural capital is considered to appreciate over time, not depreciate.

6 SUMMARY OF SEEDING AND PLANTING GUIDANCE

6.1 Decision Making Procedure

Previous sections of this report have presented detailed information on the factors which influence the success or failure of saltmarsh vegetation establishment. Figure 6.1 summarises the questions which must be answered and the decisions which might apply when determining the need for, and procedure for undertaking, a saltmarsh restoration or creation initiative. At each step on the flowchart, reference is made to the relevant Sections of this report.

6.2 Physical and Chemical Conditions

Each potential saltmarsh creation or restoration initiative will have its own unique site characteristics which will require assessment and, in some cases, management or manipulation. Table 6.1 serves to summarise some of the most important physical (and chemical) characteristics required of a saltmarsh creation or restoration site. Cross references are made to the relevant Sections of this report in order to ensure that the reader has the opportunity to consider these factors in more detail. The purpose of this summary table is to highlight the most critical needs. In many cases where these conditions are achieved, not only will conditions be suitable for seeding or planting, but natural colonisation will probably occur. In cases where the site in question does not meet these criteria, it is important to be aware that any seeding or planting initiative is likely to have a low chance of success.

Table 6.1: Desirable physical and chemical conditions for successful saltmarsh establishment

Characteristic	Constraints
Exposure to waves and currents (Section 3.2.1)	Saltmarsh species will not establish or survive in exposed sites; protection against waves and strong currents will almost always be required at exposed sites (fetch greater than 2000m, sometimes less); for example a breakwater may be needed to "trip" waves moving inshore in order to prevent undercutting/slumping
Tidal prism (Section 3.2.2)	It is difficult to establish and maintain vegetation in areas of high velocity and scour; particular problems may exist around points of tidal entry and exit; good tidal circulation is nonetheless essential
Elevation relative to tide (Section 3.2.4)	Mean sea level to extreme high water will provide suitable elevations for many species (precise needs vary according to species); elevation which is too low or too high will inhibit species establishment, survival and community diversity/ development
Slope and drainage (Sections 3.2.5 & 3.2.10)	Steep slopes drain well but do not attenuate wave energy; poor drainage causing standing water will kill off existing species/prevent species establishing; best slopes are 3-5%; inadequate tidal flushing may lead to ponded water and accumulation of toxins, or cause hypersaline salt pannes

Characteristic	Constraints
Sedimentation regime (Section 3.2.6)	Most species withstand sedimentation rates of 3mm-10mm per annum; in excess of 25mm/year may smother some (especially pioneer) plants; rapid sedimentation will cause evolution of low or mid zone into high zone saltmarsh
Sediment grain size and depth (Sections 3.2.7 & 3.2.8); compaction (Section 3.2.9)	Planting is easier and more successful in better oxygenated sandy soils with a firmer foundation; sandy soils are less prone to scour; many low zone species can withstand finer grained sediments; shallow sediment depth will restrict vegetation growth; compacted soil will inhibit root growth so low ground pressure equipment should be used
Nutrient levels (Sections 3.3.1 & 3.3.3)	Adequate nutrient levels (nitrogen, phosphorus, potash) can promote rapid vegetation establishment although there are no long term benefits of fertilisation; excessive nutrient levels can lead to eutrophication and algal mats smothering vegetation
Salinity (Section 3.3.2)	Some seeds and young seedlings may be sensitive to full strength salinity; undesirable species may establish if salinity is too low

6.3 Species Selection

Where vegetation cover is specifically required in order to attenuate wave energy, it will be necessary to promote species which are potentially "useful" for flood defence purposes. These are species which resist wave energy, withstand storms, prevent erosion and, as far as possible, help to promote accretion. Accepting the importance of achieving satisfactory physical and chemical conditions for establishment, the matrix presented as Table 6.2 is designed to assist with species' selection for seeding and planting initiatives. The selection of suitable species, including potentially suitable species' mixes, is dealt with further in Section 5.2 of this report.

6.4 Planting and Seeding Options

Having selected potentially suitable species for use at a particular site, the notes in Table 6.3 provide a reminder of some of the important considerations for planting and seeding. In each case, cross reference is made to the relevant Section(s) of this report in order to enable the reader to fully understand the opportunities and constraints.

6.5 General Notes

This report has not dealt at any length with the non-technical considerations and constraints of various situations which may arise with regard to landownership (private or public), funding sources and funding partnerships, working partnerships in which engineering, planting and monitoring may be shared, and similar legal and institutional factors. Experience in the US suggests that these can be the major obstacles in determining whether or not a project will actually result, and are equally as important as the technical information presented here.

Saltmarsh flood defence and coastal protection projects require the co-operation of a technical team, made up from engineers, project managers, hydrologists, geomorphologists, numerical modellers, soils scientists, biologists and ecologists, and others. Such a team could also require assistance from landowners/agents, archaeologists, economists and other specialities to meet project goal and site requirements. Such technical teams should ideally be established at the planning stage of restoration/creation projects, and should continue throughout the life of the project. Teams may be made up of a combination of public agency and private experts, or any combination thereof, depending on the special circumstances of each project.

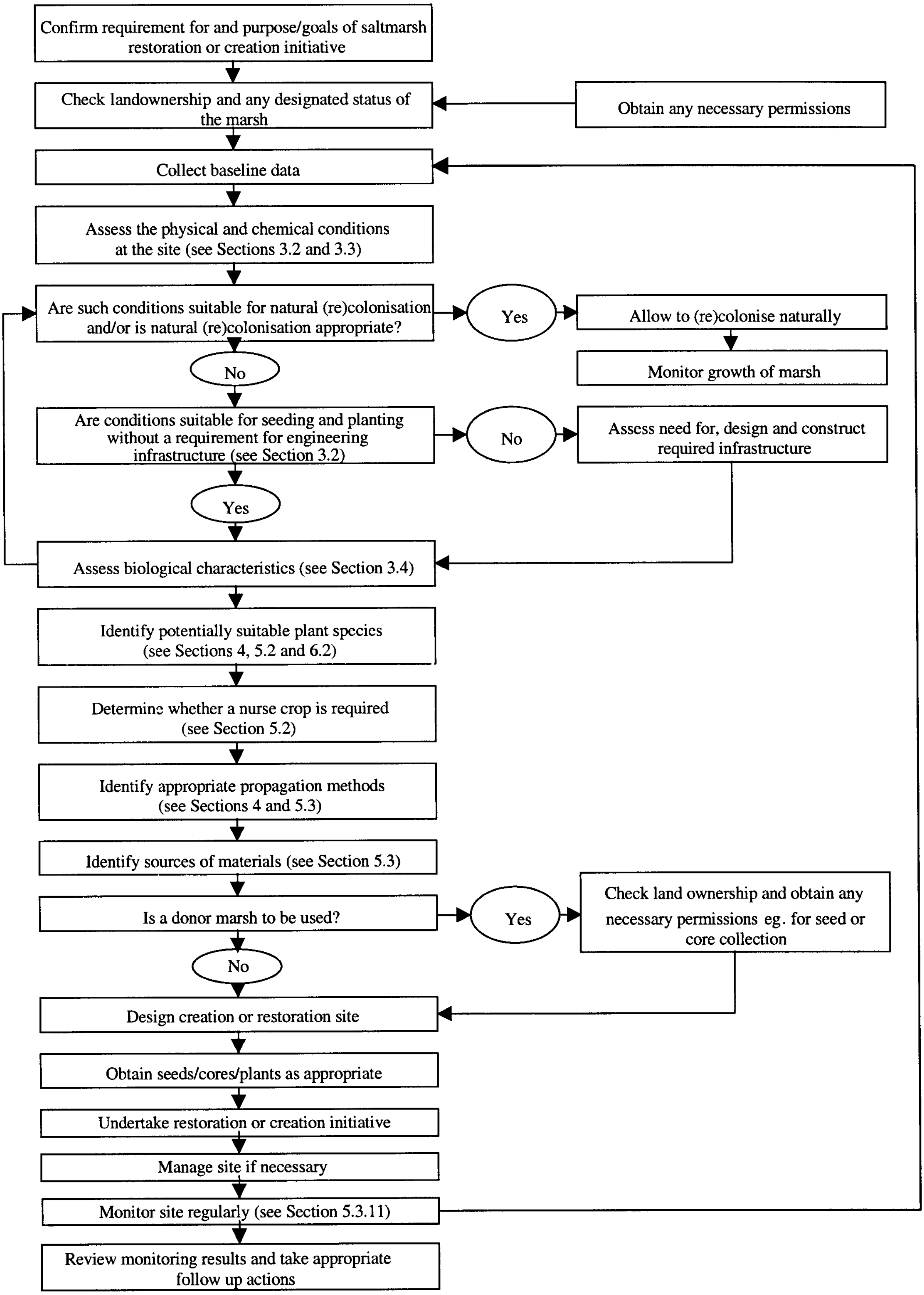

Figure 6.1: Seeding and planting decision making process

Table 6.2: Characteristics of saltmarsh species

	Tolerates complete inundation (several hours daily)	Tolerates partial inundation (several hours daily)	Only tolerates inundation on an infrequent basis	Tolerates high wave and wind energy	Tolerates moderate wave and wind energy	Tolerates almost no wave energy	Tolerates up to 35 ppt salinity	Tolerates brackish conditions (5-20 ppt)	Tolerates fresh water conditions only (0-5 ppt)	Can be grown from vegetative propagules	Can be grown from seeds	Establishes cover in less than 2 years after planting
Spartina anglica, European cordgrass	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓
Salicornia/Sacrocornia spp., glassworts	✓	✓		✓	✓	✓	✓	✓		✓		✓
Puccinellia maritima, common saltmarsh grass	✓	✓			✓		✓	✓		✓	✓	✓
Atriplex portulacoides, sea purslane	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓
Suaeda maritima, annual sea-blite		✓		✓	✓		✓	✓			✓	✓
Limonium vulgare, common sea lavender	✓	✓	✓		✓	✓	✓	✓			✓	
Aster tripolium, sea aster	✓	✓			✓		✓	✓			✓	
Triglochin maritima, sea arrowgrass	✓	✓			✓		✓	✓		✓	✓	
Plantago maritima, sea plantain	✓	✓			✓		✓	✓			✓	
Atriplex prostrata, spear-leaved orache		✓			✓			✓			✓	
Seriphidium maritimum, sea wormwood			✓			✓		✓			✓	
Armeria maritima, thrift		✓			✓		✓	✓			✓	
Festuca rubra, red fescue			✓		✓			✓			✓	✓
Spergularia spp., sea-spurreys		✓				✓	✓	✓			✓	
Cochlearia spp., scurvy-grasses			✓		✓			✓			✓	✓
Agrostis stolonifera, creeping bent			✓			✓			✓		✓	✓
Phragmites australis, common reed		✓			✓			✓		✓	✓	✓
Juncus spp., rushes		✓			✓			✓		✓	✓	✓
Carex spp., sedges			✓			✓			✓		✓	✓
Typha angustifolia, lesser bulrush		✓			✓			✓		✓	✓	✓
Typha latifolia, bulrush			✓			✓			✓	✓	✓	✓
Elytrigia spp., sea couch and common couch		✓				✓		✓			✓	✓
Scirpus maritimus, sea club-rush		✓			✓			✓		✓	✓	

Table 6.3: Notes on seeding and planting options

Option	Points of Note
Local materials	Where possible, the source of seeds/plants/etc. should be an existing marsh close to the restoration or creation site to ensure genetic adaptation to local conditions
Sprigs	Transplanting of sprigs of some species taken from a suitable existing (donor) site can prove successful given satisfactory physical conditions (see Section 2.3.1)
Turfs	Turfs, comprising top soil with rooted plant material and a seedbank, can be removed, stored and replanted firmly, at the same soil depth and elevation as the surrounding area. Turfs are usually re-planted at removal site (eg. following engineering works). Pegging may be needed to prevent turfs washing away. See Sections 3.4.1 and 5.3.6, also Sections 2.3.4 and 2.3.5.
Collection of strandline material	Drift materials may be collected from nearby marsh areas and transported for distribution at a (suitably protected) new site (see, for example, Section 2.3.6)
Cores (plugs)	Cores or plugs can be taken from a suitable existing (donor) marsh areas and transplanted to facilitate colonisation (see Section 5.3.4 and examples in Sections 2.3.2 and 2.3.7)
Vacuuming of seedheads	Seedheads at a nearby marsh may be "hoovered", stored (if necessary) and hand sown (see example in Section 2.3.5)
Nurse crop	A nurse crop can be designed to provide cover to germinating and growing seeds. It can also be used where vegetation establishment is required to promote accretion and hence create conditions suitable for the establishment of other species. See Section 5.2 and example in Section 2.4.3
Direct sowing of seeds	Direct sowing is generally only suitable for high zone (and possibly well protected mid zone) species. Seed sources and vegetation establishment from seeds are discussed in Section 5.3
Planting nursery-raised plants	These may need to be considered when a donor natural marsh site cannot be used. Plants may be potted or bare rooted. Transplanting these plants is discussed in Section 5.3.5
Timing	The establishment period is critical because the planted or seeded area is at risk from drought (high zone marsh), predation, wind/wave energy, etc. October to December and March to April inclusive is best for mid and high zone species and spring for low zone species (see Section 3.4.2)
Designated sites	Many natural British saltmarshes are protected by nature conservation designations. Permissions will therefore be required before taking any seeds, cores, etc. from such sites (see Section 5.3.1).

7 KEY FINDINGS AND RECOMMENDATIONS

7.1 Key Findings

The key findings of this research can be summarised as follows:

1. Saltmarsh vegetation can only be established successfully if the physical as well as biological conditions are satisfactory. Chemical conditions, unless there is reason to believe that the site is contaminated, are of lesser importance. Physical conditions such as exposure and elevation are of critical importance. This means that a saltmarsh creation or restoration initiative may need to include engineering works designed to achieve conditions which are suitable for vegetation establishment.
2. Assuming that satisfactory physical conditions are achieved, and that there are existing saltmarshes within the general area of the proposed creation or restoration site, there is a high likelihood that colonisation by saltmarsh species will occur naturally. Natural colonisation should be considered as the preferred option for saltmarsh vegetation establishment: it is likely to be both more sustainable and less expensive than managed colonisation. Planting or seeding initiatives may nonetheless be useful in situations where there are no existing saltmarshes in the area and/or where natural colonisation is deemed to be undesirable from either a flood defence or a nature conservation perspective (for example, where natural colonisation would not produce vegetation cover quickly enough to meet flood defence objectives, or in environmentally sensitive sites where potentially undesirable species might establish if natural colonisation is permitted). A specific example of the potential application of such planting and seeding techniques, would be to ensure rapid establishment of vegetation along the toe of counterwalls or similar earth structures constructed on managed realignment sites.
3. The various saltmarsh species have different biological characteristics. These characteristics, in turn, govern the suitability of different species for seeding, transplanting, turfing, etc., and hence for their use in flood defence projects.
4. There are inherent difficulties in establishing saltmarsh vegetation from seed in low zone saltmarsh areas due to wave energy and inundation as well as the presence of fine-grained sediments which may smother germinating seeds and young seedlings. Seeding is only recommended in mid to high zone sites, or as part of a mixture including vegetative propagules where the latter provide protection (eg. as a nurse crop) while seeds are germinating and establishing.
5. Transplants are more likely than seeds to succeed in low zone saltmarsh sites, particularly sites of low to moderate wave energies. Moderate wave energy conditions on a site are likely to cause some washout of propagules, and could result in a need for protection. High wave energy sites will require some protection if transplants are to grow and survive. Ensuring such protection might involve the provision of a breakwater, for example a breached embankment or a specially designed structure which still allows intertidal connection.
6. Either seeding or transplanting techniques or both may be used in the mid and high zone saltmarshes given the more protected conditions.
7. One or more of the following techniques for saltmarsh vegetation establishment may be appropriate for saltmarsh creation or restoration initiatives depending on the prevailing (or modified) physical conditions at the site:
   - natural colonisation
   - seeding alone

- planting with seeding
- planting alone
- provision of protection via the breaching of an existing embankment, combined with natural colonisation, seeding, and/or planting (managed landward realignment)
- provision of protection via the placement of a temporary or permanent breakwater(s), combined with natural colonisation, seeding and/or planting (managed seaward realignment)
- any combination of the above, for example at different parts of the site

8. In situations where the existing elevation is too low for effective vegetation establishment (eg. in some cases where managed realignment is proposed), the placement of suitable fill or dredged material may be required in order to raise eroded or degraded areas to a suitable intertidal elevation.
9. There is a significant amount of relevant existing information on saltmarsh creation and restoration available, both from UK experience and, particularly, from North America. Future planting and seeding initiatives need to draw on the lessons already learned.
10. It is essential that existing saltmarsh creation and restoration initiatives (as well as any future schemes) are properly monitored. Changes can thus be recorded and any necessary responses properly planned and implemented. Also, potentially valuable information can be gathered to assist in the design of future schemes.

7.2 Recommendations

7.2.1 Data gaps and research needs

Although there is a considerable amount of information available from North America and many of the genera and species are the same or very similar, the investigations undertaken as part of this research have identified a number of gaps in existing British information. In particular, more needs to be known about harvesting and storage methods; propagation, and propagule selection; and site selection, preparation and protection.

This report notes that the low, mid and high saltmarsh zones are likely to require different approaches in terms of seeding and planting and suggests particular species mixes accordingly. Based on existing experiences, particularly in North America, it seems likely that the low zone saltmarsh can most efficiently and effectively be restored using vegetative propagules, whilst the mid zone can be restored using a combination of seeds and propagules, and the high zone using seeds only. However, this has not been tested in controlled conditions in Britain. Such testing is needed to enable predictability and replicability to be assessed; to understand how each species and its propagules respond under different conditions; and (where appropriate) to enable saltmarsh restoration to become a more routine component of flood defence projects. In a situation of limited resources, trials involving the species likely to be suitable for use in the low saltmarsh zone need the first, most urgent attention if flood defence objectives are to be met. An improved understanding of low zone species is considered to be essential for flood defence as these species play a critical role in maintaining and protecting the lower part of the slope, and hence in reducing wave energy and associated erosion. Resources permitting, experiments involving mid, and then high, zone species are also suggested.

Throughout the following recommendations, it is important to bear in mind that the type of vegetative propagule to be used in a trial will depend on the species being used. Some species propagate via stolons, others by rhizomes, and others by dividing large plant clumps into smaller rooted plants which can then be transplanted. In both field and laboratory trials, each species would need to be treated according to its individual growth habits in order to determine if vegetative propagation is the most effective method. Since all of the species identified in this report can produce seeds, all would need to be tested for seed production, germination viability and seeding feasibility as there is so little existing information available in the UK in this respect.

7.2.2 Harvesting

Field trials are recommended in order to determine the most appropriate techniques for the harvesting of saltmarsh seeds. Different methods of harvesting have been discussed in Section 5.3 of the report but further work is required in order to establish relative success rates. The various techniques which should be investigated include collection of seeds from the strandline, hand collection, and vacuuming of wild seed heads (see Section 5.3.2). The advantages and disadvantages of each technique, including any resulting damage caused to the existing saltmarsh, the degree of success of harvesting and the ease of collection, should all be recorded.

<u>Harvesting trials for low and mid zone saltmarsh species are considered to be a high priority area for further research</u>.

7.2.3 Field trials and demonstration sites

A number of field trials and/or demonstration sites are needed in order to test and confirm or refine the suggested species' mixes for different salt marsh zones. Such trials would need to cover seeding, planting (including the use of cores) and transplanting techniques in order to further develop the technology and, if necessary, adapt North American experience to British conditions.

In addition to trials involving different elevations (this is considered to be one of the most critical factors determining likely success or failure), the trials should include experiments with planting and transplanting techniques (depth, equipment) for both seeds and vegetative propagules. They should include nurse crops (see below), and also plant spacing requirements in order to identify optimum densities for different species depending on the speed at which vegetation cover is required. This latter point will be important if cost effectiveness is to be maximised (ie. a higher density of planting is likely to be required where speed of cover is an important factor).

As part of such trials, it would also be useful to undertake species-specific experiments in order to confirm/identify viable periods for seeding and planting in various geographical locations.

<u>The field testing of recommended low and mid zone saltmarsh species at one (or preferably more) planting site(s) within the appropriate elevational range is considered to be a high priority area for further research</u>. Fixed parameters would include soil texture (fine-grained

sand) and elevation. Random parameters could include species, propagule type, fertiliser treatment (see below) and plant spacing.

7.2.4 Site preparation

Field trials might also include further evaluations of different forms of site preparation (ploughing, removal of vegetation, etc. versus simply transplanting or broadcasting and raking in).

7.2.5 Field storage and holding procedures

Other recommended field trials include field storage methods for both seeds and propagules of all low and mid zone species (similar to laboratory trials listed below) and holding procedures for temporary removal and stockpiling of seed banks and turfs of all low, mid and high zone species (moisture levels, need for enclosure, need for shade to prevent stress, etc.).

<u>Field trials to identify storage and stockpiling methods for low and mid zone saltmarsh species are considered to be a high priority area for further research</u>.

7.2.6 Laboratory trials

In addition to (and in some cases preceding) field trials, laboratory trials of seed storage, seed production, germination and raising young plants are recommended. Seed storage under moist conditions, in salt, brackish or fresh water, dry, at room temperature, and in cold conditions should all be investigated as should the period required to break dormancy. The storage of vegetative propagules (see note above) will require similar experiments.

Seeds should be tested for viability and percentage germination, and controlled growth experiments could be undertaken using different substrates (sand, silt/clay, dredged material, initial and long term survival rates). Finally, controlled survival experiments in wave tanks to determine the ability of different species to withstand energy could be useful. Many of these recommended trials might be undertaken by, or in association with, a seed laboratory.

<u>Laboratory trials to identify storage methods for low and mid zone saltmarsh species seeds are considered to be a high priority area for further research. Also of high priority are laboratory tests for germination and seedling growth (in peat pots, seed beds or both) for all species under consideration (low, mid and high zones species)</u>.

7.2.7 Fertiliser trials

In both laboratory and field trials, the application of fertilisers should be investigated to establish whether their use speeds up the initial growth rate of low and mid zone saltmarsh vegetation, and whether or not this early growth is useful, in flood defence terms, in ensuring a more rapid cover of vegetation. High nitrogen fertilisers, all-purpose fertilisers, natural fertilisers (eg. manure), slow release fertilisers and placement around the plant in various ways should all be investigated.

Investigations involving fertilisers should ideally be carried out on at an experimental site where there is adequate prior knowledge of the sediment quality of the substrate and where there is enough space to ensure that plots can be separated (to determine differences in growth rates of various applications). Fertilisers will almost certainly assist high zone species since they will receive relatively little input from their infrequent inundation.

7.2.8 Nurse crops

The benefit of using a nurse crop to establish marsh vegetation in areas where young plants would otherwise be too vulnerable to survive, needs to be investigated. This would involve the planting or seeding of comparative areas of saltmarsh both with and without using a nurse crop as protection, and identifying associated plant survival rates. If this experiment were carried out at locations of differing exposures it should also provide useful information on a threshold over which it would be beneficial to use a nurse crop for the best chance of plant survival. The ultimate demise of the nurse crop and the subsequent colonisation of the site by the desired species will require careful monitoring.

7.2.9 Model studies

Model studies of the effects of wave energies, actual inundation, and duration of inundation on individual species or groups of species, especially low or mid zone species are recommended. Of particular relevance would be the modelling of wave run-up at typical tidal ranges, and different water depths and exposures based on typical shoreline configurations. For example, it might be possible to model conditions similar to the situation at Horsey Island (in the vicinity of the lighters) as a "standard" (or precedent) that is working, and then model conditions similar to those at Tollesbury (exposed), or Bosham (semi-exposed to protected). Such modelling would help to identify "survival thresholds" which would, in turn, assist managers in determining whether or not it is worthwhile proceeding with vegetation establishment as part of their flood defence operations, with or without a permanent breakwater, as appropriate.

7.2.10 Nursery area(s)

Work is required to identify an area suitable for the setting up of a pilot or demonstration saltmarsh nursery area(s). This nursery area should be designed specifically to provide a source of plants for transplanting. Related to this, further investigations will be required (or an application will need to be prepared) to determine whether or not such a site might attract funding from one of the countryside agencies or from MAFF, and how such a venture could eventually become commercially viable.

7.2.11 Grazing

Further research is required on the potential impact of certain species of birds (such as geese) on vegetation establishment and the techniques that can be used to discourage grazing, particularly on seedlings.

7.2.12 Site development and protection

When potential saltmarsh creation or restoration sites are identified, it is recommended that the opportunity be taken to experiment with materials such as dredged material (to achieve the correct elevation for planting); strategically placed breakwaters (temporary or permanent, detached or attached structures using stone, rubble, lighters, etc. to provide protection from wave energy); and geotextiles, filled tubing (eg. using dredged material), sand-filled biodegradable bags, hay bale fences, brushwood fencing, and similar as potential mechanisms to promote accretion and/or for stabilisation and protection of the site.

7.2.13 Use of volunteers

Opportunities to involve, and make best use of, any available volunteers (eg. for planting initiatives) should also be explored.

7.2.14 Monitoring prescriptions

It is recommended that standard monitoring prescriptions be prepared with the potential for application not only at new experimental or operational sites, but also at some existing sites. Consistency in monitoring is required in order to improve understanding and hence the success rate of future initiatives.

7.2.15 Database

It is recommended that consideration be given to the production and maintenance, in an accessible location, of a central standardised database covering all saltmarsh creation and restoration initiatives in England and Wales (both Agency and non-Agency schemes). This database would need to include a number of criteria which would allow users to determine the type of scheme, location, physical, biological and chemical characteristics of the site, techniques used, success and failures of different aspects and references for any reports that were produced. It would also provide information on contacts for each scheme. It is envisaged that the database would be updated on a regular basis, and would be designed to include the results of any monitoring.

7.2.16 Recording growth and establishment

Valuable data could be collected by visiting natural and previously regenerated saltmarshes at different times of year and recording periods of maximum growth and seedling establishment. This data would be of use when planning future schemes.

7.2.17 Potential trial site

A saltmarsh creation site in Suffolk is planned to go ahead within the next two years. This is a managed realignment scheme that will probably use dredged material to create an area of intertidal saltmarsh and mudflat in the Orwell Estuary. There is potential for this scheme to be used as a demonstration site covering a number of the above recommendations. Alternatively (or in addition), the site could provide a very useful reference site for monitoring the timing of seedling establishment and growth under different conditions and the establishment of different species in different locations within the tidal zone.

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APPENDIX A

GLOSSARY

APPENDIX A. Glossary Pertinent to British Saltmarshes

BERM---see embankment

BIOLOGICAL BENCHMARK---the point within a habitat in which a significant demarcation is noted. In the case of saltmarshes, the limits of elevation at which a particular desired species is growing.

BREACHING---the cutting and shaping of an existing embankment to allow intertidal exchange into a degraded or former saltmarsh.

COMMERCIAL SPECIES---those plant species which can be easily collected, stored, and propagated for use in large-scale saltmarsh restoration or creation projects.

DONOR MARSH---a natural or manmade saltmarsh that is vigorous and healthy enough to tolerate collection of seeds, cores, etc. for transplantation to a new saltmarsh site.

EMBANKMENT--- an earthen or stone engineered structure which serves as a division between small bodies of water, or as a habitat and erosion protective structure for marshes.

FUNCTION---the roles that saltmarshes play within their ecological landscape, for example, storm attenuation, sediment management, shoreline protection, and fish and wildlife habitat.

DREDGING---an engineering practice whereby sediment is removed for a navigation channel or other location where deepening of a water body is desired, and the material is placed away from that location into a containment site, or used beneficially in numerous ways such as the creation or restoration of saltmarshes.

GEOMORPHOLOGY---a physical science that studies the geology, hydrology, and morphology of land forms, including saltmarshes, to better understand their function, value, and means of duplication via restoration and creation.

HYDROLOGY---a science which studies the physical, biological, and chemical elements in water, specifically to saltmarshes, a very important quality and quantity factor in determining success or failure of projects.

MANAGED REALIGNMENT---includes managed advance and managed retreat described below.

MANAGED ADVANCE---the placement of protective structures to seaward of an eroding shoreline, and backfilling with to an intertidal elevation, thereby aiding in the formation of saltmarsh and protection of the shoreline.

MANAGED RETREAT---the breaching or removal of existing protective structures to allow intertidal connection to previously protected land, to encourage and re-establish saltmarsh.

NURSE CROP---plant species that are planted to serve as cover and protection for young seedlings and other saltmarsh species until the less hardy species can survive on their own.

PROTECTIVE STRUCTURE---an engineered structure such as an embankment, jetty, breakwater, or sea wall.

SALTMARSH---any area vegetated with hydrophytic vegetation within the intertidal zone, which may be sea strength, brackish, or nearly fresh water influenced. Halophytic (salt-tolerant) vegetation occurs within highest salinity intertidal zones.

SALTMARSH CREATION---the building of a saltmarsh where no saltmarsh previously existed, in which all factors mandatory to success of a saltmarsh must be provided: hydric soils, hydrology, energy protection, and appropriate hydrophytic vegetation. This is an expensive process with unpredictable results.

SALTMARSH PROTECTION---the use of artificial structures or frontal marsh plantings to provide shelter for an existing degraded or eroding saltmarsh.

SALTMARSH RESTORATION---the building of a saltmarsh where saltmarsh previously existed, and where one or more of the factors mandatory to success of a saltmarsh are already in place. Usually, that one factor that prevails over long periods of time is hydric soils. Hydrology, protection, and re- establishment of hydrophytic species are carried out to restore the saltmarsh.

SEEDING---the act of sowing, broadcasting or drilling saltmarsh species seeds into the substrate of a new saltmarsh site to vegetate the site.

SOILS AND GEOLOGY---the physical science of soils and rocks, in saltmarshes, a critical substrate factor that must be met in the restoration or creation of saltmarshes.

TRANSPLANTS---vegetative propagules consisting of single stems, multiple stems, seedlings, tubers, rhizomes, stolons, and non-seed means of reproduction of a plant species.

VEGETATIVE PROPAGATION---the act of planting or placing vegetative propagules into a substrate for the purposes of restoration or creation of a new saltmarsh.

WAVE ENERGY---a critical factor, coupled with wind and boat traffic, that must be evaluated and engineered to meet before a new saltmarsh can be successfully established.

APPENDIX B

ADDITIONAL FIGURES

Figure 2.1 Tollesbury managed realignment site showing remains of hedgerows acting as baffles (Section 2.1.1).

Figure 2.2 Orplands managed realignment site exhibiting a wide diversity of vegetation (Section 2.2.3).

Figure 2.3 Thornham Bay managed realignment site. Originally an area of rough ground covered with scrap cars and other rubbish (Section 2.2.4).

Figure 2.4 Horsey Island beneficial use of dredgings scheme. Lush vegetation had developed over part of the site within three months of the placement of the dredged material (Section 2.2.7).

Figure 2.5 Horsey Island pipeline project. Tidal water enters at the far end of the site via a pipeline through the sea wall (Section 2.2.8).

Figure 2.6 Saltmarshes surrounding Horsey Island showing a “flower garden” of sea lavender (Section 2.2.8).

Figure 2.7 New area of saltmarsh created behind a dune at Holkham Bay, Norfolk (Section 2.2.9).

Figure 2.8 Remains of Tollesbury planting experiments that failed due to the low elevation (Section 2.3.1).

Figure 2.9 *Spartina anglica* planting at Bosham, Chichester Harbour. Sprigs were growing well and forming seed heads approximately two months after planting (Section 2.3.2).

Figure 2.10 *Spartina anglica* planting at Wytch Farm, Dorset. General die-back of the species is now causing erosion (Section 2.3.3).

Figure 2.11 Vegetation was transplanted using turfs at Shotover Moor Marsh, Dorset (Section 2.3.4).

Figure 2.12 *Spartina anglica* was planted using turfs at Cleaval Point, Dorset (Section 2.3.5).

Figure 4.1 *Spartina* stands on the North Humber coastline (Section 4.4.1).

Figure 4.2 Monostand of *Salicornia* on the saltmarshes of the River Colne, Essex (Section 4.4.2).

Figure 4.3 *Atriplex portulacoides* forming a dense “pillow” of ground cover (Section 4.4.3).

Figure 4.4 *Aster tripolium* on the saltmarshes of the River Colne, Essex (Section 4.4.7).

Figure 4.5 *Plantago maritima* typically growing in clumps on the saltmarshes of the River Colne, Essex (Section 4.4.9).

Figure 4.6 The white flowers of *Cochlearia* spp. on the saltmarshes of Sunk Island, North Humber Coast (Section 4.4.15).